Propagation and transplanting techniques for native plant species: Living shorelines applications in Atlantic Canada

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Abstract

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By Carly C. Wrathall

Natural shoreline management practices, such as living shorelines, are being explored for their use as an alternative to traditional armoring methods such as riprap. Literature surrounding living shorelines lacks coherence particularly in regards to what methods are available, which is leading coastal zone managers to rely on incomplete science when considering the living shoreline approach. One of the pivotal methods of living shoreline projects is the addition of vegetation (*Spartina* spp.) to the low and mid marsh intertidal zones. There are several methods to accomplish this including transplants, seeds and burying wrack material. The best success was found with transplants (both greenhouse grown and harvested from existing marshes) and seeding methods. Understanding how these vegetation addition methods function in Atlantic Canada will aid in the further development of living shorelines in in this area.

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Chapter 1: Introduction and Literature Review

1.1 Introduction

Traditional shoreline protection practices within the coastal zone have included shoreline armoring such as riprap placement, revetments, breakwaters, groins and jetties (Gittman et al. 2015; Gianou, 2014; Gittman et al. 2014; Pilkey et al. 2012). These static structures work by deflecting wave energy, channeling water flow, and/or interrupting the flow of sediment. While these methods have worked in the past, it is increasingly proven that they are not able to keep up with the demands of climate change and sea level rise, such as increased wave action and coastal flooding, leading to further land loss, increased maintenance and replacement costs (RAE, 2015; Gianou, 2014; Gittman et al. 2014; Bilkovic and Mitchell, 2013; Jackson et al. 2013; Currin et al. 2009; MDE, 2008, Bozek and Burdick, 2005; Moschella et al. 2005; Rogers and Skrabal 2001; Shipman, 2001; Zelo et al. 2000). As well, these methods have well documented negative impacts such as increased scouring, wave energy deflection (which can lead to adjacent erosion), loss of ecosystem services and functions and degradation of intertidal habitats (RAE, 2015; Gianou, 2014; Gittman et al. 2014; Bilkovic and Mitchell, 2013; Jackson et al. 2013; Currin et al. 2009; MDE, 2008; Bozek and Burdick, 2005; Moschella et al. 2005; Rogers and Skrabal, 2001; Shipman, 2001; Zelo et al. 2000). Natural shoreline management provides alternative approaches to traditional shoreline engineering, and includes management practices such as living shorelines, which is the use of natural materials placed strategically to enhance natural ecosystem characteristics and provide benefits such as erosion and flood mitigation (RAE, 2015; Gittman et al. 2015; Manis et al. 2015; Pilkey et al. 2015; NOAA, 2014; Gianou, 2014; Currin et al. 2009). In addition, these techniques can provide a multitude of ecosystem services and functions such as habitat creation, fisheries support, and increased usability of the coast (Gittman et al. 2016; RAE, 2015; Gianou, 2014; NOAA, 2014; Currin et al. 2009; Armitage et al. 2006; Cooper et al. 2001).

One of the most common methods identified when using the living shoreline approach is the addition of plant material to the coastal zone, which increases aquatic habitat for fish, birds and invertebrates, buffers wave energy and mitigates coastal erosion. The most common species of plants that are used in living shoreline projects are salt marsh and dune species, which can tolerate both high inundation and salinity levels, such as the *Spartina spp*. and *Ammophila spp*. (Porter et al. 2015, van Loon-Steensma and Slim, 2013;; Townend et al. 2010; Wilson et al. 2001; Meyer et al. 1997). Eastern North American salt marshes are dominated by *Spartina* species, perennial, rhizomatous grasses, commonly *S. alterniflora, S. patens and S. pectinata,* which are found in the low, mid and high marsh zones respectively (Konisky and Burdick, 2004; Fang et al. 2004; Anastasiou and Brooks, 2003). These three species are dominant, but co-occur with other common salt marsh species including *Juncus gerardii, Plantago maritima, Salicornia depressa* and *Sueda maritima* (Mittelhauser et al. 2010). This research focused mainly on *Spartina spp*., due to their frequent use in living shoreline projects, hardiness, and adaptability within the coastal zone (Currin et al. 2009; MDE, 2008; Bruno, 2000).

Coastal ecosystems, including tidal salt marshes and dune systems, are described as the active, dynamic, transitional zone of the coast, that are able to geomorphologically shift and change in response to natural and anthropogenic disturbances (Figure 1.1) (van Loon-Steensma and Slim, 2013; Meyer et al. 1997; Townend et al. 2010). The coastal zone can be simply defined as the interface between land and sea, that includes shallow waters and low-lying shoreline ecosystems such as salt marshes and dunes (Mitra, 2011; Rochette, 2010; CBCL Limited, 2009). Depending on the jurisdiction, the limitation of landward and seaward boundaries of the coastal zone can vary (Davidson-Arnott, 2010; CBCL Limited, 2009). The coastal zone is under continued pressure from human impact (e.g., coastal development), climate change (e.g., increasing storm intensity, increasing temperatures, changing precipitation patterns) and sea-level rise (e.g., increasing coastal flooding and erosion), which puts this area at risk for increased loss of habitat, and leaves shorelines vulnerable to erosion and flooding (MEA, 2005; MDE, 2008; Gittman et al. 2015).

Increased land loss due to erosion and coastal flooding is becoming an important issue for coastal zone managers (MDE, 2008). The coastal zone is highly valuable for many reasons including tourism, fisheries, transport and recreation (Patterson et al. 2014). However, human activities, such as coastal development, are degrading coastal ecosystems at an alarming rate, and further, climate change and sea-level rise (SLR) are threatening the integrity of coastal ecosystems (Dahl and Steadman, 2013; MEA 2005). Anthropogenic activities have led to the direct (e.g., infrastructure and coastal development) and indirect (e.g., erosion, climate change and sea level rise) loss of coastal habitat throughout the world (GBF, 2014; Houser, 2010; Townend et al. 2010; Ravens et al. 2009; Cooper et al. 2001; Wilson et al. 2001; Rozas and Minello 2001; Moy and Levin, 1991; Cranford et al. 1989).

living shorelines attempt to provide an alternative to engineered methods, and reclaim or restore some of these degraded areas.

Atlantic Canada is no exception to this; loss of coastal habitat such as tidal salt marshes throughout the region is estimated to be between 60-80%, mainly as a consequence of anthropogenic activities such as agricultural dyking, infrastructure and coastal development over the last 400 years (van Proosdij et al. 2006; Hanson and Calkins, 1996). This degradation and destruction represents significant loss of critical coastal habitat, species and ecosystem services and functions (Temmerman et al. 2013; Feagin et al. 2009; Armitage et al. 2006; Wilson et al. 2001; Boorman and Ashton, 1997). In addition to the loss of habitat and ecological function, the increased presence of the built environment within the coastal zone has required ever increasing efforts and expenditures to protect vulnerable infrastructure (Cooper et al. 2001; Temmerman et al. 2013). Natural shoreline management strategies, such as living shorelines, have been identified as viable strategies to reduce current and future risks associated with human impact and climate change (including sea level rise, storm surge and erosion hazards), mitigate the damage to valuable coastal infrastructure and have the ability to reclaim some of this lost habitat (Temmerman et al. 2013; Wilson et al. 2001; Moy and Levin, 1991).

The United States has been a leader in living shoreline innovation and implementation in North America. However, the majority of their shoreline management still falls under engineered approaches, and Gittman et al. (2014) estimate that 14% of shorelines in the United States have been hardened by engineered structures. It has been estimated that there have been over 200 successful living shorelines created in the United

States, many of which are found along the eastern seaboard, particularly in the states of Maryland, Delaware and Virginia (Fear and Bendell, 2011; Chesapeake Bay Trust, 2014). The practice has spread to other areas as well, such as the Gulf coast where Galveston Bay, Texas has completed several living shorelines employing a multitude of methods, and San Francisco Bay, California where they have had success with oyster reefs and similar methods (GBF, 2014; ESA PWA, 2012; NC, 2012).

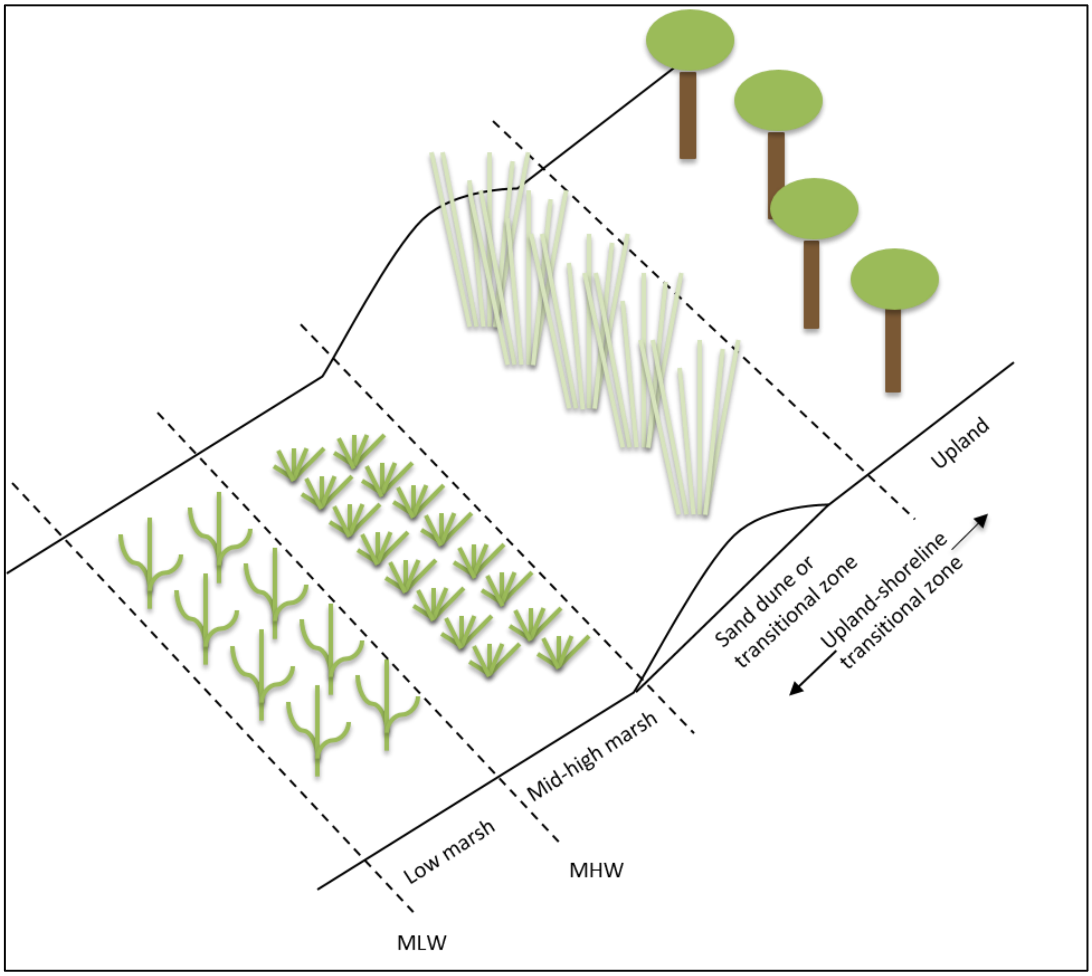

Figure 1.1 *Example of a coastal ecosystem including the intertidal (MLW- mean low water and MHW-mean high water)), dune (sand dune) and upland zones*

1.2 Traditional engineering methods

Traditionally, shoreline management has been approached by engineering hard structures, such as rip-rap, breakwaters, revetments, groins and jetties (Gittman et al. 2015; Gianou, 2014; Gittman et al. 2014; Pilkey et al. 2012). Riprap, breakwaters, and revetments provide protection from wave energy, by breaking and deflecting waves before they reach land. This mitigates erosion and slows the loss of valuable land and infrastructure. Groins and jetties alter the hydrological flow of the coast, which can be used to channel flow of water and sediment to and away from areas of concern (Shipman 2001, Zelo et al. 2000). These structures are common sites around many areas of the coast, and are still the main methods of shoreline management in many areas of the world (Miller et al. 2005, Gittman et al. 2015).

However, while these methods work well under ideal circumstances such as low wave energy, there are significant negative impacts associated with them, that are providing the reasoning for needing alternatives such as living shorelines (Gittman et al. 2015; Gianou, 2014; Arkema et al. 2013). These engineered structures are susceptible to damage from storm events and wave impact, which are costly to maintain and replace when damaged (RAE, 2015; Gittman et al. 2015; Currin et al. 2009; Bozek and Burdick, 2005; Rogers and Skrabal, 2001). Structures such as groins and jetties can (unintentionally) alter sediment and current flow, which can starve beaches and marshes down stream of valuable sediment replenishment, leading to the degradation and loss of these systems (RAE, 2015; Ravens et al. 2009 Shipman, 2001; Currin et al. 2010; Zelo et al. 2000). Large structures such as riprap and revetments can deflect wave energy causing increased erosion of adjacent properties, as well as increased scouring at the toe of these structures (Bilkovic and Mitchell, 2013). These static structures remove the ability of the coastal zone to move and adapt to changes and alter the coastal habitat that would exist naturally, and cause increased risk of invasive species, leading to further loss of coastal ecosystem services and functions (Bilkovic and Mitchell, 2013). Many of these structures also decrease the usability of the coast line, by replacing beaches and marshes with large structures not intended for human use. The cumulative negative effects of engineered structures tend to be underestimated, as research tends to favour a site-specific approach and ignore the impacts on the system as a whole (McDougal et al. 1987; Currin et al. 2009; RAE 2015). What is being missed with this site-specific approach is that increasing the amount of engineered structures in an area can mean more severe effects for the system as a whole (McDougal et al. 1987; Currin et al. 2009; RAE, 2015).

1.3 Living shorelines in the coastal zone

Practices of living shoreline creation, including salt marsh and dune restoration and creation, have been valued for their ability to reclaim lost habitat, and as alternatives to traditional shoreline armoring techniques for mitigation of shoreline erosion and coastal flooding, throughout the world including in the United States (Bromberg and Bertness, 2005; Moy and Levin, 1991). Living shorelines, in short, attempt to provide shoreline stabilization, erosion and coastal flooding mitigation and enhance ecosystem services and functions, while minimizing the adverse effects found with engineered approaches and keeping the connectivity between land and sea (Gittman et al. 2015; Manis et al. 2015; Pilkey et al. 2015; RAE, 2015; NOAA, 2014; Gianou, 2014; Bilkovic and Mitchell, 2012;

Currin et al. 2009). This is done through the use of natural materials, such as vegetation, placed so as to have minimal interferences with coastal biogeomorphological processes (Manis et al. 2015; RAE, 2015; NOAA, 2014; GBF, 2014; Latta and Boyer, 2012.; Currin et al. 2009). These projects have been conducted under various names, including living shorelines and soft shoreline stabilizations since the late 1980's (Gittman et al. 2016; Gianou, 2014; Patterson et al. 2014; Pilkey et al. 2012). The definition and applications of living shorelines are discussed extensively in Chapter 2.

The addition of plant material and/or seeds to a shoreline or marsh surface has been shown to be an effective mechanism to enhance and stabilize coastal shorelines, through wave attenuation, compaction and solidification of soil (Bilkovic and Mitchell, 2013; Rozas and Minello, 2001; Meyer et al. 1997, Moy and Levin, 1991). Transplanting of plugs (independent plants grown from seed that have both established root mass and above ground biomass) and the use of seeds directly on the marsh surface, are common methods to the majority of living shoreline projects (Utomo et al. 2010, Rozas and Minello 2001, Moy and Levin 1999). *Spartina alterniflora* is a common species used in these projects as it has a large native geographical range (from Newfoundland to the Gulf of Mexico) and can tolerate both tidal inundation, and a range of salinity (Manis et al. 2015). Understanding which methods of vegetation addition will work in the unique climate in Atlantic Canada, will impact the success of potential living shoreline projects, as alternatives such as seeds and plug transplants from adjacent marshes may need to be used due to the lack of available suppliers of intertidal vegetation.

1.4 Thesis organization

This research is motivated by the need to increase the coherence of living shoreline literature, in which there is a significant lack of peer-reviewed, comprehensive research regarding the different methods and monitoring protocols that exist. There is great potential for living shorelines to be used as an alternative to traditional engineered structures, however, without concrete guidance, protocols and documented results, it makes it difficult for coastal zone managers to rely on a method based on incomplete science. This research is also motivated by the lack of active planting of the intertidal zone in Canada, particularly in Nova Scotia that is crucial to living shoreline success (i.e., vegetation addition), identifying alternatives to purchasing *Spartina spp.* plugs from greenhouses, as they are not readily available in this area and a need to understand how these methods work in our unique climate.

This thesis is divided into two main chapters, where Chapter 2 explores scientific and grey literature, and evaluates a set of common methods available for living shoreline applications within the coastal zone, including intertidal planting and the use of sills and other low-lying structural materials. This chapter pulls together a synthesis summary of what a living shoreline is through evaluating commonalities throughout literature and identify the present gaps within literature. One of the common living shoreline methods identified in Chapter 2, vegetation addition, is the focus of Chapter 3, which includes both a germination and vegetation addition experiment. In this chapter, common seed storage techniques are used on *Spartina spp.* to determine the best rates of germination. Followed by a vegetation addition experiment targeting *S. alterniflora* and *S. patens,* where four methods of vegetation addition are used and the survival of the species is evaluated over a growing season.

The research objectives are therefore summarized as:

1) Critically review living shorelines methods in literature, including grey literature and non-peer reviewed literature such as technical or community reports and guidance documentsto provide a general understanding, for all practitioners, of common methods that may be applicable to living shoreline construction.
2) Apply seed storage treatments to 3 common intertidal plant species to determine which produces the highest rates of germination.
3) Determine the health index and survival rates of intertidal vegetation (*S. alterniflora* and *S. patens*) using four methods of vegetation addition, common to living shoreline projects.

Chapter 2: Synthesis Review of Living Shorelines Applications

2.1 Introduction

Previous methods of coastal protection and shoreline management around much of the world, have included man-made or engineered structures, often referred to as "hard" approaches, such as rock revetments (rip rap), sea walls, groins and jetties (Figure 2.1) (Gittman et al. 2015; Gianou, 2014; Gittman et al. 2014; Pilkey et al. 2012). While these engineered methods are familiar and have well developed methods in engineering literature, they are costly to maintain, susceptible to major damage from storm energy and wave impact, change or remove habitat, alter sediment flow, reduce usability of the shore and ultimately result in a decrease of ecosystem services and functions (RAE, 2015; Gianou, 2014; Gittman et al. 2014; Bilkovic and Mitchell, 2013; Jackson et al. 2013; Currin et al. 2009; MDE, 2008, Bozek and Burdick, 2005; Moschella et al. 2005; Rogers and Skrabal 2001; Shipman, 2001; Zelo et al. 2000). As well, the cumulative negative effects of hardened approaches tend to be underestimated as studies often ignore the whole system in favour of a site-specific approach, where more engineered structures generally mean more severe effects (McDougal et al. 1987; Currin et al. 2009; RAE, 2015).

There is increasing evidence supporting the use of nature-based coastal defense, as enhancing natural ecosystems can mitigate erosion and coastal flooding, as well as increase desired ecosystem services and functions (Sutton-Grier et al. 2015, COPRI 2014). Natural shoreline management or "soft" approaches, namely living shorelines, offer an alternative to engineered shoreline protection and have the added benefit of habitat enhancement or creation, increases usability of shorelines, improvement of water quality, and provide natural benefits for human enjoyment (Figure 2.2) (Gittman et al. 2016; RAE, 2015; Gianou, 2014; NOAA, 2014; Currin et al. 2009; Shipman, 2001). Bilkovic and Mitchell (2013) further discuss the potential ecological tradeoffs of using natural or naturalized shorelines, such as increased filtration capacity due to the increase of fauna and epifauna such as oysters, muscles, barnacles and clams. This living shoreline approach has been identified for the ability to enhance the natural resilience of shorelines to recover from disturbance, in particular during large storms and hurricanes, mostly due to the ability of coastal vegetation to recover from major disturbance such as storm surge and increased wave energy (Gittman et al. 2014).

The term "living shoreline" has been increasingly popular among community groups and government organizations working with coastal and shoreline management, particularly along the Atlantic coast of the United States (Currin et al. 2009). To date, no precise definition of a living shoreline has been given in peer reviewed or grey literature, and the exact terminology can differ depending on location (Gittman et al. 2016; Gianou, 2014; Patterson et al. 2014; Pilkey et al. 2012; Shipman, 2001). For example, living shorelines have also been called soft shoreline stabilization, bio-engineering, and green shorelines (RAE, 2015; Gianou, 2014; Patterson et al. 2014). It is also difficult to pinpoint exactly what a typical living shoreline resembles and which methods are used in constructing a living shoreline.

The goal of the living shoreline approach is to provide soil stabilization, erosion mitigation, enhance ecosystem services and functions, and support a variety of flora and fauna, using natural structures, or a mix of natural and hardened structures (*hybrid living shorelines*), while keeping the connectivity with land and sea (Gittman et al. 2015; Manis et al. 2015; Pilkey et al. 2015; RAE, 2015; NOAA, 2014; Gianou, 2014; Currin et al. 2009). Living shorelines employ natural materials such as vegetation and biodegradable mats, stones, fill and other structural materials, strategically placed so as not to disrupt the land-water continuum of the natural ecosystem, and to have minimize interference with coastal, estuarine, or geomorphological processes, except in the event that that is the purpose (e.g., creating crescent beaches) (Manis et al. 2015; RAE, 2015; NOAA, 2014; GBF, 2014; Latta and Boyer, 2012; Currin Et al. 2009).

Hybrid living shorelines, which use a mix of soft and hard approaches, are an alternative option for higher-energy systems such as those with a very large fetch, or strong currents (RAE, 2015; Sutton-Grier et al. 2015; Currin et al. 2009; MDE, 2008; NRC, 2007). This can includethe use of vegetation addition with engineered structures such as sills (Currin et al. 2009). These can still incur the negative impacts associated with engineered structures, such as wave energy deflection and scouring, but allow living shorelines to be used in areas where the wave energy may be too high to exist in a purely natural state (Gianou 2014).

Living shorelines often create or restore a narrow strip of coastal habitat (e.g., dune, salt marsh, and submerged aquatic vegetation such as eel grass beds), which can be quite productive, and produce a significant amount of ecosystem services and functions (Sutton-Grier et al. 2015, COPRI 2014, Wolanski et al. 2009; Silliman and Bortolus, 2003). However, some regulators have questioned how many ecosystem services and functions a narrow strip of coastal habitat can truly provide when compared to natural shorelines (Gittman et al 2015; NOAA, 2014; GBF, 2014; Gianou, 2014; Currin et al. 2009; Minello et al. 1994). That is not to say that they cannot enhance these features, but rather living shorelines do not provide *equivalent* features, as a natural, intact, unaltered shoreline may.

Currently, peer-reviewed scientific literature is just now emerging in the area of living shorelines, particularly around the individual methods that can be applied when constructing a living shoreline. This lack of peer reviewed data is forcing coastal zone managers to rely on incomplete science when constructing living shorelines (Feagin et al. 2015; Sutton-Grier et al. 2010; Zelo et al. 2000). Even fewer studies have looked at the success of living shorelines in sustaining and maintaining ecosystem services and functions where only short-term (less than 3 years) benefits and impacts have been assessed (Gittman et al. 2015). However, there is a significant bank of grey literature available, including new documents from Restore America's Estuaries (2015) and Miller et al. (2015) that focus on aspects of implementing living shorelines.

This chapter outlines a variety of methods found to be common across living shoreline projects. It must be understood that potential living shoreline sites will require a site-specific design to meet the needs in that particular area/ecosystem, and therefore it is recommended to select the best methods to fit the needs of a particular site and desired outcome (RAE, 2015; Currin et al. 2009). This is by no means meant to be a complete list of methods, as the practices of living shorelines are evolving rapidly, but instead aims to provide an understanding of some of the more common methods successfully used by community groups, governments, industry and individuals.

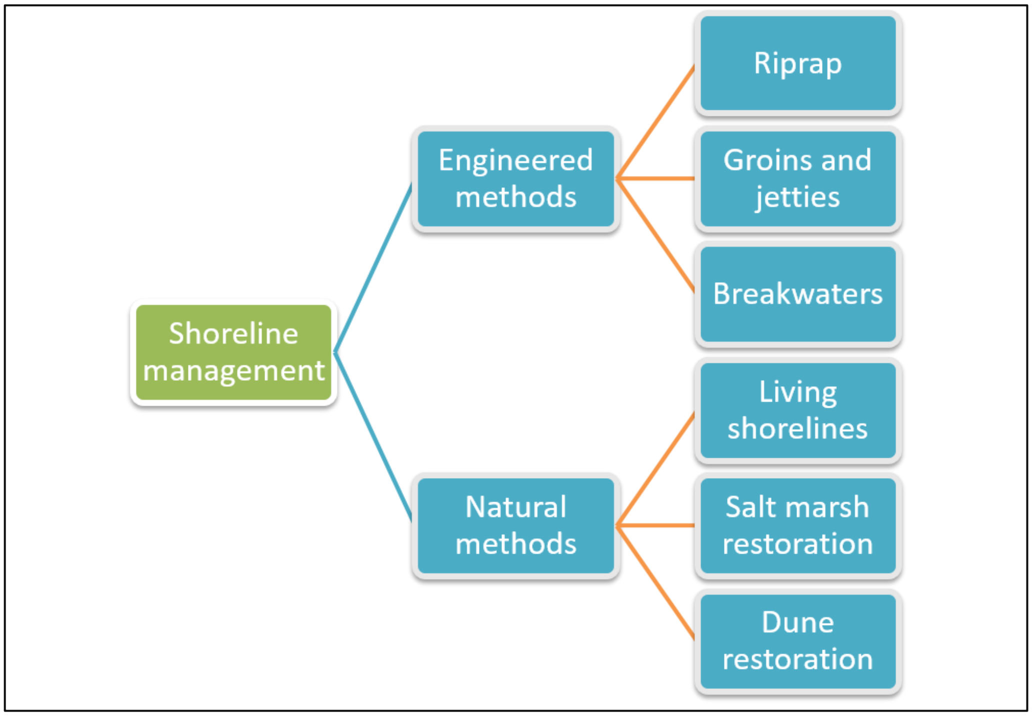

Figure 2.1*: Diagram showing the branches of shoreline management, and examples of methods under each branch*

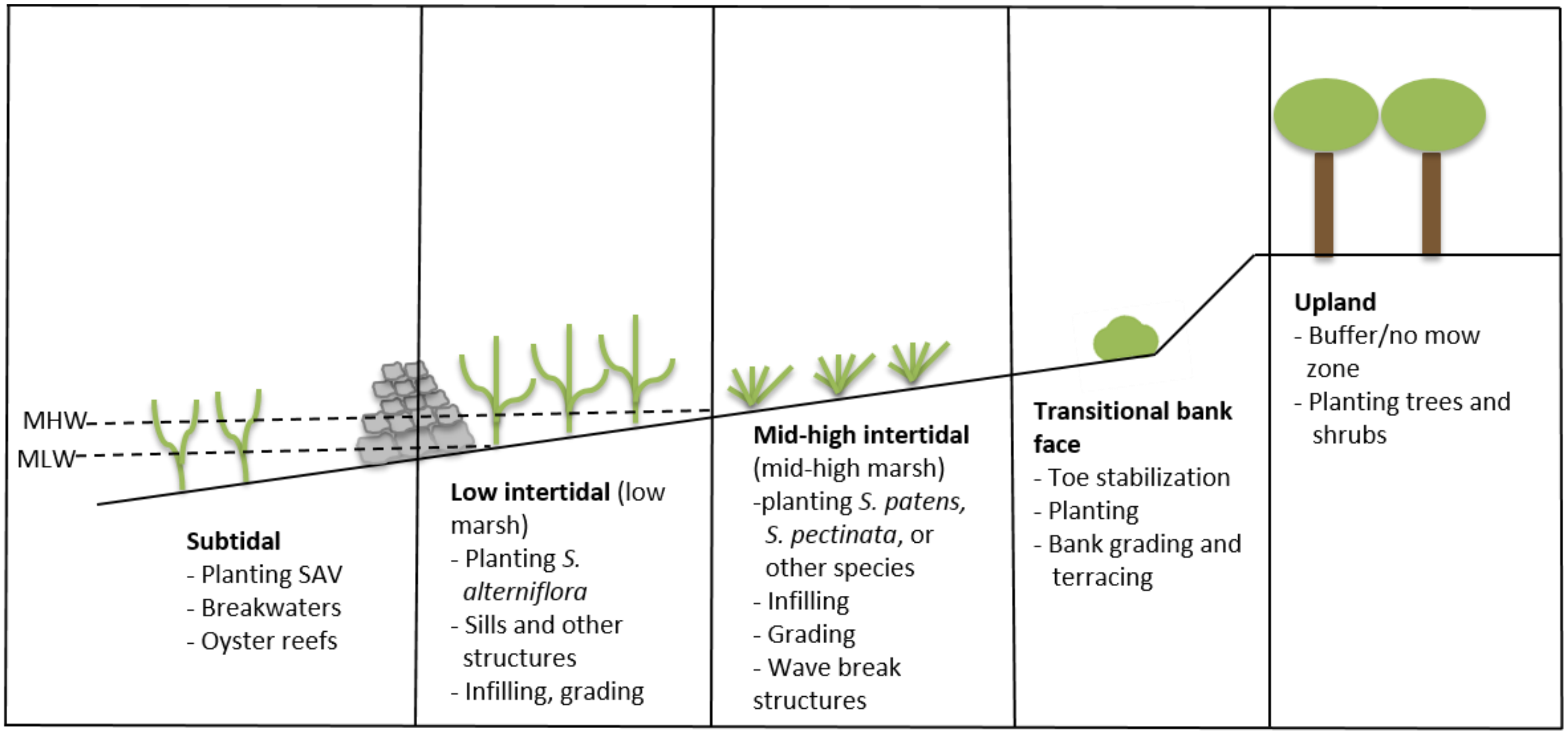

Figure 2.2: *Simplified living shoreline example, with examples of methods that can be used in each zone; MHW=mean high water, MLW= mean low water, SAV= submerged aquatic vegetation*

2.2 Examples of living shorelines methods

Living shoreline methods tend to be very site specific (RAE, 2015; Currin et al. 2009). Physical and geomorphological characteristics such as, sheltered or exposed climate (fetch), currents, water depth, sediment/substrate type, and existing vegetation community, play a significant role in determining which methods of living shorelines can be used at a particular site (RAE, 2015; GBF, 2014). One of the major issues encountered while researching how different groups construct living shorelines is the lack of quantitative data for physical and geomorphological parameters such as sediment type used for infill, length of sills, number of vegetation plugs used, and measurements of fetch.

