5-16-2022

# Impacts of Human Development and Salt Marsh Characteristics on Variation in the Growth and Reproduction of Spartina alterniflora

Alora Lovely

UNIVERSITY OF NEW HAVEN

HONORS PROGRAM

2021-2022 Honors Thesis

# Impacts of Human Development and Salt Marsh Characteristics on Variation in the Growth and Reproduction of *Spartina alterniflora*

Alora Lovely

A thesis presented in partial fulfillment of the requirements of the Undergraduate Honors Program at the University of New Haven.

| | |
|---|---|
| Thesis Advisor: | Roman N. Zajac (Signature) |
| Department Chair: | (Signature) |
| Honors Program Director: | (Signature) |

5-16-22

Date

## Abstract

This study focused on how human development may impact salt marshes using the common native species *Spartina alterniflora* as an indicator. Salt marshes are vital coastal ecosystems that help protect against major flooding and can filter pollutants from the water. Like many environments, salt marshes have been impacted by human development in many ways, from construction of cities and roadways to pollution from industrial facilities and equipment. The salt marshes that once dominated many coastlines along the North American Atlantic coast have been destroyed or reduced in size dramatically with the extensive development that has occurred along these shores. Three local salt marshes in the New Haven, CT, area were selected for this study based on their level of human development in the surrounding area, including the highly developed Long Wharf area in New Haven harbor, the relatively less impacted Sandy Point at the mouth of New Haven harbor, and a marsh in Branford which is located within a low human impact coastal landscape. At each marsh, *Spartina alterniflora* was the dominant species in the low marsh where samples were taken. At each site, samples of the stems and inflorescences of *Spartina alterniflora* were sampled along a transect and processed to determine their sizes and wet and dry weights. These were then compared to assess differences among the marshes relative to the impact gradient. Results indicated that although plant characteristics were statistically different among each site, there were no clear relationships to the impact gradient as it appeared that *Spartina alterniflora* was being impacted differently by the surrounding development and natural environment conditions.

## Introduction

One of the most common and productive marine habitats within the United States are salt marshes, which are affected both directly and indirectly by human development (Crosby et al.

2015). Salt marshes can be found along both coasts of the United States and other parts of the world in middle and high latitudes (Jia et al. 2015). Salt marshes are valuable ecosystems as they can act as a storm buffer, filter out pollutants, and are critical habitat for a variety of marine species (Jia et al. 2015). Many marine and terrestrial species, including fish, invertebrates, and birds use salt marshes as a place to feed, breed, and raise young (Kennish et al. 2014). Salt marshes are also economically useful for water purification, tourism, and for commercial fishing (Kearney and Turner 2016). Marshes can be subjected to harsh conditions caused by both natural and anthropogenic conditions, which can significantly affect plant and animal life (Jia et al. 2015). Both direct and indirect impacts can cause significant damage and decline to a salt marsh, causing many plants, marine invertebrates, and even land vertebrates to be impacted as well.

There are many species of marsh plants that exist across the globe, each found in different tidal zones within the marsh, including various species of grasses, shrubs, and herbs (Jia et al. 2015). *Spartina alterniflora* is one of the dominant species along the U.S. Atlantic coast found along the seaward edge or low tidal range (Crosby et al. 2015). This species is monospecific and is found in both a tall and short form, both of which are used in studies of salt marshes (Anderson and Treshow 1980). In this study, *Spartina alterniflora* will be used as the scientific name. The scientific name for this species is still currently under debate. A phylogenetic study done in 2014 revealed that this grass is actually a subtribe of *Sporobolus* (Bortolus et al. 2019). Even though morphology and DNA evidence now show that this grass species is a sister species to *Spartina*, *Spartina* is still favored and used over *Sporobolus* (Bortolus et al. 2019).

