HYDROGEOMORPHOLOGY AND HORIZONTAL MOVEMENT OF *JUNCUS ROEMERIANUS*

by

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Juncus roemerianus, black needlerush, is common in high marshes and occasionally in low marshes along the Mid-Atlantic and southern USA. Previous work found that *J. roemerianus* patches remained relatively stable in the absence of disturbance and under normal variations in flooding across a marsh. Disturbance will occur from storms through wrack (dead plant material) deposition and promote plant community shifts to reduce *J. roemerianus* patch size. I hypothesized that horizontal movement of *J. roemerianus* patch borders varies among hydrogeomorphic locations related to differences among those sites. A summary of the relationships between patch border dynamics, the condition of *J. roemerianus*, bordering communities, and environmental factors is shown in a conceptual model. The borders of patches of *J. roemerianus* within different areas of a salt marsh were tracked at Upper Philips Creek (UPC). UPC is located on the Delmarva Peninsula and is part of the Virginia Coast Reserve Long-Term Ecological Research (LTER) site. In 1990, eight 3 x 8 m permanent plots, which contained the interface between *J. roemerianus* and other species, were established throughout the UPC marsh. Two hundred squares within 1 x 2 m quadrats within the plots were assessed for ground cover. Every year from 1990 to 2014 ground cover was identified visually and non-destructively. Differences in horizontal movement of *Juncus* patch border were found among geomorphic locations within the marsh. Expansion occurred at high marsh locations both away from and near a creek with rapid rates of horizontal movement of *Juncus* outwards. Little to no expansion was observed at one low marsh site and a high marsh site bordering a hollow with slow rates of horizontal movement of *Juncus* outwards. Wrack reduced patch size at one low marsh site in 1994 without full recovery by 2014. This study helps better understand the geomorphic setting and context for this plant and helps track community structure and environmental factors associated with patches of *J. roemerianus* within the salt marsh. This is the first time that rates of horizontal movement of *Juncus* and community changes have been assessed in this way. It also helps in understanding ecosystem state changes associated with the long-term effect of sea-level rise versus wrack disturbance.

HYDROGEOMORPHOLOGY AND HORIZONTAL MOVEMENT OF *JUNCUS ROEMERIANUS*

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INTRODUCTION

Salt marshes have been the subject of ecological studies for many years [Adams, 1963; Rublee and Dornseif, 1978; Eleuterius and Eleuterius, 1979; Oertel, et al., 1989]. Important aspects of their ecology are the many interactions among plant species (Bertness and Ellison 1987) and ecological responses to pronounced changes in environmental conditions (Tylianakis et al. 2008; Harmon et al. 2009; Harley 2011). Salt marshes provide the type of system that allows plants to be studied under gradients of environmental conditions. These coastal wetlands are transition zones between the aquatic and terrestrial worlds (Niering, 1985).

Salt marshes are on protected shorelines and edges of estuaries throughout the world. Many salt marshes are along the east coast of the United States and along the Gulf of Mexico. On the west coast there are fewer. Most of the salt marshes in the United States lie between New Jersey and northern Florida, particularly in the Carolinas and Georgia (Weis and Butler, 2009). In 2009, there were roughly 110.1 million acres (4.456×10^7 hectares) of wetlands in the conterminous USA. Of all US wetlands in 2009, around 95 % were freshwater and 5 percent marine or estuarine (saltwater). Approximately 66.7 % of the saltwater wetlands consisted of salt marshes (Dahl, 2011).

Important aspects to study within salt marshes are the rates and causes of community changes. The movement of boundaries between patches of *Juncus roemerianus* Scheele and other types of saltmarsh species has been observed (Eleuterius, 1984; Brinson and Christian, 1999). *J. roemerianus* is a commonly found saltmarsh plant known as the black needlerush. Eleuterius (1976, 1984) estimated the distribution of *J. roemerianus* and found the following. It was native along the coast from Maryland to Florida and westward to Texas. In the south Atlantic states *J. roemerianus* dominated 20.7% of marshes, and on the Gulf coast *J.*

roemerianus dominated 7.3% of the marshes; however, it covered more marsh area on the Gulf than the Atlantic. In all of North America, the black needlerush dominated approximately 320,000 hectares of salt marsh. Current estimates are similar (Skaradek, 2007; Skaradek and Henson, 2007; Eleuterius, 1976; Eleuterius, 1984).

This graminoid is a monocotyledon from the rush family Juncaceae. It is a course and rigid grass-like perennial that forms in clusters with leaves that are terete (i.e., stiff and strong). Flowers begin to form on *J. roemerianus* between the months of May and October, and the maturing of *J. roemerianus* seeds occurs from July to November. Black needlerush has wide tolerance for environmental conditions (Eleuterius, 1984; Woerner and Hackney, 1997). In low saline soils, *J. roemerianus* is productive with leaf height reaching over 2.2 m; however, in high salinity zones this plant is repeatedly less than 0.3 m tall. It can tolerate pH levels from 4-7, and it is found in infrequently flooded areas. This stress tolerator serves is a key structural component in marshes (Grime, 1979). During a given year, new leaves break through the soil surface and continue to grow, while dead shoots remain upright for extensive periods. Typically, this results in dense stands of *J. roemerianus*, high in biomass and distinct from the other vegetation (Williams & Murdoch, 1972; Eleuterius, 1975, Eleuterius and Caldwell, 1981; Christian et al., 1990; Higinbotham et al., 2004). These leaves, both live and dead, accumulate densely and, without difficulty, can surpass 1000 leaves per m^2. Only a small amount of light infiltrates the soils surface, and the "thicket" of *J. roemerianus* leaves offers a habitat for diverse saltmarsh animals (Stout, 1984; Skaradek, 2007; Skaradek and Henson, 2007).

Brinson and Christian (1999) conducted a study over a period of six years on rates and causes of community changes within a salt marsh in Virginia, USA. They observed the boundary between patches of *J. roemerianus* and other types of saltmarsh species. The objective was to determine how community changes happened over years and to determine if wrack deposits initiate boundary changes by being a source of disturbance. In their conclusion Brinson and Christian (1999) indicated that *J. roemerianus* patches seemed relatively stable. Some decreases in size were related to wrack disturbance at the site that had the most recurrent and deepest tidal flooding. The patch stability is owed in part to *J. roemerianus's* extensive tolerance for a wide range of hydroperiod, meaning the time period and manner the salt marsh is covered by water. Lastly, there was a tendency for *J. roemerianus* to remain over a variety of geomorphic locations and to display losses where wrack disturbance and flooding interrelate. My thesis research is an extension and enhancement of the efforts of Brinson and Christian (1999). This project was conducted at Upper Phillips Creek (UPC) in Virginia every year from 1990 to 2014. To my knowledge, no one has ever examined the horizontal movement of *Juncus* as thoroughly.

Conceptual Model

In the study by Brinson and Christian (1999), *J. roemerianus* patch border position seemed relatively stable over a variety of geomorphically different sites. Patch border retreated where wrack disturbance and more frequent flooding were interrelated. Based on extended information I hypothesized that changes in *J. roemerianus* patch size varies among hydrogeomorphic locations related to differences among those sites. A summary of the relationships between patch border dynamics, the condition of *J. roemerianus*, bordering communities, and environmental factors is shown in my conceptual model (Figure 1). Patch border dynamics involve the interaction among *J. roemerianus,* its bordering communities, and environmental factors. The environmental conditions directly include hydroperiod, salinity, wrack, and soil organic matter. Disturbance from storms through wrack (dead plant material) deposition promotes rapid plant community shifts away from *J. roemerianus*. Lastly, the conceptual model shows that the environmental drivers: precipitation patterns, tidal flooding, elevation, and storminess all contribute to the aforementioned environmental conditions, as well as the condition of *J. roemerianus* and the bordering communities. Indirectly these environmental conditions and drivers contribute to patch border dynamics and the differences among locations in horizontal movement of the border.

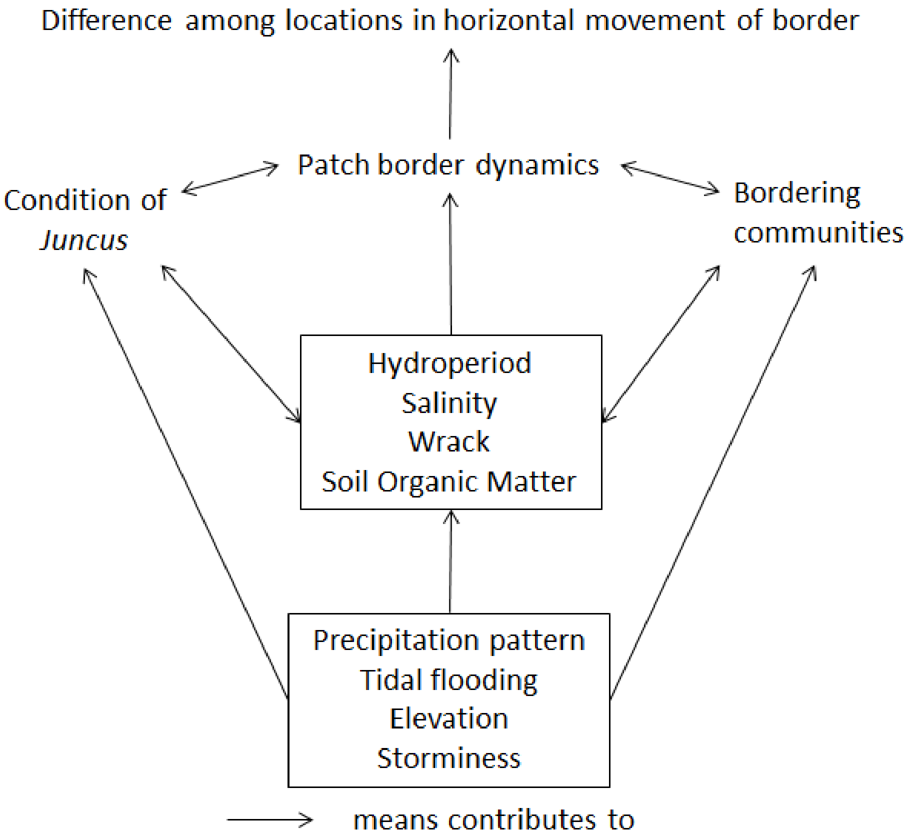

Figure 1: A conceptual model related to hydrogeomorphology was made to show how different environmental factors relate to the horizontal movement of *J. roemerianus* patch borders.

Research Objectives

The following objectives were tailored to the hypotheses and conceptual model.

1. To assess differences in the following aspects among four locations with different hydrogeomorphologies within a salt marsh:
   A. horizontal movement of *Juncus*
   B. conditions of *Juncus* (biomass, density and height),
   C. condition of bordering communities (type and biomass),
   D. environmental conditions (hydroperiod, salinity, wrack, and soil organic matter),
   E. environmental drivers (precipitation patterns, tidal flooding, elevation, and storminess)

2. To assess how measured factors explain the differences in horizontal movement of *Juncus* among the four hydrogeomorphic locations.

LITERATURE REVIEW

The following literature review was structured to reflect my conceptual model. First, the general structure of salt marshes is discussed, followed by the dominant plant species found within different regions of a salt marsh. Second, general information is discussed on various spatial patterns within salt marshes related to conceptual/ecosystem state change models similar to mine. Also, discussed within this section are environmental conditions that can change the landscape of marshes, specifically related to *J. roemerianus*. The third section discusses the biology and ecology of *J. roemerianus*. Fourth, disturbance and stress is discussed along with relevant environmental conditions (hydroperiod, salinity, wrack, and soil organic matter) and environmental drivers (precipitation patterns, tidal flooding, elevation, and storminess). For the purpose of my study storminess will refer to the occurrence of storms (nor'easter or hurricanes), the amount rainfall, wind, high tide conditions, and how frequently wrack is moving. Generalities about each aspect regarding the nature of the marsh will be given in each section, followed by studies relevant to *J. roemerianus*.

Salt Marshes

Salt marshes often can be divided into high marsh and low marsh. The high marsh is located at higher elevations, or the upper border of a salt marsh, and tends to have salinity levels resulting from multiple processes such as tidal flooding, rain, ground water, evaporation, and transpiration. However, salinity levels can depend on location; for example, in the southern marshes, salinity can be high (Nestler, 1977) because of relatively high evapotranspiration. These high marshes get flooded only occasionally by spring tides (Nestler, 1977; Weis and Butler, 2009) and can survive the high rates of sea-level rise if there is sufficient mineral deposition and organic soil formation (Day et al., 2008). The low marsh is at the lower elevations in a salt marsh with soil salinity levels closer to those found in tidal waters. These plants are often submerged by most, if not all, high tides (Weis and Butler, 2009) making flooding quite frequent (Wiegert and Freeman, 1990).

J. roemerianus and *Spartina alterniflora* Loisel make up the majority of plant biomass in tidal salt marshes along the mid-Atlantic coast, Gulf coast, and south-east coast of the US (Eleuterius, 1976a; Stout, 1984; Wiegert and Freeman, 1990). Salt marshes may consist of a variety of different plants in addition to *J. roemerianus* and *S. alterniflora*. Other plants that are common in these temperate regions along the east coast of the United States are *Distichlis spicata* (Loisel) Greene and *Spartina patens (*Aiton) Muhl (Weis and Butler, 2009). Some studies conducted in south-eastern US marshes have found that *S. alterniflora* tends to dominate the low marsh elevations with salty soil environments (Weis and Butler, 2009; Wiegert and Freeman, 1990), but *S. patens*, *J. roemerianus*, and *Salicornia* spp. can still be found (Weis and Butler, 2009). *J. roemerianus* is most commonly found in south-eastern, Gulf and mid-Atlantic US marshes at higher elevations with less flooding and in environments where the soil is less salty (Weis and Butler, 2009; Wiegert and Freeman, 1990).

Conceptual/Ecosystem state change models related to spatial patterns within a marsh

Christian et al. (2000) extended the efforts by Brinson et al. (1995) by developing a conceptual model related to mine, in that they focused on changes in the salt marsh relative to sea-level rise and disturbances. They examined geomorphic categorizations for wetlands controlled by sea-level using a spatial scale suitable for restoration. The scale includes an ecosystem state change model (extended from Hayden et al., 1995), which defines the mechanisms of converting from one coastal ecosystem state to another. Also, included in Christian et al. (2000) is a state change continuum for coastal wetlands.

Brinson et al. (1995) postulated changes in ecosystem state, for coastal mainland marshes at the Virginia Coast Reserve, during the transition from terrestrial forest to shallow estuarine locations. Categories of ecosystem states are based on dominating plants in a community and soil and sediment characteristics. Changes among five states were defined from the viewpoint of a fixed forest site experiencing transition from one ecosystem state to another, with rising sea level being the leading force of overall change. It was postulated that all five states had self-maintaining properties and were therefore resilient to some variations in sea-level rise. On the other hand, transitions amid states were aided by disturbance or exposure to severe stress. For alteration to take place, it was necessary for resistance to be overcome by actions that were more sudden than sea level increasing. The potential disturbances include erosion and wrack deposition, and stresses such as high salinity, flooding, and accumulation of plant toxins. Events like these enable replacement of plant species and sediment condition modifications. The processes accountable for triggering a state to cross a threshold are distinct for each form of transition.

Condition of *J. roemerianus*

J. roemerianus, also known as black needle-rush (Eleuterius, 1976), black grass, and Roemers rush (Skaradek and Henson, 2007; Skaradek, 2007), is adapted to many environmental conditions (Eleuterius, 1984; Woerner and Hackney, 1997; Skaradek and Henson, 2007). This saltmarsh plant inhabits the edge of ditches and shorelines of bays and streams of tidal systems. It occupies soils stretching from practically pure sand to a blend of loam and clay. *J. roemerianus* also cultivates soils rich in organics, like peat. This rush is frequently established in constructed marshes, which are used for the treatment of dilute organic wastes. It has a high tolerance to anaerobic environments and to calcium carbonate (Skaradek and Henson, 2007).

Thick patches of *J. roemerianus* form profound fibrous root systems, making them really good at protecting shorelines, sieving suspended solids, taking up nutrients, and facilitating substrate oxidation. The species can endure a wide range of salinity, so it is sometimes used in restoration of tidal estuaries throughout the Atlantic and the Gulf coastlines. As salinity in the water of a salt marsh decreases, the amount of other plant species in association with *J. roemerianus* usually rises; however, it's understood that species of *Spartina* are more forbearing of salinity and inundation (Skaradek and Henson, 2007). Also, many species such as muskrats, waterfowl, marsh rabbit, nutria, rice rat, and non-game birds consume this saltmarsh plants' seeds and vegetative parts (Skaradek and Henson, 2007; Skaradek, 2007).

In Christian et al (1990), *J. roemerianus* dominated an ample area of an irregularly waterlogged salt marsh at the Cedar Island National Wildlife Refuge, North Carolina, USA. Along a 1.6 km transect into the marsh, they observed aspects of growth, senescence, and decomposition. The study was over salinity and hydroperiod gradients that passed over 3 diverse vegetational regions. From the edge of the marsh towards the interior, a gradual decrease was seen in hydroperiod and salinity (Brinson et al., 1991). "The lack of response to gradients in hydroperiod and salinity is indicative of the broad range of environmental conditions to which *J. roemerianus* is adapted." (Brinson, 1991). There was an average of 812 g of dry mass m^{-2} for aerial, yearly net primary production of *J. roemerianus*. This is a similar rate to that of *J. roemerianus* in additional NC marshes. Ecosystem changes within the marsh dealing with salinity and hydroperiod occurred from the edge towards the inner regions of the marsh. *J. roemerianus* lack of dominance in the innermost area could have been a result of competitive advantages of different species in an environment of lesser salinity and shorter hydroperiod. Standing dead leaves had a slow rate of decomposition. Assuming this permanence and perseverance of standing dead, biomass removal by physical processes such as storms and fire may be more important than decomposition.

Disturbance and stress events related to environmental conditions and drivers

This section will consist of a discussion about disturbance, stress, and some dieback events. Also included are environmental conditions (hydroperiod, salinity, wrack, and soil organic matter) as well as various environmental drivers (precipitation patters, tidal flooding, elevation, and storminess). Generalities about each aspect regarding the nature of the marsh will be given, as well as what is known about *J. roemerianus* for each section.

Keusenkothen and Christian (2004) describe disturbance as “a stressor on an ecosystem that has the potential to modify a community and (1) is either short-term or (2) begins with a relatively abrupt change in condition.” On a broader scale, Odum et al. (1995) defines disturbance as an aspect of the environmental pulsing paradigm that affects many parts of the organization of ecosystems and its dynamics. The terms “press” and “pulse” were first used by Bender et al. (1994) to differentiate between two perturbations by examining how populations respond to disturbances. Glasby and Underwood (1996) define “perturbation” as a process in which an enormous disturbance event causes a reaction “in terms of altered densities or composition of species in a population or assemblage.” They use “pulse” as a short-term disturbance that produces an abrupt change in species abundance from which the group convalesces as soon as the disturbance comes to an end. Also, they define “press” as a continuous disturbance that causes perpetual change to the large quantity of species.

Weather, biota, and human activity are three general categories that can all contribute to disturbance events within salt marshes. “The potential for the occurrence of each disturbance and the response are dependent on the ecogeomorphologic positions of the ecosystems

(Keusenkothen and Christian, 2004).” Fagherazzi et al. (2004) defined ecogeomorphology, from the terms ecology and geomorphology, as “the discipline that studies the coupled evolution of geomorphological and ecosystem structures.” This definition seems appropriate to my work at Upper Phillips Creek. Keusenkothen and Christian (2004) discuss ecogeomorphology with a perspective on ecosystem state changes related to sea-level rise. They also studied a localized disturbance, which included a case study of trampling deer. They focused on four different communities (*J. roemerianus* community, *D. spicata*/*S. patens* community, short *S. alterniflora* community, and Creek bank community) and two ecosystems states (organic high marsh and mineral low marsh) at Upper Phillips Creek marsh, emphasizing the significance of ecogeomorphology on the rate of recurrence and response to disturbance. Keusenkothen and Christian (2004) cited many studies within other ecosystems that show trampling by deer can reduce above-ground biomass of plants, alter soil bulk density, organic content, and even elevation. The *J. roemerianus* community was considerably affected by trampling. Above-ground biomass, and relative elevations showed a decrease. Significant amounts of *D. spicata* were found in the trampling areas, with significantly less amounts of *J. roemerianus*. Their results showed that “trampling may slow marsh surface accretion in high and low marsh ecosystem states in different ways due to differences in ecogeomorphology.”

A number of scientists have studied the significance of physical disturbances within saltmarsh plant communities (Redfield, 1972; Reidenbaugh and Banta, 1980; Hartman et al., 1983; Bertness and Ellison, 1987; Brinson et al., 1995; Valiela and Rietsma, 1995). Ecosystem state changes is often initiated by a disturbance in external controlling forces (Brinson et al. 1995). He et al. (2013) applied the stress-gradient hypothesis (SGH) and studied whether or not an increase in environmental stress caused disturbances in species interactions among plant communities within various ecosystems throughout the world. They referred to stress as any biotic, physical, or resource factor (light, water, and nutrients) that may cause a reduction in the fitness level of plants. The results of He et al. (2013) confirm how stress changes the relationships between plants in coastal marshes. These plants have to compete in order to survive by adapting to changes in stress, or the stress will cause a decrease in their ability to grow and reproduce. Understanding other environmental factors is important in regions with enduring tidal inundation, increased salinity, and insufficient nutrients that may be altering plant productivity (Shafer and Hackney, 1987). Various environmental conditions and environmental drivers, related to those in my conceptual model, have been studied to see how increases in these stresses and disturbances affect plant communities.

Disturbances and stresses related to environmental conditions (hydroperiod, salinity, wrack, and soil organic matter)

Saltmarsh plants respond to the stressors (or a press if referring to the definition from Glasby and Underwood (1996)) salinity (Parrondo et al., 1978; Hester et al., 1998; Katembe et al., 1998). Salinity can be good for plants, especially in a salt marsh; however, too much salt in the root zone of plants can have damaging effects on patches by negatively impacting their growth and causing stress. Also, if there is excess salt in the area of the roots then the plants will not be able to retrieve water from surrounding soils (http://waterquality.montana.edu/docs/methane/basics_highlight.shtml).

It was revealed through transplant studies conducted via Eleuterius (1989) that *J. roemerianus* vegetation within high soil water salinity regions of a tidal marsh could be effectively relocated to regions of the marsh having lower salinity levels; however, inverse transplants would not occur successfully. His results showed evidence of "ecotypic differentiation” in *J. roemerianus*, meaning the length of leaves was considerably diverse among the three populations studied. These populations included mature short leaves in hypersaline areas, mature moderate length leaves in less saline areas, and the longest leaves in low salinity areas. Soil water salinity is what initiated this phenotypic plasticity of *J. roemerianus* and its genetic variation, indicating that in order to survive, adaptation and salt tolerance are extremely important (Eleuterius, 1989).

Saltmarsh plants respond to disturbances that are sudden and unexpected; for example, storm-induced wrack deposition (Tolley and Christian, 1999; Valiela and Rietsma, 1995; Brewer et al., 1998). The initiation of wrack is a disturbance, but the long-term laying of the wrack is a stress (Glasby and Underwood 1996). In New England saltmarsh communities, as well as high marsh areas along the east coast of North America, most physical disturbances result from wrack (Reidenbaugh and Banta, 1980; Hartman et al., 1983; Bertness and Ellison, 1987). The majority of wrack is made up of dead *S. alterniflora* from preceding growing seasons. The dead plant debris gets moved by flooding, storms, and tides to higher elevations within the marsh (Reidenbaugh and Banta, 1980; Hartman et al., 1983; Bertness and Ellison, 1987). This wrack covers species long enough to cause mortality to the vegetation beneath it, often times leaving bare patches in its place (Reidenbaugh and Banta, 1980; Hartman et al., 1983; Bertness and Ellison, 1987). When a mosaic pattern is seen within plant communities, it may be explained by wrack disturbances (Brinson, 1991). Physical movement of wrack and resultant effects on localized seasonal production results in these spatial patterns (Reidenbaugh and Banta, 1980; Hartman et al., 1983).

Studies related to disturbances from wrack and spatial patterns within salt marshes have been conducted. For example, Valiela and Rietsma (1995) calculated the disturbance of saltmarsh vegetation as well as assessed the hypothesis that disturbance and species richness are connected. This was done by observing disruption in vegetation by 195 wrack mats that were isolated over Great Sippewissett Marsh. Highest and lowest species richness were in correspondence with highest and lowest disturbance rates. Also, Bertness and Ellison (1987) studied spatial patterns of saltmarsh plant communities as well as their edaphic factors within a New England salt marsh. They looked at disturbances caused by wrack and how it impacts the abundance of plants within a community. They hypothesized "that plant distributions correspond to their physiological tolerances" (Bertness and Ellison, 1987). They found that physical disturbance and interspecific competition interact with plant physiological tolerances to create the notable spatial patterns within the saltmarsh plant community.

Impacts of wrack and flooding on two neighboring communities within a Virginia high salt marsh were observed in 1994 and 1995. This was done by manipulating inundation of tidal creek water and wrack existence independently and together. Inundation changes alone produced slight response in several categories of plant biomass (Tolley and Christian, 1999). In Tolley and Christian (1999), *J. roemerianus, S. patens*, and *D. spicata* were all affected by wrack deposition and expectedly displayed a substantial decrease in aboveground biomass. Also, Brinson and Christian (1999) stated there was a tendency for *J. roemerianus* to display losses where wrack disturbance and flooding interrelate. When covered by wrack, *S. patens* and *J. roemerianus* tend to die, and then *S. alterniflora, D. spicata*, (Brinson and Christian, 1999) and *Salicornia europaea* replace those high marsh species within tidal marshes because they are better colonizers (Bertness and Ellison, 1987). Salt marshes can transition into complete cover by *S. alterniflora* if the areas near a creek bank are exposed to deep flooding twice a day (Brinson et al., 1995). It is also possible that the original mix of species will be reestablished by succession as long as elevation is not extremely altered (Bertness, 1991).

Restoration after wrack deposition relies on the species (Tolley and Christian, 1999). In Tolley and Christian (1999), *S. patens* and *D. spicata* recovered from wrack deposition within one growing season; however, *J. roemerianus* did not. Since the wrack deposition effects considerably surpassed the experimentally increased inundation effects, the potential interactions between the two were masked. Amplified inundation could have inhibited the establishment of bare areas by certain species after the elimination of wrack from an area. The results of Tolley and Christian (1999) validated that deposition of wrack can be the reason for the redistribution of species among the high marsh community. Inundation changes possibly have a larger effect on the restoration of the plant community following deposition of wrack than it does devoid of wrack deposition.

The structure and function of plant species within a salt marsh also collectively get influenced by disturbance, climate, and soil conditions (Thonicke et al., 2001). As coastal wetlands are eroding, they will experience local rises of organic and inorganic suspended sediments (Cahoon et al. 2009). Blum and Christian (2004) hypothesized that environmental conditions would change the landscape of the marsh and play an important role in transgression during sea-level rise in locations where sediment was limited. Specifically, at Upper Phillip’s Creek Marsh, they proposed that certain biological processes have an effect on marsh surface elevations within low (intermediate height *S. alterniflora*), mid (short *S. alterniflora*, *D. spicata*, and *S. patens*), and high marsh regions (*J. roemerianus*). The buildup of organic matter supports surface accretion, specifically in mid and high marsh zones, while the deposit of sediments supports vertical surface accretion in the low marsh zone. After studying the root production and decomposition within the three different marsh zones, their hypothesis that “biological processes contribute to geomorphic changes that result in transgression” was supported. Their results state that differences in sediment accretion among three marsh zones, because of the buildup of organic matter, are associated with the proficiency of root production by plants and to the differences in how vulnerable the plant roots are to decomposition. “Root production was significantly different among the three zones and may be related to differences in plant type, growth form, or sediment pore water chemistry (Blum and Christian, 2004).”

Disturbances and stresses related to environmental drivers (precipitation patterns, tidal flooding, elevation, and storminess)

Environmental drivers both directly and indirectly affect marsh environmental factors, biota. There is substantial amount of overlap in various environmental conditions: tidal flooding, salinity, and elevations (Eleuterius, 1989; Woerner and Hackney, 1997; Touchette, 2006). Following are studies associated with precipitation, flooding, elevations, and storms (disturbances or pulses (Odum et al., 1995)) with some aspects related to salinity. Also discussed are these environmental drivers (factors that cause measureable changes) (Cahoon et al. 2009) more specifically related to *J. roemerianus*.

In a study on a Cedar Island marsh, water level records and porewater salinity measurements were taken over two years. Flooding from the estuary, as well as precipitation and evapotranspiration are what regulate water table fluctuations. Precipitation can moderate the concentration of salinity in areas of the marsh where water depth is shallow, and summer months are shown to have higher evapotranspiration rates within the marsh (Brinson et al., 1991). During the growing season, in both Cedar Island and Virginia Coast Reserve (VCR) marshes, water levels are expected to be lower than the marsh surface because of evapotranspiration and decreased frequency of flooding (Christian et al. 2000). During the winter months, marsh regions are waterlogged constantly by storm tides and precipitation. During this season the marsh is supplied with plenty of surface water, and evapotranspiration is low and does not successfully get rid of the water (Christian et al. 2000).

Pennings et al. (2005) studied elevation differences among flooding, salinity, and competition by conducting field and laboratory experiments. Both flooding and salinity had an effect on the lower elevation limit of *J. roemerianus*, but competition did not. Results of this study propose that there is expected geographical variation among ecological interactions because of differences in the physical environment. For example, at lower elevations the stress from salinity most likely has a more essential role in determining plant spatial patterns.

Touchette (2006) conducted work, similar to that of Eleuterius (1989), to determine how important ecological factors, such as soil-water salinity are in influencing spatial patterns in plant water relations within a *J. roemerianus* brackish marsh. Vegetation found alongside the shoreline of a marsh and plants found along the upper boundary of a marsh undergo different relationships with water, which likely contribute to differences perceived in aboveground biomass. The low marsh elevation zone experiences a very small amount of diluted saline waters, being the most saline. In the mid-marsh zone, tidal waters experience dilution of freshwater periodically. The upper marsh elevation zone, which is the least saline, is upheld predominantly by upland freshwaters. Low marsh plants had greater leaf abundance and aboveground biomass than did the mid and upper marsh zones (Touchette, 2006).

Salt marshes respond to flooding beyond storm-induced wrack deposition. Webb and Mendelssohn (1996) determined that dieback of vegetation within marsh plant communities was not only caused by an increase in salinity alone, but it was caused by increased submergence predominantly in combination with increased salinity (Webb and Mendelssohn, 1996). There is also believed to be a strong seasonal component related to the hydrology of intermittently flooded marshes. This is related to changes in sea level, storm action, and temperature variations (Brinson et al., 1991). During the late fall to early spring, on a Cedar Island marsh, the highest extent of estuarine flooding is caused by storms with northeasterly winds (Brinson et al., 1991). During the winter and spring, strong winds can cause extreme flooding up to a one meter depth, which may last as long as three days (Brinson et al., 1991).

Sea-level rise

One purpose of my study is to help understand long-term effects of increased flooding from sea-level rise versus wrack deposition on *Juncus* patches. To do this, understanding sea level rise is crucial. In the 20th century the sea level rise on a global scale was roughly 1.7 mm per year; however, relative sea level rise rates for the mid-Atlantic region (New York to North Carolina) were higher, falling amid 2.4 and 4.4 mm each year (Anderson et al., 2009). The Intergovernmental Panel on Climate Change (IPCC) made a projection in the year 2007, that there will likely be a global sea level rise between 19 and 59 centimeters by the year 2100. Other studies have proposed a global sea level rise of a meter or more by the end of the 21st century. However, there is no known agreement on just how much the sea level will rise globally because of rapid changes in ice flow from Greenland and Antarctica (Anderson et al., 2009). Trail et al. (2011) estimates state that by the year 2100, global sea level rise could be as much as 1.8 m.

Cahoon et al. (2009) discussed effects of the rates of sea-level rise over the next few decades in North Carolina non-tidal coastal wetlands using three scenarios of wetlands accretionary dynamics. Scenario 1, referred to as the non-drowning scenario, expects sea-level rise to maintain a constant rate of 2 to 4 mm per year (like that of the twentieth century). Sea level rise scenarios 2 and 3 both predict accelerated rates of sea-level rise. One projected effect is called drowning (Scenario 2). In this case, rates of vertical accretion are unable to match accelerating sea-level rise rates, and barrier islands persist unharmed. Wetlands, such as salt marshes, will experience collapsing and internal breakup of the marsh (Cahoon et al. 2009). Scenario 3, referred to as the barrier islands breached scenario, experience the collapse of some portions of the barrier islands. This collapse would be because of the Albermarle-Pamlico (A-P) regions of North Carolina experiencing the transition from a non-tidal estuary to an astronomic tidal regime (Cahoon et al. 2009).

Coastal impact models can aid in defining the susceptibility of regions and populations to variations in sea level (McLeod et al. 2010). However, there are a wide range of models (each with strengths and weaknesses) that are well-matched for diverse management goals (McLeod et al. 2010). Reyes (2009) assessed landscape wetland models that were geographically explicit, highlighting models that integrated environmental dynamics and responses into the landscape to exemplify ecosystem methodologies. He emphasized landscape models that triggered long-term modifications because of climate change, sea-level rise, and variations in patterns of land use and land cover. Reyes (2009) states that a variety of organisms (diverse vegetation and fauna) and their interactions occur in particular areas and have different responses to universal or local environmental drivers. When a wetland has water flowing over it, the vegetation may respond differently with sediment deposition, time period of inundation, and nutrient inputs. When there is an increase in the biomass of plants, then the movement of water and tidal channel morphology could consequently be changed (Reyes, 2009).

Disturbances and stresses related to environmental conditions and environmental drivers are an important aspect of my study. To further the understanding of this literature, my work assesses differences among four locations with different hydrogeomorphologies within a salt marsh. Again, I will assess how measured factors explain the differences in horizontal movement of *Juncus* among the four hydrogeomorphic locations related to my conceptual model.

METHODS

Definition of Terms

Location: Sampling occurred at four different locations within Upper Phillips Creek marsh (UPC). Location 1 is the low marsh area near a tidal creek, Location 2 is the organic high marsh area away from the creek, Location 3 is the subsiding high marsh area near a pond, and Location 4 is the high marsh area near a creek. Brinson and Christian (1999) measured the distances from each of the four locations to the creek in the year 1990. Location 1 was 20 m from the creek, location 2 was 300 m, location 3 was 120 m, and location 4 was 60 m.

Site: There are two sites within each location. These are referred to as sites A and B. The approximate distances between sites A and B at each location are generally more than 20 meters and less than 50 meters apart.

Plot position: Within each site there is an "in" and an "out" plot. "In" means the permanent plot area that was inside a *J. roemerianus* patch when the original boundary was established, and "out" means the permanent plot area that was outside the *J. roemerianus* (containing other plant species) when the original boundary was established.

Last continuous *Juncus*: refers to the very last grid (within 10 columns) that *Juncus* was continuously found from the "in" plot. This number can range from 1 to 20.

***Juncus*:** *Juncus roemerianus* unless otherwise specified

Wrack: When referring to wrack, I really mean wrack and litter combined. For all data sets, dating back to 1990, the wrack and litter data for ground cover were combined. However, the majority of what was found was wrack with very little litter.

Study site

The site under study is the Upper Phillips Creek (UPC) marsh, positioned at latitude of +37.28300 and longitude of -75.91300 (Figure 2). UPC is within the Virginia Coast Reserve (VCR), located on the Delmarva Peninsula, Virginia, USA, which is one of 24 U.S. Long-Term Ecological Research (LTER) sites (http://www.lternet.edu/lter-sites) The VCR barrier island/lagoon system is made up of approximately 14,000 ha, partly owned by The Nature Conservancy (TNC), and it spans 110 km along the Atlantic shore of the Delmarva Peninsula (http://www.vcrlter.virginia.edu/lteriii/projdesc.html).

UPC marsh starts at an upland pine forest and freshwater swamp and goes through a high marsh area in which *D. spicata*, *S. patens* and *J. roemerianus* dominate. It then stretches down to a low marsh area in which *S. alterniflora* is the dominant species. The tidal range, on average, is 150 cm (Christiansen 1998). At UPC near location 3, the porewater salinity ranges from 8 in the winter to 30 in the late summer (Buck 2001).

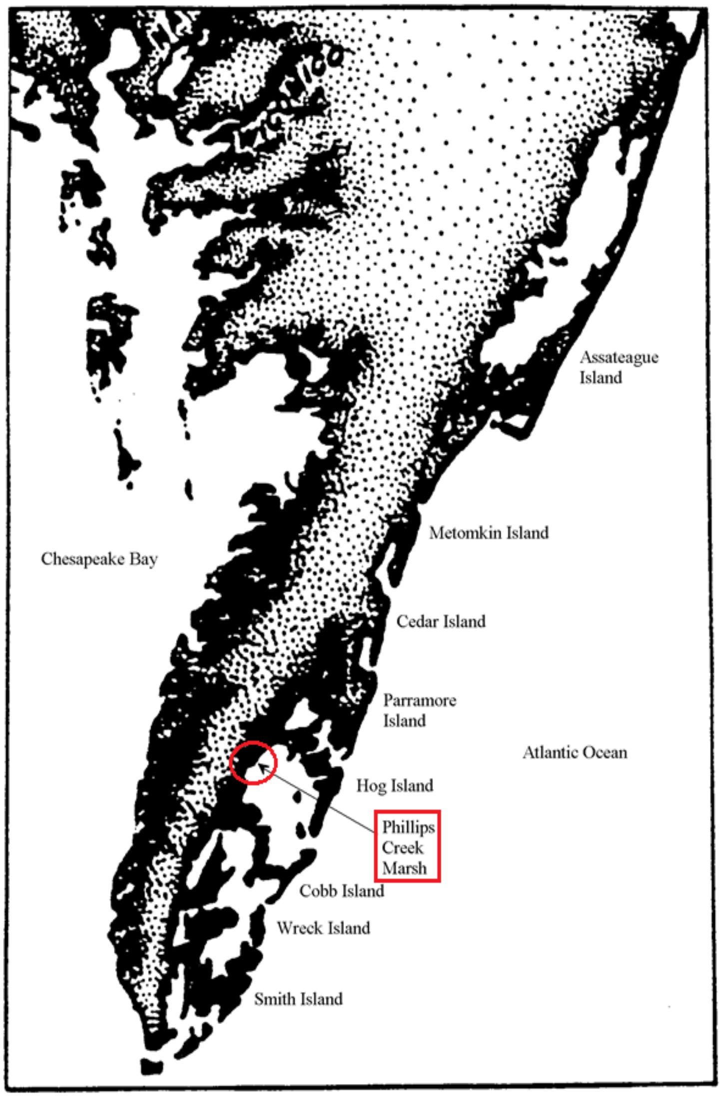

Figure 2: Delmarva Peninsula with position of Upper Phillips Creek marsh. (Tracy Buck 2001 thesis and Hayden *et al*. 1995)

Experimental Design

In 1990, eight 3 x 8 m permanent plots were established within the Upper Phillips Creek marsh. The plant species present at each location in 1990 and 2014 are shown in Table 1. Relative elevation and distance from creek are as reported in Brinson and Christian (1999). Two sites (A and B) were positioned in each of the 4 different locations (Figure 3). Each site covered the boundary between a *Juncus* patch (4 x 3 m) and the adjacent plant community (4 x 3 m) (Figure 4).

For the purpose of my thesis I sampled during the years 2012, 2013, and 2014. I am including data previously collected by Mark M. Brinson, Robert R. Christian, and their students from 1990 through 2011.

Table 1: Important species and their position (measured in 1990) relative to the creek at Upper Phillips Creek marsh.

