The Influence of Tidal Creek Networks on Wetland Vegetation Colonization in a Macro-tidal System

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ABSTRACT

Six years of research and experience with restoring Bay of Fundy (Nova Scotia) salt marshes have shown that salt marsh plant species can colonize readily without planting, if the barriers to tidal flow are removed and suitable abiotic conditions (i.e. elevation) are present. Reactivated hybrid creek networks are potentially highly important to the restoration process, as they may represent the primary transport mechanism for seeds and vegetative material for re-colonization. It is unknown how important the hybrid creeks are for the colonization of target species (*Spartina alterniflora; S. patens; Salicornia europaea; Suaeda maritima; Atriplex spp.*). Utilizing the Cogmagun River salt marsh restoration site (Hants County), restored in 2009, this research set out to discover if there was a relationship between proximity to creeks and the colonization rates of target salt marsh species. We were also interested in finding out if seedling coverage of *Suaeda maritima* in the previous year had a relationship with colonization rates in the following year. The results showed that colonization rates were positively related to proximity to the main tidal creek for four out of five target species (*S. alterniflora, S. europaea, S. maritima, and Atriplex spp.).* The presence of *S. maritima* in the previous year did increase the colonization rates of newly established communities. These results provide a fine-scale complement to existing and ongoing macro-scale studies and further clarify the relationships between abiotic properties of a recently restored tidal wetland and colonization.

ACKNOWLEDGEMENTS

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1. Introduction

1.1 Salt marshes

Salt marshes are defined by habitats that contain halophytic plant communities and other associated animals, which are tolerant of salt water (Doody 2001). They are typically inundated by the tides, and can have rapid sediment accumulation. Salt marshes are found along the shores of middle and high latitudes (30° to 70°) (de Blij et al. 2005) around the world (Visser and Baltz 2009; Chapman 1977), and are most extensively found in the northern hemisphere (Doody 2001). Salt marshes are generally found in sedimentary environments, with micro-tidal (<2m) or macro-tidal (<6m) regimes. Macro-tidal regimes can be further broken down into low macro-tidal (4-6m), and high macro-tidal (>6m) (Davidson-Arnott et al. 2002). Tides may be diurnal, semidiurnal or mixed (Visser and Baltz 2009; Davies 1964).

1.1.1 Creation of salt marshes

The development of salt marshes results from the movement and deposition of sediment. Doody (2008) explains that the sediment for developing saltmarshes originates from three main sources: erosion from elevated land, erosion of sea cliffs, and reworking of sub-tidal banks. When sediment is eroded from elevated land, it is transported via the rivers into the sea. When erosion from sea cliffs occurs, the tides and long-shore drifts transport the sediment. Coastal waters transport the sediment when it is scoured from sub-tidal banks. Salt marshes are found in areas that border saline bodies of water (Davidson-Arnott et al. 2002; Mitsch and Gosselink 1986; Adam 1990), and can develop in a wide range of geomorphic environments. Some areas of salt marsh formation include bays, river mouths, estuaries, and deltas (Davidson-Arnott et al. 2002; Doody 2001).

1.1.2 Sediment Accretion and Elevation

Sedimentation increases when sediment exceeds the carrying capacity of the creeks during tidal inundation, and this is called the "Creek Model" of sediment accretion (Pratolongo et al. 2009). Such sedimentation results in increased grain size adjacent to creek margins as a response to decreasing amounts of overflow with distance from the creek margin (Pratolongo et al. 2009; Christiansen et al. 2000; Temmerman et al. 2004; Leonard et al. 2002).

1.1.3 Vegetation Patterns

Within the salt marsh, there are two elevation zones: the submergence (low) and emergence (high) marsh zones (Visser and Baltz 2009). The vegetation at these two zones change in species composition based on elevation (Visser and Baltz 2009). The boundary between these two zones can be recognized by the dominant vegetation along the salinity gradient, as one dominant competitor will displace another (Crain et al. 2004; Bertness et al. 1992).

The lower limits of salt marshes are defined as the "seaward margin of emergent vascular plants" (Pratolongo et al. 2009; Adam 1990). Common pioneer species such as *Salicornia spp.*, *Suaeda spp.*, and *Spartina alterniflora* usually cover these areas during the first stages of succession (Pratolongo et al. 2009; Doody 1992, 2001; Boorman 1999). In the mid-level of the salt marsh, where there is less tidal flooding, there is a greater opportunity for more plant species to colonize. The observed zonation patterns in salt marshes are thought to reflect the fundamental environmental gradient (which includes salinity, elevation, and nitrogen levels) as opposed to the physical accumulation of physical biotic matter (Mitsch and Gosselink 2007). This zonation (and the subsequent patterns) in salt marshes is a secondary aspect of halophytic vegetation organization. Within a species tolerance range, distribution may be patchy (Silvestri et al. 2005; Chapman 1977; Silvestri et al. 2000; Marani et al. 2003). The presence of dead material at a site may be beneficial in trapping seeds that are carried in by the incoming tide, as well as providing a sheltered area for seedlings to begin growth.

1.2 Succession

Succession is the natural progression of changes that occur in a community during vegetation development, from the initial colonization to the climax community in any given geographical area (Raven et al. 1999; Meffe and Carroll 1997). In salt marshes, succession is a primary process that is controlled by both biotic and abiotic factors. There are two kinds of succession that occur: allogenic succession, and autogenic succession. Allogenic succession involves the development of plant communities that is governed by their responses to environmental factors (Gleason 1917; Mitsch and Gosselink 2007), and autogenic succession is that which occurs independently of continuing change in external environmental conditions (McCook 1994).

Plant reproduction, germination, and development depend on various environmental and biotic factors including inter- and intra- specific competition (Silvestri et al. 2005; Costa et al. 2003; Lenssen et al. 2004), by edaphic factors (Wang et al. 2010; Silvestri et al. 2005; Mitsch and Gosselink 1993; van Wijnen and Bakker 1999; Rogel et al. 2001), and by grazing (Silvestri et al. 2005; Tessier et al. 2003; Lenssen et al. 2004). The distribution of plant communities along an elevation gradient is affected by the environment and various abiotic factors, which are chiefly controlled by environmental influences (Wang et al. 2010; Ranwell 1972) such as salinity (Wang et al. 2010; Cooper 1982; Silvestri et al. 2005), flooding (Visser and Baltz 2009; Wang et al. 2010; Cooper 1982; Pennings et al. 2005), and nutrient availability (Levine et al. 1998; Wang et al. 2010). Both plant species richness and composition depend on the occurrence of suitable abiotic conditions (Erfanzadeh et al. 2010; Grubb 1977; Peach and Zedler 2006).

1.3. Salt Marsh Colonization

The seeds necessary for colonization of a newly created salt marsh have generally emigrated from surrounding areas (Alphin and Posey 2000), whether it is via hydrochory (water dispersal) or wind dispersal (Chang et al. 2007; Engels et al. 2011; Rand 2000). Closely linked to these above ground processes is underground production and decomposition (Townend et al. 2010). Production that occurs below ground is equal to or exceeds what occurs above ground, and that the presence of above ground litter does not generally make a significant contribution to the sedimentation of the marsh surface (Townend et al. 2010; Blum and Christian 2004). The regeneration of species vegetative (especially perennial graminoids) occurs in the springtime from stored carbohydrates in the rhizomes present in the ground (Smith III and Odum 1981; Seneca and Broome 1972; Stroud 1976).

