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RESTORATION OF NATIVE PLANT COMMUNITIES IN SAND DUNE SYSTEMS OF PLUM ISLAND, NEWBURY, MASSACHUSETTS

by

Natalie Feldsine
B.S., University of New Hampshire, 2014

THESIS

Submitted to the University of New Hampshire in Partial Fulfillment of

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in

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This thesis has been examined and approved in partial fulfillments of the requirements for the degree of Master of Science in Plant Biology by:

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Original approval signatures are on file with the University of New Hampshire Graduate School

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ABSTRACT

The impacts of Superstorm Sandy on coastal resources of the eastern United States have brought the importance of resilient sand dune systems into focus. While dunes are primarily dominated by American beachgrass (*Ammophila breviligulata*), a host of other native species commonly occur in these systems, providing diversity and habitat complexity that is often not recognized or incorporated into dune restoration initiatives, and could benefit sites where dune dieout is a concern. Dieout refers to the death of *A. breviligulata* occurring in large patches. The goal of this study was to explore the importance of biodiversity on dune resiliency by using a variety of native species (in addition to *A. breviligulata*) to stabilize and revegetate dunes impacted by coastal storms, foot traffic, encroachment and other impacts in dunes on the north shore of Massachusetts. Chapter I examines the natural history of Plum Island, Newbury, Massachusetts. Chapter II details how field experiments were used to determine which native dune species may be well suited for restoration by recording plant survivorship, growth rate, and relative ability to trap and accrete windblown sand in foredune habitats. Comparisons were also made to examine the differences in sand accretion capability of three experimental treatments: 1) a single species (*A. breviligulata* only), 2) a low diversity (*A. breviligulata* with *Solidago sempervirens*), and 3) higher diversity plots (*A. breviligulata* with *S. sempervirens*, *Lathyrus japonicus*, and *Cakile edentula*). Finally, diversity and percentage cover were compared between control site (healthy, natural dunes) versus restoration areas and dunes exhibiting signs of dune dieout. Based upon the results of three planting efforts, *S. sempervirens* and *L. japonicus* appear to be best suited for restoration plantings. However, relative sand accretion was not affected by diversity level (low or high). Instead, sand accretion was most affected by proximity to the ocean. As expected, percentage cover was greatest in the reference sites, compared to the restoration areas and dunes with dieout. However, plant species diversity was greatest in dieout areas. While the benefits of diversity (structural, habitat, and ecological complexity) are essential to maintaining functional coastal ecosystems, the quantitative effects of diversity on dune resiliency will require further study to determine the species, planting methods, and planting times required for restoration efforts. Finally, Chapter III describes how this research was incorporated into local Science, Technology, Engineering, Art, and Math (STEAM) initiatives.

CHAPTER I

NATURAL HISTORY OF THE DUNES OF PLUM ISLAND

Geology & Climate

Plum Island is a barrier beach island, 13 km in length, that formed as the Wisconsin Ice Sheet retreated approximately 6,300 years ago (McDonnell, 1981; FitzGerald *et al.*, 1994; Hein *et al.*, 2016). Plum Island projects from the mainland into the Atlantic Ocean, specifically into the Gulf of Maine, which is an important influence on the local climate. It is part of the Merrimack Embayment barrier system, which is the longest barrier system found within the Gulf of Maine (Hein *et al.*, 2012). Plum Island, as part of this barrier system, is considered a true barrier island and is bordered by associated salt marshes, anthropogenic freshwater marshes, and intertidal sand flats (Hein *et al.*, 2012). Average annual temperatures for Plum Island range between 1.4°C during the winter and 19.9°C during the summer (McDonnell, 1981). Storm winds typically prevail from the east, with northeasterly storms having the greatest impact on dune formation (McDonnell, 1981). At the northern end of the island, at the mouth of the Merrimack River, the mean semidiurnal tidal range is 2.44 meters while the spring range is 2.84 meters. In the Plum Island River, at the southern end of the island, the mean range is 2.65 meters and spring range is 3.02 meters (McIntire & Morgan, 1962).

Due to past glaciation, the coastline of New England is characterized by an irregular shoreline and differential weathering of regional bedrock (FitzGerald *et al.*, 1994). The island was primarily formed from a combination of glacial-fluvial sediments from the Merrimack River and marine deposits (Hein *et al.*, 2016). Barrier islands are specialized ecosystems that separate ocean from coastal shorelines (Feagin *et al.*, 2005). These formations are important for protecting inland areas from storm surges and winds but are also threatened by major erosion effects and coastal development (Feagin *et al.*, 2005). In the early 1900s, the United States Army Corps of Engineers (USACE) constructed jetties to address the highly dynamic migration of sediments at the northern end of the island, due to concerns surrounding navigation hazards (Hein *et al.*, 2016). The southern two-thirds of the Island is composed of the Parker River National Wildlife Refuge and is characteristic of a barrier beach dune system (McDonnell, 1981). This southern portion of Plum Island also features a glacial drumlin with a 9.14 meters-high sea cliff (McIntire & Morgan, 1962). The primary physiographic zones composing the Refuge from east to west include beach, foredune, interdune, and backdune (McDonnell, 1981).

Coastal Dune Formation

Dunes form through the interaction of wind, wave action, vegetation, and sand movement. Sand is typically supplied from eroded coastal formations and riverine sediments (Reckendorf *et al.*, 1985). As sand migrates onshore, it dries and is blown onto the dune surface by coastal winds. Aboveground vegetation intercepts the wind-blown sand while roots and other belowground structures hold the sand in place. Waves seasonally erode the dunes and deposit sands offshore, particularly during the winter months, and then move sand landward during summer months. Dunes form over the course of several years, with accumulating layers of sand, vegetation, and organic material provided by dead vegetation and wrack. Vegetation is essential to dune formation, and dunes experience wind erosion in areas where vegetation is sparse and sand is exposed (Reckendorf *et al.*, 1985). These blowout areas are often precursors to larger, active areas of sand movement and erosion unless plant cover is maintained (Reckendorf *et al.*, 1985).

Three zones typically form in healthy dune systems: foredune, interdune, and backdune (Dunlop & Crow, 1985; Sperduto & Kimball, 2011). The foredune is the most dynamic zone, characterized by constant exposure to wind and water and is dominated by *A. breviligulata* (Miller *et al.*, 2010; Sperduto & Kimball, 2011). The foredune is the most recently formed dune zone, creating a ridge parallel to the shoreline (Reckendorf *et al.*, 1985). This zone experiences coastal environmental stresses including salt spray, seawater overwash, fast-draining soil, poor nutrient availability, high temperatures, high wind, drought, and shifting substrate (García-Mora *et al.*, 1999; Purvis *et al.*, 2015). The interdune is a transition zone between the foredune and the backdune and is dominated by beachgrass (*Ammophila breviligulata*) and hairy hudsonia (*Hudsonia tomentosa*) (Sperduto & Kimball, 2011). The backdune is typically the most diverse, as it is usually sheltered, except in times of strong winds and storms (Dunlop & Crow, 1985). The backdune is also characterized as being the oldest section of dune, specifically an older dune which is now located landward of the newly forming foredune. Backdune systems can be comprised of beach grass grasslands, maritime shrub thickets, wooded slopes, and wet hollows (Dunlop & Crow, 1985; Sperduto & Kimball, 2011). Under natural conditions, they would extend to the upper reaches of the salt marshes to landward. Disturbed sand dunes are less effective storm surge protection and more vulnerable to invasive species (Landi, Ricceri & Angiolini, 2012). Aside from major meteorological events and development, trampling by beachgoers and vehicles also comprise a threat to stable dunes.

Role of Native Dune Flora

In addition to physical forces, dunes are also dependent on biotic factors – particularly dune vegetation. Dune plants are characterized into three main groups: dune builders, burial-tolerant stabilizers, and burial-intolerant stabilizers (Miller *et al.*, 2010). Dune builders are characterized as plants that grow rapidly following burial by sand and are essential in foredune habitats (Miller *et al.*, 2010). These species typically have upright growth habits that lead to rapid accumulation of sand and usually steep dune slopes (Stallins, 2001). Burial-tolerant and -intolerant species are typically associated with dune areas located further away from the seaward edge, such as the interdune and backdune (Miller *et al.*, 2010). These functional types do not contribute to vertical dune growth but can still benefit dune resiliency by providing stability and erosion control (Stallins, 2001). Powerful storms are more likely to impact the foredune and consequently, this zone is a common area for dune restoration efforts.

Plants capable of surviving foredune environmental conditions are characterized as perennial or summer annuals with vegetative height above 15 cm, thick spreading or deep belowground structures, leaf adaptations to coastal environmental stresses, ability to withstand burial by sand, and ability to disperse seeds or vegetative structures via seawater (García-Mora *et al.* 2000). Plants that contain the necessary structural adaptations and physiological mechanisms to survive in this environment are thought to be important drivers of dune formation (García-Mora *et al.*, 1999).

Dune flora commonly found within foredune habitats were selected for this experiment and included seaside goldenrod (*Solidago sempervirens*), beach pea (*Lathyrus japonicus*), and American sea rocket (*Cakile edentula*). While these plants can tolerate some degree of burial, *A. breviligulata* is best suited to high levels of sand deposition (Maun & Lapierre, 1984). Sand accretion and associated nutrient inputs limit the growth and distribution of dune flora (Gilbert *et al.*, 2008). However, while existing stands of *A. breviligulata* can withstand sand deposition, seed germination is optimized when burial is only two to four cm deep (Maun & Lapierre, 1986).

American beachgrass (*A. breviligulata*) is considered the most prevalent and ecologically important native dune species of northern North America and is regarded as an ecosystem engineer (Cheplick, 2005). *A. breviligulata* is commonly planted during restoration efforts, and often is the only dune species planted. As a perennial graminoid, *A. breviligulata* can colonize large swaths of dune and can decrease the prevalence of annual dune species, such as *C. edentula* (Cheplick, 2005). *A. breviligulata* can also spread via rhizome expansion and asexual ramet production (Cheplick, 2005). Such growth habits allow windblown sand to be deflected downward by aboveground biomass and trapped within belowground biomass. Sand accretion around *A. breviligulata* stands can benefit vegetative growth, with increased plant height, leaf area, number of rhizomes, and chlorophyll concentration associated with increased nutrient input (Disraeli, 1984). In fact, *A. breviligulata* is capable of withstanding burial up to 59-100 cm of sand (Disraeli, 1984; Maun & Lapierre, 1984). However, burial has been shown to reduce shoot density (Maun & Lapierre, 1984).

Flowering dune plants are also important for pollinator populations. *S. sempervirens, L. japonicus*, and *C. edentula* are especially vital because healthy pollinator populations are essential for facilitating plant reproduction (Potts *et al.*, 2009). In areas where pollinator habitats have been reduced, reductions of seed and fruit production has occurred (Kearns & Inouye, 1997). This is problematic for habitats that have low levels of biodiversity, such as coastal dunes. Dune stability is impacted by the percentage of plant cover, seed bank viability, and reproductive success of native plants (Purvis *et al.*, 2015). While some dune plants exhibit rhizomatous growth, others, such as *C. edentula,* rely on seed dispersal for reproduction. Reduction of plant diversity or fragmentation of important habitats leads to reductions in floral resources for pollinators such as adult bees, adult butterflies, and butterfly larvae (Kearns & Inouye, 1997; Potts *et al.*, 2009). Studies have shown that bee and butterfly abundance and diversity are positively correlated with floral cover and species richness (Potts *et al.*, 2009). Legumes, such as *L. japonicus*, are especially beneficial for bumblebee community composition (Potts *et al.*, 2009).

Maintaining native dune communities is important because these systems are characterized by small numbers of specialist species that are restricted to topographically-defined zones and are responsible for regulating storm-generated overwash disturbance (Stallins, 2001). Dune plant functional type (*i.e.*, whether a species is a dune-builder, burial-tolerant, or burial-intolerant) determines the extent to which a particular species can contribute to sand accretion (Stallins, 2001). In stressful habitats like coastal dunes, maintaining plant diversity may be even more important to community structures because facilitation between species becomes more influential as stresses increase (McLaren & Turkington, 2011). Additionally, arbuscular mycorrhizal fungi (AMF), while not examined in this study, have also been recognized for their importance for dune plant communities (Koske & Gemma, 1997). AMF may serve as an indicator of dune resilience and growth since sites that were recently planted with *A. breviligulata* (1- and 2-year-old sites) lacked AMF (Koske & Gemma, 1997).

Dune Management Concerns

Coastal dunes are currently protected under the Federal Coastal Zone Management Act of 1972 (Clifford, 2015). A study by Gornish and Miller (2012) analyzed a decade of vegetation data on a barrier island in Florida to examine how the plant communities change in response to storm events and how this information could be useful in dune restoration following storm events. They note that restoration of coastal dunes can be difficult as dune systems are dynamic. They also note that, historically, dune restoration efforts have involved the transplant of monocultures in primarily the foredune zone despite research recommendations that encourage the use of a variety of species to improve dune resiliency (García-Mora *et al.* 2000).

Large beach erosion events typically involve slow recovery periods (Hill *et al.,* 2004). Stable dunes are also more likely to recover from major storm events because the volume of sand found within the backdune can provide sand toward rebuilding whereas dunes with high coastal development have very little sand to contribute (Hill *et al.*, 2004). Hard structures, such as houses and roads, prevent sediment from shifting and feeding dune systems and decrease the size of the dune and thus increase the time needed for dune recovery (Hill *et al.*, 2004). As increased dune elevation diminishes the likelihood of overwash, lower dune elevations are particularly concerning for coastal communities and specifically impact private property located directly landward of dunes and beaches (Feagin *et al.*, 2005). Additionally, decreased sand accretion leads to decreased vigor of important dune species, such as *A. breviligulata,* because the nutrient inputs are likewise decreased (Seliskar & Huettel, 1993). These factors surrounding developed beaches all contribute to dune and beach damage and hinder recovery following strong storms. Human pressure on dune systems, including increased development and beach traffic, further contributes to dune fragmentation and increased need for beach nourishment projects (Purvis *et al.*, 2015).