Upper Phillips Creek Marsh			1990		Presence (+) or Absence (-) of species for 1990					
Geographic position within marsh	**Location**	**Sites**	**Relative Elevation (m)**	**Distance from Creeks (m)**	***Juncus roemerianus***	***Spartina alterniflora***	***Spartina patens***	***Distichlis spicata***	***Salicornia* spp.**	***Limonium nashii***
Organic High	2	2A and 2B	1.4	300	+	-	+	+	-	-
Subsiding	3	3A and 3B	1.18	120	+	+	+	+	-	-
Near-creek High	4	4A and 4B	1.28	60	+	+	-	+	+	-
Near-creek Low	1	1A and 1B	1.22	20	+	+	-	+ *	+	+
* = very low abundance										

Figure 3: Upper Phillips Creek site positions from my study (1A-B to 4A-B), and transects from Amanda Floyds study (numbers 1-9).

Ground cover

Every year (once a year) from 1990 to 2014, observations of ground cover were made on 1 x 2 m permanent subplots with 1 x 1 m on both sides of the original interface (Figure 4). The Upper Phillips Creek Site permanent plots were accessible by walking through the salt marsh.

Caution was taken not to crush or flatten the zones studied or excessively disturb them. Subplots were visually sampled within a 1 x 1 m PVC quadrat using white string to divide the quadrat into 100 10 x 10 cm grids (Figure 5). Each year the quadrat was placed in the two permanent positions within each plot. The type of ground cover within each of the 200 grids was determined. Species were ranked in order of cover dominance inside each grid from 1990 until 2014. If at least half the grid was bare soil, the designation of bare was given to the grid. Each grid was assigned 1-3 categories of plant and ground cover. The number of grids containing different categories of cover per 200 possible were computed (in a 2 x 1 m permanent subplot).

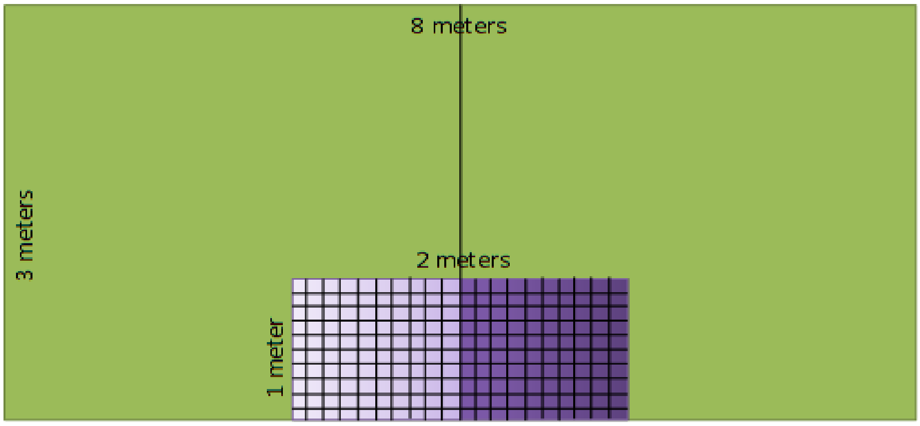

Figure 4: 3 x 8 m permanent plot with 1 x 2 m permanent subplots. *Juncus* patch and adjacent plant community.

Figure 5: Dr. Brinson with a 1 x 1 m quadrat.

The grids were counted for each taxon of plant (*Juncus*, *S. alterniflora*, *S. patens*, *D. spicata*, *Limonium nashii*, and *Salicornia* spp.) and each type of ground cover (litter, wrack, and bare) for all 8 plots. I focused on the dynamics of *Juncus* and wrack (with little litter), and studied information on which row the last continuous *Juncus* grid is located for every year and every plot. Also, the number of grids of *Juncus* and wrack each year was tracked. All of these data were used to determine how *Juncus* patch borders have moved and changed over time.

Changes in position of border of *Juncus* patches

Using the same data set as the ground cover data, I measured the last continuous *Juncus*. This was measured within the 1 x 2 m plots and gave information on which row the last continuous *Juncus* grid was located in for every year and every plot. This method was a continuous method with a maximum of 20 grid units possible, so some of the *Juncus* may have gone undetected that may have been picked up by the ground cover data set.

I extended my observations within 1 x 2 m permanent plots to have better inference on the dynamics of patches. First, in April of 2014, I measured the distance of the current border of *Juncus* and adjacent plants from the original border of *Juncus* and adjacent plants at each of 8 sites. This was done by using a piece of PVC pipe 3 m long and laying it along the original border. The PVC pipe was marked at 30 cm intervals across the 3 m for a total of 11 measurements. Another “T” shaped PVC pipe was placed on top of the 3-m long PVC pipe every 30 cm to make a right angle with the original border to ensure that I was measuring a perpendicular line out to the current border of *Juncus*. These 11 measurements were taken by extending a tape measure out from the base of the “T” shaped PVC pipe to the current border of *Juncus* and then recorded. The measurements showed how far towards the “in” or “out” *Juncus* extended at each PVC interval mark.

Floyd (2007) established 9 6-m transects within UPC in 2004, with 3 m of each inside a patch of *Juncus* and 3 m inside a mixed community of *S. patens* and *D. spicata*. These transects were established in 2004 in each of low, middle, and high marsh areas (labeled 1-9 in Figure 3). I measured the position of the interface at each location by using a tape measure on April 5, 2014.

Aboveground biomass of Juncus and other plant species

Aboveground biomass was measured in August 1990, February 1992, August 2013, and August 2014. These measurements were taken outside the 1 m x 2 m plots for ground cover but within each 3 m x 8 m permanent plot. Sampling differed slightly among years, but generally was random and 1.5-2 m away from the edge of the larger plot. A PVC pipe quadrat was used to measure a plot size of 0.0625m^2 (0.25m x 0.25m) for the years 1992, 2013, and 2014. The PVC pipe quadrat was $0.25\ \text{m}^2$ (0.5m x 0.5m) for the year 1990. There was a total of 16 aboveground biomass samples for the years 1990, 2013, and 2014, and 32 samples for the year 1992. Aboveground biomass samples were taken at each "in" and "out" area (duplicates in 1992). The plants were clipped at the base, as close to the soil as possible. They were then placed in a trash bag, tied up, and labeled with the location and date. They were taken to the lab and placed in the freezer. The plant species were separated and the different categories included *Juncus* leaves that were all green, part green, part brown, and standing dead. Other categories were *S. alterniflora* live and dead, *S. patens* live and dead, *D. spicata* live and dead, and *Salicornia* spp. live and dead. For *Juncus* "all green" means plants that are entirely green or >95% green, "part green" means the green portion of culms that have started to die, "part brown" means the brown portion of culms that have started to die, and "standing dead" means plants that are entirely dead. For the other plant species "live" means plants that have at least some portion of green on them, and "dead" means culms that are entirely brown or dead. For the years 2013 and 2014, the dead biomass for *S. alterniflora, S. patens*, and *D. spicata* were combined.

After separating the *Juncus* leaves, the number of growing (meaning all green) *Juncus* leaves were counted as well as the number of senescing (meaning part green and part brown) *Juncus* leaves for all four years. Then the growing height (cm) (meaning all green) and the total height (cm) (meaning the whole leaf, green and brown) of *Juncus* leaves (up to 20) was measured with a ruler. Samples were dried in the oven at 85°C and weighed to the nearest 0.1 g.

Site characterization

To characterize sites, measurements of other variables associated with my conceptual model were taken on both sides of the original patch interface at each of the 8 sites. The variables included macro-organic matter (August 1990, August 1991, July 1992, and June 2014), soil bulk density (August 1990, August 1991, July 1992, and June 2014), water depth (May to November 2014), and salinity (May to November 2014). All of the field data and measurements were analyzed in the laboratory at East Carolina University.

To determine macro-organic matter and soil dry bulk density (live and dead organic matter not passing through a 1-mm sieve) cores with a diameter of 3.7 cm were taken to 10-cm depth in the 4 different locations (sites A and B at each location, each containing an "in" and "out" of *Juncus*). In July of 2014, a total of 4 cores were taken within each community (i.e., in and out) within each site opposite the side of the permanent plots. A random number chart was used to determine the position of cores. The core was inserted into the soil and constantly twisted while pushing down slightly. A rubber stopper was inserted at the top, and the core was rocked back and forth to loosen the surrounding soil to try and pull the core up without losing any soil. Cores were extruded onto a cutting board. Soil from deeper than 10 cm was removed from the sample with a flat blade knife. The core samples were placed in Ziploc bags, sealed, and labeled and then returned to the laboratory.

The macro-organic matter (MOM) was separated by washing all the inorganic matter/dirt away on a 1 mm sieve. The samples were placed on the aluminum foil pans and dried at 85°C until constant weight to 0.01 g (Gallagher 1974). Approximately 1-2 g of plant samples were then homogenized through a Wiley Mill using a 40 mesh screen. Aluminum weigh pans or crucibles were marked by sample number, and then weighed to 0.01 g. Then the samples were put on the aluminum pans or crucibles, and dry weight was recorded. The homogenized samples were placed into the muffle furnace, burned at 500ºC for 3 hours and cooled overnight. This process, known as Loss on Ignition (LOI), burns off all of the organic material leaving only the inorganic contents as ash. Then, this ash weight is subtracted from the dry weight, giving the Ash Free dry mass (or the weight of organic materials), which was recorded in thousandths to 0.001. Percentage LOI of dry mass was converted to MOM as g ash free dry mass per m^2 to 10-cm depth using bulk density and core volume.

Soil dry bulk density (g/cm^3) was measured by taking one cores weight (g) from each area and dividing it by the volume (cm^3). Cores of 10 cm in length were dried at 105°C to constant weight. The cores were weighed to nearest 0.001 g and the data were recorded. The core volume was estimated the same way as the MOM data, giving a volume of 107.5 cm^3.

On Monday, April 21, 2014, PVC wells were placed in the marsh to a depth of 25 cm to measure water depth and salinity. Wells were designed by Buck (2001) and refurbished from her study. As in Buck 2001, the PVC wells were ½" (1.27 cm) with 1/8" (0.32 cm) holes drilled in them from ground level to 25 cm below the surface. The holes permitted water to be collected in the wells from adjacent soil, and 1 mm^2 mesh nylon screen was wrapped around the end with holes to slow the accumulation of sediments. The wells were placed opposite the permanent plots (on the right side of the larger plots looking into plot from outside *Juncus*) approximately 1 m from the original border of *Juncus*, and 0.5 m in from the edge of the 3 m x 8 m plots. The wells were placed within each "in" and "out" area of the 2 sites located at each of the 4 different locations for a total of 16 different salinity wells in the salt marsh. The water depth and salinity were checked once per month for the months of May, June, July, August, September, and November of 2014. The height of the salinity well above ground was measured by placing a ruler at ground level and measuring to the top of the well. Then, a wooden rod (labeled with measurements) was placed into the wells until the end hit the bottom. The original total height of the well was measured (in inches) by keeping a finger on the top of the rod exactly at the top of the well and measuring down to the very end. The height of well below ground was recorded by taking the difference between the aboveground height of the well and the original total height of the well. The measurements for water depth within the well were recorded by removing the rod from the well and measuring it from the point of wetness down to the tip. Lastly, the water depth relative to ground level were found by taking the measurement for the wet portion of the rod and subtracting the height of the well below ground. To account for the displacement of water, when using the wooden rod to measure water depth, the formula below was used.

$$h_w = \frac{h_{(w+r)} * (r_w^2 - r_r^2)}{r_w^2}$$

h_w = height of water without rod

$h_{(w+r)}$ = height of water measured on rod

r_w^2 = radius^2 of the well

r_r^2 = radius^2 of the rod

After recording the water level measurements, each well was pumped dry. This was done by using a self-made tool. A H20 Blaster Water Squirter was assembled with a short piece of a water hose on the end connected to a long piece of rubber tubing on the end. The long rubber tubing was connected to a rod to keep it straight so that it would easily reach the bottom of the wells. Once all of the water was pumped out of the well, I waited for the well to fill up again. Once it refilled the water within the well was sampled for interstitial water salinity using a refractometer.

Data and Statistical Analyses

The data were managed and initially analyzed as Excel documents. Averages, variances, and standard deviations for each plot were calculated, and graphs were made to compare data. The program R was used to analyze my data further. This included analyzing the ground cover data, last continuous *Juncus* data, *Juncus* border measurements data, Floyd (2007) transects data, aboveground biomass data (including biomass, density, and height), macro-organic matter (ash free dry mass) data, soil bulk density data, salinity data, and water depth data. For each response variable a table of results including median and means was generated, as well as a box and whisker plot. A design plot describing the locations, a multi-way ANOVA table, and a Tukey's post-hoc test for differences among locations was also often included. If the ANOVA interaction between location and year was significant at 0.05 level, an interaction plot was created. If the interaction between year and location was not significant at 0.05 level, then a post-hoc test was calculated if locations were significant. Transformations were not done because the focus of my study was on the significance of locations and their interactions. ANOVAs did not include repeated measures because year contributions to the response variable variation were addressed as a main effect.

Rates of horizontal movement of *Juncus* were calculated for all four measures of position change. For each location (1-4) and site (A or B), a regression line, r^2, rates (cm/y), and period of years were shown in the calculation of rate of horizontal movement for the last continuous

Juncus and *Juncus* ground cover data. Each grid unit equals 10 x 10 cm, so grid units are in decimeters (dm). Regressions were calculated in Excel on the period of years it took for each site to reach the first maximum (20 grids for LCJ and 200 grids for ground cover). For Last Continuous *Juncus* the outer limit of measurement was 20 grid units, so the data from the results were converted into rates of change for horizontal movement (cm/y). The rate calculations came from a regression slope (grid/year x 10 cm) of distance vs year. The same periods of years for each location and site were used for the *Juncus* ground cover data as were for the Last Continuous *Juncus* data to get the rates of the number of grids per year. The rate calculations came from the slope of the line (dm^2/m/year divided by 10 dm/m times 10 cm/dm to get cm/y). For locations that didn't reach the outer limit, a linear regression was done on the whole 24 year period. Rates of horizontal movement of 3-m wide *Juncus* patch borders (cm/y) were calculated for location and site, and then that distance was divided by the 24 years of study. Also, the rates for horizontal movement for the transect study (cm/y) was calculated by taking the average distances from each area and dividing by the number of years between the measurement date and the set up date (10 years).

RESULTS

The organization of results reflects my conceptual model. First, Table 2 is shown as an overview of the four, studied locations, including distances from a tidal creek, and the presence and absence of important species within my locations for the years 1990 and 2014 (Table 2). The distance from creeks column helps to identify the difference in hydrogeomorphology of locations, which links to species presence within the 1 x 2 m permanent plots. Some species have disappeared within a location (or certain sites) since the first year of study (1990). In the organic high marsh location (location 2), *S. patens* and *D. spicata* were both present in 1990 and no longer present in 2014. This is because *Juncus* overgrew the whole plot. In the near-creek high marsh location (location 4), *D. spicata* and *Salicornia* spp. were both present in 1990 and were shown to have disappeared by 2014; *S. alterniflora* has replaced them. In the near-creek low marsh location (location 1), *D. spicata* is shown to have been in very low abundance in 1990, and had greater presence in 2014. The subsiding marsh location (location 3) had the same species over the entire time.

Table 2: Characteristics of locations. Plant species are identified, as well as their whereabouts (measured in 1990) relative to the creek at Upper Phillips Creek marsh. The presence and absence of species within the marsh is indicated for the years 1990 and 2014. Distances to the creek are from Brinson and Christian (1999).

Upper Phillips Creek Marsh			1990	Presence (+) or Absence (-) of species (1990/2014)					
Geographic position within marsh	**Location**	**Sites**	**Distance from Creeks (m)**	***Juncus roemerianus***	***Spartina alterniflora***	***Spartina patens***	***Distichlis spicata***	***Salicornia* spp.**	***Limonium nashii***
Organic High	2	2A and 2B	300	+ / +	- / -	+ / -	+ / -	- / -	- / -
Subsiding	3	3A and 3B	120	+ / +	+ / +	+ / +	+ / +	- / -	- / -
Near-creek High	4	4A and 4B	60	+ / +	+ / +	- / -	+ / -	+ / -	- / -
Near-creek Low	1	1A and 1B	20	+ / +	+ / +	- / -	+ * / +	+ / +	+ / +
* = very low abundance									

I present data that show how the border of *J. roemerianus* moves and the difference in horizontal movement among the 4 locations at Upper Phillips Creek. These data show statistical differences among locations for rate of change between the original and current boundaries of *J.*

roemerianus, as well as give insight on patch border dynamics and the movement of adjacent plant communities. The ground cover data show statistical changes in ground cover relative to location and the importance of wrack (combined with little litter) and bordering communities. Aboveground biomass data summarize the condition of *J. roemerianus* and neighboring plants at each location. The site characterization section describes results within each of the 4 locations for environmental factors listed in my conceptual model: salinity, water depth, MOM as ash free dry mass, soil dry bulk density, and elevation.

The results are generally presented with a design plot, box plot, ANOVA table, and post-hoc test table. When statistically significant interactions were found by ANOVA, an interaction plot is presented. In all of the design plots, the horizontal black line is the overall mean for the response variable. The vertical lines represent the explanatory variables, and the distance of each vertical line (the hash marks) gives a sense of the importance of the factor in explaining the variation in the data. These hash marks are at the mean for the group defined by the level of the factor.

In all of the box plots, the darkest line in the middle of each box and whisker plot represents the median value for the response variable. The lower part of the box, known as the first quartile (Q1), is the median of the bottom half of the data. The upper part of the box, known as the third quartile (Q3), is the median of the top half of the data. One whisker extends out from the bottom of the box to the minimum nonoutlier value, and the other whisker extends out from the top of the box to the maximum nonoutlier value. The small circles indicate any outliers in the data.

A post-hoc test, more specifically Tukey's test, was used to test the differences in the 4 locations for each data set. The first column within related tables, "Location," shows the two locations being compared. The second column, “Difference,” shows the difference between the two locations. The third column, “Lower 95% CI,” shows the lower value of the 95% confidence interval (CI) of the differences. The fourth column, “Upper 95% CI,” shows the upper value of the 95% CI of the differences. The last column, “P value adjusted,” represents the P value adjusted for multiple comparison. Also, for some of the design plots in my study with location as an explanatory variable, locations are ranked according to these post-hoc tests. They are ranked by statistically significant post-hoc categories (a-d), with “a” being the highest and the letter farthest along the alphabet being the lowest. Any letters (a-d) may be combined in order to display which locations are similar. Where these letters are displayed, an ANOVA showed no significant interaction between location and year. If an ANOVA indicated that there was significant interaction between location and year, most of the time a post-hoc test was not done, an interaction plot is shown, and patterns are explained in text.

An interaction plot shows a response variable on the y-axis and time on the x-axis. The means of the response variable for each location are displayed with connecting lines between samplings.

Patch border dynamics and horizontal movement of *Juncus* across the original border

Last Continuous Juncus

The following section expresses how *J. roemerianus* is related to patch border dynamics. It describes how the *J. roemerianus* border is moving horizontally. Again, “last continuous *Juncus*” refers to the very last grid (within each of the 10 columns) in which *Juncus* was found, continuous from the “in” plot. This number can range from 1 to 20, and can’t have a value greater than 20. So, the information from the data are limited when the column meets the 20th grid. Each grid unit equals 10 x 10 cm. Thus, a mean of 10.6 grid units equals 106 cm from the edge of the plot interior to the *Juncus* patch. The units in the following sub-sections are in decimeters (dm).

Averaged over the 8 sites, the borders of *Juncus* patches have expanded from 1990 to 2014 (Table 3). Note, that the number 1 represents that *Juncus* is $\geq$ 0.9 m inward from the original boundary, 10 and 11 divide the original boundary established in 1990, and 20 represents that *Juncus* is $\geq$ 0.9 m outward from the original boundary. In 1990 the mean value across the 10 rows for *Juncus* was at 10.5 dm, which was near the predicted original boundary of 10 dm, and the standard deviation was 2.2. By 2014, the mean value moved out to 15.3 dm, with a standard deviation of 5.5. Also, the standard deviations are shown to have increased over time as the differences among locations increase. Furthermore, there is a general trend outward with various years of inward movement. Inward movement may have been related to storm events, which is discussed later.

Table 3: Descriptive statistics of position of *Juncus* border over all locations in grids of 1 dm in length. The numbers 1-20 represent the row in which *Juncus* was found within the 1 x 2 m permanent plot. The number 1 is at the most inward portion of the "In" area of each site. Numbers 10 and 11 represent the most outward portion of the "In" and the most inward portion of the "Out" area (in that order) in which *Juncus* was found. Right around these two numbers lies the original horizontal boundary between *Juncus* and bordering communities. The number 20 represents the most outward portion of the "Out" area in which *Juncus* was found.
*Note: Number of samples for all years (1990 to 2014) was 80, except the year 2011 had only 40 samples. Locations 2 and 3 were not sampled during this year.

LCJ	min	Q1	median	Q3	max	mean	sd
1990	5	9	10	12	17	10.5	2.2
1991	6	9	10	12	18	10.6	2.1
1992	5	10	10	12	20	11.2	2.5
1993	6	10	10	11	20	10.9	2.8
1994	9	10	11	12	20	11.8	2.7
1995	0	10	11	13	20	11.1	4.6
1996	0	10	12	13	20	11.2	4.8
1997	0	9.8	11	13.3	20	11.1	4.9
1998	0	9.8	12	15	20	11.9	5.1
1999	0	9	13	15.3	20	12.1	5.4
2000	0	9.8	12.5	16	20	12.6	5.4
2001	0	10.8	14	17.3	20	13.6	5.5
2002	0	10	14	18.3	20	13.3	5.9
2003	0	11	14	20	20	14.1	5.9
2004	0	12	15	20	20	14.4	6.0
2005	0	12	15	20	20	14.5	5.8
2006	0	13	15.5	20	20	14.7	5.8
2007	0	10	16	20	20	14.5	5.8
2008	0	13	16	20	20	14.9	5.8
2009	0	14	16	20	20	15.4	5.5
2010	0	13	15.5	20	20	15.2	5.6
2011	0	9	18	20	20	14.4	6.6
2012	0	10.8	15	20	20	14.8	5.4
2013	1	10.8	15	20	20	14.7	5.6
2014	1	14	16.5	20	20	15.3	5.5

The design plot shows data for the mean of the Last Continuous *Juncus* (LCJ) data related to the 3 explanatory variables year, location, and site (Figure 6). The mean values of location for Last Continuous *Juncus* were averaged for each location and over all the years, 1990 to 2014 (Figure 6). ANOVA for Last Continuous *Juncus* data for locations, found individual locations do act differently from one another (p<0.0001 level) (Table 4). Also, there was a significant interaction between location and year at the p=0.001 level (Table 5). Locations 4 and 2 were barely significantly different (p=0.05), and all of the other locations were significant at the p<0.0001 level (Table 6).

Differences in LCJ among locations can be found for data aggregated across years. A very large amount of variation occurred at location 1 (because of site B to be discussed later), especially at the lower end where 2 outliers are seen in the box plot (Figure 7). At location 4, there was little to no variation because the LCJ reached the upper limit of 20 grids quickly. The *Juncus* border at location 2 reached the upper limit as well, just for not as long as at location 4. This is why there was little variation shown towards the upper limit of location 2 (Figure 7).

The difference among years (1990-2014) was statistically significant (Table 4). As expected, the mean for the year 1990 was approximately 10 dm, which was where the original border between *J. roemerianus* and adjacent plant communities was established (Figure 6). The year 2009 had the highest mean, followed very closely by year 2014. Site B had a lower mean value, which was probably largely because of location 1 site B (Figure 6).

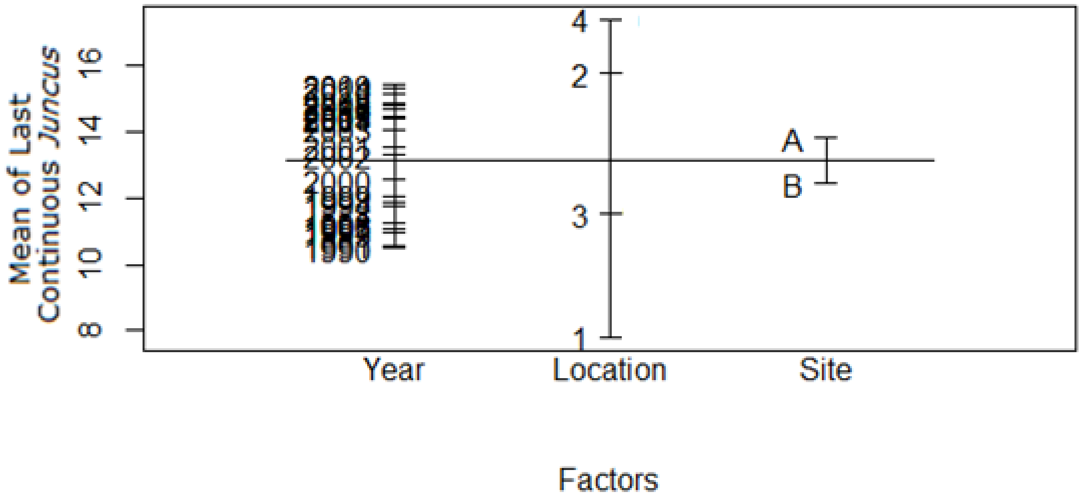

Figure 6: The mean of the last continuous *Juncus* (dm) for the various groups created by the explanatory variables: year, location, and site.

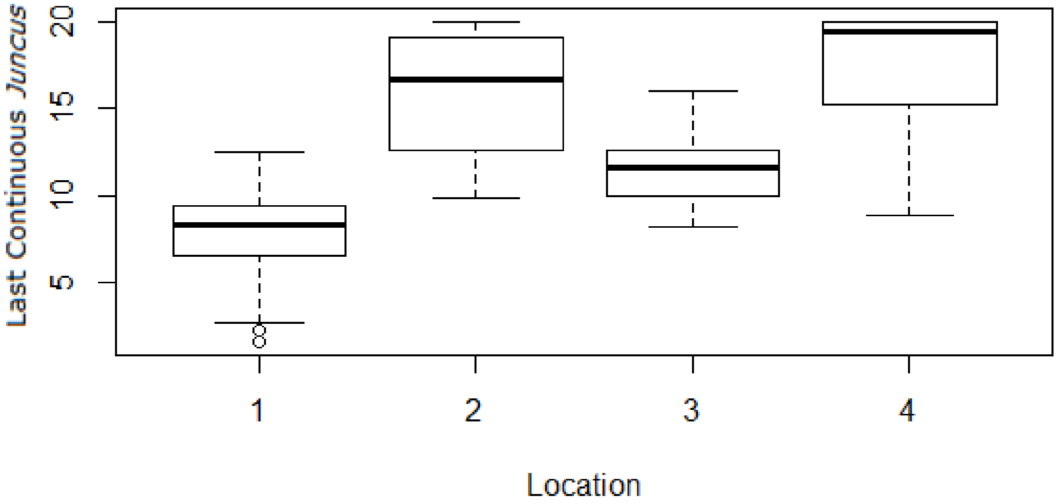

Figure 7: Last continuous *Juncus* (dm) descriptive statistics for the 24 years at each location. Shows how far "in" or "out" *Juncus* moved relative to the original border.

Table 4: Last continuous *Juncus* data. ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Year	24	572.0	23.8	3.888	< 0.0001 ***
Location	3	2816.1	938.7	153.139	< 0.0001 ***
Site	1	94.5	94.5	15.417	< 0.000126 ***
Residuals	167	1023.7	6.1		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 5: Last continuous *Juncus* data. ANOVA year * location Interaction.

ANOVA summary for year * locations					
	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Year	24	572.0	23.8	4.752	< 0.0001 ***
Location	3	2816.1	938.7	187.156	< 0.0001 ***
Year:Location	70	626.6	9.0	1.785	0.00407 **
Residuals	98	491.5	5.0		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 6: Last continuous *Juncus* data. Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	8.0036	6.4466	9.5606	0.000
3-1	3.7411	2.1841	5.2981	0.000
4-1	9.6300	8.0890	11.1710	0.000
3-2	-4.2625	-5.8353	-2.6897	0.000
4-2	1.6264	0.0694	3.1834	0.037
4-3	5.8889	4.3319	7.4459	0.000

The patterns for means of LCJ were shown for each of the 8 sites (Figure 8 and Figure 9). High marsh sites for locations 2 and 4 moved outward the fastest over the years. The outer limit of means (i.e., 20 grid units) was reached during the years 2001 to 2011 by site 4A. Throughout the years 2004 and 2011, site 4B also reached the outer limit. Site 2B reached the outer limit during the years 2005 through 2014; though, there were no data for this site for the year 2011. However, it can be assumed that it was at or beyond the outer limit (Christian, personal communication). Sites at location 3 moved little. The low marsh location (location 1) moved inward.

The potential impacts of storm-induced wrack can be seen. The low marsh locations were likely to be impacted by wrack more than the high marsh locations. Location 1 site B experienced a major inward spike in 1995. Also, Location 4 site B experienced a relatively large inward spike in 2011, and a relatively large outward spike in 2013. The years of inward movement for various locations occurred between 1992 and 1993, 1994 and 1995, 1996 and

1997, 2001 and 2002, 2006 and 2007, and between years 2012 and 2013. Also, inward movement started in the year 2009 and continuously moved inward through 2010 and into 2011.

Major storms causing significant wrack events occurred at major dips or spikes on the graphs. These storms are indicated by vertical grey lines (Figure 8 and Figure 9). The *Juncus* information in both graphs is the same except for the positions of the vertical grey lines. The grey lines in Figure 8 show the years in which nor'easters occurred, and in Figure 9 they represent the years in which hurricanes occurred and impacted Upper Phillips Creek. Nor'easters occurred near UPC during the years 1994, 1996, 1998, 2000, 2007, 2009, 2011, and 2013 (Figure 8). Hurricanes occurred near UPC during the years 1996, 1998, 1999, 2003, 2004, 2005, 2006, 2008, 2011, 2012, 2013, and 2014 (Figure 9).

The definition of hurricanes refers to historical records that list tropical storms as causing significant damage in eastern Virginia (http://www.erh.noaa.gov/akq/adobe_pdf/Hurrhist.pdf). The source of information on hurricanes throughout my thesis also comes from the aforementioned site. The source of information on nor'easters throughout my thesis comes from the following sites (http://www.erh.noaa.gov/lwx/Historic_Events/va-winters.htm , http://www.nhc.noaa.gov/data/tcr/index.php?season=2012&basin=atl , http://www.stormsurge.noaa.gov/event_history_2010s.html). The definition of nor'easters refers to the biggest winter storms in Virginia, which bring high pressure, artic flow of cold and dry air (http://www.erh.noaa.gov/lwx/Historic_Events/va-winters.htm), and some that even deposit wrack over the marsh.

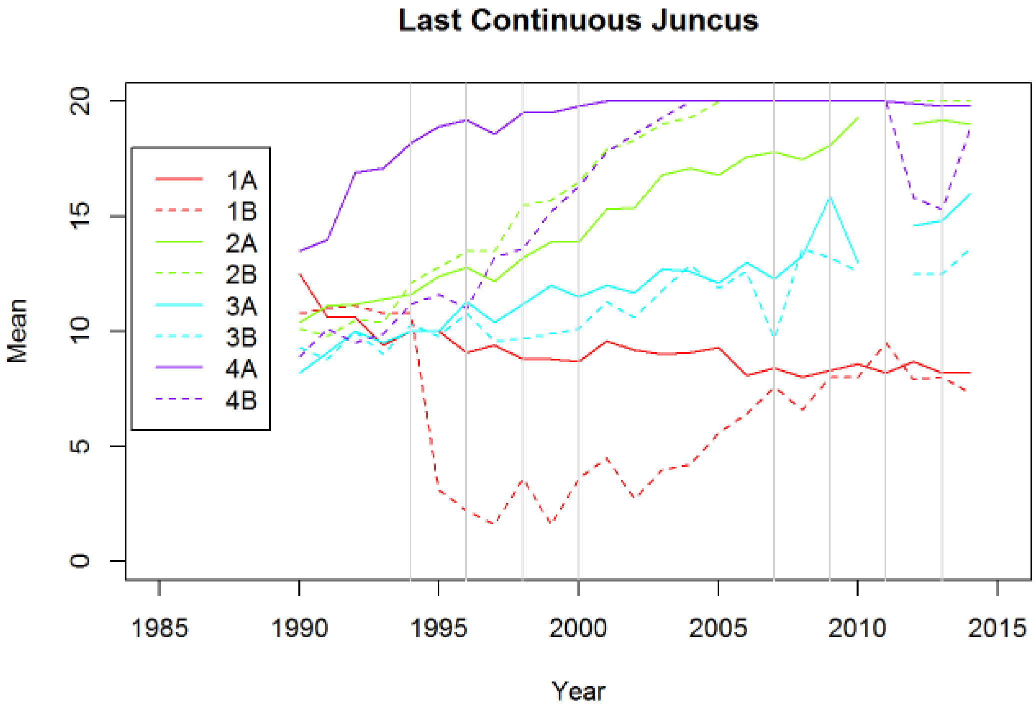

Figure 8: Last continuous *Juncus* mean values (dm) averaged for all 10 rows in which *J. roemerianus* was found at each location and site within the marsh for all the years 1990 through 2014. The vertical lines show times of potential major wrack events caused by nor'easters.

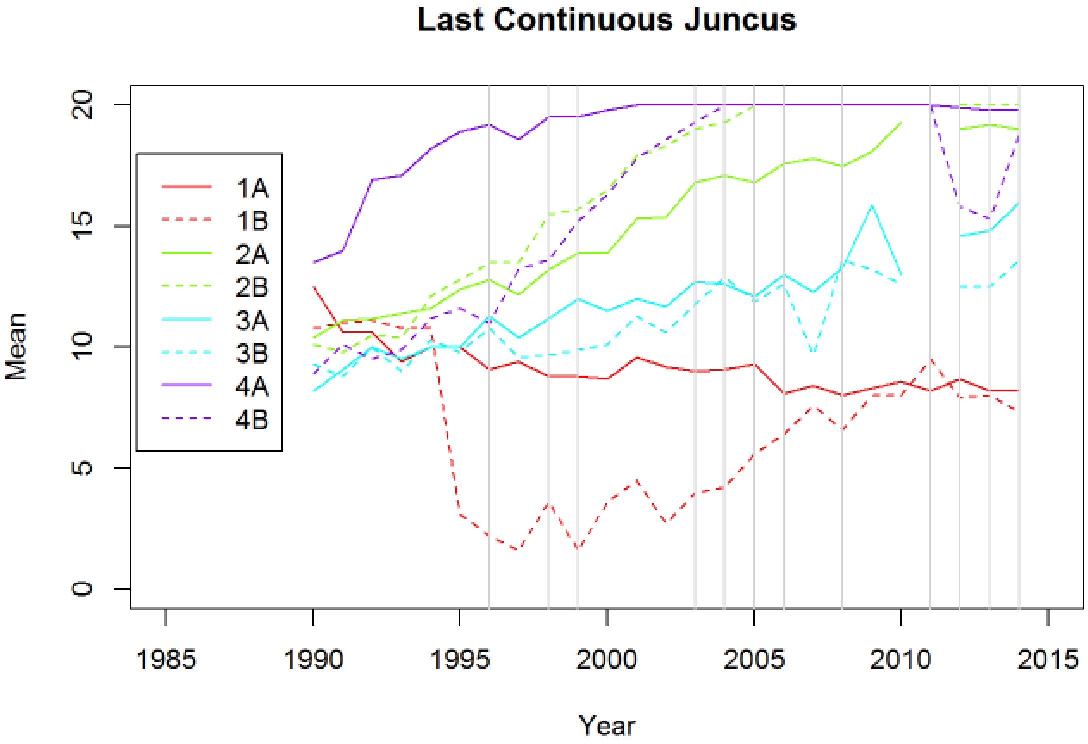

Figure 9: Last continuous *Juncus* mean values (dm) averaged for all 10 rows in which *J. roemerianus* was found at each location and site within the marsh for all the years 1990 through 2014. The vertical lines show times of potential major wrack events caused by hurricanes.

The years of inward movement is indicated by inward movement of LCJ position. This was determined by a dip of at least 2 dm (occurring at least at one site). Years with this inward movement were compared to occurrences of storms and wrack (Table 7). To determine whether or not wrack was present during the years of inward movement, 50 or more grids had to contain wrack between those time periods. Usually when a nor'easter occurred a great amount of wrack was deposited on the marsh, however that was not the case in 2009-2010. The nor'easter in 1994 seemed to be the most important, showing the biggest dip at location 1 site B (Figure 8). Also, in 2011, there was a large dip at location 4 site B (Figure 8). This is likely due to the fact that there was a major nor'easter and a major hurricane that occurred during the period of years 2010-2011 (Table 7).

Table 7: The presence or absence of a Nor'easter or Hurricane, along with the presence or absence of wrack, is noted for the period of years with inward movement.

Years of Inward Movement	Major Nor'easter	Major Hurricane	Wrack
1992-1993	-	-	+
1994-1995	+	-	+
1996-1997	+	+	+
2001-2002	-	-	-
2006-2007	+	+	+
2009-2010	+	-	-
2010-2011	+	+	+
2012-2013	+	+*	+

Note: Inward movement was continuously noted from 2009 until 2011.
* = 2 hurricanes occurred during those years.

Ground cover for Juncus

Ground cover data for *Juncus* were related to factors location, site, and year (Figure 10). The difference among locations was statistically significant at the $p<0.0001$ level (Table 8). Location 4 had the most *Juncus* at a mean over the 24 years of approximately 190 grids or dm^2, followed by location 2 around 160 dm^2, then location 3 at 115 dm^2, and location 1 with the least amount of *Juncus* at 70 dm^2 (Figure 10). However, there was a significant interaction between location and year at p=0.01 (Table 9). A larger amount of variation occurred at location 1 (because of site B) (Figure 11). At location 4, very little variation occurred at the upper portion of the box plot because it almost reached the maximum of 200 dm^2 (Figure 11). An interaction plot of *Juncus* ground cover (dm^2) is also shown for the four locations over the 24 years (Figure 12). The year and location interaction (Table 9) was probably because of location 4, which had the highest amount of grids with *Juncus* over the majority of the years (Figure 12). However, all locations were similar in 1990. Also, location 4 showed two major decreases in 2005 and in 2011, largely because of wrack occurrence at site B. At location 4 there were 198.4 dm^2 grids containing *Juncus* in 2011 and 144 dm^2 in 2012, and then it went back up to 172 dm^2 by 2014. Location 2 has been steadily increasing since 1990, reaching 195 dm^2 by 2014. Location 3 also steadily increased over the years, reaching 147 dm^2 by 2014. Location 1 started out with the highest amount of grids containing *Juncus* in 1990, but has been slightly decreasing over the years. Its major decrease was in 1994 because of wrack deposited at site B. Location 1 had the lowest amount of grids containing *Juncus* at 52.5 dm^2 by 2014.

The difference between years and sites were also statistically significant (Table 8). Year was statistically significant at the p=0.001 level, and sites were statistically significant at the p<0.0001 level (Table 8). A further ANOVA for interactions was done, and there was no significant interaction between year and site. Also, year 2009 had the highest mean, and the year 1990 had the lowest mean (Figure 10). Site B was less than site A, again reflecting the impact of wrack.