Common living shoreline practices include vegetation addition (planting or seeding) within the intertidal (and/or subtidal) and upland zones, adding low stone structures (sills) and infilling or grading back banks to reduce the steepness of slopes. If the area is medium-high wave energy, then it is recommended to use a wave breaking structure (hardened or biodegradable) to maximize the success of the project. However, again, it depends on the site, and the desired outcome(s) of the project (e.g., habitat creation or shoreline stabilization). Many of the common categories of living shoreline methods, found within the literature search, are outlined in the following sections and a summary table of various characteristics can be found in Appendix A.

2.2.1 Initial decisions and preparation

The initial decision that should be made is whether or not a living shoreline is appropriate to use at a particular site. In areas where there is minimal erosion, or no critical land or infrastructure at immediate risk, simply not doing anything is often the preferred response (MDE, 2008, Zelo et al. 2000). However, if the initial goal(s) is to protect or create coastal habitat, doing nothing does not address those issues and can lead to the continued degradation of coastal ecosystems and infrastructure. The State of Maryland (USA) has a preferred approach to shoreline management that puts no action first, followed by living shorelines where they are applicable, and finally engineered practices as a last resort (MDE, 2008) (Figure 2.3).

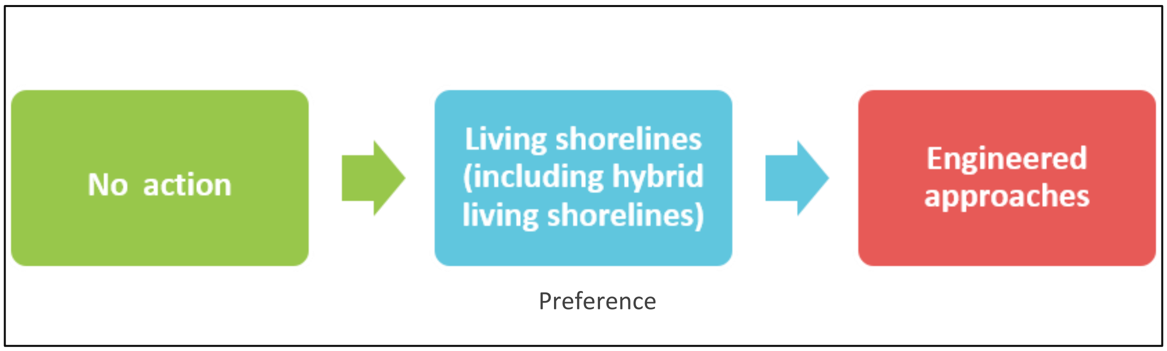

Figure 2.3: *The preferred approach in Maryland, from no action, to living shorelines where they are applicable to engineered approaches as a last resort*

The design phase should take a site-specific direction, but also include an understanding of how the living shoreline will impact adjacent prosperities (i.e., impact sediment flow or wave energy deflection) and the ecosystem as whole (MDE, 2008; NRPC, [No date]). Important characteristics to take into account for the design include; bank erosion rate, elevation, tidal flooding, shoreline orientation, wave energy, prevailing wind directions, wave direction, currents, existing vegetation community and soil type (RAE. 2015; NOAA, 2014; MDE, 2008; NRPC, [No date]). Upland influences also cannot be ignored, and any potential influences from the upland (erosion, runoff, fresh water inputs) need to be addressed in the initial stages, as it can influence bank erosional rates and vegetation establishment (MDE, 2008). Materials to be considered for the design include, the need for (and availability of) vegetation, sediment for infilling, erosion control structures or fencing, and structural materials (GBF, 2014). This can be limited by budget and availability of materials, for example limited greenhouses that sell native intertidal vegetation. Wave energy or fetch (the distance wind can blow across water generating waves), is an important characteristic to take into consideration, as it is used as a proxy for determining wave energy (Table 1). A fetch of less than 1.6 km (medium wave energy) is what is recommended by the National Oceanic and Atmospheric Administration (NOAA) for a living shoreline with no engineered or structural supports (NOAA, 2014). For living shorelines with a fetch larger than 1.6km, it is usually recommended to use structural supports (Table 1). A description of structure materials can be found in subsections 2.2.5 and 2.2.6.

Before beginning any construction such as infilling or planting, the sites must first be prepared, cleared of debris such as dead plant material/trees (although some can be saved for use in the living shoreline), garbage, and any unwanted or crumbing hard structures such as old rip rap (NOAA, 2014). Other preparations that can be completed at this point include constructing drainage channels for upland runoff, and secure structures that are going to be kept on site (MDE, 2008).

Wave Energy	Fetch Length
Very Low	0.8km
Low	0.8-1.6km
Medium	1.6-8.0km
High	8.0km-24.1km
Very High	>24.1km

***Table 1**: Wave energy as determined by the fetch of a particular site. Using the longest fetch. (Modified) Hardaway et al. (1984).*

2.2.2 Beach nourishment and slope grading

Beach nourishment

Sand must be naturally occurring in a system in order for beaches to be continuously replenished without human interference (MDE, 2008). When this is not the case, beach nourishment (also commonly called: beach replenishment, enhancement, or feeding) can be used as a way of restoring sand to eroding beaches (Gianou, 2014; Patterson et al. 2014; Shipman, 2001). This is typically done by using dredged materials from the sea floor and spraying or shoveling the sediment onto the eroding beaches (Shipman, 2001; MDE, 2008). This can also be done with sediment brought in from other areas, or purchased (clean fill). However, it has been recommended by experts such as the Maryland Department of Environment, that sediments used should be natural to the area to decrease risks associated with bringing in foreign sediment (i.e., invasive species) (Shipman, 2001; MDE, 2008). Other characteristics that should be taken into account when pursuing this method include, the need for structures such as groins to retain sediment, destruction and replacing of existing vegetation communities, and the grain size of sediment used, which is important as larger sediment may erode slower if erosional rates are low (MDE, 2008).

While armoring can starve a beach of sediment by interrupting the flow of sediment, it is important to understand that beach nourishment can address the symptoms without actually dealing with the underlying cause of erosion on the beach (Shipman, 2001; MDE, 2008). This means, for example, if you have a beach that is starved of sediment from an existing groin, adding sediment is only a temporary fix, as the beach is still not being replenished naturally and will continue to erode and need to be replenished repeatedly. Therefore, beach nourishment is often seen as a temporary fix (Shipman, 2001; MDE, 2008). This method can also be used in combination with salt marsh or dune restoration for increased habitat enhancement. There are some negative ecological effects to this method as well. This can include burying existing vegetation communities, and as with any mass addition of sediment, this can lead to increased suspended sediment content which has a negative impact on benthic communities (Shipman, 2001). However, there are ways to avoid, or mitigate impacts of suspended sediment such as using containment structures such as construction booms and other containment structures such as erosion fencing (GBF, 2014).

Burying bulkheads and other hard structures (e.g., rip rap) is also an option and can be done as part of beach nourishment, or separately (Zelo et al. 2000). This is commonly done when removing a structure will be very expensive, and a more cost effective option is to bury the structure, re-grade the beach, and plant vegetation (Zelo et al. 2000). Given enough time, established vegetation can solidify soils, and sediments and help to build protective dunes (Feagin et al. 2015).

Infilling and Slope Grading

The purpose of infilling or grading slopes is to mitigate erosion, and/or create platforms for plants and other structures to be placed (Figure 2.4). This is done through creating a gentle slope, which decreases erosion through reducing wave impact at the toe, and allows vegetation to establish by providing a more favourable environment to plant into (NOAA, 2014; MDE, 2008; GBF, 2014). The Maryland Department of Environment (2008) recommends a 3:1-5:1 slope for upland cliffs that are to be graded, and also recommends that grading should be combined with other methods such as planting, to increase success, as simply grading alone will not protect against further erosion (MDE, 2008). Adding ditches and channels to cliffs when grading, to drain runoff, can also help mitigate erosion from upland water sources such as storm water runoff (MDE, 2008). Potential runoff impacts from upland sources must be addressed or there may be an increased risk of damage or burial to the areas below (e.g., intertidal zone) (MDE, 2008).

Infilling within the intertidal zone often uses dredged material from on site, or ‘clean’ (uncontaminated) fill that is purchased (NOAA, 2014; Shipman, 2001). The most common slope used when infilling the intertidal zone is 10:1 (GBF, 2014; Hardaway et al. 2010; MDE 2008) (Figure 2.4). Sand is usually the main constituent of infill, and it is recommended by the Maryland Department of Environment that particle size not be less than 0.149 um (or fine sand), or there is an increased risk of erosion and fine sediments can make the water more turbid (MDE, 2008; Shipman, 2001). Using structural materials, biodegradable mats, erosion fencing or construction booms to capture and hold in sediment is also an option to reduce turbidity in water (GBF, 2014; NOAA, 2014). Leftover fill may be pushed into the water to create a larger marsh platform, or removed from site. Materials such as burlap or other biodegradable sacks such as coir fiber, can also be used to create marsh platforms, when adding free sediment is not appropriate (Malizzi, 2013; Rozas and Minello, 2001). These are stacked on top of each other and vegetation is often planted on the top layer to aid in compacting sediment (Figure 2.5).

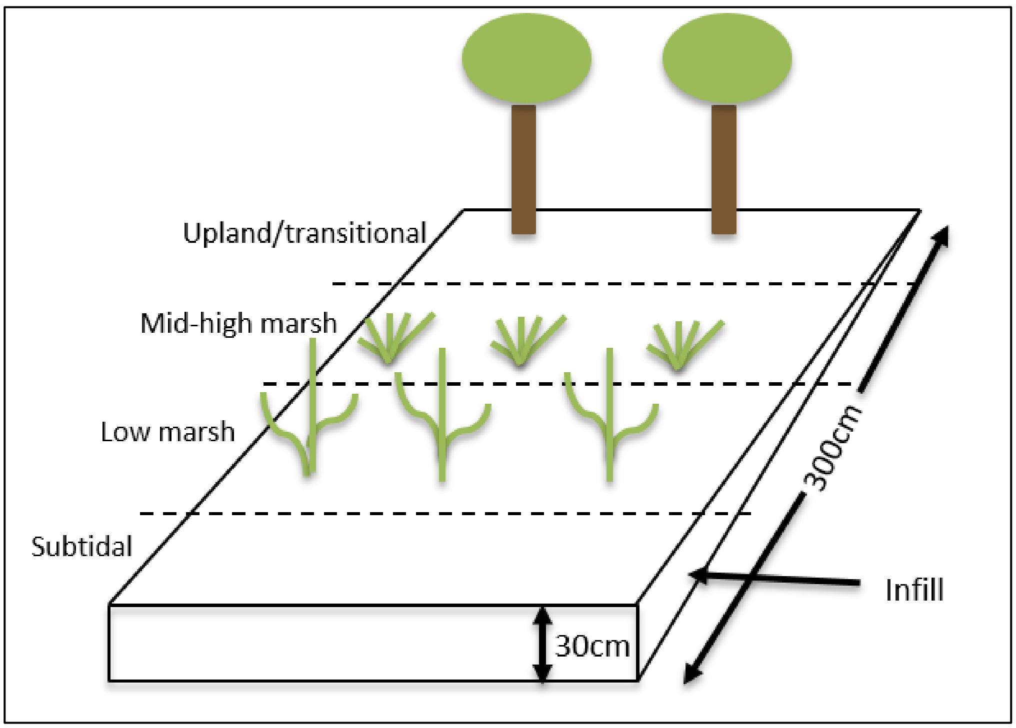

Figure 2.4: *Showing a 10:1 slope on an infilled shoreline*

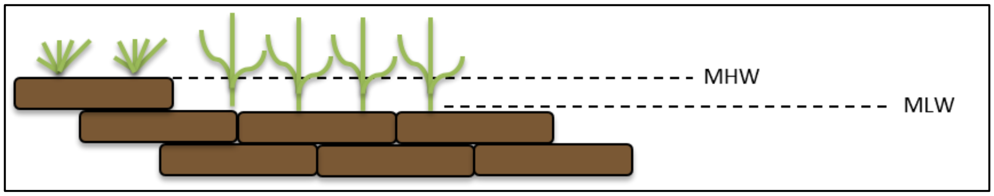

Figure 2.5: *Showing between mean low water (MLW) and mean high water (MHW) using burlap sacks to build a marsh platform*

2.2.3 Vegetation addition: intertidal planting and submerged aquatic vegetation

Vegetation addition through means of planting or seeding is one of the most common methods used in living shorelines projects, as vegetation provides a wide variety of benefits including dissipating wave energy, compacting soils and increasing habitat (Feagin et al. 2015). When deciding to add vegetation in a living shoreline, soil type, erosional rates, tidal range, inundation period, fresh water inputs, and plant type are all important characteristics to evaluate prior to planting in order to ensure success and minimize the risks of dislodgement, stress and mortality.

Plant selection is very important, and should mimic existing habitat (MDE 2008). Varied (shallow and deep) and dense root systems help to solidify soils, and plants should be selected based on type of environment and availability. Plants used need to be able to withstand short-term stressors such as flooding and burial by sediment deposition and long-term stressors such as sea level rise (NOAA, 2014; Feagin et al 2015; Maun, 1994; Feagin et al. 2009; Manis et al. 2015). As well, preference should be given to native vegetation in order to increase the chances of survival and minimize issues with invasive species (e.g., commonly in Nova Scotia, *Rosa multiflora* is used in landscaping and is invasive) (MDE, 2008; HRM, 2015). As an example, a short list of Nova Scotia native vegetation suitable for living shoreline projects is shown in Appendix B (Mittelhauser et al. 2010, Boland 2012). This list is a mix of species that are able to survive on or near shorelines (i.e., a mix of intertidal and upland vegetation) and able to grow varied root systems that can stabilize soils and capture sediment. Included in Appendix B is also a list of common invasive species to avoid. Choosing plants that are ecosystem engineers such as *S. alterniflora*, that are adapted to accrete (capture) sediment, act as soil modifiers to promote cohesion of sediments, alter hydrodynamics though attenuating waves and have a good ability to recover and reproduce, can aid in the success of the living shoreline, and are very commonly used (Feagin et al. 2015; Currin et al. 2009; MDE, 2008; Bruno, 2000)

The methods of transplanting vary depending on the size of the project and the desired outcome. *Spartina alterniflora* (and *S. patens* in higher marsh areas) is commonly used in living shoreline projects because of the ability to create strong sods, and mitigate wave energy, where some studies suggest that *S. alterniflora* can reduce wave height by 90% within 20m from the shore (Knutson et al. 1982; Currin et al. 2009; NOAA, 2014; MDE, 2008). This species also has a large (native) geographical range (from Newfoundland, Canada to the Gulf of Mexico coast) (Manis et al. 2015; MDE, 2008). Due to its frequency of use in living shoreline projects, *S. alterniflora* is used as the main example in the planting methods below.

Plugs of the desired species are planted into preexisting or created marsh platforms or sand flats. However, when this is not possible, there are other methods, such as planting into sand bags, or burlap sacks, which create a temporary platform until vegetation establishes and consolidate soils (Figure 2.5) (Malizzi, 2013; Rozas and Minello, 2001). Plugs tend to be planted in multiple rows along the surface, and eventually the vegetation spreads rhizomatously and grows in between the rows (Figure 2.6). Using planting methods such as the steaking method outlined in Figure 2.7, which can be used for both intertidal and subtidal plugs, is an example of how to plant plugs when sediment conditions may not be favourable or plants risk being scoured out (e.g., high wave energy) (Latta and Boyer, 2012).

Prior to planting, it is important to consider how the plugs are gown, handled, and the methods you use to plant the plugs, to avoid damage and increase the chances of survival. Methods to increase success include growing plants to a reasonable size, not allowing roots to dry out, proper handling of plant tissue and roots to avoid injury, and the amount of time required to properly condition plants (acclimatization) prior to transplantation (Anastasiou and Brooks, 2003). How long transplant plugs should be grown (or how long they should grow before being transplanted from adjacent marshes), varies in literature. For example, Fang et al. (2004) maintained their germinated seedlings for 12 weeks, and Manis et al. (2015) allowed 6 months of growth for rhizome cultivars of *S. alterniflora* prior to transplantation.

Spartina alterniflora plugs are planted in an elevational range that allows for the plugs to be submerged in water at high-tide (MHW) (Figure 2.8). The exact spacing will depend on the site size, as well as the availability of plugs and it is important to remember that the plugs at the front (closest to the subtidal zone) will face the harshest conditions and therefore planting more in that area will increase success As you move from the tidal minimum (MLW), spacing increases from 20cm to as far as 3m, depending on the size of the site, and the availability of plugs (GBF, 2014; Bergen et al. 2000). Further, Bergen et al. (2000) found that plugs planted on a salt marsh remediation site, spaced 30cm apart, had the best rhizome spread. Timing of planting is also important, as starting after winter allows the whole growing season for plants to establish, as well as the benefits of lower tides to decrease stress on young seedlings (GBF, 2014; NOAA, 2014). Transplants (and seeds) can be planted at any point during the year, however spring is recommended as it allows a full growing season to occur (GBF, 2014; NOAA, 2014). Another consideration is the elevation within the tidal frame that you are planting intertidal vegetation, as certain species can only survive within certain elevational zones. For example, *S. alterniflora* survives, due to lack of competition, best in the low marsh zone where inundation periods are highest, and *S. patens* survives better in the mid-high marsh zones where inundation is less intense (Porter et al. 2015; Stammermann and Piasecki, 2012; Konisky and Burdick, 2004; Bergen et al. 2000). Planting these species within the wrong zones can lead to decreased plant health and survival (MDE, 2008).

Seeding is also another option for adding vegetation to a surface. This is done though the direct placement of seeds (burying them, or just placing them on the surface), aerial seeding (dropping seed from a drone, helicopter or balloon), and burial of wrack material, the dead plant mats that wash up on the shores in coastal areas (Minchinton, 2013; Utomo et al. 2010; Fang et al. 2004). This can present problems in intertidal areas as seeds can be washed away, even when buried. Wrack material can hold abundant amounts of seeds, however, it is difficult to determine the type of seeds available in the wrack, and literature suggests that the seeds are predominately from the high marsh and upland transitional zones (Glogowski, 2013; Minchinton, 2013; Leck, 2003). This can cause issues, for example, when you bury wrack in the low marsh, and the majority of seeds are higher marsh/upland species that likely cannot survive in the low marsh.

Planting submerged aquatic vegetation (SAV) such as *Zostera marina* (Eel grass) is another way to mitigate wave energy, stabilize sediment below the intertidal zone and provide habitat (NOAA, 2014; Latta and Boyer, 2012; Rozas and Minello, 2001). Literature surrounding the use of SAV in living shoreline projects is very limited, however it is a viable method of wave attenuation (Latta and Boyer, 2012). Planting plugs (independent, live plants with existing roots and above ground biomass) using the staking method can be used for submerged aquatic vegetation (SAV), Figure 2.7 shows how this method can be used in both the intertidal and subtidal zones (ESA PWA, 2012). Spacing of 25 plants within 1.5x1.5 m quadrats for SAV is recommend from projects in San Francisco Bay (ESA PWA 2012). Seeding can also be used with SAV, where seeds are placed in floating sacks and allowed to disperse as they float on waves (ESA PWA 2012).

Figure 2.6: *Rows of Spartina patens plugs transplanted into an eroding sand bar in Maryland, USA*

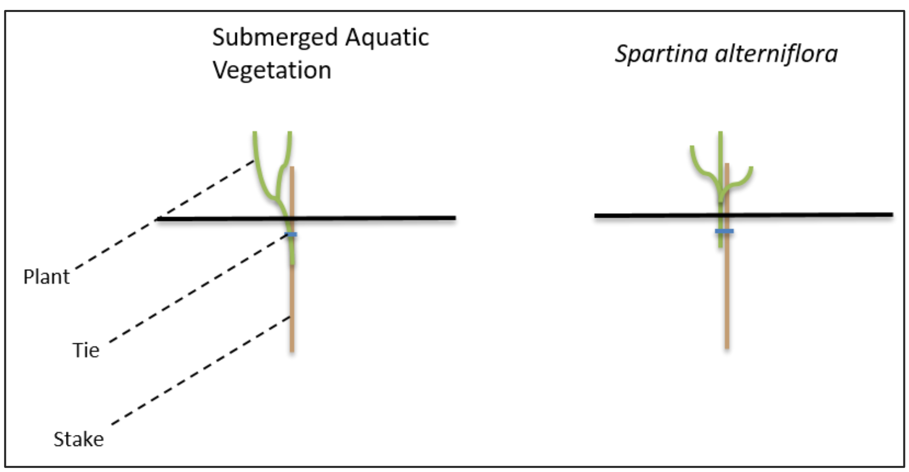

Figure 2.7: *A method of vegetation addition for plugs in the intertidal and subtidal zones, here call the staking method and shown using submerged aquatic vegetation (e.g., Zostera marina) and Spartina alterniflora plugs*

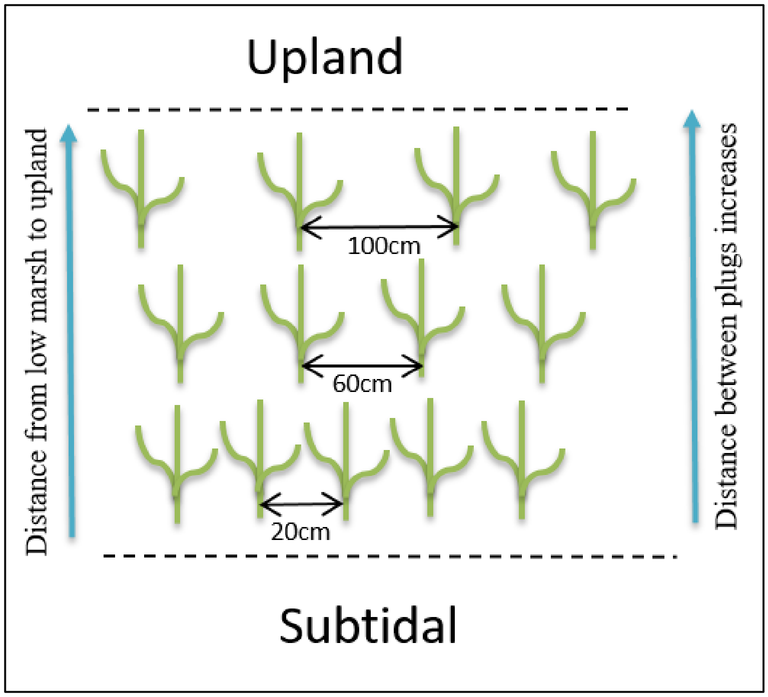

Figure 2.8: *A scenario showing plug spacing indicating as you move from the end of the intertidal zone, to the upland transitional zone, spacing increases*

2.2.4 Vegetation addition: upland planting

It is important to remember that upland planting within the terrestrial zone can also be used as a component of a living shoreline to mitigate issues from upland influences, this area is above the coastal zone, but can have impacts for areas below such as fresh water inputs, storm water runoff, soil slumping and erosion. Upland vegetation serves several purposes such as capturing run off, stabilizing the slope crest, and securing soil on the cliff face (NOAA, 2014). This uses general landscaping practices for planting upland vegetation, and newer methods such as rain gardens, buffer zones and channels, can be used to capture and remove runoff (Davis, 2009). Plant selection for upland planting is again important, as plants with varied, dense root masses work best at anchoring soils, as well in coastal areas, need to be salt tolerant (MDE, 2008; NRPC, [No date]). Lawn grasses, which are often used in conjunction with hardened structures such as riprap, do not provide the same level of erosion mitigation, as the root systems are very shallow and the do not provide equivalent storm water or runoff filtration (GBF, 2014; NRC, 2007; Watts, 1987). A list of potential plants for use in living shoreline projects is shown in Appendix B, which is by no means a complete list, but a starting point for native plant selection for living shoreline projects. Aside from traditional landscaping methods, live staking of *Salix* spp. (willow spp.), *Alnus* spp. (alder spp.) and *Cornus stolonifera* (Red-osier dogwood) is another method of vegetation addition to a slope crest or face (Zelo et al. 2000; NRPC [no date]). This is where branches are removed, and placed into the ground directly, and are able to grow roots from these cuttings (NRPC [no date]). However, the use of appropriate techniques is extremely important, and some studies such as Zelo et al. (2000) have found

50-70% mortality of stakes with bad technique. The size, species and elevation are all important characteristics to evaluate when using live staking. For example, it is not advisable to stake *Salix* spp (willow). into areas of the toe that are inundated with tidal water frequently, as willows will not be able to tolerate that much saline water.

2.2.5 Bio-logs, sills and other low-lying structures

Low-lying structures can be used to dampen wave energy, aid vegetation establishment, and to help sediment to accrete (NOAA, 2014). These can be accomplished using bio-degradable materials such as coir (coconut fiber) or burlap, or more resilient materials such as stone. These structures are used in higher energy systems, where added protection is needed for vegetation and soils (MDE, 2008). Using structures to create hybrid living shorelines are very common, as sills have comprised almost half of all living shoreline projects completed in the U.S. (Chesapeake Bay Trust, 2014; Fear and Bendell, 2011). These structures should not impede water flow or movement of fish or fowl, and this can be addressed by adding gaps or staggering placement (MDE, 2008). Debris materials, such as sticks or logs, can be used in a similar way to protect against wave energy and capture sediment (Zelo et al. 2000). Offshore structures such as oyster balls and reefs can help to break waves before they reach the shore, and can also be used to create habitat for oysters, muscles, and barnacles (Currin et al. 2009).

Bio-logs

Bio-logs, or coir logs, are made of biodegradable fabrics such as burlap or coconut fiber (coir) and are meant as temporary structures that biodegrade over time (in approximately 5 years) (GBF, 2014; NOAA, 2014; Pilkey et al. 2012). These structures are best suited in low to medium energy environments (less then 5km of fetch) and can be placed parallel to the shore to act as a wave break or stabilize the toe of a cliff (GBF, 2014; NOAA, 2014). They are often filled with soil or sand, and transplants of appropriate vegetation can be planted into the tops, as shown in Figure 2.9, which will allow roots to further secure the bio-logs to the ground (Gianou, 2014; GBF, 2014). The logs need to be secured into place, wood or bamboo stakes are a good option as opposed to rebar, as they are natural material and will biodegrade over time as well (Figure 2.9).

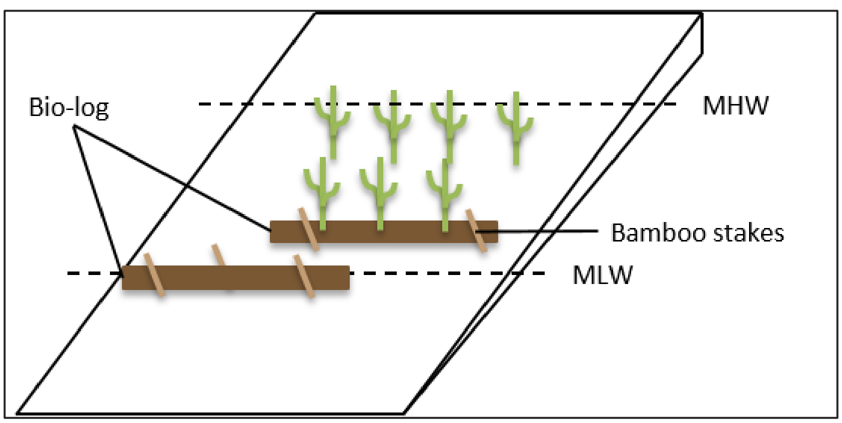

Figure 2.9: *A common use of bio-logs in the intertidal, transitional and upland zones, with and without the addition of plant material*

Sills

Sills are commonly used throughout living shoreline projects in the United States, where over half of constructed living shorelines included sills (Gittman et al. 2015; Fear and Bendell, 2011; COPRI 2014). These low-lying stone structures are placed parallel to the shoreline in medium to high-energy systems, and can be continuous or gapped (segmented) structures that allow water and organisms to flow freely through (NOAA, 2014; Bilkovic and Mitchell, 2013; Currin et al. 2009; MDE, 2008) (Figure 2.10). Sills may have a net positive ecological benefit (as opposed to using only traditional hardened structures like stone revetments or riprap), as they have a smaller ecological foot print then traditional structures, are able to be colonized by filter feeding epifauna and can allow for higher abundances of fishes and biomass (Gittman et al. 2016; Bilkovic and Mitchell, 2013; van Loon-Steensma and Slim, 2013). Sills are constructed of stones stacked on top of each other, in a line or pyramid shape, and are held together with rebar or wire (GBF, 2014) (Figure 2.11). It is recommended that the sills do not crest more than 30 cm above MHW, and the structure should not be placed directly on the marsh (MDE, 2008). Biodegradable fabrics can be used under sills and other structures to minimize sediment displacement and sinking (NOAA, 2014; MDE, 2008). Sills are most commonly used in conjunction with marsh planting to protect existing marsh vegetation and further capture and secure sediments behind sills (Currin et al. 2009).