Dune Wildlife

Of the various wildlife common to coastal New England, the piping plover (*Charadrius melodus*) is a bird that particularly relies on coastal dune habitats. Piping plovers are ranked as threatened under the Federal Endangered Species Act (ESA) of 1973 and protected under the Federal Migratory Bird Treaty Act of 1918 (Maslo, *et al.*, 2011; Clifford, 2015). While the presence of piping plovers does not directly impact dune stability, dune restoration efforts could conflict with plover protection strategies. Population declines, since the species was listed in 1986, are primarily attributed to habitat loss resulting from human development (Seavey, *et al.*, 2011). These birds nest on the beaches and dunes along the Atlantic Coast from Nova Scotia south to North Carolina and their preferred habitat consists of areas with sparse vegetation, such as in the edges of the foredune, and following erosive storms (Clifford, 2015). Breeding success is positively impacted by overwash events that contribute to preferred breeding habitat (*e.g.*, dune blowouts and overwash fans) and foraging habitat (*e.g.*, ephemeral pools, tidal flats, and wrack deposits) (Elias, *et al.*, 2000; Maslo *et al.*, 2011).

The United States Fish and Wildlife Service (USFWS) Atlantic Coast Piping Plover Population Recovery Team has partnered with the USACE to incorporate habitat enhancement features into beach stabilization efforts, including reduced beach elevation, unvegetated nesting areas, tidal ponds, and unvegetated pathways (Maslo *et al.*, 2011). As vegetation coverage increases during dune recovery, their nesting habitat area decreases and densely vegetated dunes serve as barriers to chick movements and increase predation risk (Loegering & Fraser, 1995;

Maslo *et al.*, 2011; Clifford, 2015). During the breeding season, nesting areas are marked with rope fencing and activities within the area are restricted to prevent nest disturbance (Clifford, 2015). Such protections are known to be important for the success of the species, however they can also restrict sites available for dune restoration for two reasons: one being that plovers prefer nesting sites with low density vegetation, and the second being that areas roped off for protection cannot be planted. Without careful planning, restoration efforts, including dune building and beach nourishment, can minimize the availability of long-term suitable nesting and foraging habitat (Elias, *et al.*, 2000; Maslo, *et al.*, 2011). Human presence (*e.g.* beach recreation, dune planting efforts) near nests is additionally problematic because it may cause adult plovers to flush from the nest, which could lead to nest failure or abandonment (Clifford, 2015).

However, it is the issue of sparse vegetation and dune elevation that can lead to challenges for restoration efforts of dune vegetation and piping plover nesting habitat, the latter seeking to reduce *A. breviligulata* density by transplanting to existing or potential dune restoration areas were nesting habitats have not been recorded (Clifford, 2015). Cooperation between dune management groups is encouraged to create as much habitat for both dune plants and plovers as possible. Dunes that are densely vegetated and marked for thinning could serve as a source of *A. breviligulata* that could then be transplanted to areas that are marked for dune restoration. This could serve as a mutually beneficial practice for both parties.

Beachgrass Dieout

A. breviligulata dieout (also referred to as die-off) is also a concern for managers of coastal dune systems of the eastern U.S. coast. Over the course of the past 25 years, *A. breviligulata* has been dying in large patches, thought to be due to predation from root-feeding nematodes, which contributes to decreasing dune stability and increased erosion (Seliskar & Huettel, 1993). As key drivers of dune building, the loss of this species can be problematic for dune resilience, especially in combination with other threats (*e.g.* coastal development, sea-level rise, recreation). In some areas of the Mid-Atlantic, up to 65% of coastal foredunes have been affected by dieout (Seliskar & Huettel, 1993). Within the Gulf of Maine, dieout has been observed at various locations between Newbury, MA and Hampton NH and identified for remediation (Moore, *et al.,* 2020). Moore, *et al.* (2020) examined three dieout sites on Plum Island, Newbury, MA and extending earlier work from the Delmarva peninsula (Seliskar, 1995), found that soil amendments in the form of lime and fertilizer treatments can increase *A. breviligulata* survival and percentage cover. Arbuscular mycorrhizal fungi (AMF) may also play an important role in *A. breviligulata* productivity. AMF form mutualistic relationships with plant roots, providing enhanced nutrient availability in exchange for carbohydrates from the plant (Little & Maun, 1997). Glasshouse experiments conducted by Little and Maun (1996) demonstrated that sand inoculated with AMF increased root biomass and root:shoot ratio, especially in combination with sand burial. However, Little and Maun (1997) also noted that in natural settings, other factors such as soil texture and position within dune zones, were stronger determinants of species richness and *A. breviligulata* abundance, compared to AMF and presence of parasitic nematodes. In older dune habitats with various stages of dune succession, there may be potential for *A. breviligulata* to spread throughout dune zones. Much of the available dune habitat in coastal New England is adjacent to existing development which restricts dune migration and so, while the observed advantages of soil amendments on *A. breviligulata* productivity are promising, dieout continues to be a challenge in dune management. This issue highlights the value in the study of other native dune species as potential plantings with goals to increase species diversity, ecological health and dune resilience for restoration efforts. If studies surrounding other dune species show promising results, it may influence dune restoration strategies to incorporate a variety of measures to both enhance vegetative growth through soil amendments and through planting species that are less susceptible to pathogens associated with dieout.

Conclusion

In the fall of 2012, the eastern seaboard experienced the dramatic effects of Hurricane Sandy, a huge extratropical cyclone later dubbed a “Superstorm”. The extreme coastal erosion, including the temporary loss of beaches and dunes and the permanent loss of residences, has since prompted a renewed effort to restore natural storm barriers. Plum Island, a barrier island off the northern coast of Massachusetts, weathered some of the worst impacts of the storm. In subsequent years, local municipalities worked with state and federal agencies to nourish the Plum Island dunes with additional sand and *A. breviligulata* plantings. In efforts to further stabilize these dunes, researchers from the University of New Hampshire worked with the Town of Newbury to obtain funding which would allow for further study of dune resilience. As a result, I examined the effects of dune biodiversity on sand accretion. After examining the plant communities in nearby, undisturbed, coastal New England dunes, I selected *C. edentula, L. japonicus,* and *S. sempervirens* as my experimental species. These species possess the structural and physiological traits necessary to withstand the environmental stresses associated with the ever-changing foredune environment. In addition to previously planted *A. breviligulata*, the effects of these herbaceous species were observed in relation to dune restoration efforts.

CHAPTER II

EXPERIMENTAL RESTORATION OF NATIVE DUNE PLANTS

Introduction

In recent years, very large storms such as Hurricane Sandy have greatly impacted coastal communities of the Northeast and once again highlighted the importance of sand dune systems in protecting landward communities. While storms of this magnitude are considered relatively rare for the New England coast, they can cause significant coastal damage and disrupt shoreline processes (FitzGerald *et al.*, 1994). In areas where beach erosion is ongoing, even small storms and weather events can greatly influence sand loss, especially with the acceleration of sea level rise. Coastal dune formation is a dynamic process, influenced by ocean waves and currents and onshore winds (Sperduto & Kimball, 2011). In stable dune systems, there is typically a seasonal movement of sand, with greatest accretion during summer months and greatest erosion during winter months when the sand is eroded from dunes and forms offshore bars (Hill *et al.*, 2004). Major storms, alter this cycle by drastically shifting great volumes of sand, rates of erosion and accretion, and short-term shoreline movement (Hill *et al.*, 2004). In systems where the beach is influenced by development and man-made structures, this seasonal change is less certain (Hill *et al.*, 2004). Regions where dunes have been significantly fragmented result in foredunes that can be characterized as short-term environmental islands separated by areas of high disturbance (García-Mora *et al.* 2000). Despite the disruption of natural dune cycles by development, sand dune systems are essential for protecting inland areas from storm surges and high waters (Gornish & Miller, 2012). Additionally, sand dunes are much less expensive to maintain compared to human-engineered structures and therefore, stable dunes are financially and ecologically beneficial for coastal communities (Feagin et. al., 2010).

Plum Island in Newbury, Massachusetts is an important site for exploring dune resilience because the area has been impacted by coastal development and disturbances, such as hurricanes and other large storms, which have weakened dune resiliency. Despite some evidence of disturbance, Plum Island represents various stages of dune building (accretion) and loss (erosion) and is well-suited for experimental study. Plum Island experienced significant beach erosion after Superstorm Sandy. In the aftermath, Plum Island garnered national media attention leading to a series of beach nourishment and beachgrass planting initiatives focusing on the dominant dune plant species, American Beachgrass (*Ammophila breviligulata*). Dune formation in these affected areas is still ongoing and the mixed results of restoration planting success suggest that additional study is warranted. Floral diversity in dunes is particularly important because dune areas that have low plant species diversity are at greater risk for erosion and are of low-quality habitat for other species (Purvis *et al.*, 2015). As natural, stable dunes have greater floral diversity, I hypothesized that increased species diversity in restoration plantings could have beneficial influence on rebuilding coastal dunes as detailed above.

Research Objectives

The goal of the field experiments was to develop a dune restoration plan that includes planting a variety of native dune species which could then be easily implemented by property owners and community volunteers. Dune sand accretion relies on plant growth because sand accumulation increases as plant size, density, and root depth increases (Feagin et. al., 2010). It was hypothesized that restoration plots with greater species diversity would result in increased sand accretion when compared with plots with lower species diversity. The three treatments of the field experiments included 1) single species plots of *A. breviligulata* only, 2) low diversity plots limited to *A. breviligulata* and seaside goldenrod (*Solidago sempervirens*), and 3) high diversity plots comprising *A. breviligulata*, *S. sempervirens*, beach pea (*Lathyrus japonicus*), and American sea rocket (*Cakile edentula*). Comparisons were made between treatments to determine 1) which of the three dune species selected for transplant experiments were best suited for restoration work, 2) which treatment level (Low Diversity versus High Diversity) contributed most to sand accretion, and 3) which planting season (spring versus fall) resulted in greatest transplant survival. Additionally, stable dunes were anticipated to have greater species diversity and percentage cover vegetation when compared to dunes that were undergoing restoration and/or impacted by beachgrass dieout. Quantifying vegetation cover and species diversity will help evaluate the relationships between coastal development, dune stability, and ecological communities (Purvis *et al.*, 2015).

Site Description

Plum Island is a barrier island located along the north shore of Massachusetts, United States in the Gulf of Maine (Appendix A). As a barrier island spanning the Towns of Newburyport, Newbury, Rowley, and Ipswich, Plum Island is an example of a dynamic coastal system with beaches and dunes subject to a cycle of erosion and accretion where the foredune zone is characterized by episodic shifts and rebuilding (McDonnell, 1979; Hill *et al.*, 2004). The Parker River National Wildlife Refuge comprises almost two-thirds of the island, representing one of the largest areas of protected dune habitat north of Cape Cod (McDonnell, 1979). For the purposes of this this study, field experiments, restoration areas, and associated reference sites were limited to the Town of Newbury, MA (Appendix B). All restoration areas are located within the foredune zone and are delineated by fencing on the inland side which separates town property from private property (Figure 2.1). The restoration areas were dunes artificially placed above the high tide line and planted with *A. breviligulata* following Hurricane Sandy and prior to these field experiments. The reference site was located south of the experimental sites, off Temple Road and directly adjacent to Parker River National Wildlife Refuge (Figure 2.2). While several dieout event sites have been identified in the area, this study focused on one, large and well-documented site located at the end of 43rd Street, Newburyport (Figure 2.3) which was later utilized for soil amendment research aimed at hastening recovery from dieoff impacts (Moore *et al.*, 2020).

Figure 2.1. Dune restoration area within the foredune zone with previously planted *A. breviligulata*. Fencing indicates end of restoration area and beginning of adjacent beachfront properties.

Figure 2.2. View from the peak of the reference dune located off Temple Road showing scattered *A. breviligulata*, *S. sempervirens* to the background left, and *L. japonicas* in the foreground.

Figure 2.3. Example of dieout event with dry, withered stems of *A. breviligulata* remaining amidst isolated patches of *L. japonicus, S. sempervirens,* and *C. edentula* in the background.

Methods and Materials

Flora survey

A survey of dune flora was conducted in late summer and fall of 2014. Walking transects were conducted through the reference dune, dieout area and restoration areas, (Appendix A). Additional species occurrence records were obtained from digital herbarium specimens using the Herbarium Specimen Data Sharing Portal from the Consortium of Northeastern Herbaria (CNH), as well as from the Hodgdon Herbarium (NHA) at the University of New Hampshire, and observations from a previous study (McDonnell, 1979).

Experimental design

Control plots (C) contained a single species and experimental plots were divided into two levels: low diversity (LD) and high diversity (HD). Control (C) plots contained *A. breviligulata* that had been planted during prior restoration efforts and any other naturally recruited dune species. Low diversity (LD) plots included established *A. breviligulata* and transplanted *S. sempervirens*, which was chosen for LD plots because it is readily available from local nurseries. The HD plots contained *A. breviligulata* and were planted with *L. japonicus, C. edentula,* and *S. sempervirens.* Experimental plots were 3x3 meters in dimension with 2 meters of separation between plots to the north and south, and 1 meter of separation between plots to the east and west (Figure 2.4, 2.5) due to the space restrictions in the restoration areas in which the plots were located. Arrays of 6 plots were established with the south side of the arrays falling on previously established beach profile transects. For three of the four restoration areas, there were two arrays; the fourth having only one due to space restrictions. Placement of arrays within each restoration area was determined by the distance between the western boundary fence of the area and the eastern (seaward) fence. Each array location along their transect was determined using a random number generator. They were adjusted further to ensure that all arrays could fit within the area with at least a 1-meter buffer between them.

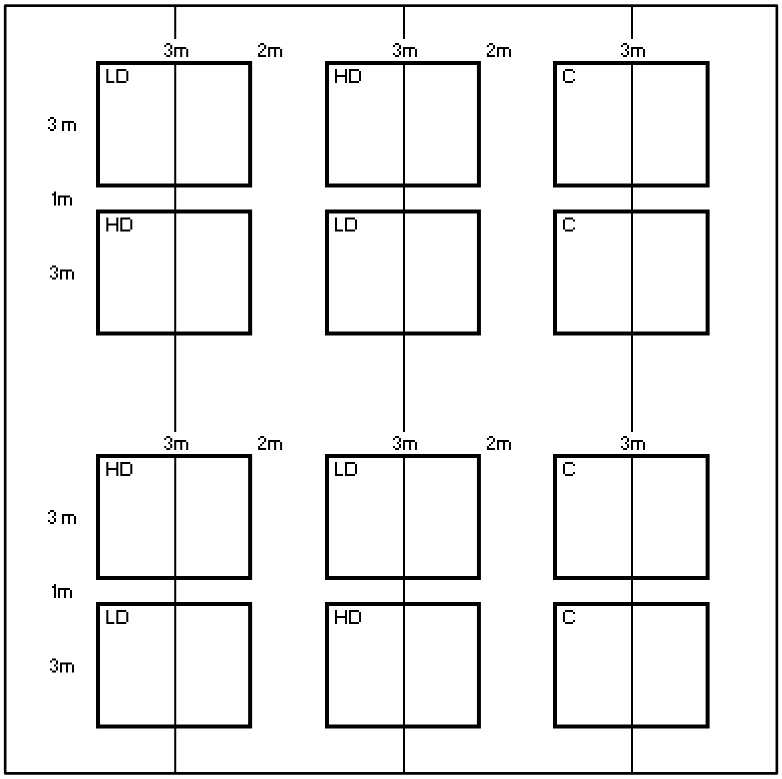

Figure 2.4. Diagram of experimental design setup for one location showing two arrays with control (C), low diversity (LD), and high diversity (HD) plots. Lines through the plots demonstrate center lines, with one of those lines falling on a transect associated with a rebar rod for elevation measurements.