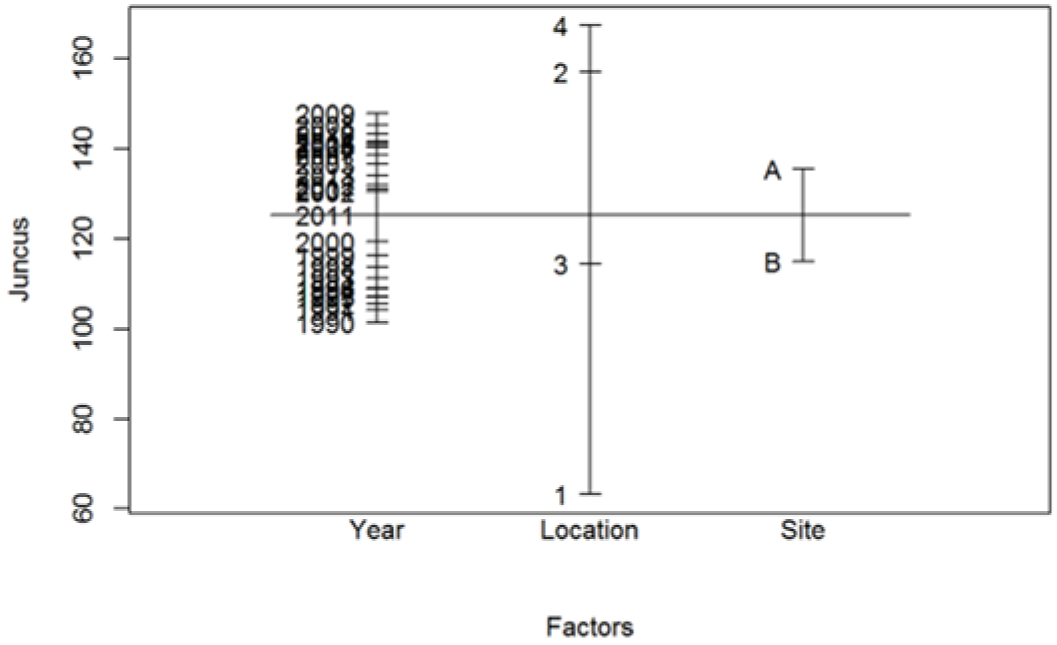

Figure 10: Ground cover data for *Juncus* (dm^2) related to the factors location, site, and year.

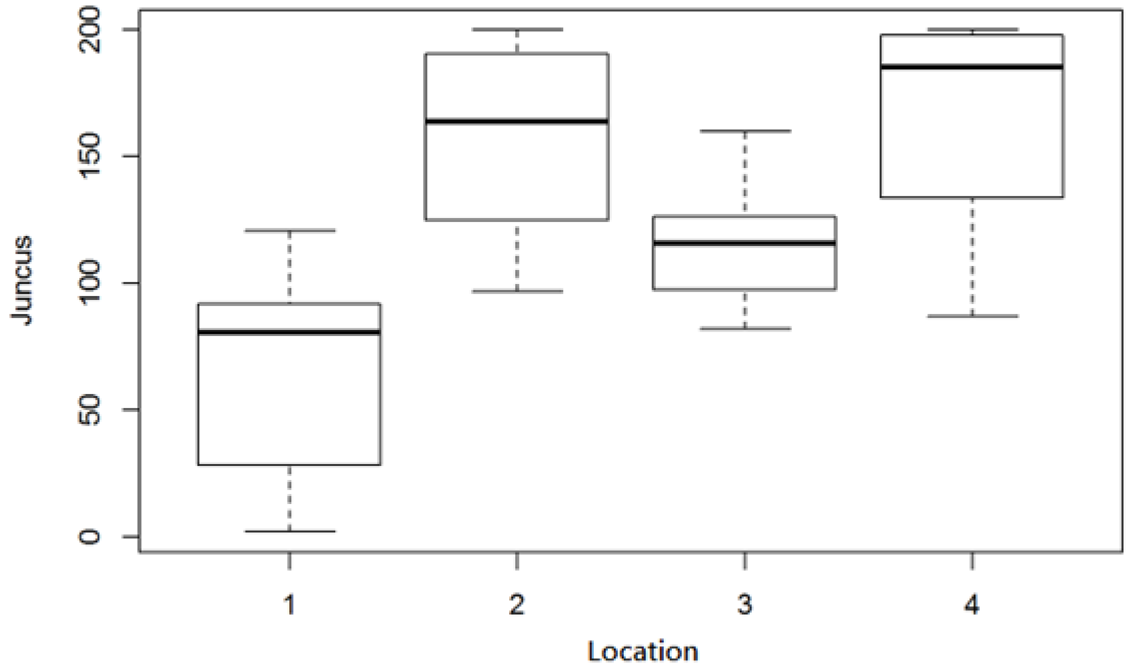

Figure 11: Ground cover of *Juncus* (dm^2) assessed over the 25 samplings for each location. Shows how far "in" or "out" *Juncus* moved relative to the original border.

Table 8: Ground cover data for *Juncus*. ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Year	24	46144	1923	2.22	0.0018 **
Location	3	335992	111997	129.45	< 0.0001 ***
Site	1	20715	20715	23.94	< 0.0001 ***
Residuals	167	144483	865		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 9: Ground cover data for *Juncus*. ANOVA year * location Interaction.

ANOVA summary for year * locations					
	Df	*Sum Sq*	*Mean Sq*	*F value*	*Pr(>F)*
Year	24	46144	1923	2.33	0.0019 **
Location	3	335992	111997	135.67	< 0.0001 ***
Year:Location	70	84297	1204	1.46	0.0422 *
Residuals	98	80902	826		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

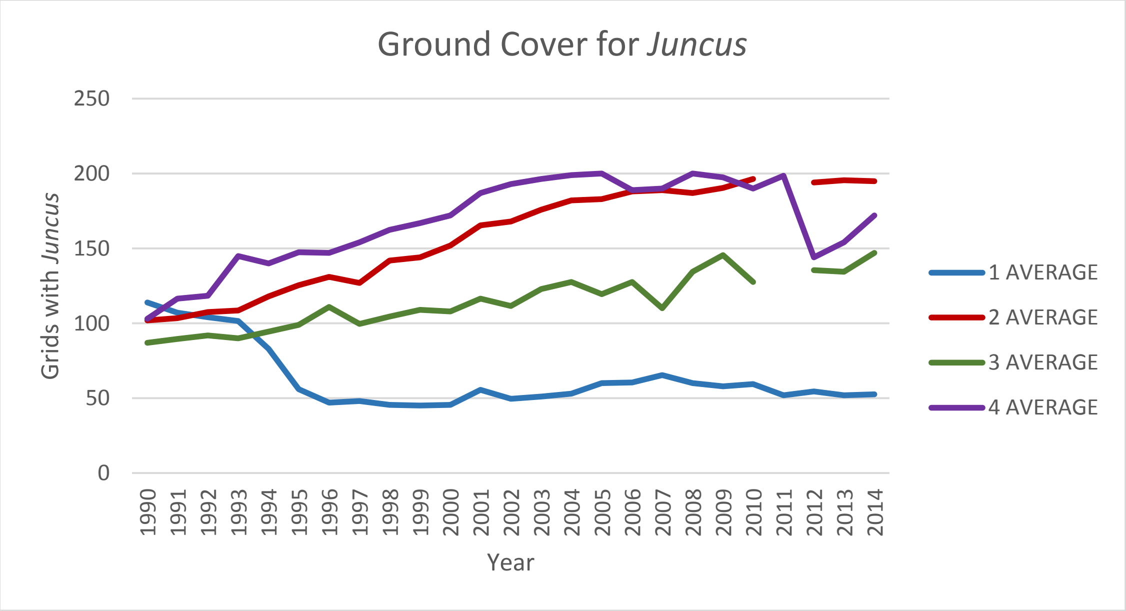

Figure 12: Ground cover data for *Juncus* (dm^2) over the 24 years for each of the four locations.

Ground cover for Wrack

The Ground cover data for wrack were related to factors location, site, and year (Figure 13). The difference among locations was statistically significant at the $p<0.0001$ level (Table 10). Location 4 had the highest average amount of wrack, at 30 dm^2. Locations 1 and 2 were similar with 10-12 dm^2, and location 3 had the lowest amount at 5 dm^2 (Figure 13). The distribution of wrack was quite patchy. Location 1 had a median value of only 0 dm^2 with many outliers (Figure 14). One outlier was as high as 200 dm^2, meaning at least one of the 2 sites at location 1 reached 200 dm^2. This 200 dm^2 was likely because of the large amount of wrack deposited in 1994 at location 1 site B. Location 2 had a median value at 0 dm^2, with some variation between the 2 sites, up to 50 dm^2. Also, in location 2, some outliers ranged up to 75 dm^2 (Figure 14). Location 3 also had a median value at 0 dm^2 with no variation, but many outliers. The outliers range from 0 dm^2 to 100 dm^2. Location 4 had a median value at 5 dm^2 with variation up to 100 dm^2. One outlier ranged up to 150 dm^2 (Figure 14).

The year 1994 had a much higher mean than the rest of the years and contributed much to the source of outliers (Figure 13). There was a significant interaction between year and location ($p=0.001$) (Table 11). An interaction plot of grids containing wrack (dm^2) was also shown for the four locations over the 24 years (Figure 15). Location 1 showed a spike in 1994, because of the nor'easter, causing wrack to reach 143 dm^2. Location 4 showed a spike in 2006, causing wrack to reach 72.5 dm^2. There was also a large spike in 2011, causing wrack to reach 64.5 dm^2 and 86 dm^2 by 2012. After 2012 the wrack decreased to 52 dm^2 by the year 2014. The year and location interaction (Table 11) was probably because of location 1 site B and location 4 site B. The difference between years and sites were also statistically significant at the $p=0.001$ level (Table 10). However, a further ANOVA including interactions was done, and there was no significant interaction between year and site. Although there was no significant interaction, a relationship can still be seen with various sites (Figure 16). The large amount of variation from location 4 (Figure 14) comes largely from location 4 site B (Figure 16). Also, the large variation at location 1 (Figure 14) can be explained because of location 1 site B (Figure 16). With so many outliers and differences between means and medians, these data are probably far from normal. Therefore, they do not meet the assumptions of the ANOVA; though, everything looks significant.

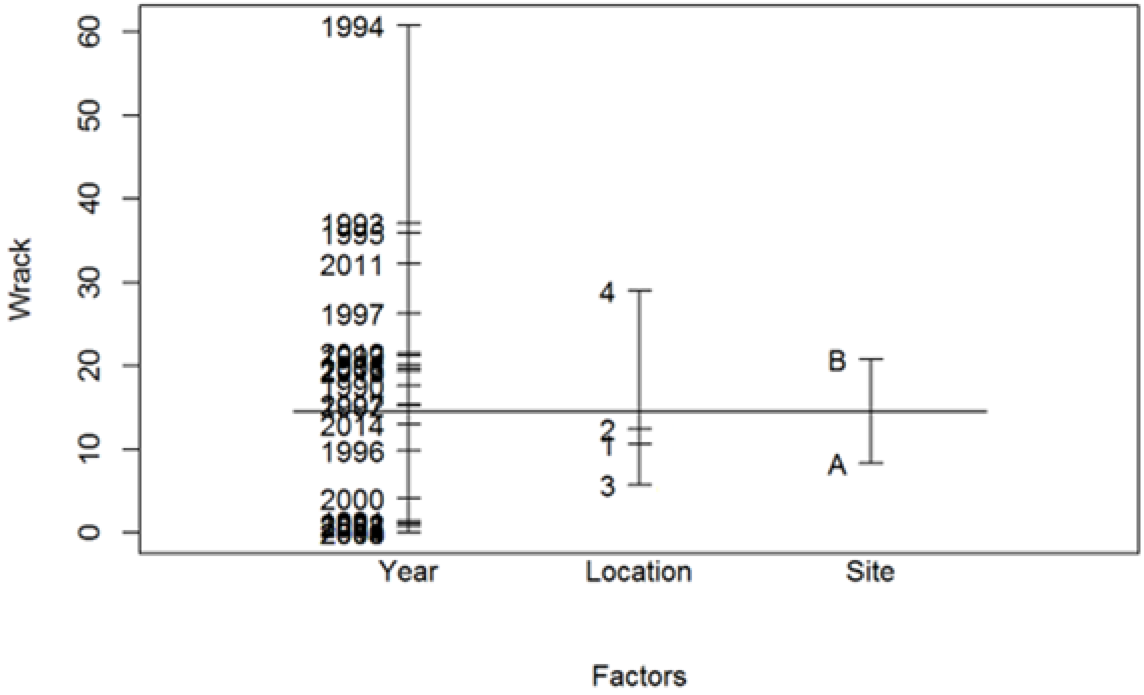

Figure 13: Ground cover data for wrack (dm^2) related to the factors location, site, and year.

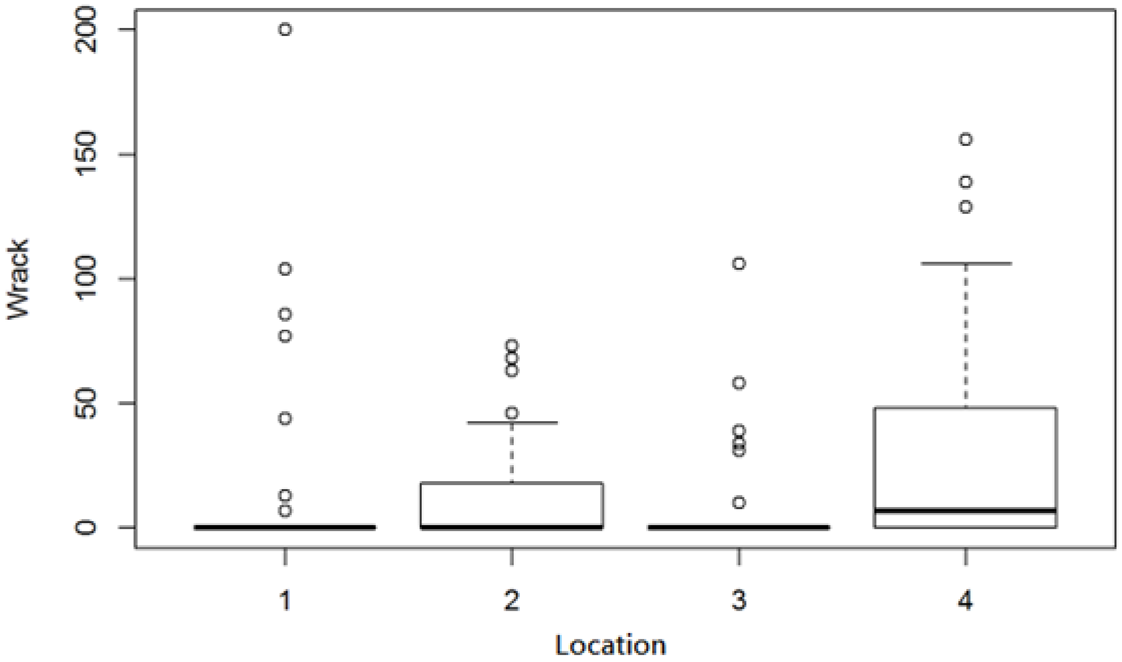

Figure 14: Ground cover data for wrack (dm^2) assessed over the 25 samplings for each location.

Table 10: Ground cover data for Wrack. ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	24	44200	1842	2.27	0.00134 **
Location	3	14424	4808	5.93	0.00072 ***
Site	1	7656	7656	9.45	0.00247 **
Residuals	167	135343	810		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 11: Ground cover data for Wrack. ANOVA year * location Interaction.

ANOVA summary for year * locations					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	24	44200	1842	2.90	0.00012 ***
Location	3	14424	4808	7.57	0.00013 ***
Year:Location	70	80730	1153	1.82	0.00324 **
Residuals	98	62268	635		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

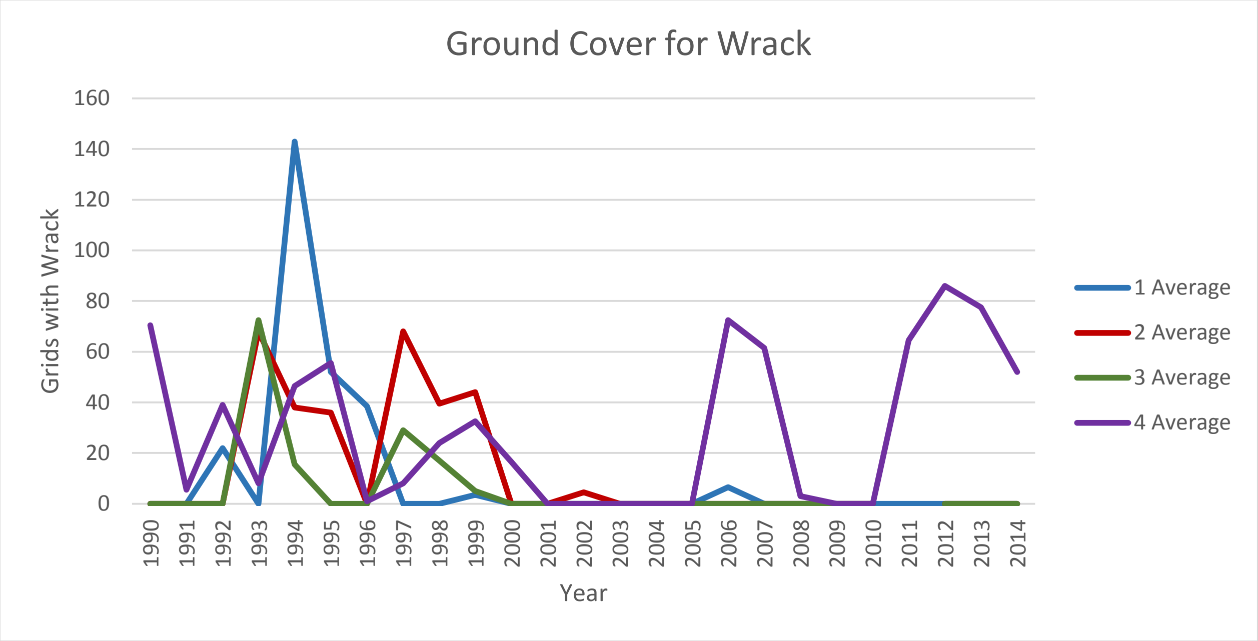

Figure 15: Ground cover data for wrack (dm^2) over the 24 years for each of the four locations.

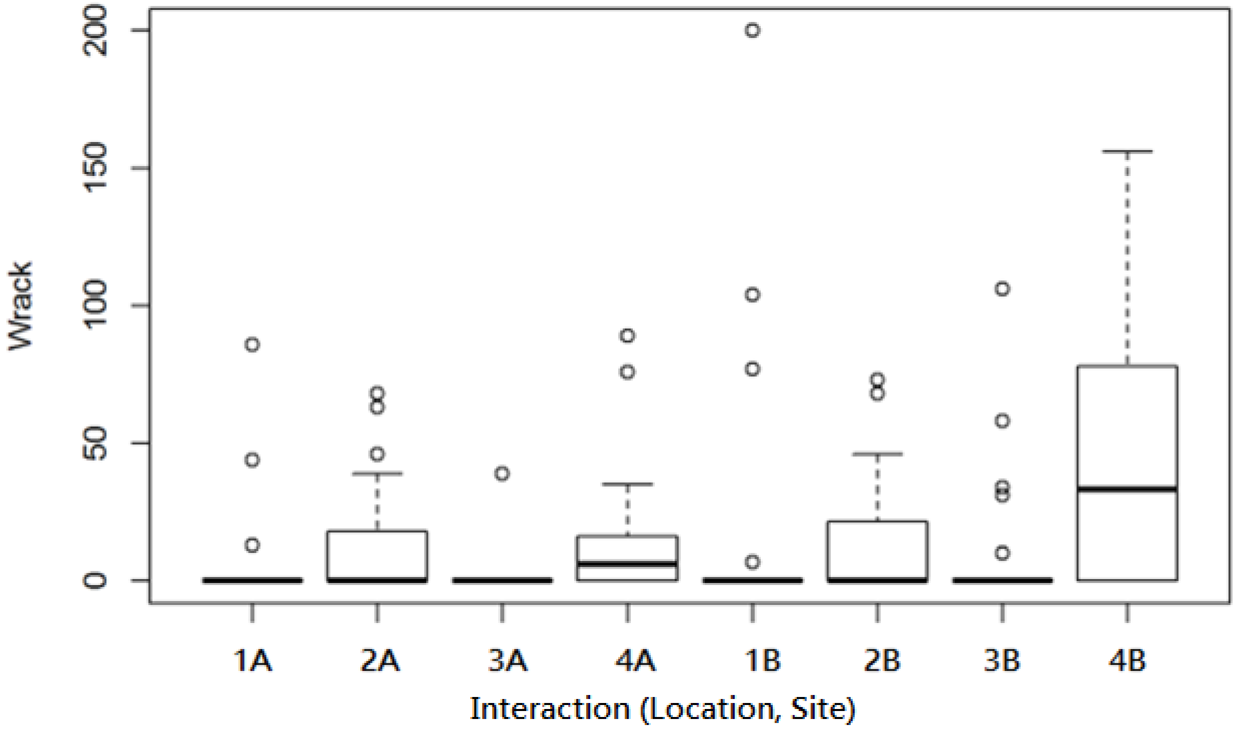

Figure 16: Ground cover data for wrack (dm^2) assessed over the 25 samplings for each location and site.

Wrack clearly had an effect on *Juncus*, especially at the Near-creek Low marsh (Location 1 site B) (Figure 17) and the Near-creek High marsh (Location 4 site B) (Figure 18). On both graphs, the x-axis shows the years sampled, and the y-axis shows the number of 10 x 10 cm grids per the 200 possible (in a 2 x 1 m permanent subplot) that included that category of plant and ground cover.

Location 1 site B (Figure 17) experienced a major wrack increase (a maximum of 200 grid units) in the year 1994 and a decrease in *Juncus* (from 109 grid units in 1993 to 78 grid units in 1994). This was mainly because of the nor'easter that occurred in year 1994. *Juncus* reached its lowest point of 2 grid units in 1997. As the wrack diminished completely (0 grid units) in the year 2000, *Juncus* began to recover (15 grid units) in the year 2001, and was at 29 grid units in the year 2014. The year 1994 and location/site 1B had the highest wrack cover over my whole study.

Figure 18 shows many increases and decreases in *Juncus* vs Litter/Wrack over the years at Location 4 site B. Major hurricanes and nor'easters, in relation to wrack deposition from nor'easters, are what caused the fluctuations in *Juncus* the majority of the time (Figure 8 and Figure 13). In 1991, *Juncus* was at 100 grid units, and wrack was at 3 grid units. By the year 1992, *Juncus* had decreased to 87 grid units, because of the increase in wrack to 78 grid units. In 1993, wrack decreased to 0 grid units; therefore, *Juncus* was able to increase to 129 grid units. Wrack stayed fairly low (between 0 grid units and 56 grid units) from the years 1996 to 2010, which allowed *Juncus* to reach its maximum value of 200 grid units by the year 2005. However, in the year 2011 a wrack event occurred causing wrack to increase to 129 grid units and then to its peak of 156 grid units by 2012. By the year 2012, *Juncus* had decreased to 90 grid units because of the impacts of wrack cover. Lastly, by the year 2014, wrack began to decrease to 86 grid units, allowing *Juncus* to recover to 146 grid units.

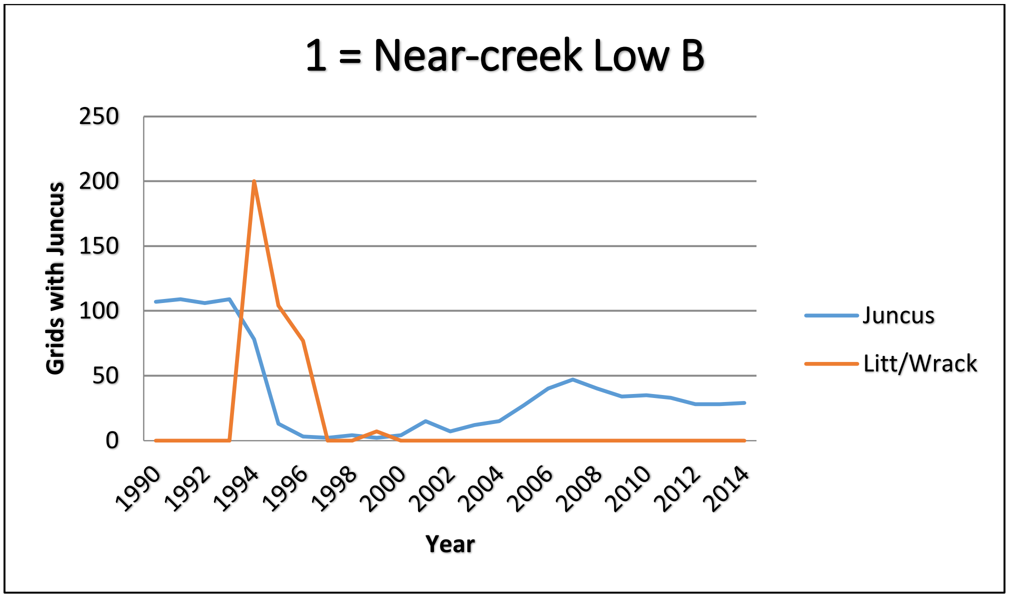

Figure 17: Permanent plot data on groundcover for *Juncus* vs. Litter/Wrack (dm^2) for Location 1 Site B from 1990 to 2014.

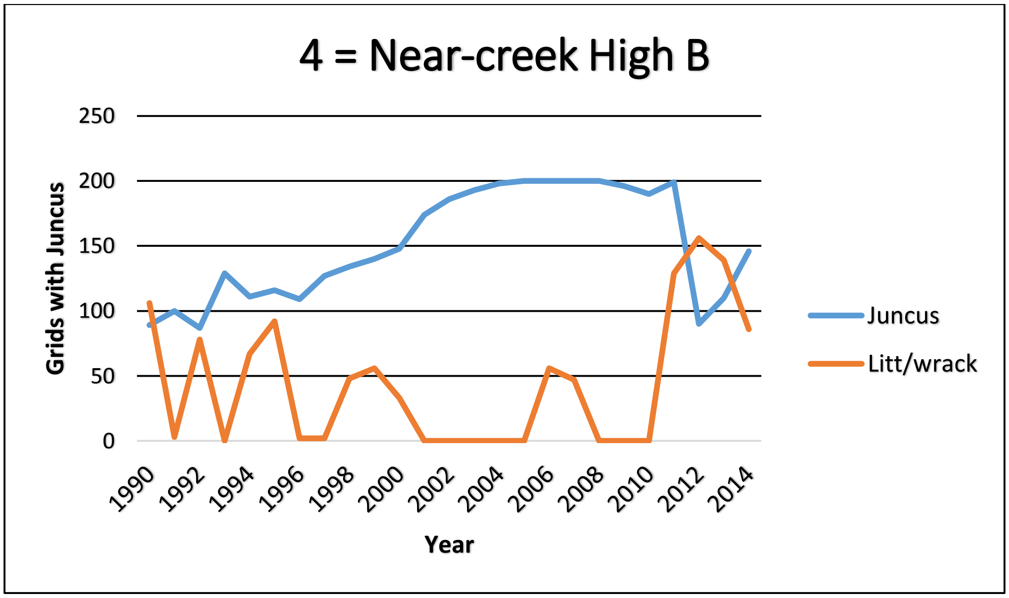

Figure 18: Permanent plot data on groundcover for *Juncus* vs. Litter/Wrack (dm^2) for Location 4 Site B from 1990 to 2014.

Juncus 3-m Wide Border Position

The following section addresses movement of the 3-m wide border along all 8 *J. roemerianus* patches. In this case, the original *Juncus* border boundary line (where a PVC pipe was placed) was set at 0 cm. The border in summer 2014 was compared to the original 3-m wide border in 1990. The 11 measurements taken at each site (every 30 cm from 0 to 300 cm) were used to determine how far “in” or “out” the border has moved since 1990. This was done to give insight on *Juncus* patch border dynamics at a larger scale than for the 1-m wide plots.

Figure 19 shows that location 4 had the highest mean for *Juncus* border data measurements at 250 cm, followed by location 2 at 150 cm; while locations 1 and 3 had very similar and lower means at 10 cm ($p = 0.999$) (Table 14). The 1 x 2 m plots had an upper limit of 100 cm when compared to this method. The wider border at locations 2 and 4 exceeded the limits of the plots while the borders at 1 and 3 remained within the 1 x 2 m plot limits. There was insignificant difference between the two sites (A and B) (Table 13).

The PVC marks 0-120 cm were considered edge of the 1 x 2 m plots, and all of the other PVC marks were considered non-edge. The differences among locations for edge effects to the 1 x 2-m plots were barely significant ($p=0.051$) (Table 13). Thus, an edge effect for the original 1 x 2 m plots may be present as the distances at PVC marks 0 and 120 were lower than the rest of the measurements (Figure 19 and Table 12). This decrease in movement likely came from the disturbance of walking outside the edge of the quadrats for the annual 1 x 2 m ground cover measurements.

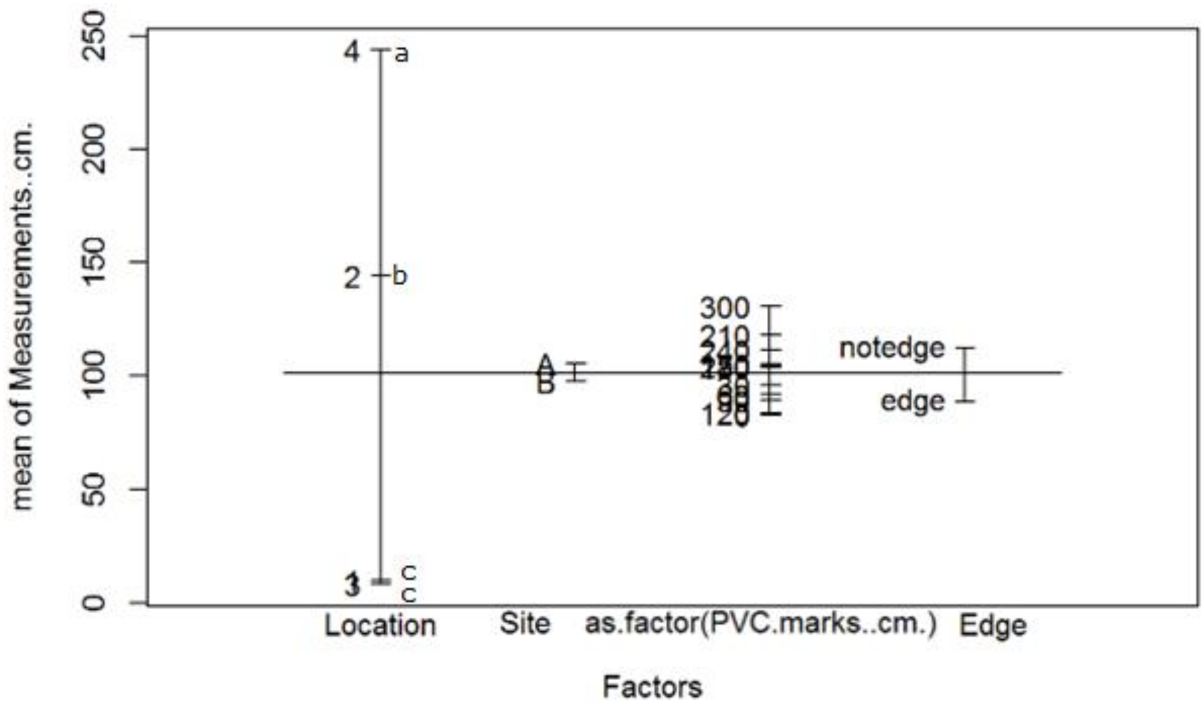

Figure 19: *Juncus* 3-m wide border position (cm) related to the factors location, site, PVC marks, and edge. The locations were ranked by statistically significant post-hoc categories (a-d), with “a” being the highest and the letter farthest along the alphabet being the lowest. Any letters (a-d) may be combined in order to display which locations were similar or different in patterns.

Table 12: Mean values in order of lowest to highest along with their corresponding PVC mark.

Mean values (cm)	PVC Marks (cm)
83.0	0
83.6	120
89.3	90
92.0	60
96.0	30
103.9	180
104.4	270
105.1	150
111.6	240
118.1	210
130.8	300

Table 13: *Juncus* border data. ANOVA summary for location, site, and edge.

ANOVA summary for location + site + edge					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	863782	287927	93.31	< 0.0001 ***
Site	1	1384	1384	0.45	0.505
Edge	1	12062	12062	3.91	0.051 .
Residuals	82	253016	3086		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 14: *Juncus* border data. Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	134.364	89.85	178.88	0.000
3-1	-1.818	-46.33	42.69	0.999
4-1	234.136	189.62	278.65	0.000
3-2	-136.182	-180.69	-91.67	0.000
4-2	99.773	55.26	144.29	0.000
4-3	235.955	191.44	280.47	0.000

Figures 20 and 21 show evident differences among locations and provide details of the data summarized in Figure 19 by highlighting the fact that at location 1 site B, the 1 x 2 m plot was not representative of the larger length. Location 1 Site B was largely responsible for the large amount of variation shown in location 1 as a whole (both A and B combined) (Figure 20). At location 1 site B the impacts of wrack on *Juncus* were much more severe with inward movement than beyond the 1 x 2 m plot (Figure 21). At site 1B there was a major dip in the data between 30 cm and 150 cm, showing that *Juncus* has moved a lot more inward (Figure 21). Also, the wider border at locations 2 and 4 exceeded the limits of the 1 x 2-m plots.

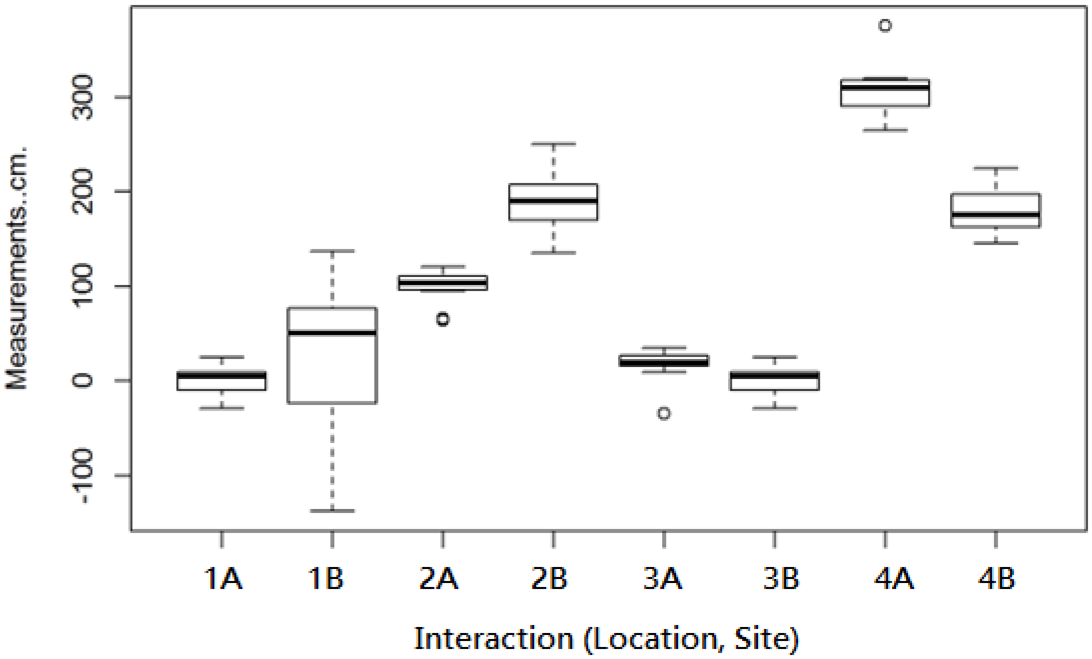

Figure 20: *Juncus* border measurements (cm) by site. These data indicate how far inward (negative values) or outward (positive values) *Juncus* moved from 1990 until 2014.

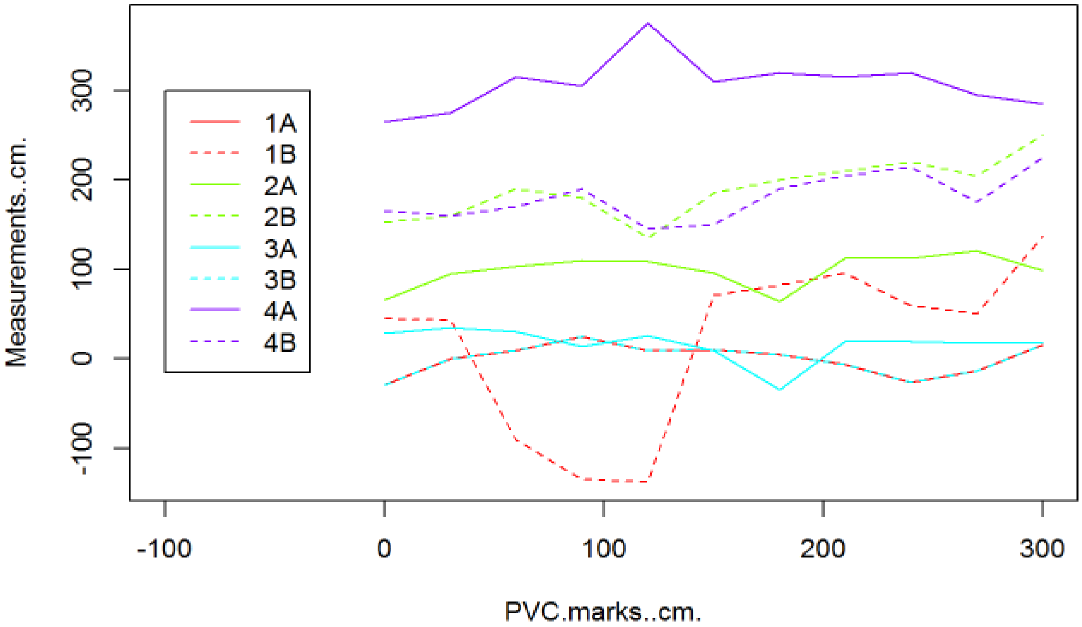

Figure 21: *Juncus* border measurements (cm). A plot of the shapes over the 3-m wide PVC marked boundary. The closer the measurements were to 300 cm, the further outwards the *Juncus* moved. The closer to -100 the measurements were, the further inwards the *Juncus* has moved.

Transect Position

The following data are an extension of transect measurements conducted by Floyd (2007). The location of the border in 2004 was considered 0 cm. These data (measured April 5, 2014) show how far *J. roemerianus* has moved away from the original position in 9 6-m transects, established in 2004 (Figure 3). No inferential statistics were used for these data because only 9 measurements were taken (Table 15). These 9 observations support aforementioned sections regarding Last Continuous *Juncus* and *Juncus* Border Position. The 9 transects were clustered into 3 distinct areas. Transects 1, 2, and 3 were considered the Transition zone, with a mean of 121.7 cm and a standard deviation of 85.0 cm (Table 15). Transects 4, 5, and 6 were near location 1, with a mean of 58.7 cm and a standard deviation of 62.9 cm. Transects 7, 8, and 9 were near location 2, with a mean of 149.0 cm and a standard deviation of 54.6 cm. All but one of these measurements support my data on how *J. roemerianus* is moving outwards.

Table 15: Measurements (cm) for all 9 transects moved outwards, except for transect 5.

Transect	Location	Measurement (cm)	Mean (cm)	Standard Deviation (cm)
1	Transition	125	121.7	85.0
2		205		
3		35		
4	Near 1	125	58.7	62.9
5		0		
6		51		
7	Near 2	170	149.0	54.6
8		87		
9		190		

Juncus and Bordering Communities

The following data for total growing, senescing, and standing dead *Juncus* is for “In” samples only. The following data for total live and total dead bordering communities is for “Out” samples only. For all design plots in this section the horizontal line shows the overall mean for all locations and sites (32 total). Also, note that all aboveground biomass data for the years 1990, 2013, and 2014 were collected in August. However, the aboveground biomass data for the year 1992 were collected in February.