1.3.1 Hydrochory

Hydrochory is the process of seed transportation in the water column (Huiskes et al. 1995; Johansson and Nilsson 1993). It is one of the major dispersal mechanisms for plants located near river corridors (Johansson and Nilsson 1993). In sites that are completely flooded by water, and where there is high gap dynamics (in areas where vegetation has been damaged by flooding or sedimentation) the use of water as a dispersal vector is high (Ozinga et al. 2004). The damage caused by the flooding and/or sedimentation thus increases the availability of "safe sites" for colonization of plant communities (Ozinga et al. 2004). It is noted that in areas where there is occasional flooding (intermediate soil moisture levels) there is the possibility for high impact on species composition through dispersal by water (Ozinga et al. 2004).

1.3.2 Wind dispersal

S. alterniflora and *S. patens* both use wind as a seed dispersal mechanism. In order for wind to be successful at dispersal, it needs to overcome its limitations with the height and density of the surrounding vegetation (Ozinga et al. 2004). Height of vegetation is important to consider as the propagules are more reliably blown when caught in updrafts above the canopy (Ozinga et al. 2004; Tackenberg 2001; Nathan et al. 2002). The density of the surrounding vegetation also plays an important role, as adjacent plants may directly intercept propagules (Ozinga et al. 2004; Greene and Johnson 1996).

1.4 Restoration in the Bay of Fundy

The restoration of salt marshes in Nova Scotia has generally occurred around the Bay of Fundy area due to the high degree of historical loss (Bowron[1], 2012). This land was traditionally dyked to make agricultural lands, and efforts are being undertaken, where feasible, to restore natural salt marsh systems. As much as eighty-five percent of the original salt marsh area in the Bay of Fundy was lost since the settling of Europeans, and through the activity of dyking (MacDonald et al. 2010; Ganong 1903; Hanson and

Calkins 1996). The salt marshes around the Bay of Fundy have a typical topography of narrow low marsh bordering a higher wide upper marsh (Pratolongo et al. 2009). The typical dominant salt marsh vegetation in the seaward margin of the marsh (low marsh) is *S. alterniflora, Suaeda maritima*, *Salicornia europaea*, and *Atriplex patula* (Pratolongo et al. 2009). The typical dominant salt marsh vegetation in the landward margin marsh (high marsh) is: *S. patens*, *Triglochin maritima*, and *Juncus gerardii* (Chmura et al. 1997; Pratolongo et al. 2009).

Wetlands in Nova Scotia provide many different ecosystem services. Of all the services offered by the ecosystem, an important one is water quality and filtering. According to GPI Atlantic (2007), Nova Scotia is losing approximately 2.3 billion dollars a year in lost ecological services. Sara Wilson (2000) states that wetlands perform many highly valuable functions, including nutrient cycling, protection against erosion, floods and storms, water purification and are an area of highly diverse species habitats. Coastal wetlands provide imperative protection of the coastline during storms, hurricanes and floods (Farber 1987**)**. Coastal wetlands act as control devices during floods; they hold excess floodwaters during high rainfall (USGS National Wetlands Research Center n.d.). GPI Atlantic (2007) remarks that Nova Scotia has lost sixty-two percent of its saltwater wetlands and seventeen percent of its freshwater wetlands since its colonization about 11 000 years ago (Nova Scotia Museum of Natural History 2010), and that conservation measures should be put in place to prevent any further loss.

Remediation of a disturbed wetland or saltmarsh is done when human or natural influences have altered the landscape, which has caused the prior designation of the land to change. An example of this is the change from a wetland into agriculture land. Nova Scotia has a long history of altering coastal wetlands into agricultural lands through the construction of dykes and aboiteau which prevent the tidal flooding of the former wetland areas behind the structures (Bowron[3] 2010). Although socially and historically significant, many of these dyked systems are no longer in use or hold a high value as agricultural lands, and so have the potential to be returned to their former wetland condition (Bowron[3] 2010). This type of change can be remediated using hydrologic methods. This is done by reinstating hydrologic networks between diked land and altered wetlands by breaching a dyke which allows for the re-establishment of the natural hydraulic regime (Wilcox and Whillans 1999; Bowron[3] 2010).

Colonization is usually rapid for the first few years after restoration, and tends to slow down and a climax community is established (Alphin and Posey 2000; Moy and Levin 1991; Levin et al. 1996; Simenstad and Thom 1996, Diggory and Parker 2011). The restored area has lower species richness in the climax community compared to a primary successional community (Diggory and Parker 2011; Grismer et al. 2004; Wolters et al. 2008).

Seed dispersal by tidal creek networks occurs up slopes, when the tide overflows the bank of the creek (Armel et al. 2008; Huiskes et al. 1995; Wolters and Bakker 2002). This explains why some plants are found in closer proximity to a creek.

1.5 Study Objectives

The objectives of this study were to 1) investigate whether colonization of salt marsh target species was dependent on distance from the creek, 2) investigate if there was a difference between primary and secondary creek effects on colonization rates, 3) investigate whether the amount of dead plant material and variables related to tidal flooding have an influence on the percent cover of colonizing vegetation, and 4) determine whether the presence of *Suaeda maritima* in the previous year has an effect on the colonization rates of the following year.

2. Research Design and Field Methods

2.1 Site Description

The Cogmagun River salt marsh restoration site is 6.9 ha of tidal wetland (Bowron et al. 2011) located in Hants County, Nova Scotia. It is part of the Cogmagun River, which drains into the Avon River estuary from the east (Davis and Browne 1996). This tidal wetland is part of the Windsor Lowlands located in the Shubenacadie River sub-unit (Davis and Browne 1996) and consists of a landscape that has low elevations, gentle relief, and imperfectly drained soils. Above high water (the perimeter of a body of water where the land has been covered by water so long as to mark a distinct character upon the vegetation where it extends into the water (Province of Nova Scotia 2009), the land is colonized by major tree species such as spruce (*Picea spp.*), fir (*Abies spp*.), white birch (*Betula papyrifera*), red maple (*Acer rubrum*), eastern hemlock (*Tsuga canadensis*), and white pine (*Pinus strobus*) (Davis and Browne 1996).

The site was previously a 4.8 ha salt marsh along the Cogmagun River, and was dyked in 1991 by Ducks Unlimited Canada (DUC) in order to create a freshwater pond for waterfowl (Bowron et al. 2011). High maintenance costs associated with maintaining the dyke and water control structure and the challenge of preventing saltwater intrusion into the pond resulted in the decision by DUC and the property owners (Red Fox Farm) in 2003 to cease all maintenance activities. Through a partnership with Nova Scotia Transportation and Infrastructure Renewal (NSTIR), it was decided in 2009 to take a more active role in the restoration of the site (Bowron[1] 2012; Bowron et al. 2011).

In 2009, CBWES Inc. in partnership with NSTIR restored the Cogmagun River salt marsh site in order to reintroduce natural tidal flow into an area that was a freshwater impoundment. This involved the breaching of the dyke as well as excavating a channel that allowed for the restoration of full tidal flooding into the former salt marsh system (Bowron et al. 2011). The breach of the dyke around the freshwater area began the restoration process, and the re-establishment of a regular tidal flow has initiated the recovery of previous tidal wetland conditions and provided access for a various range of estuarine species (vegetation, fish, and birds) (Bowron et al. 2011). A one-year pre-restoration and five-year post restoration monitoring program was put into place: pre-restoration monitoring took place in 2009, and the first year of post-restoration monitoring took place in 2010 (Bowron et al. 2011).