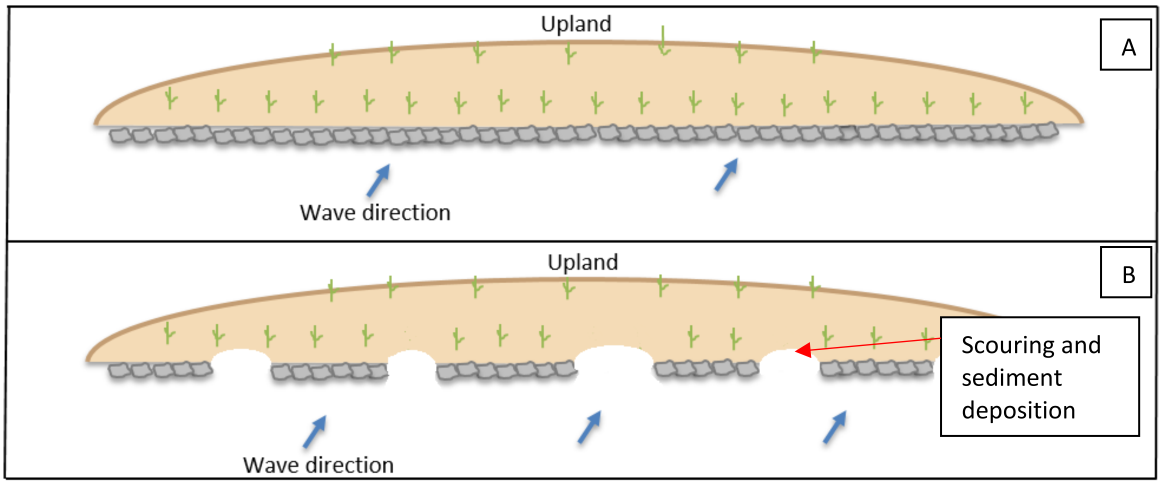

Figure 2.10: *A) A continuous still showing the wave energy striking the sill instead of the foreshore marsh or dune. B) segmented sill showing wave energy striking the sill, but also allowing water (and some wave energy) to flow through to the shore, and areas where there would be scouring and sediment deposits.*

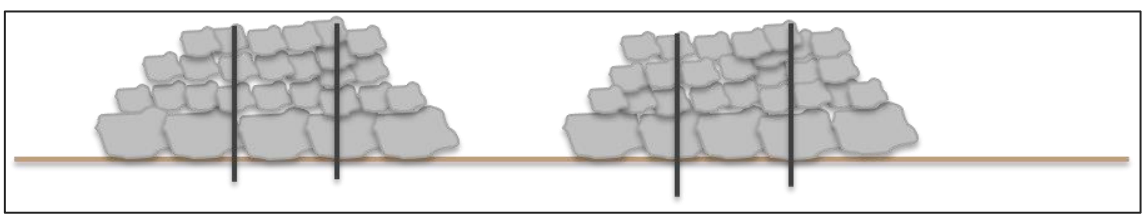

Figure 2.11: *Showing the construction of a gapped sill using stacked rocks, and rebar placed through the sill and into the ground for support*

Debris

Debris material is placed along shorelines, similar to bio-logs or sills, and is secured in place using wooden stakes, bamboo or rebar (Gianou, 2014; Zelo et al. 2000). The debris can be bundled up, fastened and placed in areas of the shore where extra protection is needed, for example, along the toe of a cliff, or on terraces on the cliff face (Zelo et al. 2000). Using debris typically composed of sticks, trees, *Salix* spp., *Alnus* spp. and man-made materials such as tires, act as a wave brake, help retain sediment (especially on sandy beaches), compact soils and disperse wave energy (Zelo et al. 2000; Gianou, 2014). Debris may also carry live plant material (e.g., *Salix* spp., *Alnus* spp.), rhizomes and seeds, which may aid in vegetating surfaces where they are placed, as sediments build up and conditions become more favourable (Zelo et al. 2000; Gianou, 2014).

Oyster Reefs

Oyster reefs and domes provide a wave break similar to other structures such as sills and breakwaters, but can also add an element of habitat creation for epifauna such as oysters (Manis et al. 2015; GBF, 2014; Pilkey et al. 2012; Currin et al. 2009). These methods have been implemented in Nova Scotia in 2012 to mitigate wave energy and create habitat (Clean Foundation [No Date]). Oyster structures can be used in medium-high energy systems where more significant wave energy dissipation is needed (NOAA, 2014; Currin et al. 2009). The level of wave attenuation can be significant when paired with other living shoreline methods such as vegetation addition (Manis et al. 2015). These structures are installed below the MHW line, with the top cresting above the water (Latta and Boyer, 2012; Pilkey et al. 2012). There are many options when considering using oysters as a structural material. For example, oyster shells (or crushed oyster shells) can be mixed with cement and rocks to create breakwaters or riprap (Figure 2.12.A) (GBF, 2014; Latta and Boyer, 2012; NC, 2012). When constructing cement oyster reefs, 80% sediment from the area and 20% oysters, is what is recommended from the San Francisco Bay project (Latta and Boyer, 2012). Using dome shaped structures (oyster balls) is also common, and work in the same way as a reef (Figure 2.12.B). Reef balls are hollow and allow the recruitment of oysters and other epifauna such as barnacles and muscles (Latta and Boyer, 2012, 2012; Pilkey et al. 2012). In another example, Manis et al. (2015) used a mesh mat with adult oysters attached vertically, which are placed in the low-mid intertidal zone (Figure 2.12.C). These structures should be placed on biodegradable fabrics, such as coir or permanent mats to reduce settlement into substrate (Latta and Boyer, 2012; Manis et al. 2015).

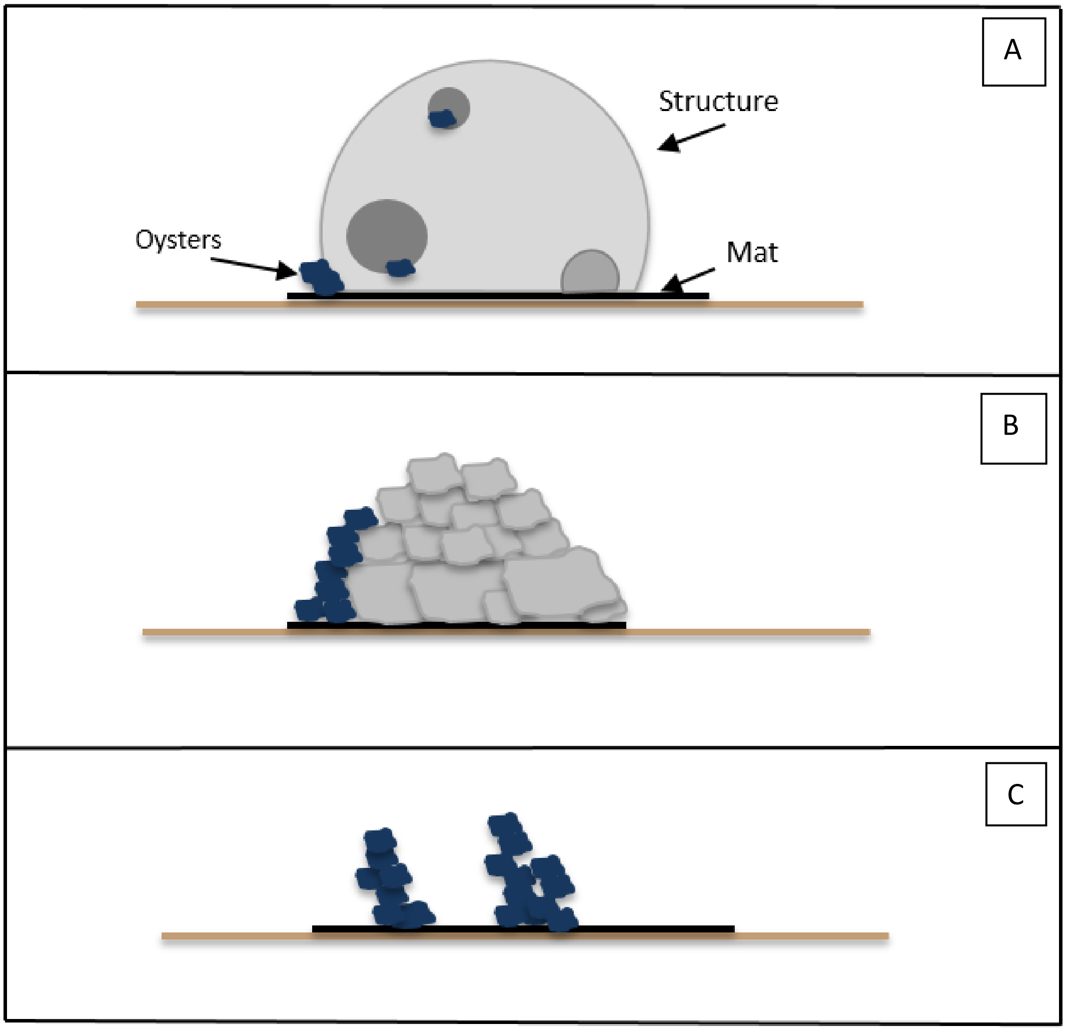

Figure 2.12: *A) An oyster reef ball showing oyster attachment in dark blue B) a living sill with oyster habitat C) mats of oysters with no rock material used*

2.2.6 Large structures: breakwaters, rip rap and other offshore structures

Higher wave energy systems often require larger, more engineered offshore structures to dissipate wave energy, help to mitigate erosion of existing or newly created shorelines, and help protect habitat (GBF, 2014). When constructing offshore structures, the following should be taken into account: substrate type, e.g., do you need to use a mat underneath; construction material, e.g., concrete can be affected by high salinities; shape (e.g., higher energy should use pyramid shape so it does not fall over) and height (waves can crest, or not, cresting allows for water movement over sills, but still dampens wave energy) (GBF, 2014).

Caution needs to be used to ensure that structures allow for the flow of birds, benthic and nekton communities into and out of intertidal habitat (Gittman et al. 2016). Structures such as groins and jetties can be used in conjunction with living shoreline methods such as beach nourishment, where they are used to capture sediment, but should only be used when sediment budget and flow are taken into account, as to minimize sediment starvation of other adjacent areas (Gianou, 2014). It is strongly recommended to seek consultation with a qualified engineering and hydrological professionals prior to building any "engineered" structures, as they are much more complicated to build and can catastrophically fail if not constructed correctly.

2.3 Monitoring and maintenance

There is minimal literature on the monitoring and maintenance for living shoreline projects. Completed living shoreline sites need monitoring and maintenance in ordered to determine success and as well to evaluate different techniques applied. Depending on what the desired outcome of the living shoreline site is (e.g., erosion control or habitat creation) this will determine the methods and length of monitoring. Monitoring for a minimum of 3 years will ensure that vegetation is established, and benthic communities are thriving according to Gittman et al. (2016). Gianou (2014) recommends monitoring every 8 years for projects that have been dominated by erosion control. Based mainly on salt marsh restoration literature, depending on the scope of the project, site and design, monitoring can include different activities such as monitoring vegetation health and type, bird or fish species presence and sediment deposition (Bowron et al. 2013, Neckles et al. 2002). Maintenance can include activities such as debris removal, replanting vegetation, adding additional fill material and ensuring structural materials remain in place (NOAA, 2014; Pilkey et al. 2012; MDE, 2008).

2.4 Conclusions

Living shorelines are proving to be a competitive alternative to traditional engineered approaches to shoreline management. Discussed in this chapter are some of the more common methods that can be applied when constructing a living shoreline, but again, it is not a complete list. The methods are evolving as more groups implement the living shoreline approach, and tailor the techniques to their specific site. With this increase in popularity, an increase in living shoreline publications is already being observed, with several major publications being released in recent years. The methods discussed here, while not a complete list, should provide a snapshot of what is available to coastal zone managers, and practitioners when considering the living shoreline approach.

There are difficulties facing living shoreline practitioners in Atlantic Canada, and we face an uphill battle. In the United States, areas that have had the most success with living shorelines practices have included areas of sheltered bays such as Chesapeake Bay and San Francisco Bay, where wave energy and currents are reduced (Chesapeake Bay Trust, 2014; ESA PWA 2012; Latta and Boyer 2012). Nova Scotia and New Brunswick, for example, while do have their share of sheltered coasts, also hold significant coastline that directly face large water bodies such as the Atlantic Ocean, Bay of Fundy and Northumberland Straight. These areas would be significantly more challenging to work in, due to the environmental (e.g., proximity to direct hits from storms, increased erosion from wave and wind energy) and hydrological (e.g., strong currents and high wave energy) conditions present. Areas such as the Bay of Fundy, will be particularly difficult to construct living shorelines in, as it is a hyper-tidal system with tides ranging up to 16m and extremely strong currents in areas such as the Minas Passage, as a result this area would likely need large structural materials to support living shorelines (Archer, 2012; O'laughlin et al. 2014). As well, we face significant winter ice conditions may make newly establishing living shoreline projects vulnerable to damage and degradation (e.g., upheaval, vegetation removal, sediment removal/deposition) (Argow et al. 2009; Greene, 2009). However, projects in New England, which face similar ice conditions, have had success with methods such as planting intertidal vegetation (Ewanchuk and Bertness 2003).

However, the major hurdle we are facing in Atlantic Canada is navigating the regulatory and legislative framework for both provincial and federal approvals is something not discussed in this chapter. This is a major hurdle to completing living shoreline projects in Atlantic Canada. To date, the living shoreline projects in Nova Scotia, completed by groups such as the Ecology Action Centre and ACAP Cape Breton, have entirely worked in the terrestrial zone due to this. Until this framework is laid out, it may be difficult to construct living shorelines within the coastal zone as working within the intertidal zone is federal jurisdiction (Department of Fisheries and Oceans), land access is the responsibility of either private land owners, municipalities, provincial or federal departments such as Environment or Natural Resources, or Parks Canada. There is currently no process for practitioners to receive permits or permissions from any of these groups.

There are limitations associated with living shorelines. Firstly, is their ability to be constructed in higher energy systems without the use of structural materials (sills, breakwaters, oyster reefs), which are costly and difficult to construct (MDE, 2008). While living shoreline sites are incredibly adaptable for medium-higher energy sites, there are exceptions where hardened structures are likely more useful as vegetation may be unable to establish without additional protection in high-energy environments (Bruno 2000). However, it is important to reiterate that they can be used in conjunction with living shorelines as hybrid living shorelines. Hybrid living shorelines, such as a marsh-sill combination, may still incur some negative impacts such as a possible reduction in bioturbation, the disturbance and mixing of sediments, and (undetermined) impacts on certain nutrient cycles and oxygenation of the area (Bilkovic and Mitchell, 2013) Few studies have focused on the use of hardened structures in living shorelines (i.e., sills) (Bilkovic and Mitchell, 2013). However, there are still more positive impacts of using a hybrid living shoreline as opposed to traditional engineered structures.

A major hurdle to living shorelines, however, is the lack of quantitative data on how to properly construct living shorelines. This gap within literature should be a concern to practitioners interested in constructing living shorelines, as they are required to rely on incomplete science, and not fully understanding the difficulties and limitations of using certain methods. There has been minimal peer-reviewed studies comparing the benefits of living shorelines, in terms of ecosystem services and functions, as compared to hardened shorelines or natural (unaltered) shorelines. As well, data surrounding the success of living shoreline projects is almost non-existent, and while some methods such as planting intertidal vegetation can be inferred from salt marsh restoration literature, the success of methods such as, the use of bio-logs or debris, are not well documented.

Chapter 3: Storage, Germination, and Field Establishment of *Spartina* Species for Living Shorelines

3.1 Introduction

One of the prevailing techniques used in living shoreline projectsis the addition of plant material to a marsh surface, sand flat or intertidal zone (Fang et al. 2004; Rozas and Minello, 2001; Minello, 2000). The initial step to growing transplant plugs for use in these projects is to understand the best methods to both store and germinate seeds of the targeted species, of which there are many biological and environmental variables that may impact success. Having the ability to keep seeds in long-term storage allows for access to large quantities of viable seeds for larger projects, including use for both the direct placement of seeds and growing viable seedlings (plugs) (Esley-Quirk et al. 2008; Fang et al. 2004). How these species are stored has the potential to impact germination rates, and there is variability within the literature on the best method to store seeds. As well, there is genetic variability in different geographical populations which may impact germination rates, seed and seedling characteristics (Fang et al. 2004; Chung et al. 2004, Esley-Quirk et al. 2008). Fang et al. (2004) suggests that *Spartina* spp. seed germination is highly variable and can be dependent on the geographic population that seeds were collected from.

The physical and environmental variables that may impact germination rates (in a controlled setting such as a greenhouse) can include (but not limited to); the need for stratification, use of saline or fresh water when storing and germinating (as a potential stratification process needed to break dormancy), soil type, and length of time to germinate

(Deng et al. 2009; Chung et al. 2004; Bruno, 2000; Cordazzo, 2001; Callaway and Josselyn, 1992). Storage of seeds wet or dry has been studied quite extensively throughout *Spartina* spp. literature, and studies such as Chung et al. (2004), Bruno (2000), and Callaway and Josselyn (1992) have shown that *Spartina* sp. germinate significantly better when stored wet. This would simulated natural germination conditions for many halophytic species, which spend a significant amount of time wet. Testing the success of germination between the three dominant native *Spartina* species (*Spartina alterniflora, S. patens, S. pectinata*) will allow us to determine what species are viable for growing plugs or direct seeding, and which are better suited as transplants from existing marshes. This is particularly important in Atlantic Canada where currently there are no suppliers of halophytic vegetation. Understanding how these plugs and seeding methods function in our unique climate will aid in the further development of living shoreline projects.

Natural re-colonization of a marsh, mud or sand flat can be very low when compared to the addition of vegetative material through methods such as direct seeding and transplanting vegetation (Bergen et al. 2000) Bergen et al. (2000) suggests that *S. alterniflora* has difficulty recolonizing on restored and remediated tidal flats where they are susceptible to high levels of erosion and predation. A common method of vegetation addition used in many natural shoreline management projects, such as active restoration, creation and living shorelines, is the addition of plant material through a variety of methods such as direct placement of seeds and transplants (plugs). This added plant material helps to facilitate plant community development, consolidate soils and enhance ecosystem services and functions such as, buffering from wave energy and storm surge (Bergen et al.

2000; Bruno, 2000). Added plant material typically includes transplants that are grown from seed (plugs) or transplanted from adjacent areas, directly seeding surfaces, and burying wrack material, which is normally full of abundant and varied seeds and propagules (Glogowski, 2013; Utomo et al. 2010; Minchinton, 2006; Fang et al. 2004; Anastasiou and Brooks, 2003; Leck 2003; Huckle et al. 2002; Rozas and, 2001; Minello, 2000).

Eastern North American salt marshes are dominated by *Spartina* species, commonly *S. alterniflora, S. patens and S. pectinata* (Konisky and Burdick 2004, Anastasiou and Brooks 2003, Fang et al. 2004). These three species are dominant, but co-occur with other common salt marsh species including *Juncus gerardii, Plantago maritima, Salicornia depressa* and *Sueda maritima* (Mittelhauser et al. 2010). In a natural environment, *Spartina* spp. are known to follow elevation and salinity gradients, where *S. alterniflora* is found in the harsh low marsh and able to withstand higher inundation periods, salinities and wave conditions and act as an ecosystem engineer adapted to grow in a variety of substrates; and *S. patens* is found dominantly in the middle (or high) marsh zone as sediment, inundation and wave condition become more favorable for establishment (Porter et al. 2015; Konsky and Burdick, 2004; Bruno, 2000). *Spartina pectinata* is generally found in extreme high marsh and upland or brackish transitional zones (Porter et al. 2015; Gedye et al. 2012; Kim et al. 2012). However, these species can have considerable overlap with in the zones (Porter et al. 2015). For example, *Spartina patens* can be found in both the mid-marsh along with *S. Alterniflora* in low marsh transition zone or with *J. gerardii* in a high marsh transition zone. (Porter et al. 2015, Anastasiou and Brooks 2003, Wilson et al. 2001, Callaway and Josselyn 1992, Bertness 1999, Cranford et al.1989,).

More specifically, *Spartina alterniflora* is an erect grass that grows in single stands and acts as pioneering species on eastern North American salt marshes, where it can modify habitats to facilitate the development of salt marsh plant communities (Stammerman and Piasecki, 2012; Gedan and Bertness, 2009; Konsikey and Burdick 2004; Huckel et al. 2002; Bruno, 2000; Wilson et al. 2007). *Spartina patens*, a finer hay like grass, has historical importance from use on Acadian dykelands, such as use for sod when building dykes, as well as harvesting for hay (Bleakney et al. 2004). *Spartina pectinata* is an erect grass that is the tallest of the three species and grows in single stands similar to *S. alterniflora* (Gedya et al. 2012). *Spartina alterniflora* and *S. pectinata* have both been explored for their use in carbon sequestration and as biofuel crops, as they produce large amounts of biomass (Gedye et al. 2012; Boorman and Ashton, 1997; Moy and Levin 1991). The flowering times and seed production of the three species vary both annually and geographically, with most populations flowering in the late fall (Fang et al. 2004; Anastasiou and Brooks, 2003; Wilson et al. 2001).

Transplantation of live plants is a common method to add vegetation to the coastal zone. These can be grown from seed into plugs, if the facilities to do so are available, or transplanted directly from adjacent marshes (Konsky and Burdick, 2004; Anastasiou and Brooks, 2003). Using transplants from surrounding areas (termed adjacent transplants), allows for transplants to be used when there are no nursery plants available (Konsky and Burdick, 2004). Anastasiou and Brooks (2003) suggests using plants from within a 160 km radius to promote genetic homogeneity, and also to assure that the plugs are not accustomed to a different set of environmental conditions. While this is an efficient way to add vegetation, the seedlings can be susceptible to transplant shock, up-rooting and removal from wave action and damage from human impacts such as trampling (MDE, 2008; Anastasiou and Brooks, 2003; Bruno, 2000). Seed placement (direct seeding), is another method of adding vegetation, where seeds are placed on the surface, or buried, and allowed to germinate (Utomo et al. 2010; Fang et al. 2004). Seeding can prove to be problematic as tidal energy may remove seeds as the tides ebb and flow, and newly germinated seedlings are susceptible to high rates of mortality and removal.

3.2 Research objectives and hypotheses

This research focuses on Nova Scotia due to the availability of study sites, however still has implications for other areas in Atlantic Canada. The project evaluates the different techniques of storage and germination of *Spartina* spp. seeds for plugs and direct seeding, to be used in natural shoreline management projects such living shorelines or active restoration projects . As well, this project will evaluate which methods of vegetation addition show the highest rates of survival on two field sites (Eastern Passage and Lawrencetown Lake) over a growing season, until the time of peak biomass, where we expect a reduction in growth (Cranford et al. 1984).

The following objectives were identified:

1. Determine the best method(s) to store (frozen or cold) quantities *of S. alterniflora, S. patens and S. pectinata* seeds to produce the highest germination rates.
2. Determine the best method (transplants, seeding and wrack burial) to establish vegetation growth along shorelines.

3. Determine if a *S. patens* community can be established at the Eastern Passage- *S. patens* study site, due to the lack of *S. patens* community at that site.
4. Determine if elevation gradients (relative to sea level) play a major role in survival of seedlings and plugs.

The following hypotheses were evaluated:

1. Freezing seeds and germinating in salt water will increase germination rates of the three species because it simulates natural environmental conditions (winter conditions and saline water) for these species.
2. Plugs (both grown plugs and transplants used from the sites) of *S. alterniflora* and *S. patens* at both sites will perform better than direct seeding and wrack germination.
3. Survival of plugs and seedlings will be highest in the elevational zones where they are found in the natural environment.
4. Physical (elevation, fetch, seed source) and biological (interspecific competition) will be limiting factors on the survival rates *S. patens* transplants and seedlings at the Eastern Passage- S. patens site.

3.3 Methods

3.3.1 Storage trials

Seed collection

To capture genetic and phenotypic differences in populations, I collected seeds on both the Atlantic and Bay of Fundy coasts in Nova Scotia, Canada, between Oct 1st and Oct

20th, 2014. Rainbow Haven Beach and Conrad's Beach contain two salt marshes that lie on the Atlantic Ocean (Figure 3.1). Both sites were observed to be dominated by *S. alterniflora*, with smaller populations of *S. patens* and *S. pectinata*, as well as other halophytes such as *Limolium nashii* and *Salicornia depressa.* On the Bay of Fundy coast, Windsor salt marsh and Cogmagun salt marsh were used for collection (Figure 3.2). Windsor salt marsh was observed to be dominated by populations of *S. alterniflora* and *S. patens,* as well as small patches of *S. pectinata*. Cogmagun salt marsh lies on the Cogmagun river, and is dominated by *S. alterniflora*, *S. patens*, *Juncus gerardii* and *Carex paleacea.*

I targeted three common salt marsh species for collection, *S. alterniflora*, *S. patens* and *S. pectinata*. Seed heads were checked regularly from early September until the time of collection in October, to determine when seed sets were ready for collection as this can vary year from year, and geographically as well (Fang et al. 2004; Callaway and Josselyn, 1992; Mobberley, 1956). To collect the seeds, I cut the seed heads off the stalks on site and placed them in pre-labeled bags. Upon returning to the Ecology of Plants in Communities Laboratory at Saint Mary's University, seeds were washed in tap water to remove sediment and sprayed with a 5% concentration of Safer's Defender Garden fungicide (USA), to reduce mold (Fang et al. 2004; Li et al. 2010). Seeds were stored damp (approximately 10 ml of water) in a standard refrigerator at 3-4^{o}C until sorting and counting took place approximately 4 days later (Fang et al. 2004), approximately 1500 seeds of each species were collected in this process.

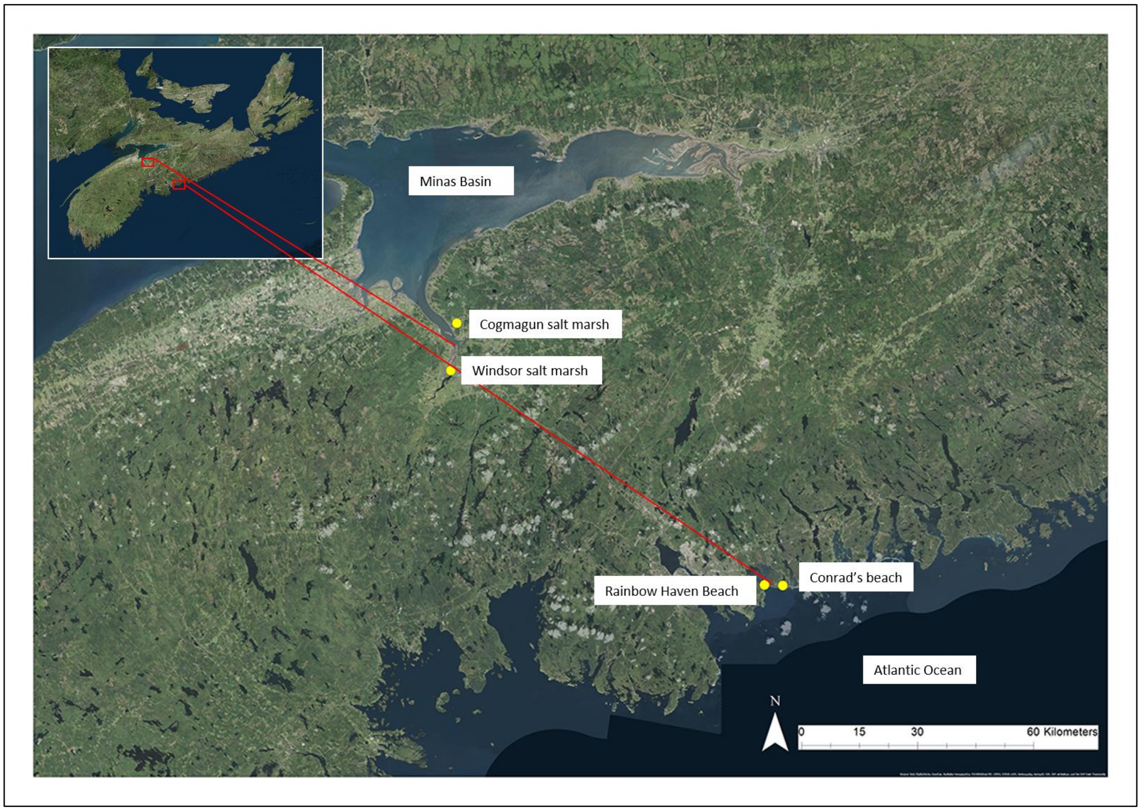

Figure 3.1: *Seed collection sites along the Atlantic and Bay of Fundy Coasts, Nova Scotia, Canada*

Figure 3.2: *Seed collection site at Rainbow Haven, Spartina alterniflora pictured*

Storage treatments and germination

I used two storage treatments for each species, storage cold in a refrigerator at 3-4^{o}C, and frozen in a (standard) freezer at -8^{o}C. For each species 640 individual seeds were counted out, half of these went into frozen storage, and half into cold storage for 2.5 months to simulate winter conditions. Once the 2.5 months had passed, seeds removed from storage and allowed to thaw for 12 hours before being placed into germination treatments; salt (1% NaCl) and fresh (tap) water (Fang et al. 2004).