Total Growing Juncus Biomass g/m^2

The design plot (Figure 22) shows Total Growing (meaning leaves that were all green) *Juncus* Biomass g/m^2 related to the factors location, site, and year. The difference among all locations had a $p = 0.052$ (Table 16), which is barely significant. All locations shown in the post-hoc tests were statistically indistinguishable, although large mathematical differences were seen (Table 17). Location 3 had the highest total growing *Juncus* biomass and 1 had the lowest. Locations 3 and 2 were the most similar, followed by locations 2 and 4, and then locations 4 and 1. The interaction plot (Figure 23) shows a large interaction between year and location, revealing a different relationship than Figure 22. The big difference in the interaction plot is locations 1 and 4 compared to locations 2 and 3 (Figure 23). Locations 1 and 4 had the same trend over the years, and locations 2 and 3 had the same trend. Locations 1 and 4 both start out with a high Total Growing *Juncus* Biomass in the year 1990 and drop drastically by the year 2014. These two locations are most susceptible to wrack. Locations 2 and 3 maintained relatively constant Total Growing *Juncus* Biomass throughout the years.

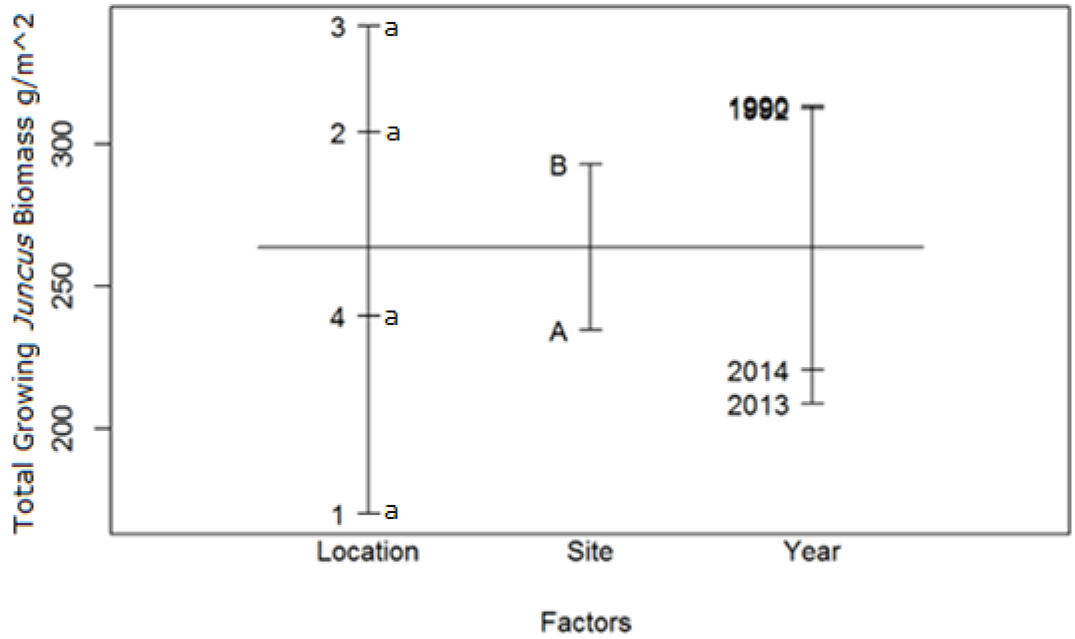

Figure 22: Mean of total growing *J. roemerianus* biomass g/m² related to the factors location, site, and year.

Table 16: Total growing *Juncus* biomass g/m². ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	77729	25910	1.70	0.194
Location	3	136090	45363	2.98	0.052 .
Site	1	27182	27182	1.78	0.194
Residuals	24	365955	15248		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 17: Total growing *Juncus* biomass g/m² data. Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	134.19	-42.847	311.2	0.188
3-1	171.24	-5.797	348.3	0.061
4-1	69.60	-107.432	246.6	0.708
3-2	37.05	-139.982	214.1	0.940
4-2	-64.58	-241.617	112.4	0.753
4-3	-101.64	-278.667	75.4	0.413

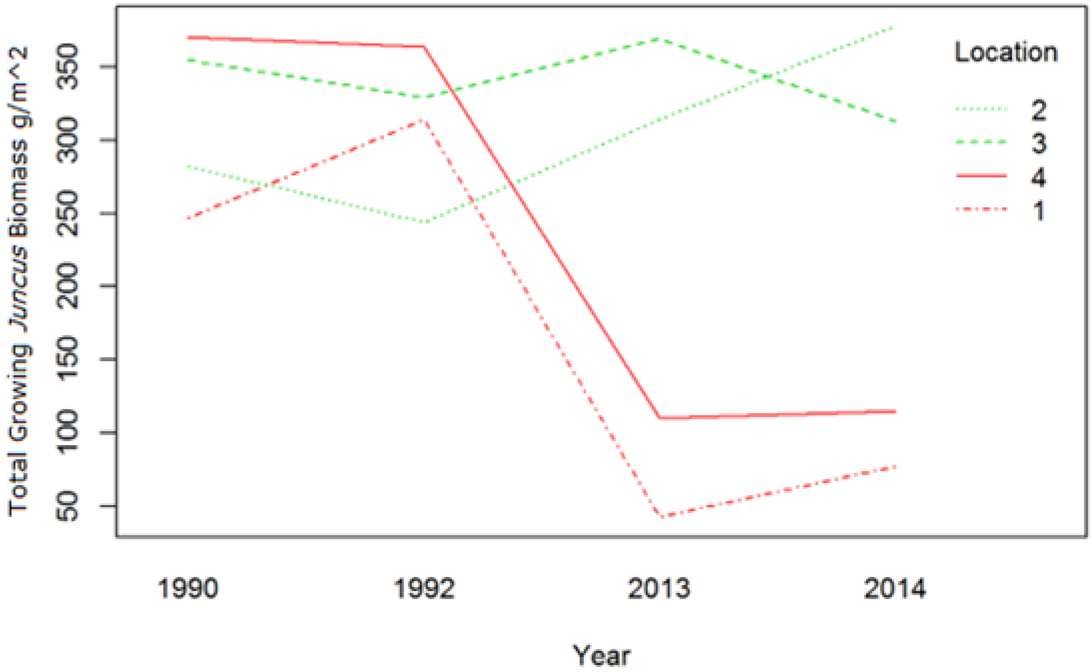

Figure 23: Mean of total growing *Juncus* biomass g/m² over the years 1990, 1992, 2013, and 2014.

Total Senescing Juncus Biomass g/m²

Total Senescing (meaning part green and part brown leaves) *Juncus* Biomass g/m² was related to factors location, site, and year in Figure 24. The difference among locations was statistically significant at p<0.0001 (Table 18). Location 1 had the lowest total senescing *Juncus* biomass at 250 g/m^2, and location 3 had the highest biomass at 950 g/m^2 (Figure 24). There was a statistically significant interaction between location and year at the p=0.001 level (Table 19). Also, the difference among years was statistically significant at the 0.001 level (Table 18). The year 2013 had the highest mean, followed by 1990, then 1992, and 2014 with the lowest. In the interaction plot (Figure 25), locations 1 and 4 start out very similar in 1990, with a total senescing *Juncus* biomass ranging between 450 and 550 g/m^2. Biomasses at these two locations differed by 2013, while locations 2 and 4 became very similar between 700-800 g/m^2. By 2014, locations 2 and 3 were similar and locations 4 and 1 were similar.

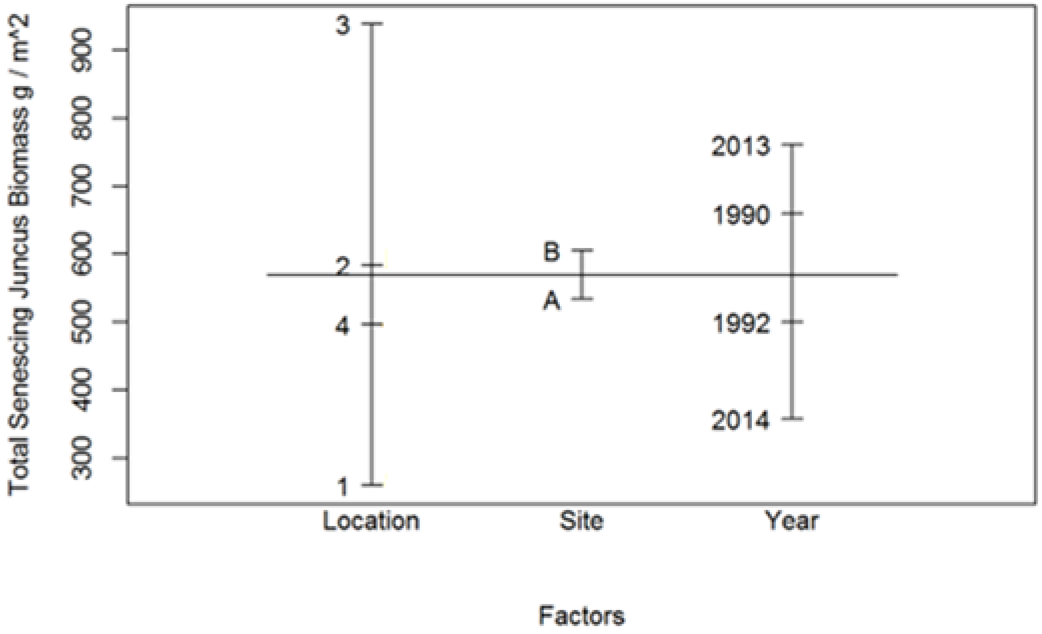

Figure 24: Means of total senescing *Juncus* biomass g/m² related to the factors location, site, and year shown in this design plot.

Table 18: Total senescing *Juncus* biomass g/m². ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	754511	251504	7.27	0.0012 **
Location	3	1902091	634030	18.33	< 0.0001 ***
Site	1	40022	40022	1.16	0.2928
Residuals	24	830139	34589		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 19: Total senescing *Juncus* biomass g/m². ANOVA year * location Interaction.

ANOVA summary for year * location					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	754511	251504	18.9	< 0.0001 ***
Location	3	1902091	634030	47.7	< 0.0001 ***
Year:Location	9	657541	73060	5.5	0.0016 **
Residuals	16	212620	13289		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

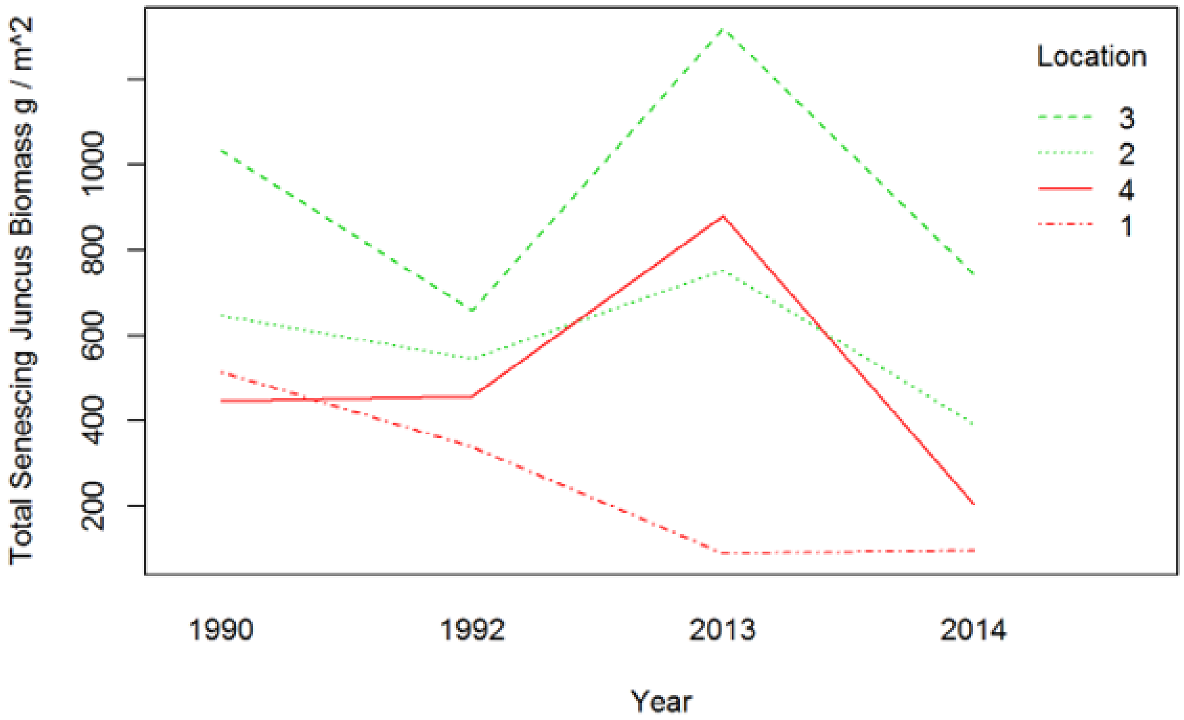

Figure 25: Mean of total senescing *Juncus* biomass g/m² over the years 1990, 1992, 2013, and 2014.

Standing Dead Juncus Biomass g/m^2

The design plot shows the Standing Dead *Juncus* Biomass g/m² related to the factors location, site, and year (Figure 26). The difference among locations was statistically significant at the $p<0.0001$ level (Table 20). Location 3's standing dead biomass was 1500 g/m^2, whereas the other locations ranged between 550 and 850 g/m^2 (Figure 26). Locations 3 and 2, and locations 4 and 3 were different from one another, with statistical significance at the 0.01 level (Table 21). Locations 3 and 1 were statistically significant in difference at the 0.001 level. Also, locations 2, 4 and 1 were all similar, which can be seen in the design plot and post hoc test (Figure 26 and Table 21).

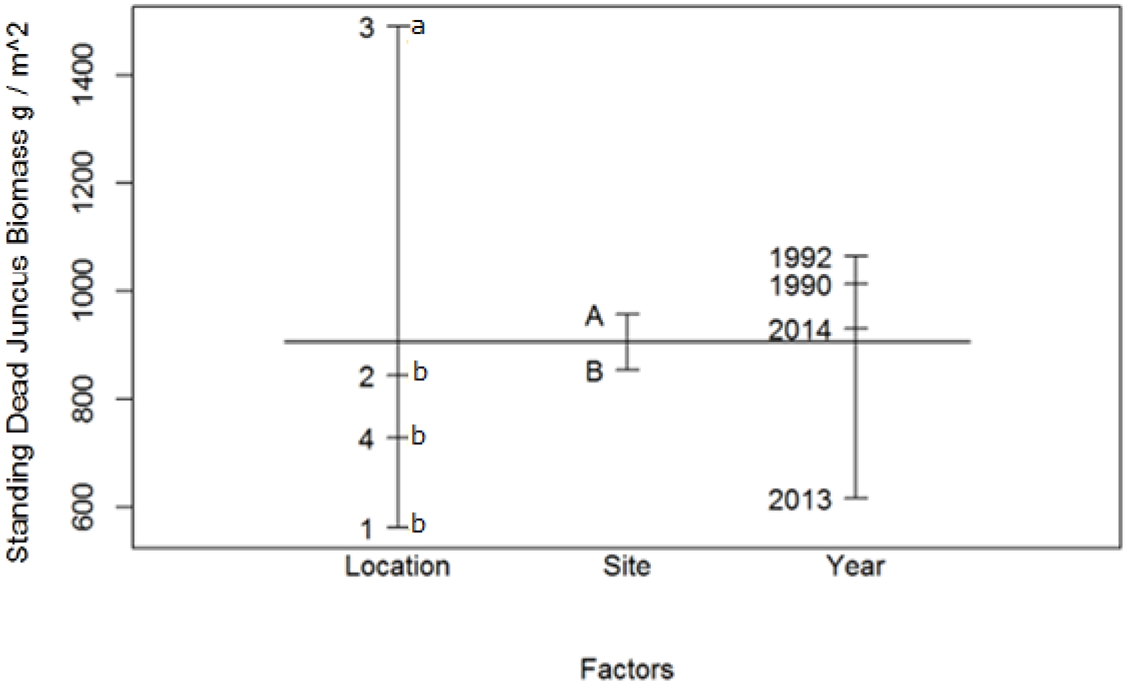

Figure 26: Mean of standing dead *J. roemerianus* biomass g/m² related to the factors location, site, and year.

Table 20: Standing dead *Juncus* biomass g/m². ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	964428	321476	2.29	0.10352
Location	3	3956863	1318954	9.41	0.00027 ***
Site	1	83285	83285	0.59	0.44827
Residuals	24	3363144	140131		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 21: Standing dead *Juncus* biomass g/m². Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	282.3	-259.5	824.1	0.496
3-1	928.2	386.3	1470.0	0.000
4-1	167.3	-374.5	709.1	0.834
3-2	645.9	104.0	1187.7	0.015
4-2	-115.0	-656.8	426.8	0.937
4-3	-760.8	-1302.7	-219.0	0.004

Total Live Bordering Communities g/m²

The design plot shows the Total Live Bordering Communities Biomass g/m² related to the factors location, site, and year (Figure 27). Location 4 had the highest mean at 460 g/m², and location 3 had the lowest mean of total live biomass of bordering communities at 225 g/m²; however, there was no significant difference among them (Figure 27 and Table 22). The difference among sites was statistically significant at the 0.01 level (Table 22). This was largely because of location 1 site B. However, a further ANOVA including interactions was done and showed no significant interaction between year and site.

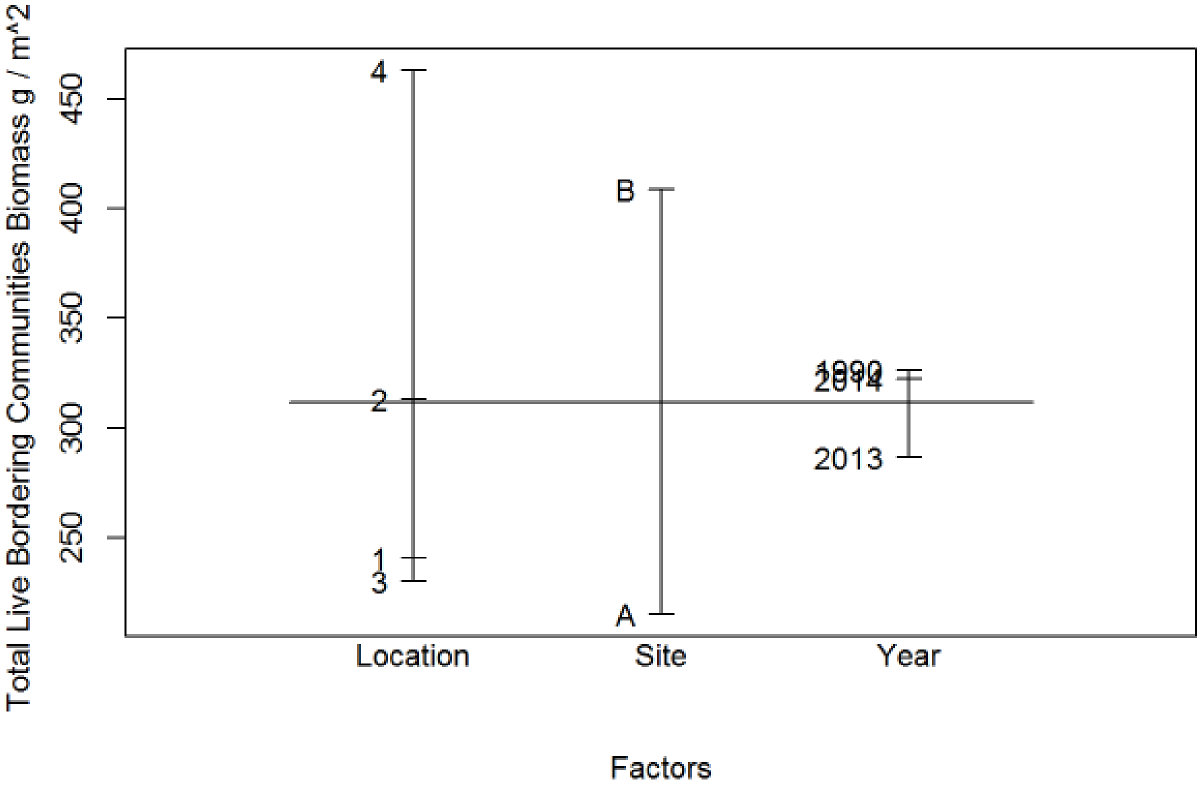

Figure 27: Mean of total live bordering communities' biomass g/m² related to the factors location, site, and year. *There was a slight amount of *Juncus* found in location 4 site A "out" in the year 2013. Note: The data for the year 1992 was not included because it was collected in February. All other years were collected in August.

Table 22: Total live bordering communities' biomass g/m². ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	2	7599	3799	0.08	0.925
Location	3	207148	69049	1.42	0.270
Site	1	224870	224870	4.64	0.046 *
Residuals	17	823780	48458		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

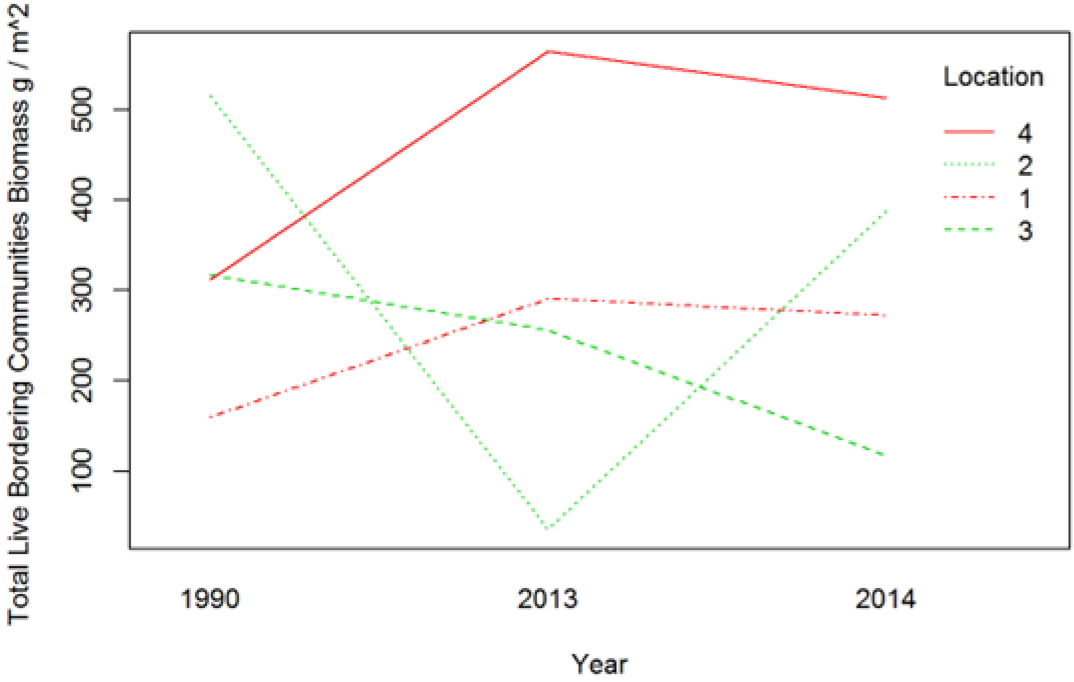

Figure 28: Mean of total live bordering communities biomass g/m² shown over the years 1990, 1992, 2013, and 2014. Note: The data for the year 1992 was not included because it was collected in February. All other years were collected in August.

Standing Dead Bordering Communities g/m²

The Standing Dead Bordering Communities Biomass g/m² related to the factors location, site, and year is shown in the design plot (Figure 29). Location showed significant differences at the 0.001 level (Table 23). Location 2 had the highest mean at 575 g/m^2, and location 1 had the lowest mean of standing dead biomass of bordering communities at 150 g/m^2 (Figure 29 and

Figure 30). There was significant difference among locations with about a 5 fold difference between locations 1 and 2, but it did not show up in the post-hoc test (not shown in a table). This may be a result of violating assumptions of ANOVA. For location 2 site A, the median was around 400 g/m^2. However, there was a very large amount of variation ranging from 0 to 1400 g/m^2 (Figure 31). The difference among years was also significant (Table 23); however, the interaction between year and locations was not statistically significant (Table 24). The year 1992 had a much higher mean for standing dead biomass of bordering communities than the other years, which, again may be because the data were collected in February. The next highest mean was in the year 1990, then 2013, and 2014. Although the ANOVA interaction between years and location was not significant, there is clearly an interaction between the two (Figure 30). Locations 3 and 4 started out with a similar biomass at 450 g/m^2 in the year 1990. However, by the year 2014 locations 2 and 4 had a similar biomass at 200 g/m^2 and 1 and 3 had a more similar biomass at 75 g/m^2 (Figure 30).

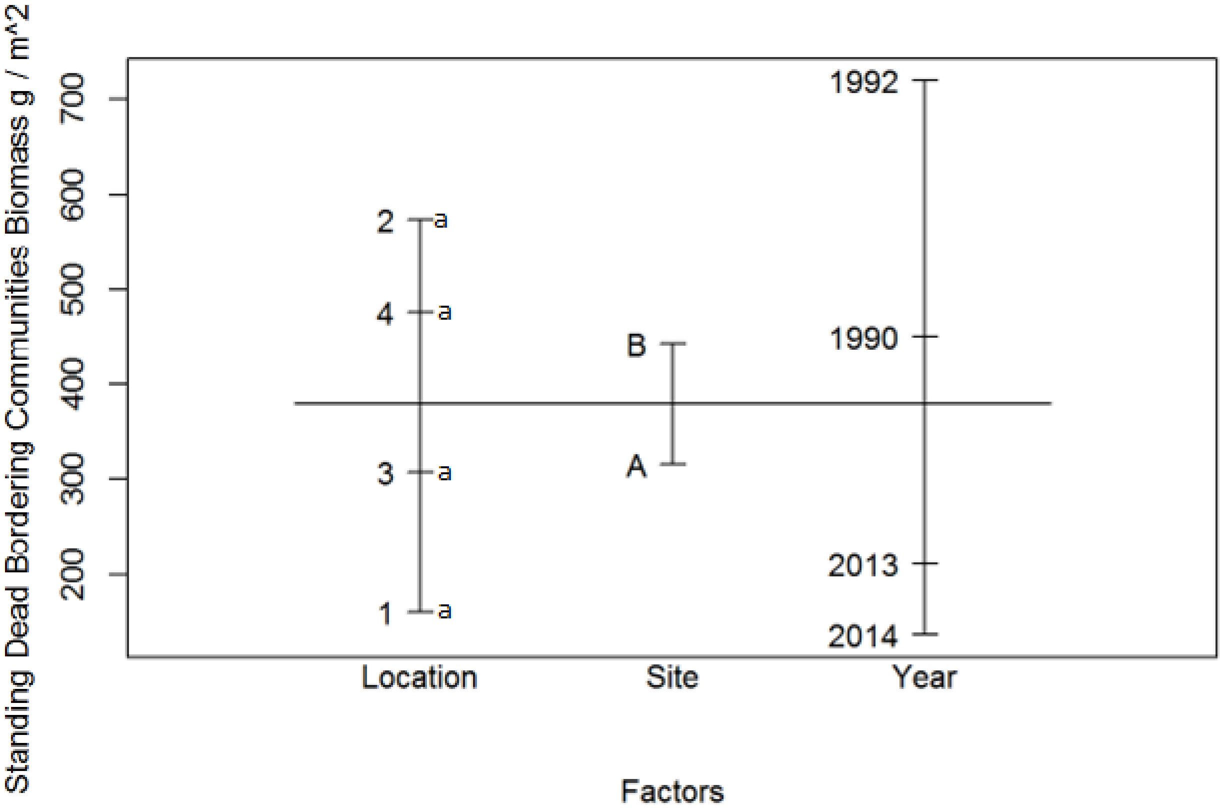

Figure 29: Mean of standing dead bordering communities' biomass g/m² related to the factors location, site, and year. *There was a slight amount of *Juncus* found in location 4 site A "out" in the year 2013. *Also, year 1992 was sampled in February. All other years were sampled in August.

Table 23: Standing dead bordering communities' biomass g/m². ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	1665947	555316	12.14	< 0.0001 ***
Location	3	801836	267279	5.84	0.0038 **
Site	1	129352	129352	2.83	0.1056
Residuals	24	1097880	45745		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 24: Standing dead bordering communities' biomass g/m². ANOVA year * location Interaction.

ANOVA summary for year * location					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	1665947	555316	14.10	< 0.0001 ***
Location	3	801836	267279	6.79	0.0037 **
Year:Location	9	597017	66335	1.68	0.1739
Residuals	16	630215	39388		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

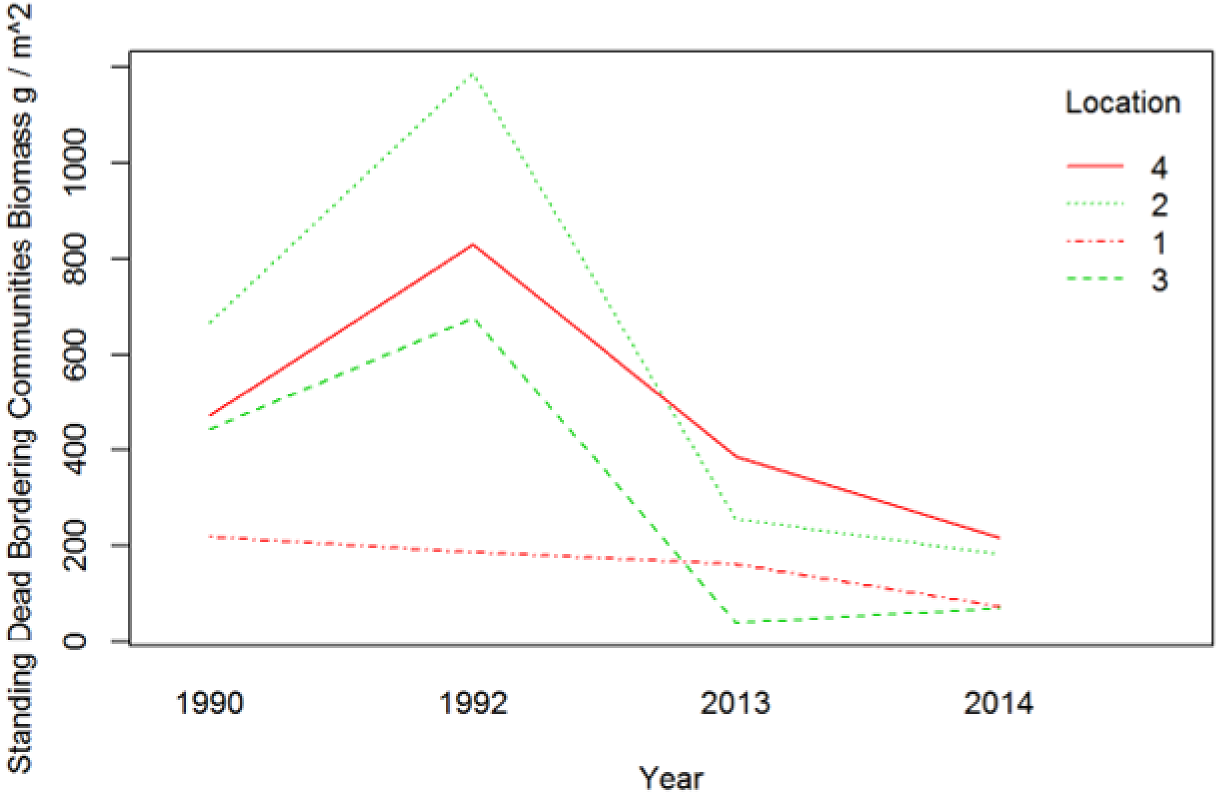

Figure 30: Mean of standing dead bordering communities' biomass g/m² shown over the years 1990, 1992, 2013, and 2014.

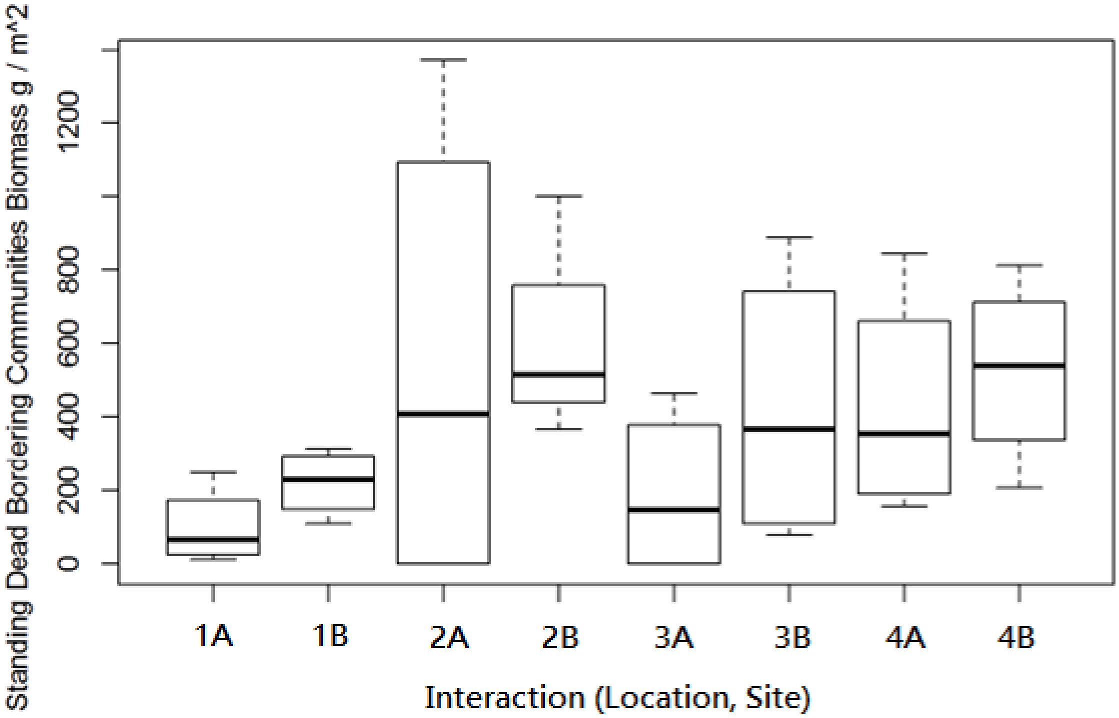

Figure 31: Standing dead bordering communities biomass (g/m²) by site, shown over the years 1990, 1992, 2013, and 2014.

Other Conditions of *Juncus*

Density data on growing *Juncus* leaves (per m^2) and senescing *Juncus* leaves (per m^2), and height data on *Juncus* leaves (cm) are all for "In" samples only.

Density data on Growing Juncus leaves

The Total Mean Number of Growing *Juncus* leaves (>95% green) per m^2 was related to location, site, and year in the following design plot (Figure 32). The difference among locations was not statistically significant (Table 25). Location 3 had the highest mean of growing *Juncus* leaves at 600 leaves per m^2 (Figure 32). Location 4 had a mean of 475 leaves per m^2, which falls right around the overall mean of *Juncus* leaves (Figure 32). Location 2 had a mean of 425 leaves per m^2, while location 1 had the lowest mean of 400 leaves per m^2 (Figure 32). The difference between years and sites were both statistically significant at the p=0.01 level (Table 25). The year 1992 had the highest mean, followed by 1990, then 2013, and 2014 with the lowest (Figure 32). However, a further ANOVA including interactions was done, and there was no significant interaction between year and site (Table 26).

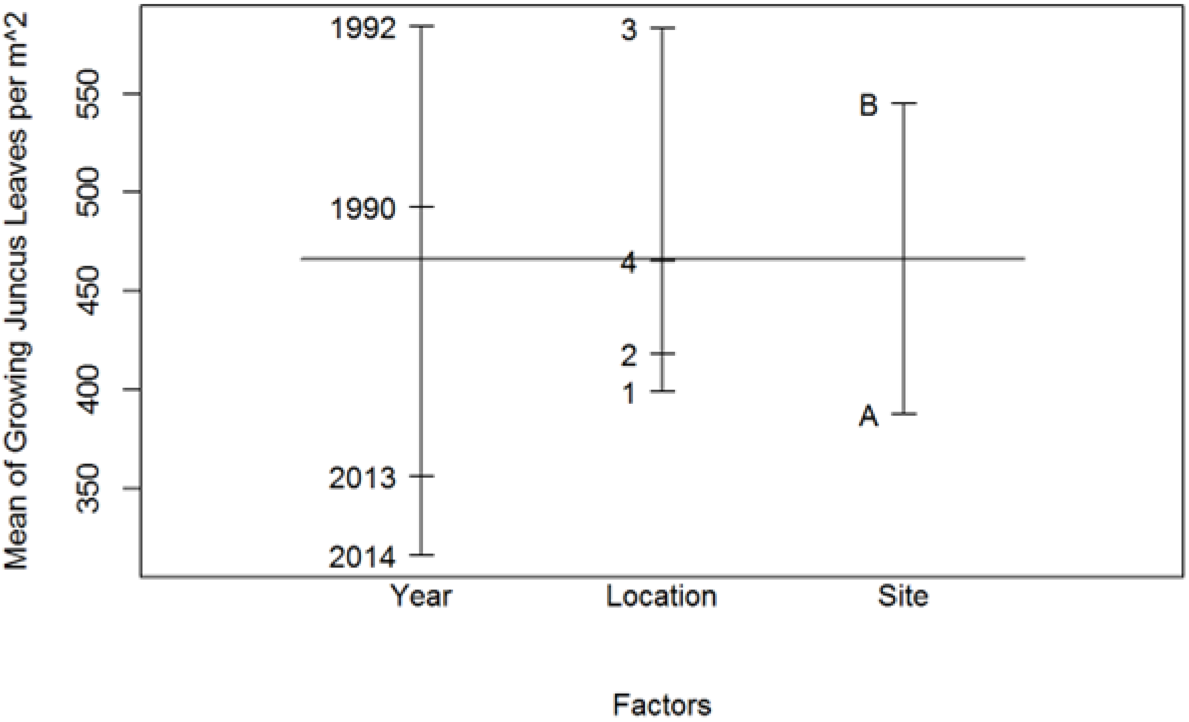

Figure 32: Mean of growing *Juncus* leaves per m^2 related to the factors location, site, and year.

Table 25: The number of growing *Juncus* leaves per m^2. ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	505192	168397	3.47	0.027 *
Location	3	205012	68337	1.41	0.259
Site	1	247748	247748	5.10	0.031 *
Residuals	32	554646	48583		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 26: The number of growing *Juncus* leaves m². ANOVA year * site Interaction.

ANOVA summary for year * site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	505192	168397	3.24	0.035 *
Site	1	247748	247748	4.76	0.037 *
Year:Site	3	94830	31610	0.61	0.615
Residuals	32	1664828	52026		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Density data on Senescing Juncus leaves

The Total Mean Number of Senescing *Juncus* leaves (<95% and >0% green) per m^2 was related to factors location, site, and year in the following design plot (Figure 33). The difference among locations differed statistically at only p=0.046 level. Location 3 had the highest mean number of senescing *Juncus* leaves at 550 per m^2, and location 2 had a mean number of 425 leaves per m^2. Locations 1 and 4 had the lowest and very similar mean number of senescing *Juncus* leaves at 350 leaves per m^2 (Figure 33). The difference among years was statistically significant at the p<0.0001 level (Table 27). The year 1990 had the highest mean, followed by 1992, then 2013, and 2014 with the lowest (Figure 33). There was no significant interaction between year and location (Table 28).