Figure 2 outlines the Cogmagun River salt marsh restoration site, and the sample area used for this study. Three sample areas were identified for this study: a primary creek and two secondary creeks. Both the secondary creeks are found at the eastern end of the site, which were farthest away from the breach in the primary creek (referred to as the mouth of the primary creek).

2.2 Field Collection of Data

Five target plant species were chosen, as they are key wetland indicators as well as early colonizers. These species were: *S. alterniflora*, *S. patens, Salicornia europaea*, *Suaeda maritima*, and *Atriplex spp*. A series of transects were set out on June 9, 2011 spaced 50m apart and running perpendicular to the main tidal channel (primary creek) throughout the entire restoration site (Figure 1, black circles). Along the two secondary creeks that were found, the transects were placed 20m in from and parallel to the primary creek, and perpendicular to the secondary creek along both sides (Figure 1). Along the secondary creek found furthest back at the side, a transect was placed north of the creek, and at the other secondary creek, transects were placed both north and south of the creek. The first transect along the primary creek was placed 15m parallel from the secondary creek located at the back of the study site (Figure 1). Each transect line was composed of five sample stations, spaced at five meter intervals (at 0, 5, 10, 15, and 20m) (Figure 1).

The vegetation community was sampled on June 20, 2011 and August 19, 2011 using a modified Point Intercept Method, with $1m^2$ plots (Roman et al. 2002) at each sample station. The Point Intercept Method uses non-permanent $1m^2$ quadrat plots that are positioned at intervals (5m) along each transect line. Each quadrat is divided into twenty-five squares, and a small wooden dowel is placed vertically into each square one at a time; any plant that touches the dowel once is recorded. Photographs were taken of each plot along the transect line. Figure 3 depicts the appropriate placement of the quadrat along the transect, as well as two example photographs of the plots sampled during the study.

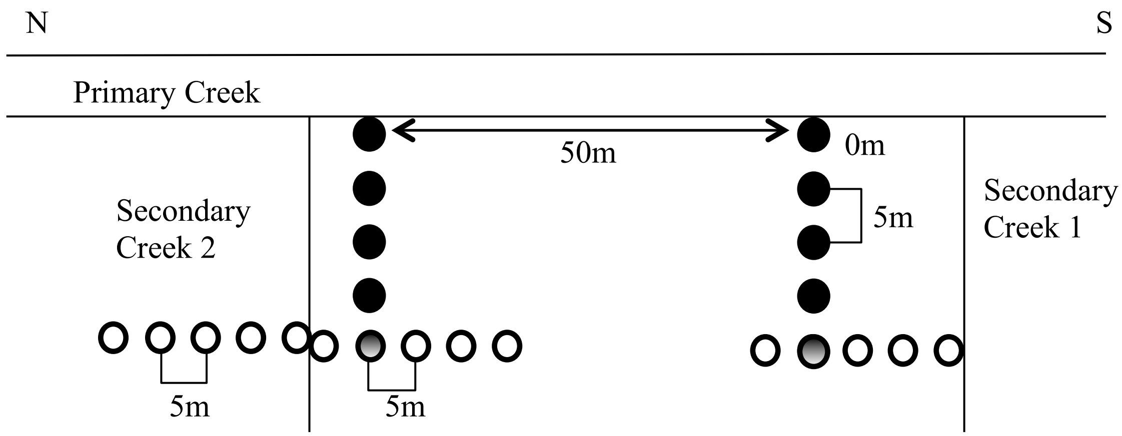

Figure 1: Schematic diagram of study layout procedures involving the primary creek, secondary creeks, and transect set up. All measurements are in meters. Note: figure not to scale.

When sampling the vegetation at each sample station throughout the study site, the bottom left corner of the quadrat was placed over the flag, and the quadrat was placed down, while facing away from the primary creek. When sampling along the secondary creek transects, the quadrat was placed while facing away from the secondary creek, not the primary creek. It was still positioned over the flag in the left bottom corner. Plant species that were present within the quadrat were recorded and a small wooden dowel (3mm diameter) (Bowron et al. 2011) was held vertically above the intercept and lowered until it touched the ground. Any species that touched the dowel was counted as a hit, and this was recorded. In order to count as a hit, the species only needed to touch the dowel anywhere; it could be touching multiple times and still recorded as just one single hit. This process was repeated for all 25 intercepts within the quadrat (Bowron et al. 2011). Other categories such as standing water, wood, dead material, and bare ground were also recorded if they hit the dowel. Both remnant *S. maritima* and *T. angustifolia* were recorded during the June 20th survey if observed along the transects, regardless of being found within the sampling plots, as either a "1" for present, and "0" for not present.

Transects and sampling stations were surveyed with a GPD Trimble® Pathfinder Pro XR using the Coordinate Reference System (CRS) with Universal Transverse Mercator (UTM) in Canadian Geodetic Vertical Datum 28 (CGVD 28) to produce a digital map of the study setup (Figure 2), as well as to enable the relocation of sampling stations

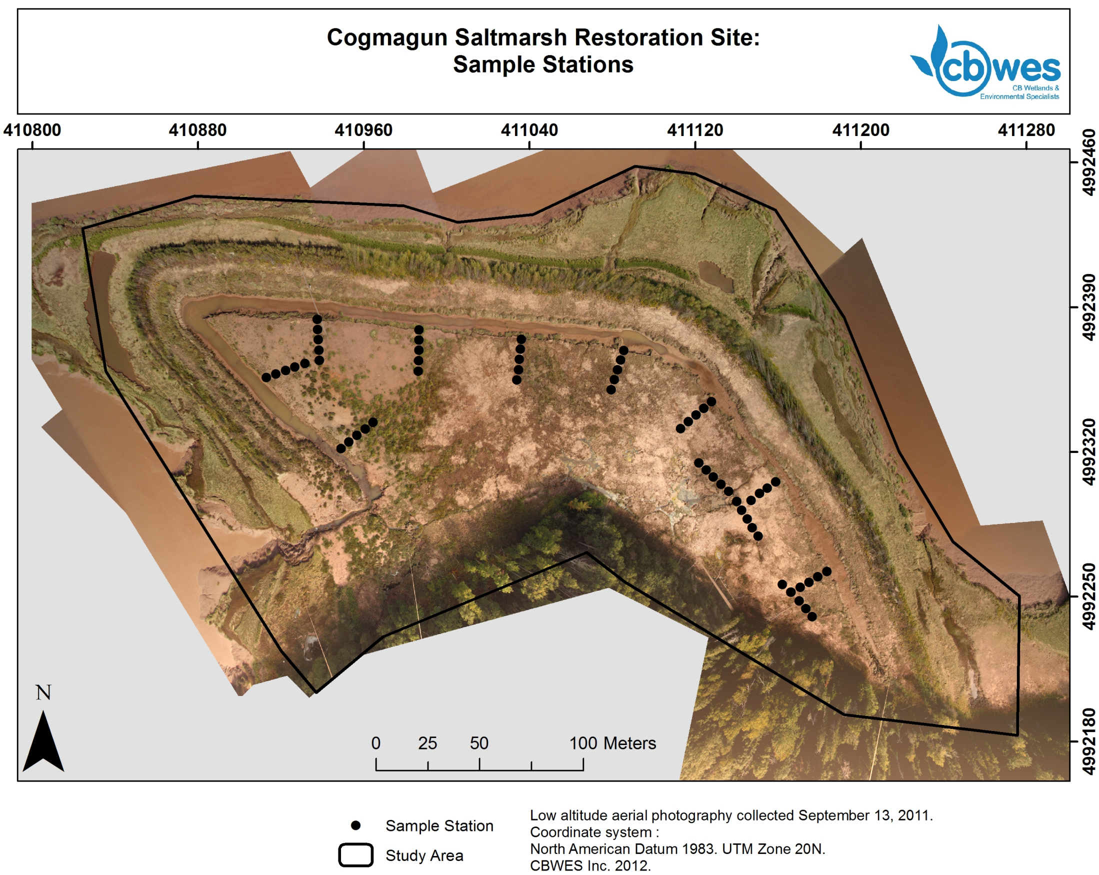

Figure 2: Cogmagun salt marsh restoration study site and sample stations. Map courtesy of CBWES (2011). Transect T9 located closest to breach in the dyke.