Seeds were placed into 4 treatments for germination:

- *Frozen seeds germinated in tap water*
- *Frozen seeds germinated in salt (1%) water*
- *Cold seeds germinated in tap water*
- *Cold seeds germinated in salt (1%) water*

For each of the four treatments, 20 seeds from each species were placed into separate petri dishes, lined with two layers of Whatman (90 um) filter paper, and 8 replicates were used for each treatment. Seeds were placed into the growth chamber at Saint Mary's University (25^{o}C, 40% relative humidity) until germination began (Elsey-Quirk et al. 2008; Cordazzo, 2001) (Figure 3.3.A). Seeds remained in the growth chamber for 35 days from March 8th- April 11th, 2015. Once radicles reached 3 cm and coleoptiles reached 0.5 cm I removed the seeds and stored them in the greenhouse where they were kept alive until eventual transplantation in spring 2015 (Li et al. 2010; Bruno, 2000) (Figure 3.3.B and Figure 3.3.C). I placed seedlings into pots with a mixture of 60% potting soil and 40% sand and watered daily (Figure 3.3.D). Unfortunately, due to inadequate greenhouse facilities, 95% the seedlings did not survive until planting could occur.

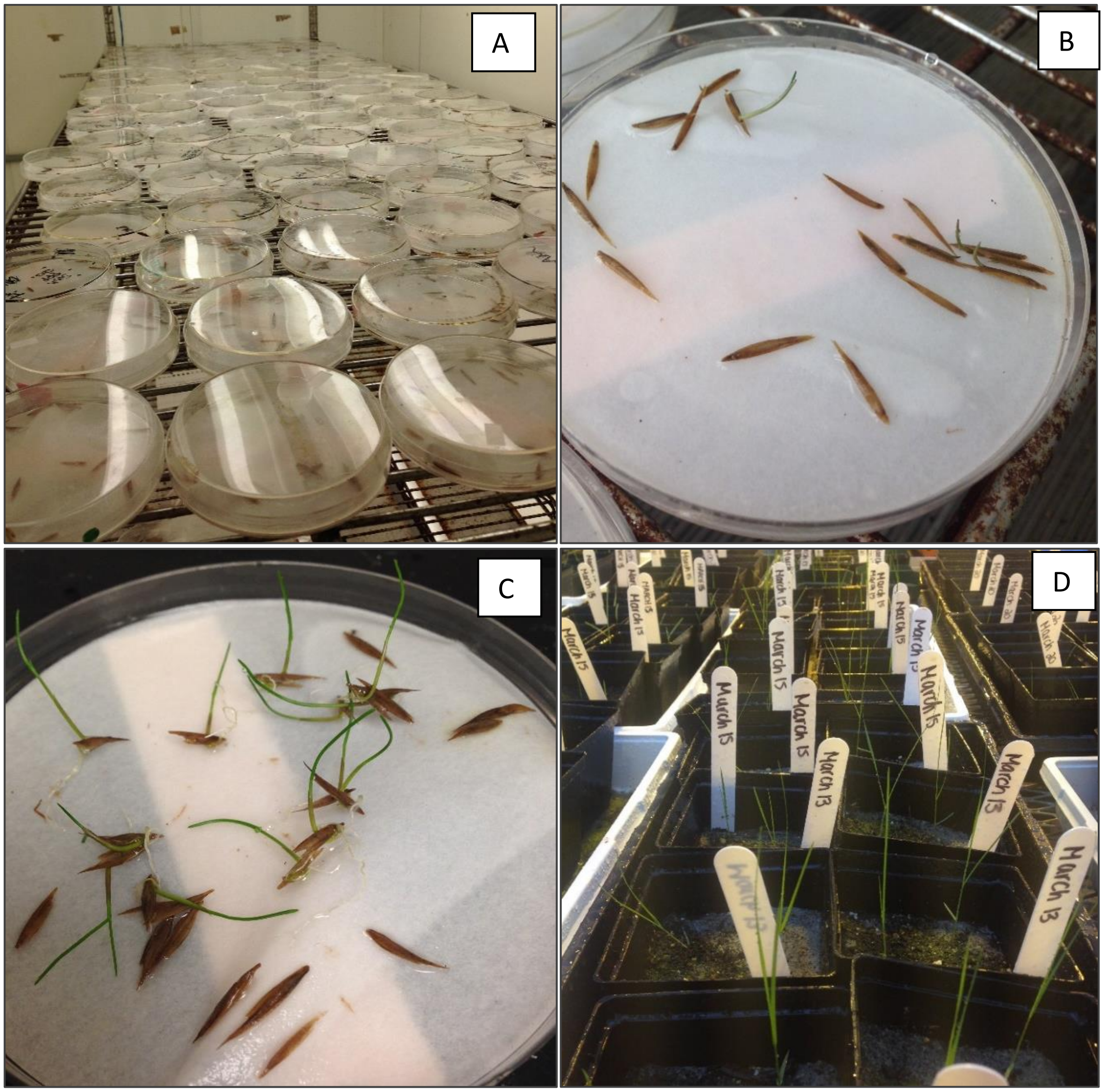

Figure 3.3: *Germination of Spartina spp. A) replicates of petri dishes in the growth chamber at Saint Mary's University; B) germinating Spartina alterniflora 10 days after going into the growth chamber C) Germinating Spartina pectinata 10 days after going into the growth chamber D) Spartina alterniflora growing in the greenhouse at Saint Mary's University, approximately 1 month after germination*

3.3.2 Field experiments

Site descriptions

Eastern Shore, Nova Scotia

Both study sites, McCormack's Beach and Lawrencetown Lake, are located on the eastern shore of Nova Scotia, Canada (Figure 3.4) with a tidal range of approximately 2m (Manson, 1999). The eastern shore faces the Atlantic Ocean, and is composed of glacial deposited till in the form of drumlins, which are readily eroding and supplying a portion of sediment to the shorelines of the area (Barnes and Piper, 1978; Wang and Piper, 1982). The eastern shore has also been found to be vulnerable to aspects of climate change and sea level rise (Carter et al. 1990; Manson, 1999). Salt marshes are a common features along the coast of Nova Scotia and are typically dominated by *Spartina* Spp. including *S. alterniflora*, *S. patens and S. pectinata* with a growing season from approximately May- September (Porter et al. 2015; Cranford et al. 1989). Not withstanding the dominance of S*partina* spp. Nova Scotia salt marshes tend to be diverse and hold a range of populations of halophytes and brackish species (Porter et al. 2015). Despite the apparent abundance of salt marshes, they have been, and continue to be, at risk from human impact (e.g., coastal development) and climate change (increased coastal flooding, erosion, warming waters, and increased invasive species). It has been estimated that Nova Scotia has lost 60% of their coastal salt marshes (van Proosdij et al. 2006; Hanson and Calkins, 1996).

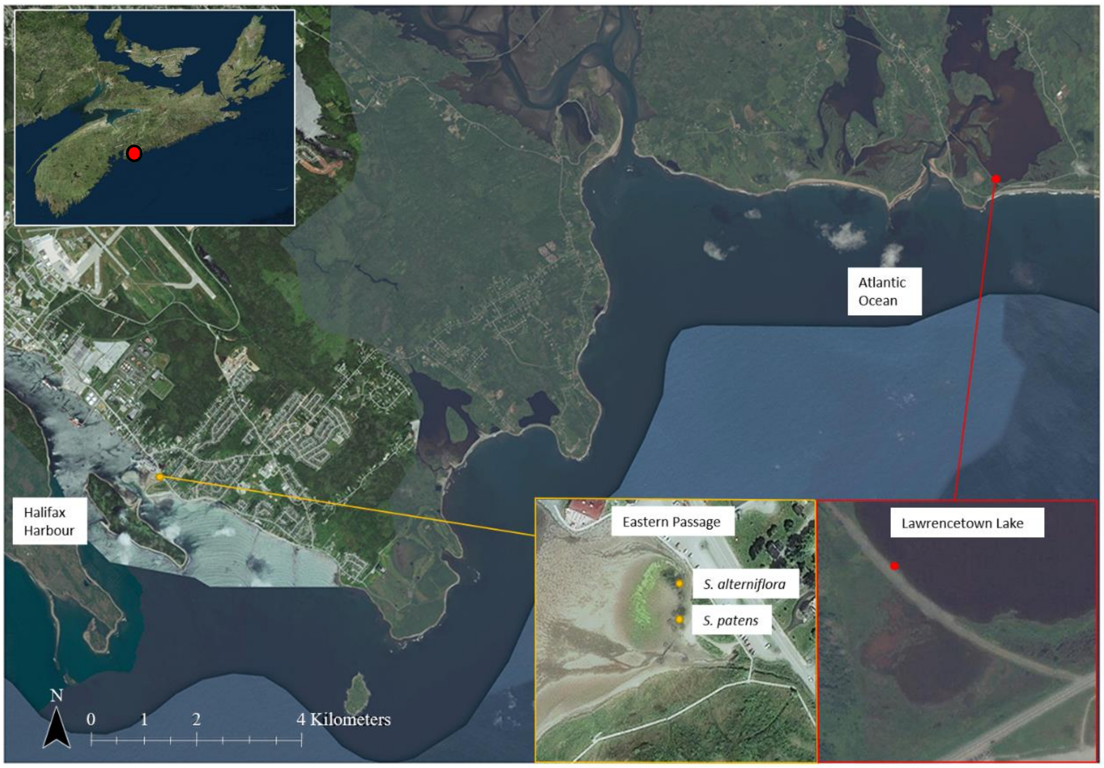

Figure 3.4: *Study sites, Eastern Passage (Spartina alterniflora and Spartina patens sites) and Lawrencetown, Eastern Shore, Nova Scotia, Canada*

Eastern Passage (McCormack's Beach), Nova Scotia

McCormack's Beach in Eastern Passage is a depositional drift aligned beach, with a large sand flat marsh, that lies in the Halifax Harbor, in the southwestern-most portion of the Eastern shore (Manson, 1999; Emerson and Grant, 1991). Lying to the West-south-west of the study site are two islands composed of eroding drumlins; Lawlor Island is composed of 3 drumlins, and McNab's Island is composed of 10 drumlins (Manson, 1999). However, Manson (1999) showed that the beach may have formed from sand eroded from adjacent Barrie Beach, after it was artificially lowered, and not from the eroding drumlins of the two islands. There are existing salt marsh and dune communities at the site, as well as a large submerged aquatic vegetation (SAV) and epifauna community (Barrell and Grant, 2015). *Spartina alterniflora* is observed to be dominant in the tidal low marsh area, with patches of *Sueda maritima*, and *Raphanus raphanistrum* in the mid marsh zone. In the dune habitat *Ammophila* spp. dominates, with a mix of *Lathyrus japonicus* and *Rose* sp. There is no *S. patens* community on this marsh. This area has a relatively small fetch (average fetch is approximately 800m) due to Lawlor and McNab's islands cutting off the fetch, and normally very protected against wave energy except in North-west winds (Emerson and Grant, 1991). Human impact at this site is observed to be very high, where people frequent it for recreational use (Figure 3.9). McCormack's beach is a public access beach with a popular boardwalk, picnic area and clam digging sections, and the area of Fisherman's Cove (adjacent to the site) is a thriving fishing community. As well, the area has been subject to sewage outflows, which is a continual ongoing problem when sewage treatment plants bypass processes during heavy rain events (Auld, 2009).

There are two experiment sites at McCormack's beach which, for the field trials, have been designated Eastern Passage- *S. alterniflora* plots and Eastern Passage- *S. patens* plots (Figure 3.5). The Eastern Passage- *S. alterniflora* plots are low marsh and dominated by only *S. alterniflora* and the Eastern Passage- *S. patens* plots are located in a mid-high marsh area with a mix of *S. alterniflora* and high marsh/upland species (there is no *S. patens* present at the site). This was done so that both *S. alterniflora* and *S. patens* could be used at this site. The average fetch at this site is 0.9km (low wave energy), except in the northwest direction where the fetch is much longer at 8.7km (high wave energy). Both study sites are located behind existing vegetation to further reduce any exposure to wave energy, and therefore minimizing the adverse impact of wave energyat both sites within McCormack's Beach. However, there is an evident current when the tide ebbs and flows that lies to one side of the plots (Figure 3.5)

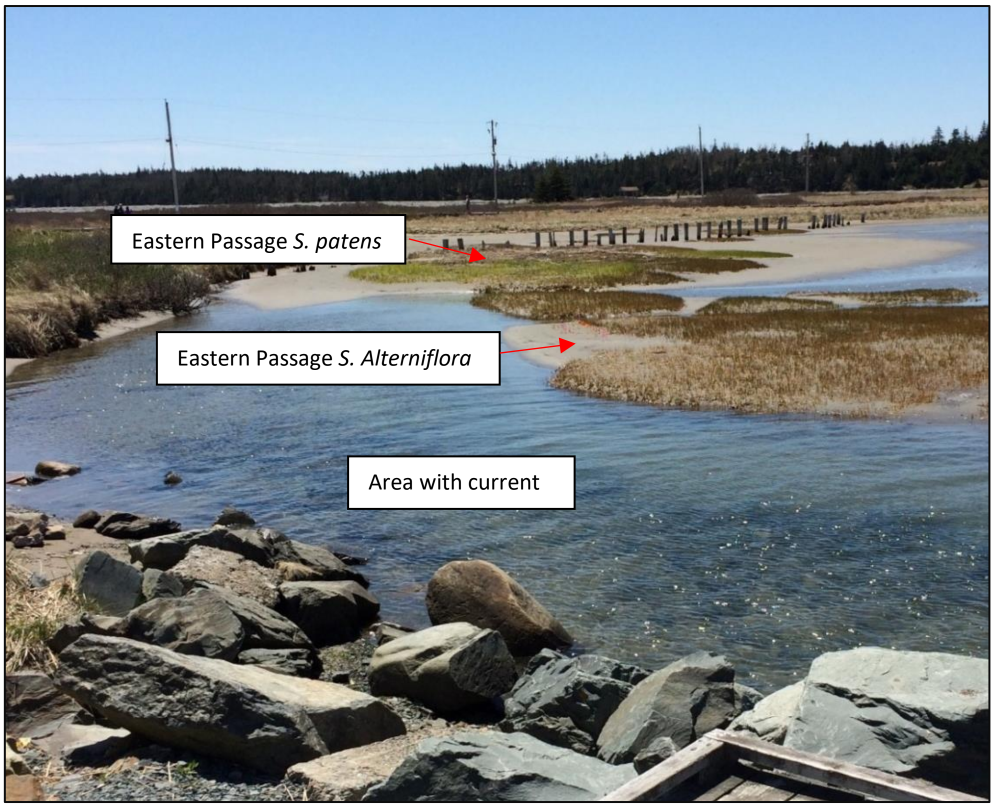

Figure 3.5: *Eastern passage showing the location of both the Spartina alterniflora and Spartina patens plots. Pictured here is also the extent of the existing vegetation*

Lawrencetown Lake, Lawrencetown, Nova Scotia

Located along Route 207 (Marine Drive) in Lawrencetown, Halifax County, this study site lies on the South-west end of Lawrencetown Lake (Figure 3.4). The site is part of a large tidal salt marsh system that extends around most of the edges of Lawrencetown Lake. Located to the west of the site is a large drumlin and quarry (Bowron et al. 2013). Adjacent to the study site is a previous salt marsh restoration project completed by Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) and CB Wetlands & Environmental Specialists (CBWES Inc.) in 2007 (Bowron et al. 2013). To the south of the site lies Lawrencetown Beach, a sandy dune system that faces the Atlantic Ocean and Route 207. Vegetation in the area follows the typical salt marsh species zonation, and is dominated by species such as, *S. alterniflora, S. patens, J.* g*erardii, Carex paleacea* and a mix of upland species including *Rose spp*., *Raphanus raphanistrum, and Daucus carota* (Bowron et al. 2013). The soils at this site were observed to be more fibrous and composed of peat, in contrast to the sandy sediment found at Eastern Passage. Despite being located directly adjacent to a heavily used trail system, human impact at this site is significantly less than at McCormack's Beach at Eastern Passage, as accessibility is difficult due to large boulders and minimal exposed shoreline. There would be some direct freshwater influence from this trail system, as it sits at a higher elevation and rainwater would run off onto the marsh surface below.

The site was divided into 5 small microsites all of which lie along a narrow, exposed shoreline (Figure 3.8), and are dominated by only *S. alterniflora*. Elevational profiles could not be created for this site as measurements were not taken in lines, asat the Eastern Passage sites, because the vegetation community at Lawrencetown was very disjointed. Average fetch was also much larger at Lawrencetown Lake then at Eastern Passage at approximately 1.8 km placing it into the high wave energy zone (Table 1).

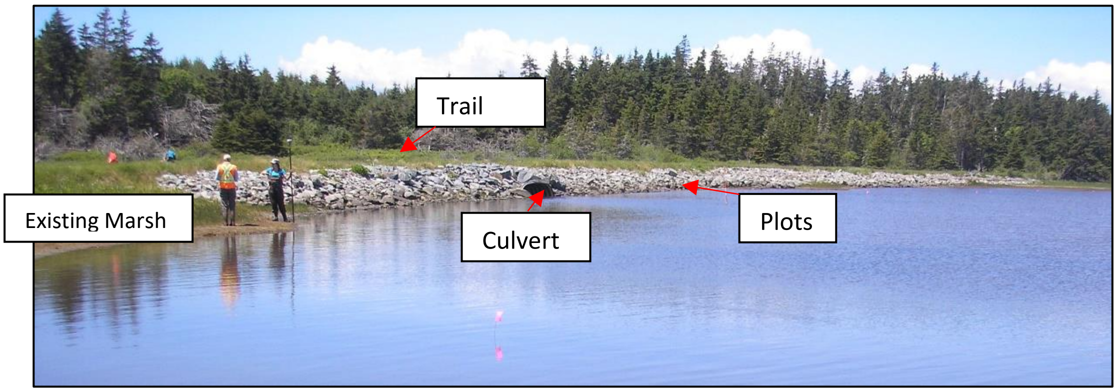

Figure 3.6: *Lawrencetown Lake, showing the existing culvert and plot location (at high tide)*

Treatments

To add vegetation to each of the sites, a mix of four treatment types were used: plug transplants, adjacent transplants (collected locally at both sites), seeds and wrack material. A mixture of Atlantic and Bay of Fundy *S. alterniflora* transplants were initially expected to be used, however at the time of planting, only transplants grown from Atlantic seeds were large enough to use. Using the staking method outlined in Latta and Boyer (2012), seedlings were attached to wooden skewer sticks at the base of the stem using paper twist ties (Figure 2.7). The skewer sticks were placed in the ground along with the root mass to anchor the seedling. For direct seeding and burial of wrack material, a hole was dug, 20 cm deep for seeds, and 30 cm for wrack material, seeds and wrack were placed in the hole, and sediment replaced on top.

3.3.3 Site Setup

Eastern Passage

There were two microsites at Eastern passage, the Eastern Passage- *S. alterniflora* site, and the Eastern Passage- *S. patens* site (Figure 3.5). A 20 by 20 cm quadrat was used at both the Eastern Passage *S. alterniflora* and *S. patens* sites. The quadrat was placed in unvegetated areas, and a wooden dowel was used to mark the location. A designated treatment was assigned to each plot. This was done using a randomized design for the 4 treatments. A total of 20 plots were used at the Eastern Passage- *S. alterniflora* plots (Figure 3.9). At the Eastern Passage- *S. patens* plots, the same method was used for 10 plots (Figure 3.10).

The type of treatment for each plot at Eastern Passage- *S. alterniflora* site is shown in Figure 3.11. There were four treatments applied to the plots: greenhouse grown plug transplants (plug transplants), adjacent transplants, seeds and wrack burial. The type of treatment for each plots at Eastern Passage- *S. patens* plots is shown in Figure 3.12, where there were two treatments applied to the plots: plug transplants and seed placement. Transplant (plug and adjacent) plots had 9 plants per quadrat spaced in rows of three. Seed plots had approximately 200 pre-weighed seeds per plot buried 5 cm below surface, with the sediment packed down loosely. Wrack plots had enough wrack material to fill each quadrat buried 10 cm below the surface with sediment loosely packed on top.

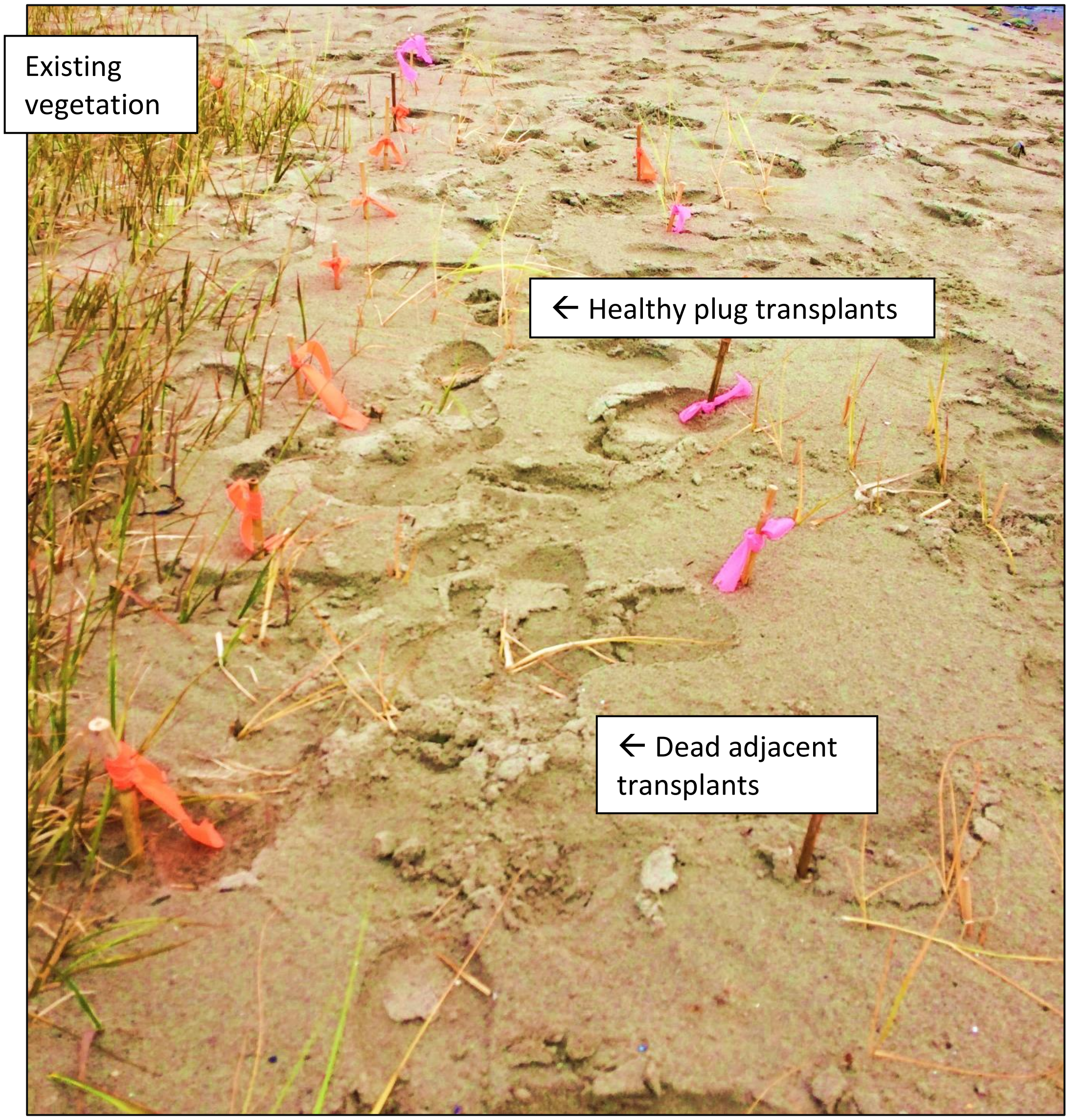

Figure 3.7: *The 19 Eastern Passage- S. alterniflora plots also showing human impact at site (foot prints)*

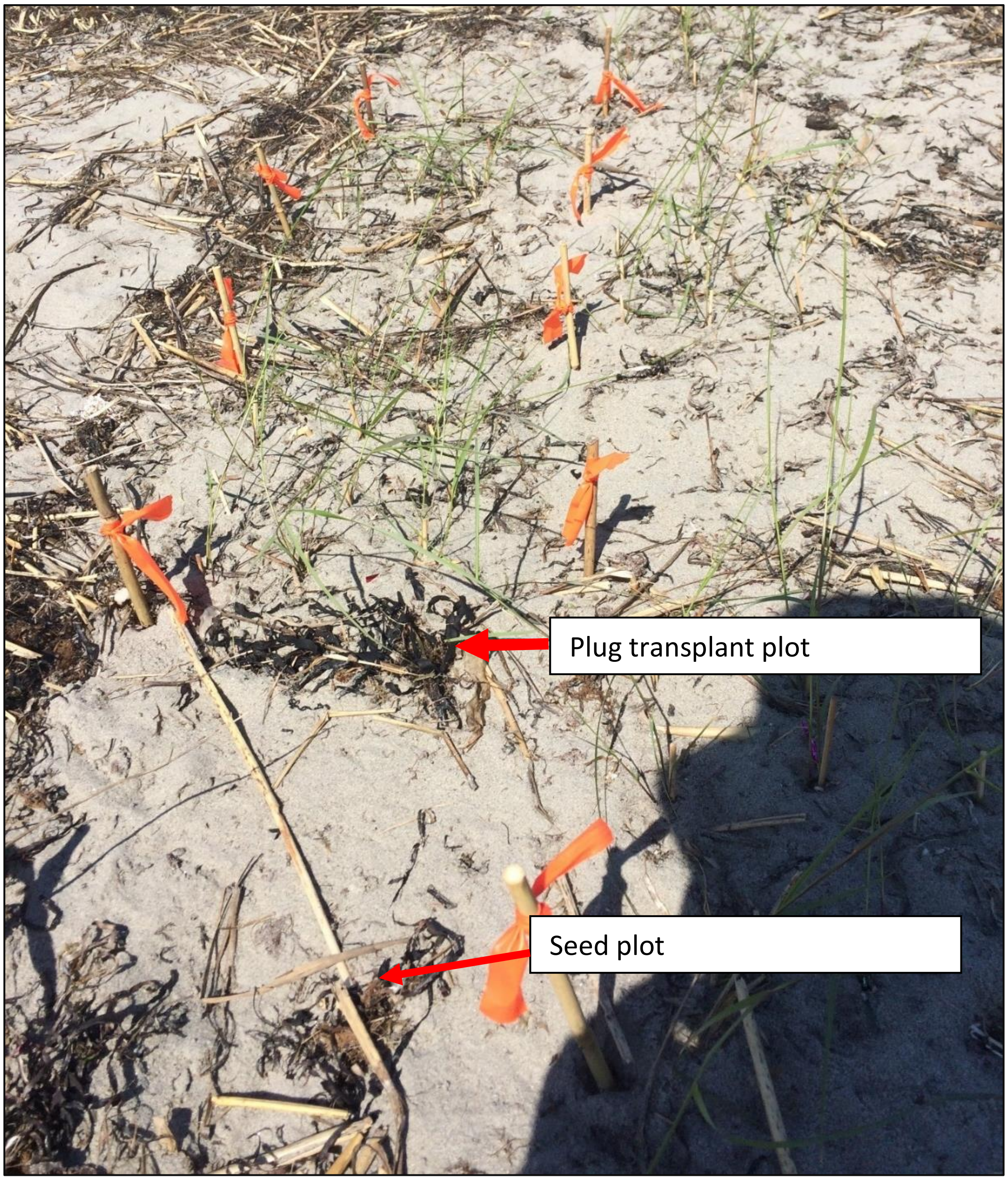

Figure 3.8: *The 10 quadrats (5 transplant, 5 seed) at the Eastern Passage- S. patens site*

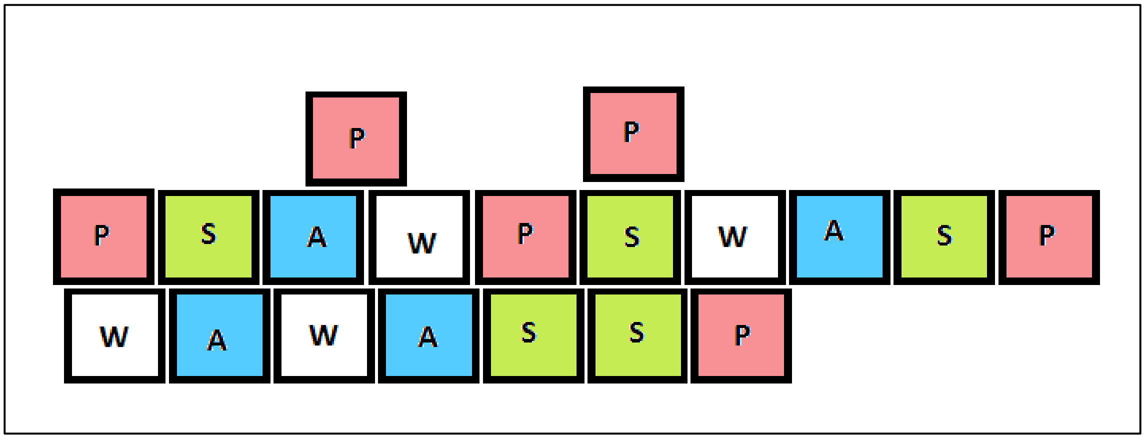

Figure 3.9: *Layout of the Eastern Passage- S. alterniflora treatment plots. P= transplant plugs, A= adjacent plugs, S=seeds and W= wrack. There are n=19 plots at this site*

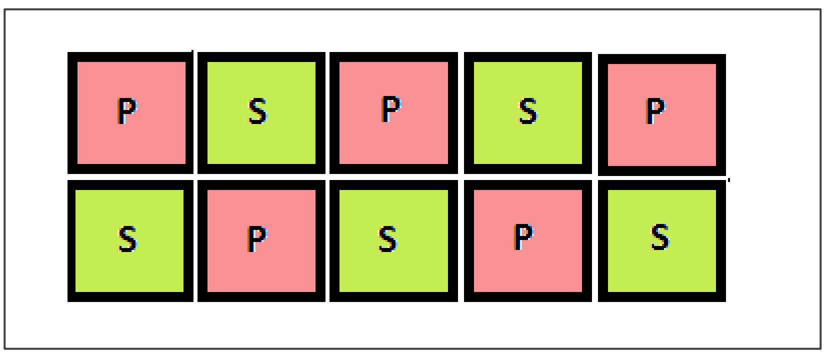

Figure 3.10: *Layout of the Eastern Passage S. patens treatment plots. P= transplant plugs and S=seeds There are n=10 plots at this site*

Lawrencetown Lake

Lawrencetown lake was sectioned into 5 microsites spaced approximate 0.5m apart. A 1x1 m quadrat was sectioned into 20 by 20 cm squares , and placed on the surface in unvegetated areas, this was done as opposed to parallel rows due to the limited space at this site, and this was seen as the most efficient way to layout the plots. The plots were placed to get a range of elevation and tidal inundation periods (low marsh, to almost subtidal). Each square was designated a treatment of transplants (adjacent or plug), seeds or wrack material. Each of the five quadrats consists of between 19-25 plots (Figure 3.13). Consideration was taken not to have two of the same treatments next to each other (ESA PWA, 2012). The type of treatment for each quadrat at Lawrencetown Lake can be found in Figure 3.13.