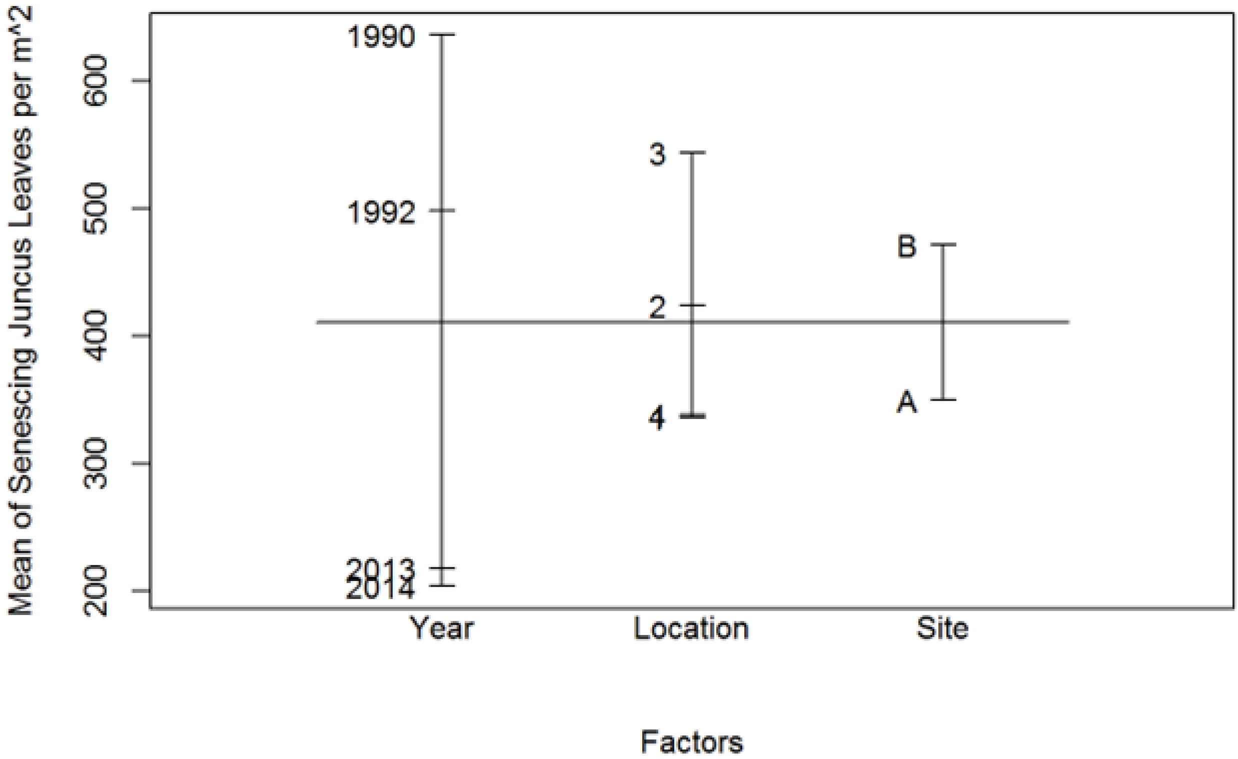

Figure 33: Mean of senescing *Juncus* leaves per m^2 related to the factors location, site, and year.

Table 27: The number of senescing *Juncus* leaves. ANOVA summary for year, location, site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	1165086	388362	12.18	< 0.0001 ***
Location	3	285294	95098	2.98	0.046 *
Site	1	146410	146410	4.59	0.040 *
Residuals	32	1020374	31887		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 28: The number of senescing *Juncus* leaves m². ANOVA year * location Interaction.

ANOVA summary for year * location					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	1165086	388362	9.19	0.00032 ***
Location	3	285294	95098	2.25	0.10847
Year:Location	9	152040	16893	0.40	0.92302
Residuals	24	1014744	42281		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Height data on Juncus

The Total Height (cm) of *Juncus* leaves (growing and senescing) was related to factors location, site, and year in the following design plot (Figure 34). The difference among locations showed statistically significant differences at the p<0.0001 level (Table 29). Locations 4 and 3, and locations 4 and 2 differed statistically at p = 0.05 (Table 31). Locations 3, 2 and 1 had similar *Juncus* heights at 125 to 135 cm. Location 1 and location 4 had similar *Juncus* heights at 115 to 125 cm (Figure 34). The difference among years were also statistically significant at the p<0.0001 level (Table 29). The year 1990 had the highest mean, followed by 1992, then 2014, and 2013 with the lowest (Figure 34). However, the interaction between year and location was not statistically significant (Table 30).

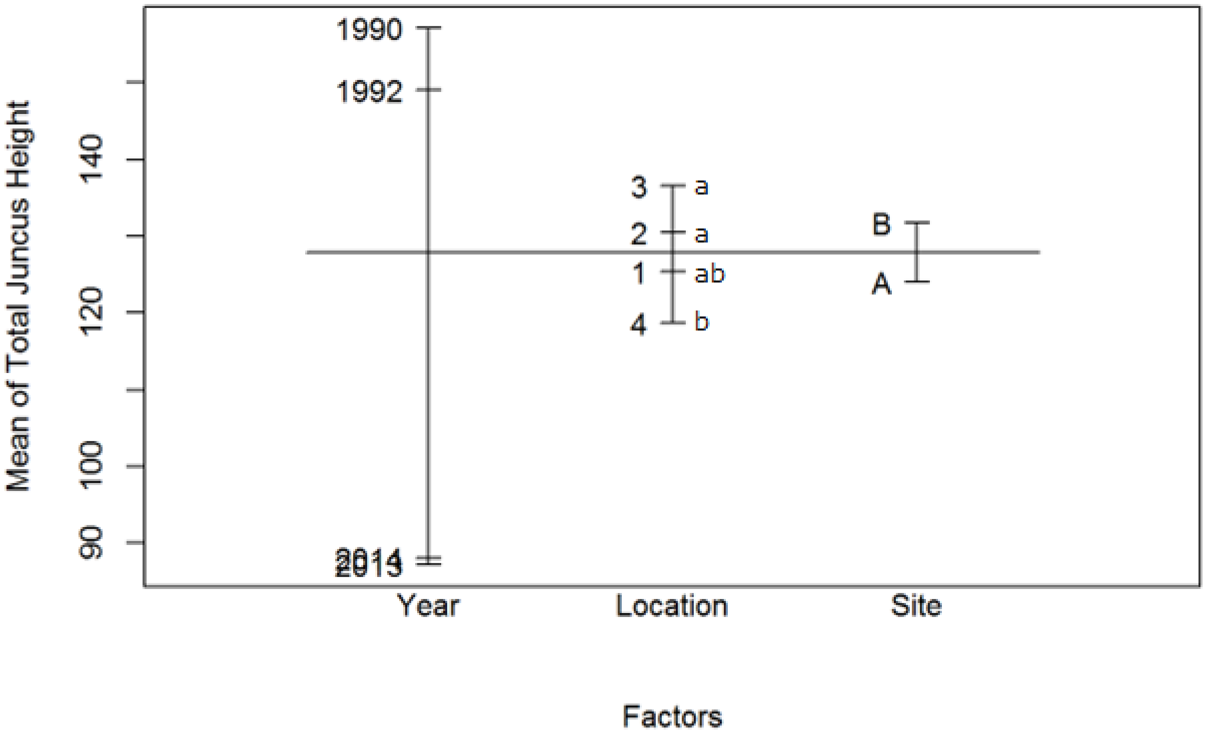

Figure 34: Total height of *Juncus* leaves (cm) related to the factors location, site, and year.

Table 29: Total height of *Juncus* leaves. ANOVA summary for year, location, and site.

ANOVA summary for year + location + site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	722931	240977	263.32	< 0.0001 ***
Location	3	61816	20605	22.52	< 0.0001 ***
Site	1	1563	1563	1.71	0.19
Residuals	734	671708	915		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 30: Total height of *Juncus* leaves. ANOVA year * location Interaction.

ANOVA summary for year * location					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Year	3	722931	240977	264.14	< 0.0001 ***
Location	3	61816	20605	22.59	< 0.0001 ***
Year:Location	9	10923	1214	1.33	0.22
Residuals	726	662348	912		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 31: Total height of *Juncus* leaves. Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	5.111	-7.0446	17.2664	0.700
3-1	11.227	-0.9286	23.3825	0.082
4-1	-6.781	-18.8542	5.2919	0.471
3-2	6.116	-5.3974	17.6295	0.520
4-2	-11.892	-23.3184	-0.4657	0.038
4-3	-18.008	-29.4344	-6.5818	0.000

Site Characterization

This section describes results for the 4 locations related to environmental factors listed in my conceptual model: water depth, salinity, macro-organic matter (MOM), and elevation.

Water Depth

The design plot shows data for mean water level, in cm, relative to the surface (i.e., horizontal line) (Figure 35). Individual locations acted differently from one another (p<0.001) (Table 32). Location 2 had the highest mean water level relative to the surface averaged over all of the months at 3 cm, and location 4 had the lowest at -2 cm) (Figure 35). Location 3 had a relative water level right around the surface level at 0 cm. Location 1 had a mean water level slightly lower than the surface around -0.5 cm. Months acted differently from one another, and were statistically significantly different at the $p<0.0001$ level (Table 32). It is shown that the summer months, June and July, had a lower mean water level relative to the surface compared to other data. The fall month, November, had the highest mean water level relative to the surface. The interaction between location and month was statistically significant at the $p<0.0001$ level (Table 33). The interaction plot (Figure 36) shows a large interaction between months and location, revealing a different relationship than Figure 35. The big difference in the interaction plot was locations 1 and 4 compared to locations 2 and 3 (Figure 36).

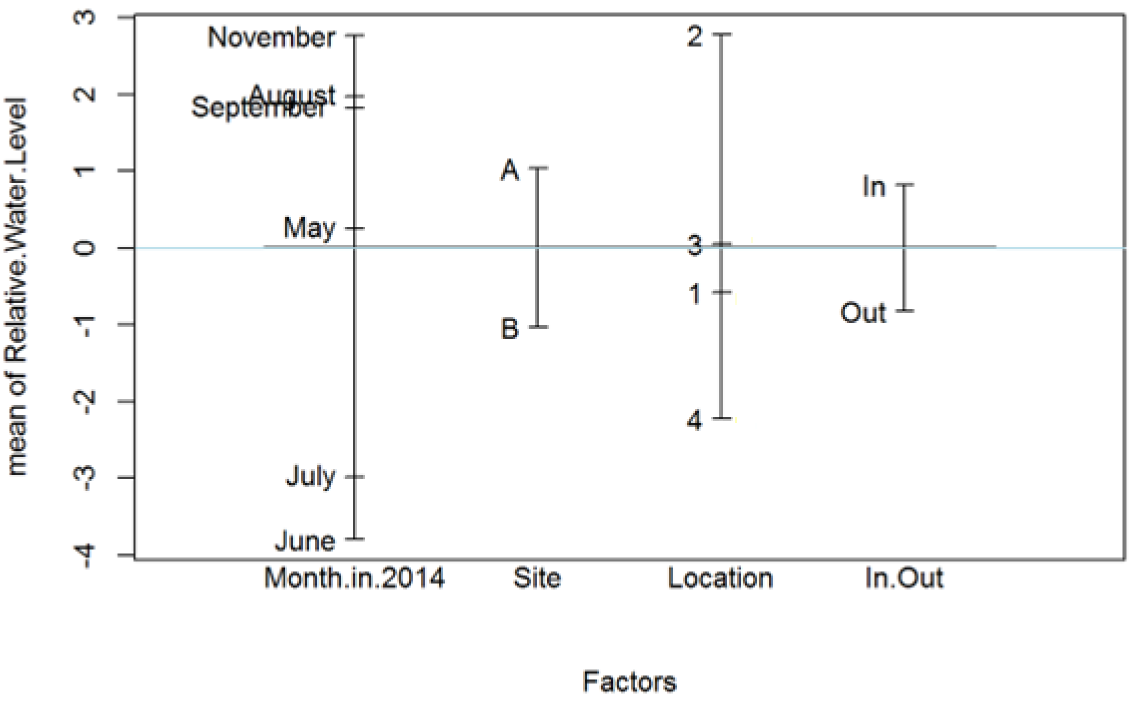

Figure 35: Response variable: relative water level (cm) and the explanatory variables: month, site, and location.

Table 32: Water level relative to the surface. ANOVA summary for locations, month in 2014, sites, in/out.

ANOVA summary for locations + month in 2014 + sites + in/out					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	360	119.9	14.36	< 0.0001 ***
Month in 2014	5	502	100.5	12.04	< 0.0001 ***
Site	1	20	20.4	2.45	0.12
In.Out	1	14	14.1	1.69	0.20
Residuals	85	709	8.3		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 33: Water level relative to the surface. ANOVA month * location Interaction.

ANOVA summary for location * month					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	360	119.9	27.26	< 0.0001 ***
Month	5	502	100.5	22.85	< 0.0001 ***
Location:Month	15	427	28.5	6.48	< 0.0001 ***
Residuals	72	317	4.4		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

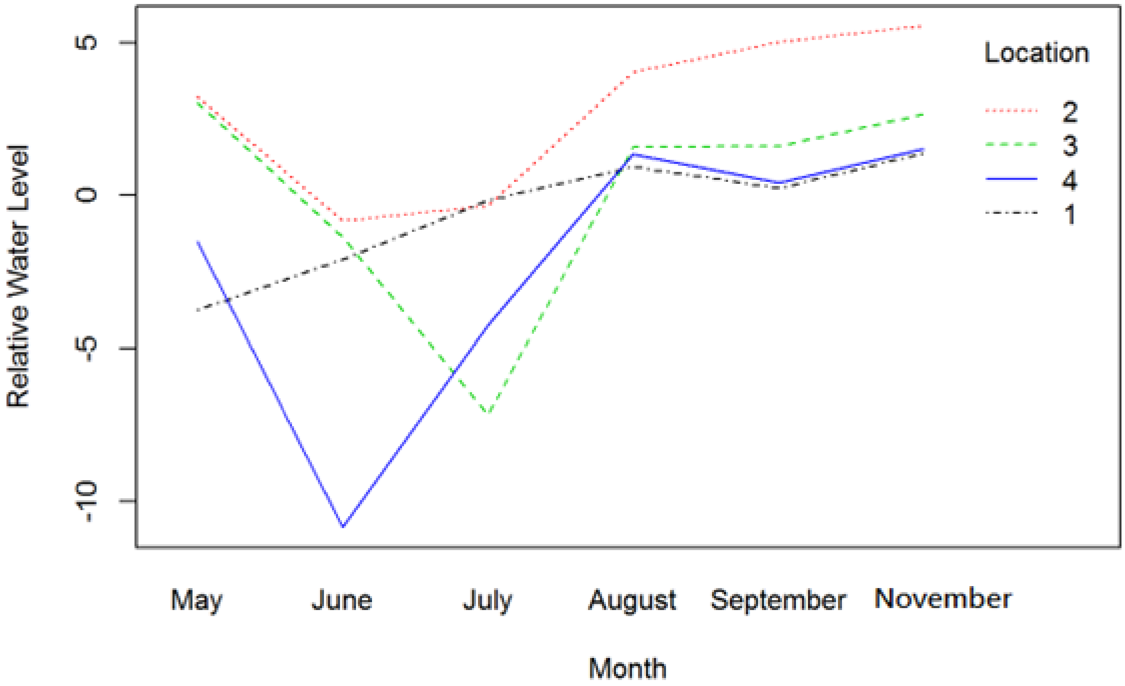

Figure 36: Mean of relative water level (cm) over the months in the year 2014 May, June, July, August, September, and November.

Salinity

The mean of salinity at UPC is shown in the design plot (Figure 37). The difference among location salinity levels was statistically significant at the p<0.0001 level (Table 34). Locations 2 and 3 both have around 12 salinity (Figure 37). Location 1 had the highest salinity at 28 averaged over all of the months, followed by location 4 at 23. The difference among the months in 2014 were statistically significant at the p<0.0001 level (Table 34). November had the highest mean of salinity followed by July, September, August, and then June. The lowest mean of salinity occurred during the month of May (Figure 37). The interaction between month and location was statistically significant (p<0.0001) (Table 35) as shown in the interaction plot (Figure 38). The big difference in the interaction plot was locations 1 and 4 compared to locations 2 and 3 (Figure 38). In May, location 1 had a salinity level of 23, and location 4 had a salinity level of 16. They both increased in salinity level over time. By the month of November location 1 was at 35, and location 4 was at 33. In May, location 2 had a salinity level of 12, and location 3 had a salinity level of 8. They both increased in salinity over time with major peaks in July and then decrease. By the month of November, salinity rose again slightly; location 2 was at 15, and location 3 was at 17.

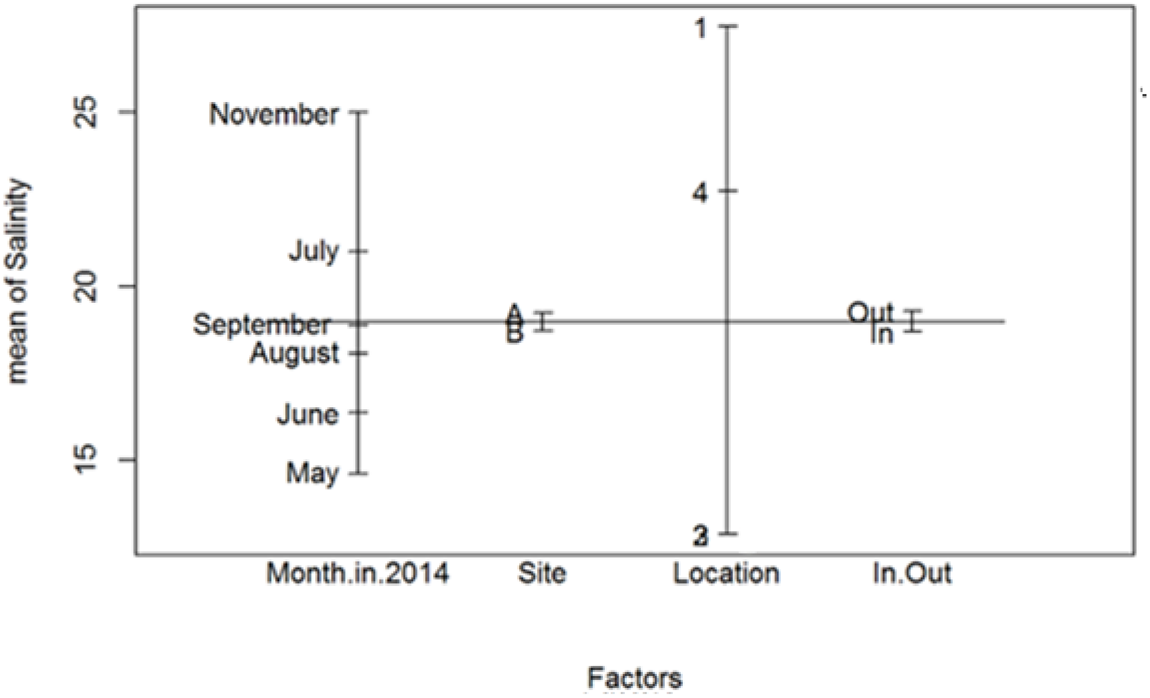

Figure 37: Response variable: mean of salinity and the explanatory variables: month (2014), site, and location.

Table 34: Salinity level data. ANOVA summary for locations, month in 2014, sites, in/out.

ANOVA summary for locations + month in 2014 + sites + in/out					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	3855	1285	50.81	< 0.0001 ***
Month in 2014	5	1071	214	8.47	< 0.0001 ***
Site	1	7	7	0.26	0.61
In/Out	1	9	9	0.35	0.56
Residuals	85	2150	25		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 35: Salinity level data. ANOVA month * location Interaction.

ANOVA summary for month * location					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	3855	1285	121.39	< 0.0001 ***
Month	5	1071	214	20.23	< 0.0001 ***
Location:Month	15	1403	94	8.83	< 0.0001 ***
Residuals	72	762	11		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

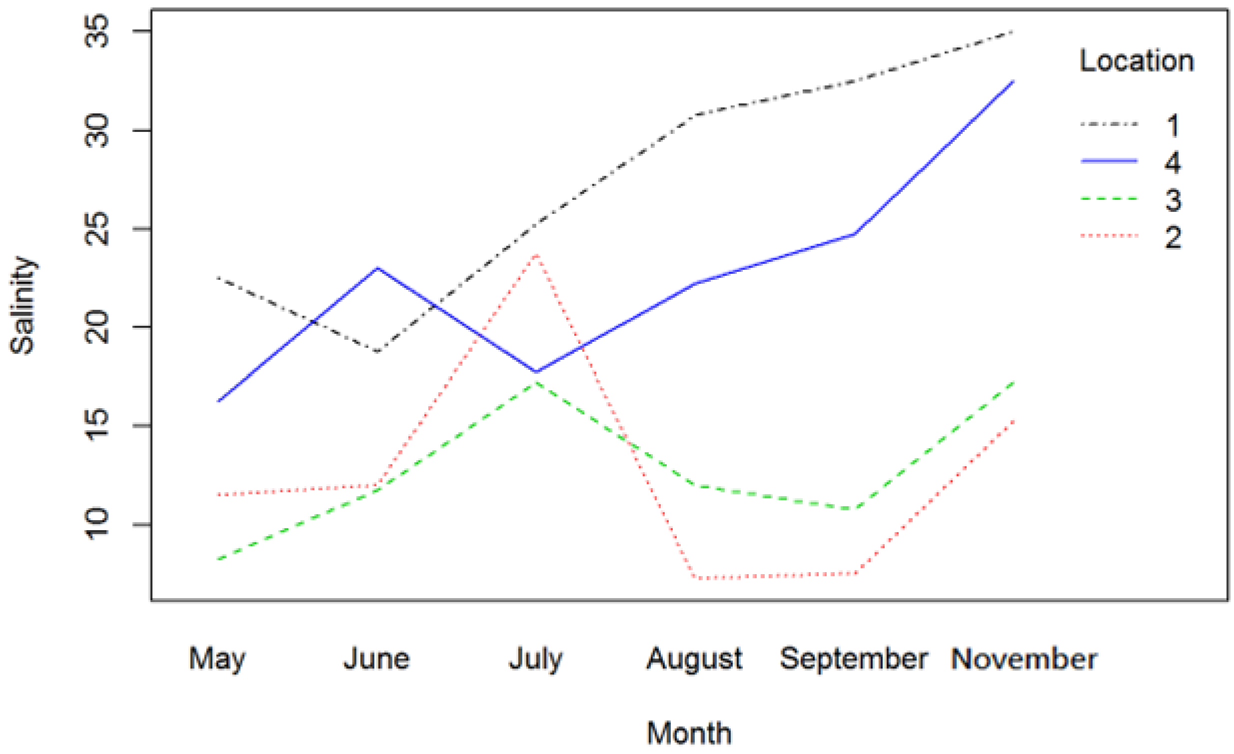

Figure 38: Mean of salinity shown over the months in the year 2014 May, June, July, August, September, and November.

Soil Bulk Density

The means of the soil bulk density (g/cm^3) are shown in a design plot (Figure 39). The difference among location soil bulk density levels was statistically significant at the p<0.0001 level (Table 36). Location 1 was statistically significant in difference from all of the other locations (Table 38), with a higher soil bulk density of 0.7 g/cm^3 (Figure 39). Locations 2, 3, and 4 had similar soil bulk densities (Table 38), ranging between 0.1 to 0.3 g/cm^3 with location 3 being the lowest (Figure 39). Also, there was a lot of variation at location 1 between sites A and B (Figure 40). The sites were statistically significant in difference at the p=0.001 level (Table 36). There was a significant interaction between location and site at the p<0.0001 level (Table 37).

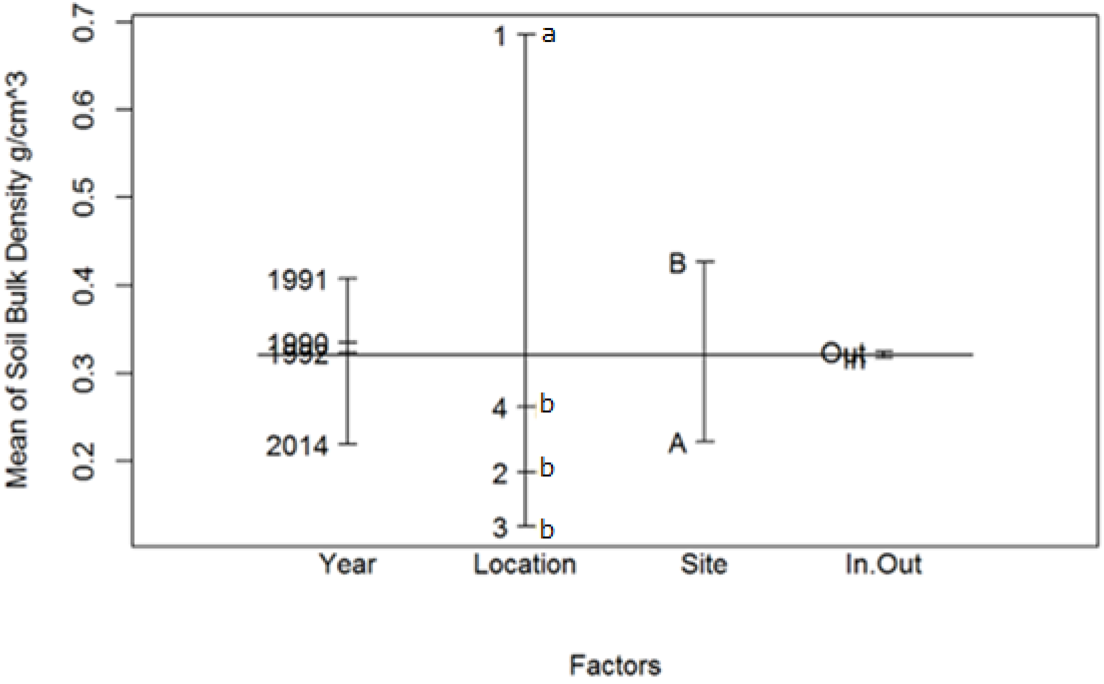

Figure 39: Response variable: mean of soil bulk density (g/cm^3) and the explanatory variables: year location, site, and in/out.

Table 36: Soil bulk density data. ANOVA summary for locations, year, sites, and in/out.

ANOVA summary for location + year + site + in/out					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	3.01	1.003	14.24	< 0.0001 ***
Year	3	0.29	0.095	1.35	0.2679
Site	1	0.57	0.575	8.16	0.0061 **
In/Out	1	0.00	0.001	0.01	0.9166
Residuals	53	3.73	0.070		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 37: Soil bulk density data. ANOVA location * site Interaction.

ANOVA summary for location * site					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	3.009	1.003	35.0	< 0.0001 ***
Site	1	0.575	0.575	20.1	< 0.0001 ***
Location:Site	3	2.474	0.825	28.8	< 0.0001 ***
Residuals	54	1.546	0.029		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 38: Soil bulk density data. Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	-0.49900	-0.7622	-0.2358	0.000
3-1	-0.56063	-0.8331	-0.2882	0.000
4-1	-0.42325	-0.6865	-0.1600	0.000
3-2	-0.06163	-0.3341	0.2108	0.932
4-2	0.07575	-0.1875	0.3390	0.872
4-3	0.13738	-0.1351	0.4098	0.546

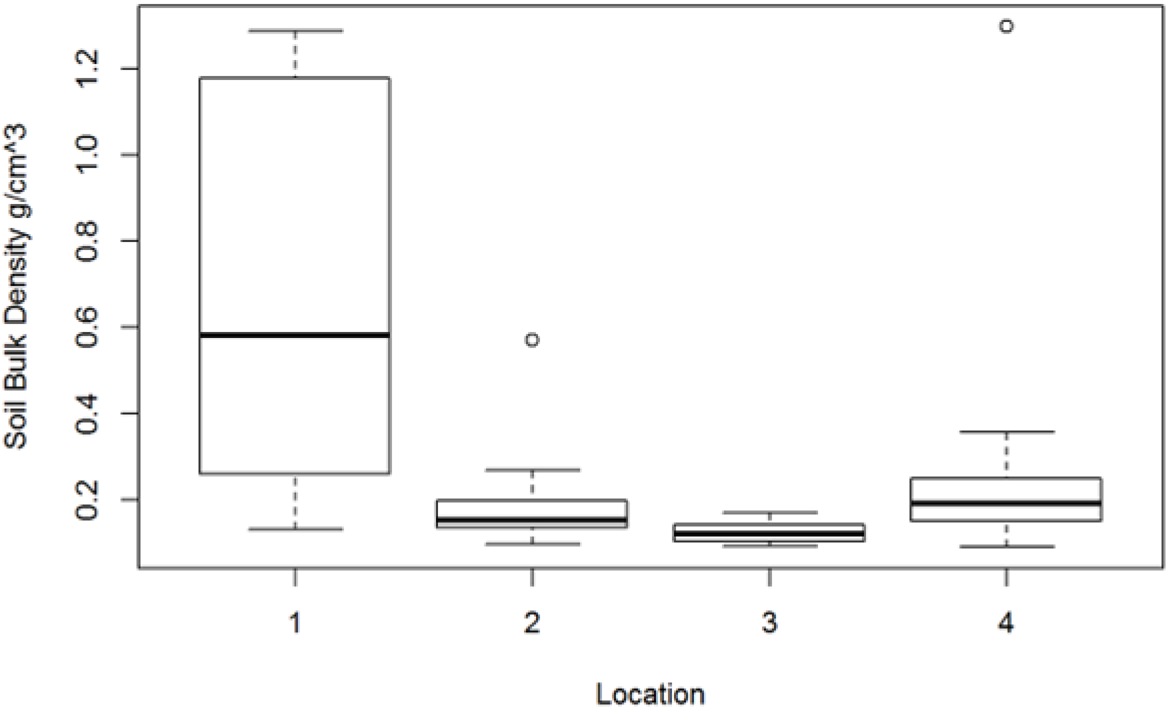

Figure 40: Boxplot for the response variable: soil bulk density (g/cm^3) defined by the explanatory variable: location. Soil bulk density (assessed over the 4 years: 1990, 1991, 1992, and 2014) at each location in the marsh.

Macro-organic matter (MOM)

The design plot shows the means of the MOM (g ash free dry mass /m^2 to 10 cm) with respect to explanatory variables (Figure 41). Individual locations acted differently from one another and showed a statistical significance at the p<0.0001 level (Table 39). Location 2 had the highest mean at 4250 g/m^2, while location 1 had the lowest at 2500 g/m^2 (Figure 41). Locations 3 and 4 were the most similar (p=0.265), followed by locations 1 and 4 (p=0.160) (Table 41). Also, the “in” and “out” sites were statistically different at the p<0.0001 level (Table 41). However, there was no statistically significant interaction between location and the in/out sites (Table 40) with areas outside the original *Juncus* patch having more MOM than inside.

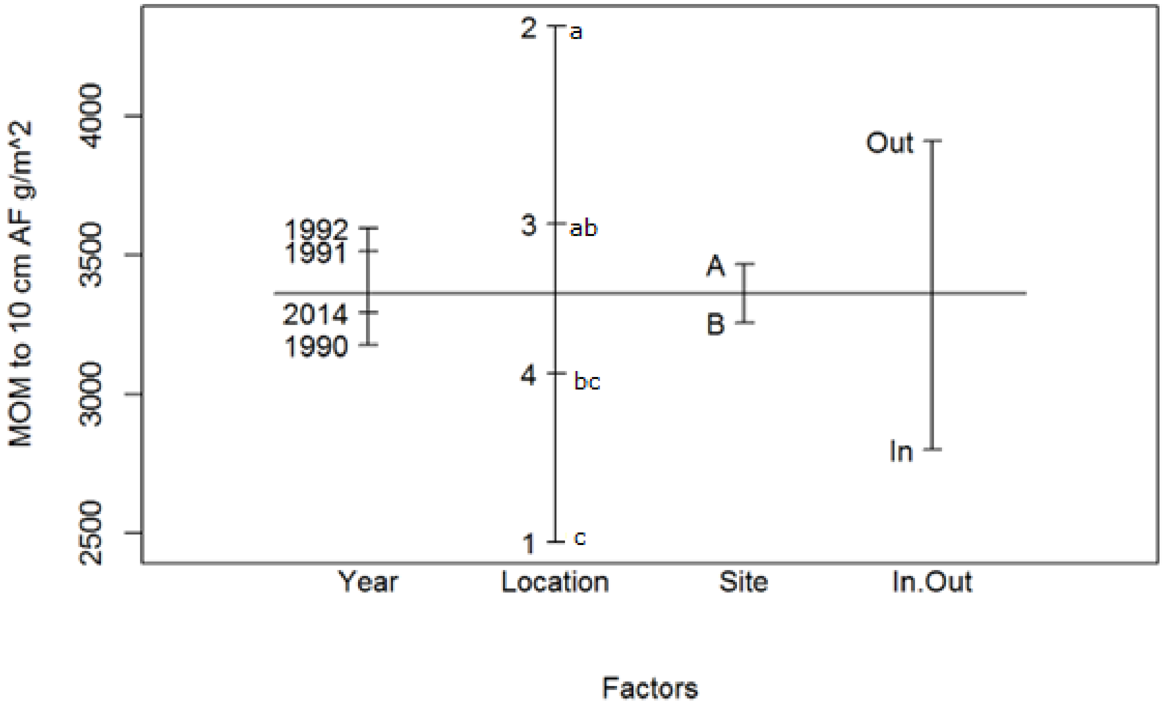

Figure 41: An overall look at the relationship between the response variable: mean of MOM to 10 cm AF (g/cm2) and the explanatory variables: year location, site, and in/out.

Table 39: MOM data. ANOVA summary for locations, year, sites, and in/out.

ANOVA summary for locations + sites + in/out					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	53257629	17752543	20.03	< 0.0001 ***
Year	3	2114810	704937	0.80	0.50
Site	1	1015790	1015790	1.15	0.29
In/Out	1	35901291	35901291	40.50	< 0.0001 ***
Residuals	104	92181241	886358		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 40: MOM data. ANOVA location * in/out Interaction.

ANOVA summary for location * in/out					
	Df	Sum Sq	Mean Sq	F value	Pr(>F)
Location	3	53257629	17752543	20.32	< 0.0001 ***
In.Out	1	35923922	35923922	41.12	< 0.0001 ***
Location:In/Out	3	3546590	1182197	1.35	0.26
Residuals	105	91742619	873739		
Significant codes: 0 = *** 0.001 = ** 0.01 = * 0.05 = .					

Table 41: MOM data. Post-hoc test for locations.

Location	**Difference**	**Lower 95% CI**	**Upper 95% CI**	**P Value adjusted**
2-1	1858.2	1099.8	2616.67	0.000
3-1	1147.3	388.8	1905.75	0.001
4-1	610.4	-148.0	1368.89	0.160
3-2	-710.9	-1476.0	54.15	0.079
4-2	-1247.8	-2012.9	-482.71	0.000
4-3	-536.9	-1301.9	228.22	0.265

Rates

Rates of Horizontal Movement for Last Continuous Juncus

Rates of horizontal movement were calculated for each measure *Juncus* position. The rate calculations are from the slope of the regression of position versus year (Table 42). The year's column shows the period of years it took for each location to reach the first column maximum of 20 grids. For locations that did not reach 20 grid units, a regression was done on the whole time period. Location 4 site A had the greatest rate at 17.0 cm/y for the period of years 1990 to 1992. This location is different from the rest in that it reached the outer limit of *Juncus* very quickly. Location 2 site B had the next highest rate, reaching the outer limit at a rate of 7.1 cm/y for the years 1990 to 2000. Location 4 site B was next to reach the outer limit at a rate of 6.9 cm/y for the years 1990-2000, followed by location 2 site A with a rate of 4.4 cm/y for the years 1990 to 2010. Location 3 site A (rate of 2.6 cm/y for 1990 to 2014) and location 3 site B (rate of 1.8 cm/y for 1990 to 2014) had lower rates than locations 2 and 4. Location 1 site A had the lowest rates at

-1.1 cm/y for the years 1990-2014. Location 1 site B had a rate of 3.8 cm/y for the period of years 1995-2014. Location 1 site B was different in that there was a huge dip from 1994 to early 2000s because of wrack; therefore, the regression was calculated on the years 1995-2014. These periods of years were used to show that there was growth at this low marsh site even after disturbance. However, location 1A had a bigger decrease and was more consistent over time. Locations 2, 3, and 4 all had rates that continued to move outward, and location 1 had a rate of change that moved inward.

Table 42: Last continuous *Juncus* data. Regression, r^2, rates (cm/y), and years for each location and site.

	Last Continuous *Juncus*				
Location	**Site**	**Regression**	**r^2**	**Rate (cm/y)**	**Years**
1	**A**	y = -0.1105x + 10.588	0.6442	-1.1	1990-2014
1	**B**	y = 0.3815x + 1.2942	0.8311	3.8	1995-2014
2	**A**	y = 0.4442x + 9.6762	0.9707	4.4	1990-2010
2	**B**	y = 0.7109x + 8.4982	0.9554	7.1	1990-2000
3	**A**	y = 0.2646x + 8.6256	0.891	2.6	1990-2014
3	**B**	y = 0.1804x + 8.8101	0.7171	1.8	1990-2014
4	**A**	y = 1.7x + 11.4	0.8576	17.0	1990-1992
4	**B**	y = 0.6918x + 7.7127	0.9045	6.9	1990-2000

*Rate calculations are from slope (grid/year x 10 cm)

Rates of Horizontal Movement for 3-m wide Juncus patch borders

Average distances (cm) and rates for horizontal movement (cm/y) are shown for the 3-m wide *Juncus* border data for each location and site (Table 43). Average distance was divided by the number of years of the study (i.e., 24 years) in order to obtain the rate (cm/y). Location 4 moved at the fastest overall rate (site A at 12.8 cm/y, and site B at 7.5 cm/y), followed by location 2 (site A at 4.1 cm/y site B at 7.9 cm/y). Locations 1 and 3 moved much slower, both with one site moving inward. Location 1 site A had a rate of -0.004 cm/y, and location 1 site B had a rate of 0.8 cm/y. Location 3 site A had a rate of 0.7 cm/y, and location 3 site B had a rate of -0.004 cm/y.

Table 43: Average distances (cm) and rates (cm/y) for each location and site from initial 3-m border.

Location	**Site**	**Average Distance (cm)**	**Rate (cm/y)**
1	**A**	-0.09	-0.004
1	**B**	20.00	0.8
2	**A**	98.82	4.1
2	**B**	189.82	7.9
3	**A**	16.36	0.7
3	**B**	-0.09	-0.004
4	**A**	307.27	12.8
4	**B**	180.91	7.5

Rates of Horizontal Movement for Transect Study

Rates for horizontal movement (cm/y) were calculated for the transect study by Floyd (2007) (Table 15). The average distances from each area in 2014 were calculated, and then each distance was divided by the number of years between the measurement and the set up date (i.e., 10 years) to obtain the rate (cm/y) (Table 44). The group of transects near location 2 moved at the fastest rate (15.0 cm/y), and the group of transects near location 1 moved at the slowest rate (5.9 cm/y). The group of transects in the transition zone moved at a rate of 12.2 cm/y, which is between that of the other two groups, but with a higher standard deviation than any of the other groups.

Table 44: Measurements (cm), means (cm), standard deviations (cm), and rates (cm/y) for each transect group.

Transect	Location	Measurement (cm)	Mean (cm)	Standard Deviation (cm)	Rate (cm/y)
1 2 3	Transition	125 205 35	121.7	85.0	12.2 ± 8.5
4 5 6	Near 1	125 0 51	58.7	62.9	5.9 ± 6.3
7 8 9	Near 2	170 87 190	149.0	54.6	15.0 ± 5.5

Rates of Horizontal Movement for Ground Cover for Juncus

For each location and site for the Ground Cover data, a regression line, r^2, rates (dm^2/y converted to cm/y), and period of years are shown (Table 45). The same periods of years for each location and site were used for these data as were for the Last Continuous *Juncus* data. Location 4 had the highest overall rates of increase in grids (and corresponding distance) containing *Juncus* per year (site A at 16.5 cm/y, and site B at 5.4 cm/y), followed by location 2 (site A at 4.5 cm/y site B at 7.0 cm/y). Locations 1 and 3 had lower rates of grids containing *Juncus* per year. Location 3 site A had a rate of 2.8 cm/y, and location 3 site B had a rate of 1.9 cm/y. Location 1 site A had a rate of -1.2 cm/y, and location 1 site B had a rate of 2.0 cm/y. This location (location 1) experienced inward movement, because there was major wrack impact there. Again, location 1 site B was different in that there was a big period of inward movement from 1994 to early 2000s. Therefore, the regression was calculated on the years 1995-2014 to show growth at this site even after disturbance. Locations 2, 3, and 4 all had rates continuing to move out, and location 1 had a rate of change that continues moving inward.