2.3 Statistical Analysis of Data

In order to test the effects of distance from the mouth of the primary creek (point of entry of tidal water to the site), distance from the creek, amount of dead material, elevation, hydro-period, flooding frequency, and mean inundation time on colonization, the data was separated into two groups (primary creek transects, and secondary creek transects) and analysed separately using multiple linear regression. Variance was assessed using Levene's test, and all non-homogeneous data was transformed using log(x+1), and the linear regression was re-run.

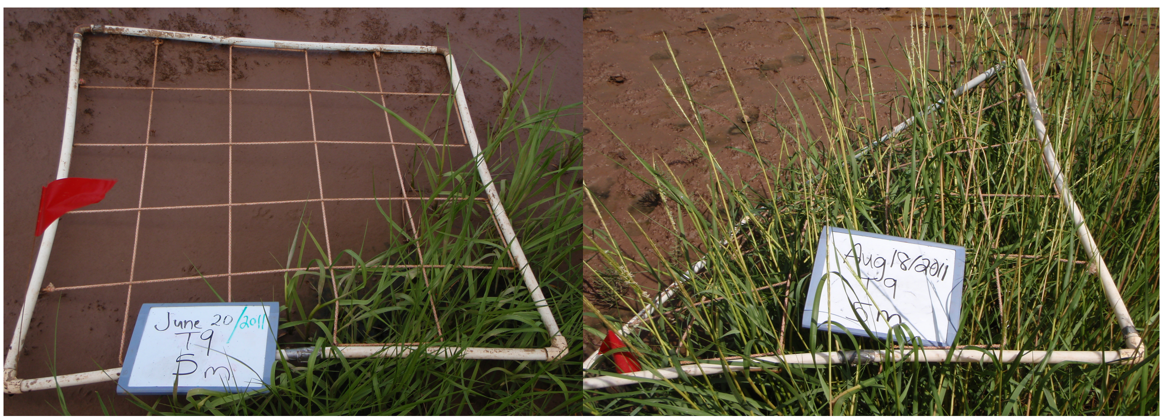

Figure 3: Plot on transect 9 at 5m with quadrat sampling in June (left) and August (right), 2011. Note the flag is place in the bottom left corner of the quadrat, and *S. alterniflora* as well as bare ground can be seen. Images taken by A. Bijman.

In order to investigate the role of previous *S. maritima* on the abundance of this species in 2011, the dataset was also separated into plots with and without *S. maritima* in 2010 (assumed with visual confirmation from dead plant material in 2011), the first full growing season following the restoration of tidal flow. A multiple regression linking *S. maritima* colonization in 2011 to environmental variables was run separately for both datasets. To determine whether initial colonization of *S. maritima* was related to distance from the creek and distance to the breach at the front of the site, a logistic regression was used, with presence/absence of *S. maritima* in 2010 used as the dependent variable.

Statistical analysis was done with IBM® SPSS® 19 Statistics software, and the logistic regression was done with the R statistical package (R Development Core Team (2011), Version: 2.14.2). Unless otherwise stated, $\alpha = 0.05$ thus results are statistically significant where $p < \alpha$.

2.3.1 Calculating predicted hydro-period, flooding frequency, and mean inundation time

The predicted tides were retrieved using "Tides and Currents" software created by Nautical Software Inc. (Nobeltec Navigation®, 2011). These tidal heights were then converted from chart datum to CGVD 28 based on the observed tides. This conversion was used as a correction factor for height differences.

A hydro-period is the percentage of time that water is over the marsh (Reed 1990). The hydro-period was calculated using a 5-minute interval; the elevation of the study site, as well as the predicted tide. When the tide height is at or higher than that of the individual sample stations, then it was considered underwater and counted towards the hydro-period. The amount of time underwater per year was calculated, and then converted to a percentage.

The flooding frequency is the number of times the study site is flooded. Using only the high tide data, it was possible to determine the number of times the study site was inundated each year.

The mean inundation time was calculated by dividing the hydro-period by the flooding frequency, as a function of elevation relative to the tidal frame.

3. Results

Overall, a total of twelve plant species were found during the vegetation survey, including four out of the five target salt marsh species (*S. patens* was not found within the plots). Figure 4 shows the four target species listed above that were found throughout the study. Figure 6 displays a graphical representation of the four target species found (a-d) and their average percent cover during each sampling period. Both Figure 6 and Figure 7 show the average percent cover of all of the halophytic plant species found at the study site. Figure 8 shows the average percent cover of the other categories found at the Cogmagun salt marsh restoration site within the plots, as well as the only non-halophytic species found within the plots. Bare ground and/or dead material was found in all the plots, and average percent cover of bare ground and dead material combined decreased from June to August. While the average percent cover of dead material decreased throughout the summer, the average percent cover of bare ground increased throughout the summer. Figure 5 depicts a remnant *S. maritima* plant established in 2010 that was found along a transect, and was classified as "present". The presence of remnant *S. maritima* proved to be an important part of the colonization and subsequent re-colonization in the following year on the restoration site (outlined in section 3.4 *S. maritima* Presence).

3.1 Percent Cover

3.1.1 Target Species

In June, the average percent cover of *Atriplex spp*. declined with increasing distance from the creek (p = 0.028) (Figure 6a) and greatly declined with increasing elevation (p = 0.020). *S. alterniflora* increased in percent cover with increasing distance from creek (p = 0.048) (Figure 6c) and significantly increased with the predicted frequency of flooding (p = 0.003). *S. maritima* average percent cover decreased as distance from creek increased (p = 0.001) (Figure 6d).

In August, the average percent cover of *Atriplex spp*. strongly declined with increasing elevation (p = 0.038), and also decreased with increasing distance from the creek (p = 0.005) (Figure 6c). *S. alterniflora* average percent cover strongly increased as the predicted frequency of flooding increased (p = 0.011). The average percent cover of *S. maritima* increased as the distance from the mouth of the primary creek increased (p = 0.001) decreased when distance from the creek increased (p = 0.000) (Figure 6d) and decreased by the amount of dead material present (p = 0.002).

3.1.2 Other Species and Categories

In June, the average percent cover of bare ground decreased with increasing amounts of dead material (p = 0.000). Average percent cover of *T. angustifolia* decreased when the distance increased from the mouth of the primary creek (p = 0.034), and greatly decreased by the amount of dead material present (p = 0.001).

In August, the average percent cover of bare ground decreased by the amount of dead material present (p = 0.000). *S. maritimum* average percent cover increased with increasing distance from the mouth of the primary creek (p = 0.026), and decreased by the amount of dead material present (p = 0.001).