Figure 2.5. Experimental area 1 (EXP 1) with orange flags designating plot corners and fencing on the seaward edge. Throughout the entire experimental component of my work, clearly worded signs were installed to inform beachgoers about project. A contact name and number was listed for those seeking further information.

Plant Sourcing, Grow-out and Procedures

Lathyrus japonicus and *C. edentula* seeds were collected in the fall of 2014 from the reference and restoration dunes on Plum Island in the town of Newbury, Massachusetts. These seeds were overwintered in the cold room at UNH's Jackson Estuarine Laboratory (maintained at constant 4^{o}C). These seeds were then sown in the spring of 2015 by students from Dover High School (Dover, NH). The plants were grown in the school's greenhouse in a potting soil comprised of 50:50 sand and commercial compost mix in 6-celled seedling starter trays until the plants were transplanted in the spring (for more information on engaging local area schools in this project, see Chapter 3). A second set of beach pea seeds were sown in May 2015, and transplanted in the fall. These seeds were grown outdoors in a potting soil, sand, and compost mixture in Jiffy 5 x 7.5 cm peat pots. An additional collection of *L. japonicus* seeds occurred in February 2016, from Newbury, MA and Hampton, NH. (Figure 2.6).

Solidago sempervirens plugs were obtained from New England Wetland Plants, Inc. (NEWP), in Amherst, MA, USA. *Solidago sempervirens* 5.1 cm plugs were transplanted directly into the dunes during the Spring 2015 session whereas the plugs designated for the Fall 2015 and Spring 2016 session received additional treatment. The *S. sempervirens* plugs provided by NEWP were transplanted into deeper pots during Spring 2015 to encourage root growth before transplanting into the dune in Fall 2015. These pots were constructed using one piece of newspaper that was folded to a length of 30 cm, rolled around a wooden dowel (5 cm diameter). The bottom of this newspaper tube was then folded inward to create a base for the pot and a final length of 20 cm. Edges of the newspaper pot were secured with masking tape, filled with a blend of potting soil, sand, and compost, and one *S. sempervirens* plug was transplanted into the pot (Figure 2.7). Newspaper pots were chosen because the newspaper was biodegradable and deep, narrow peat pots were especially difficult to source. The Spring 2016 *S. sempervirens* transplants received a different treatment. These plugs were transplanted using the same potting blend as Fall 2015 but were transferred to 5 x 7.5 cm peat pots. *Cakile edentula* seedlings, collected for the Spring 2015 plantings, were transplanted from nearby dunes into 5 x 7.5 cm peat pots using the same potting blend and then established in the experimental plots.

Plants were installed within experimental units on three different dates: May 26, 2015 (Spring 2015), October 8, 2015 (Fall 2015), and May 13, 2016 (Spring 2016). During each of the three plantings, four individuals of each species were transplanted into the appropriate high and low diversity plots. These individuals were planted in a haphazard location within the plot and between already established beach grass. The Fall 2015 high diversity plantings were reduced to *L. japonicus* and *S. sempervirens* due to lack of viable *C. edentula* seedlings (the seeds failed to germinate).

Figure 2.6. *Lathyrus japonicus* seeds among overwintering dune plants. Seeds shown here were collected during February 2016. A kitchen sieve was used to easily separate seeds from sand and other debris.

Figure 2.7. *Solidago sempervirens* plants after being transplanted into newspaper pots and placed in a plastic tub to maintain shape and stability of the pots.

Plant Survivorship & Percentage cover

Plant survivorship (surviving transplants versus total number of transplants by species) was measured approximately one month from each planting date. Mean transplant survival of the three different species was compared for each planting season. Percentage cover was measured using a 0.25 m^2 quadrat both before and one month after experimental plantings. For each plot, percentage cover was visually estimated at three random positions within the plot area. Percentage cover measurements between treatments from Spring 2015 and Spring 2016 were then compared. For the comparisons between the reference, restoration, and dieout dunes, percentage cover was visually estimated at 21 random locations in each area using the 0.25 m^2 quadrat. Mean percentage cover and standard error (SE) were used to compare 1) between the reference dune, restoration, and dieout areas, and 2) between HD, LD, and control plots.

Elevation

Elevation change was used as a proxy for sand accretion with positive change associated with increased sand accretion and negative change associated with decreased accretion and was calculated by comparing the average difference between Spring 2015 elevation prior to planting and Spring 2016 elevation after three planting sessions. Elevation was obtained using rod and laser level (accuracy +/- 3.2 mm over 61m) as well as with a Leica Real Time Kinematic (RTK) Global Positioning System (GPS) (+/-1.2-1.6cm). Elevations and GPS were measured with respect to NAD88. A 1.83 m rebar rod was hammered into the sand dune to a depth of 1.68 m as a temporary benchmark of known elevation using the RTK GPS. All elevation measurements (m) were corrected relative to these known elevations. Elevation readings were collected at the top and bottom (sand level) of the rebar, as well as at three points for every plot: back-center, center-center, and front-center. These three readings were used to calculate a mean elevation for each plot and were then used to calculate mean elevation change and standard error (SE) for each treatment. Elevation was measured before and after each planting, on May 27, September 16, November 15 of 2015 as well as May 6 and June 7 of 2016. Change in elevation of treatments were then compared in JMP 15 using a single factor ANOVA ($\alpha = 0.05$). Comparisons were also made among the different treatments and between seaward and landward plots in JMP 15 using a two-factor ANOVA with replication ($\alpha = 0.05$).

Results

Flora Survey

The flora survey conducted in late summer and fall 2014 in Newbury, Massachusetts identified fifteen species of plants within the survey area (Figure 2.4). Of the fifteen species observed, coastal sand dunes are primarily dominated by perennials (ten species), followed by annuals (four species) and biennials (one species) (Table 2.1). *Cakile edentula* is primarily an annual species but is also classified as a facultative biennial or perennial. Nine species are known to inhabit the foredune zone, while there are ten species capable of inhabiting the interdune (Sperduto & Kimball, 2011. Of the species observed, only five are typically present within the backdune zone. Backdunes are characteristically more diverse, however, the extent of backdune habitat was limited at the Newbury sites. Many of the species observed can span multiple zones, however, five species are restricted to the foredune. Primary growth habits include forb/herb, followed by subshrubs, graminoid, and vine species. While there is a greater variety of forb/herb than graminoid species present in the Newbury dunes, there is a greater cover of graminoid species (Figure 2.8). Of the 15 species, three had conservation status classifications within adjacent New England states but were unranked within Massachusetts. In New Hampshire, *A. breviligulata* and hairy hudsonia (*H. tomentosa*) are classified as rare and threatened, and seaside sandmat (*Chamaesyce polygonifolia*), is classified as a historical species (Table 2.1). Connecticut also classified *H. tomentosa* as rare.

Table 2.1. Flora of the Newbury coastal dunes surveyed in 2014. Species annotated with an asterisk (*) indicate that these species were present historically and recorded in herbarium records and/or McDonnell (1979). Growth habits are defined as graminoid (G), forb/herb (F/H), shrub (S), subshrub (SS), and vine(V) Life cycles are defined as annual (A), biennial (B), or perennial (P); ^ indicates *C. edentula* has been also classified as a perennial and facultative biennial. Conservation Status is defined as rare (R), threatened (T), or historical (H).

Scientific Name	Common Name	Family	Growth Habit	Life Cycle	Foredune	Interdune	Backdune	Conservation Status
Ammophila breviligulata Fern.	American Beach Grass	Poaceae	G	P	X	X		NH: R, T
Artemisia stellariana Besser	Beach Wormwood	Asteraceae	F/H	P	X	X		
Cakile edentula (Bigelow) Hook.	American Sea Rocket	Brassicaceae	F/H	A^	X			
Chamaesyce polygonifolia L.	Seaside Sandmat	Euphorbiaceae	F/H	A	X			NH: H
Juncus greenei Oakes & Tuck. *	Greene's Rush	Juncaceae	G	P		X		
Lathyrus japonicus Willd.	Beach Pea	Fabaceae	F/H, V	P	X	X		
Lechea maritima Leggett ex Britton, Sterns, & Poggenb. *	Beach Pinweed	Cistaceae	F/H, SS	P	X			
Hudsonia tomentosa Nutt. *	Hairy Hudsonia	Cistaceae	SS	P		X	X	CT: R; NH: R, T
Panicum virgatum L. *	Switch Panicgrass	Poaceae	G	P		X	X	
Polygonella articulata L. Meisn.	Coastal Jointed Knotweed	Polygonaceae	F/H, SS	A	X			
Oenothera perennis L. *	Little Evening-Primrose	Onagraceae	F/H	P		X		
Oenothera parviflora L. *	Small-Flowered Evening-Primrose	Onagraceae	F/H	B		X		
Salsola kali L.*	Russian Thistle	Chenopodiaceae	F/H	A	X			
Solidago sempervirens L.	Seaside Goldenrod	Asteraceae	F/H	P	X	X	X	
Toxicodendron radicans (L.) Kuntze	Poison-Ivy	Anacardiaceae	F/H, S, SS, V	P		X	X	

Vegetation Composition

Figure 2.8 shows that the reference dunes found south of the experimental sites on Plum Island had a greater percentage cover of dune vegetation than the restoration and dieout sites, and are dominated by *A. breviligulata* (67.3 ± 5.2%) and *L. japonicus* (10.3 ± 3.7%). The restoration areas had much lower percentage cover of live plants and were dominated by only one plant species, *A. breviligulata*, at 6.5 ± 0.8 %. Restoration areas which began as bare sand and were later planted with *A. breviligulata* individuals spaced 45.7 cm on center just prior to the experiment, were dominated by bare sand (84.6 ± 1.4 %), followed by dead vegetation (8.9 ± 2.4%) and *A. breviligulata* (6.5 ± 0.8%). The dieout areas were also dominated by bare sand (43.3 ± 5.1%), followed by cover of dead vegetation (22.2 ± 5.4%), *C. edentula* (21.1 ± 2.9%), *L. japonicus* (5.7 ± 1.6%), *S. sempervirens* (5.1 ± 0.8), and *A. breviligulata* (2.7 ± 0.2%).

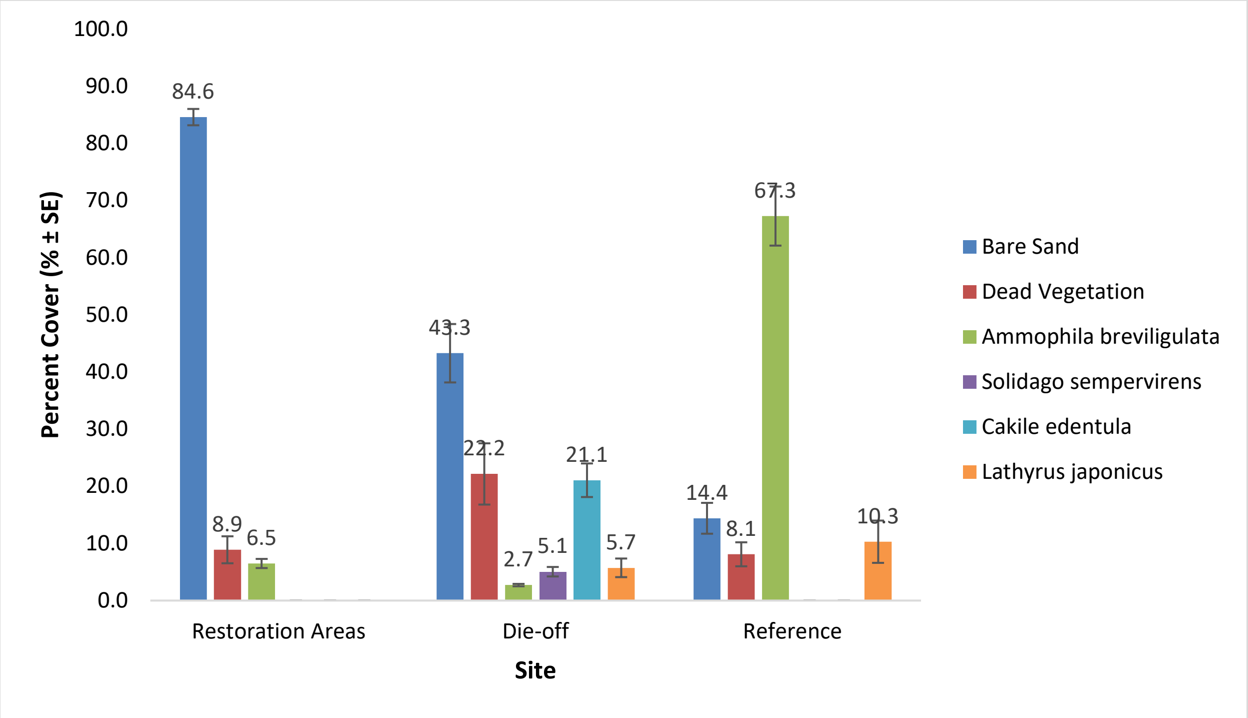

Figure 2.8. Dominant vegetation of the three different sampling areas, as demonstrated by average percentage cover (%) ± SE.