**Background**

*Reproduction and growth*

Marsh plants have different reproduction and growth strategies that allows them to grow and survive as a population in such harsh environments. *Spartina alterniflora* is thought to mainly reproduce primarily through asexual reproduction, but the species can also reproduce through sexual reproduction (Crosby et al. 2015). Asexual reproduction allows for *Spartina alterniflora* to reproduce clones quickly and sexual reproduction through seeding allows the species to spread and grow in new locations (Crosby et al. 2015). This ability to reproduce either asexual and sexual has many benefits, including expansion locally through asexual reproduction and spatial expansion over greater distances through sexual reproduction from the same plants. *Spartina alterniflora* takes advantage of polyploidy during asexual or self-fertilizing reproduction to quickly adapt to any changes in the environment and able to maintain a stable population (Anderson and Treshow 1980).

*Spartina alterniflora* can grow in two different forms depending on the number of chromosomes present, 56 chromosomes for the short form and 70 chromosomes for the tall form (Anderson and Treshow 1980). In addition of having a different number of chromosomes that determine their height, the two forms of *Spartina alterniflora* have some differences in their inflorescence, flowering time, and where they grow in the marsh. The short form has a shorter and more condensed inflorescences that flower during early summer, and is found in higher in the intertidal zone, while the tall form has a longer inflorescence that flowers later and is found on the banks of the low intertidal zone (Anderson and Treshow 1980). This study primarily focused on the tall form found along low marsh habitats. The growth rate of the two forms can be limited by many factors, for example the short form has shown to have limited growth based on the amount of nitrogen present (Anderson and Treshow 1980). With the two forms having slightly different limiting growth factors, the presence of a limiting factor may determine which

form is the most abundant in a marsh. Studies have shown that when nitrogen was introduced into a salt marsh all growth forms showed increased production, the greatest impact was on the short form (Anderson and Treshow 1980). Limiting factors such as nitrogen could have a great effect on the species composition and health of a marsh.

*Relationships with benthic organisms*

Marsh plants provide habitat for many invertebrates, both residing on the surface and burrowing into the marsh itself. Many of these invertebrates have a positive relationship or collaboration with different marsh plants such as *Spartina alterniflora*. Some examples of invertebrates that have a positive relationship with *Spartina alterniflora* are mussels and fiddler crabs. The ribbed mussel, *Geukensia demissa*, helps *Spartina alterniflora* thrive by their byssal threads holding the soil structure and filtering water through filter feeding (Bertness 1984). This mussel is also found the low intertidal zone, following a similar vertical tidal zonation as *Spartina alterniflora* (Franz 1997). Wherever *Spartina alterniflora* is located in the marsh, *Geukensia demissa* is most likely grouped in the soil at its roots. Fiddler crabs, *Uca spp.*, are beneficial for *Spartina alterniflora* because their manipulation of the soil, increaes oxygen flow through the soil and mixing of the soil layers (Bertness 1984). Like the mussels, fiddler crabs are found in the low marsh alongside *Spartina alterniflora*, usually with the taller form (Bertness 1984). The actions of both of these invertebrates help *Spartina alterniflora* and maintain populations in salt marsh environments. With both of these invertebrates having a close relationship with *Spartina alterniflora*, their presence may be able to depict the health of the marsh. Fiddler crabs will not burrow in softer sediment in there is no *Spartina alterniflora* present (Bertness 1984). Their absence could indicate a decline in the ecological health of the marsh. *Spartina alterniflora* would not be as successful without either of these invertebrates.

*Tidal Influences*

Being the transition zone between terrestrial and marine environments, salt marshes are subjected to daily changes of the tide. Depending on the type of tide an area experiences, salt marshes may experience multiple periods of flooding and sun exposure and drying out. The high productivity of a salt marsh may be linked to these tidal differences (Steever et al. 1975). Salt marshes are dependent on the tide in order to function properly. Where different marsh plant species reside in the marsh is decided by the hydrography and hydrology of the tides (Kearney and Turner 2016). If a marsh has a low tidal range, there will probably a low distribution of plant species with less visible zonation. Marshes with a high tidal range will have a greater/more distinct zonation of marsh plants. A change in tidal range would affect this zonation. The tide is perhaps the most significant factor affecting the growth and reproduction of marsh plants like *Spartina alterniflora* (Steever et al. 1975). Studies done along Long Island Sound have shown that there is a positive correlation between tidal range and marsh plants; as the tidal range of a marsh increased so did the size and abundance of the marsh plants (Steever et al. 1975). Marshes that display a significant tidal range may have a healthier and more productive plant composition than a marsh that experiences a smaller tidal range. The physical, biotic factors, and abiotic factors of a marsh vary with tidal range of the marsh (McKee and Patrick 1988). If a marsh experiences a decrease in tidal range for any reason, it could have a significant effect on the marsh plants. For example, a study in Connecticut showed that the presence of a tidal gate which reduce the tidal change led to a decrease in the biomass of *Spartina alterniflora* (Steever et al. 1975).