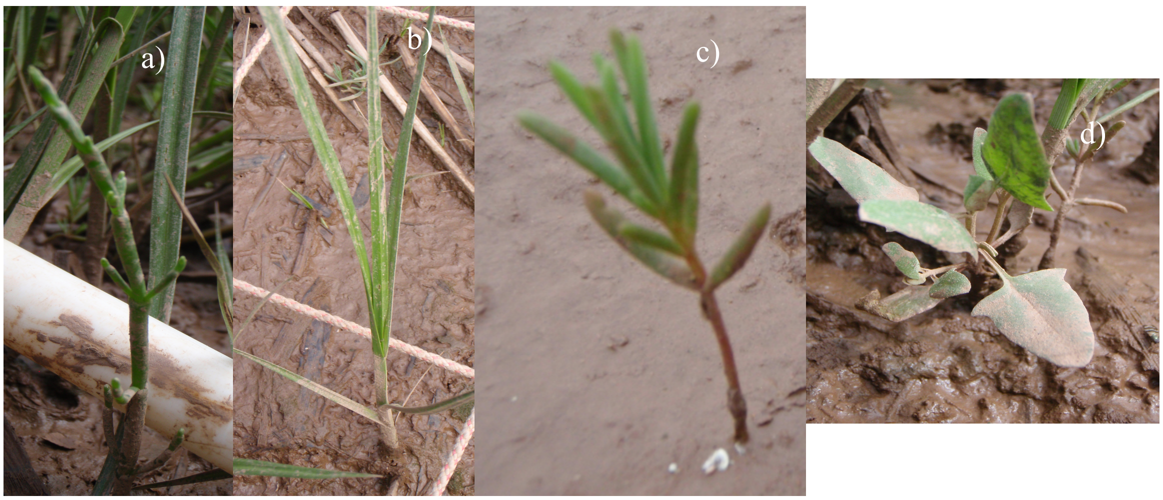

Figure 4: The four target species found at the Cogmagun salt marsh restoration site; a) *Salicornia europaea,* b) *Spartina alterniflora*, c) *Suaeda maritima*, and d) *Atriplex spp*. Images taken on June 9 and June 19, 2011 by A Bijman.

3.2 Primary Creek

3.2.1 Target Species

In August, both *S. alterniflora* and *S. maritima* colonization rates were higher in areas with greater predicted frequency of flooding (p = 0.012; p = 0.042). The colonization rates of *S. maritima* increased with distance from the mouth of the primary creek (p = 0.000), and decreased with increasing distance from the creek (p = 0.002) (Figure 6d).

3.2.2 Other Species and Categories

In June, the presence of bare ground decreased with increasing distance from the mouth of the primary creek ($p = 0.002$). Conversely, *T. angustifolia* strongly increased in the presence of dead material ($p = 0.002$), but decreased as the distance to the mouth of the primary creek increased ($p = 0.009$). Again in August, the presence of bare ground decreased in the presence of dead material ($p = 0.000$).

3.3 Secondary Creek

3.3.1 Other Species and Categories

In June, the presence of bare ground strongly decreased as the predicted hydro-period increased ($p = 0.004$). Presence of bare ground decreased when the distance from the mouth of the primary creek increased ($p = 0.018$), and when the presence of dead material increased ($p = 0.002$). The amount of *Scirpus validus* present strongly decreased when the predicted hydro-period increased ($p = 0.006$), and decreased when the distance from the mouth of the primary creek increased ($p = 0.017$). The increase in the predicted frequency of flooding ($p = 0.006$) and increase in the mean inundation time ($p = 0.010$) both strongly increased the percent cover of *S. validus*.

3.4 S. maritima *Presence*

Overall, the abundance of *S. maritima* in 2011 was positively related to the presence of adult *S. maritima* in the previous year ($p = 0.000$), and as distance from the creek increased, the likelihood of presence of *S. maritima* in the previous year decreased ($p = 0.007$) (Figure 6d).

Figure 5: Remnant plant of *S. maritima* found along one of the transects on the Cogmagun salt marsh restoration study site. Image taken on June 20, 2011 by A. Bijman.

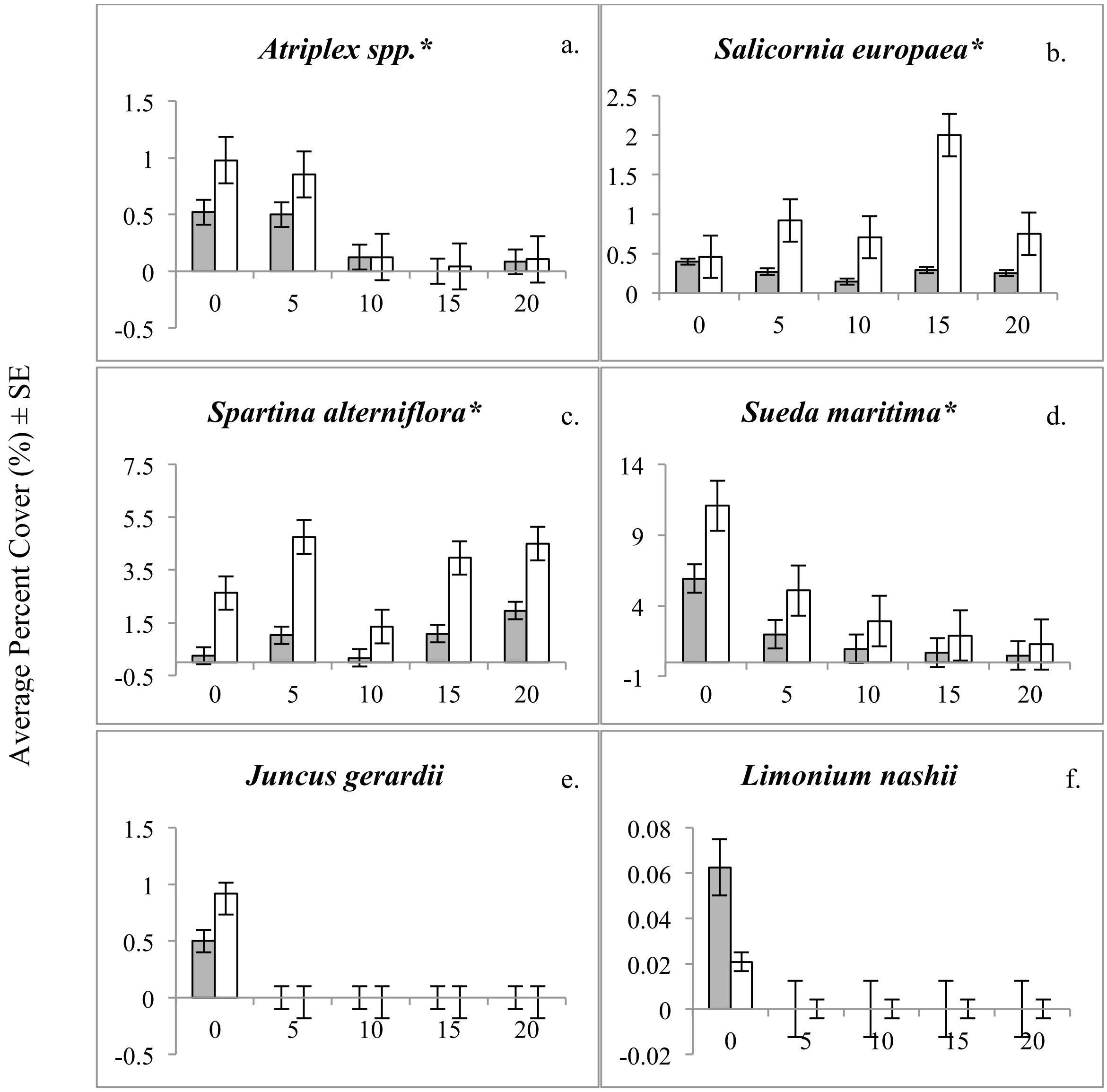

Figure 6a-f: Average percent cover versus distance from primary creek (meters) for the various halophytic species at Cogmagun salt marsh restoration site, Hants County, Nova Scotia. The symbol "*" represents a target species. Grey bars represent the sampling date June 20, 2011 and the white bars represent the sampling date August 19, 2011.