Survivorship of Dune Species

Ammophila breviligulata was not planted in the experimental plots, but rather in adjacent restoration planting areas and had 100% survival following the plantings in the Spring and Fall 2015 seasons (thus denoted to the right of the dashed line in Figure 2.9). Fall forb plantings of *S. sempervirens* and *L. japonicus* had greater survivorship than spring plantings. No data are available for *C. edentula* because it was never successfully grown for transplanting. Transplant survival was good following the Fall 2015 planting with *S. sempervirens* at 85.2 ± 0.03 % and *L. japonicus* at 64.3 ± 0.1 %. Transplant survival was low following the Spring 2015 planting with *S. sempervirens* at 4.5 ± 0.02 % and *C. edentula* at 7.1 ± 0.03 % (Figure 2.9). Spring 2016 also had low transplant survival with 0.0% survival of *L. japonicus* and one individual of *S. sempervirens* surviving resulting in 0.9 ± 0.0% survival (Figure 2.9). *Cakile edentula* was not represented in the Fall 2015 or Spring 2016 data because it was not successfully grown during the summer and was deemed unsuitable for reliable use in restoration efforts. *Lathyrus japonicus* is not represented in the Spring 2015 or 2016 data because had a 0.0% transplant survival.

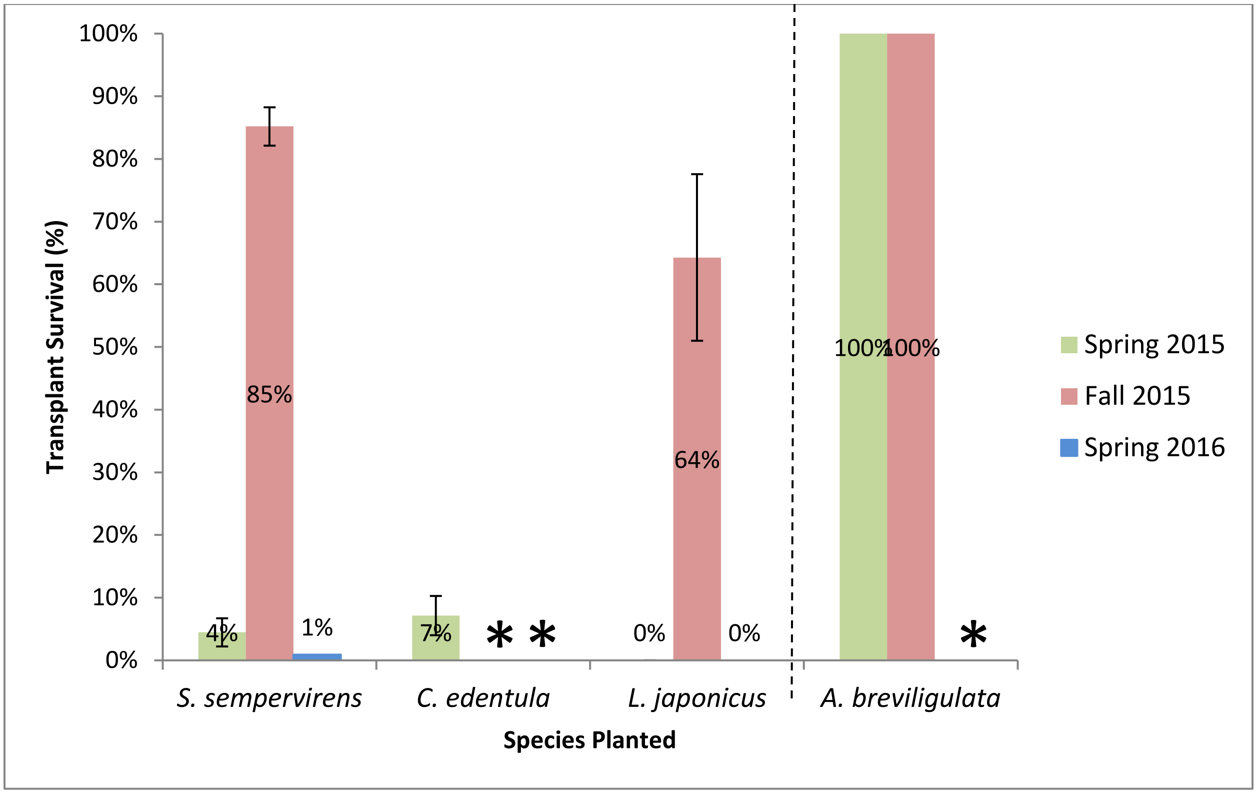

Figure 2.9. Transplant survival (%) with standard error (SE). Three different species were transplanted during Spring 2015 and two species during the Fall 2015 and Spring 2016 planting sessions. The asterisk (*) represents no data collected.

Percentage Cover of Vegetation

Average percentage cover was calculated at each site for each treatment level. The difference between percentage cover after one planting attempts (Spring 2015) was compared to percentage cover after three planting attempts (Spring 2016) to assess the annual growth of dune vegetation. Percentage cover of *A. breviligulata* has increased over the past year in all plots with the percentage cover of bare sand decreasing in all plots (Figure 2.10). *Solidago sempervirens* percentage cover increased from 0.0 ± 0.0% to 0.2 ± 0.2% in Control plots, 0.02 ± 0.02% to 0.1 ± 0.1% in HD plots, and decreased from 0.2 ± 0.09% to 0.06 ± 0.06% in LD plots. *Cakile edentula* was not observed during any of the percentage cover assessments. *Lathyrus japonicus* percentage cover increased from 0.0 ± 0.0% to 0.7 ± 0.7% in LD plots and was other 0.0 ± 0.0% in the Control and HD plots. *Lathyrus japonicus* observed during the data collections in one LD plot was naturally occurring and not from the experimental plantings. Dead vegetation percentage cover decreased in LD and HD plots while it increased in Control plots.

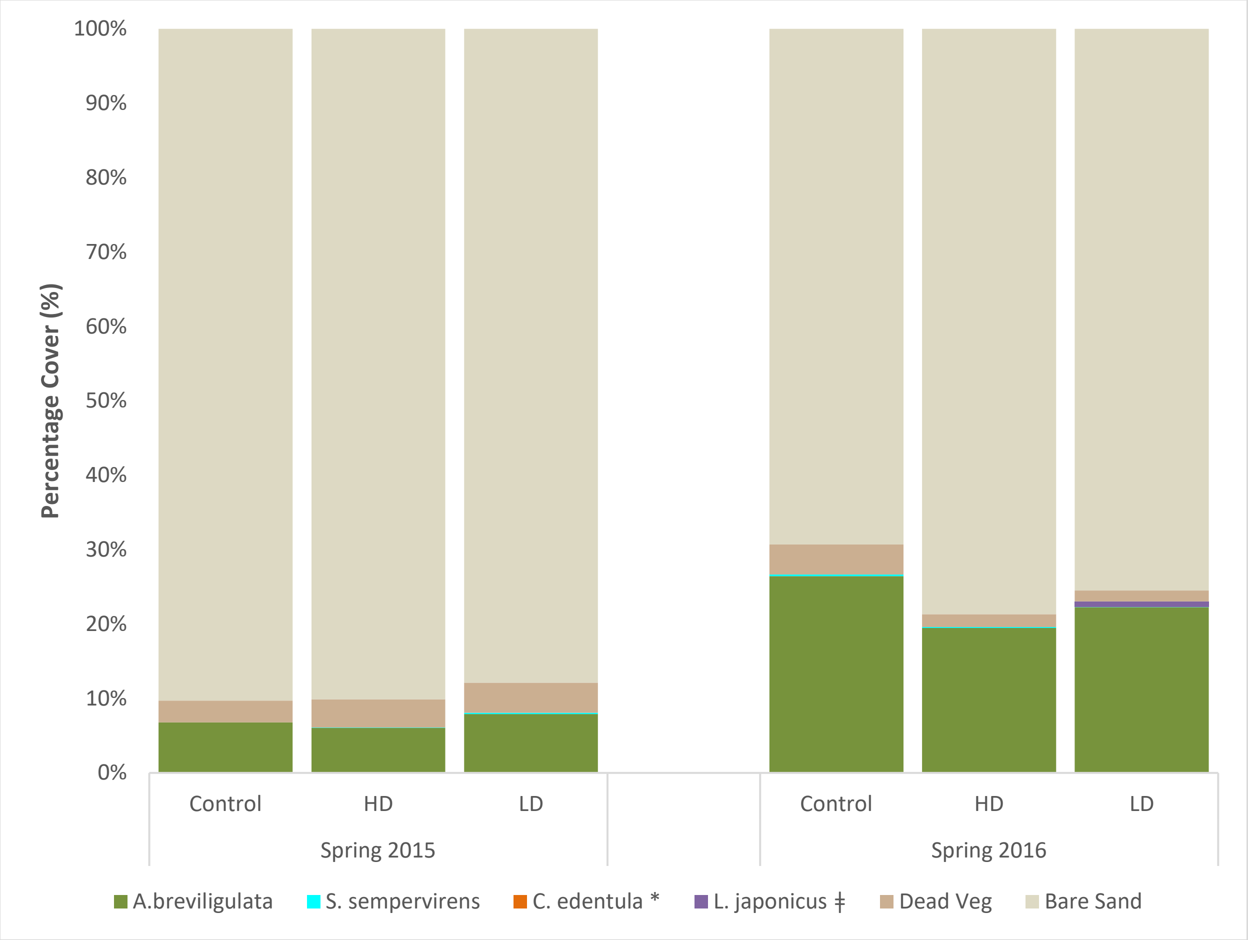

Figure 2.10. Change in percentage cover between Spring 2015 and Spring 2016 plantings. Asterisk (*) indicates that there were no observations of that species while ǂ indicates that there was one observation of naturally recruited, not planted, *L. japonicus* in a LD plot.

Sand Accretion

Overall, there was an average accumulation sand (54.4 ± 7.2 mm) over the course of the study with no pattern relating to treatment or experimental site. Average elevation change among all treatment levels was relatively similar (no significant difference; F(2, 41)=0.64, p=0.53) with the Control (63.0 ± 10.0 mm) and LD accumulation of sand 56.0 ± 10.0 mm) being slightly greater than the HD accumulation (44.0 ± 9.0 mm) (Figure 2.11). Likewise, differences between experimental sites had no significant impact on elevation change (F(3, 41)=0.98, p=0.41) (Figure 2.12). Elevation change with respect to the landward-seaward position within the foredune zone was also not significant (F(1, 41)=2.38, p=0.13) however there was a trend for more seaward than landward deposition (Figure 2.13).

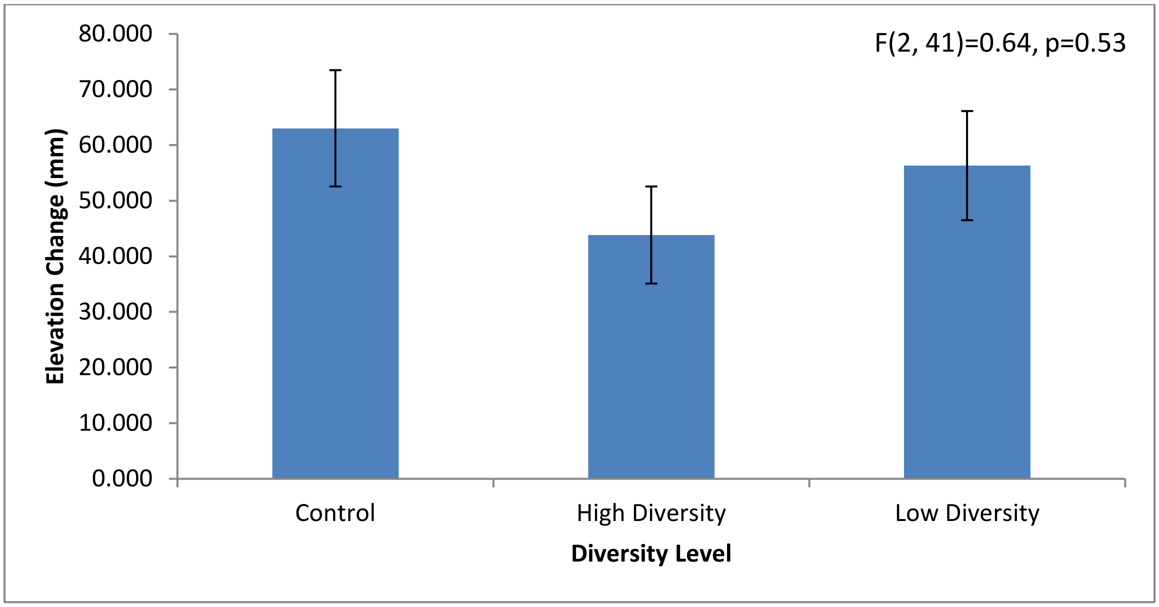

Figure 2.11. Average elevation change (± SE) between different treatments observed between sites prior to planting in Spring 2015 and after planting in Spring 2016. Total elevation change was calculated by averaging the change, per treatment, across all sites (n=14 per treatment).

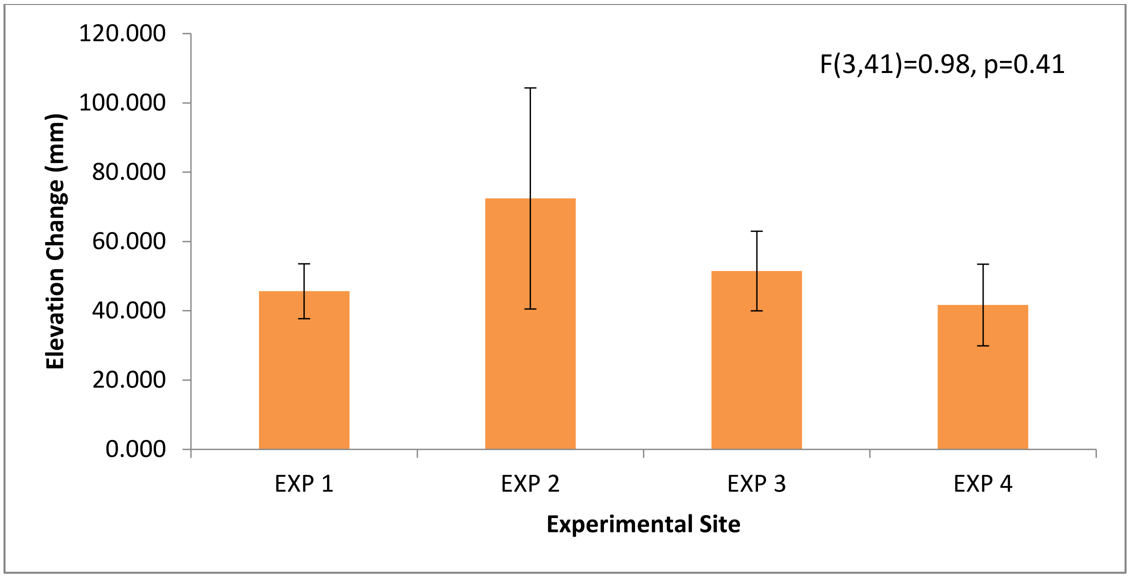

Figure 2.12. Average elevation change (± SE) of experimental sites prior to prior to planting in Spring 2015 and after planting in Spring 2016. Sites are located at the northern end of the island and total elevation change was calculated by averaging the change across all treatments.