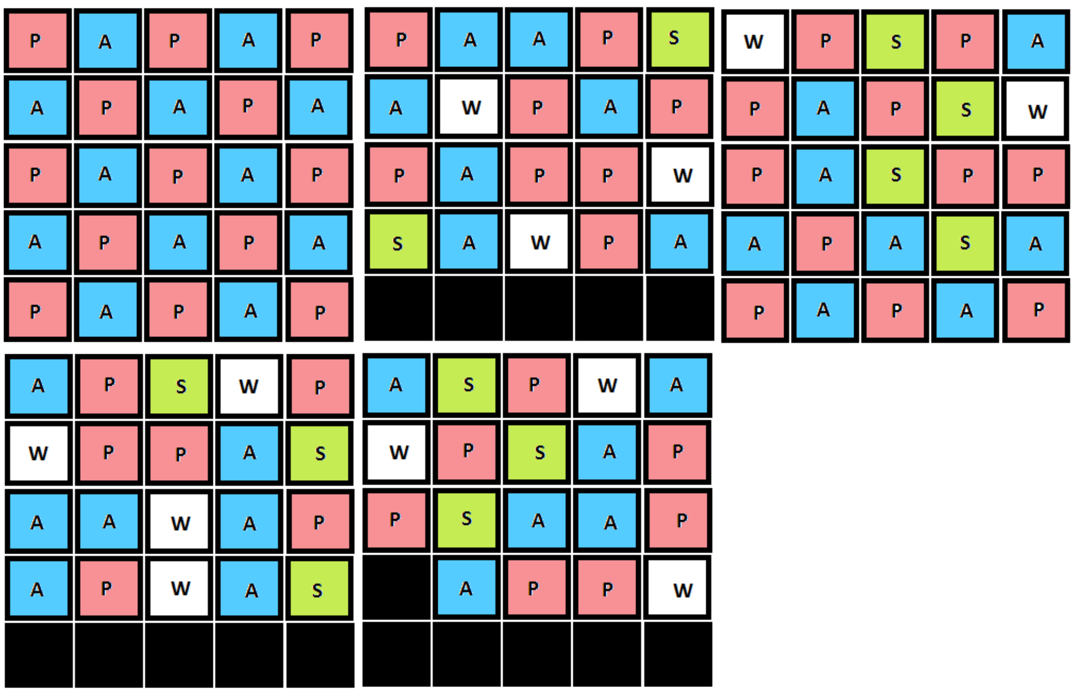

Figure 3.11: *Showing all the microsites for Lawrencetown Lake. One large square is representative of a 1x1m quadrat, each of the smaller squares are 20cm plots within the quadrats, and there was approximately 5m between each plot.. P= transplant plugs, A= adjacent plugs, S=seeds and W= wrack. There are n=109 plots at this site*

3.3.4 Monitoring

Eastern Passage was planted on May 14th, 2015 and Lawrencetown lake was planted later in the month on May 28th, 2016. The sites were monitored from May until September, every week for the first 2 months to detect any rapid changes in plant health, for the remaining time, sites were monitored every 2 weeks. During monitoring I recorded height, number of stems, plant health and other site observations. Height was measured on each plant, from the base of the plant, to the tip of tallest leaf. Plant heath was assessed using the method outlined in Anastasiou and Brooks (2003), where each plant was given a rating based on physical appearance (% of green vs brown or yellow stems), and new growth observed (plant height, number of stems). A plant was considered dead when there was no growth and green observed (plant was entirely yellow), for two consecutive monitoring events. Site characteristics such as sediment deposits, wildlife and aquatic species present, evaluation of existing vegetation, and human impact and activities were recorded during each visit. An elevational surveying was completed at both sites using a Leica Geosystem TCR 705, which measures in 5 arc-seconds, and distances to 2 mm + 2 parts per million, to calculate mean elevation as well as slope for each of the individual plots. Each plot was surveyed at the top and bottom of the quadrat, and at Lawrencetown Lake, the top, middle and bottom of each quadrat was measured as the quadrats were much larger. Fetch is used as a proxy for wave energy (Table 1), where the longer the fetch the higher the wave energy (Hardaway et al. 1984). Average fetch was measured using the Measure Tool in ArcGIS 10.1, where 10 measurements were taken at each site and the average of those 10 measurements were taken (Hardaway et al 1984). A note was made for Eastern Passage, where one distance of fetch (in the north west direction) was significantly longer than other directions, and this was stated separately as this would be considered to be the longest fetch (Hardaway et al 1984).

3.3.5 Statistical methods

To understand if the treatment varied between species an ANOVA was used to compare the treatments between species, and due to the data not being normally distributed due to the large number of zeros present, a non-parabolic Kruskal-Wallis test was run for further analysis. Physical attributes affecting the survival of plants in the field were analyzed using 1-way ANOVA for each of the plots, with elevation as a fixed factor, and health index as the dependent variable. To understand if elevation had an impact on the survival of treatments used in the field trials, a least-squares regression analysis was performed. All statistics were run on MYSTAT 13.1 and Microsoft Excel 2016.

3.4 Results

3.4.1 Storage trials and germination of *Spartina species*

When broken down per treatment in the Bay of Fundy population, fresh/cold clearly had the highest germination, and the other three treatments yielded relatively low germination (Figure 3.14.A). Both the salt/cold and fresh/cold treatments yielded the highest germination rates for the Atlantic population, whereas the two frozen treatments yielded very low germination rates for all three species (Figure 3.14.B). *Spartina patens* had the highest percentage of germination for both populations, with 73.6% from the Bay of Fundy population and 50% from the Atlantic population germinating within the given time period (Figure 3.14). *Spartina alterniflora* had the lowest total germination with just 6% germinating from the Bay of Fundy population and 31.6% germinating from the Atlantic population (Figure 3.14). As well, for *S. alterniflora*, the two frozen treatments yielded no germination for the Bay of Fundy population, as well, the fresh/frozen treatment from the Atlantic population also produced no germination. *Spartina pectinata* had 34.4% germination from the Bay of Fundy population and 46.8% germination from the Atlantic population with the best success with the fresh/cold treatment (Figure 3.14). The total germination per day is shown in Appendix H. Figures showing the rates of germination for each treatment over that period of time can be found in Appendix C. The average time for germinating seeds from the Bay of Fundy and Atlantic populations was approximately 15 days. However, generally the Atlantic population peaked later, with the majority of germination for all three species around March 28th (day 23).

An ANOVA was performed to test the null hypothesis that treatments did not differ within a species; $p= >0.001$ for all species and therefore I rejected the null hypothesis of no treatment differences. For the germination data, all species were found to be non-normal based on the Shapiro-Wilk and Anderson-Darling ($p= 0$ for all species). Transformation was attempted, of which a SQRT(x) transformation appeared to have the best outcome on the observed histograms. However, even after transformation, data were still not normally distributed ($p= 0.00$) for all species. This is likely due to the large number of zeros (non-germinated seeds) still present in the data. Since data were not normal, a Kruskal-Wallis test was performed for further analysis and the null hypothesis was rejected ($p= <0.002$)

for the all of the species of both populations, except for the *S. patens* Bay of Fundy population (p= 0.098). This indicated that the treatments did differ significantly within a species, except for *S. patens* of the Bay of Fundy population.

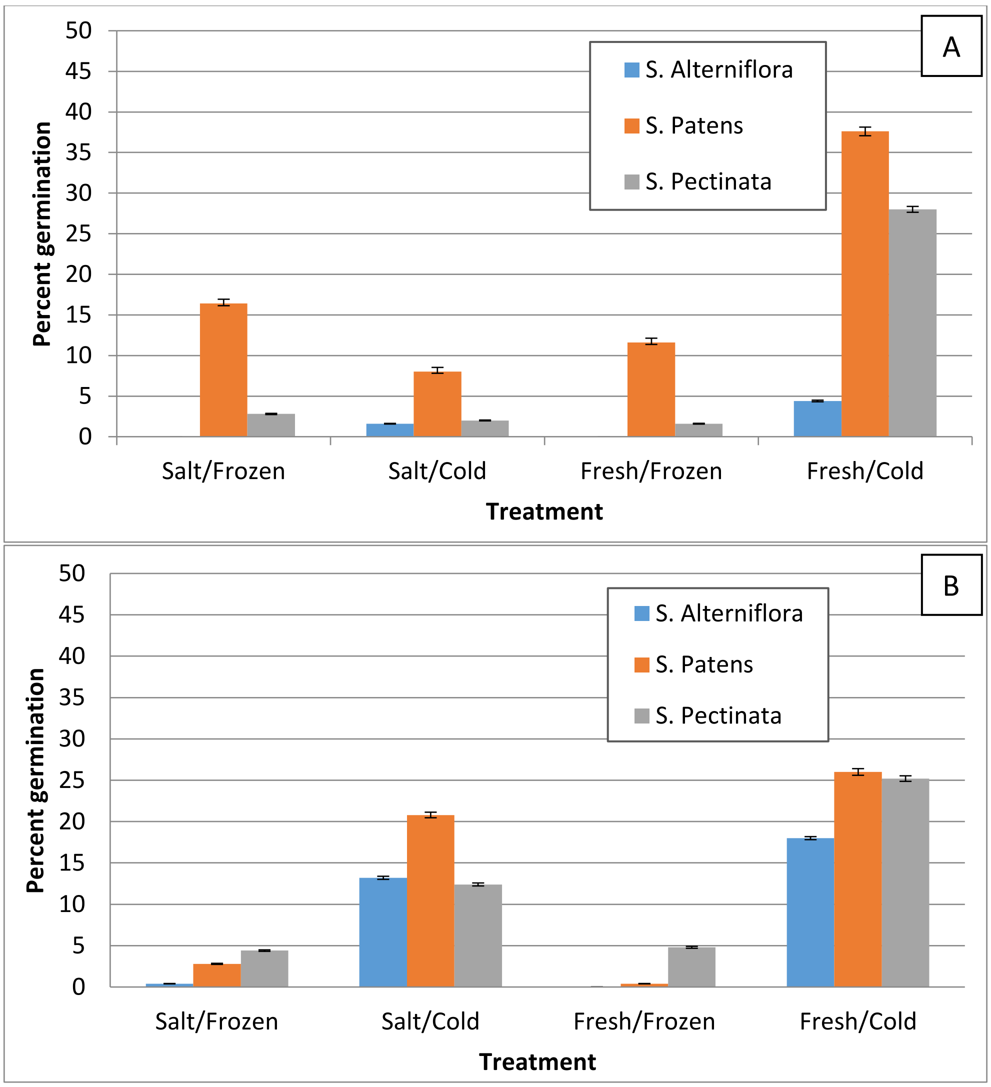

Figure 3.12: *Percent germination per treatment of each of the three species (means ± SE) in A) the Bay of Fundy population and B) the Atlantic populations*

3.4.2 Field trials Eastern Passage- *S. alterniflora* plots

Average health index of all plots

The general trend of the greenhouse grown plugs was an overall decline in health index over the growing season (Figure 3.15.A). There was complete mortality in 3 plots where all 9 plants where dead, or removed by wave energy or other hydrological forces, by the end of monitoring (Appendix D). In the remaining plots the trend was still a decline in health index over the growing season, but plants were still alive at the end of monitoring. A heavy sediment deposit was observed on July 13th and major trampling was observed on June 5th, both of these events correlate with a major decline in several plots (ID # 1, 5, 1B and 1C) (Appendix G).

In the adjacent transplant plots, an overall decline was observed from May 21st-June 15th (Figure 3.15.B). All adjacent transplants were dead by June 15th. Plot 12 shows a positive health index at July 13th, but it is likely that this was encroaching growth from existing vegetation on the site (Appendix D).

In the seed plots, plot 15 had roughly 130 seedlings germinate between 3 plots (ID # 6, 15 and 16), and in plot 16 approximately 28 germinated (Figure 3.15.C. Appendix G). However, decline followed shortly after, which again corresponds to the sediment deposit on July 13th. No germination was observed in plots 2 or 9 (Appendix D and G).

The wrack plots presented minimal germination across the plots, and one plot had no germination (Figure 3.15.D). Germination was much later in the growing season, where germination happened after July 27th. One plot (ID # 13) had germination earlier in the growing season (June 5th), health peaked until June 15th, and then began rapid decline until death before August 11th (Appendix D and G).

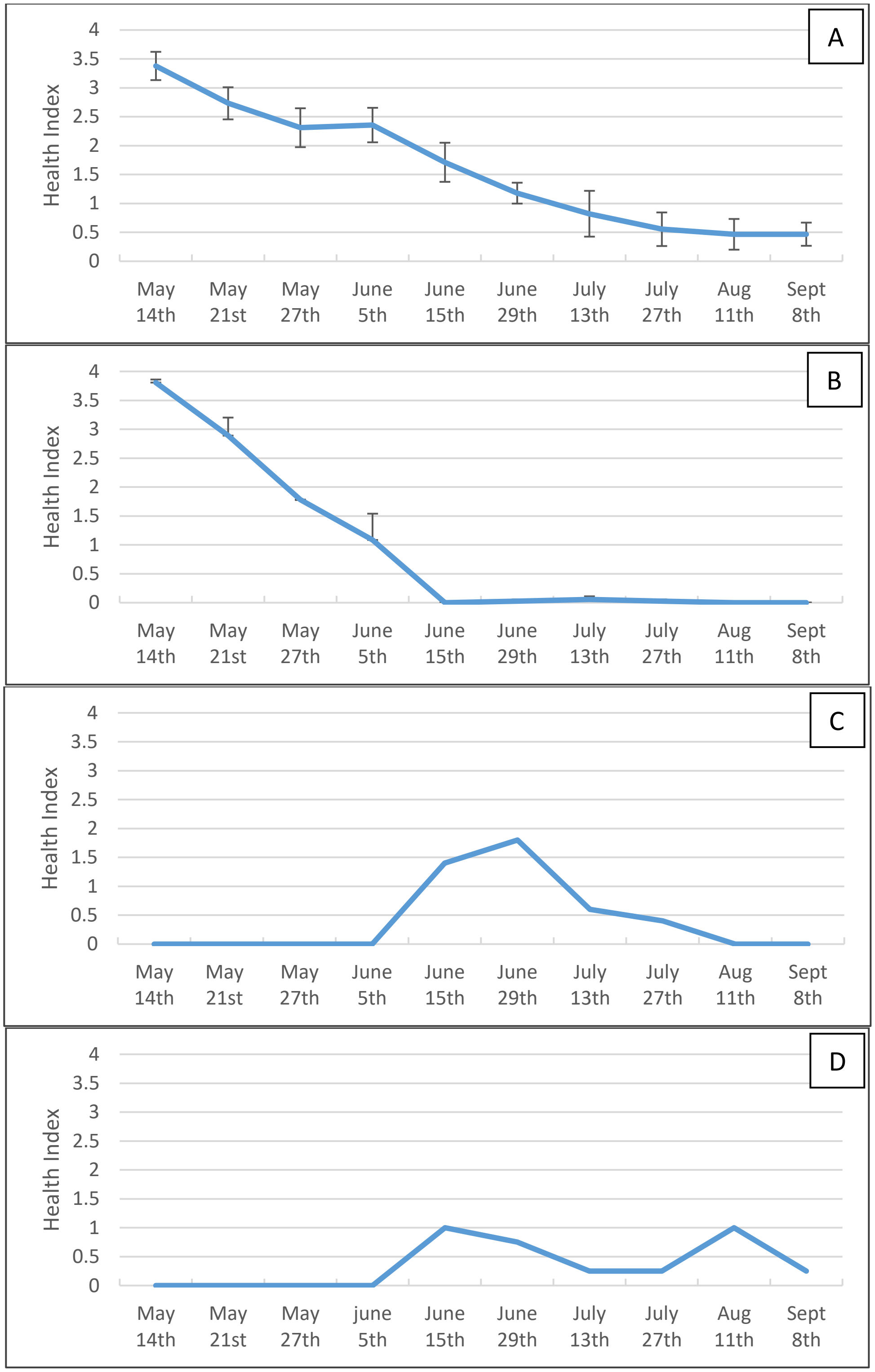

Figure 3.13: *The average health indices at the Eastern Passage- S. alterniflora plots over the monitoring season for A) plug transplant plots; B) adjacent transplant plots; C) seed plots; D) wrack plots*

Elevation for all plots

All of the plots at the Eastern Passage- *S. alterniflora* site ranged between 0.92 m and 0.97 m above sea level (relative to CGVD28 vertical datum), with zero representing sea level (Appendix E). There was minimal variation between each of the plots (p=0.98). Existing *S. alterniflora* vegetation at the site ranged from 0.85 m to 0.98 m (Figure 3.6). The elevations of the existing plots were significantly different than the treatment plots (p=0.000). The slope of each plot is also shown in Appendix E, along with the elevation of the top and bottom, and average elevation of each plot.

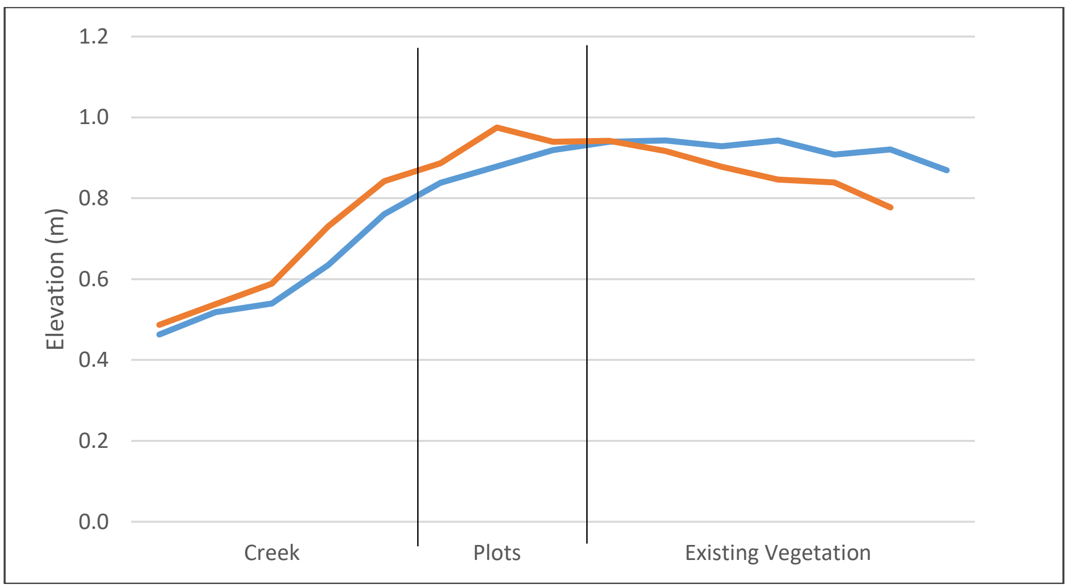

Figure 3.14: *The elevation in meters (CGVD28) of existing vegetation (relative to sea-level at 0m) at the Eastern Passage- S. Alterniflora site. The two separate lines represent two lines run parallel through existing vegetation to collect elevation data*

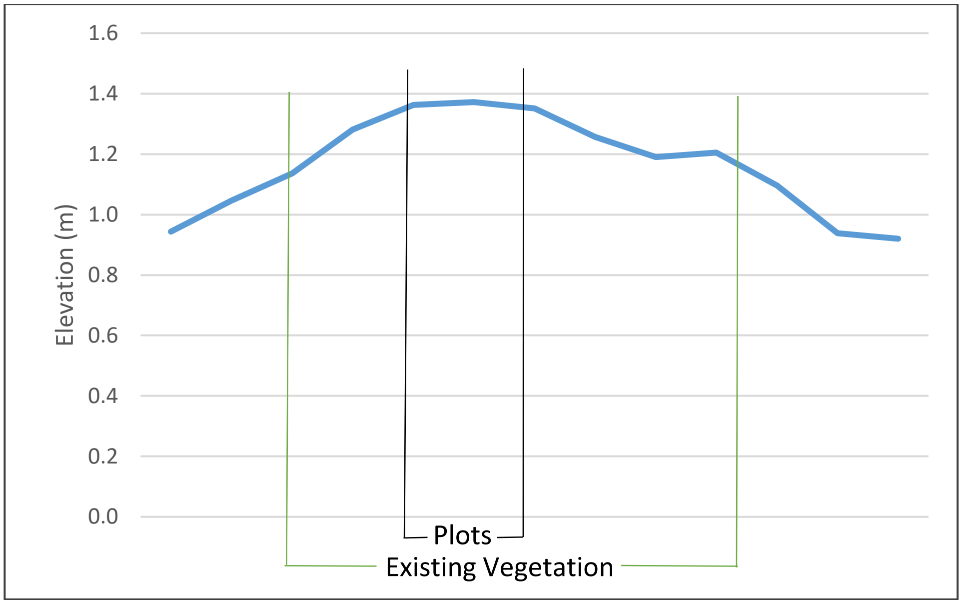

Figure 3.15: *The elevation in meters (CGVD28) of existing vegetation (relative to sea-level at 0m) at the Eastern Passage- S. patens site*

Elevation- health index regressions for all plots

A least squares regression for each of the treatments, was completed for health index and elevation. However, no regressions were run for wrack plots as only minimal germination occurred. The health index and elevation for the plug transplants are weakly negatively correlated (r^2=0.132, p=0.001), indicating that elevation may have a slight influence on health index for these plots (Figure 3.16.A). The health index and elevation for adjacent transplants are not correlated (r^2=0.037, p=0.128), indicating that elevation is likely does not have an effect on health index of the adjacent transplants (Figure 3.16.B). The health index and elevation for seed plots (*S. alterniflora*) are strongly negatively correlated (r^2=0.704, p = 0.009), indicating that elevation had an effect on the health of seedlings germinated in the seed plots (Figure 3.16.C).

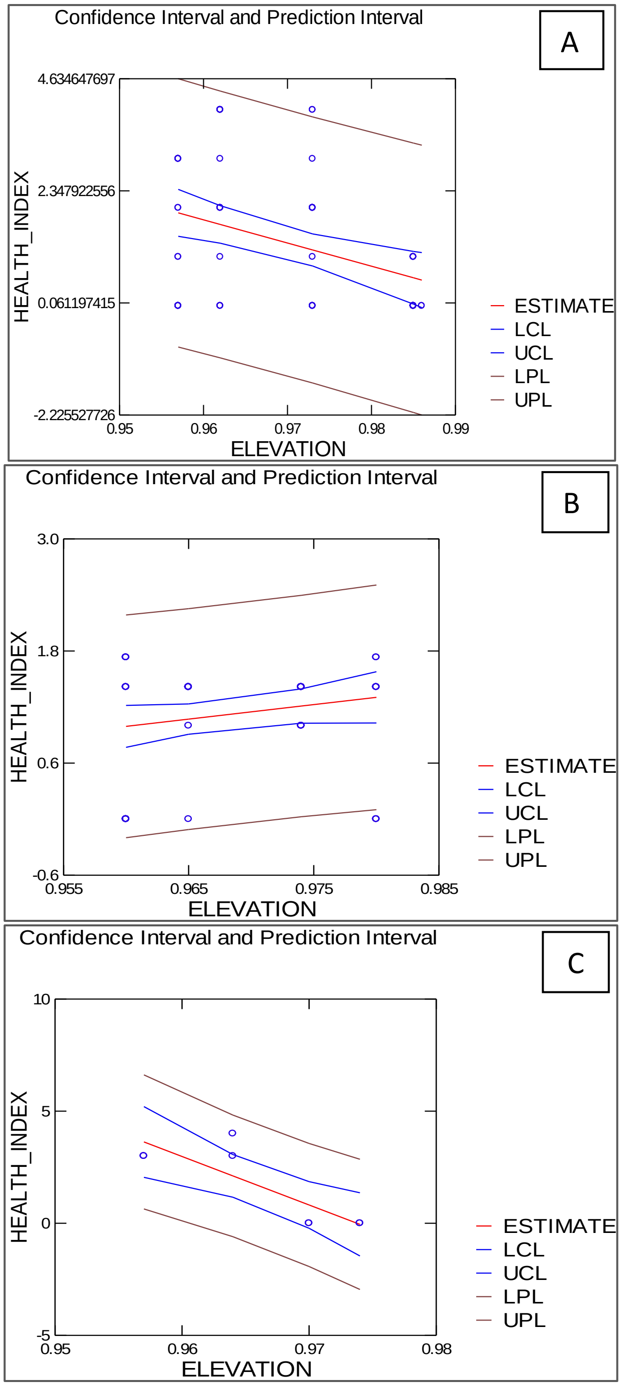

Figure 3.16*: Regression graphs from the linear regression analysis for A) plug transplants; B) adjacent transplants; and C) seeds; at the Eastern Passage- S. alterniflora sites. No regression analysis was performed on the wrack plots as there was minimal germination. LCL= Lower control limit, UCL=upper control limit, LPL= lower prediction limit, UPL = upper predication limit*

3.4.3 Field Trials: Eastern Passage- *S. Patens* Plots

Average health index for all plots

The trend of health indices for plug transplant plots over the growing season was generally positive until decline began towards the end of the growing season (peak biomass) (Figure 3.17.A). Plot 1 was the only plot to see an overall decline in health index over the growing season (Appendix D & G). Two plots (ID #7 and 9) both had an overall increase in health index and plots 3 and 5 had relatively flat, but high, health indexes over the entire growing season (Appendix D &G).

The general trend of the data for the seed plots was a relative increase in health index over the growing season (Figure 3.17.B) until the point of peak biomass where the plants in started to decline in most of the plots. Two plots (ID # 6 and 10), had consistently high health indices even towards the end of the growing season (Appendix D & G). At the end of the monitoring season (Sept 8^{th}, 2015), all plots were still considered to be "alive" but declining.

Observation of the plots one year later (June 2016) indicates that the S. patens pugs and seedlings did survive the winter and continue to grow one year later (Figure 3.22)!