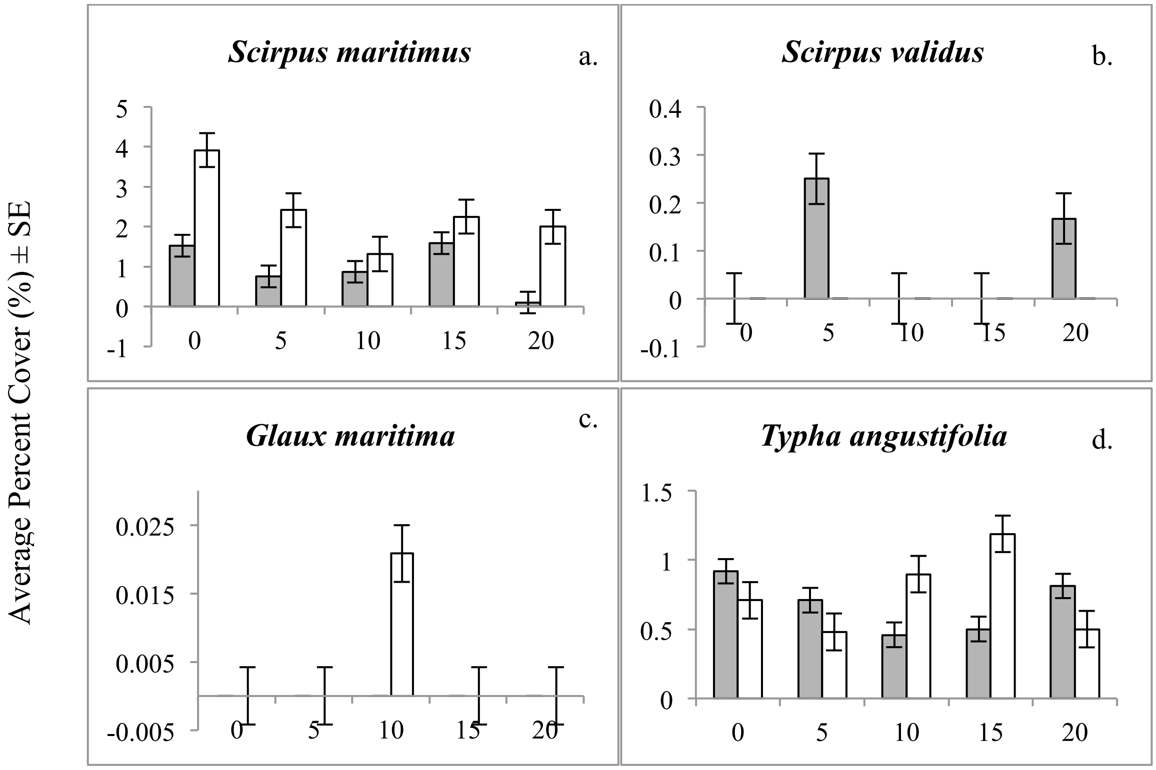

Figure 7a-d: Average percent cover versus distance from primary creek (meters) for the various halophytic species at Cogmagun salt marsh restoration site, Hants County, Nova Scotia. Grey bars represent the sampling date June 20, 2011 and the white bars represent the sampling date August 19, 2011.

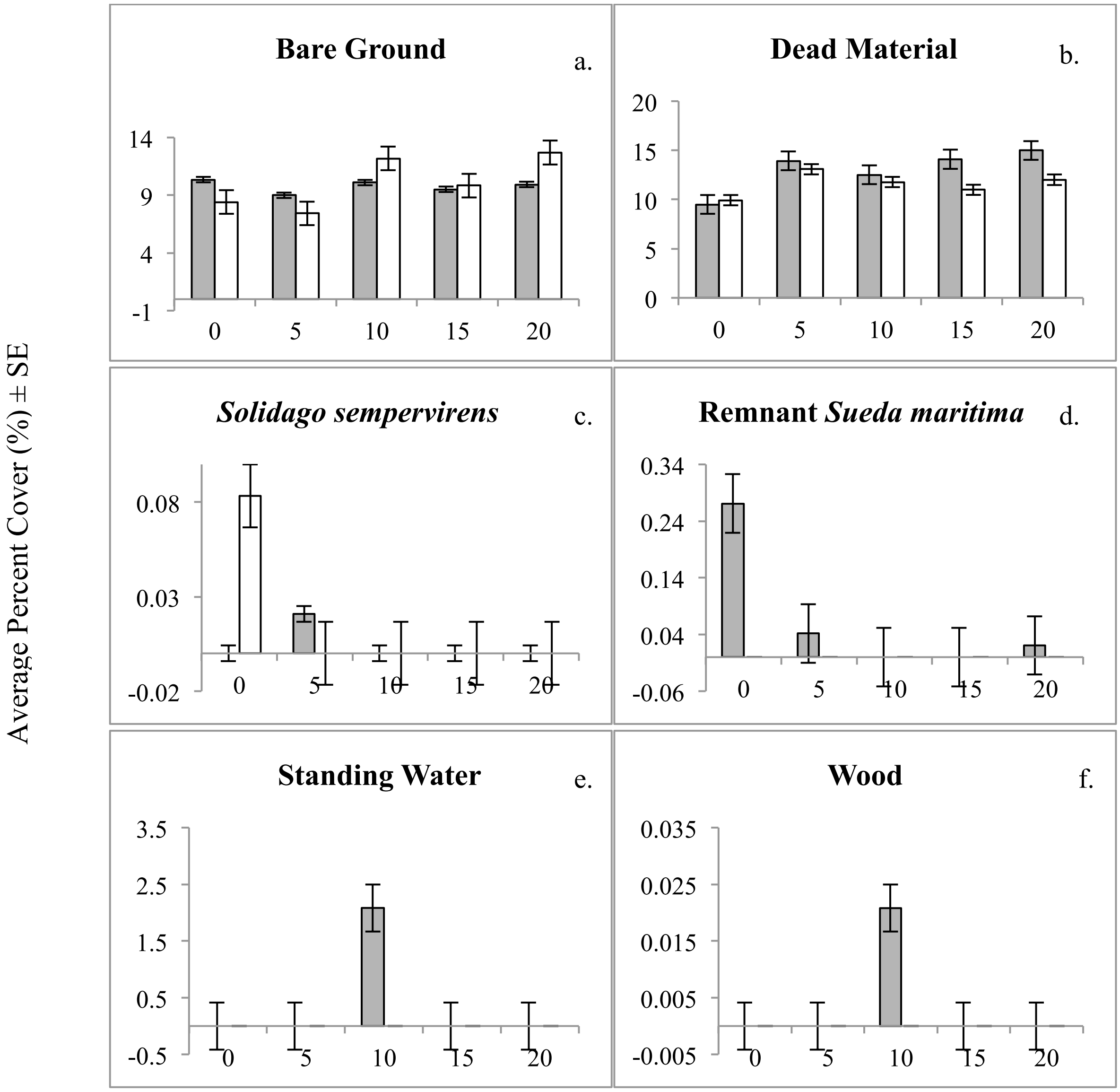

Figure 8a-f: Average percent cover versus distance from primary creek (meters) for the various plant species and other categories at Cogmagun salt marsh restoration site, Hants County, Nova Scotia. Grey bars represent the sampling date June 20, 2011 and the white bars represent the sampling date August 19, 2011.