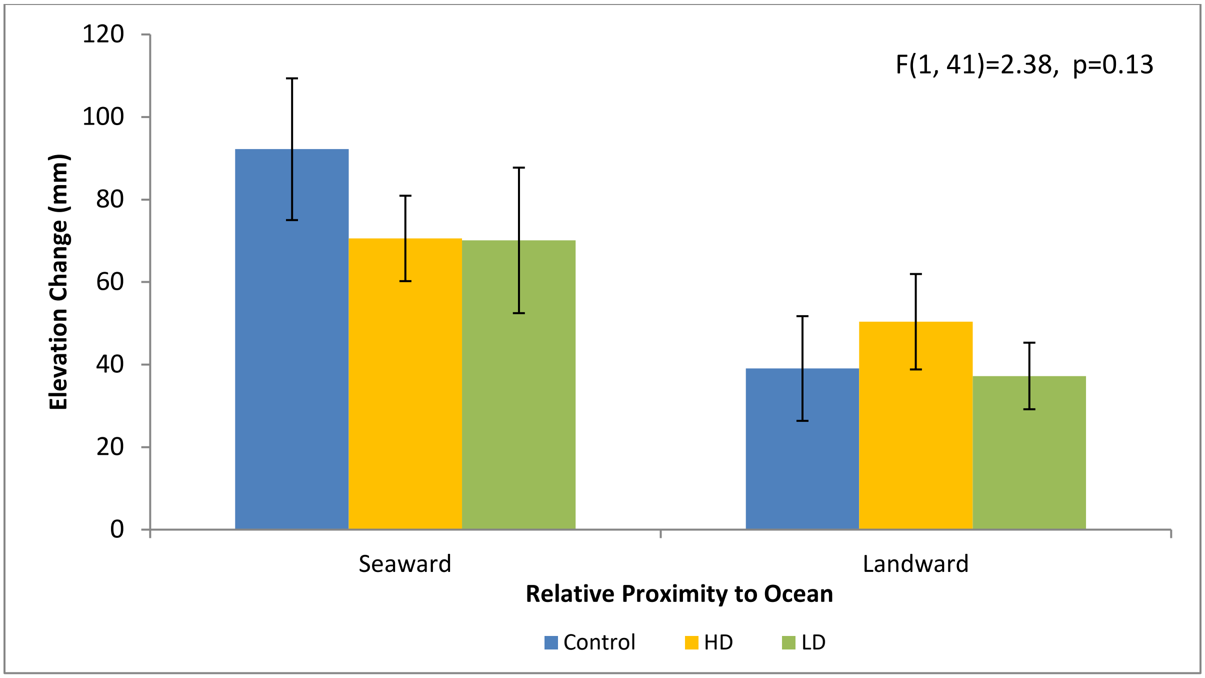

Figure 2.13. Average elevation change (±SE) among the different treatments with respect to the seaward/landward position within the foredune zone. Changes reflect elevation prior to and after three planting seasons.

Discussion

Vegetation

Survival of *A. breviligulata* was excellent for both spring and fall plantings. Based on the limited scope of my research, it appears that fall plantings are much more successful than spring plantings of herbaceous forbs within the context of the weather patterns experienced at this site during the experimental period. The spring seasons examined here were dry compared to the fall which likely impacted transplant survival. May 2015 and 2016 experienced moderate drought conditions while October 2015 experienced normal, mid-range conditions per the Palmer Drought Severity Indices (National Oceanic and Atmospheric Administration, 2016).

Solidago sempervirens was selected as the species of interest for the LD plantings because it is easy to access from local nurseries, whereas beach pea and sea rocket seeds must be harvested and grown out for plantings. For local communities seeking increased species diversity in dunes, this will be something to factor into restoration plans. The fruits of both *L. japonicus* and *C. edentula* are easily recognizable and could be collected selectively by volunteers and researchers for restoration purposes. Seed collection for large-area restoration efforts should be restricted to small groups to minimize trampling impacts on sensitive dune flora.

Interestingly, the dieout areas had far greater species observed than the restoration areas, which prompts additional considerations. This could be possibly related to a few different factors: soil pH may influence the success of beachgrass regrowth, death of beachgrass allows for other species to be released from competition; dead beachgrass provides an input of organic matter into dune sediments, which could increase nutrient and water holding capacity; and finally that *C. edentula, L. japonicus*, and *S. sempervirens* maybe be less susceptible to dune nematodes. Percentage cover for *A. breviligulata* has been found to increase when a combined treatment of fertilizer and lime was applied to dune plots (Seliskar, 1995; Moore *et al.*, 2020). In dieout areas where *A. breviligulata* population density is relatively low, the competitive interactions with other dune plants could be reduced and result in higher diversity (Huston, 1979). In stressful conditions, higher diversity can help mitigate stressful conditions through facilitation and different physiological processes, such as varying evapotranspiration and nitrogen fixation capabilities (Franks and Peterson, 2003).

Additionally, the restoration areas have experienced significant environmental disturbances over recent years including major erosion from Hurricane Sandy followed by beach nourishment, plantings, and frequent trampling by beach goers. While diversity can increase with frequent disturbances, drastic disturbances or sufficiently high frequency of disturbance can result in conditions where some populations may not be able to recover (Huston, 1979). As expected, the healthy, stable dunes had the greatest percentage cover of dune vegetation, but diversity was not as high in the dieout areas. Restoration efforts should aim for percentage cover similar to that of well-vegetated, stable reference dunes particularly as burial impacts on dune communities may lead to interactions more facilitative than competitive in areas of high plant density compared to low density (Frank and Peterson, 2003). This goal may take several years to achieve, depending on rates of sand accretion, erosion events, and plant growth rates. Percent vegetation cover increased after three restoration plantings and thus suggest that restoration plans should include monitoring of floral diversity and health and replenishment of plants where necessary.

Sand Accretion

Sand accretion did not appear to be affected by treatment during these restoration experiments. In addition, elevation changes may differ greatly based on site location depending on the age of dunes, wind patterns, and available sand for transport. Impacts of species diversity on elevation may also integrate over greater temporal scales and may need more time to become evident. The role of plant communities in foredune development are not yet as well studied compared to dune zonation and sand supply (Ciccarelli, *et al.*, 2012; Durán & Moore, 2013). Additionally, the challenges of field experiments in these habitats have led to the use of modeling as an alternative, with key factors including wind, sand transport, topography, shoreline, and vegetation cover (Feagin, *et al.*, 2005; Durán & Moore, 2013). The experimental study conducted here on Plum Island did not include direct measure of wind, aeolian transport, or shoreline characteristics with the assessments of treatment on sand accretion. However, it is likely that coastal development present directly adjacent to the experimental sites limits and influences sand movement and deposition. This limitation can confine the dunes to narrow areas of beach where plants cannot adequately disperse or grow (Feagin, *et al.*, 2005). Beach width is also an important driver of dune development, impacting, sediment supply and deposition, aeolian transport potential, and susceptibility for dune erosion (Silva, *et al.*, 2018). Beach width can vary over the course of years and decades, thus impacting dune development and the impacts of erosive events on foredune habitats (Silva, *et al.*, 2018). Along the Gulf of Mexico and Eastern United States, late-succession dune species, like those found in backdunes, are being lost because early-successional dunes are unable to develop ahead of coastal barriers such as residences, sea walls (Feagin, *et al.*, 2005).

Pressures on Dune Stability

Dune stability, particularly due to the presence of *Ammophila* spp., has been impacted by root-feeding activity by nematodes (Brinkman *et al.*, 2007) which is associated with dieout and blow outs. This is problematic as below-ground biomass of *A. breviligulata* is important for stabilizing and retaining sand and comprises 25-30% of annual net primary productivity (Maun, 1984). Community dynamics of soil organisms are important and specifically, nematode diversity can also benefit plant stability. In a three-year study, Brinkman and colleagues (2007), it was found that the impacts of strongly parasitic root-feeding nematodes such as *Meloidogyne maritima* were diminished when other weakly parasitic nematode species were present. Sand burial may also benefit plants that are negatively impacted by nematodes because the increased growth associated with burial and the subsequent increase in nutrient availability can create a time lag between root growth and colonization by strongly parasitic species (Little & Maun, 1997; Brinkman *et al.*, 2007). The health of additional plant species, including *S. sempervirens*, could also be at risk in subsequent years (Seliskar & Huettel, 1993). Additional environmental stresses, times of drought for instance, can also exacerbate the spread of *Ammophila breviligulata* dieout (Seliskar & Huettel, 1993).

Conclusion

This study provided several new insights into planting designs for restoration of coastal dune systems. The Plum Island sites allowed for comparisons to be made between the undisturbed dunes found near the Parker River National Wildlife Refuge, restored stretches of foredune, and areas impacted by *A. breviligulata* dieout. The experimental study allowed for the examination of how dune species can be grown and transplanted, how sand deposition may be impacted by the type and number of species included in plantings and their proximity to the beach zone, and how seasonality may impact survivorship for dune plantings. In the scope of this study, sand deposition was not significantly impacted by diversity plantings but was more strongly related to proximity to the sea.

Dunes are dynamic and the environmental stresses of these habitats made for interesting challenges in field study. The stretches of dune impacted by dieout had the greatest species diversity when compared with the reference and restored areas. The most common plants in these areas were the selected experimental species, which demonstrates that *L. japonicus, C. edentula,* and *S. sempervirens* are good choices for diversity plantings. These results support development of improved germination, grow-out, and transplantation techniques for *L. japonicus* and *C. edentula* (as done with *S. sempervirens*) to provide more plant species for planting designs. As dieout continues to impact dune resiliency, future studies may seek to further examine the effects of sand (burial) and nutrients (fertilizer or lime amendments) on *A. breviligulata* to determine best practices for managing sites where dune dieout is a concern. Future dune plantings may also need to include soil amendments along with transplanting.

While the experimental plantings conducted here demonstrated limited success, weather conditions and time between germination and transplant may be factors to consider in future efforts. *Solidago sempervirens* had the greatest survivorship and increase in percentage cover during the scope of this study. As this species was readily available from nurseries, these plants were the most mature transplants and it may be the most practical for communities interested in restoration. *S. sempervirens* should be considered as a useful species to include in planting plans that avoid monocultures of *Ammophila*. Planting units grown out in newsprint ‘pots’ show how innovative low-cost techniques can promote multispecies plantings. Future studies could also examine the success of directly seeding restoration areas compared to growing plants from seed and then transplanting. This could potentially allow the seeds to properly stratify during the winter months and germinate earlier in the season, as restoration efforts typically do not begin until early April. *Lathyrus japonicus* sprouts were observed as early as mid-February, when seeds were being collected. Alternatively, *C. edentula* and *L. japonicus* could be transplanted into donor gardens which would serve as a resource for local restoration projects. Once such plants are established in a donor garden, they could be selectively harvested for transplanting or reserved for seed supply.

Additionally, project managers for restoration efforts should anticipate dune planting and elevation monitoring for 3-5 years, as that is the typical time frame for the recovery of dune communities (Miller *et al.*, 2010). This study examined the impacts of species diversity on elevation throughout the course of one year. Elevation also may need to be examined over the course of several years to more accurately discern how biodiversity affects sand accretion (Miller *et al.*, 2010) and long-term elevation change (Hill *et al.*, 2004).

CHAPTER III

INCORPORATING RESEARCH INTO EDUCATIONAL OUTREACH & ENGAGEMENT

Introduction

The importance of community outreach should not be underestimated, particularly as it pertains to bridging an inherent gap between scientific research and public understanding. Too often, community members lack access to scientific findings or are unsure of how to interpret such information (Wellnitz, 2002). Science outreach has been defined as any activity in which scientists translate and broaden scientific concepts to those outside of traditional academia (Burns *et al*, 2003). Outreach is now seen as a vital tool for communicating such valuable information and creates a sense of mutual understanding between researchers and the public. It allows scientists to understand the public perspectives surrounding their areas of research, provides the public with greater understanding of environmental issues, and allows for youth and students of all ages to interact with role models from higher education institutions, stay current with advances in research, and cultivate an enthusiasm for science (McDuff, 1999; Rao *et al.,* 2007).

National organizations and programs, such as the National Science Foundation (NSF) and 3M Corporate Foundation's STEM Education Fellowship Program, have recently begun providing financial incentives to expand university outreach (Wellnitz *et al.*, 2002; Stohlmann *et al.*, 2011). Additionally, many state and federal grant opportunities now require outreach components for funded research projects. The U.S. Fish and Wildlife Service enacted the National Outreach Strategy in 1997, which sought to hire outreach professionals and also train all staff in public outreach methods (McDuff, 1999). Academic institutions, government agencies, and non-government organizations around the country have even begun to incorporate outreach components into department initiatives (Wellnitz *et al.*, 2002).

Recently, the United States has sought to emphasize the importance of science, technology, engineering, and mathematics (STEM) in education reforms via the National Science and Technology Council's Federal STEM Education 5-Year Strategic Plan (Glownia, 2016). The priority goal of this plan was to focus on P-12 STEM, undergraduate, and graduate education along with broadening participation and public engagement (Glownia, 2016). This comes after the realization that U.S. students, particularly in the middle school grades, were underperforming on national science and mathematics tests (Stohlmann *et al.*, 2011; Bryant Davis & Hardin, 2013). The U.S. National Academies suggests that STEM curricula include group activities, projects, and laboratory activities so that students may improve their communication and critical thinking skills (Bybee, 2010). STEM education is also important for fostering future generations who can make well-informed decisions regarding issues such as energy efficiency, environmental quality, natural resource use, and public health (Bybee, 2010).

One way to improve outreach and engagement with the public is to foster relationships between universities or research facilities and K-12 schools. The U.S. National Science Foundation's Math and Science Partnership (NSF-MSP) is one example of a program that is actively working to form partnerships between institutes of higher education and K-12 schools to better reform STEM education (Foster *et al.*, 2010). NSF-MSP projects also encourage the involvement of STEM faculty in K-12 education. Additionally, the Association of Public and Land Grant Universities (APLU) has undertaken an initiative that includes 123 universities with the goal to form partnerships between universities and STEM teachers to meet state education needs (Foster *et al.*, 2010). An example of this involves the American Physical Society and the American Chemistry Society to include society members in the effort of increasing the number of STEM teachers (Foster *et al.*, 2010). The Boston Science Partnership (BSP) can be seen as one such success, contributing to increases in K-12 science teaching licenses in Boston area school districts (Foster *et al.*, 2010).