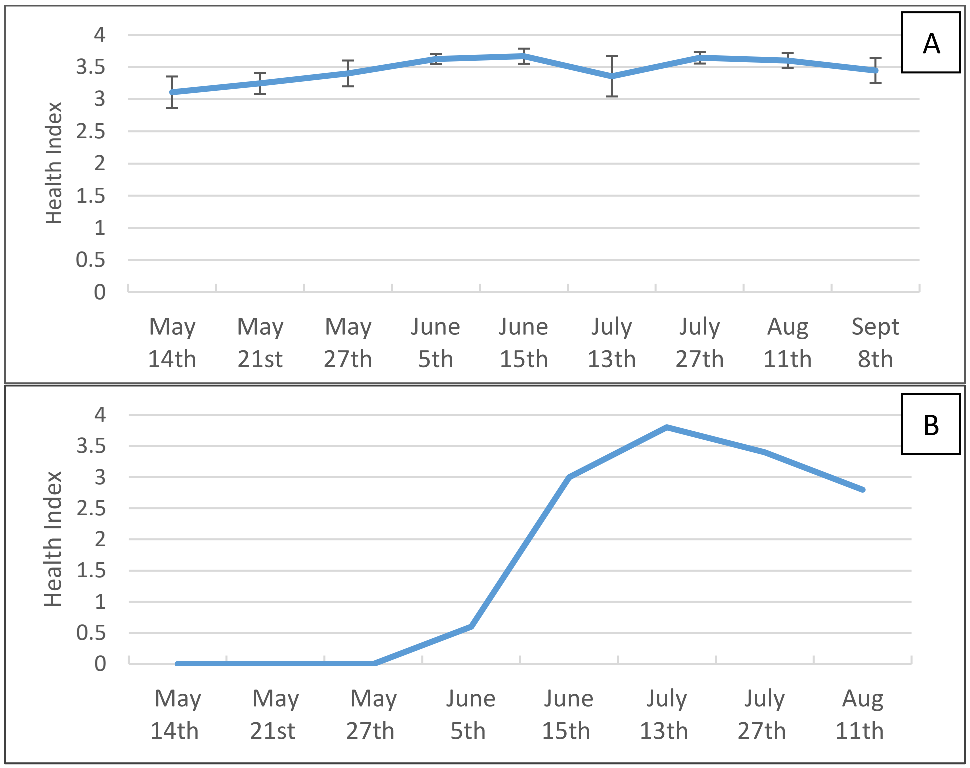

Figure 3.17: *The average health indices at the Eastern Passage- S. patens plots over the monitoring season for A) plug transplant plots and; B) seed plots*

Elevation for all plots

Elevation of the Eastern Passage- *S. patens* plots were higher within the tidal range than the Eastern Passage- *S. alterniflora* plots (p=0.000). Elevation ranges from 1.15 m to 1.16 m (CGVD28) as opposed to below 1 m in the Eastern Passage- *S. alterniflora* plots. There is also minimal variation of elevations between the various plots (p=0.875). Individual graphs for the slope of each plot are found in Appendix E. Existing high marsh vegetation at the site ranged from 1.09 m-1.37 m (Figure 3.7). The elevation of the existing vegetation plots were similar to the elevations of the treatment plots (p=0.744).

Elevation- health index regressions for all plots

The health index and elevation for plug transplants were very weakly negatively correlated (r^2=0.173, p=0.045) indicating that elevation may not be the largest influence on the health index of the plug transplants at this site (Figure 3.18.A). The health index and elevation for seed plots are not correlated (r^2=0.013, p = 0.009), indicating that elevation does not have an effect on the health of seedlings germinated in the seed plots (Figure 3.18.B).

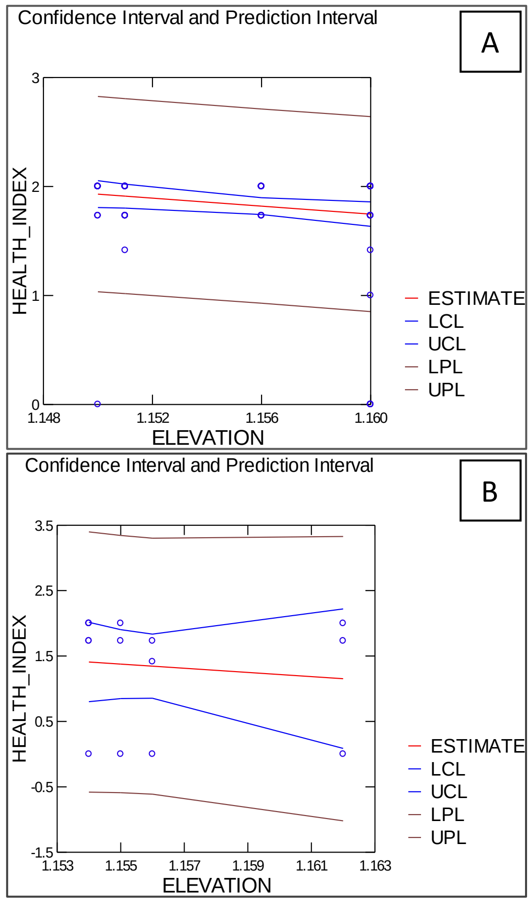

Figure 3.18: *Regression graphs from the linear regression analysis for A) plug transplants and; B) seeds; at the Eastern Passage- S. patens sites. LCL= Lower control limit, UCL =upper control limit, LPL= lower prediction limit, UPL = upper predication limit*

3.4.4 Field trials Lawrencetown Lake plots

Average health index for all plots

The general trend of the plug transplants was an overall decline in health index over the growing season for all plots within each of the quadrats (Figure 3.19.A, Appendix G). There was complete mortality in quadrat 3 and 5, at the end of the growing season (Appendix D). In quadrats 1, 2, 4 and the trend was still a major decline in health index over the growing season, but plug transplants were still alive at the end of monitoring, although the health indices were very low (> or = to a health index of 1) (Appendix D).

Over the growing season, the trend of adjacent transplants was generally a decline in health index, however, this was a much smaller decline then seen in the plug transplants at this site (Figure 3.19.B). Quadrat 1 and 2 saw a small decline over the growing season, quadrats 4 and 5 saw a slightly more rapid decline, and quadrat 3 saw an increase in health index over the growing season. Only Quadrat 5 presented germination of wrack material, which was at the end of the growing season and may have been encroaching vegetation (Figure 3.19.C). No seed plots germinated at the site.

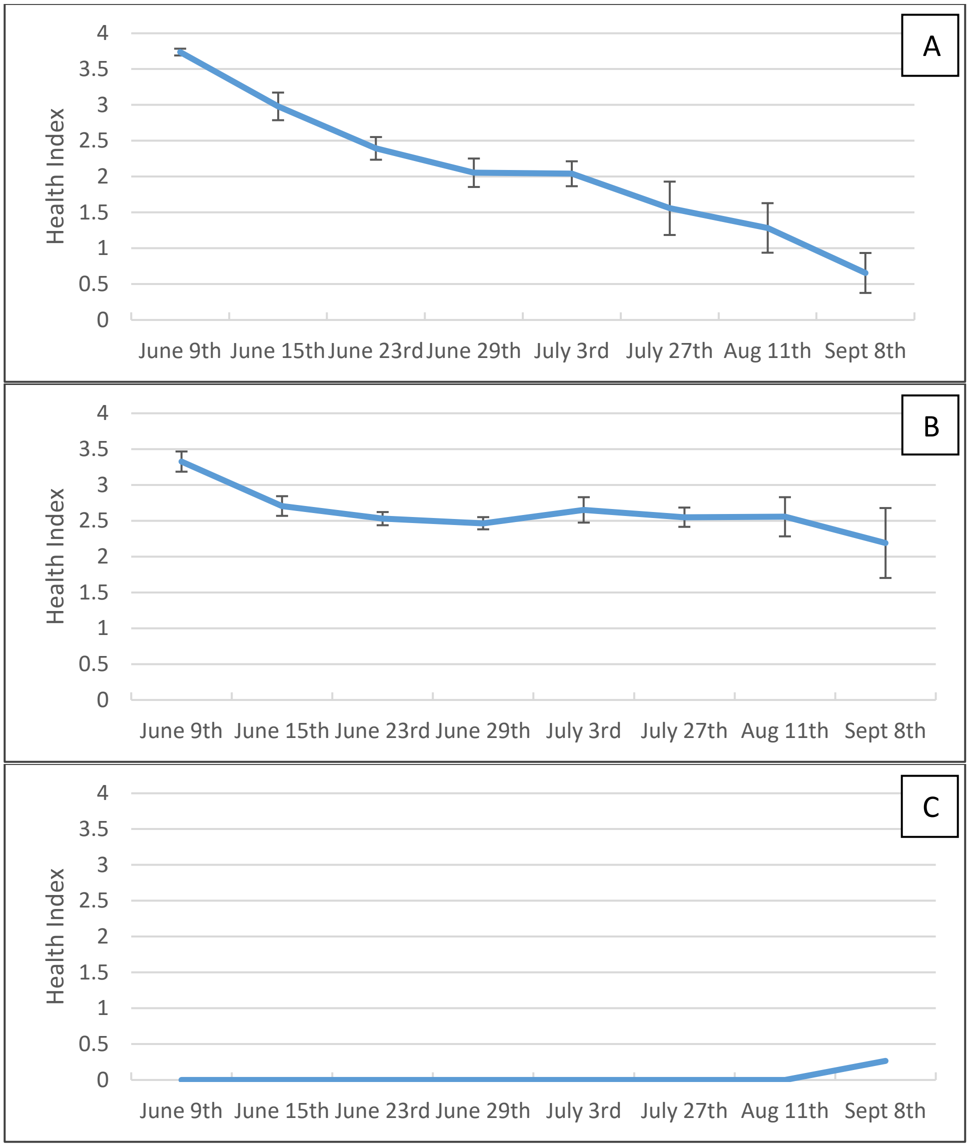

Figure 3.19: *The average health indices at the Lawrencetown Lake plots over the monitoring season for A) plug transplant plots; B) adjacent transplant plots; C) wrack plots*

Elevation for all plots

The Lawrencetown plots had the lowest elevations of all three sites at 0.40m to 0.49m above sea level (CGVD28) as compared to between 0.90m and 1.20m in both the Eastern Passage sites. Average elevation and slope for each of the quadrats is shown in Appendix E. There was a minimal difference in elevation between each of the quadrats (p=0.992). Existing *S. alterniflora* vegetation at the site ranged from 0.44m to 0.55m, which are significantly higher (elevation) than the treatment plots (p=0.029) (Appendix E).

Elevation- health index regressions for all plots

A regression (least squares) was completed for health index and elevation on plug transplants and adjacent transplants. No regressions were run for seed plots as no germination occurred, as well as wrack plots as only two seedlings germinated across all 5 quadrats. The health index and elevation for the plug transplants were not correlated (r^2=0.006, p=0.362), and the health index and elevation for adjacent transplants are also not correlated (r^2=0.000, p=0.99) indicating that elevation does not have an effect on health index of either types of transplants

3.5 Discussion and Conclusions

3.5.1 Storage treatments

Overall, the Bay of Fundy populations yielded lower rates of germination then the Atlantic population, except for *S. patens*, which has higher rates in the Bay of Fundy population (Figure 3.14). The differences in germination rates may be attributed to genetic differences in the two populations, which was not examined in this project as a possible variable. Plant traits do tend to be very variable, where flowering, seed production and growth tend to vary year to year and geographically as well (Fang et al. 2004; Mobberley, 1956). The seeds had a germination period of approximately 28 days for all species, with average peak germination (the point with the highest germination) around day 15. This is important to note when planning a planting project that would involve growing plugs, as this amount of time to germinate should be taken into account.

The fresh/cold and salt/cold treatments yielded the highest germination. In comparison, freezing the seeds yielded very low germination rates. It was initially hypothesized that freezing would mimic natural environmental conditions (winter) which may provide a sort of stratification process (where seeds need to be store cold and wet to break the dormancy period), however it appears to cause a decrease in viability, especially in the case of *S. alterniflora* where I had zero germination in the freezing treatments. If any form of stratification is needed for the seeds, clearly storing the seeds cold for a period of time provides favourable conditions.

Given the low germination rates of *S. alterniflora* observed in this study, the species likely does not colonize new marsh areas dominantly by seeds, which corresponds to what is found in literature, suggesting that *S. alterniflora* tends to spread and colonize more by rhizomes rather than seeds (Thompson, 1991; Hubbard, 1969). Studies such as Utomo et al. (2010) had better success with germination *S. alterniflora* (in both salt and fresh water) with a germination rate of 82% +/- 9% and as well agree that the cold stratification (in a refrigerator at 2-3^{o}C) is an integral step in germination of this species. In contrast, Callaway and Josselyn (1992) had lower results of germination (in a field study), with 5-30%

germination in salt water and 25-75% germination in fresh water. For growing plugs, it is still possible to use seeds of *S. alterniflora*, although lower germination rates greatly increases the amount of seeds needed. *Spartina patens* and *S. pectinata* on the other hand had higher rates of germination and may be more likely to colonize and germinate via seeds then *S. alterniflora*, although rhizomes are still the dominant way both species colonize (Kim et al. 2012). *Spartina patens* seeds had high germination rates in both populations and when the observed growth rate was much quicker for both above and below ground biomass compared to *S. alterniflora*. Approximately 40 *S. patens* seedlings were kept alive in plug trays (not used in the field experiment) for the growing season (Figure 3.20), and what was observed by the mid growing season was that they had significant above ground biomass and very large, densely packed root masses, which is characteristic for *S. patens* growing naturally (Anastasiou and Brooks, 2004). *Spartina pectinata* seedlings were also kept alive in plug trays for the growing season, and grew to approximately 70 cm tall, with significant belowground biomass as well, and two seedlings flowered in September (Figure 3.21).

Figure 3.20: *Spartina patens after spending the growing season in plug trays on the green roof at Saint Mary's University (Pictured here in early November, 2015)*

Figure 3.21: *Spartina pectinata flowering on a green roof at Saint Mary's University in early October, 2015*

3.5.2 Recommendations for storage and germination

Based on the results of this project, it is not recommended to freeze seeds as a method of storage. As convenient for seed inventories and large seeding projects as it would be to freeze seeds, it appears that this causes a significant reduction in germination success over all species, particularly in the case of *S. alterniflora* which is a common species used in shoreline management and restoration projects (NOAA 2014; Currin et al. 2009; Knutson et al. 1982). It appears as though storing the seeds cold and wet (between 2-5^{o}C) produces the highest germination rates for all of the species. Long-term storage is questionable regardless, as studies such as Morring et al. (1971) and Sayce (1988) indicate that *Spartina* spp. seeds are likely only viable for 1 year. Although this was not tested with the seeds in this experiment, as they were germinated 5.5 months after collection. There are seed viability tests available that can be used for testing long-stored seeds before beginning germination, including using tetrazolium chloride, a redox indicator that stains seeds red when they are producing metabolic reactions, (Elsey-Quirk et al. 2005). It appears as though storage has more of an impact on seed germination than the type of water (fresh or saline) seeds are germinated in, which corresponds to what was found in literature (Utomo et al. 2010; Callaway and Josselyn, 1992).

3.5.3 Field trials: *Spartina* Spp. plots at Eastern Passage and Lawrencetown Lake

Transplants

Initially it was planned to use the germinated seeds, collect height and health data in the greenhouse, and have mature seedlings to transplant in the spring, once temperatures had stabilized above the frost point. Unfortunately, due to the long spring where frost was still possible into early-mid May, coupled with an unforeseen complication keeping the seedlings warm in the greenhouse, the seedlings died approximately mid-late April (Appendix F). New seeds were germinated immediately and used for the field experiment. Due to the late spring, new transplants had a shorter time to acclimatize prior to transplantation. Appendix F shows cooler than normal temperatures lasted into May, meaning that placing the greenhouse plug transplants outside, or transplanting them, risked damage, stress and death from frost. This short acclimatization period may have added to stress during transplantation, and may account for some of the rapid health index declines shown within the first 2-3 weeks of transplanting, at both the Eastern Passage- *S. alterniflora* and Lawrencetown Lake sites.

Spartina alterniflora plug transplants were very small and had little root mass at the time of transplantation. Studies such as Fang et al. (2004) maintained their germinated seedlings for 12 weeks, and Manis et al. (2015) allowed 6 months of growth for rhizome cuttings (used for propagation) of *S. alterniflora*. However, Anastasiou and Brooks (2003) purchased seedlings grown in a nursery and transplanted them only 30 days after they had germinated. The *S. alterniflora* seedlings used for transplants at Eastern Passage had approximately 6 weeks to germinate and acclimatize, and 8 weeks for Lawrencetown. While the plug transplants survived better at Lawrencetown Lake, the transplants were still young and fragile, and coupled with high wave energy, still had a rapid decline in health index. While living shoreline literature has almost no studies evaluating the success of vegetation addition methods (such as transplants and seeding), many of the same methods are used in active restoration and remediation projects. Studies such as Bergen et al. (2000) had stronger success with their transplants, with 99% survival within the first month. They attribute this to the healthy rhizomes present, and even found rhizome spread of about 15cm after 1 year. In contrast, Utomo et al. (2010) discuss the loss of transplants on a marsh, when used for mitigating erosion, stating that the loss can be as high as 44km/year, and certain sites are much more suited for seeding as this has better success of establishment.

The conditions at the Eastern Passage- *S. patens* site were favorable for the establishment of plug transplants. These transplants not only established, they thrived with a high health index throughout the growing season. The health indices for the transplant plots indicate that this was within the proper elevational and salinity range for *S. patens* to flourish (with minimal environmental disturbance such as wave energy). Anastasiou and Brooks (2003) has shown that *S. patens* is particularly susceptible to transplant shock within the first 30 days after transplantation, where health would decline rapidly, sometimes to the point of mortality. However, they did find that after the 30-day point, the seedlings health and growth rates rebounded, but didn't fully stabilize until between 126-301 days after transplanting). Overall this study still had mortality rates as high as 40% depending on the treatment used (pH and elevation) (Anastasiou and Brooks 2003). This was not the case for the plug transplants used in this study, as there was no initial decline in health and relatively stable health indices throughout the growing season, further indicating that the conditions were favorable for *S. patens* establishment. *Spartina* spp. should peak vegetation and have a natural cycle (mortality dynamics) of reduction in grown around the end of July-August (Cranford et al. 1989). I did see this with some of the plug transplants of *S. patens*, where we saw a decline in health index after July 27th. This was an expected natural occurrence, and likely not due to stress from any environmental (or human) factors). Upon revisiting the study site the following spring (early June 2016), the *S. patens* plugs and seedlings had survived and established at the site (Figure 3.22).

The adjacent transplants of *S. alterniflora* at the Eastern Passage-*S. alterniflora* site had very little (and in some cases almost no) root mass attached, as compared to the adjacent transplants at Lawrencetown, and this likely led to the mortality of the adjacent transplants at this site. Huckle et al. (2002) used adjacently collected transplants and had very good success with survival, except in the case of intraspecific competition. Intraspecific competition was not as much of a factor at either Eastern Passage or Lawrencetown, as the majority were in areas used for plots were bare and not colonized by vegetation. The adjacent transplants at Lawrencetown Lake had a much larger root mass attached and had a higher survival rate.

Human disturbance likely played a large role in the decline and mortality of the transplant plots at the Eastern Passage- *S. alterniflora* site, due to the amount of trampling found at the site (Figure 3.9). Human traffic on sites can have a major impact and in ways not always predicted (MDE, 2008). For example, Toft et al. (2013) found that during summer months, human traffic increased in their created lower marsh zone because the low tide left a large portion open for foot traffic. This is also the case for Eastern Passage, as it is a public access beach and foot traffic increases during the summer months. This creates a case for public education and understanding of these projects and may decrease and potential damage caused.

High wave energy (fetch is used as a proxy in this study), sediment deposits and currents likely also played a role in the decline and mortality of the transplant plots at both the Eastern Passage- *S. alterniflora* and Lawrencetown Lake sites. Bruno (2000) found that the most common form of mortality for *S. alterniflora* was through burial or dislodgement during high-energy events. There was a heavy sediment deposit at the Eastern Passage- *S. alterniflora* site on July 13th, which did correspond to a decline in health for most of the plots (Appendix D). Fetch likely did not play a role in health index decline or mortality at Eastern Passage- *S. patens*, as the plots were well nestled in behind existing *S. alterniflora*, which also acts as a facilitator for further community development reducing wave energy and trapping sediment (Bruno, 2000). However, at Lawrencetown Lake, it is more likely that fetch was the dominant factor in the decline of health of the transplants as the fetch is considered to be in the medium energy zone. This is discussed further in the subsection regarding elevation and survival rates for Lawrencetown Lake.

Figure 3.22: *Showing the survival of S. patens at the Eastern Passage- S. patens site 1-year post transplanting*

Seeding

The conditions at the Eastern Passage- *S. patens* seed plots, were favourable enough to have a significant number of seedlings not only germinate, but thrive. The increasing trend of the health indices post germination for the seed plots suggests that this was within the proper elevational range for *S. patens* to flourish. This survival rate is a very good indication that *S. patens* at Eastern Passage is seed source limited, and with a supply of seeds, we would likely see *S. patens* growth on the sand flat. Seeds at the Eastern Passage-*S. alterniflora* plots germinated, but then quickly declined in health and perished. This could be due to several factors including human impact (trampling) or sediment deposition, as the decline followed the heavy sediment deposition of July 13th. Factors such as currents and elevation may have also played a role. The plots are close to the top edge of a creek (Figure 3.5), which when the tide ebbs and flows, creates a strong current that may have damaged small, vulnerable seedlings. At Lawrencetown Lake, none of the seedlings germinated, and the reason for this is attributed to scouring from wave energy (Figure 3.23). After burying the seeds and revisiting the site the next day, the seed plots within the quadrats appeared to be completely scoured out. This is likely due to the type of soil material at the site, which was not idea for planting into as it was extremely organic and bound by roots and peat, as well as the higher wave energy.

Figure 3.23: *Scouring of seed plots at Lawrencetown Lake from high wave energy (1-week post construction)*

Wrack material

There was one occurrence of wrack material germinating in quadrat 5 at Lawrencetown Lake, however, this is likely encroaching vegetation, as it appeared to originate from a rhizome outside the quadrat. Wrack material also germinated in two plots at the Eastern Passage- *S. alterniflora* site, however, it quickly declined in health and died following germination. Based on literature determining the seed variability of wrack material, it is likely that the wrack material contained a higher abundance of mid to high marsh and brackish species, and due to the elevation at which the wrack was buried (low marsh), these seeds could not survive those inundation periods, or salinities (Glogowski, 2013; Minchinton, 2006). Therefore, wrack material was not a successful method of adding plant material to the low-marsh intertidal zone at either site. Wrack material has had good success in germinating in greenhouse experiments (where it is buried to determine seed composition), and typically contains an abundant variety of seeds, therefore may have potential use in higher-marsh zones (Glogowski, 2013; Minchinton, 2013; Leck, 2003).

3.5.4 Elevation and survival at Eastern Passage

The Eastern Passage- *S. alterniflora* existing vegetation was significantly lower than the treatment plots, with a mean elevational difference of 0.051m. The regression analysis preformed on plug transplants for health index and elevation does indicate a very slight potential influence of elevation on the health index. This indicates that the elevations were likely high enough for establishment, and other factors likely played a role in health decline. There was also encroaching vegetation into the plots (i.e., from existing vegetation), which was able to survive, however, these rhizomes may be more hearty and able to survive the stress as compared to the fragile, young seedlings. There are other factors aside from elevation that can play a role in the survival of *Spartina* spp. including fetch, acidity of soils, redox potential and availably of nutrients for uptake (Anastasiou and Brooks, 2003). However, given there is an existing *S. alterniflora* community established here this species should be able to grow, and it is likely that current velocities and/or human impact played a larger role in the decline of health.

The health of adjacent transplants were very weakly correlated with elevation, which is not surprising as their rapid decline and mortality was due to the fact that the transplants had little to no root mass attached. The seed plots health indices were strongly correlated with elevation, which indicates that elevation played a role in the health index decline. This is likely due to the plots being too low for newly germinated (very weak) seedlings to establish, although we cannot rule out other factors such as sediment deposits and human impact (trampling). No correlations were run for the wrack material as there was minimal germination.

At the Eastern Passage- *S. patens* plots both transplant and seeding plots were very weakly correlated, indicating that elevation may have a small impact on health indices. However, it is likely that because elevations were within the range for *S. patens* to thrive, that the regression analysis does not tell us much about the relationship. *Spartina patens* survived and thrived because the elevations were within the range for this plant to be competitive and establish. This site was also more protected from both wave energy and human impact as it is located in amongst existing vegetation (Figure 3.24). As of June 2016, one-year post planting, both the transplant and seedling plots at this site are continuing to thrive.

***Figure 3.24**: Plug transplant and seed plots at the Eastern Passage- S. patens site growing in amongst the existing vegetation*

3.5.5 Elevation and survival at Lawrencetown Lake

The elevation of existing vegetation at Lawrencetown lake were significantly lower than the treatment plots and some of the plots were deliberately placed at elevations that were suspected to be too low to for *S. alterniflora* to be able to survive. However, the treatment plots with the lowest elevations do not necessarily have the worst health indices. For example, plot 3 has the lowest health index, but the highest elevation (Appendix E). This likely indicates that elevation may not be the primary driver of plant survival at the site. As well, there was only a mean elevational difference of 0.04 m between the existing vegetation measured and the plots.

Both plug and adjacent transplants did not show a strong correlation with elevation indicating that another factor may have impacted the health index. The most likely cause for this is physical, as soil characteristics are adequate enough for (existing) vegetation establishment at the site. Fetch likely plays a large role in this site. The average fetch is longer than 1.6 m which according to Hardaway et al. (1984) puts it in the medium wave energy zone (Table 1). A site like this would require added structural protection (also called hybrid approaches) to increase survival by reducing wave energy. As mentioned in chapter 2, these methods can include biodegradable or permanent structures such as bio-logs, low-lying sills, or off-shore structures such as oyster balls or reefs (GBF, 2014; NC, 2012).

3.5.6 Recommendations for intertidal planting

Based on of the results of this experiment, serious consideration needs to be taken in to account for not only the size of the above ground portion (biomass) of the plant, but also the size of the below ground root mass. This was indicated in both the plug and adjacent transplants. The greenhouse-grown plug transplants were not allowed enough time to grow to an acceptable size before being transplanted into the field sites. This was due to the original seedling mortality, and the limited time to germinate and grow new seedlings, while maintaining enough time in the growing season to allow the plants to establish. This meant that the plants had very weak and fragile above ground biomass, and very small root mass that was delicate and easily damaged when planting. Serious consideration also needs to be taken into account for the method used when planting these species (Anastasiou and Brooks, 2003). Improper planting methods can damage delicate root mass and lead to a decline in health or mortality

The adjacent transplants from Eastern Passage had very little root mass attached to them, and likely died as a result of this. It is not understood currently if this small root mass was a result of the genetics or more likely, the sediment composition at Eastern Passage. As a contrast the adjacent transplants from Lawrencetown Lake has a significant amount of root mass attached to the plant, and very hearty above ground biomass. These plants were more hardy then the plug transplants, but should be handled with the same care to ensure minimal damage. It also should be explored if structural materials, such as sills or breakwaters are needed in order to mitigate wave energy.

Seeds tend to be more readily available for both growing plugs, and directly seeding surfaces, then suppliers of plugs, particularly in Atlantic Canada. Seeding methods also allows for large areas to be covered very quickly. Seeding may be difficult to use in certain areas as tidal ebb and flow and wave energy can easily remove seeds and soil composition can determine the ease of burial. For example, Eastern Passage has a sandy soil, and burial works at this site because the sediment holds down the seeds so they remain buried. Whereas Lawrencetown has a highly organic soil (coupled with high wave energy) that is easily scoured out and does not work well for burial, as seen with the seeding plots. All of this need to be taken into consideration when using seeds. As well, if planting or seeding was to be completed at Lawrencetown Lake, living shoreline methods us as adding fill or using a structural component (e.g., a sill) would need to be used in conjunction to decrease wave energy and minimize scouring (NOAA, 2014; Shipman, 2001).

Wrack material holds a significant seed bank, may contain viable seeds for planting. However, it should not be relied on as a method of adding vegetation material to the mid to low intertidal zone, as while there was germination of seeds from the wrack material, it is very likely that the species that germinated could not survive in the low marsh.. Where this does have potential is in the transitional upland, or freshwater dominated areas, where species such as *Typha* spp. and *Juncus* spp. can survive (Glogowski, 2013).

Chapter 4: Summary

Shoreline management practices are beginning to shifting away from traditional engineered structures, such as rip rap and bulk heads, and evolving to include the use of natural ecosystem components. This is accomplished through the increased use of natural shoreline management practices such as living shorelines, which incorporate natural materials and work with the geomorphology, hydrology and biology of the system (Gittman et al. 2015; Manis et al. 2015; Pilkey et al. 2015; RAE, 2015; Gianou, 2014; Currin et al. 2009). In addition, these methods offer coastal land and infrastructure protection though erosion mitigation and flood prevention, while increasing other ecosystem services and functions such as habitat restoration and creation, fisheries support, and increased usability of the coastal zone (Gittman et al. 2016; Sutton-Grier et al. 2015; RAE, 2015; COPRI, 2014; Gianou, 2014; Currin et al. 2009). While traditional engineered methods, work well to deflect wave energy and mitigate erosion in certain circumstances, they are having difficulty keeping up with the impacts of climate change, as well there are negative impacts associated with purely engineered structures such as increased scouring, wave energy deflection, and alteration of intertidal and shoreline habitat (RAE, 2015; Gianou, 2014; Gittman et al. 2014; Bilkovic and Mitchell, 2013; Jackson et al. 2013; Currin et al. 2009; MDE, 2008; Bozek and Burdick, 2005; Moschella et al. 2005; Rogers and Skrabal, 2001; Shipman, 2001; Zelo et al. 2000).

Chapter 2 reviews some of the more commonly used methods when constructing a living shoreline including, bank grading, vegetation addition and low-lying structural materials such as sills. These methods were all prevalent through literature and applications. For example, marsh-sill combinations (sills and marsh vegetation addition) composed half of all living shoreline projects completed in the United States to date (Chesapeake Bay Trust, 2014). While there is an increasing bank of living shorelines literature continuing to be published, this chapter further discusses the lack of quantitative data (construction methods or monitoring) being published within this literature. This makes living shorelines a difficult decision for coastal zone managers, as this lack of data means they are relying on incomplete science. As well, no concrete definition of living shorelines has been given in peer-reviewed literature to date, and attempts to do so by researchers and practitioners have been done on a case by case basis, leading to a multitude of names and characteristics used to define what a living shoreline is (Gittman et al. 2016; Gianou, 2014; Patterson et al. 2014; Pilkey et al. 2012; Shipman, 2001). This chapter has attempted to bring together as much information on applicable methods as possible, and includes diagrams to aid coastal zone managers in comprehending the ideas behind these methods. One of the main conclusions to come out of this chapter is that this set of methods, while not a complete list, need to be applied with a site specific approach, that is to say there is no one size fits all set of living shoreline methods that can be applied to all coastal areas.