Table 1 Details of multiple linear regression analysis of species abundances versus environmental predictors (only statistically significant relationships included (α = 0.05, p < α). The symbol "*" represents a target species.

	Plant Species or Category	Significant Factor ($p < 0.05$)	Standardized Coefficients	Adjusted R^2 value	P Value of Whole Regression
Percent Cover June	*Atriplex spp*.*	Distance from creek	-0.295	0.145	0.031
		Elevation	-4.158		
	Bare ground	Distance from mouth of primary creek	-0.431	0.621	0.000
		Amount of dead material	-0.593		
	*Spartina alterniflora**	Distance from creek	0.250	0.235	0.003
		Predicted frequency of flooding	4.102		
	*Suaeda maritima**	Distance from creek	-0.469	0.158	0.023
	Typha angustifolia	Distance from mouth of primary creek	-0.423	0.175	0.015
		Dead material	0.726		
Percent Cover August	*Atriplex spp.**	Distance from creek	-0.383	0.114	0.032
		Elevation	-3.672		
	Bare ground	Amount of dead material	-0.888	0.516	0.000
	*Spartina alterniflora**	Predicted frequency of flooding	3.254	0.313	0.000
	Scirpus maritimus	Distance from mouth of primary creek	0.377	0.150	0.028
		Dead material	-0.627		
	*Suaeda maritima**	Distance from mouth of primary creek	0.508	0.402	0.000
		Distance from creek	-0.511		
		Dead material	-0.467		

Table 2 Details of multiple linear regression analysis of species abundances versus environmental predictors (only statistically significant relationships included (α = 0.05, p < α). The symbol "*" represents a target species.

	Plant Species or Category	Significant Factor (p<0.05)	Standardized Coefficients	Adjusted R^2 value	P Value of Whole Regression
Primary Creek June	Bare ground	Distance from mouth of primary creek	-0.463	0.724	0.000
	*Spartina alterniflora**	Distance from creek	0.308	0.235	0.015
		Predicted frequency of flooding	4.939		
	*Suaeda maritima**	Distance from creek	-0.572	0.267	0.008
	Typha angustifolia	Distance from mouth of primary creek	-0.655	0.208	0.025
		Dead material	0.951		
Primary Creek August	Bare ground	Dead material	-0.742	0.479	0.000
	*Spartina alterniflora**	Predicted frequency of flooding	3.988	0.311	0.003
	*Suaeda maritima**	Distance from mouth of primary creek	0.663	0.531	0.000
		Distance from creek	-0.521		
		Predicted frequency of flooding	-2.619		

Table 3 Details of multiple linear regression analysis of species abundances versus environmental predictors (only statistically significant relationships included ($\alpha = 0.05$, $p < \alpha$). The symbol "*" represents a target species.

	Plant Species or Category	Significant Factor (p<0.05)	Standardized Coefficients	Adjusted R^2 value	P Value of Whole Regression
Secondary Creek June	Bare ground	Distance from mouth of primary creek	-0.645	0.654	0.028
		Dead material	-1.273		
		Predicted hydro-period	-58.857		
		Predicted frequency of flooding	42.206		
		Mean inundation time	17.209		
	Scirpus validus	Distance from mouth of primary creek	-0.660	0.656	0.028
		Predicted hydro-period	-54.570		
		Predicted frequency of flooding	42.756		
		Mean inundation time	16.339		
	Standing Water	Predicted hydro-period	46.596	0.737	0.012
		Predicted frequency of flooding	-32.962		
		Mean inundation time	-13.162		
No *S. maritima* Presence Last Year	*Suaeda maritima**	Distance from mouth of primary creek	-0.295	0.125	0.014

4. DISCUSSION

This study examined the importance of tidal creek networks in determining the pattern of marsh vegetation at the Cogmagun salt marsh restoration site. The patterns presented were complex, and reflected various factors including distance from creek, distance from the mouth of the primary creek, and the predicted frequency of flooding.

Among the four target salt marsh plant species found (Figure 4), greater colonization rates closer to the creek edge were seen in both *S. maritima* and *Atriplex spp*. Conversely, greater colonization rates were found at greater distances from the creek edge in the case of *S. alterniflora* and *S. europaea*. The relationship between distance from creek and *S. europaea* was not found to be significant, but it followed the same general trend as *S. alterniflora*.

Other halophytic species that exhibited a trend of an increased colonization rate closer to the creek edge were *J. gerardii*, *L. nashii*, and *Scirpus maritimus*. Some plant species have a higher colonization rate closer to the creek edge because of a more optimal habitat created by sediment accretion, as well as the possibility for more seeds to fall out of the water column onto the edge. The presence of *S. maritima* and *Atriplex spp*. so close to the edge of the creek helps to enhance the rates of sediment settlement. It is suggested that vegetation promotes surface accretion, which would then increase soil elevation (Marani et al. 2006; Townend et al. 2010). Suspended sediment will accrete more rapidly during tidal flows and a higher accretion rate can be found at the creek edge (Townend et al. 2010). This biomechanical feedback system will eventually result in an increase in the elevation, which in turn alters the hydro-period, and could potentially result in a change in the vegetation community present at the creek edge, as well as the rest of the site

(Bowron[1], 2012). Accretion is important for the colonization of salt marsh plants because at higher elevations they are less subjected to inundation (Townend et al. 2010; Marani et al. 2006). The continual accretion of sediment along the creek edge, along with lower salinity (Balling and Resh 1983; Snow and Vince 1984, in Sanderson et al. 2000) creates a less stressful environment for plant growth. Past research has demonstrated the importance of abiotic gradients having an effect on vegetation distribution (Bertness and Ellison 1987; Bertness 1991; Pennings and Callaway 1992, 1996; Bertness et al. 1992). The geography of tidal channels is also important in determining vegetation distribution (Townend et al. 2010). The traditional view is that salinity and elevation are key factors in plant distribution (Reed 1990; Gray 1992; Morris et al. 2002; Boorman et al. 2001). Others believe that broader, hydrological regimes control plant distributions (Bockelmann et al. 2002; Silvestri et al. 2005). Further research still needs to be done to understand the effects of tidal creek networks in relation to macro-tidal wetland plant colonization. The results of this study are consistent with the tradition views of plant distribution in salt marshes, but also it can be seen that the creek edge, which is part of the hydrological regime, also controls plant distribution through seed dispersal, hydro-period, and sediment transport and accretion. This is important to consider in salt marsh restoration processes if the construction of creeks and/or channels is occurring. The placement and design of both primary and secondary creeks could potentially influence how quickly pioneer plant species such as *S. maritima* and *Atriplex spp*. can enter the site and begin to colonize.