Table 45: Permanent plot data – Ground cover for *Juncus*. Regression equation, r^2, rates ($dm^2/(m \times y)$ converted to cm/y), and years for each location and site.

Location	**Site**	**Regression**	**r^2**	**Rate ($dm^2/(m \times y)$**	**Rate (cm/y)**	**Years**
1	**A**	$y = -1.1923x + 104.82$	0.6949	-1.1923	-1.2	1990-2014
1	**B**	$y = 1.9549x + 0.3737$	0.6136	1.9549	2.0	1995-2014
2	**A**	$y = 4.487x + 95.167$	0.9727	4.4870	4.5	1990-2010
2	**B**	$y = 7x + 84.909$	0.9481	7.0000	7.0	1990-2000
3	**A**	$y = 2.7642x + 84.018$	0.8988	2.7642	2.8	1990-2014
3	**B**	$y = 1.877x + 86.053$	0.7331	1.8770	1.9	1990-2014
4	**A**	$y = 16.5x + 100.33$	0.9997	16.5000	16.5	1990-1992
4	**B**	$y = 5.3636x + 85.091$	0.7726	5.3636	5.4	1990-2000

*Rate calculations are from the slope of the line (dm^2/m/year divided by 10 dm/m times 10 cm/dm to get cm/y).

DISCUSSION

Summary of Variables of Conceptual Model

My conceptual model showed how various environmental factors were linked to *J. roemerianus* patches and their borders (Figure 1). Changes in *J. roemerianus* patch size vary among hydrogeomorphic locations related to differences among those locations. Differences in horizontal movement of *Juncus* patch borders were predicted among the four hydrogeomorphic locations within the salt marsh. Patch border dynamics involved the interaction among the conditions of *Juncus*, bordering communities, and disturbances and stresses related to environmental conditions (hydroperiod, salinity, wrack, and soil organic matter) and environmental drivers (precipitation patterns, tidal flooding, elevation, and storminess). My study helps to better understand the geomorphic setting and context for *Juncus* and helps track community changes and environmental factors associated with patches of this plant. Again, this is the first time that rates of horizontal movement of *Juncus* and ecosystem state changes have been assessed in this way. It also helps understanding of the long-term effect of sea-level rise versus wrack disturbance.

Summary of Results – Rates of Change for Horizontal Movement

Although there have been studies that address patches and patterns of *J. roemerianus* (Eleuterius, 1984; Christian et al. 1990; Brinson and Christian, 1999; Christian et al. 2000; Touchette, 2006), to my knowledge, there are no studies on the horizontal movement of *Juncus* at the scale in which I studied. There were different ways of determining the various rates of horizontal movement. The rates discussed included last continuous *Juncus* (cm/y), 3-m wide *Juncus* border (cm/y), Transects (cm/y), and *Juncus* ground cover (cm/y) (Table 46). All three methods for the permanent plots showed overall horizontal rates of movement ranking from highest within the high marsh near the creek (location 4) to the high marsh away from the creek (location 2) to the subsiding high marsh (location 3) to the low marsh (location 1) (Table 46).

Each method provided a different perspective on horizontal movement. The last continuous *Juncus* (LCJ) data was within the 1 x 2 m plots and had a maximum outer limit measurement of 20 grid units (dm). Because of this, some of the *Juncus* points were not detected that others on the 3-m wide border approach did. The LCJ data only highlight the *Juncus* that was continuous; therefore, if there were small patches of *Juncus* more inward or outward this *Juncus* would not be noted in this data set.

The *Juncus* ground cover data came from the same data set as the LCJ data. The *Juncus* ground cover was also measured within the 1 x 2 m plots, but had a maximum outer limit measurement of 200 grid units (dm^2). These data showed some of the *Juncus* dynamics gone undetected in the LCJ data set. Also, for these data, some *Juncus* was not detected that the 3-m wide border approach picked up.

The 3-m wide *Juncus* border data determined rates by calculating the average distances for each location/site over the 24 year period. These data went outside of the 1 x 2 m plots, therefore determined rates based on a larger area (3-m wide border) of the marsh. Although these data are shown as a whole and over a longer time period, the rates still largely agree with the 1 x 2 m plots. Also, the larger scale approach demonstrated an edge effect to the 1 x 2 m plots from sampling.

The rates of movement for the transect data were much faster than the other rates. These data were calculated over the last 10 years (2004-2014), and were in locations away from the permanent plots. However, the ranking of rates from the neighboring permanent plots (locations 1 and 2) were the same as these. The group of transects near location 1 had the slowest rate (5.9

cm/y) of horizontal movement for *Juncus*, and the group of transects near location 2 had the fastest rate (15.0 cm/y) of horizontal movement. The other group of transects were located in the transition zone, between locations 1 and 2. These rates were in between that of the other two (12.2 cm/y). These data indicate rapid horizontal growth in the transition zone. My location 4 is in a transitional zone, and the transect data from the transitional area may support the findings there.

Table 46: Rates of change for horizontal movement for last continuous *Juncus* (cm/y), *Juncus* 3-m wide border (cm/y), and *Juncus* ground cover (dm^2/y).

Rates of Horizontal Movement:	**Location**			
	1	**2**	**3**	**4**
Last Continuous *Juncus* (cm/y)	-1.1 – 3.8	4.4 – 7.1	1.8 – 2.6	6.9 – 17.0
***Juncus* 3-m Wide Border (cm/y)**	-0.004 – 0.8	4.1 – 7.9	-0.004 – 0.7	7.5 – 12.8
***Juncus* Ground cover (cm/y)**	-1.2 – 2.0	4.5 – 7.0	1.9 – 2.8	5.4 – 16.5

Explaining Horizontal Movement at Each Hydrogeomorphic Position (Location)

The following section summarizes the interrelationship among hydrogeomorphic position and horizontal movement of *Juncus* through the perspective of my conceptual model (Figure 1). Table 47 provides an overview of variables associated with the components of the conceptual model. As in Brinson and Christian (1999), the boundary between patches of *J. roemerianus* and other types of saltmarsh species was observed. The horizontal movement factors (last continuous *Juncus*, 3-m wide *Juncus* border, and ground cover for *Juncus*) showed significant interactions and/or statistically significant post hoc ratings (Table 47). The location with the highest three methods of horizontal movement was location 4, followed by location 2, location 3, and then location 1 (Table 46). Brinson and Christian (1999) and my study found that in the low marsh, patches shrunk from being hit by wrack. In high marsh areas patches of *Juncus* grew horizontally unless they were hit by wrack or bordering a hollow. More details of each of the four hydrogeomorphic locations follow.

Table 47: Significant interactions and statistically significant post-hoc rankings. For post-hoc rankings, the highest is “a” and the lowest is “c.”

	UPC Location			
	1	**2**	**3**	**4**
Horizontal movement				
Last Continuous *Juncus*	Significant year*location interaction			
***Juncus* 3-m Wide Border**	C	b	c	a
Ground Cover for *Juncus*	Significant year*location interaction			
Condition of *Juncus*				
Total Growing *Juncus* Biomass	A	a	a	a
Total Senescing *Juncus* Biomass	Significant year*location interaction			
Standing Dead *Juncus* Biomass	B	b	a	b
Number of Growing *Juncus* Leaves	No significant interactions			
Number of Senescing *Juncus* Leaves	No significant interactions			
Total Height of *Juncus* Leaves	Ab	a	a	b
Bordering Communities				
Total Live Bordering Communities	No significant interactions			
Standing Dead Bordering Communities	A	a	a	a
Environmental Conditions				
Ground Cover for Wrack	Significant year*location interaction			
Water Depth	Significant month*location interaction			
Salinity	Significant month*location interaction			
Soil Bulk Density	Significant location*site interaction			
MOM – Ash Free Dry Mass	C	a	ab	bc

High marsh – away from creek – Location 2

The high marsh away from the creek had the 2nd most growing, senescing, and dead *Juncus* biomass (Figures 22, 24, and 26), which supports Brinson and Christian (1999). This is due to the little amount of wrack, distance from the tidal creek, little tidal flooding, and lower salinity levels. Horizontal growth and movement of *Juncus* outwards is occurring at location 2, reaching the outer limit of the 1 x 2 m plots (Figures 8 and 21). This high marsh away from creek study site had the overall 2nd fastest rate of horizontal movement (Table 46), with site B reaching the outer limit during 2005 through 2014 (Figures 8 and 21). Also, the *Juncus* patches are expanding slowly. Like location 3, wrack deposition doesn’t seem to have as big as an effect at location 2 as it does at locations 1 and 4 (Figures 15, 17, and 18), partly because “wrack” in this location is mostly litter (Brinson and Christian, 1999).

The conditions of *Juncus* variables from my study include: total growing *Juncus* biomass, total senescing *Juncus* biomass, standing dead *Juncus* biomass, number of growing *Juncus* leaves, number of senescing *Juncus* leaves, and the total height of *Juncus* leaves (Table 47). All of these aspects of *Juncus* were postulated to have an effect on patch border dynamics with more robust condition promoting horizontal growth. The total growing *Juncus* biomass, the number of growing *Juncus* leaves, and the number of senescing *Juncus* leaves were similar across the four locations (Table 47). *Juncus* is most commonly found in high marshes with less frequent flooding and less salty soils (Weis and Butler, 2009; Wiegert and Freeman, 1990). The leaves in high marsh zones are said to have higher biomass, and be denser and taller than when found in low marshes (Williams & Murdoch, 1972; Eleuterius, 1975, Eleuterius and Caldwell, 1981; Higinbotham et al., 2004). Although there are no consistent trends with the conditions of *Juncus* (Table 47), these studies are supported by my high marsh away from creek location (as well as the high marsh near a pond location) for total growing *Juncus* biomass and height. Also, this location 2 (and location 3) had total growing *Juncus* biomass that stayed high across all of the years, whereas locations 1 and 4 did not.

Bordering plant communities associated with *J. roemerianus* have also been studied (Brinson and Christian, 1999; Keusenkothen and Christian, 2004). In the study by Brinson and Christian (1999), the high marsh away from the creek had the highest biomass for bordering communities. However, the biomass for these communities decreased over the last few years, and had the 2nd highest live biomass for bordering communities in 2014 (Figure 27). Both *S. patens* and *D. spicata* were present in 1990 within the 1 x 2 m plot as bordering communities, but have disappeared over the 24 years (within the 1 x 2 m plots) to be completely overcome by *Juncus*. Outside of the 1 x 2 m plot, *S. patens* and *D. spicata* are still present as bordering species. The black needlerush is the dominant species at this location, however; no *S. alterniflora* has ever been present (Brinson and Christian, 1999). This is likely because of the absence of bare areas and a very minimal amount of wrack (with much more litter present) at location 2 in earlier years (Brinson and Christian, 1999).

The biomass of bordering communities of *J. roemerianus* have a tendency to rise as salinity levels within the water decline (Woerner and Hackney, 1997). This high marsh location away from the creek had the highest mean water level relative to the surface (Figure 35) and the lowest mean salinity, tied with location 3 (Figure 37). Stasavich (1998) had a study site very similar to my location 2. At the high marsh location, away from the creek (location 2), there is little tidal flooding as determined from Stasavich (1998) and Christian et al. (2000). At her study sites hydrodynamics were very irregular. During the winter the high marsh flooded above the surface level, and during the summer the water depth reached 1 m below the surface level. The tidal flooding at this location (similar to location 3) are flooded with lower salinities, especially in the winter months when water levels are higher (Christian et al. 1990). My location 2 also had the highest MOM values (Figure 41) and the next to lowest mean of soil bulk density (Figure 39) (Brinson and Christian, 1999). The soil in this location is peaty, and the edaphic factors are very similar to location 3. Many of the environmental factors are very similar to location 3, indicating that location 2 could become like location 3 over time. Also, an increase in bare areas was noticed in the last 15 years, probably because of the low sediment supplies, which is widespread at VCR marshes (Brinson et al. 1995). Because of these bare areas there may be some other species, like *S. alterniflora*, seen in the next few years (as in location 3). The transition of location 2 to be more like location 3 over time may be caused by disturbances like sea-level rise and inundation (Brinson et al. 1995; Christian et al. 2000).

Precipitation, tidal flooding, and groundwater were three hydrologic sources identified in Stasavich (1998). Precipitation events were mainly the dominant source for hydrologic inputs belowground, almost always producing a rise in ground flooding (Stasavich, 1998). Hayden et al. (1995) studied geomorphological controls, such as storminess, at the VCR. They stated that during nor'easters and tropical storms, water levels are critical causes of raising land surface elevations through the transportation of inorganic sediments above the mean sea level. Also contributing to ecosystem state changes at the VCR is below ground organic matter accumulation (Blum and Christian, 2004) which alters land elevation. Storms bringing wrack deposition did not seem to have as much of an impact at location 2 as it did at other locations (Figure 15).

High marsh – near pond – Location 3

The subsiding marsh location is unique in that it has undergone a transition to an open pond, which lacks emergent plants (Brinson and Christian, 1999). This location is in a high marsh area but had the lowest elevation because subsidence is occurring, and the *Juncus* is bordering a pond. The elevations at this location vary greatly, and as patches of this organic rich soil subside, this location reflects a hummock and hollow landscape. These hollows may have been formed because of muskrat activity through foraging and building of trails and burrows (Brinson and Christian, 1999; Christian et al. 2000). Also, location 3 gets flooded merely during extreme high tides and storm tides. As this occurs the hollows get filled by water lasting throughout most of the year (Brinson and Christian, 1999; Christian et al. 2000). Therefore; hollow and hummock formation restricts movement in this high marsh. The lower elevation of the pond prevents extension of patches, but patch borders do not seem to erode significantly even under these conditions (Christian et al. 2000; Brinson et al. 1995).

Bertness and Ellison (1987) state that wrack increases with lower marsh elevations. They described areas in the marsh that were lowest at the edges and highest in high marshes. Given this, the most wrack disturbance would be at location 3, which had the lowest elevation of the four locations at 1.18 m (Table 1). My study may show different results because of the subsidence and pond formation occurring at location 3, as well as its distance from tidal waters (Brinson and Christian, 1999). However, my low marsh (location 1) study site would agree with the study by Bertness and Ellison (1987) because this location has shown the greatest impact from wrack disturbance.

This subsiding high marsh had the most growing, senescing, and dead *Juncus* biomass (Figures 22, 24, and 26), continuing what was found by Brinson and Christian (1999). But this robust condition does not translate into horizontal growth. The neighboring pond limits the horizontal growth of *Juncus* outwards to none or very little. As a result, location 3 had the next to slowest rate of horizontal movement overall (Table 46). Also, wrack deposition has been low over the 24 years at this location (Figures 13 and 15), and doesn't seem to play as big of a role as it does in other locations (Brinson and Christian, 1999). It is possible that the pond developed earlier from wrack deposition, but my evidence is not supportive of this.

The largest amount of *Juncus* growth at the subsiding high marsh location seems quite stable, which supports that of Brinson and Christian (1999). In 1990, there was less pond in this location, but it grew into the 1 x 2 m plot at the expense of the neighboring community. *Juncus* on the other hand did not show any erosion and has remained stable. Although the pond is bordering the *Juncus* at the original boundary line, there still aren't as many other species to compete with *Juncus* at this location as there are at others. In areas where the black needlerush is dominate, *Spartina alterniflora* is found at lower densities; however, if *Juncus* is removed then this smooth cordgrass showed excellence in its performance, by increasing in density, signifying that growth is restricted by competition from *J. roemerianus* (Skaradek and Henson, 2007). The bordering communities outside of the permanent plot consist of *S. alterniflora, S. patens*, and *D. spicata*. This location 3 had the lowest mean of total live biomass for the bordering communities (175 g/m^2), which is half of that of location 4 at 350 g/m^2 (Figure 27). Location 3 also contains many bare areas within the 1 x 2 m plots, as a result of the subsidence (Brinson and Christian, 1999).

Overall, at location 3, the storms that occurred throughout my study didn't seem to bring as much wrack to this location as it did to others (Figure 13). Also, wrack deposition did result from a nor'easter in 1994 that caused an increase in the number of grids containing bare areas. Bare areas may be caused by stress from periodic flooding and aerobic decomposition of soil organic matter when the surface of the soil gets exposed directly to the atmosphere (Brinson and Christian, 1999).

In the subsiding high marsh, there is not much tidal flooding because of the distance from a tidal source, which is supported by Stasavich (1998) and Christian et al. (2000). As in Stasavich (1998), the hydrodynamics were very irregular. Because of the subsidence occurring at location 3, it does have the 2nd highest mean water level relative to the surface, right at the ground surface level (Figure 35). It has the lowest salinity level, tied with location 2 (Figure 37), partly because of the higher water levels during winter months (Christian et al. 1990). Roberts (2000) and Buck (2001) both had study sites at the VCR that were very closely related to my location 3. Their study sites resembled a hollow and hummock marsh area. Roberts (2000) measured monthly precipitation, groundwater depth, and groundwater salinity at a UPC site similar to my location 3. Buck (2001) also measured water levels, interstitial water salinity, and precipitation at the same site. Both Roberts (2000) and Buck (2001) found that this area had high relative water level, and low averages of salinity. They also stated that their studies showed a significant differences among sites. They found that sites in summer months, like June, experienced low relative water levels, high ground water salinity, and little precipitation. All of these data support and extend the results of my location 3 data. Also, this location had the lowest mean of soil bulk density (Figure 39), and the 2nd highest mean of MOM (Figure 41) which supports Brinson and Christian (1999). These edaphic conditions indicate that the soil in location 3 is peaty (which is similar to that of location 2).

The low soil bulk density and macro-organic matter factors play a major role in location 3 having the next to slowest rate of horizontal movement (Table 46). The peaty nature of this marsh is similar to location 2, which has rapid growth. However, at this location the pond stops the horizontal growth. Wetlands, such as salt marshes, will experience collapsing and internal breakup of the marsh (Cahoon et al. 2009). This relates to my study at UPC in Virginia, specifically location 3 where subsidence has occurred. This also may be known as an eroding marsh. When the elevations are lower (as in my location 3), then sea-level rise will have more of a negative impact on plant communities (Gesch et al., 2009). Also, *Juncus* is thought to be able to persist over many more years because of the way it has maintained itself next to the hollow. This subsidence occurring at location 3 is prevalent at VCR marshes because of the low sediment supplies (Brinson et al. 1995). Brinson et al. (1995) and Christian et al. (2000) both studied ecosystem stage changes, with aspects focusing on the internal breakup and eroding of marshes at the VCR. These marsh transitions occur because of disturbances such as rising sea level, flooding regimes, and wrack deposition (Brinson et al. 1995; Christian et al. 2000). In addition, the resistance of *Juncus* during this erosional process may be what allows *Juncus* to persist in the low marsh.

High marsh – near creek – Location 4

This high marsh near a creek location is unique in that it is in a transition zone from a high marsh to a low marsh. It had the next to lowest growing, senescing, and dead *Juncus* biomass in my study (Figures 22, 24, and 26), as well as in the study by Brinson and Christian (1999). However, as in location 1, the numbers in 2013 and 2014 were even lower than they were in 1990 and 1992 (Figure 23), which could be related to wrack deposition from storms (Brinson and Christian, 1999). Wrack disturbance is one of the most important aspects of my study; and in most locations where it occurred, it caused decreases in outward horizontal movement. My work supports and extends that of Brinson and Christian (1999) and Tolley and Christian (1999), in that the effects of wrack disturbance varied depending on the position in the salt marsh. Their study site was near my location 4, and we both agree that when the amount of wrack decreases in this zone, *Juncus* is able to recover slowly. Therefore, although there is wrack deposition and wrack push back, there is still horizontal *Juncus* growth at this location. Also, since this is near a creek the wrack disturbances should be more frequent (Brinson and Christian, 1999). The overall rates of horizontal movement at this location are faster than all of the other locations (Table 46). As a result, *Juncus* has moved the farthest out and reached beyond the outer limits of the 1 x 2 m plots (Figures 8 and 21).

The bordering community (Figure 27), which consists of mostly *S. alterniflora*. *D. spicata* and *Salicornia spp.*, were present in 1990 within the 1 x 2 m plot, but have disappeared at location 4 site A over the 24 years to be completely overcome by *Juncus* (Brinson and

Christian, 1999). They are, however, still present as bordering communities outside of the 1 x 2 m plot at location 4 site A. Location 4 site B consists largely of *S. alterniflora* as the bordering community along with bare areas. Brinson and Christian (1999) stated that patch stability is owed in part to *J. roemerianus* extensive tolerance for a wide range of hydroperiod. This is shown in my study, specifically at location 4 site B (Figure 18). At this site, *S. alterniflora* was more dominant in the early years, but has been outcompeted by *Juncus* since around 1997. However, if wrack occurs *Juncus* will decrease, allowing *S. alterniflora* to increase and possibly outcompete *Juncus* (as it did in location 1 site B).

At the high mash location, near the creek (location 4) there is intermediate tidal influence. At marshes at the VCR and the Cedar Island marsh, water source and hydrology are important to understand (Christian et al. 2000). Evapotranspiration has a major effect on water levels causing them to be below the surface of the marsh during growing seasons (Christian et al. 2000). This location had the lowest mean water level relative to the surface (Figure 35) and the 2nd highest mean salinity level (Figure 37), which are closely related to that of location 1. Taylor (1995) stated that salinity values can be altered depending on tidal flooding and evapotranspiration, as well as rainfall and freshwater runoff from upland neighboring communities. Tolley (1996) stated that salinity levels may decrease during a storm event permitting species less tolerant to salinity to occupy the area. Taylor (1995) and Tolley (1996) had study sites that were near my location 4. Their locations also had low water levels and salinity levels very closely related to mine. During the growing season, at the Cedar Island marsh and marshes at the VCR, evapotranspiration has a major effect on the water levels causing them to be below the surface of the marsh (Christian et al. 2000). This study supports my results at location 4, in which the mean water level is below that of the marsh surface (lowest of all the locations). Also, this location may support the fact that the soil beneath the layer of wrack holds more moisture because of reduced evapotranspiration (Taylor, 1995). In addition, this location had the next to lowest mean of MOM (Figure 41) and the 2nd highest mean of soil bulk density (Figure 39), which is also very similar to that of location 1.

This high marsh location near a creek had significantly more wrack than all of the other locations (Figures 13 and 18) with the next to highest relative elevation at 1.28 m (Table 1). This location 4 is a high marsh near a creek that has been eroding into the high marsh (Brinson and Christian, 1999; Brinson et al. 1995). The outer limit (i.e., 20 grid units) for both sites at location 4 was reached by the year 2011 (Figures 8 and 21). The years 2011, 2012, and 2013 all contributed to major wrack deposition at both location 4 site A, and especially at location 4 site B, because of the nor'easters and hurricanes that occurred during this period (Table 7). A very minimal amount of wrack was deposited at location 4 site A. However, at location 4 site B there was a large amount of wrack deposition, which caused a major period of inward movement by *Juncus* in 2011 that continued into 2013 (Figures 8 and 21). In 2013, *Juncus* finally started recovering from the wrack and moved outwards again for the last year of study. This high marsh near creek location is unique in that it had many years of repeated recovery for *Juncus*, which supports that of Tolley and Christian (1999). Tolley (1996) stated that plant species may take numerous years to re-establish and become species specific. Despite the major inward spike, overall, location 4 had the fastest rate of horizontal movement (Table 46).

Low marsh – Location 1

There is a large site difference between the low marsh location sites A and B (Figures 8, 17, and 21). This location has shown the greatest impact from wrack disturbance, with wrack deposition being very prevalent, especially at location 1 site B (Figure 17). Location 1 site B is greatly impacted by the excessive amount of wrack cover from major storms. There was wrack push back, in addition to high salinity levels and regular tidal flooding, which caused no horizontal *Juncus* growth and no movement of *Juncus* outwards. Location 1 has an overall slower rate of horizontal movement than all of the other locations (Table 46), showing a trend of inward movement, supporting and extending that of Brinson and Christian (1999). This location showed a decline in *Juncus* cover, with very large differences in wrack cover and bare soil. Location 1 site B experienced a major dip in 1994 because of the nor'easter that occurred. The regression, however, was calculated on the periods of years after this major wrack event. This was to show that there is slow growth at this low marsh site even after disturbance. The rate at location 1 site B, however, was faster than that of location 1 site A. This may because of slight differences in inundation and responses to disturbance at these sites. Another factor may be that there is a mix of species at location 1 site B and not at location 1 site A. The growth at location 1 site B is in a previous *Juncus* area where rhizomes may already exist, meaning it is not growth into a new area. My study extends and agrees with Brinson and Christian (1999) in that over the whole 24 year period, location 1 had the least amount of growing, senescing, and dead *Juncus* biomass (Figures 22, 24, and 26) partly because of wrack disturbance (Brinson and Christian, 1999).

I found that *Juncus* can be found over a wide range of hydrogeomorphic conditions; however, for all of these factors related to the conditions of *Juncus*, there was no clear and consistent difference among geomorphic positions (Table 47). It is clear, though, that location 1 (the low marsh) is less in the majority of these categories, agreeing with the statement that high marsh *Juncus* is higher in biomass, and denser and taller than when found in low marshes (Williams & Murdoch, 1972; Eleuterius, 1975, Eleuterius and Caldwell, 1981; Higinbotham et al., 2004). The total growing *Juncus* biomass for this location 1 (as well as location 4) were high in 1990 and 1992, but dropped drastically in 2013 and 2014. This is largely due to wrack deposition.

In my study, the total live bordering communities showed no significant differences among locations, and the standing dead bordering communities were also similar across the four locations (Table 47). For the standing dead bordering communities an important interaction was seen between locations 2 and 4 compared to locations 1 and 3. The bordering communities (Figure 27) at location 1 site B consist of *S. alterniflora*, *D. spicata*, *Salicornia spp*., and *L. nashi*, while location 1 site A is largely *S. alterniflora*. The low marsh (location 1), with a relative elevation of 1.22 m (Table 1), is lower than the other locations (with the exception of subsidence occurring at location 3). The findings at location 1 sites A and B would agree with the study by Bertness and Ellison (1987) in that lower marsh elevations are subject to wrack disturbances. They also said that *D. spicata* and *S. patens* were more prone to wrack disturbances than was *S. alterniflora*. My study supports theirs because location 1 site B (consisted of *D. spicata*, *Salicornia spp*., *S. alterniflora*, and *L. nashi*) experienced much more wrack deposition than did site A (which was largely *S. alterniflora*) (Figure 17).

Pennings et al. (2005) studied flooding, salinity, and competition by conducting field and laboratory experiments. Both flooding and salinity had an effect on the lower elevation limit of *J. roemerianus*, but competition did not. This study supports the fact that neighboring communities may not be that critical to horizontal movement. Results of this study propose that there is expected geographical variation among ecological interactions because of differences in the physical environment. For example, at lower elevations the stress from salinity most likely has a more essential role in determining plant spatial patterns.

In the low marsh (location 1), there is more regular, dominant tidal flooding. Water source and hydrology is important to recognize, as it greatly affects the zones within a salt marsh (Christian et al. 2000). The plants in low marshes are often submerged by most, if not all, high tides (Weis and Butler, 2009) causing more frequent flooding (Wiegert and Freeman, 1990). Some decreases in patch size were related to wrack disturbance at the site that had the most recurrent and deepest tidal flooding (Brinson and Christian, 1999), as in my location 1 study site. Also, location 1 had the next to lowest mean water level relative to the surface (Figure 35) and the highest mean salinity level (Figure 37) (which supports data from Stasavich 1998; Roberts 2000; Christian et al. 2000; Buck 2001). My data show water depth and salinity had a significant month and location interaction (Table 47). Also, *S. alterniflora* is adapted to higher levels of salinity and flooding than is *Juncus*. There is a substantial amount of overlap in salinity levels when studying *Spartina* areas compared to *Juncus* areas. *Spartina* is usually found in more saline zones and at lower elevations, and *Juncus* is usually found in less saline zones and at higher elevations (Woerner and Hackney, 1997).

This low marsh location had the highest mean soil bulk density (Figure 39) and lowest mean of MOM (Figure 41) (Brinson and Christian, 1999) because the soils at this location are mineral soils. For soil bulk density there was a significant location and site interaction (Table 47). The low elevation, position relative to a tidal creek, high bulk density and low mass of MOM are all characteristics of low marsh and separating features of low marsh from high marsh in marshes of the VCR (Brinson et al. 1995; Christian et al. 2000). All of these factors contribute to my location 1, being the least supportive of *Juncus* growth, and having the slowest overall rates of horizontal movement (Table 46).

The rates of horizontal movement at this location are slower overall than all of the other locations (Table 46), with some periods of inward movement. For the last continuous *Juncus* and the 3-m wide *Juncus* border studies, location 1 sites A and B look similar over the whole 24 year period (Figures 8 and 21). However, location 1 site A continued to decrease throughout all of the years of study, while location 1 site B experienced a major period of inward movement (Figures 8 and 21) because of the storm in 1994 (Table 7) that deposited a large amount of wrack (Brinson and Christian, 1999). Outward movement did not occur again for location 1 site B until around 2004. This site continued to increase until the notable periods of storms occurred starting in 2011 (as explained in location 4). Although no wrack deposition was recorded, the hurricanes and nor'easters brought strong winds and precipitation that affected this location 1 site B, causing it to continue to decrease until the last year of study (in 2014). Also, an increase in the number of bare areas resulted in the years following 1994 because of the wrack deposition at this location (Brinson and Christian, 1999). Brinson and Christian (1999) stated that patch stability is owed in part to *J. roemerianus's* extensive tolerance for a wide range of hydroperiod. This is shown in my study, specifically at location 1 site B. When the nor'easter occurred in 1994, causing major wrack deposition, the *Juncus* biomass decreased allowing *S. alterniflora* to increase and become the dominate species (Figure 17). When the amount of wrack finally decreased, *Juncus* was able to recover, however, at a slow rate (Tolley and Christian, 1999).

CONCLUSION

Implications

Climate change has major consequences on the ecogeomorphology of coastal wetlands (Day et al. 2008). Reyes (2009) reviewed landscape wetland models, emphasizing integration of environmental dynamics and responses into the landscape. He highlighted landscape models that triggered long-term modifications because of climate change, sea-level rise, and variations in patterns of land use and land cover. Climate change will modify sea-level rise, which according to Trail et al. (2011) will greatly affect wetland communities along the coast. As sea-level rises, the carbon within a salt marsh will be dispersed, fluctuating among different regions of vegetation, and will be contingent upon the dynamics of production and decomposition as well as historic organic and inorganic deposition (Elsey-Quirk et al. 2011). Elsey-Quirk et al. (2011) also state that "relative sea level rise may alter the distribution and quantity of carbon within coastal wetlands, altering the relative proportion of plant zones, causing species shifts and landward migration, and contributing to the direct loss of wetland area." Salt marshes will continue to accrete vertically with sea-level rise, diminishing the marsh surface via shoreline erosion (Christian et al. 2000). It is well known that sea-level rise is an enduring factor that is in control of ecosystem state changes (Brinson et al. 1995). The future of salt marshes are contingent upon horizontal movement, as well as the aptitude to grow vertically because of sea-level rise (Christian et al. 2000).

Understanding environmental variables is essential in zones where persistent inundation, high salinity, and inadequate amounts of nutrients may be altering plant productivity (Shafer and Hackney, 1987). Water source and hydrology are important to understand, as they affect the zones within a salt marsh (Christian et al. 2000). As a result of relative sea-level rise, a shift in species may occur, causing species in the high marsh to be replaced by species in the low marsh as the salt marsh moves inland (Elsey-Quirk et al. 2011). A high marsh that may be dominated by *Juncus*, *D. spicata*, and *S. patens* will eventually go through an ecosystem state change transition to a low marsh. In the meantime, the associated low marsh will be eroding. "Thus the marsh is identified by its vegetation and factors affecting that vegetation, by its hydrogeomorphic position, and with respect to its probable future with respect to sea-level change (Christian et al. 2000)." Also, *Juncus* is a southern species, and because of the climate change and temperature increases, it may be expanding its range northward. *Juncus* may or may not persist with the affects from storms, flooding, and sea-level rise.

Conceptual Model

This study is important in that it provides a long term data set for the Virginia Coast Reserve (VCR) and The Nature Conservancy (TNC) that tracks community structure and environmental factors within the salt marsh. This study also helps in understanding of ecosystem state changes of salt marshes associated with disturbance and sea-level rise. As seen in my study and conceptual model (Figure 42), flooding and inundation indirectly from sea-level rise vary depending on the location within UPC salt marsh associated with elevation differences and distances from a creek. Although, climate change and sea-level rise are not in conceptual model explicitly, the various environmental drivers in which I studied are all related to climate change. Also, sea level has risen over 24 years with potential for decreases in the marsh surface elevation (Robert Christian, personal communication, re: surface elevation table results).

Juncus and the neighboring species get affected by the environmental factors listed in my conceptual model (Figure 1). This in turn causes patch border dynamics among communities (Brinson and Christian, 1999; Cahoon et al. 2009; Reyes 2009; Christian et al. 2000; Blum and

Christian 2004), contributing to differences among locations in horizontal movement of the border. The borders of patches between *Juncus* and other saltmarsh species within different areas of a salt marsh were tracked at Upper Philips Creek (UPC) in Virginia from 1990 to 2014. *Juncus* patches seemed relatively stable, over a variety of geomorphically different locations, in the fact that none have disappeared in 24 years. However, patch size is growing, shrinking or maintaining itself depending on hydrogeomorphic location within the salt marsh and the associated environmental factors in my conceptual model (Figure 42).

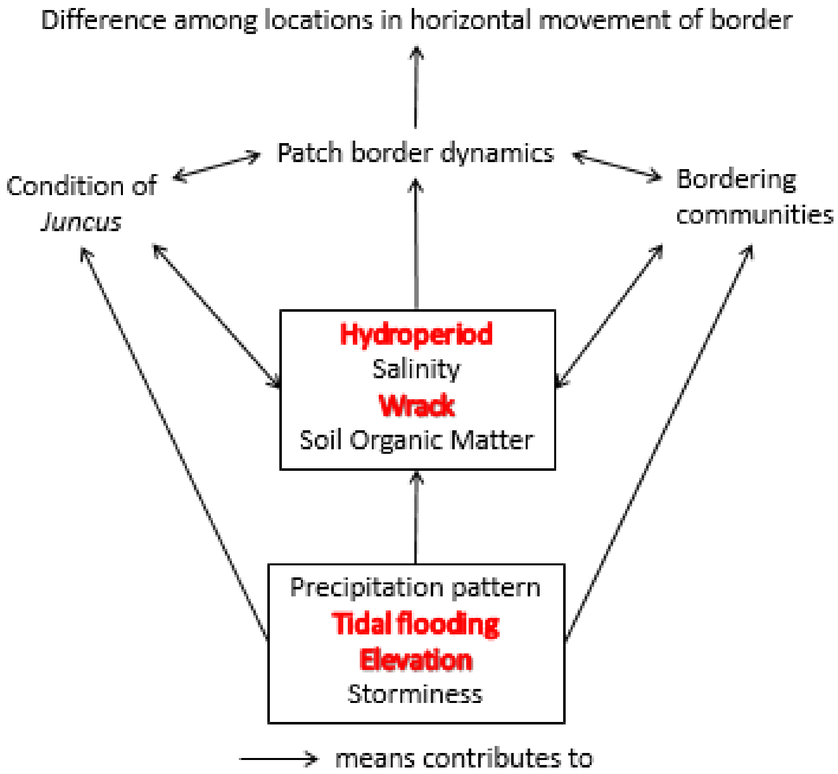

Figure 42: New conceptual model highlighting most important factors.

Hydroperiod, wrack deposition, frequency of tidal flooding, and elevation differences seem to be the most important aspects of my conceptual model relating to horizontal movement of border (Figure 42). All of the other various environmental factors did not show clear trends in horizontal movement of *Juncus*. In the low marsh, the patches may be hit by wrack and shrink. Wrack reduced patch size at low marsh site 1B in 1994 without full recovery. Expansion of

Juncus has occurred at high marsh sites both away from and near a creek. In high marsh areas patches are growing horizontally unless they are hit by wrack or bordering a hollow. If a hollow and hummock formation occurred, the movement in the high marsh was restricted, but the patch borders did not seem to erode significantly. However, in the case of high marsh near creek location there has been both *Juncus* expansion and wrack deposition. The horizontal growth of *Juncus* is enhanced at the transition from high marsh to low marsh and can continue while other high marsh plants cannot. Patch border retreated where wrack disturbance and flooding interrelate. Therefore, *Juncus* patch hydrogeomorphic setting and environmental factors within my conceptual model associated with location matter.