The methods reviewed in Chapter 2 indicated that planting intertidal vegetation was an extremely common method in living shoreline projects, it was noted that these methods had not yet been applied (or at least documented) in the Atlantic Canadian provinces (Nova Scotia, New Brunswick, Prince Edward Island and Newfoundland). Success of planted vegetation can depend heavily on horticultural practices prior to planting and planting techniques used. Demonstration of appropriate techniques and quantification of their effects may help local practitioners and planners further develop a region's capacity to implement these technologies. Given this, four methods of vegetation addition were attempted at two sites using *S.alterniflora* (at the Eastern Passage- *S. alterniflora* and Lawrenctown Lake sites) and one site of *S. patens* (at the Eastern Passage – *S. patens* site), both common intertidal species (Konisky and Burdick, 2004). Seeds were initially germinated for use as transplants, due to the lack of available suppliers, by applying four storage treatments to the seeds (germinated in freshwater/stored frozen, freshwater/stored cold, saltwater/frozen, saltwater/cold). The three targeted species, *S. alterniflora, S. patens, S. pectinata* all had varying germination rates depending on the storage treatment. For *S. alterniflora*, saltwater/frozen yielded the lowest germination, and freshwater/cold yielded the highest rate of germination. *Spartina patens*, which had the highest overall germination, and *S. pectinata*, the best germination success was found with the freshwater/cold treatment, and the least success with either of the frozen treatments.

In applying the vegetation addition methods, I had minimal success with the survivability of *S. alterniflora* transplants I grew due to the fact they were likely too young to be transplanted into the sites, and this caused almost complete mortality at both sites. A regression analysis indicated that the health index was not dominantly impacted by elevation at both sites, but from other forces (e.g., fetch, currents, human impact). Of the (adjacent) transplants used, I had marginally better success with health indices of the transplants at Lawrencetown Lake, and a regression analysis indicated that elevation was not the main factor of health index at this site either, but more likely that the fetch was too large. As indicated in Chapter 2, a fetch of 1.6 km or more likely requires some type of structural protection (sill or bio-log), and the average fetch at Lawrencetown Lake was measured at approximately 1.6km (Hardaway et al. 1984). *Spartina alterniflora* seeds germinated at both the Eastern Passage- *S. alterniflora* and Lawrencetown Lake sites, but quickly died, likely due to stress from currents, wave actionand human impacts such as trampling. As well, at the Lawrencetown Lake site, seeds were scoured out by wave impact in less than 1 week, indicating that wave energy played a larger role at this site. Wrack material followed the same trend, where some seeds germinated at the Eastern Passage *S. alterniflora* site, but quickly died due to likely due to low elevations and the wrack being composed of higher-marsh species (Glogowski, 2013; Minchinton, 2013; Leck, 2003). As well scouring occurred in the wrack plots at Lawrencetown Lake, which lead to no germination of wrack material.

The *S. patens* seeds and plug transplants did exceptionally well at the Eastern Passage- *S. patens* site, with health indices remaining high for the extent of the growing season. The likely reason for the high survival rates was that elevations were in the range for *S. patens* to thrive (elevations at the *S. patens* plots were significantly higher than the Eastern Passage- *S. alterniflora* plots), as well there was added protection from wave energy due to existing vegetation communities. Upon checking the site 1 year later, the plants have survived, and continue to thrive at the site, indicating that I was able to establish a *S. patens* community at the Eastern Passage- *S. patens* site (Figure # 3.22).

What this chapter establishes is that there are a multitude of factors that can impact the success and survival of vegetation within the intertidal zone. Physical and environmental factors such as wave climate, elevation, tidal inundation, and soil characteristics can impact transplant and seedling health. As well, human disturbance such as trampling, had a large impact at the Eastern Passage- *S. alterniflora* site, and reinforces the importance of public education and proper site selection when working in public areas such as sand flats or beaches.

The living shoreline approach to shoreline management is proving to be a viable option when there is concern regarding critical land or infrastructure eroding, flooding or degrading. Traditional engineered methods, while they have been proven to work in the past, they are facing increased pressure from climate change and maintenance costs. There is a wide variety of living shoreline methods available to suit most sites, depending on the site characteristics and goals of the project (e.g., habitat creation or erosion mitigation). The seed germination and vegetation addition in Chapter 3 have implications for living shoreline projects in Atlantic Canada, as there are no greenhouses with intertidal vegetation available, so alternative methods (seeds, wrack, adjacent or grown transplants) would likely need to be used. This research has demonstrated that the physical conditions of the sites (elevation, wave energy and currents), as well as the health of transplants, and viability of seeds, can be the main determinates of success of vegetation addition methods in living shoreline projects. Finally, the survival of some of the plants at the field sites confirms that local plant material can be used in living shoreline projects in Atlantic Canada. Further development of local capacity to produce native shoreline plant species at commercial scales would help facilitate the development of large-scale living shorelines projects.

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Appendix A: Summary table of living shoreline methods and some of the major benefits associated with them.

		Potential benefits associated with using living shoreline methods									
		Habitat Creation	Wave energy dissipation	Soil compaction	Run-off capture	Decreases slope steepness	Addresses Shoreline/dune erosion	Vegetation addition	Sediment accretion and retention	Usability of shoreline	Increased shoreline buffer
Example living shoreline methods	Beach nourishment	x	x			x	x		x	x	x
	Bank grading		x			x				x	
	Infilling		x				x		x		
	Upland planting	x	x	x	x		x	x	x		
	Intertidal planting	x	x	x			x	x	x	x	x
	Subtidal planting	x	x	x			x	x			
	Sills		x				x		x		
	Bio-logs	x	x				x		x		
	Debris	x	x				x		x		
	Oyster reefs	x	x								
	Breakwaters		x								

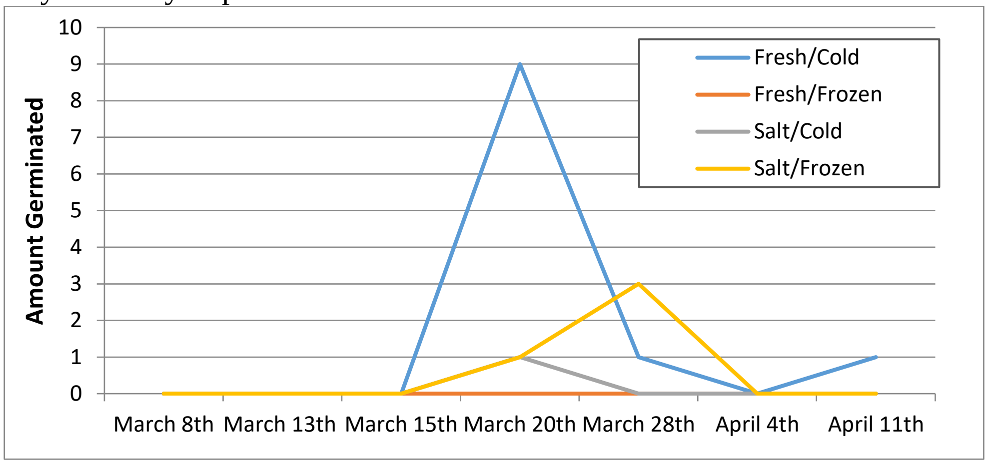
Appendix B: Potential species for use in Living Shoreline projects in Nova Scotia

Coastal species (Dune and Salt marsh)			
Species Name	**Common Name**	**Vegetation Type**	**Notes**
Spartina alterniflora	Smooth Cordgrass	Grass	low intertidal
Spartina patens	Saltmeadow cordgrass	Grass	mid-high intertidal
Spartina pectinata	Erect cordgrass	Grass	high intertidal to transitional
Juncus gerardii	Black grass	Grass	high intertidal to transitional
Ammophila breviligulata	Beach grass	Grass	Dune grass
Elymus repens	Quack grass	Grass	Dune grass
Elymus virginicus	Virginia Wild Rye	Grass	Dune grass
Upland Species (Terrestrial)			
Species Name	**Common Name**	**Vegetation Type**	**Notes**
Raphanus raphanistrum	Wild Radish	herbaceous perennial plant	Edible
Lupinus spp.	Lupines	herbaceous perennial plant	Garden lupine may be invasive (Mittelhouser et al. 2010)
Achillea milefolium	Common Yarrow	herbaceous perennial plant	Edible
Vaccinium angustifolium	Low-bush blueberry	Shrub	edible
Morella carolinisnsis	Northern Bayberry	Shrub	Edible
Cornus stolonifera	Red-osier dogwood	Shrub	can grow roots from cuttings
Swida rugosa	Round leaf dogwood	Shrub	Swida alterniflora can also be used
Rosa spp.	Rose species	Shrub	See below for invasive species
Salix spp.	Willow species	Shrub	can grow roots from cuttings
Alnus spp.	Alder species	Tree	can grow roots from cuttings
Acer spp.	Maple species	Tree	See below for invasive species
Picea spp.	Spruce trees	Tree	
Pinus spp.	Pine trees	Tree	

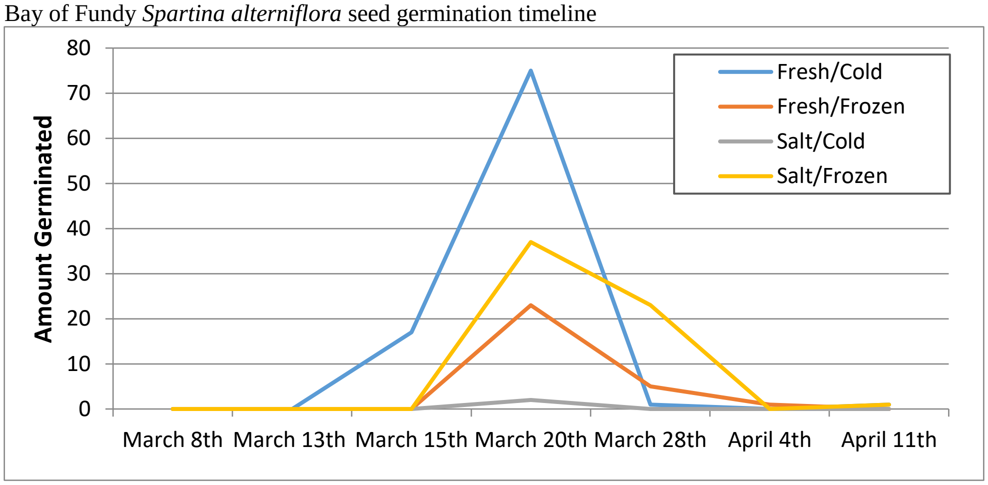
Undesirable species			
Species Name	**Common Name**	**Vegetation Type**	**Notes**
Phragmites australis	Common reed	Grass	Aggressively Invasive
Heracleum mantegazzianum	Giant hogweed	herbaceous perennial plant	Poisonous
Tussilago farfara	Coltsfoot	herbaceous perennial plant	Invasive
Fallopia japonica	Japanese knotweed	herbaceous perennial plant	Invasive
Rose muntiflora	Multiflora rose	Shrub	Invasive
Lythrum salicaria	Purple loostrife	herbaceous perennial plant	Invasive
Lawn grass	Sod	Grass	Shallow root systems
Acer platanoides	Norway Maple	Tree	Aggressively invasive in natural areas

Appendix C: Timeline of germination graphs

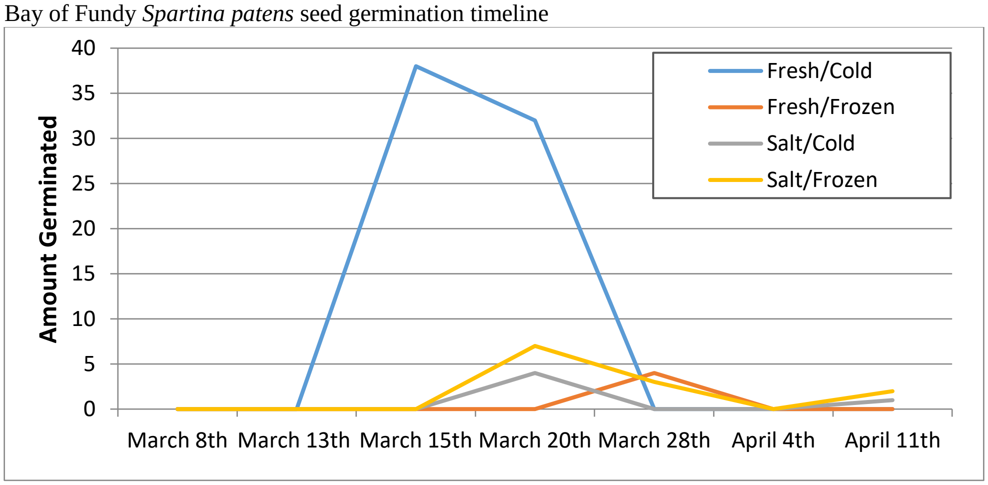
Bay of Fundy Population



Bay of Fundy *Spartina alterniflora* seed germination timeline

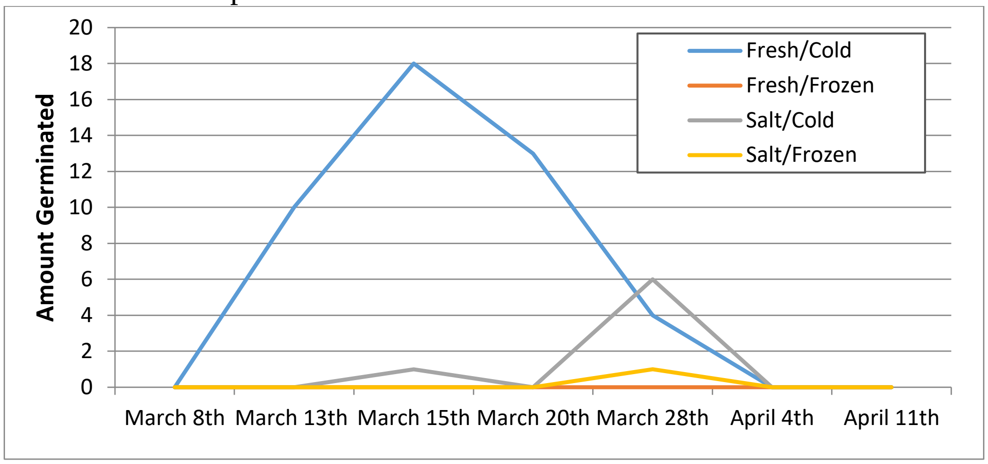


Bay of Fundy *Spartina patens* seed germination timeline

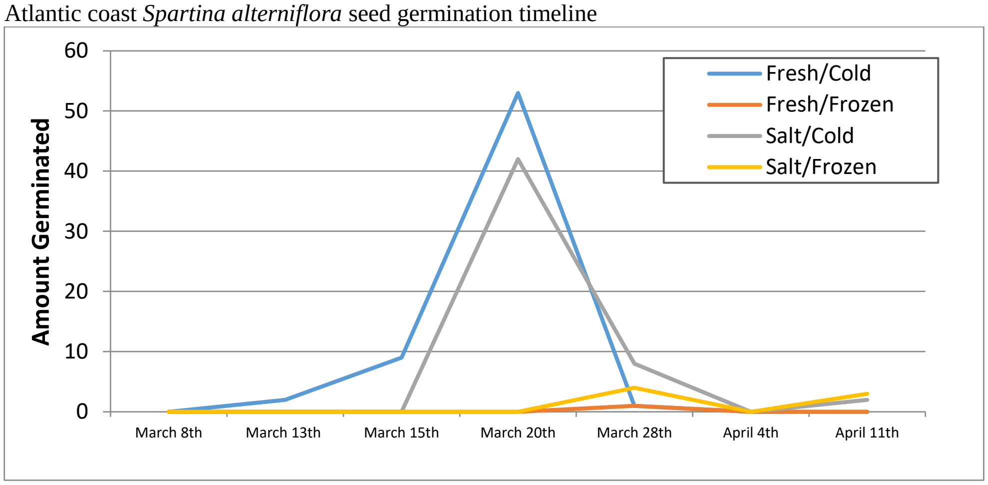


Bay of Fundy *Spartina pectinata* seed germination timeline

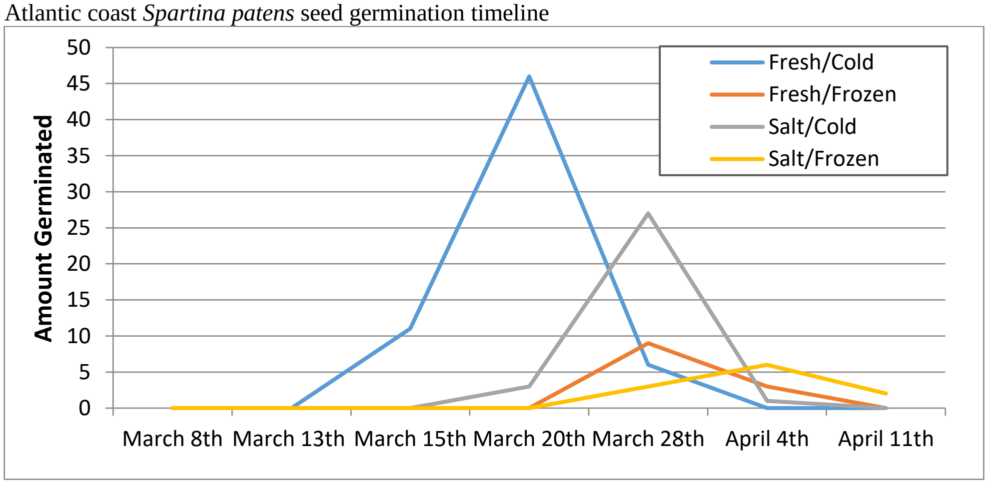
Atlantic Coast Population



Atlantic coast *Spartina alterniflora* seed germination timeline



Atlantic coast *Spartina patens* seed germination timeline

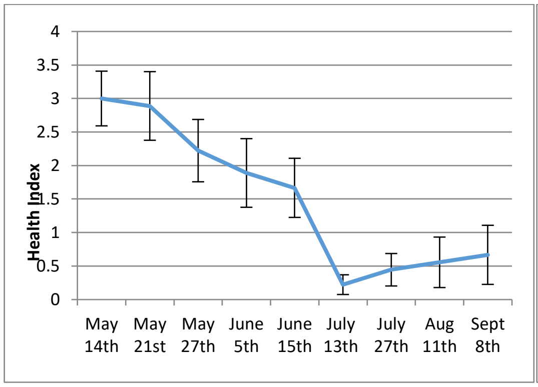


Atlantic coast *Spartina pectinata* seed germination timeline

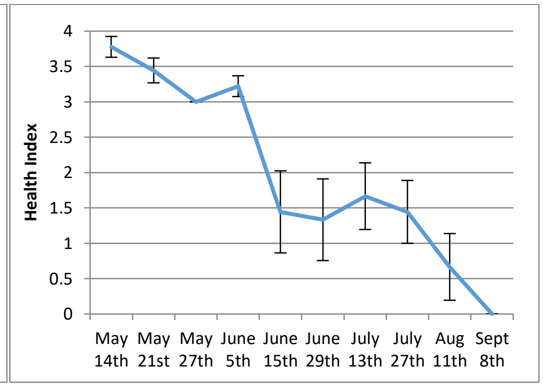
Appendix D: Individual health index graphs for each of the sites broken down by treatment

Eastern Passage- *S. alterniflora* Site Health Index graphs

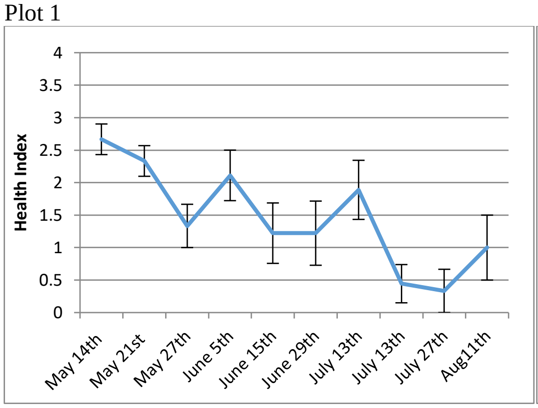
Plug transplant plots



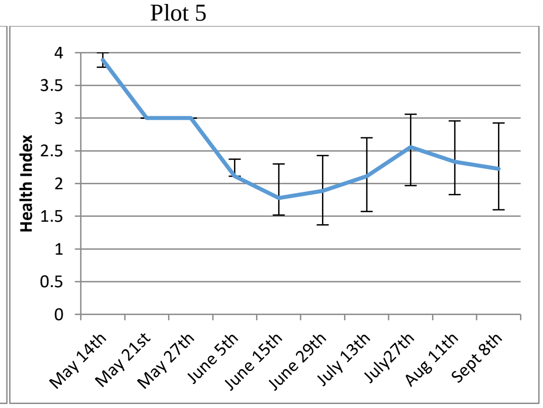
Plot 1



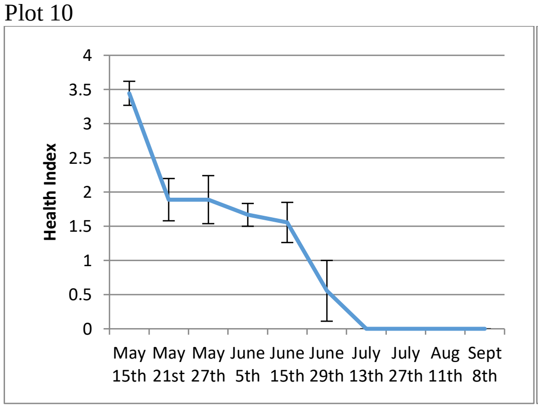
Plot 5



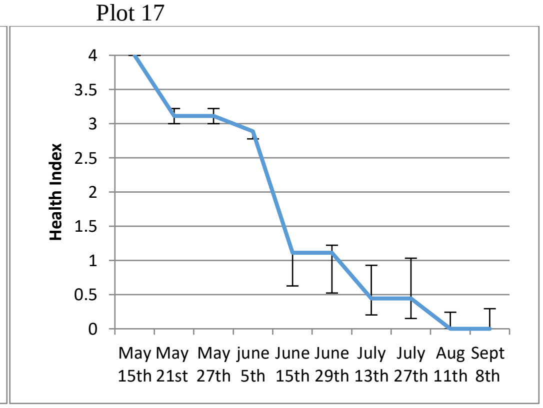
Plot 10



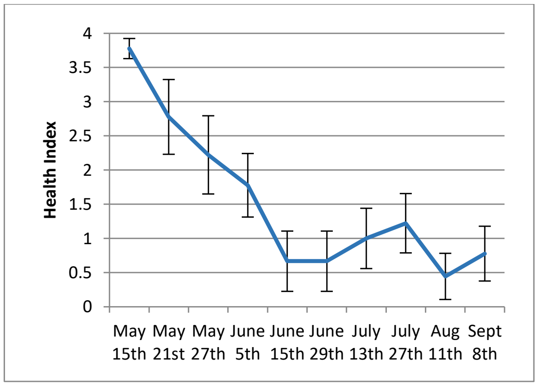
Plot 17



Plot 1B



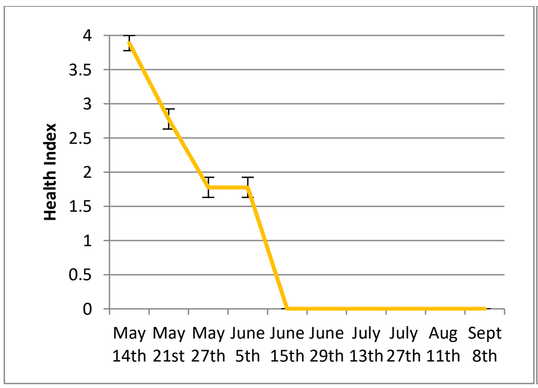
Plot 1c



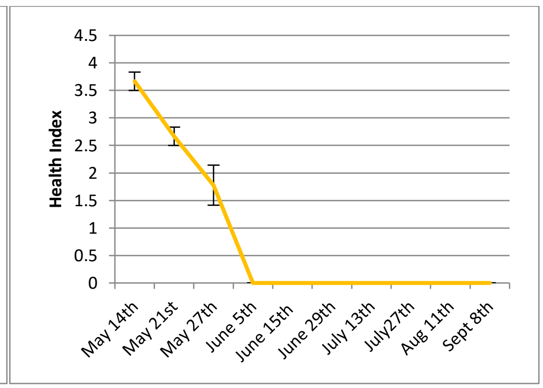
Plot 1D

Eastern Passage- *S. alterniflora* Site Health Index graphs

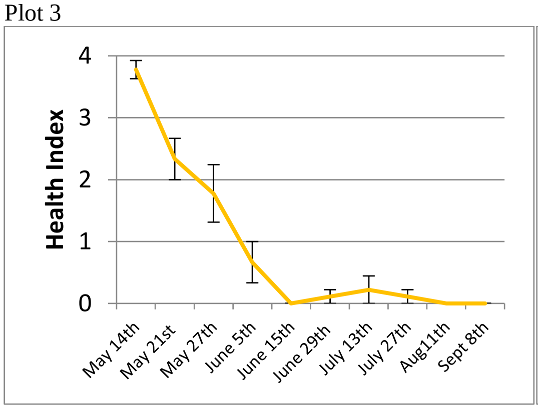
Adjacent transplant plots



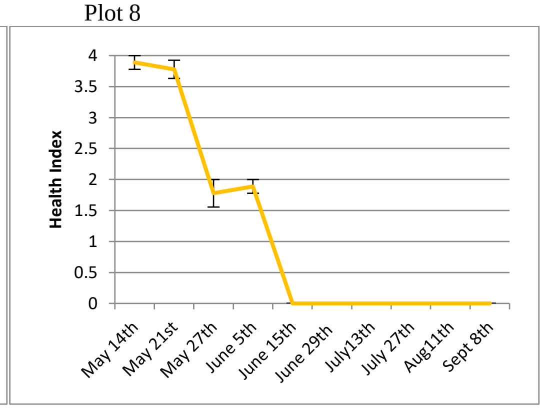
Plot 3



Plot 8

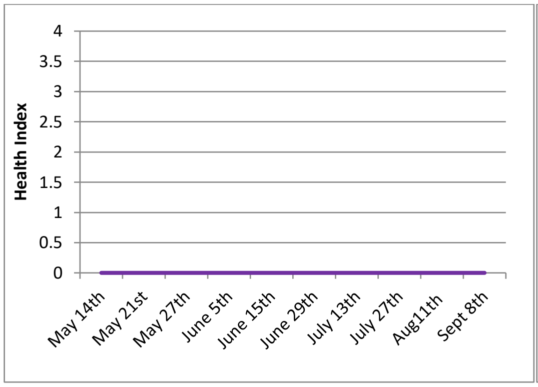


Plot 12

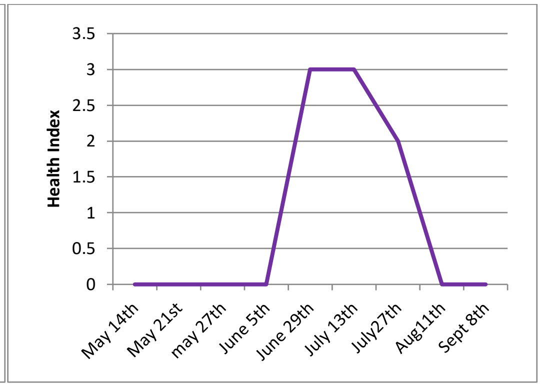


Plot 14

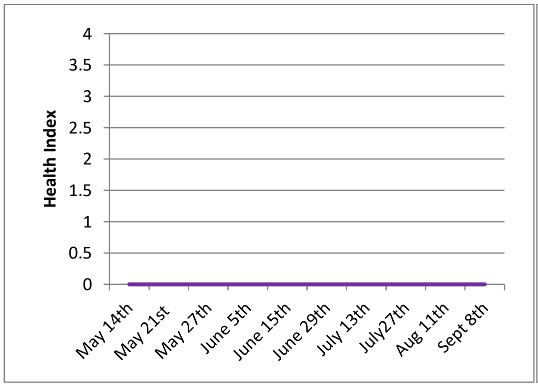
Eastern Passage- *S. alterniflora S*ite Health Index graphs
Seeding plots