S. alterniflora, a more salt tolerant species, was found with a greater percent cover farther away from the creek edge. The distribution of *S. alterniflora* is typically limited to the low marsh because of its ability to cope with the high frequency of flooding, and it also has rhizomes, which are able to oxygenate in anoxic soils (Bertness 1991; Gleason 1980). *S. alterniflora* also has the ability to germinate under high salinities, which can occur further away from the creek edge, within the low marsh. The farther away from the creek edge you go, elevations slightly decrease and sediment accretion decrease, and mean inundation time periods, and sediment and salt deposition increases. This means that there would be longer mean inundation time periods and an increased presence of salt being absorbed into the sediment (Pétillon et al. 2010). Understanding the morphology of salt marshes, particularly in the Bay of Fundy, has significance to the design of restoration projects and the future predictions of the rate and the nature of its recovery. In this study, *S. alterniflora* was positively affected by the predicted frequency of flooding (Table 1 and Table 2). Therefore, the greater the time a site is under water, the more likely that *S. alterniflora* would be present. A study done by Pétillon et al. (2010) found that there was a significant linear relationship between inundation frequency and species turnover. This means the greater the frequency and duration an area of the salt marsh is flooded by tidal waters, the greater the shift towards more species of salt tolerant vegetation. This accounts for *S. alterniflora* colonizing the low marsh, but is farther away from the primary creek edge than other species.

Prior to restoration, the entire site was dominated by *Typha angustifolia*. A majority of this died when restoration occurred and tidal flow was restored. Much of the dead *T. angustifolia* stands remained on the site as extensive mats of dead material (Bowron[2] 2012). This material is slowly being broken down and being removed from the site through decomposition, ice processes in the winter, storm surges, and high spring tides. The presence of these dead mats may be affecting colonization rates of some species because they are currently covering up much of the available bare ground. Specifically, the percent cover of both *Scirpus maritimus* and *Suaeda maritima* increased when there was an increase in bare ground available; they are both excellent pioneer species, and the presence of newly exposed bare ground lead to an increase in percent cover. Conversely, the presence of dead material may be stabilizing the marsh surface and providing a kind of sediment trap, which could be resulting in an increase in elevation and suitable abiotic conditions for the growth and colonization by halophytic species. Further monitoring of the increase in exposure of bare ground and subsequent colonization at the site could lead to greater understanding in plant colonization mechanisms.

An important target species at the Cogmagun restoration site was *S. maritima*. It exemplified the relationship between proximity to a creek and colonization rates throughout the field season (Figure 6d), and it had a strong spatial relationship with distance to the creek edge. Remnant adult plants of *S. maritima* from the previous year were found closer to the creek edge. When no remnant *S. maritima* plants were found from the previous year, new colonizers were still likely to be found farther from the mouth of the primary creek. These results could be explained by the hydrodynamics of the site: as the water moves through the primary channel, the energy decreases. By the time the water reaches the back end of the site, velocity has significantly decreased, which can allow for more sediment particles (floc) to accrete along the creek edge. Furthermore, any seeds that are travelling by water can drop out of the water column and be deposited onto the marsh surface in the same area. *S. maritima* is a good target species because it can expand rapidly even in areas of frequent inundation (Pétillon et al. 2010) along creek edges. Tidal currents are known to be important for the seed dispersal of halophytes (Huiskes et al. 1995; Rand 2000; Pétillon et al. 2010; Erfanzadeh et al. 2010).

Flooding frequency, mean inundation time, and the predicted hydro-period are important factors to consider in the ever-changing salt marsh system. They affect primary succession because different types of vegetation can grow in different areas. These hydrological factors directly influence environmental conditions such as salinity levels, competition (between pioneer plant species colonizing the same stressful environment), and seed deposition (Minden et al. in press). The competition between plants in highly stressful environments, like that of a creek edge, has direct effects on the community composition on newly restored tidal regime salt marshes. Minden et al. (in press) found that these species had a higher canopy height and stem mass fraction in response to the competitive and stressful environment. Sediment accretion reintroduced by tides may be an obstacle to seedling growth, causing mortalities because of burial (Davy et al. 2011), however, such sediment can also play an important role by creating a slight elevation that can provide seedlings with an area for colonization (like *S. maritima*). The salinity of the soil is thought to be one of the main environmental factors (Wang et al. 2010; Ranwell 1972; Cooper 1982; Silvestri et al. 2005) that control the distribution of plant communities along an elevation gradient (Erfanzadeh et al. 2010; Grubb 1977; Peach and Zedler 2006).

4.1 Limitations of the Study and Future Recommendations

While two sampling events were sufficient to reveal a noticeable change in vegetation, sampling once a month throughout the growing season and into the fall months, along with multiyear sampling, would have provided a larger dataset, upon to which draw conclusive results. Sampling in the fall season would allow for the identification of reproductive outputs of the plants and could help to indicate how seeds are being transported around the site. Another variable that could be taken into consideration is the canopy height and stem mass fraction (as done my Minden et al. in press), because this could lead to determination if there was also a strong competitive effect in the plants closer to the creek edge as opposed to further away.

There were three sources of errors when calculating the hydro-period, predicted flooding frequency, and mean inundation time. One source of error is associated with the Real Time Kinematic (RTK) satellite navigation, accurate in the vertical to15 cm, which allows for small error in the provided points in Figure 2.

Another source of error is the conversion from chart datum to CGVD28 in order to enter the predicted tidal variables obtained from the Tides and Currents software (page 14). The last source of error is that the conversion factor was estimated using predicted tides and not actual tides. The predicted tides do not always match the actual tides due to other environmental factors, such as weather, winds, storm surges, and barometric pressure (Graham 2012). This could have affects the results because the data that was used may not have been the true occurrences, which could have different impacts upon the plant community, thus changing the results of the study.

Another source of error was the statistical tests that were used (multiple linear regression), as it only examines the effect of each variable when all of the other variables are held constant. This could help explain some confusing results relating to *S.*

alterniflora because it was found in areas further away from the creek edge, but was also found in areas with a higher inundation frequency; increased distance away from the creek should result in lower inundation frequencies. While the general pattern that was observed (Figure 6d) is for *S. alterniflora* to be found farther from the creek and at a set distance from the creek, although they tend to colonize areas that have greater flooding frequencies (closer to the creek).

This study provides data on plant colonization in a newly restored salt marsh. It also shows importance of creeks in relation to colonization by pioneer plant species. In the future, I would recommend that such studies be repeated over several years, perhaps before the start of tidal flow restoration and then for five years after restoration to allow for species turnover and changes in primary and secondary succession.

5. CONCLUSIONS

This study suggests that colonization of pioneer plant species following the restoration of a more natural tidal regime to a salt marsh system is dependent, in part, on the distance from tidal creek networks. It was found that for this study site there was a strong spatial relationship along the edge of the primary creek in relation to that of the colonization rates of target salt marsh species and the increase in percent plant cover growth, as the season progressed. The presence of *Suaeda maritima* in the previous year had an effect on the colonization rates in the following year. As the distance from the mouth of the primary creek increased, *S. maritima* was found closer to the creek edge, and was found farther away from the mouth of the primary creek when there were no remnant plants. This supports the idea that tidal creek networks may play a positive role in seed dispersal and plant colonization. Once established, local plants create a new seed source that can enhance further colonization; creek proximity and outside seed sources then become less important.

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