Throughout New England, universities are actively involved with a number of STEM programs. The Center for STEM Education at Northeastern University works to develop and organize outreach programs that connect STEM education with K-16 education in Boston and the Commonwealth of Massachusetts. Other New England universities provide outreach opportunities including the University of Vermont with their Chemistry Camp for Elementary School Students, and Youth Agriculture Project, as well as Boston University's U-Design Summer Program, The Artemis Project which allows high school girls to explore the field of computer science, and the Technology Innovation Scholars Program (TISP).

Outreach between research universities and K-12 education can be mutually beneficial. Benefits to university faculty involved in STEM outreach efforts can include improved college-level teaching skills, experience with K-12 education, and interdisciplinary research (Foster *et al.*, 2010). For example, faculty involved with the North Cascades and Olympic Science Partnership (NCOSP) have cited increased use of inquiry-based teaching following involvement in the partnership which could benefit higher-institution coursework (Foster *et al.*, 2010). For graduate students in particular, outreach provides an opportunity to prepare for future careers in teaching through communicating with different audiences, collaborating with other teaching partners, and engaging students in STEM fields of inquiry (Milliman, 1996; Page *et al.*, 2011; Love Stowell *et al.*, 2015). Students who participate in these opportunities can expect to improve in confidence and public speaking skills as well as learn how to develop teaching strategies and experiment with different pedagogical practices (Wellnitz, 2002; Page *et al.*, 2011; Kaser *et al.*, 2013; Love Stowell *et al.*, 2015). Another benefit is that graduate students gain experience in communicating science to non-discipline audiences (Rao *et al.*, 2007). As researchers and professors often have extensive administrative and academic demands, having graduate students focus on outreach as part of their graduate curriculum allows for shared responsibility of outreach requirements (McDuff, 1999). Additionally, STEM outreach training allows graduate students to implement these components in their post-graduate careers (McDuff, 1999).

For K-12 students, benefits of outreach can contribute to enhanced achievement in science including improved performance on Advanced Placement exams and increased participation in advanced science courses and programs outside of school, and pursuit of careers in science (Markowitz, 2004). Other potential benefits are an increased motivation for learning, positive associations with school, as well as increased teamwork, critical thinking, and problem-solving skills (Stohlmann *et al.*, 2011). Young students, particularly those in K-12 education, need to understand the societal impacts of science in order to truly understand today's culture (Jacob *et al.*, 1991). Reforms in science education have led to the principle that students should be involved frequently and actively in opportunities that resemble scientific research (Markowitz, 2004). Science outreach programs, like those described here, provide additional insight into the nature of ecological issues and scientific research (Markowitz, 2004). Additionally, teacher involvement in such programs has been shown to improve attitudes toward teaching inquiry-based science (Jacob *et al.*, 1991; Markowitz, 2004).

Outreach and engagement initiatives can be achieved in many ways. Researchers can be involved in public workshops, volunteer efforts, speaking engagements, or K-12 extracurricular activities, among many others. At University of New Hampshire (UNH) for example, the New Hampshire (NH) Sea Grant Extension program is a collaborative effort between the UNH Cooperative Extension and NH Sea Grant, where researchers and community members can work together to address coastal challenges. NH Sea Grant oversees many community initiatives, a small selection of which include the Climate in the Classroom program, stormwater management assistance, the Coastal Landowner Technical Assistance Program, support for sustainable fisheries, and the Beach Microplastics Monitoring Program. Notably, researchers with the UNH Coastal Habitat Restoration Team have been leading dune restoration workshops with community volunteers and local school groups for over five years. These workshops have provided participants with an opportunity to learn about current research surrounding coastal dune restoration and actively participate in replanting efforts. Workshops with hands-on involvement gives participants a greater understanding of coastal systems and appreciation for local ecosystems. The Stewardship Network: New England also provides many opportunities for citizens and scientists to engage in cooperative efforts which include the Coastal Research Volunteer (CRV) program, water quality monitoring, conservation training and various other volunteer events associated with local and regional STEM organizations. Another example comes from the summer of 2015 when UNH researchers were involved in workshops with the Museum Institute for Teaching Science (MITS) 2015 Summer Professional Development Institute for 6-12 educators. MITS provides 6-12 educators with the opportunity to learn about inquiry-based pedagogy and regional science and engineering practices.

Outreach Methodology

A community outreach and education plan was developed through a collaboration with Dover Middle School (Dover, NH). Dover Middle School hosts an extended learning program centered on providing students with an avenue to explore topics related to science, technology, engineering, arts, and mathematics (STEAM Academy). The primary objective of programs such as these are meant to enhance students' understanding and attitudes regarding science (Markowitz, 2004). The program consisted of six after-school sessions, each of which had a main topic. One goal for the curriculum was to use a variety of teaching tools to improve student understanding, including hands-on activities and group-based problem-solving. Such teaching methods have been implemented in other outreach programs, including the Gateway to Technology program that partnered graduate students with the Johnson Middle School in Minnesota (Stohlmann *et al.*, 2011). I also sought to provide students with a greater understanding of coastal sand dune systems and introduce them to current research conducted at a local university. Each week, there were two components to the session: an informational presentation and an interactive group project. Resources for these activities were funded by the William R. Spaulding Marine Program Endowment in Support of Marine Biology Research at Jackson Estuarine Laboratory and the Dover STEAM Academy. Materials and instructions for the activities associated with the following six sessions can be found in Appendix D.

Curriculum Development

Session 1: Introduction to Dune Formation and Function

The goal of this first session was to inform students about how coastal sand dunes form, how they benefit coastal communities, and the status of current threats to dune habitats.

Demonstrating the processes of coastal dune erosion is essential for understanding how coastal communities are impacted by development, storms, and the local ecology. When a survey was conducted on public awareness of marine issues, participants remarked that they felt somewhat to slightly informed about coastal erosion, and somewhat concerned to concerned about the same topic (Gelcich, *et al.*, 2014). This session began with an open discussion to try and assess what students currently knew about beach dunes. This was then followed by a PowerPoint presentation and short video which further illustrated major points (Barnagat Bay Partnership. 2013). Students then participated in an activity that demonstrated beach erosion. Each pair of students constructed a dune mesocosm using sand, water, plant clippings to simulate vegetation, sponge, and a plastic paint tray (Figure 3.1). This style of mesocosm has often been used in lesson plans to illustrate coastal erosion but was modified to include plant matter, which was meant to simulate impacts of vegetation on dune stability (Science Buddies Staff, 2014). Students were instructed to create a dune on the elevated side of the paint tray with water in the lower side of the paint tray. A sponge was used to create waves that would erode the mock dune. Using approximately equal force to create waves, students were asked to observe the wave effects on mock dunes with no vegetation, low density vegetation, and high-density vegetation. Students sketched dune profiles to illustrate the different scenarios (Appendix D).


Figure 3.1. Dune mesocosm with plant cuttings, water in the basin, and a sponge to create waves.

Session 2: The Importance of *Ammophila breviligulata*

Subsequent STEAM Academy sessions began with a review of the topics discussed in the previous week. The second session focused on American beachgrass (*Ammophila breviligulata*) and how it is an essential component of coastal dune landscapes. Students were shown a PowerPoint that illustrated why *A. breviligulata* is well adapted to dune environments, with particular attention given to the dune stabilizing qualities of the roots and rhizomes, best time for planting, and the potential threat from nematodes. Students were then given the opportunity to explore the scientific method through a planting experiment where students planted *A. breviligulata* in clear plastic tubes, which were developed based on the use of terrariums as teaching tools for ecosystem studies (Gunckel, 1999). The tubes were capped at one end to prevent sand and water loss, filled with sand, and then planted with one bare root plug (Figure 3.2). The plugs were sourced from the Hampton Beach State Park Community Beachgrass

Garden, which is a site being used to propagate *A. breviligulata* for future restoration efforts. Students, working in pairs, assembled a total of four planting tubes which were used to examine the effects of burial on *A. breviligulata*. The control tube received no additional sand, while the other experimental tubes received varying amounts to simulate different levels of burial. Students determined the experimental sand levels, which allowed them to participate in the experimental design process and marked the height of the sand above the initial planting level. Students observed *A. breviligulata* growth over the next three weeks by examining the increased length of the leaves as well as the increased color in the leaves of the plants that received additional sand. Using the clear plastic tube allow students to clearly observe and record the amount of growth exhibited by *A. breviligulata* under different burial scenarios, which illustrates how important this species is for dune revegetation. While many lesson plans use bottles or glassware to house terrariums, none were found that used clear plastic pipes for taller plant specimens.

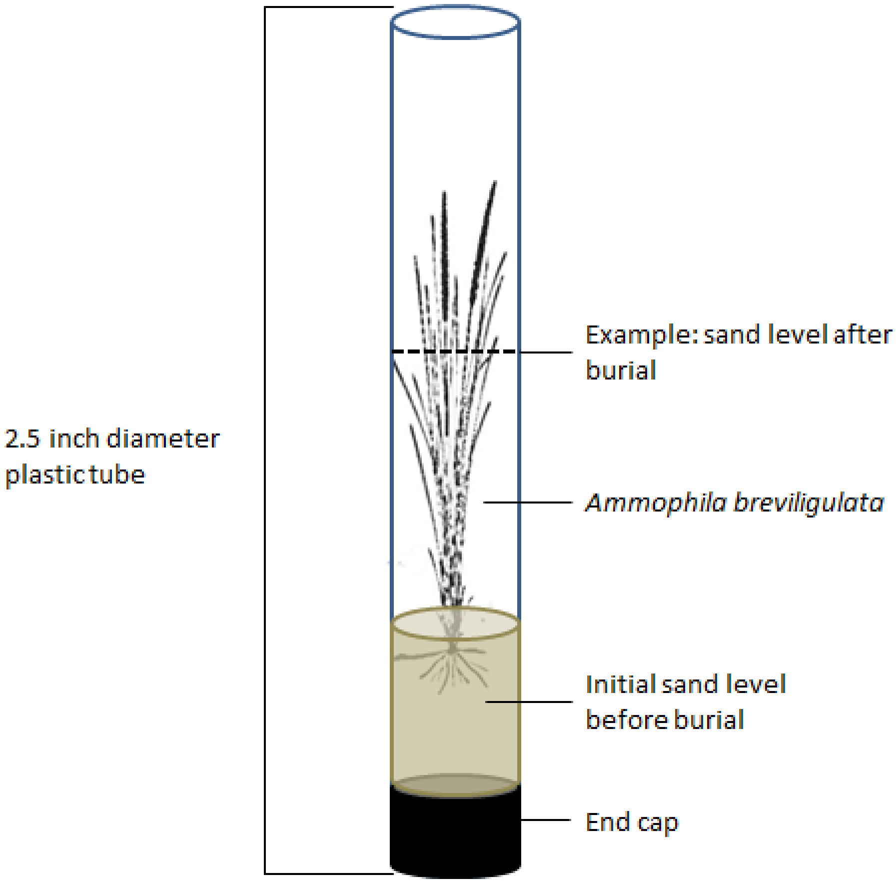

Figure 3.2. Diagram of burial microcosms for observing the response of *Ammophila breviligulata* to high levels of sand accretion. Initial sand level should be at least 5 cm above root stock of *A. breviligulata*. The level of burial above the initial is determined by the students and recorded.

Session 3: Plant Diversity in Coastal Sand Dunes

The third session focused on the importance of plant diversity. Students learned how diversity helps to improve ecosystem resiliency by providing a variety of morphological structures, varying phenology, and resistance against pathogens. It was during this session that students were introduced to the three dune species that were used during the restoration experiments. The importance of collecting and preserving plant specimens was also discussed and demonstrated with an herbarium specimen activity. Students were instructed on how to press plants using a plant press and then mount dried plants for herbarium specimens. Pressed and dried specimens of beach pea (*Lathyrus japonicus*), American sea rocket (*Cakile edentula*), and seaside goldenrod (*Solidago sempervirens*) were provided along with the associated collection information and supplies required for mounting (Appendix D). The backs of individual plants were coated with diluted glue and then placed in the approximate center of the herbarium paper and allowed to dry. Students copied down collection information onto cardstock to create the necessary herbarium tag, which was then affixed to the herbarium paper in the bottom right corner. This session emphasized the importance of maintaining specimen records and critical thinking, as students discussed the potential benefits of using herbarium specimens in future research.

Session 4: Review of Dune Terms & Topics

The fourth session served as a review of the material covered in the previous sessions. Students began by discussing what they had learned about coastal dunes thus far. This allowed all students another opportunity to review the major topics. A crossword puzzle was selected as the activity and students were asked to first try to complete the puzzle individually (Appendix

D). After students demonstrated that they had answered the questions to the best of their ability, they were instructed to ask one another questions about the terms they were missing. Before the end of the session, all the correct answers were discussed. This session focused on problem-solving and communication as students were encouraged to make the associations between important terms and concepts and to communicate those ideas with their peers.

Session 5: The Relationship between Nematodes & *A. breviligulata*

The penultimate session focused on the interaction between nematodes and the common dune grass, *A. breviligulata*. The issue of beachgrass dieout was discussed along with the ramifications of beachgrass losses for dune stability. Students were then asked to use compound light microscopes to examine a variety of nematode species, draw what they saw under the microscope and compare the different species. Slides of nematodes were obtained from the United States Department of Agriculture (USDA) Nematode Collection, which is located at the USDA Nematology Laboratory, Beltsville, Maryland. Slides were selected by referencing the nematode species found on damaged dunes in a previous study (Seliskar & Huettel, 1993). The goal of this session was to inform students about ecological interactions that occur within coastal dunes, as well as their impacts.

Session 6: Field Visit and Restoration Planting

The final STEAM Academy session took place on the dunes on Plum Island, Newbury, Massachusetts and centered on the importance of field work. While this session required the most logistics, especially regarding school policies and student transportation, the students and parent chaperones noted that it was very rewarding. The purpose of this field trip was to show students examples of restoration dunes and allow them to participate in a small replanting effort. Students planted *A. breviligulata* and *S. sempervirens* in a small area of dune that was designated for restoration. Students were first given a demonstration of the planting technique which required 1) digging a hole deep enough (the length of a typical gardening trowel) so that the top of the plug was covered by approximately 5 cm of sand, 2) adding a handful of peat moss and a few pellets of slow-release fertilizer, 3) placing the plug into the hole and covering with sand, and 4) tamping down around the plug to minimize air pockets (Figure 3.4, 3.5). This session provided an opportunity for students, parents, and teachers to visit a site that is currently under habitat restoration and they also had the direct experience of transplanting 148 *S. sempervirens* and 200 *A. breviligulata* plants.