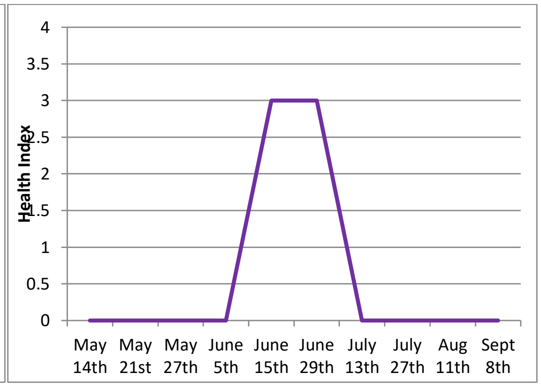
Plot 2



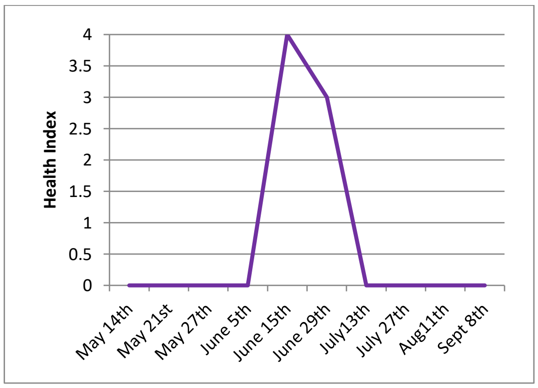
Plot 6



Plot 9

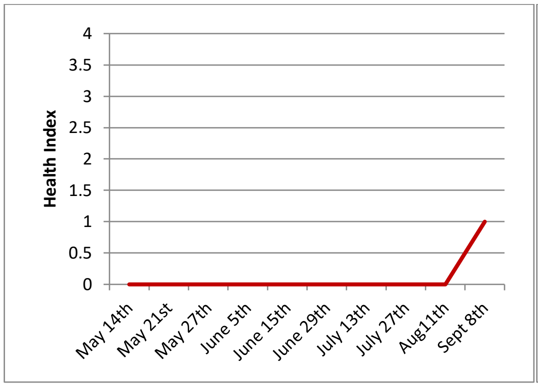


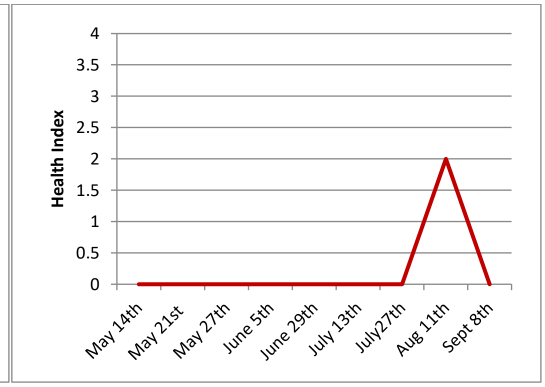
Plot 15



Plot 16

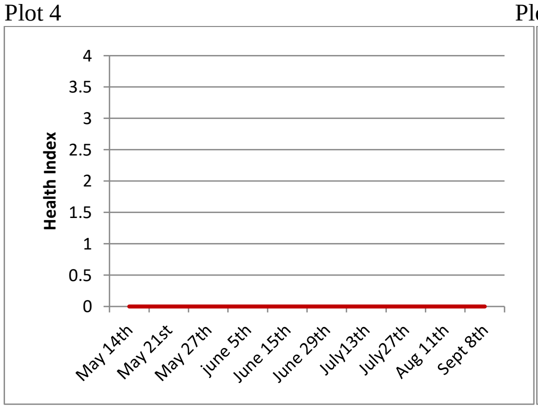
Eastern Passage- *S. alterniflora* Site Health Index graphs
Wrack plots

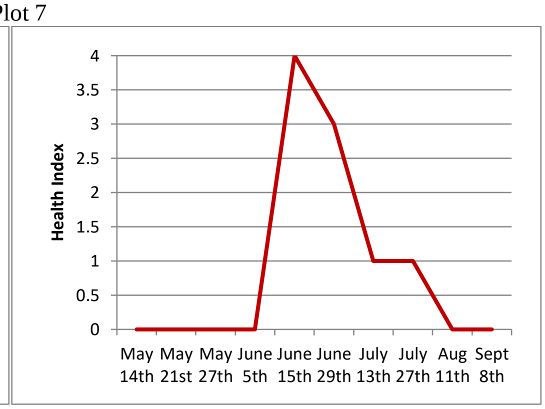




Plot 4

Plot 7



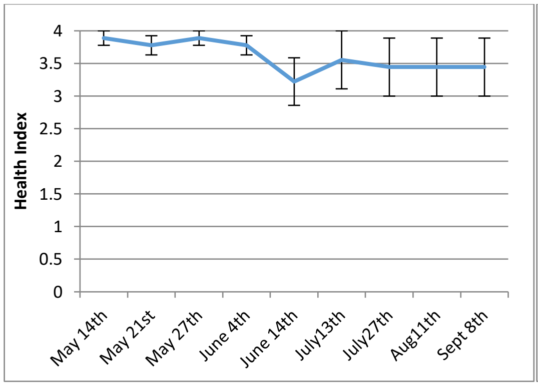


Plot 11

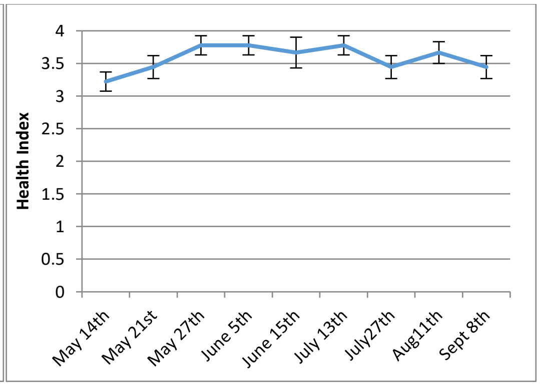
Plot 13

Eastern Passage- *S. patens* Site Health Index graphs

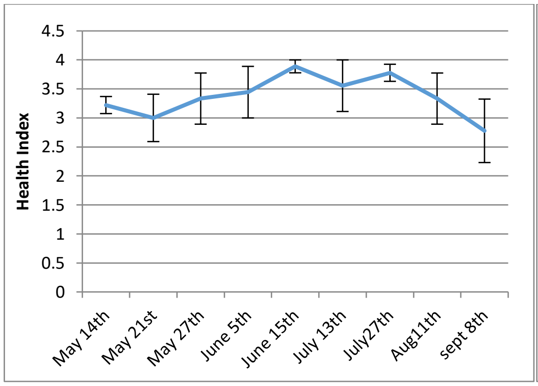
Plug transplant plots



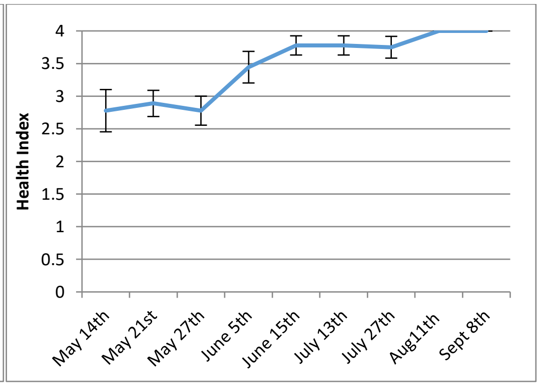
Plot 1



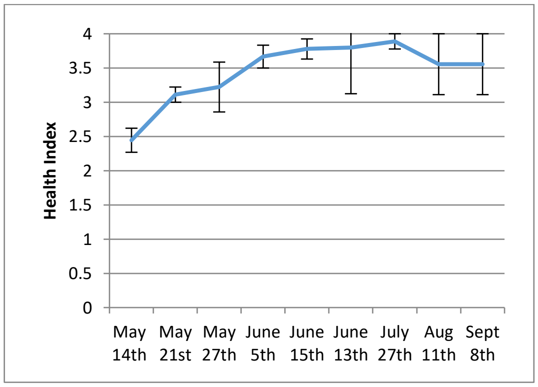
Plot 3



Plot 5

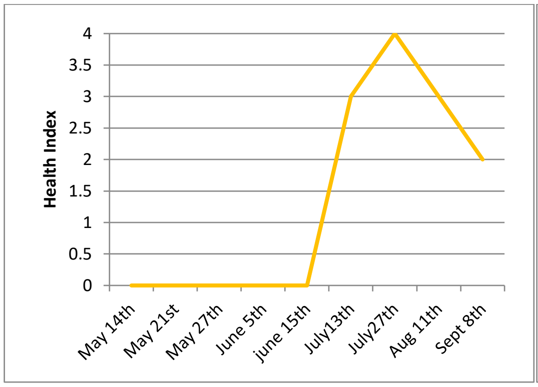


Plot 7

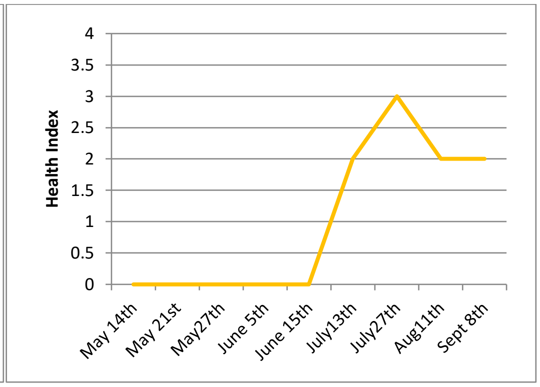


plot 9

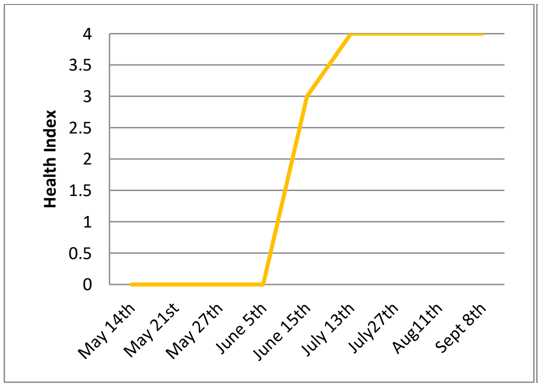
Eastern Passage- *S. patens* Site Health Index graphs
Seeding plots



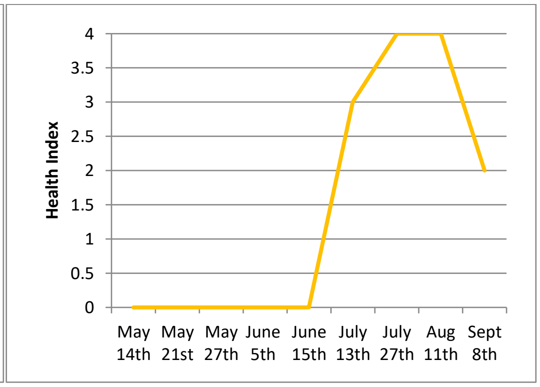
Plot 2



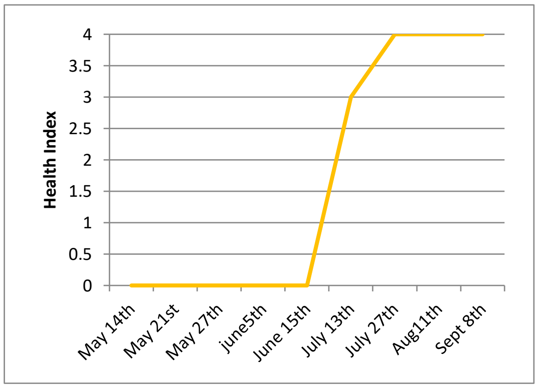
Plot 4



Plot 6



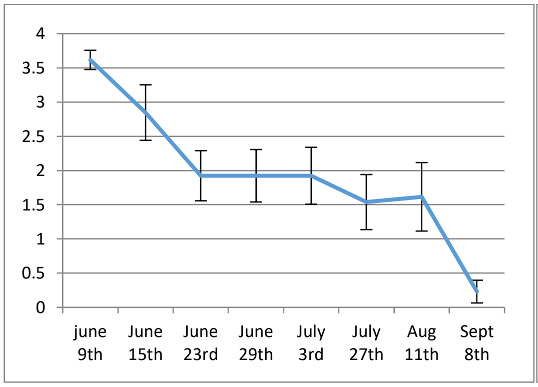
Plot 8



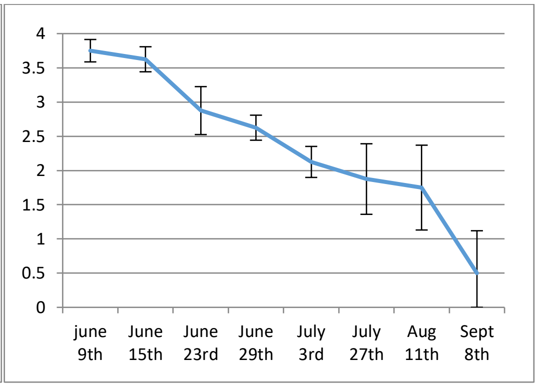
Plot 10

Lawrencetown Lake Health Index graphs

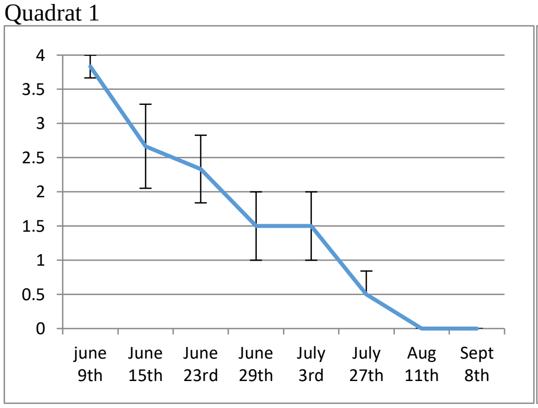
Plug transplant plots



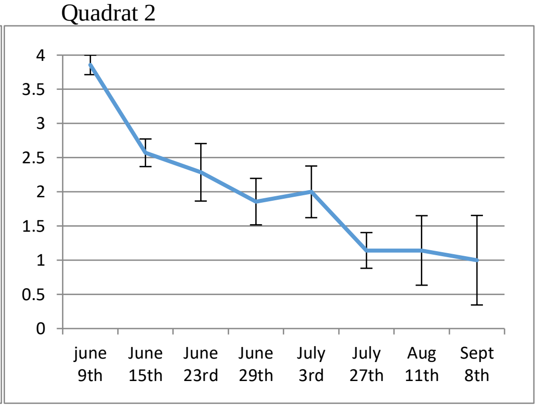
Quadrat 1



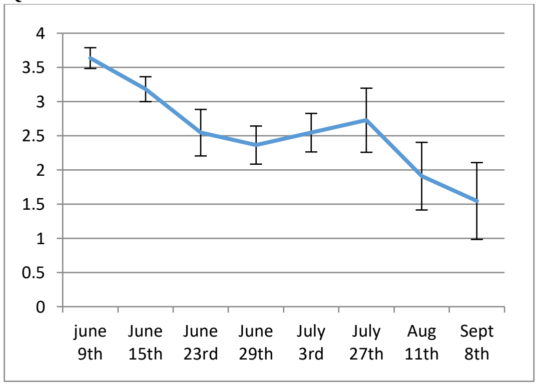
Quadrat 2



Quadrat 3



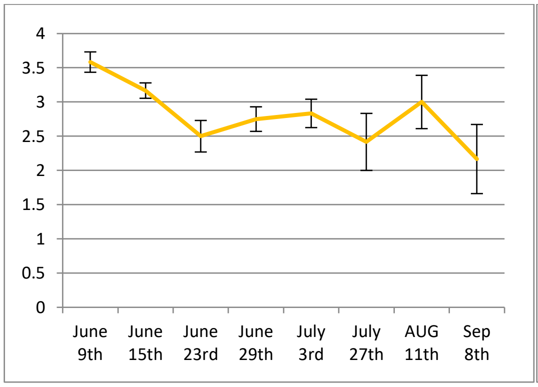
Quadrat 4



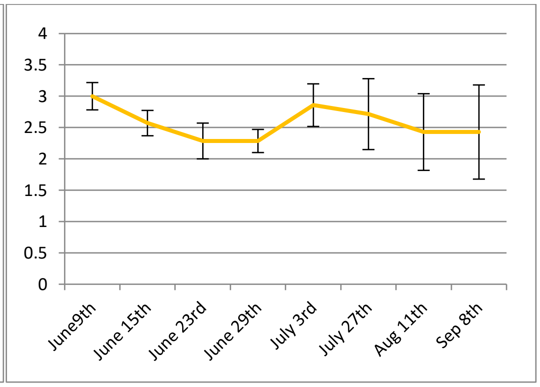
Quadrat 5

Lawrencetown Lake Health Index graphs

Plug transplant plots



Quadrat 1



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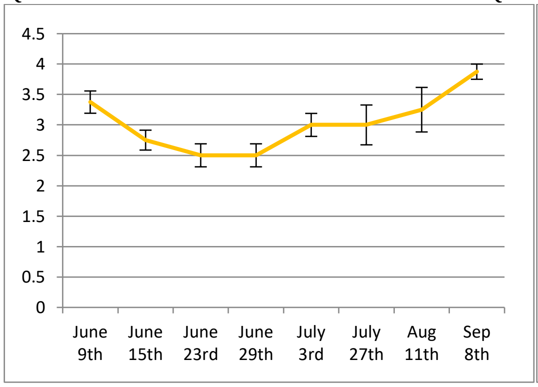
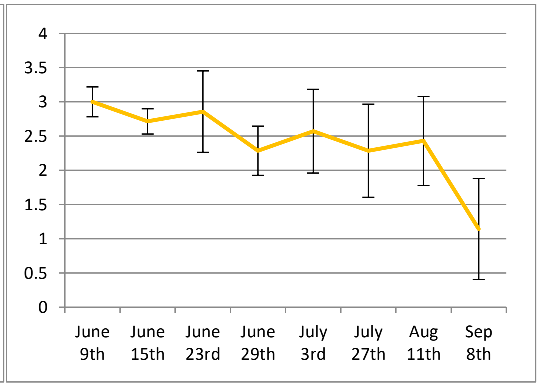
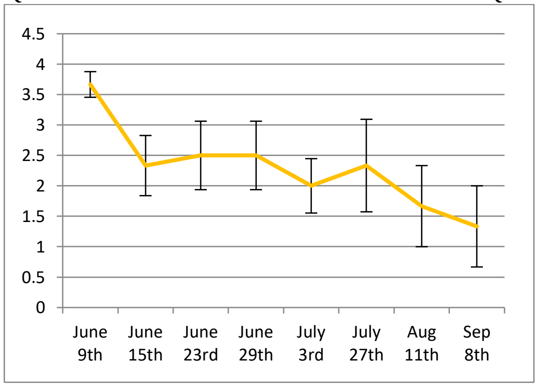


Quadrat 3



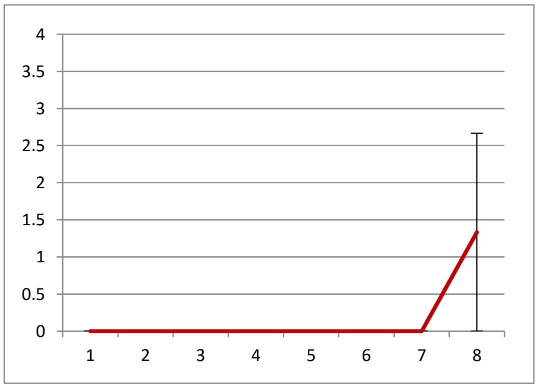
Quadrat 4



quadrat 5

Lawrencetown Lake Health Index graphs

Wrack plots



Quadrat 5

Appendix E: Elevation and slope for each of the treatment quadrats per site

Eastern Passage- *S. alterniflora* Site

Quadrat #	Slope	Average elevation (m)
1	0.015	0.916
5	-0.027	0.948
10	-0.033	0.917
17	-0.033	0.926
1B	-0.015	0.973
1C	-0.024	0.971

Showing slope and average elevation for plug transplant plots at the Eastern Passage-*S. alterniflora* site

Quadrat	Slope	Average Elevation (m)
3	-0.025	0.95
8	-0.015	0.96
12	-0.01	0.921
14	-0.016	0.931

Showing slope and average elevation for adjacent transplant plots at the Eastern Passage-*S. alterniflora* site

Quadrat #	Slope	Average Elevation (m)
2	-0.007	0.949
6	-0.002	0.961
9	-0.026	0.94
15	-0.017	0.929
16	-0.013	0.917

Slope and average elevation for seed plots at the Eastern Passage-*S. alterniflora* site

Quadrat #	Slope	Average Elevation (m)
2	-0.007	0.949
6	-0.002	0.961
9	-0.026	0.94
15	-0.017	0.929
16	-0.013	0.917

Slope and average elevation for wrack plots at the Eastern Passage-*S. alterniflora* site

Eastern Passage- *S. patens* site

Quadrat	Slope	Average Elevation (m)
1	0.009	1.160
3	-0.013	1.151
5	0.011	1.150
7	-0.008	1.156
9	-0.005	1.160

Showing slope and average elevation for plug transplant plots at the Eastern Passage-*S. patens* site

Quadrat	Slope	Average elevation (m)
2	0.003	1.162
4	-0.011	1.156
6	0.013	1.154
8	0.001	1.155
10	0.005	1.154

Slope and average elevation for seed plots at the Eastern Passage-*S. patens* site

Quadrat	Slope	Average Elevation (m)
1	-0.023	0.471
2	-0.053	0.43
3	-0.002	0.485
4	-0.03	0.396
5	-0.045	0.433

Slope and average elevation for the five quadrats at the Lawrencetown Lake site

Appendix F: Relevant climate data, temperature and snow cover

Month	2015 Average Temperature	Average Temperature Climate normals	2015 Snowfall (cm)	Climate Normals snowfall (cm)	Rainfall (mm)	Rainfall Normals	Total Precipitation	Precipitation Normals
March	-4.73	-0.7	153.7	31.1	32.8	96.9	178,1	125.2
April	1.95	4.3	26.2	11.9	80.1	105,3	103.3	117.7
May	11.42	9.2	0.4	1.7	56.6	118.9	57	120.6
June	13.28	14.3	0	0	154.1	117.9	154.1	117.9
July	18.61	18.1	0	0	117.4	103.4	117.4	103.4
August	20.73	18.5	0	0	76.1	91.8	76.1	91.8
September	17.15	15.1	0	0	75.6	103	75.6	103
October	8.64	9.6	0.03	0.2	190.4	130.3	190.3	130.5

Climate data for Halifax showing 2015 vs the Climate Normals (Environment Canada, 2015)

Appendix G: Layout of plots at Eastern Passage and Lawrencetown Lake

Layout of the Eastern Passage *S. alterniflora* Plots

ID	Treatment	Notes
1	Plug Transplants	Some encroaching vegetation
2	Seeds- Lawrencetown	No growth
3	Adjacent Transplants	Not enough root mass attached to transplant
4	Wrack- Lawrencetown	Some growth at end of growing season
5	Plug Transplants	Trampled
6	Seeds- Windsor	Germinated, then became stressed and died
7	Wrack- Lawrencetown	Some growth, then death
8	Adjacent Transplants	Not enough root mass attached to transplant
9	Seeds- Windsor	*S. Patens*. No Growth
10	Plug Transplants	Encroaching vegetation
11	Wrack- Lawrencetown	No growth
12	Adjacent Transplants	Not enough root mass attached to transplant
13	Wrack- Lawrencetown	Growth, then stressed and death
14	Adjacent Transplants	Not enough root mass attached to transplant
15	Seeds- Rainbow Haven	Heavy sediment deposit early July, death of seedlings
16	Seeds- Rainbow Haven	*S. Patens*. Heavy sediment deposit early July, death of seedlings
17	Plug Transplants	Survived.
1B	Plug Transplants	In existing vegetation. Transplants buried mid growing season
1C	Plug Transplants	In existing vegetation. Transplants buried mid growing season
1D	Plug Transplants	Encroaching vegetation

Layout of the Eastern Passage *S. alterniflora* Plots

Plot ID	Treatment	Notes
1	Plug Transplant	Existing vegetation, higher marsh species
2	Seeds- Windsor	Existing vegetation, higher marsh species
3	Plug Transplant	Existing vegetation, higher marsh species
4	Seeds- Cogmagun River	Existing vegetation, higher marsh species
5	Plug Transplant	Existing vegetation, higher marsh species
6	Seeds Windsor/ Rainbow Haven	Existing vegetation, higher marsh species
7	Plug Transplant	Existing vegetation, higher marsh species
8	Seeds - Windsor	Existing vegetation, higher marsh species
9	Plug Transplant	Existing vegetation, higher marsh species
10	Seeds- Cogmagun River	Existing vegetation, higher marsh species

Layout of the Eastern Passage *S. patens* plots

Quadrat	ID #	Treatment	PlantID #	Treatment
1	1	Plug Transplant	14	Adjacent Transplant
	2	Adjacent Transplant	15	Plug Transplant
	3	Plug Transplant	16	Adjacent Transplant
	4	Adjacent Transplant	17	Plug Transplant
	5	Plug Transplant	18	Adjacent Transplant
	6	Adjacent Transplant	19	Plug Transplant
	7	Plug Transplant	20	Adjacent Transplant
	8	Adjacent Transplant	21	Plug Transplant
	9	Plug Transplant	22	Adjacent Transplant
	10	Adjacent Transplant	23	Plug Transplant
	11	Plug Transplant	24	Adjacent Transplant
	12	Adjacent Transplant	25	Plug Transplant
	13	Plug Transplant		

Layout of Quadrat 1 at Lawrencetown Lake

Quadrat	ID#	Treatment	Plant ID #	Treatment
2	1	Seeds	11	Wrack
	2	Plug Transplant	12	Plug Transplant
	3	Adjacent Transplant	13	Plug Transplant
	4	Adjacent Transplant	14	Adjacent transplant
	5	Plug Transplant	15	Plug Transplant
	6	Plug Transplant	16	Adjacent transplant
	7	Adjacent Transplant	17	Plug Transplant
	8	Plug Transplant	18	Wrack
	9	Wrack	19	Adjacent transplant
	10	Adjacent Transplant	20	Seeds

Layout of Quadrat 2 at Lawrencetown Lake

Quadrat	ID #	Treatment	Plant ID #	Treatment
3	1	Adjacent Transplant	14	Adjacent Transplants
	2	Plug Transplant	15	Plug Transplant
	3	Seeds	16	Adjacent Transplants
	4	Plug Transplant	17	Seeds
	5	Wrack	18	Adjacent Transplants
	6	Wrack	19	Plug Transplant
	7	Seeds	20	Adjacent Transplants
	8	Plug Transplant	21	Plug Transplant
	9	Adjacent Transplant	22	Adjacent Transplants
	10	Plug Transplant	23	Plug Transplant
	11	Plug Transplant	24	Adjacent Transplants
	12	Plug Transplant	25	Plug Transplant
	13	Seeds		

Layout of Quadrat 3 at Lawrencetown Lake

Quadrat	ID #	Treatment	PlantID #	Treatment
4	1	Plug Transplant	11	Plug Transplant
	2	Wrack	12	Adjacent Transplant
	3	Seeds	13	Wrack
	4	Plug Transplant	14	Adjacent Transplant
	5	Adjacent Transplant	15	Adjacent Transplant
	6	Seeds	16	Seeds
	7	Adjacent Transplant	17	Adjacent Transplant
	8	Plug Transplant	18	Wrack
	9	Plug Transplant	19	Plug Transplant
	10	Wrack	20	Adjacent Transplant

Layout of Quadrat 4 at Lawrencetown Lake

Quadrat	ID #	Treatment	Plant ID #	Treatment
5	1	Adjacent Transplant	11	Plug Transplant
	2	Wrack	12	Adjacent Transplant
	3	Plug Transplant	13	Adjacent Transplant
	4	Seeds	14	Seeds
	5	Adjacent Transplant	15	Plug Transplant
	6	Plug Transplant	16	Wrack
	7	Adjacent Transplant	17	Plug Transplant
	8	Seeds	18	Plug Transplant
	9	Plug Transplant	19	Adjacent Transplant
	10	Wrack		

Layout of Quadrat 5 at Lawrencetown Lake

Appendix H: Germination per day for both populations

Species	Treatment	March 13th	March 15th	March 20th	March 28th	Apr 4th	April 11th
S. alterniflora	Fresh/Cold	0	0	9	1	0	1
S. alterniflora	Fresh/Frozen	0	0	0	0	0	0
S. alterniflora	Salt/Cold	0	0	1	3	0	0
S. alterniflora	Salt/Frozen	0	0	0	0	0	0
S. patens	Fresh/Cold	0	17	75	1	0	1
S. patens	Fresh/Frozen	0	0	23	5	1	0
S. patens	Salt/Cold	0	0	9	10	0	1
S. patens	Salt/Frozen	0	0	28	13	0	0
S. pectinata	Fresh/Cold	0	38	32	0	0	0
S. pectinata	Fresh/Frozen	0	0	0	4	0	0
S. pectinata	Salt/Cold	0	0	4	0	0	1
S. pectinata	Salt/Frozen	0	0	3	3	0	1

Total germination per treatment for the Bay of Fundy population

Species	Treatment	March 13th	March 15th	March 20th	March 28th	Apr 4th	April 11th
S. alterniflora	Fresh/Cold	10	18	13	4	0	0
S. alterniflora	Fresh/Frozen	0	0	0	0	0	0
S. alterniflora	Salt/Cold	0	11	8	13	1	0
S. alterniflora	Salt/Frozen	0	0	0	1	0	0
S. patens	Fresh/Cold	2	9	53	1	0	0
S. patens	Fresh/Frozen	0	0	0	1	0	0
S. patens	Salt/Cold	0	0	42	8	0	2
S. patens	Salt/Frozen	0	0	0	4	0	3
S. pectinata	Fresh/Cold	0	11	46	6	0	0
S. pectinata	Fresh/Frozen	0	0	0	9	3	0
S. pectinata	Salt/Cold	0	0	3	27	1	0
S. pectinata	Salt/Frozen	0	0	0	3	6	2

Total germination per treatment for the Atlantic population