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APPENDIX A. LAST CONTINUOUS *JUNCUS* DATA

Location	Plot	Row	1990	1991	1992	1993	1994	1995	1996
1	A	A	11	10	10	9	10	10	9
1	A	B	13	10	10	10	10	10	9
1	A	C	12	10	10	10	10	10	9
1	A	D	10	10	10	9	10	10	9
1	A	E	11	9	10	9	10	10	10
1	A	F	13	9	10	9	10	10	9
1	A	G	13	12	10	9	10	10	10
1	A	H	14	12	12	10	10	10	10
1	A	I	14	12	12	9	10	10	8
1	A	J	14	12	12	10	10	10	8
1	B	A	12	12	12	13	12	12	11
1	B	B	12	12	12	12	12	12	11
1	B	C	12	12	13	13	12	3	0
1	B	D	12	13	13	13	13	2	0
1	B	E	12	12	11	12	10	2	0
1	B	F	10	10	10	10	9	0	0
1	B	G	9	9	10	10	10	0	0
1	B	H	9	9	10	7	10	0	0
1	B	I	9	11	10	8	10	0	0
1	B	J	11	10	10	10	10	0	0
2	A	A	10	10	10	11	11	12	12
2	A	B	10	10	10	11	11	13	11
2	A	C	10	10	10	10	11	13	13
2	A	D	12	12	13	13	12	13	13
2	A	E	12	13	13	13	12	13	13
2	A	F	10	12	11	13	11	11	13
2	A	G	10	10	10	10	11	10	13
2	A	H	10	10	11	10	11	13	13
2	A	I	10	12	12	11	12	12	13
2	A	J	10	12	12	12	14	14	14
2	B	A	10	10	11	11	12	13	14
2	B	B	11	10	11	11	12	12	13
2	B	C	10	11	12	11	12	13	13
2	B	D	10	10	10	10	12	13	13
2	B	E	10	9	10	10	12	13	13
2	B	F	10	9	10	9	11	11	13
2	B	G	10	10	10	11	12	11	12
2	B	H	10	10	11	11	13	13	13

2	**B**	**I**	10	10	10	10	13	14	16
2	**B**	**J**	10	9	10	10	12	15	15
3	**A**	**A**	9	9	10	9	10	10	10
3	**A**	**B**	9	9	10	9	10	10	10
3	**A**	**C**	8	9	10	10	10	10	10
3	**A**	**D**	8	9	10	10	10	10	11
3	**A**	**E**	8	10	10	10	10	10	12
3	**A**	**F**	8	9	10	9	10	10	12
3	**A**	**G**	8	9	10	10	10	10	12
3	**A**	**H**	8	9	10	10	10	10	12
3	**A**	**I**	8	9	10	9	10	10	12
3	**A**	**J**	8	9	10	9	10	10	12
3	**B**	**A**	5	6	10	6	10	7	8
3	**B**	**B**	7	6	10	7	10	8	9
3	**B**	**C**	7	8	10	8	10	9	10
3	**B**	**D**	7	9	10	9	10	10	11
3	**B**	**E**	9	10	10	10	10	10	12
3	**B**	**F**	11	10	10	10	11	11	12
3	**B**	**G**	12	10	10	10	11	11	12
3	**B**	**H**	12	10	10	10	11	11	12
3	**B**	**I**	12	10	10	10	10	11	11
3	**B**	**J**	11	9	10	10	10	10	11
4	**A**	**A**	9	10	16	11	15	16	16
4	**A**	**B**	13	13	17	15	15	17	16
4	**A**	**C**	13	15	17	17	19	16	20
4	**A**	**D**	14	14	17	17	18	20	20
4	**A**	**E**	16	16	20	19	20	20	20
4	**A**	**F**	15	16	15	20	20	20	20
4	**A**	**G**	14	11	18	19	19	20	20
4	**A**	**H**	17	17	17	20	19	20	20
4	**A**	**I**	14	18	13	17	19	20	20
4	**A**	**J**	10	10	19	16	18	20	20
4	**B**	**A**	9	9	10	10	11	13	13
4	**B**	**B**	8	9	10	10	11	12	10
4	**B**	**C**	9	10	10	10	11	12	10
4	**B**	**D**	9	11	10	10	12	12	12
4	**B**	**E**	10	11	5	10	13	13	12
4	**B**	**F**	9	11	10	10	13	13	11
4	**B**	**G**	8	10	10	10	10	11	11
4	**B**	**H**	9	11	10	9	11	11	11
4	**B**	**I**	9	10	10	10	10	10	10

4	**B**	**J**	9	9	10	10	10	9	10

Location	**Plot**	**Row**	**1997**	**1998**	**1999**	**2000**	**2001**	**2002**	**2003**
1	**A**	**A**	9	9	9	9	10	9	9
1	**A**	**B**	9	9	9	9	10	10	9
1	**A**	**C**	10	9	9	8	10	9	9
1	**A**	**D**	9	9	9	9	10	9	10
1	**A**	**E**	10	9	9	10	10	10	10
1	**A**	**F**	10	9	9	9	10	9	9
1	**A**	**G**	10	9	9	9	9	10	9
1	**A**	**H**	9	9	9	8	8	9	8
1	**A**	**I**	9	8	8	8	9	8	8
1	**A**	**J**	9	8	8	8	10	9	9
1	**B**	**A**	0	12	0	13	14	14	14
1	**B**	**B**	4	13	12	12	14	13	12
1	**B**	**C**	12	11	4	11	12	0	13
1	**B**	**D**	0	0	0	0	5	0	1
1	**B**	**E**	0	0	0	0	0	0	0
1	**B**	**F**	0	0	0	0	0	0	0
1	**B**	**G**	0	0	0	0	0	0	0
1	**B**	**H**	0	0	0	0	0	0	0
1	**B**	**I**	0	0	0	0	0	0	0
1	**B**	**J**	0	0	0	0	0	0	0
2	**A**	**A**	11	11	13	13	14	14	18
2	**A**	**B**	11	12	13	13	14	15	18
2	**A**	**C**	11	12	13	12	14	16	18
2	**A**	**D**	13	14	14	15	16	16	18
2	**A**	**E**	13	15	15	16	16	16	18
2	**A**	**F**	14	15	16	15	16	17	16
2	**A**	**G**	12	15	14	14	15	15	16
2	**A**	**H**	12	12	13	13	16	15	16
2	**A**	**I**	12	12	14	14	16	15	14
2	**A**	**J**	13	14	14	14	16	15	16
2	**B**	**A**	14	16	16	17	17	17	18
2	**B**	**B**	16	17	16	17	17	17	18
2	**B**	**C**	12	14	15	16	16	17	18
2	**B**	**D**	12	14	14	14	16	19	20
2	**B**	**E**	12	14	13	14	16	18	20
2	**B**	**F**	11	12	13	15	17	17	19

2	**B**	**G**	12	14	14	14	20	19	17
2	**B**	**H**	14	18	18	19	20	20	20
2	**B**	**I**	16	18	19	20	20	19	20
2	**B**	**J**	16	18	19	19	20	20	20
3	**A**	**A**	11	11	12	12	12	11	12
3	**A**	**B**	10	11	11	11	12	11	12
3	**A**	**C**	11	11	12	11	12	11	12
3	**A**	**D**	11	11	12	12	12	12	13
3	**A**	**E**	11	12	12	12	12	12	13
3	**A**	**F**	10	11	12	12	12	12	13
3	**A**	**G**	10	11	12	11	12	12	13
3	**A**	**H**	10	11	12	11	12	12	13
3	**A**	**I**	10	12	13	12	12	12	13
3	**A**	**J**	10	11	12	11	12	12	13
3	**B**	**A**	7	7	7	7	7	7	8
3	**B**	**B**	7	7	8	9	8	8	9
3	**B**	**C**	9	9	9	10	10	9	11
3	**B**	**D**	10	10	10	10	12	10	13
3	**B**	**E**	10	11	10	11	13	12	13
3	**B**	**F**	11	11	12	12	13	12	13
3	**B**	**G**	11	11	12	12	13	12	13
3	**B**	**H**	11	11	11	12	13	12	13
3	**B**	**I**	11	10	11	9	13	12	14
3	**B**	**J**	9	10	9	9	11	12	11
4	**A**	**A**	17	19	19	18	20	20	20
4	**A**	**B**	16	18	19	20	20	20	20
4	**A**	**C**	16	18	17	20	20	20	20
4	**A**	**D**	18	20	20	20	20	20	20
4	**A**	**E**	20	20	20	20	20	20	20
4	**A**	**F**	20	20	20	20	20	20	20
4	**A**	**G**	20	20	20	20	20	20	20
4	**A**	**H**	20	20	20	20	20	20	20
4	**A**	**I**	19	20	20	20	20	20	20
4	**A**	**J**	20	20	20	20	20	20	20
4	**B**	**A**	16	15	17	20	20	20	20
4	**B**	**B**	17	15	17	20	20	20	20
4	**B**	**C**	15	16	18	20	20	20	20
4	**B**	**D**	14	16	17	17	20	20	20
4	**B**	**E**	13	12	14	14	19	20	20
4	**B**	**F**	12	12	14	14	18	18	20
4	**B**	**G**	12	13	13	14	17	18	19

4	**B**	**H**	13	13	14	14	14	17	18
4	**B**	**I**	11	12	14	15	15	17	18
4	**B**	**J**	9	12	14	15	15	16	18

Location	Plot	Row	2004	2005	2006	2007	2008	2009	2010
1	**A**	**A**	9	9	9	9	8	9	9
1	**A**	**B**	9	10	9	9	8	9	9
1	**A**	**C**	9	9	8	8	8	8	9
1	**A**	**D**	9	9	9	10	8	8	9
1	**A**	**E**	9	10	9	9	8	9	10
1	**A**	**F**	10	10	9	9	8	10	9
1	**A**	**G**	9	9	7	8	8	8	9
1	**A**	**H**	9	9	7	7	8	8	8
1	**A**	**I**	9	9	7	8	8	7	7
1	**A**	**J**	9	9	7	7	8	7	7
1	**B**	**A**	14	15	14	15	16	15	15
1	**B**	**B**	14	15	15	16	16	16	15
1	**B**	**C**	14	13	14	15	15	16	15
1	**B**	**D**	0	13	14	14	15	15	15
1	**B**	**E**	0	0	5	11	0	14	14
1	**B**	**F**	0	0	0	0	0	1	0
1	**B**	**G**	0	0	0	1	2	1	2
1	**B**	**H**	0	0	2	2	2	2	2
1	**B**	**I**	0	0	0	2	0	0	1
1	**B**	**J**	0	0	0	0	0	0	1
2	**A**	**A**	16	15	16	16	14	15	16
2	**A**	**B**	18	16	17	16	16	16	18
2	**A**	**C**	18	18	18	17	18	18	19
2	**A**	**D**	18	18	18	19	18	19	20
2	**A**	**E**	18	18	18	19	18	19	20
2	**A**	**F**	17	17	18	18	18	19	20
2	**A**	**G**	18	17	17	19	18	19	20
2	**A**	**H**	14	17	18	17	18	19	20
2	**A**	**I**	16	17	18	18	18	18	20
2	**A**	**J**	18	15	18	19	19	19	20
2	**B**	**A**	17	20	20	20	20	20	20
2	**B**	**B**	19	20	20	20	20	20	20
2	**B**	**C**	19	20	20	20	20	20	20
2	**B**	**D**	20	20	20	20	20	20	20
2	**B**	**E**	20	20	20	20	20	20	20

2	**B**	**F**	19	20	20	20	20	20	20
2	**B**	**G**	20	20	20	20	20	20	20
2	**B**	**H**	20	20	20	20	20	20	20
2	**B**	**I**	20	20	20	20	20	20	20
2	**B**	**J**	19	20	20	20	20	20	20
3	**A**	**A**	12	12	13	13	14	15	13
3	**A**	**B**	12	12	13	13	14	16	13
3	**A**	**C**	12	12	13	13	14	16	13
3	**A**	**D**	12	12	13	14	14	16	13
3	**A**	**E**	13	12	13	13	13	16	13
3	**A**	**F**	13	12	13	12	13	16	13
3	**A**	**G**	13	12	13	12	13	16	13
3	**A**	**H**	13	12	13	11	13	16	13
3	**A**	**I**	13	13	13	11	13	16	13
3	**A**	**J**	13	12	13	11	12	16	13
3	**B**	**A**	8	8	7	7	8	9	8
3	**B**	**B**	11	9	8	9	11	9	9
3	**B**	**C**	12	12	12	10	13	11	11
3	**B**	**D**	13	13	13	10	14	14	14
3	**B**	**E**	14	13	14	10	15	15	14
3	**B**	**F**	14	13	15	10	15	15	14
3	**B**	**G**	14	13	15	11	15	15	14
3	**B**	**H**	15	12	15	10	15	15	15
3	**B**	**I**	15	13	14	10	15	15	15
3	**B**	**J**	13	13	13	10	15	14	12
4	**A**	**A**	20	20	20	20	20	20	20
4	**A**	**B**	20	20	20	20	20	20	20
4	**A**	**C**	20	20	20	20	20	20	20
4	**A**	**D**	20	20	20	20	20	20	20
4	**A**	**E**	20	20	20	20	20	20	20
4	**A**	**F**	20	20	20	20	20	20	20
4	**A**	**G**	20	20	20	20	20	20	20
4	**A**	**H**	20	20	20	20	20	20	20
4	**A**	**I**	20	20	20	20	20	20	20
4	**A**	**J**	20	20	20	20	20	20	20
4	**B**	**A**	20	20	20	20	20	20	20
4	**B**	**B**	20	20	20	20	20	20	20
4	**B**	**C**	20	20	20	20	20	20	20
4	**B**	**D**	20	20	20	20	20	20	20
4	**B**	**E**	20	20	20	20	20	20	20
4	**B**	**F**	20	20	20	20	20	20	20

4	**B**	**G**	20	20	20	20	20	20	20
4	**B**	**H**	20	20	20	20	20	20	20
4	**B**	**I**	20	20	20	20	20	20	20
4	**B**	**J**	20	20	20	20	20	20	20

Location	**Plot**	**Row**	**2011**	**2012**	**2013**	**2014**
1	**A**	**A**	9	9	8	8
1	**A**	**B**	8	10	8	8
1	**A**	**C**	8	9	9	8
1	**A**	**D**	7	9	9	9
1	**A**	**E**	9	9	9	8
1	**A**	**F**	9	9	9	9
1	**A**	**G**	8	9	8	9
1	**A**	**H**	6	8	8	8
1	**A**	**I**	9	8	7	7
1	**A**	**J**	9	7	7	8
1	**B**	**A**	15	14	15	15
1	**B**	**B**	16	15	15	14
1	**B**	**C**	15	15	15	16
1	**B**	**D**	15	15	15	14
1	**B**	**E**	15	11	11	1
1	**B**	**F**	0	0	1	1
1	**B**	**G**	14	2	2	3
1	**B**	**H**	2	2	2	2
1	**B**	**I**	2	1	2	1
1	**B**	**J**	1	4	2	6
2	**A**	**A**		16	17	18
2	**A**	**B**		17	18	18
2	**A**	**C**		18	17	19
2	**A**	**D**		19	20	19
2	**A**	**E**		20	20	19
2	**A**	**F**		20	20	20
2	**A**	**G**		20	20	20
2	**A**	**H**		20	20	19
2	**A**	**I**		20	20	19
2	**A**	**J**		20	20	19
2	**B**	**A**		20	20	20
2	**B**	**B**		20	20	20
2	**B**	**C**		20	20	20
2	**B**	**D**		20	20	20

2	**B**	**E**		20	20	20
2	**B**	**F**		20	20	20
2	**B**	**G**		20	20	20
2	**B**	**H**		20	20	20
2	**B**	**I**		20	20	20
2	**B**	**J**		20	20	20
3	**A**	**A**		14	16	16
3	**A**	**B**		14	14	16
3	**A**	**C**		14	14	16
3	**A**	**D**		14	14	16
3	**A**	**E**		15	15	16
3	**A**	**F**		15	15	16
3	**A**	**G**		15	15	16
3	**A**	**H**		15	15	16
3	**A**	**I**		15	15	16
3	**A**	**J**		15	15	16
3	**B**	**A**		7	8	6
3	**B**	**B**		9	9	9
3	**B**	**C**		10	10	12
3	**B**	**D**		13	13	15
3	**B**	**E**		14	14	15
3	**B**	**F**		14	14	16
3	**B**	**G**		15	14	16
3	**B**	**H**		15	15	16
3	**B**	**I**		14	14	16
3	**B**	**J**		14	14	15
4	**A**	**A**	20	20	20	20
4	**A**	**B**	20	19	19	20
4	**A**	**C**	20	20	19	19
4	**A**	**D**	20	20	20	19
4	**A**	**E**	20	20	20	20
4	**A**	**F**	20	20	20	20
4	**A**	**G**	20	20	20	20
4	**A**	**H**	20	20	20	20
4	**A**	**I**	20	20	20	20
4	**A**	**J**	20	20	20	20
4	**B**	**A**	20	10	20	20
4	**B**	**B**	20	18	20	20
4	**B**	**C**	20	19	19	20
4	**B**	**D**	20	19	17	19
4	**B**	**E**	20	19	19	20

4	**B**	**F**	20	18	17	17
4	**B**	**G**	20	17	16	18
4	**B**	**H**	20	5	15	17
4	**B**	**I**	20	17	5	19
4	**B**	**J**	20	16	5	18

APPENDIX B. *JUNCUS* AND WRACK GROUND COVER DATA

Year	Location	Site	*Juncus* (dm^2)	Wrack/Litt (dm^2)
1990	**1**	**A**	121	0
1990	**1**	**B**	107	0
1990	**2**	**A**	103	0
1990	**2**	**B**	101	0
1990	**3**	**A**	82	0
1990	**3**	**B**	92	0
1990	**4**	**A**	117	35
1990	**4**	**B**	89	106
1991	**1**	**A**	105	0
1991	**1**	**B**	109	0
1991	**2**	**A**	110	0
1991	**2**	**B**	97	0
1991	**3**	**A**	91	0
1991	**3**	**B**	88	0
1991	**4**	**A**	133	8
1991	**4**	**B**	100	3
1992	**1**	**A**	102	44
1992	**1**	**B**	106	0
1992	**2**	**A**	110	0
1992	**2**	**B**	105	0
1992	**3**	**A**	90	0
1992	**3**	**B**	94	0
1992	**4**	**A**	150	0
1992	**4**	**B**	87	78
1993	**1**	**A**	94	0
1993	**1**	**B**	109	0
1993	**2**	**A**	113	63
1993	**2**	**B**	104	73
1993	**3**	**A**	90	39
1993	**3**	**B**	90	106
1993	**4**	**A**	161	16
1993	**4**	**B**	129	0
1994	**1**	**A**	88	86
1994	**1**	**B**	78	200
1994	**2**	**A**	116	30
1994	**2**	**B**	120	46
1994	**3**	**A**	98	0
1994	**3**	**B**	91	31
1994	**4**	**A**	169	26

1994	**4**	**B**	111	67
1995	**1**	**A**	99	0
1995	**1**	**B**	13	104
1995	**2**	**A**	123	32
1995	**2**	**B**	128	40
1995	**3**	**A**	100	0
1995	**3**	**B**	98	0
1995	**4**	**A**	179	19
1995	**4**	**B**	116	92
1996	**1**	**A**	91	0
1996	**1**	**B**	3	77
1996	**2**	**A**	127	0
1996	**2**	**B**	135	0
1996	**3**	**A**	113	0
1996	**3**	**B**	109	0
1996	**4**	**A**	185	0
1996	**4**	**B**	109	2
1997	**1**	**A**	94	0
1997	**1**	**B**	2	0
1997	**2**	**A**	122	68
1997	**2**	**B**	132	68
1997	**3**	**A**	104	0
1997	**3**	**B**	95	58
1997	**4**	**A**	181	14
1997	**4**	**B**	127	2
1998	**1**	**A**	87	0
1998	**1**	**B**	4	0
1998	**2**	**A**	130	39
1998	**2**	**B**	154	40
1998	**3**	**A**	112	0
1998	**3**	**B**	97	34
1998	**4**	**A**	191	0
1998	**4**	**B**	134	48
1999	**1**	**A**	88	0
1999	**1**	**B**	2	7
1999	**2**	**A**	133	46
1999	**2**	**B**	155	42
1999	**3**	**A**	120	0
1999	**3**	**B**	98	10
1999	**4**	**A**	194	9
1999	**4**	**B**	140	56

2000	**1**	**A**	87	0
2000	**1**	**B**	4	0
2000	**2**	**A**	139	0
2000	**2**	**B**	165	0
2000	**3**	**A**	115	0
2000	**3**	**B**	101	0
2000	**4**	**A**	196	0
2000	**4**	**B**	148	33
2001	**1**	**A**	96	0
2001	**1**	**B**	15	0
2001	**2**	**A**	152	0
2001	**2**	**B**	179	0
2001	**3**	**A**	120	0
2001	**3**	**B**	113	0
2001	**4**	**A**	200	0
2001	**4**	**B**	174	0
2002	**1**	**A**	92	0
2002	**1**	**B**	7	0
2002	**2**	**A**	154	6
2002	**2**	**B**	182	3
2002	**3**	**A**	117	0
2002	**3**	**B**	106	0
2002	**4**	**A**	200	0
2002	**4**	**B**	186	0
2003	**1**	**A**	90	0
2003	**1**	**B**	12	0
2003	**2**	**A**	163	0
2003	**2**	**B**	189	0
2003	**3**	**A**	127	0
2003	**3**	**B**	119	0
2003	**4**	**A**	200	0
2003	**4**	**B**	193	0
2004	**1**	**A**	91	0
2004	**1**	**B**	15	0
2004	**2**	**A**	171	0
2004	**2**	**B**	193	0
2004	**3**	**A**	126	0
2004	**3**	**B**	129	0
2004	**4**	**A**	200	0
2004	**4**	**B**	198	0
2005	**1**	**A**	93	0

2005	**1**	**B**	27	0
2005	**2**	**A**	166	0
2005	**2**	**B**	200	0
2005	**3**	**A**	121	0
2005	**3**	**B**	118	0
2005	**4**	**A**	200	0
2005	**4**	**B**	200	0
2006	**1**	**A**	81	13
2006	**1**	**B**	40	0
2006	**2**	**A**	176	0
2006	**2**	**B**	200	0
2006	**3**	**A**	130	0
2006	**3**	**B**	125	0
2006	**4**	**A**	178	89
2006	**4**	**B**	200	56
2007	**1**	**A**	84	0
2007	**1**	**B**	47	0
2007	**2**	**A**	178	0
2007	**2**	**B**	200	0
2007	**3**	**A**	123	0
2007	**3**	**B**	97	0
2007	**4**	**A**	180	76
2007	**4**	**B**	200	47
2008	**1**	**A**	80	0
2008	**1**	**B**	40	0
2008	**2**	**A**	175	0
2008	**2**	**B**	199	0
2008	**3**	**A**	133	0
2008	**3**	**B**	136	0
2008	**4**	**A**	200	6
2008	**4**	**B**	200	0
2009	**1**	**A**	82	0
2009	**1**	**B**	34	0
2009	**2**	**A**	181	0
2009	**2**	**B**	200	0
2009	**3**	**A**	159	0
2009	**3**	**B**	132	0
2009	**4**	**A**	199	0
2009	**4**	**B**	196	0
2010	**1**	**A**	84	0
2010	**1**	**B**	35	0

2010	**2**	**A**	193	0
2010	**2**	**B**	200	0
2010	**3**	**A**	130	0
2010	**3**	**B**	125	0
2010	**4**	**A**	190	0
2010	**4**	**B**	190	0
2011	**1**	**A**	71	0
2011	**1**	**B**	33	0
2011	**2**	**A**	NA	NA
2011	**2**	**B**	NA	NA
2011	**3**	**A**	NA	NA
2011	**3**	**B**	NA	NA
2011	**4**	**A**	198	0
2011	**4**	**B**	199	129
2012	**1**	**A**	81	0
2012	**1**	**B**	28	0
2012	**2**	**A**	188	0
2012	**2**	**B**	200	0
2012	**3**	**A**	146	0
2012	**3**	**B**	125	0
2012	**4**	**A**	198	16
2012	**4**	**B**	90	156
2013	**1**	**A**	76	0
2013	**1**	**B**	28	0
2013	**2**	**A**	191	0
2013	**2**	**B**	200	0
2013	**3**	**A**	147	0
2013	**3**	**B**	122	0
2013	**4**	**A**	198	16
2013	**4**	**B**	110	139
2014	**1**	**A**	76	0
2014	**1**	**B**	29	0
2014	**2**	**A**	190	0
2014	**2**	**B**	200	0
2014	**3**	**A**	160	0
2014	**3**	**B**	134	0
2014	**4**	**A**	198	18
2014	**4**	**B**	146	86

APPENDIX C. *JUNCUS* 3-M WIDE BORDER POSITION DATA

Location	Site	PVC marks (cm)	Measurements (cm)
1	A	0	-29
1	A	30	0
1	A	60	9
1	A	90	25
1	A	120	9
1	A	150	10
1	A	180	5
1	A	210	-6
1	A	240	-26
1	A	270	-14
1	A	300	16
1	B	0	45
1	B	30	43
1	B	60	-90
1	B	90	-135
1	B	120	-138
1	B	150	71
1	B	180	82
1	B	210	96
1	B	240	59
1	B	270	50
1	B	300	137
2	A	0	66
2	A	30	95
2	A	60	103
2	A	90	110
2	A	120	109
2	A	150	96
2	A	180	64
2	A	210	112
2	A	240	112
2	A	270	121
2	A	300	99
2	B	0	153
2	B	30	160
2	B	60	190
2	B	90	180
2	B	120	135
2	B	150	185

2	**B**	180	200
2	**B**	210	210
2	**B**	240	220
2	**B**	270	205
2	**B**	300	250
3	**A**	0	28
3	**A**	30	35
3	**A**	60	30
3	**A**	90	14
3	**A**	120	26
3	**A**	150	9
3	**A**	180	-35
3	**A**	210	19
3	**A**	240	19
3	**A**	270	17
3	**A**	300	18
3	**B**	0	-29
3	**B**	30	0
3	**B**	60	9
3	**B**	90	25
3	**B**	120	9
3	**B**	150	10
3	**B**	180	5
3	**B**	210	-6
3	**B**	240	-26
3	**B**	270	-14
3	**B**	300	16
4	**A**	0	265
4	**A**	30	275
4	**A**	60	315
4	**A**	90	305
4	**A**	120	375
4	**A**	150	310
4	**A**	180	320
4	**A**	210	315
4	**A**	240	320
4	**A**	270	295
4	**A**	300	285
4	**B**	0	165
4	**B**	30	160
4	**B**	60	170

4	**B**	90	190
4	**B**	120	145
4	**B**	150	150
4	**B**	180	190
4	**B**	210	205
4	**B**	240	215
4	**B**	270	175
4	**B**	300	225

APPENDIX D. TRANSECT POSITION DATA

Transect	Location	Measurement (cm)	Mean (cm)	Standard Deviation (cm)
1	Near 1	125	121.7	85.0
2		205		
3		35		
4	Nearest 1	125	58.7	62.9
5		0		
6		51		
7	Near 2	170	149.0	54.6
8		87		
9		190		

APPENDIX *E. JUNCUS* BIOMASS DATA

Total Growing *Juncus* Biomass g/m^2

Location	Site	In/Out	1990	1992	2013	2014
1	A	In	186.96	335.04	84.96	133.6
1	B	In	306.68	293.84	0	20.48
2	A	In	82.6	266.32	269.76	324.48
2	B	In	481.48	220.64	358.56	431.2
3	A	In	457.6	275.44	196.16	307.84
3	B	In	251.44	382.8	541.92	318.24
4	A	In	340.12	269.6	116.16	110.24
4	B	In	400.4	458	104.32	119.52

Total Senescing *Juncus* Biomass g/m^2

Location	Site	In/Out	1990	1992	2013	2014
1	A	In	573.12	272.16	178.4	161.44
1	B	In	454.56	405.28	0	30.72
2	A	In	602.44	483.68	742.24	312.64
2	B	In	688.6	605.04	765.76	469.92
3	A	In	827	582.4	1307.2	687.52
3	B	In	1240.84	736.8	1331.84	794.88
4	A	In	503.08	361.2	785.92	169.76
4	B	In	391.32	553.84	974.72	237.76

Standing Dead *Juncus* Biomass g/m^2

Location	Site	In/Out	1990	1992	2013	2014
1	A	In	892.16	736	73.44	1157.28
1	B	In	884.36	747.76	0	0
2	A	In	419.08	1030.56	1129.76	742.88
2	B	In	951.72	1077.04	645.6	752.8
3	A	In	1772.44	1150.88	1053.12	1622.88
3	B	In	2155.96	2150.64	873.28	1137.12
4	A	In	908.04	768.4	694.56	1157.92
4	B	In	115.4	853.04	464.96	867.2

APPENDIX F. BORDERING COMMUNITIES BIOMASS DATA

Total Live Bordering Communities g/m^2

Location	Site	In/Out	1990	1992	2013	2014
1	A	Out	165.68	4.16	129.6	215.2
1	B	Out	153.36	12.32	452.16	329.12
2	A	Out	634.36	13.36	0	0
2	B	Out	398.52	1.2	70.56	776.48
3	A	Out	84.2	10.24	0	0
3	B	Out	551.04	17.92	512.64	234.24
4	A	Out	320.56	4	483.84	547.52
4	B	Out	302.12	22.16	645.6	478.24

Standing Dead Bordering Communities g/m^2

Location	Site	In/Out	1990	1992	2013	2014
1	A	Out	250.36	98.96	12.32	35.68
1	B	Out	187.72	272.72	312.16	111.2
2	A	Out	816.96	1371.04	0	0
2	B	Out	517.88	1001.76	512.32	366.56
3	A	Out	292.16	465.2	0	0
3	B	Out	594.44	888.72	78.24	140.64
4	A	Out	479.84	844.72	156.8	227.04
4	B	Out	464.28	812.96	614.88	209.12

APPENDIX G. DENSITY DATA ON GROWING AND SENESCING *JUNCUS* LEAVES

Year	Location	Site	In/Out	Sample	Number of Growing *Juncus* leaves per m^2	Number of Senescing *Juncus* leaves per m^2
1990	**1**	**A**	**In**		106	185
1990	**1**	**B**	**In**		172	128
1990	**2**	**A**	**In**		39	100
1990	**2**	**B**	**In**		170	176
1990	**3**	**A**	**In**		107	153
1990	**3**	**B**	**In**		127	298
1990	**4**	**A**	**In**		99	97
1990	**4**	**B**	**In**		165	134
1992	**1**	**A**	**In**	**3**	29	20
1992	**1**	**A**	**In**	**2**	47	27
1992	**1**	**B**	**In**	**5**	36	30
1992	**1**	**B**	**In**	**6**	44	30
1992	**2**	**A**	**In**	**4**	13	13
1992	**2**	**A**	**In**	**5**	44	43
1992	**2**	**B**	**In**	**4**	38	56
1992	**2**	**B**	**In**	**3**	16	20
1992	**3**	**A**	**In**	**1**	13	13
1992	**3**	**A**	**In**	**6**	51	38
1992	**3**	**B**	**In**	**6**	77	56
1992	**3**	**B**	**In**	**2**	45	45
1992	**4**	**A**	**In**	**2**	24	20
1992	**4**	**A**	**In**	**6**	19	18
1992	**4**	**B**	**In**	**2**	31	32
1992	**4**	**B**	**In**	**5**	57	37
2013	**1**	**A**	**In**		7	7
2013	**1**	**B**	**In**		0	0
2013	**2**	**A**	**In**		10	29
2013	**2**	**B**	**In**		28	14
2013	**3**	**A**	**In**		26	11
2013	**3**	**B**	**In**		38	25
2013	**4**	**A**	**In**		38	10
2013	**4**	**B**	**In**		31	13
2014	**1**	**A**	**In**		13	16
2014	**1**	**B**	**In**		4	2
2014	**2**	**A**	**In**		29	15
2014	**2**	**B**	**In**		31	6
2014	**3**	**A**	**In**		24	13
2014	**3**	**B**	**In**		32	26

2014	**4**	**A**	**In**		10	11
2014	**4**	**B**	**In**		15	13

APPENDIX H. HEIGHT DATA ON *JUNCUS* LEAVES

Year	Location	Site	In/Out	Sample	Total Height (cm)
1990	1	A	In		145.1
1990	1	A	In		163.9
1990	1	A	In		108
1990	1	A	In		144.8
1990	1	A	In		191.7
1990	1	A	In		175.5
1990	1	A	In		133.3
1990	1	A	In		148.1
1990	1	A	In		177.2
1990	1	A	In		160.8
1990	1	A	In		169
1990	1	A	In		166.5
1990	1	A	In		158
1990	1	A	In		148.9
1990	1	A	In		138.1
1990	1	A	In		108.8
1990	1	A	In		115.3
1990	1	A	In		141.4
1990	1	A	In		102.4
1990	1	A	In		143.5
1990	1	B	In		151.1
1990	1	B	In		164.2
1990	1	B	In		153.7
1990	1	B	In		136.2
1990	1	B	In		159.7
1990	1	B	In		196.1
1990	1	B	In		145.5
1990	1	B	In		122
1990	1	B	In		157.2
1990	1	B	In		105.7
1990	1	B	In		172.6
1990	1	B	In		128.4
1990	1	B	In		110.6
1990	1	B	In		132.3
1990	1	B	In		149.3
1990	1	B	In		179
1990	1	B	In		119.3
1990	1	B	In		166.3
1990	1	B	In		156.6

1990	**1**	**B**	**In**		164.5
1990	**2**	**A**	**In**		85.6
1990	**2**	**A**	**In**		217.7
1990	**2**	**A**	**In**		142.5
1990	**2**	**A**	**In**		179.5
1990	**2**	**A**	**In**		211.3
1990	**2**	**A**	**In**		161.2
1990	**2**	**A**	**In**		185.9
1990	**2**	**A**	**In**		148.3
1990	**2**	**A**	**In**		120.8
1990	**2**	**A**	**In**		90.3
1990	**2**	**A**	**In**		140.3
1990	**2**	**A**	**In**		127.8
1990	**2**	**A**	**In**		103.7
1990	**2**	**A**	**In**		127.6
1990	**2**	**A**	**In**		143
1990	**2**	**A**	**In**		121.5
1990	**2**	**A**	**In**		102.5
1990	**2**	**A**	**In**		142.1
1990	**2**	**A**	**In**		101.6
1990	**2**	**A**	**In**		123.3
1990	**2**	**B**	**In**		195.2
1990	**2**	**B**	**In**		217
1990	**2**	**B**	**In**		218.5
1990	**2**	**B**	**In**		217.5
1990	**2**	**B**	**In**		184.1
1990	**2**	**B**	**In**		217.8
1990	**2**	**B**	**In**		185
1990	**2**	**B**	**In**		163.4
1990	**2**	**B**	**In**		198.8
1990	**2**	**B**	**In**		185.1
1990	**2**	**B**	**In**		185
1990	**2**	**B**	**In**		192.2
1990	**2**	**B**	**In**		226.5
1990	**2**	**B**	**In**		201.1
1990	**2**	**B**	**In**		198.2
1990	**2**	**B**	**In**		156.5
1990	**2**	**B**	**In**		217.7
1990	**2**	**B**	**In**		214
1990	**2**	**B**	**In**		137.7
1990	**2**	**B**	**In**		178.7

1990	**3**	**A**	**In**		188.9
1990	**3**	**A**	**In**		144.7
1990	**3**	**A**	**In**		191.8
1990	**3**	**A**	**In**		169.8
1990	**3**	**A**	**In**		207
1990	**3**	**A**	**In**		177.8
1990	**3**	**A**	**In**		229.4
1990	**3**	**A**	**In**		181.7
1990	**3**	**A**	**In**		200.8
1990	**3**	**A**	**In**		205.6
1990	**3**	**A**	**In**		201.8
1990	**3**	**A**	**In**		178.9
1990	**3**	**A**	**In**		163.3
1990	**3**	**A**	**In**		174.9
1990	**3**	**A**	**In**		171.1
1990	**3**	**A**	**In**		205.8
1990	**3**	**A**	**In**		158.3
1990	**3**	**A**	**In**		157.8
1990	**3**	**A**	**In**		126.6
1990	**3**	**A**	**In**		229
1990	**3**	**B**	**In**		137.8
1990	**3**	**B**	**In**		186.3
1990	**3**	**B**	**In**		189.4
1990	**3**	**B**	**In**		121.2
1990	**3**	**B**	**In**		162.5
1990	**3**	**B**	**In**		181.2
1990	**3**	**B**	**In**		145.2
1990	**3**	**B**	**In**		112.2
1990	**3**	**B**	**In**		155.2
1990	**3**	**B**	**In**		112.4
1990	**3**	**B**	**In**		165.1
1990	**3**	**B**	**In**		142.8
1990	**3**	**B**	**In**		126
1990	**3**	**B**	**In**		104.4
1990	**3**	**B**	**In**		134.6
1990	**3**	**B**	**In**		146
1990	**3**	**B**	**In**		164.4
1990	**3**	**B**	**In**		193.4
1990	**3**	**B**	**In**		167.2
1990	**3**	**B**	**In**		201.8
1990	**4**	**A**	**In**		180.6

1990	**4**	**A**	**In**		155
1990	**4**	**A**	**In**		166.9
1990	**4**	**A**	**In**		187.8
1990	**4**	**A**	**In**		159.7
1990	**4**	**A**	**In**		190
1990	**4**	**A**	**In**		174.5
1990	**4**	**A**	**In**		135.6
1990	**4**	**A**	**In**		155.4
1990	**4**	**A**	**In**		161.5
1990	**4**	**A**	**In**		161.5
1990	**4**	**A**	**In**		139.4
1990	**4**	**A**	**In**		159.8
1990	**4**	**A**	**In**		149.3
1990	**4**	**A**	**In**		159.7
1990	**4**	**A**	**In**		154.1
1990	**4**	**A**	**In**		123.6
1990	**4**	**A**	**In**		125.7
1990	**4**	**A**	**In**		112.1
1990	**4**	**A**	**In**		144.8
1990	**4**	**B**	**In**		198.6
1990	**4**	**B**	**In**		143
1990	**4**	**B**	**In**		140
1990	**4**	**B**	**In**		84.2
1990	**4**	**B**	**In**		100.4
1990	**4**	**B**	**In**		161.5
1990	**4**	**B**	**In**		149.3
1990	**4**	**B**	**In**		107.6
1990	**4**	**B**	**In**		126.5
1990	**4**	**B**	**In**		137.1
1990	**4**	**B**	**In**		159
1990	**4**	**B**	**In**		122.8
1990	**4**	**B**	**In**		122.2
1990	**4**	**B**	**In**		107.6
1990	**4**	**B**	**In**		153.9
1990	**4**	**B**	**In**		155.5
1990	**4**	**B**	**In**		190
1990	**4**	**B**	**In**		141.3
1990	**4**	**B**	**In**		109.2
1990	**4**	**B**	**In**		134
1992	**1**	**A**	**In**	**3**	89.5

1992	**1**	**A**	**In**	**3**	114.7
1992	**1**	**A**	**In**	**3**	124.6
1992	**1**	**A**	**In**	**3**	182.6
1992	**1**	**A**	**In**	**3**	108.9
1992	**1**	**A**	**In**	**3**	118
1992	**1**	**A**	**In**	**3**	106.7
1992	**1**	**A**	**In**	**3**	146.8
1992	**1**	**A**	**In**	**3**	148.9
1992	**1**	**A**	**In**	**3**	127.7
1992	**1**	**A**	**In**	**3**	164.2
1992	**1**	**A**	**In**	**3**	184.7
1992	**1**	**A**	**In**	**3**	168.2
1992	**1**	**A**	**In**	**3**	99.7
1992	**1**	**A**	**In**	**3**	131.9
1992	**1**	**A**	**In**	**3**	145.4
1992	**1**	**A**	**In**	**3**	137.9
1992	**1**	**A**	**In**	**3**	100.8
1992	**1**	**A**	**In**	**3**	182.3
1992	**1**	**A**	**In**	**3**	131.1
1992	**1**	**A**	**In**	**2**	180.7
1992	**1**	**A**	**In**	**2**	142.5
1992	**1**	**A**	**In**	**2**	172.9
1992	**1**	**A**	**In**	**2**	180.7
1992	**1**	**A**	**In**	**2**	168
1992	**1**	**A**	**In**	**2**	128.6
1992	**1**	**A**	**In**	**2**	170.9
1992	**1**	**A**	**In**	**2**	196.5
1992	**1**	**A**	**In**	**2**	153.1
1992	**1**	**A**	**In**	**2**	157.6
1992	**1**	**A**	**In**	**2**	148.6
1992	**1**	**A**	**In**	**2**	126.1
1992	**1**	**A**	**In**	**2**	99.6
1992	**1**	**A**	**In**	**2**	149.4
1992	**1**	**A**	**In**	**2**	169.3
1992	**1**	**A**	**In**	**2**	157.7
1992	**1**	**A**	**In**	**2**	172.1
1992	**1**	**A**	**In**	**2**	166
1992	**1**	**A**	**In**	**2**	173.9
1992	**1**	**A**	**In**	**2**	114

1992	**1**	**B**	**In**	**5**	83
1992	**1**	**B**	**In**	**5**	122.9
1992	**1**	**B**	**In**	**5**	115.2
1992	**1**	**B**	**In**	**5**	128.6
1992	**1**	**B**	**In**	**5**	125.1
1992	**1**	**B**	**In**	**5**	170.8
1992	**1**	**B**	**In**	**5**	179.7
1992	**1**	**B**	**In**	**5**	129.1
1992	**1**	**B**	**In**	**5**	98.6
1992	**1**	**B**	**In**	**5**	123.6
1992	**1**	**B**	**In**	**5**	167.6
1992	**1**	**B**	**In**	**5**	164.3
1992	**1**	**B**	**In**	**5**	118
1992	**1**	**B**	**In**	**5**	127
1992	**1**	**B**	**In**	**5**	150.2
1992	**1**	**B**	**In**	**5**	178
1992	**1**	**B**	**In**	**5**	159.8
1992	**1**	**B**	**In**	**5**	138.7
1992	**1**	**B**	**In**	**5**	158.2
1992	**1**	**B**	**In**	**5**	111.7
1992	**1**	**B**	**In**	**6**	104.4
1992	**1**	**B**	**In**	**6**	124
1992	**1**	**B**	**In**	**6**	141.5
1992	**1**	**B**	**In**	**6**	122.9
1992	**1**	**B**	**In**	**6**	144.1
1992	**1**	**B**	**In**	**6**	135.6
1992	**1**	**B**	**In**	**6**	189.3
1992	**1**	**B**	**In**	**6**	103.7
1992	**1**	**B**	**In**	**6**	101.3
1992	**1**	**B**	**In**	**6**	160.9
1992	**1**	**B**	**In**	**6**	164.1
1992	**1**	**B**	**In**	**6**	140.9
1992	**1**	**B**	**In**	**6**	135.2
1992	**1**	**B**	**In**	**6**	176.8
1992	**1**	**B**	**In**	**6**	142.4
1992	**1**	**B**	**In**	**6**	124.7
1992	**1**	**B**	**In**	**6**	136.6
1992	**1**	**B**	**In**	**6**	96.7
1992	**1**	**B**	**In**	**6**	142.8
1992	**1**	**B**	**In**	**6**	128.3