Figure 3.3. STEAM Academy students and instructor prior to planting. Planting took place along the seaward edge of the foredune located in the background. Student faces blurred for privacy.

Figure 3.4. Dover STEAM Academy student planting beachgrass (*A. breviligulata*) into the dune, after digging a hole deep enough so that the surface of the plug was thoroughly covered and filled with a handful of peat moss and a few pellets of slow-release fertilizer. Student face blurred for privacy.

Figure 3.5. STEAM Academy students and parents planting beachgrass (*A. breviligulata*) and seaside goldenrod (*S. sempervirens*). Plantings took place on November 18, 2015.

Success Metrics and Curriculum Evaluation

The scope of STEM programs throughout the country are variable but include similar goals and tactics. Goals are often to improve academic skills, provide hands-on learning experiences, exposure to STEM topics, increase interest in STEM fields, and boost confidence (Kitchen, *et al.*, 2017). Shared tactics include lectures, interacting with STEM professionals, field trips and development of STEM projects and activities (Kitchen, *et al.*, 2017). Participation in site visits and hands-on activities have been shown to lead to improved student engagement (Byrant Davis & Hardin, 2013). Out-of-school STEM programs can provide opportunities for students to develop skills not provided in traditional classroom curricula and to expand interest in

STEM (Baran, *et al.*, 2016; Cutucache, *et al.*, 2016). Student interaction with faculty and graduate students has been shown to be a rewarding component of out-of-school STEM programs, allowing STEM participants to envision themselves in similar roles (Constan & Spicer, 2015). The curriculum developed for Dover STEAM Academy agreed with several of these key components, but further reflection has identified areas for improvement, particularly regarding pedagogy and evaluation.

During curriculum development, the design of after school STEM opportunities should include clear identification of the desired goals and content (Baran, *et al.*, 2016). The curriculum I developed met these two criteria, but future program revisions could benefit from a more defined pedagogical strategy, like that of the Learning Cycle Approach or problem-based learning. The Learning Cycle Approach organizes STEM content according to the following phases: engagement (questioning and identifying the problem), exploration (carrying out the scientific method), explanation (communication and interpretation), and evaluation (applying STEM knowledge) (Dass, 2015). Another pedagogy alternative could be problem-based learning (PBL), like that implemented in the University of Nebraska at Omaha program NE STEM 4U. In the NE STEM 4U program, undergraduate STEM students were tasked with providing after-school learning activities for K-8 students (Cutucache, *et al.*, 2016). Problem-based learning requires students to apply knowledge to real-life problems through inquiry and the exploration of new concepts (Evans, *et al.*, 2014). In the case of dune restoration, PBL may be the more applicable approach in STEM outreach programs. The curriculum presented here for the Dover STEAM Academy provided the knowledge basis but could be expanded through including PBL components. In addition, it would be worthwhile to plan additional activities beyond the allotted timeframe. In instances where activities proceed faster than expected, too much downtime can lead to behavior challenges among bored students (Byrant Davis & Hardin, 2013). While this was not a major concern during my involvement with Dover STEAM Academy, it is an important consideration in program development.

Evaluation is also recommended for future iterations of the curriculum developed here. Evaluation of STEM programs is important as it can provide important metrics for obtaining future funding, especially among National Science Foundation programs (Friedman, 2008). One particular challenge of evaluating student participants in the STEAM Academy or similar programs, is that it can be difficult to measure changing attitudes if participants are self-selecting and already demonstrate increased interest in science (Constan & Spicer, 2015). Examining the effectiveness of such programs can be conducted internally by project leaders or externally by trained evaluators. In the case of my involvement with Dover STEAM Academy, it would have been worthwhile to collaborate with evaluators trained in such assessments, especially considering that statistically relevant evaluations are lacking in STEM pre-college programs (Constan & Spicer, 2015). Useful metrics could have been obtained through self-reflection surveys, interviews, exit surveys, Dimensions of Success (DoS) assessments, and long-term post-test assessments (Cutucache, *et al.*, 2016). In other outreach programs run by graduate students, like the Foundations in Math and Science (FSM) program through Indiana University, evaluations were conducted through the use of pre-tests, post-tests, exit surveys, and demographic surveys (Schwab *et al.*, 2018). Dimensions of Success can be a valuable tool for evaluating out-of-school STEM programs because it can be used to make national comparisons, contribute to broader databases, and provide clear definitions of program quality (Shah *et al.*, 2018). This tool provides a standardized, rubric-based assessment, compared to the more common usage of project-specific surveys or written assessments that cannot be used to crosscompare STEM programs (Shah *et al.*, 2018). However, DoS requires collaboration with a trained observer, whereas other means of evaluation could be conducted by program instructors. Determining the method of evaluation for a program like the Dover STEAM Academy would depend on factors like funding, type of activity (pre-planned and instructor-led versus student-guided), and accessibility to trained evaluators.

Based on this preliminary review of STEM-program development and evaluation strategies, future iterations of the curriculum developed here could include more direct links to defined pedagogy and assessment methods, including:

1) Revise the curriculum to incorporate Problem-based Learning (PBL) to allow students to explore knowledge and solutions relating to a real concern, in this case, dune restoration and coastal challenges.
2) Plan for additional activities in the event students finish tasks early or if the curriculum needs to be adapted for longer programs.
3) Develop pre-test to assess prior student knowledge and post-test to determine what students gained from the program.
4) Develop an exit survey to determine what students found enjoyable or difficult.
5) If teachers are involved in program delivery, include an exit survey to assess what they found beneficial and what changes they would recommend.
6) If feasible, enlist trained evaluators to incorporate Dimensions of Success (DoS) assessments, which would allow for standardized comparisons with other STEAM programs.

Inclusion of such teaching and assessment metrics for the Dover STEAM Academy could have provided a baseline, quantitative evaluation for curriculum implementation in subsequent years.

Conclusion

STEM outreach and engagement continues to be an important aspect of the United States education system, especially considering that current metrics indicate that there are not enough graduates progressing to STEM careers relative to international competition (Stohlmann *et al.*, 2011; Bryant Davis & Hardin, 2013; Kitchen, *et al.*, 2017; Shah *et al.*, 2018). Program evaluation and models that control for student characteristics have found that students who participate in STEM programs are 1.4 times more likely to report STEM career aspirations as they leave high school; in programs that focused on real-world problems, that number increased to 1.8 times more likely (Kitchen, *et al.*, 2017). Engagement with middle school students, in programs like the Dover STEAM Academy, is especially important as this age range is critical for career development (Tillinghast, *et al.*, 2020). In addition, this opportunity allowed UNH researchers to connect with the local community (stakeholders included teachers, administrators, parents, and middle school students), and for the exploration of outreach as a component of this thesis. Areas for curriculum improvement include the implementation of STEM pedagogy and program evaluation.

CONCLUSION

Fall forb plantings resulted in greater transplant survival likely due to normal precipitation conditions compared to the spring plantings which occurred during mild droughts. *Ammophila breviligulata* was successful regardless of the planting season and remains a valuable species for dune plantings. *Solidago sempervirens* is a native species which can be sourced from local nurseries, thus providing easy access to plants for restoration efforts. It also had the highest transplant survival of the selected diversity plantings. Additionally, *S. sempervirens* provides important foraging resources for local pollinators which may benefit species stability. The results of this study suggest that *Solidago sempervirens* is a suitable candidate for restoration plantings in New England.

Similarly, *Lathyrus japonicus* had the best transplant survival during the fall. Additionally, it has nitrogen-fixing capabilities which are beneficial to low-nutrient habitats such as coastal dunes. Further research is needed to determine the best transplanting methods for *L. japonicus*, but it is suggested that fall restoration efforts consider this species for diversity plantings. *Cakile edentula* was not a successful candidate for transplanting. It is, however, a quick-growing annual with easily identifiable seeds and may be a viable candidate for direct seeding.

Ammophila breviligulata had the greatest transplant survival and percentage cover increase compared to any of the diversity plantings and is still an important species to include in restoration plantings for its dune-building capabilities. However, the ongoing issue of beachgrass dieout is of concern in coastal dune management and impacted areas may not benefit from additional beachgrass replenishment. After observing naturally recruited seaside goldenrod, beach pea, and American sea rocket in dieout areas, all three species could be considered for restoration sites affected by beachgrass dieout.

Elevation change was not directly related to percent vegetation cover or plant diversity but trended to increase with proximity to the sea. Overall, the experimental areas experienced an increase in sand accretion during the temporal scope of the study. As this study was conducted solely in the foredune zone, where sand is highly mobile and plants are subject to more stressful conditions than other dune zones, diversity effects could differ in the interdune and backdune.

Outreach is recognized as a vital tool for connecting researchers and the public. This is particularly beneficial for students, both at the college-level and K-12. It provides an opportunity for college students to practice their teaching skills, improve confidence, and learn how to translate scientific topics for more general audiences. For students in elementary, middle, or high school, outreach programs provide them with resources and knowledge that may otherwise be lacking from their education.

The program developed here for the Dover STEAM Academy sought to inform students about one of the state’s rarest natural habitats. Session topics surrounded dune restoration efforts, including: how dunes form and protect coastlines; the importance of biodiversity and common dune species of New England; threats to dune resiliency including nematode infestations; and planting methods for restoring dune habitats. Each session began with a review of the preceding instruction and proceeded with a new topic and activity. Materials were selected so that the majority of supplies were readily available and affordable for STEAM Academy instructors to obtain for future outreach sessions.

This outreach program was deemed necessary because successful dune restoration is dependent on community engagement. The program provided an opportunity for UNH researchers to connect the local community and younger generation to their work restoring regional coastal dunes. Overall, the students and teachers involved seemed to thoroughly enjoy the experience and appreciated the opportunity to enhance their knowledge of coastal dune processes. Future implementation of the curriculum would include a defined pedagogy and evaluation processes. Collaborating with the STEAM Academy allowed me to explore outreach as a component of my graduate student research experience.

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APPENDICES

APPENDIX A. MAP OF PLUM ISLAND

APPENDIX B. BOTANICAL DESCRIPTION OF SELECTED DUNE SPECIES

***Ammophila breviligulata* Fern.**

POACEAE

Ammophila breviligulata, commonly known as American beachgrass, is a species of coastal and inland sand dunes and beaches, and can be found along the Atlantic coastline from Newfoundland south to North Carolina, as well as along the shores of the Great Lakes and Lake Champlain (Haines, 2011, Gleason & Cronquist, 1991). A member of the Poaceae family, it is an herbaceous perennial that colonizes sandy sites via rhizomatous growth. Leaf blades are characterized by glabrous culms that are 5-10 dm in length, with scabrous pubescence on the upper surface (Gleason & Cronquist, 1991). Growth habit can be seen in Figure C1. *Ammophila breviligulata* typically flowers in late July through September with a panicle that ranges in size from 21-36.5 cm long, glumes acuminate at the apex with the lower glume 11-13 mm long (Haines, 2011) (Figure C2). The subspecies, *A. breviligulata* ssp. *champlainensis* is restricted to the shores of Lake Champlain, flowers in June through mid-July, and has a shorter lower glume at 9-10.5 mm long (Haines, 2011).

Ammophila breviligulata is characterized as a dune builder, due to its upright growth habits which induce rapid vertical accumulation of sand, and positive growth responses to burial (Stallins, 2003). Reproduction is primarily achieved through rhizomatous growth and research has shown that minimal biomass is allocated to sexual reproduction (Maun, 1984). Seedlings that are initially successful are considered rare and unpredictable as seedlings are highly susceptible to desiccation, burial by sand, and erosion (Maun, 1984).

Figure B1. Growth habit of healthy *A. breviligulata*

Figure B2. Inflorescence of *A. breviligulata* (photo © Arthur Haines, Native Plant Trust).

Cakile edentula **Bigelow**

BRASSICACEAE

Cakile edentula, also referred to as American sea rocket, is commonly found on Atlantic beaches on a variety of substrates (Haines, 2011). *C. edentula* ssp. *edentula* var. *edentula* ranges from Labrador south to the Outer Banks of North Caroline (Maun *et. al.*, 1990). This species frequently colonizes the foredune of coastal beaches and is an annual, biennial or facultative perennial (Maun *et. al.*, 1990). Stems are typically succulent to suffrutescent with glabrous crenate to dentately lobed ovate leaves (Maun *et. al.*, 1990). Flowers of the inflorescence are 4-merous and actinomorphic, white to light purple. Post-fertilization, a thin septum develops within a unilocular ovary which then separates the two ovules into distinct distal and proximal segments resulting in an indehiscent two-segmented silique (Maun *et. al.*, 1990). The distal segment is deciduous and has greater dispersal range than the proximal segment.

Figure B3. Growth habit of *C. edentula* (photo © Arthur Haines, Native Plant Trust).

Figure B4. Flowers of *C. edentula* (photo © Arthur Haines, Native Plant Trust).

Lathyrus japonicus

FABACEAE

Lathyrus japonicus, commonly known as beach pea or beach vetchling, is often found on Atlantic coastal sites, including beaches, dunes, and salt marshes, from Maine south to Connecticut (Haines, 2011). There are also disjunct populations found on the shores of Lake Champlain in Vermont (Haines, 2011). Plants sometimes exhibit pubescence, but are commonly glabrous when found in protected sites (Haines, 2011). Flowers are light purple to pink to purple, zygomorphic and 5-merous. Flowering begins as early as April and continues through the beginning of August. Flowers are pollinated by bees, particularly bumble bees, and fruits consist of green legumes with five to eight seeds. Plants can also reproduce vegetatively through rhizomatous growth.

In areas where *A. breviligulata* dominates, *L. japonicus* may develop a scrambling habit and flowering is typically reduced (Brightmore & White, 1963). Deciduous foliage contributes to pockets of organic matter within dune substrate (Brightmore & White, 1963). *L. japonicus*, in both vegetative, dormant, and seedling states, are typically frost resistant (Brightmore & White, 1963). Shoots have been observed toward the end of February. However, seedlings exhibit high mortality under early summer drought conditions (Brightmore & White, 1963). Mature plants can survive drought but flowering and number of seeds produced is reduced (Brightmore & White, 1963). Established, mature plants can withstand sand burial up to 40 cm while smaller plants are killed by burial of 15 cm (Brightmore & White, 1963). Plants can tolerate salt spray but exhibit high mortality when submerged in salt water for prolonged periods (Brightmore & White, 1963). Seeds, however, can remain viable and buoyant in sea water for up to five years (Brightmore & White, 1963).