1992	**2**	**A**	**In**	**4**	145.4
1992	**2**	**A**	**In**	**4**	173.7
1992	**2**	**A**	**In**	**4**	165.9
1992	**2**	**A**	**In**	**4**	177.8
1992	**2**	**A**	**In**	**4**	122
1992	**2**	**A**	**In**	**4**	132
1992	**2**	**A**	**In**	**4**	177
1992	**2**	**A**	**In**	**4**	152.1
1992	**2**	**A**	**In**	**4**	99.2
1992	**2**	**A**	**In**	**4**	104.4
1992	**2**	**A**	**In**	**4**	75.5
1992	**2**	**A**	**In**	**4**	66.4
1992	**2**	**A**	**In**	**4**	97.9
1992	**2**	**A**	**In**	**5**	118.4
1992	**2**	**A**	**In**	**5**	199.6
1992	**2**	**A**	**In**	**5**	119.9
1992	**2**	**A**	**In**	**5**	103.1
1992	**2**	**A**	**In**	**5**	195.5
1992	**2**	**A**	**In**	**5**	147
1992	**2**	**A**	**In**	**5**	103.3
1992	**2**	**A**	**In**	**5**	197.8
1992	**2**	**A**	**In**	**5**	163.8
1992	**2**	**A**	**In**	**5**	209.4
1992	**2**	**A**	**In**	**5**	114.1
1992	**2**	**A**	**In**	**5**	188.4
1992	**2**	**A**	**In**	**5**	165.1
1992	**2**	**A**	**In**	**5**	200.9
1992	**2**	**A**	**In**	**5**	139.3
1992	**2**	**A**	**In**	**5**	144.4
1992	**2**	**A**	**In**	**5**	204
1992	**2**	**A**	**In**	**5**	186
1992	**2**	**A**	**In**	**5**	152.4
1992	**2**	**A**	**In**	**5**	67.5
1992	**2**	**B**	**In**	**4**	101
1992	**2**	**B**	**In**	**4**	202.1
1992	**2**	**B**	**In**	**4**	185
1992	**2**	**B**	**In**	**4**	174
1992	**2**	**B**	**In**	**4**	122.8

1992	**2**	**B**	**In**	**4**	242.3
1992	**2**	**B**	**In**	**4**	221.8
1992	**2**	**B**	**In**	**4**	119.3
1992	**2**	**B**	**In**	**4**	232.7
1992	**2**	**B**	**In**	**4**	272.1
1992	**2**	**B**	**In**	**4**	207.2
1992	**2**	**B**	**In**	**4**	201
1992	**2**	**B**	**In**	**4**	211.6
1992	**2**	**B**	**In**	**4**	179
1992	**2**	**B**	**In**	**4**	187.8
1992	**2**	**B**	**In**	**4**	232.3
1992	**2**	**B**	**In**	**4**	226.2
1992	**2**	**B**	**In**	**4**	86.3
1992	**2**	**B**	**In**	**4**	141.2
1992	**2**	**B**	**In**	**4**	185
1992	**2**	**B**	**In**	**3**	105.6
1992	**2**	**B**	**In**	**3**	196.3
1992	**2**	**B**	**In**	**3**	166.3
1992	**2**	**B**	**In**	**3**	180.5
1992	**2**	**B**	**In**	**3**	140.5
1992	**2**	**B**	**In**	**3**	131.2
1992	**2**	**B**	**In**	**3**	118.5
1992	**2**	**B**	**In**	**3**	83.3
1992	**2**	**B**	**In**	**3**	173.2
1992	**2**	**B**	**In**	**3**	61.4
1992	**2**	**B**	**In**	**3**	163.3
1992	**2**	**B**	**In**	**3**	119
1992	**2**	**B**	**In**	**3**	95.3
1992	**2**	**B**	**In**	**3**	123.6
1992	**2**	**B**	**In**	**3**	183.1
1992	**2**	**B**	**In**	**3**	216.7
1992	**2**	**B**	**In**	**3**	105.1
1992	**2**	**B**	**In**	**3**	104.4
1992	**2**	**B**	**In**	**3**	97.9
1992	**2**	**B**	**In**	**3**	101.8
1992	**3**	**A**	**In**	**1**	150.6
1992	**3**	**A**	**In**	**1**	172.5
1992	**3**	**A**	**In**	**1**	136.4
1992	**3**	**A**	**In**	**1**	137.6

1992	**3**	**A**	**In**	**1**	98.5
1992	**3**	**A**	**In**	**1**	124
1992	**3**	**A**	**In**	**1**	112.7
1992	**3**	**A**	**In**	**1**	101.1
1992	**3**	**A**	**In**	**1**	117.9
1992	**3**	**A**	**In**	**1**	109.3
1992	**3**	**A**	**In**	**1**	126.2
1992	**3**	**A**	**In**	**1**	110.7
1992	**3**	**A**	**In**	**1**	157.4
1992	**3**	**A**	**In**	**6**	186.6
1992	**3**	**A**	**In**	**6**	148.8
1992	**3**	**A**	**In**	**6**	209.7
1992	**3**	**A**	**In**	**6**	189
1992	**3**	**A**	**In**	**6**	131.6
1992	**3**	**A**	**In**	**6**	164.9
1992	**3**	**A**	**In**	**6**	227.2
1992	**3**	**A**	**In**	**6**	146.2
1992	**3**	**A**	**In**	**6**	179.2
1992	**3**	**A**	**In**	**6**	194.3
1992	**3**	**A**	**In**	**6**	168.1
1992	**3**	**A**	**In**	**6**	208.1
1992	**3**	**A**	**In**	**6**	173.4
1992	**3**	**A**	**In**	**6**	166.5
1992	**3**	**A**	**In**	**6**	153.5
1992	**3**	**A**	**In**	**6**	169.1
1992	**3**	**A**	**In**	**6**	138.4
1992	**3**	**A**	**In**	**6**	115.8
1992	**3**	**A**	**In**	**6**	143.6
1992	**3**	**A**	**In**	**6**	181.5
1992	**3**	**B**	**In**	**6**	125.2
1992	**3**	**B**	**In**	**6**	110.6
1992	**3**	**B**	**In**	**6**	116.7
1992	**3**	**B**	**In**	**6**	159.1
1992	**3**	**B**	**In**	**6**	183
1992	**3**	**B**	**In**	**6**	194.3
1992	**3**	**B**	**In**	**6**	147.3
1992	**3**	**B**	**In**	**6**	197.2
1992	**3**	**B**	**In**	**6**	157.4
1992	**3**	**B**	**In**	**6**	127.9

1992	**3**	**B**	**In**	**6**	152
1992	**3**	**B**	**In**	**6**	142.5
1992	**3**	**B**	**In**	**6**	172.4
1992	**3**	**B**	**In**	**6**	191.5
1992	**3**	**B**	**In**	**6**	192
1992	**3**	**B**	**In**	**6**	139.4
1992	**3**	**B**	**In**	**6**	209.6
1992	**3**	**B**	**In**	**6**	176.4
1992	**3**	**B**	**In**	**6**	133
1992	**3**	**B**	**In**	**6**	206.3
1992	**3**	**B**	**In**	**2**	116.7
1992	**3**	**B**	**In**	**2**	137.5
1992	**3**	**B**	**In**	**2**	167.6
1992	**3**	**B**	**In**	**2**	175.6
1992	**3**	**B**	**In**	**2**	195.2
1992	**3**	**B**	**In**	**2**	153.4
1992	**3**	**B**	**In**	**2**	171.3
1992	**3**	**B**	**In**	**2**	152.3
1992	**3**	**B**	**In**	**2**	167.1
1992	**3**	**B**	**In**	**2**	153.5
1992	**3**	**B**	**In**	**2**	120.9
1992	**3**	**B**	**In**	**2**	174.1
1992	**3**	**B**	**In**	**2**	179.2
1992	**3**	**B**	**In**	**2**	172.4
1992	**3**	**B**	**In**	**2**	128.3
1992	**3**	**B**	**In**	**2**	198.2
1992	**3**	**B**	**In**	**2**	142
1992	**3**	**B**	**In**	**2**	133.4
1992	**3**	**B**	**In**	**2**	144.5
1992	**3**	**B**	**In**	**2**	133.3
1992	**4**	**A**	**In**	**2**	129
1992	**4**	**A**	**In**	**2**	204.5
1992	**4**	**A**	**In**	**2**	94.5
1992	**4**	**A**	**In**	**2**	154.5
1992	**4**	**A**	**In**	**2**	112.6
1992	**4**	**A**	**In**	**2**	171.8
1992	**4**	**A**	**In**	**2**	173.4
1992	**4**	**A**	**In**	**2**	184.7
1992	**4**	**A**	**In**	**2**	202.4

1992	**4**	**A**	**In**	**2**	184.7
1992	**4**	**A**	**In**	**2**	147.5
1992	**4**	**A**	**In**	**2**	186.5
1992	**4**	**A**	**In**	**2**	173.3
1992	**4**	**A**	**In**	**2**	174.4
1992	**4**	**A**	**In**	**2**	132.6
1992	**4**	**A**	**In**	**2**	169.3
1992	**4**	**A**	**In**	**2**	145
1992	**4**	**A**	**In**	**2**	145.8
1992	**4**	**A**	**In**	**2**	194.9
1992	**4**	**A**	**In**	**2**	69
1992	**4**	**A**	**In**	**6**	116.8
1992	**4**	**A**	**In**	**6**	177.5
1992	**4**	**A**	**In**	**6**	143.2
1992	**4**	**A**	**In**	**6**	104.6
1992	**4**	**A**	**In**	**6**	111.5
1992	**4**	**A**	**In**	**6**	106.2
1992	**4**	**A**	**In**	**6**	101.1
1992	**4**	**A**	**In**	**6**	150.7
1992	**4**	**A**	**In**	**6**	113.3
1992	**4**	**A**	**In**	**6**	163.6
1992	**4**	**A**	**In**	**6**	112.3
1992	**4**	**A**	**In**	**6**	117.6
1992	**4**	**A**	**In**	**6**	117.8
1992	**4**	**A**	**In**	**6**	151
1992	**4**	**A**	**In**	**6**	105.1
1992	**4**	**A**	**In**	**6**	162.4
1992	**4**	**A**	**In**	**6**	156.4
1992	**4**	**A**	**In**	**6**	142.2
1992	**4**	**A**	**In**	**6**	102.9
1992	**4**	**B**	**In**	**2**	110.5
1992	**4**	**B**	**In**	**2**	150.5
1992	**4**	**B**	**In**	**2**	179.5
1992	**4**	**B**	**In**	**2**	131.7
1992	**4**	**B**	**In**	**2**	180.7
1992	**4**	**B**	**In**	**2**	163.5
1992	**4**	**B**	**In**	**2**	109.3
1992	**4**	**B**	**In**	**2**	125
1992	**4**	**B**	**In**	**2**	98.8

1992	**4**	**B**	**In**	**2**	102.3
1992	**4**	**B**	**In**	**2**	172.3
1992	**4**	**B**	**In**	**2**	126
1992	**4**	**B**	**In**	**2**	157.7
1992	**4**	**B**	**In**	**2**	146.5
1992	**4**	**B**	**In**	**2**	120.8
1992	**4**	**B**	**In**	**2**	136.8
1992	**4**	**B**	**In**	**2**	151.5
1992	**4**	**B**	**In**	**2**	125.8
1992	**4**	**B**	**In**	**2**	161.4
1992	**4**	**B**	**In**	**2**	172.4
1992	**4**	**B**	**In**	**5**	105.4
1992	**4**	**B**	**In**	**5**	131
1992	**4**	**B**	**In**	**5**	196.2
1992	**4**	**B**	**In**	**5**	210
1992	**4**	**B**	**In**	**5**	126.9
1992	**4**	**B**	**In**	**5**	183.5
1992	**4**	**B**	**In**	**5**	189.9
1992	**4**	**B**	**In**	**5**	145.9
1992	**4**	**B**	**In**	**5**	178.4
1992	**4**	**B**	**In**	**5**	191.7
1992	**4**	**B**	**In**	**5**	99.1
1992	**4**	**B**	**In**	**5**	183.2
1992	**4**	**B**	**In**	**5**	158.3
1992	**4**	**B**	**In**	**5**	187.1
1992	**4**	**B**	**In**	**5**	137.6
1992	**4**	**B**	**In**	**5**	200.8
1992	**4**	**B**	**In**	**5**	125.3
1992	**4**	**B**	**In**	**5**	151.3
1992	**4**	**B**	**In**	**5**	128.2
1992	**4**	**B**	**In**	**5**	95
2013	**1**	**A**	**In**		68
2013	**1**	**A**	**In**		68
2013	**1**	**A**	**In**		63
2013	**1**	**A**	**In**		56
2013	**1**	**A**	**In**		51
2013	**1**	**A**	**In**		53
2013	**1**	**A**	**In**		19
2013	**1**	**A**	**In**		85

2013	**1**	**A**	**In**		83
2013	**1**	**A**	**In**		61
2013	**1**	**A**	**In**		67
2013	**1**	**B**	**In**		N/A
2013	**2**	**A**	**In**		107
2013	**2**	**A**	**In**		91
2013	**2**	**A**	**In**		65
2013	**2**	**A**	**In**		81
2013	**2**	**A**	**In**		98
2013	**2**	**A**	**In**		89
2013	**2**	**A**	**In**		91
2013	**2**	**A**	**In**		92
2013	**2**	**A**	**In**		97
2013	**2**	**A**	**In**		96
2013	**2**	**A**	**In**		57
2013	**2**	**A**	**In**		89
2013	**2**	**A**	**In**		78
2013	**2**	**A**	**In**		120
2013	**2**	**A**	**In**		87
2013	**2**	**A**	**In**		86
2013	**2**	**A**	**In**		85
2013	**2**	**A**	**In**		103
2013	**2**	**A**	**In**		84
2013	**2**	**A**	**In**		60
2013	**2**	**B**	**In**		114
2013	**2**	**B**	**In**		97
2013	**2**	**B**	**In**		99
2013	**2**	**B**	**In**		97
2013	**2**	**B**	**In**		70
2013	**2**	**B**	**In**		97
2013	**2**	**B**	**In**		71
2013	**2**	**B**	**In**		93
2013	**2**	**B**	**In**		107
2013	**2**	**B**	**In**		93
2013	**2**	**B**	**In**		101
2013	**2**	**B**	**In**		108
2013	**2**	**B**	**In**		65
2013	**2**	**B**	**In**		66
2013	**2**	**B**	**In**		106
2013	**2**	**B**	**In**		108
2013	**2**	**B**	**In**		102

2013	**2**	**B**	**In**		106
2013	**2**	**B**	**In**		89
2013	**2**	**B**	**In**		100
2013	**3**	**A**	**In**		132
2013	**3**	**A**	**In**		63
2013	**3**	**A**	**In**		107
2013	**3**	**A**	**In**		87
2013	**3**	**A**	**In**		112
2013	**3**	**A**	**In**		111
2013	**3**	**A**	**In**		103
2013	**3**	**A**	**In**		107
2013	**3**	**A**	**In**		126
2013	**3**	**A**	**In**		94
2013	**3**	**A**	**In**		129
2013	**3**	**A**	**In**		130
2013	**3**	**A**	**In**		140
2013	**3**	**A**	**In**		124
2013	**3**	**A**	**In**		72
2013	**3**	**A**	**In**		135
2013	**3**	**A**	**In**		149
2013	**3**	**A**	**In**		133
2013	**3**	**A**	**In**		71
2013	**3**	**A**	**In**		79
2013	**3**	**B**	**In**		93
2013	**3**	**B**	**In**		107
2013	**3**	**B**	**In**		91
2013	**3**	**B**	**In**		70
2013	**3**	**B**	**In**		82
2013	**3**	**B**	**In**		112
2013	**3**	**B**	**In**		118
2013	**3**	**B**	**In**		110
2013	**3**	**B**	**In**		82
2013	**3**	**B**	**In**		98
2013	**3**	**B**	**In**		107
2013	**3**	**B**	**In**		63
2013	**3**	**B**	**In**		59
2013	**3**	**B**	**In**		117
2013	**3**	**B**	**In**		104
2013	**3**	**B**	**In**		98
2013	**3**	**B**	**In**		81
2013	**3**	**B**	**In**		93

2013	**3**	**B**	**In**		82
2013	**3**	**B**	**In**		96
2013	**4**	**A**	**In**		75
2013	**4**	**A**	**In**		73
2013	**4**	**A**	**In**		20
2013	**4**	**A**	**In**		77
2013	**4**	**A**	**In**		82
2013	**4**	**A**	**In**		71
2013	**4**	**A**	**In**		81
2013	**4**	**A**	**In**		82
2013	**4**	**A**	**In**		67
2013	**4**	**A**	**In**		90
2013	**4**	**A**	**In**		56
2013	**4**	**A**	**In**		46
2013	**4**	**A**	**In**		25
2013	**4**	**A**	**In**		90
2013	**4**	**A**	**In**		89
2013	**4**	**A**	**In**		26
2013	**4**	**A**	**In**		66
2013	**4**	**A**	**In**		45
2013	**4**	**A**	**In**		71
2013	**4**	**A**	**In**		76
2013	**4**	**B**	**In**		84
2013	**4**	**B**	**In**		88
2013	**4**	**B**	**In**		107
2013	**4**	**B**	**In**		75
2013	**4**	**B**	**In**		78
2013	**4**	**B**	**In**		102
2013	**4**	**B**	**In**		94
2013	**4**	**B**	**In**		86
2013	**4**	**B**	**In**		105
2013	**4**	**B**	**In**		27
2013	**4**	**B**	**In**		100
2013	**4**	**B**	**In**		76
2013	**4**	**B**	**In**		86
2013	**4**	**B**	**In**		79
2013	**4**	**B**	**In**		79
2013	**4**	**B**	**In**		85
2013	**4**	**B**	**In**		89
2013	**4**	**B**	**In**		100
2013	**4**	**B**	**In**		97

2013	**4**	**B**	**In**		87
2014	**1**	**A**	**In**		96
2014	**1**	**A**	**In**		88
2014	**1**	**A**	**In**		78
2014	**1**	**A**	**In**		78
2014	**1**	**A**	**In**		90
2014	**1**	**A**	**In**		66
2014	**1**	**A**	**In**		67
2014	**1**	**A**	**In**		75
2014	**1**	**A**	**In**		76
2014	**1**	**A**	**In**		84
2014	**1**	**A**	**In**		99
2014	**1**	**A**	**In**		35
2014	**1**	**A**	**In**		52
2014	**1**	**A**	**In**		108
2014	**1**	**A**	**In**		54
2014	**1**	**A**	**In**		79
2014	**1**	**A**	**In**		38
2014	**1**	**A**	**In**		85
2014	**1**	**A**	**In**		87
2014	**1**	**A**	**In**		92
2014	**1**	**B**	**In**		69
2014	**1**	**B**	**In**		51
2014	**1**	**B**	**In**		66
2014	**1**	**B**	**In**		12
2014	**1**	**B**	**In**		30
2014	**1**	**B**	**In**		43
2014	**2**	**A**	**In**		108
2014	**2**	**A**	**In**		93
2014	**2**	**A**	**In**		85
2014	**2**	**A**	**In**		68
2014	**2**	**A**	**In**		77
2014	**2**	**A**	**In**		100
2014	**2**	**A**	**In**		115
2014	**2**	**A**	**In**		109
2014	**2**	**A**	**In**		25
2014	**2**	**A**	**In**		81
2014	**2**	**A**	**In**		105
2014	**2**	**A**	**In**		114
2014	**2**	**A**	**In**		70

2014	**2**	**A**	**In**		108
2014	**2**	**A**	**In**		87
2014	**2**	**A**	**In**		91
2014	**2**	**A**	**In**		34
2014	**2**	**A**	**In**		92
2014	**2**	**A**	**In**		104
2014	**2**	**A**	**In**		79
2014	**2**	**B**	**In**		137
2014	**2**	**B**	**In**		122
2014	**2**	**B**	**In**		112
2014	**2**	**B**	**In**		87
2014	**2**	**B**	**In**		98
2014	**2**	**B**	**In**		56
2014	**2**	**B**	**In**		114
2014	**2**	**B**	**In**		38
2014	**2**	**B**	**In**		116
2014	**2**	**B**	**In**		92
2014	**2**	**B**	**In**		93
2014	**2**	**B**	**In**		110
2014	**2**	**B**	**In**		92
2014	**2**	**B**	**In**		101
2014	**2**	**B**	**In**		110
2014	**2**	**B**	**In**		110
2014	**2**	**B**	**In**		120
2014	**2**	**B**	**In**		60
2014	**2**	**B**	**In**		118
2014	**2**	**B**	**In**		44
2014	**3**	**A**	**In**		134
2014	**3**	**A**	**In**		128
2014	**3**	**A**	**In**		104
2014	**3**	**A**	**In**		114
2014	**3**	**A**	**In**		112
2014	**3**	**A**	**In**		133
2014	**3**	**A**	**In**		121
2014	**3**	**A**	**In**		35
2014	**3**	**A**	**In**		131
2014	**3**	**A**	**In**		112
2014	**3**	**A**	**In**		82
2014	**3**	**A**	**In**		119
2014	**3**	**A**	**In**		76
2014	**3**	**A**	**In**		112

2014	**3**	**A**	**In**		134
2014	**3**	**A**	**In**		95
2014	**3**	**A**	**In**		108
2014	**3**	**A**	**In**		104
2014	**3**	**A**	**In**		116
2014	**3**	**A**	**In**		89
2014	**3**	**B**	**In**		128
2014	**3**	**B**	**In**		58
2014	**3**	**B**	**In**		115
2014	**3**	**B**	**In**		27
2014	**3**	**B**	**In**		110
2014	**3**	**B**	**In**		117
2014	**3**	**B**	**In**		120
2014	**3**	**B**	**In**		86
2014	**3**	**B**	**In**		74
2014	**3**	**B**	**In**		83
2014	**3**	**B**	**In**		114
2014	**3**	**B**	**In**		121
2014	**3**	**B**	**In**		93
2014	**3**	**B**	**In**		116
2014	**3**	**B**	**In**		107
2014	**3**	**B**	**In**		120
2014	**3**	**B**	**In**		111
2014	**3**	**B**	**In**		117
2014	**3**	**B**	**In**		115
2014	**3**	**B**	**In**		101
2014	**4**	**A**	**In**		106
2014	**4**	**A**	**In**		80
2014	**4**	**A**	**In**		82
2014	**4**	**A**	**In**		65
2014	**4**	**A**	**In**		63
2014	**4**	**A**	**In**		92
2014	**4**	**A**	**In**		73
2014	**4**	**A**	**In**		46
2014	**4**	**A**	**In**		82
2014	**4**	**A**	**In**		61
2014	**4**	**A**	**In**		101
2014	**4**	**A**	**In**		82
2014	**4**	**A**	**In**		57
2014	**4**	**A**	**In**		60
2014	**4**	**A**	**In**		80

2014	**4**	**A**	**In**		47
2014	**4**	**A**	**In**		80
2014	**4**	**A**	**In**		97
2014	**4**	**A**	**In**		60
2014	**4**	**A**	**In**		80
2014	**4**	**B**	**In**		103
2014	**4**	**B**	**In**		100
2014	**4**	**B**	**In**		100
2014	**4**	**B**	**In**		82
2014	**4**	**B**	**In**		61
2014	**4**	**B**	**In**		71
2014	**4**	**B**	**In**		89
2014	**4**	**B**	**In**		95
2014	**4**	**B**	**In**		59
2014	**4**	**B**	**In**		52
2014	**4**	**B**	**In**		91
2014	**4**	**B**	**In**		107
2014	**4**	**B**	**In**		84
2014	**4**	**B**	**In**		98
2014	**4**	**B**	**In**		59
2014	**4**	**B**	**In**		97
2014	**4**	**B**	**In**		45
2014	**4**	**B**	**In**		106
2014	**4**	**B**	**In**		96
2014	**4**	**B**	**In**		94

APPENDIX I. WATER DEPTH DATA

Month in 2014	Location	Site	In/Out	Water Level Relative to Soil Surface (cm)
May	1	A	In	0.1016
May	1	A	Out	-3.2004
May	1	B	In	-5.1308
May	1	B	Out	-6.8326
May	2	A	In	4.2164
May	2	A	Out	1.3462
May	2	B	In	4.4196
May	2	B	Out	3.048
May	3	A	In	4.826
May	3	A	Out	6.9596
May	3	B	In	2.413
May	3	B	Out	-2.0574
May	4	A	In	1.016
May	4	A	Out	-0.6604
May	4	B	In	-2.1844
May	4	B	Out	-4.2672
June	1	A	In	0.5334
June	1	A	Out	-2.1336
June	1	B	In	-2.667
June	1	B	Out	-4.1656
June	2	A	In	1.5494
June	2	A	Out	-0.889
June	2	B	In	-2.1844
June	2	B	Out	-1.8542
June	3	A	In	-5.2578
June	3	A	Out	3.0226
June	3	B	In	-0.254
June	3	B	Out	-3.0226
June	4	A	In	-7.1882
June	4	A	Out	-9.8298
June	4	B	In	-10.8204
June	4	B	Out	-15.5702
July	1	A	In	2.1336
July	1	A	Out	-1.6002
July	1	B	In	-0.8636
July	1	B	Out	-0.3302
July	2	A	In	3.4544
July	2	A	Out	0.508
July	2	B	In	-1.1176

July	**2**	**B**	**Out**	-4.2672
July	**3**	**A**	**In**	-7.2136
July	**3**	**A**	**Out**	-2.8448
July	**3**	**B**	**In**	-7.5184
July	**3**	**B**	**Out**	-11.1252
July	**4**	**A**	**In**	-3.7846
July	**4**	**A**	**Out**	-3.7846
July	**4**	**B**	**In**	-4.1148
July	**4**	**B**	**Out**	-5.3848
August	**1**	**A**	**In**	5.9436
August	**1**	**A**	**Out**	-0.4318
August	**1**	**B**	**In**	-0.8636
August	**1**	**B**	**Out**	-0.8636
August	**2**	**A**	**In**	6.1214
August	**2**	**A**	**Out**	0.6096
August	**2**	**B**	**In**	5.4864
August	**2**	**B**	**Out**	3.8862
August	**3**	**A**	**In**	2.286
August	**3**	**A**	**Out**	2.413
August	**3**	**B**	**In**	2.6162
August	**3**	**B**	**Out**	-0.9906
August	**4**	**A**	**In**	4.4196
August	**4**	**A**	**Out**	0.508
August	**4**	**B**	**In**	3.1496
August	**4**	**B**	**Out**	-2.667
September	**1**	**A**	**In**	2.3368
September	**1**	**A**	**Out**	0.2032
September	**1**	**B**	**In**	-0.6604
September	**1**	**B**	**Out**	-0.8636
September	**2**	**A**	**In**	4.953
September	**2**	**A**	**Out**	5.2832
September	**2**	**B**	**In**	4.4196
September	**2**	**B**	**Out**	5.4864
September	**3**	**A**	**In**	2.286
September	**3**	**A**	**Out**	1.8796
September	**3**	**B**	**In**	4.953
September	**3**	**B**	**Out**	-2.6924
September	**4**	**A**	**In**	3.0226
September	**4**	**A**	**Out**	0.4064
September	**4**	**B**	**In**	0.6858
September	**4**	**B**	**Out**	-2.4638

November	**1**	**A**	**In**	3.81
November	**1**	**A**	**Out**	0.7366
November	**1**	**B**	**In**	0.2032
November	**1**	**B**	**Out**	0.7366
November	**2**	**A**	**In**	3.683
November	**2**	**A**	**Out**	4.953
November	**2**	**B**	**In**	7.493
November	**2**	**B**	**Out**	6.0198
November	**3**	**A**	**In**	1.7526
November	**3**	**A**	**Out**	8.2296
November	**3**	**B**	**In**	3.3528
November	**3**	**B**	**Out**	-2.7432
November	**4**	**A**	**In**	1.8796
November	**4**	**A**	**Out**	1.4732
November	**4**	**B**	**In**	2.286
November	**4**	**B**	**Out**	0.4064

APPENDIX J. SALINITY DATA

Month in 2014	Location	Site	In/Out	Salinity (0/00)
May	1	A	In	15
May	1	A	Out	16
May	1	B	In	30
May	1	B	Out	29
May	2	A	In	15
May	2	A	Out	12
May	2	B	In	11
May	2	B	Out	8
May	3	A	In	10
May	3	A	Out	9
May	3	B	In	8
May	3	B	Out	6
May	4	A	In	20
May	4	A	Out	15
May	4	B	In	14
May	4	B	Out	16
June	1	A	In	14
June	1	A	Out	15
June	1	B	In	22
June	1	B	Out	24
June	2	A	In	13
June	2	A	Out	14
June	2	B	In	11
June	2	B	Out	10
June	3	A	In	14
June	3	A	Out	13
June	3	B	In	11
June	3	B	Out	9
June	4	A	In	27
June	4	A	Out	25
June	4	B	In	21
June	4	B	Out	19
July	1	A	In	22
July	1	A	Out	25
July	1	B	In	24
July	1	B	Out	30
July	2	A	In	24
July	2	A	Out	25
July	2	B	In	22

July	**2**	**B**	**Out**	24
July	**3**	**A**	**In**	20
July	**3**	**A**	**Out**	20
July	**3**	**B**	**In**	15
July	**3**	**B**	**Out**	14
July	**4**	**A**	**In**	18
July	**4**	**A**	**Out**	17
July	**4**	**B**	**In**	19
July	**4**	**B**	**Out**	17
August	**1**	**A**	**In**	31
August	**1**	**A**	**Out**	29
August	**1**	**B**	**In**	30
August	**1**	**B**	**Out**	33
August	**2**	**A**	**In**	9
August	**2**	**A**	**Out**	10
August	**2**	**B**	**In**	5
August	**2**	**B**	**Out**	5
August	**3**	**A**	**In**	13
August	**3**	**A**	**Out**	17
August	**3**	**B**	**In**	8
August	**3**	**B**	**Out**	10
August	**4**	**A**	**In**	23
August	**4**	**A**	**Out**	24
August	**4**	**B**	**In**	16
August	**4**	**B**	**Out**	26
September	**1**	**A**	**In**	33
September	**1**	**A**	**Out**	33
September	**1**	**B**	**In**	31
September	**1**	**B**	**Out**	33
September	**2**	**A**	**In**	10
September	**2**	**A**	**Out**	9
September	**2**	**B**	**In**	6
September	**2**	**B**	**Out**	5
September	**3**	**A**	**In**	9
September	**3**	**A**	**Out**	8
September	**3**	**B**	**In**	14
September	**3**	**B**	**Out**	12
September	**4**	**A**	**In**	22
September	**4**	**A**	**Out**	28
September	**4**	**B**	**In**	20
September	**4**	**B**	**Out**	29

November	**1**	**A**	**In**	36
November	**1**	**A**	**Out**	31
November	**1**	**B**	**In**	37
November	**1**	**B**	**Out**	36
November	**2**	**A**	**In**	15
November	**2**	**A**	**Out**	17
November	**2**	**B**	**In**	14
November	**2**	**B**	**Out**	15
November	**3**	**A**	**In**	15
November	**3**	**A**	**Out**	17
November	**3**	**B**	**In**	19
November	**3**	**B**	**Out**	18
November	**4**	**A**	**In**	33
November	**4**	**A**	**Out**	34
November	**4**	**B**	**In**	28
November	**4**	**B**	**Out**	35

APPENDIX K. SOIL BULK DENSITY DATA

Year	Location	Site	In/Out	Density (g/cm³)
1990	1	A	In	0.263
1990	1	A	Out	0.292
1990	1	B	In	1.18
1990	1	B	Out	1.288
1990	2	A	In	0.212
1990	2	A	Out	0.152
1990	2	B	In	0.178
1990	2	B	Out	0.211
1990	3	A	In	0.171
1990	3	A	Out	0.094
1990	3	B	In	N/A
1990	3	B	Out	N/A
1990	4	A	In	0.245
1990	4	A	Out	0.09
1990	4	B	In	0.193
1990	4	B	Out	0.118
1991	1	A	In	0.259
1991	1	A	Out	0.255
1991	1	B	In	1.176
1991	1	B	Out	1.251
1991	2	A	In	0.147
1991	2	A	Out	0.151
1991	2	B	In	0.569
1991	2	B	Out	0.268
1991	3	A	In	0.142
1991	3	A	Out	0.124
1991	3	B	In	0.137
1991	3	B	Out	0.115
1991	4	A	In	0.253
1991	4	A	Out	1.298
1991	4	B	In	0.225
1991	4	B	Out	0.15
1992	1	A	In	0.416
1992	1	A	Out	0.292
1992	1	B	In	1.026
1992	1	B	Out	1.268
1992	2	A	In	0.133
1992	2	A	Out	0.153
1992	2	B	In	0.175

1992	**2**	**B**	**Out**	0.185
1992	**3**	**A**	**In**	0.153
1992	**3**	**A**	**Out**	0.169
1992	**3**	**B**	**In**	0.135
1992	**3**	**B**	**Out**	0.103
1992	**4**	**A**	**In**	0.357
1992	**4**	**A**	**Out**	0.26
1992	**4**	**B**	**In**	0.188
1992	**4**	**B**	**Out**	0.175
2014	**1**	**A**	**In**	0.176
2014	**1**	**A**	**Out**	0.131
2014	**1**	**B**	**In**	0.953
2014	**1**	**B**	**Out**	0.744
2014	**2**	**A**	**In**	0.097
2014	**2**	**A**	**Out**	0.101
2014	**2**	**B**	**In**	0.117
2014	**2**	**B**	**Out**	0.137
2014	**3**	**A**	**In**	0.112
2014	**3**	**A**	**Out**	0.092
2014	**3**	**B**	**In**	0.099
2014	**3**	**B**	**Out**	0.104
2014	**4**	**A**	**In**	0.152
2014	**4**	**A**	**Out**	0.156
2014	**4**	**B**	**In**	0.203
2014	**4**	**B**	**Out**	0.135

APPENDIX L. MACRO-ORGANIC MATTER (MOM) DATA

Year	Location	Site	In/Out	Sample	MOM to 10 cm AF g/m²
1990	1	A	In	1	1405
1990	1	A	In	2	2907
1990	1	A	Out	1	4962
1990	1	A	Out	2	4263
1990	1	B	In	1	1255
1990	1	B	In	2	831
1990	1	B	In	3	1289
1990	1	B	Out	1	2197
1990	1	B	Out	2	2564
1990	1	B	Out	3	1570
1990	2	A	In	1	4834
1990	2	A	In	2	3312
1990	2	A	Out	1	5498
1990	2	A	Out	2	5093
1990	2	B	In	1	5766
1990	2	B	In	2	3896
1990	2	B	Out	1	4156
1990	2	B	Out	2	4501
1990	3	A	In	3	3548
1990	3	A	In	4	4402
1990	3	A	Out	4	4176
1990	3	A	Out	3	3187
1990	3	B	In	3	1476
1990	3	B	In	4	4576
1990	3	B	Out	3	3212
1990	3	B	Out	4	3323
1990	4	A	In	3	2130
1990	4	A	In	4	2931
1990	4	A	Out	3	2815
1990	4	A	Out	4	2456
1990	4	B	In	3	2224
1990	4	B	In	4	1921
1990	4	B	Out	3	2658
1990	4	B	Out	4	2646
1991	1	A	In	1	3061
1991	1	A	In	3	1839
1991	1	A	Out	1	5271
1991	1	A	Out	3	4233
1991	1	B	In	1	829

1991	**1**	**B**	**In**		N/A
1991	**1**	**B**	**Out**	**1**	1665
1991	**1**	**B**	**Out**	**3**	3050
1991	**2**	**A**	**In**	**1**	3347
1991	**2**	**A**	**In**	**3**	2913
1991	**2**	**A**	**Out**	**1**	4400
1991	**2**	**A**	**Out**	**3**	3034
1991	**2**	**B**	**In**	**1**	5521
1991	**2**	**B**	**In**	**3**	3518
1991	**2**	**B**	**Out**	**1**	5379
1991	**2**	**B**	**Out**	**3**	5119
1991	**3**	**A**	**In**	**1**	2143
1991	**3**	**A**	**In**	**3**	2988
1991	**3**	**A**	**Out**	**1**	3253
1991	**3**	**A**	**Out**	**3**	3314
1991	**3**	**B**	**In**	**1**	3940
1991	**3**	**B**	**In**	**3**	4251
1991	**3**	**B**	**Out**	**2**	5441
1991	**3**	**B**	**Out**	**3**	4992
1991	**4**	**A**	**In**	**1**	3105
1991	**4**	**A**	**In**	**3**	2411
1991	**4**	**A**	**Out**	**1**	3128
1991	**4**	**A**	**Out**	**3**	3304
1991	**4**	**B**	**In**	**1**	2981
1991	**4**	**B**	**In**	**3**	3506
1991	**4**	**B**	**Out**	**1**	3947
1991	**4**	**B**	**Out**	**3**	3031
1992	**1**	**A**	**In**	**1**	2495
1992	**1**	**A**	**Out**	**1**	3942
1992	**1**	**B**	**In**	**1**	1177
1992	**1**	**B**	**Out**	**1**	1393
1992	**2**	**A**	**In**	**1**	3935
1992	**2**	**A**	**Out**	**1**	5261
1992	**2**	**B**	**In**	**2**	3445
1992	**2**	**B**	**Out**	**1**	5586
1992	**3**	**A**	**In**	**1**	3728
1992	**3**	**A**	**Out**	**1**	4321
1992	**3**	**B**	**In**	**1**	3632
1992	**3**	**B**	**Out**	**1**	5302
1992	**4**	**A**	**In**	**1**	3421
1992	**4**	**A**	**Out**	**2**	3398

1992	**4**	**B**	**In**	**1**	2543
1992	**4**	**B**	**Out**	**1**	4001
2014	**1**	**A**	**In**	**1**	1415
2014	**1**	**A**	**In**	**4**	1867
2014	**1**	**A**	**Out**	**2**	4287
2014	**1**	**A**	**Out**	**3**	3599
2014	**1**	**B**	**In**	**2**	1024
2014	**1**	**B**	**In**	**4**	1450
2014	**1**	**B**	**Out**	**1**	3037
2014	**1**	**B**	**Out**	**3**	2616
2014	**2**	**A**	**In**	**3**	2833
2014	**2**	**A**	**In**	**4**	3840
2014	**2**	**A**	**Out**	**2**	4324
2014	**2**	**A**	**Out**	**3**	5483
2014	**2**	**B**	**In**	**1**	2843
2014	**2**	**B**	**In**	**4**	1709
2014	**2**	**B**	**Out**	**1**	6384
2014	**2**	**B**	**Out**	**2**	5128
2014	**3**	**A**	**In**	**1**	2492
2014	**3**	**A**	**In**	**4**	4708
2014	**3**	**A**	**Out**	**3**	2978
2014	**3**	**A**	**Out**	**4**	2817
2014	**3**	**B**	**In**	**1**	1604
2014	**3**	**B**	**In**	**2**	2484
2014	**3**	**B**	**Out**	**2**	4693
2014	**3**	**B**	**Out**	**3**	4171
2014	**4**	**A**	**In**	**2**	2793
2014	**4**	**A**	**In**	**4**	1861
2014	**4**	**A**	**Out**	**2**	4848
2014	**4**	**A**	**Out**	**3**	3916
2014	**4**	**B**	**In**	**1**	2325
2014	**4**	**B**	**In**	**3**	2147
2014	**4**	**B**	**Out**	**2**	5225
2014	**4**	**B**	**Out**	**4**	4448