Figure B5. Inflorescence and leaves of *L. japonicus*.

Figure B6. Sprawling growth habit of *L. japonicus* along the dune surface.

***Solidago sempervirens* L.**

ASTERACEAE

Solidago sempervirens is commonly known as seaside goldenrod and is found primarily along New England Atlantic coastlines from Maine south to Connecticut (Haines, 2011). Common native habitats include coastal marshes, beaches, and sand dunes, while it is considered non-native at inland sites, such as those found in Berkshire and Worcester County, MA (Haines, 2011). This is a perennial species that is a codominant species of northeast Atlantic coastal dunes with *A. breviligulata* and is also associated with *C. edentula* and *L. japonicus* (Lonard *et al.*, 2015). Leaves are simple, narrowly ovate to oblanceolate, 10-40 cm long and 1-7 cm wide, and alternately arranged with entire margins (Lonard *et al.*, 2015). Plants are long-lived and commonly overwinter as basal rosettes. *S. sempervirens* has a symbiotic relationship with arbuscular mycorrhizal fungi (AMF), particularly in the lateral roots, with as many as six fungal species having been found on plants in coastal dunes of Rhode Island (Lonard *et al.*, 2015). The inflorescence consists of capitula, characteristic of the Asteraceae, that are arranged in a panicle. Actinomorphic capitula are composed of both ray and disc florets that are yellow in color. Bloom time ranges from late July to November with fruits maturing in late November and dispersing through late April (Lonard *et al.*, 2015). Seeds are contained within indehiscent achenes and are capable of germination after exposure to saltwater (Lonard *et al.*, 2015). However, the seeds and seedlings are not tolerant of excessive burial with seedlings unable to tolerate even 5 cm of sand (Lonard *et al.*, 2015). Mature plants can survive up to 56 cm of sand and can experience increased vigor as a result (Lonard *et al.*, 2015).

Figure B7. Growth habit of *S. sempervirens*

Figure B8. Inflorescence of *S. sempervirens*

APPENDIX C. OUTREACH SUPPLIES & WORKSHEETS

Supplies

Session 1: Dune Erosion Simulation

- Sand
- Water for wetting sand and simulating waves
- Sponges
- Plant clippings to simulate dune plants; small-leaved plants are suggested for the simulation exercise
- 9 in. plastic paint roller trays
- Printed worksheets

Session 2:

- *Ammophila breviligulata* plants for transplanting
- Sand
- Water
- Meter tape
- Permanent markers
- 2.5 inch diameter clear plastic tubes with one end cap
- Printed worksheets

Session 3:

- Printed crossword puzzles and worksheets

Session 4:

- Slides of nematodes
- Examples of damaged and healthy beachgrass
- Compound light microscopes

Session 5:

- *Ammophila breviligulata* and *Solidago sempervirens* plants
- Trowels
- Osmocote® Plus Outdoor & Indoor Smart-Release® Plant Food
- Peat moss

Name:____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 1: What Are Dunes?

1. List 3 reasons why coastal sand dunes are important:

____

____

____

2. In the box below, draw an intact dune. Label the 3 different dune zones. Draw some waves and some coastal homes where they would typically occur.

3. List 3 threats to coastal sand dunes:

____

____

____

4. In the boxes below, draw the side profile of a coastal sand dune:
    a. A coastal sand dune with no plants:

    b. A coastal sand dune with some plants:

    c. A coastal sand dune with a lot of plants:

5. What did you notice happened when you increased the number of plants on the sand dune?

____

____

Name:____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 2: The Wonders of Beachgrass

1. List 3 reasons why beachgrass is a good plant for planting in the dunes:

    ____

    ____

    ____

2. What are **rhizomes**? What is their purpose?

    ____

    ____

    ____

3. In the box below, draw several beachgrass plants connected by rhizomes. Be sure to include roots belowground!

4. When is the best time to plant beachgrass to restore the dunes? Why can't you plant during other times of the year?

   ____

   ____

   ____

5. There is a microscopic organism that is attacking beachgrass.
   a. What is this organism called?__________________________

   b. What part of the plant is it attacking? ___________________

   c. What do you think people could do to stop nematodes from attacking roots?

      ____

      ____

      ____

Beachgrass Planting Experiment:

As a group, we will plant beachgrass in clear tubes. In each tube we will simulate burial by sand by adding sand to different heights. We will observe the beachgrass each time we meet to see if the beachgrass has grown through the sand and if the roots have gotten any deeper.

Name:_____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 3: Plant Diversity

1. List two reasons why plant diversity is important.
    a. ____
    b. ____

2. Why is it important to collect and preserve plant specimens?

____

____

____

3. What is the difference between an **annual** and a **perennial** plant?

____

____

____

4. What are three plants, other than beachgrass, that are found in New England sand dunes?

____

____

____

Activity: Create an herbarium specimen using one of the dried plants provided. Be sure to include all necessary information on the label.

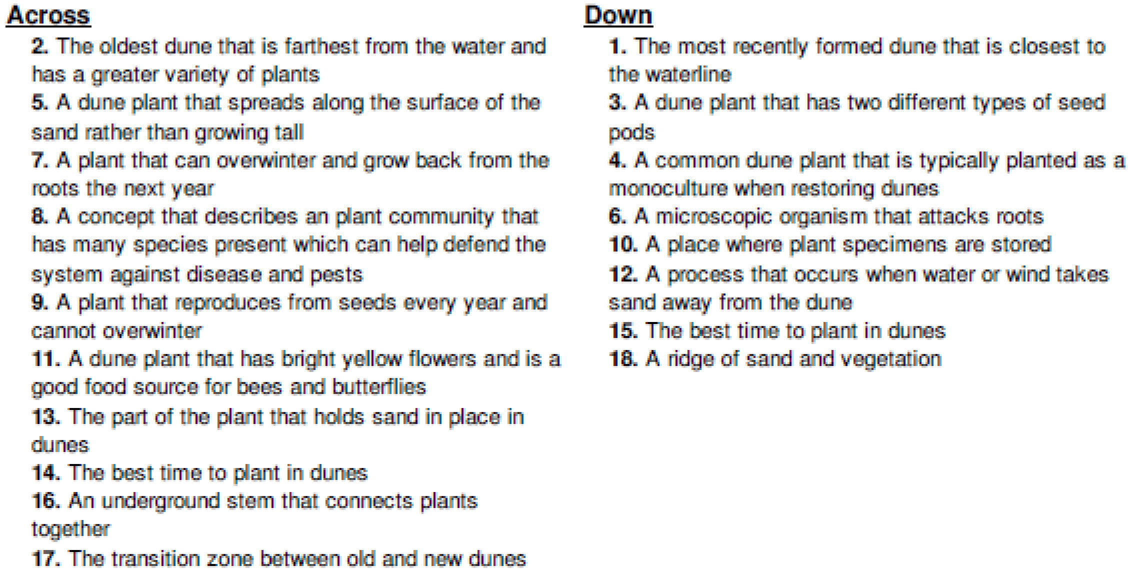
Name:_____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 4: Review of Concepts and Dune Vocabulary

1. Today we will be using a crossword puzzle to test our knowledge of some of the terms and concepts we have been discussing. After all students have completed the puzzle to the best of their ability, we will discuss the answers as a group.



Across

2. The oldest dune that is farthest from the water and has a greater variety of plants
5. A dune plant that spreads along the surface of the sand rather than growing tall
7. A plant that can overwinter and grow back from the roots the next year
8. A concept that describes an plant community that has many species present which can help defend the system against disease and pests
9. A plant that reproduces from seeds every year and cannot overwinter
11. A dune plant that has bright yellow flowers and is a good food source for bees and butterflies
13. The part of the plant that holds sand in place in dunes
14. The best time to plant in dunes
16. An underground stem that connects plants together
17. The transition zone between old and new dunes

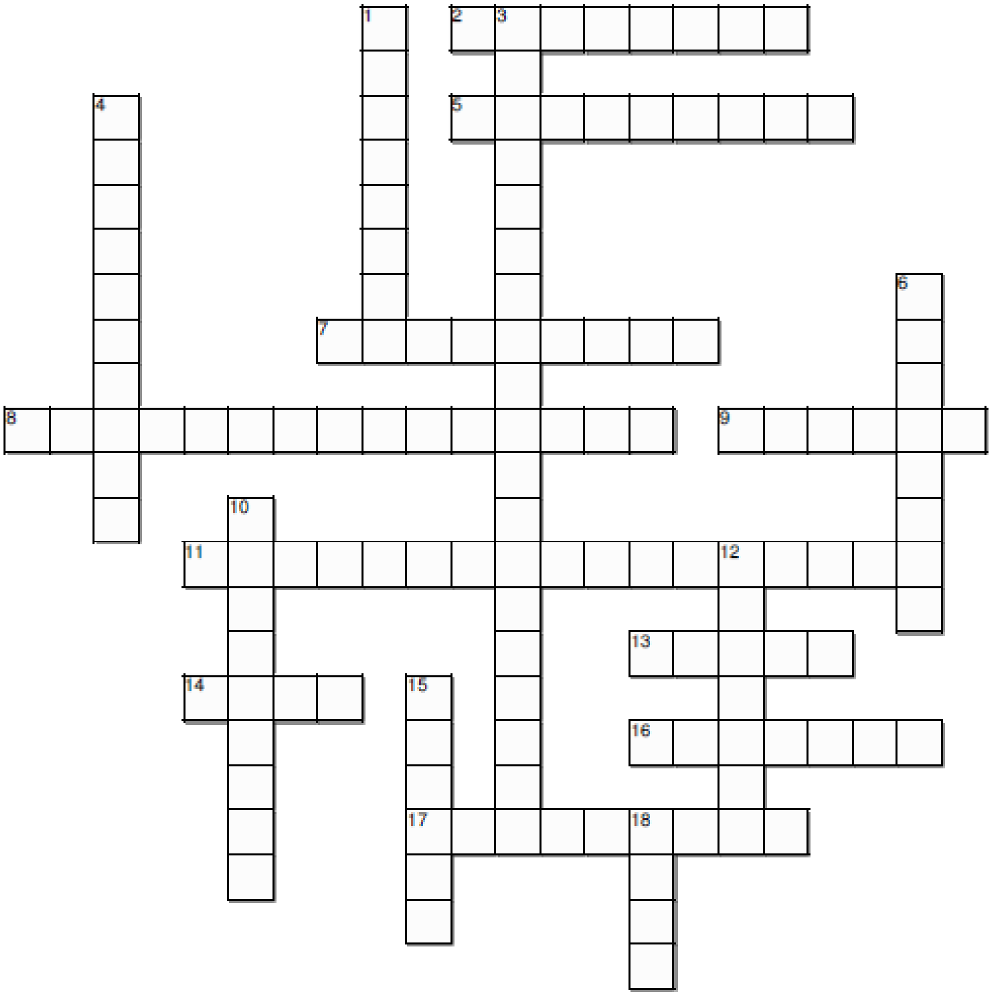
Down

1. The most recently formed dune that is closest to the waterline
3. A dune plant that has two different types of seed pods
4. A common dune plant that is typically planted as a monoculture when restoring dunes
6. A microscopic organism that attacks roots
10. A place where plant specimens are stored
12. A process that occurs when water or wind takes sand away from the dune
15. The best time to plant in dunes
18. A ridge of sand and vegetation

Name: ______________________________

ALL ABOUT DUNES

Complete the crossword below



Name:_____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 4: Review of Concepts and Dune Vocabulary

Crossword Answers:

<u>Across</u>
2. backdune
5. beach pea
7. perennial
8. biodiversity
9. annual
11. seaside goldenrod
13. roots
14. fall
16. rhizome
17. interdune

<u>Down</u>
1. foredune
3. American sea rocket
4. beachgrass
6. nematode
10. herbarium
12. erosion
15. spring
18. dune

Name:____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 5: Nematodes and Plant Health

1. What are nematodes?

   ____

   ____

2. What do nematodes feed on?

   1. ____
   2. ____
   3. ____
   4. ____

3. The type of nematodes affecting beachgrass feed on the ____________ of a plant and are considered to be _________________________.

4. How does this impact the health of the beachgrass?

   ____

   ____

Activity: Slides of nematodes were shared by the United States Department of Agriculture Nematode Collection (USDANC). Choose **3** out of the 8 slides to draw what you see under the microscope. Be sure to write which species you are observing and what magnification they are being viewed at.

Ditylenchus radieicola
Meloidogyne sasseri
Hoplolaimus galeatus
Belanolaimus maritimus
Longidorus biformis
Tylenchorhynchus aduncus
Xiphinema chambersi
Xiphinema americanum

Slide #1

Species name____

Magnification ______

Slide #2

Species name____

Magnification ______

Slide #3

Species name____

Magnification ______

Slide #4

Species name____

Magnification ______

Name:_____________________________

Grade:______

Date:_______

Dover STEAM Academy & UNH
Dune Restoration
Day 6: FIELD TRIP INFORMATION

Dear Parents & Guardians,

Your child will be attending a field trip as part of their enrollment in the Dover STEAM Academy. This field trip will be to Plum Island, Newbury, MA on Wednesday, November 18, 2015. The purpose of this trip is to allow the students to visit coastal sand dunes, observe experimental plots, and participate in restoration plantings. Below is the tentative schedule:

2:30 – Depart Dover Middle School, Dover, NH
3:30 – Arrive Plum Island, Newbury, MA
3:30-5:00 – Participate in activities described above
5:00 – Depart Plum Island, Newbury, MA
6:00 – Arrive Dover Middle School, Dover, NH

Please ensure that your child has proper attire for this trip. It will likely be cold so coats, gloves, and hats are strongly encouraged. Additionally, sneakers or boots are the suggested footwear.

If you have any questions regarding transportation, chaperoning, or any other policies, please contact Fran Meffen, STEAM Academy Director and Guidance Counselor at Dover Middle School. She can be contacted at F.Meffen@dover.k12.nh.us

Please detach the permission slip below and have your child bring it to the next Dover STEAM Academy session.

Thank you,
Natalie Feldsine
Nay53@wildcats.unh.edu

(Please Detach)

I am allowing my child, ___________________________________, to attend the field trip to Plum Island, Newbury, MA on November 18, 2015 as part of the Dover STEAM Academy program.

____________________________________(parent/guardian signature _______________(date)