*Sea Level Rise*

In addition to tidal influences, sea level rise can have a significant impact on salt marshes. Being a coastal intertidal environment, sea level rise can be a serious problem for salt marshes. The ranges of many marsh plants are determined by multiple factors; tolerance to flooding in the low marsh and interspecific plant competition in the high marsh (Donnelly and Bertness 2001). Sea level would directly impact these factors that create the zonation seen between the low and high marsh. The ranges of species would be impacted and forced to change in order to survive. As sea level rise accelerates, the distribution of species and marsh loss are at stake (Warren and Niering 1993). Some marshes within the United States have already showed signs of some plants replacing others in the marsh, such as *Juncus geradi* being replaced by *Spartina patens* in the high marsh and *Spartina patens* being replaced by *Spartina alterniflora* settling in different elevations (Warren and Niering 1993). As sea level continues to rise, more marshes will be at risk for a zonation change or being lost in extreme cases.

*Human impacts on diversity and growth*

Human have had many impacts on salt marshes and the marsh species *Spartina alterniflora*. These impacts have been negative, neutral, and even beneficial for the species. As stated previously, impacts to salt marshes can direct or indirect, such as removal or filling of marsh areas, waste dumping, climate change, tidal changes, and more. Some marsh areas face decline and damage naturally through storms, erosion, and sea level rise (Kennish et al. 2014). Adding human influenced decline on top of these natural factors could cause greater decline to occur.

Climate change can affect terrestrial or marine environment across the globe in a variety of ways. It can alter the hydrologic parameters that allow the marsh to function and thus affect the species within the marsh (Hartig et al. 2002). Salt marshes can be affected by climate change

by erosion from severe storms and rising sea levels which can impact marshes for long periods of time (Kennish et al. 2014). Impacts from climate change might not be seen immediately, but rather can be gradual and impacts accrue over long periods of time. Through erosion and rising sea levels, marshes will slowly get smaller and smaller. Change from anthropogenic processes such as ditching will also cause changes in the water level, leading to less water pooling in salt marshes (Kennish et al. 2014). Anthropogenic changes like ditching may seem minor intentionally with long term affects that follow. These anthropogenic changes can cause the composition, abundance, and distribution of salt marsh plants by causing variation in the environment (Kennish et al. 2014).

*Spartina alterniflora* has benefited in some cases from human impacts, and in some cases negatively impacting other marsh species, by being introduced to new environments and becoming an invasive species. This Atlantic species has been introduced to many different coasts globally and it has had a severe impact where introduced. In 1979, *Spartina alterniflora* was introduced to China for ecological engineering purposes, but the species ability to adapt and reproduce quickly caused it to start to dominating areas outside the original area of introduction (Wan et al. 2014). Mudflats and mangrove forests in China have also been taken over due to *Spartina alterniflora* being introduced nearby (Wan et al. 2014). This human impact has proven to be beneficial for *Spartina alterniflora* as it does not have its usually competitors or herbivores keeping it controlled. In these new locations, there may be little to stop it from further spreading except perhaps direct human intervention.

*Study objectives*

In this study I determined the potential impacts of human development on the growth (size) and reproduction of *Spartina alterniflora* by studying three different locations with varying

levels of development: Long Wharf, Sandy Point, and Branford. I predicted *Spartina alterniflora* would have the lowest growth (smallest size) and reproductive output in salt marshes that show the greatest level of human development. The highest growth (largest size) and reproductive output would be found in less disturbed marsh systems.

**Methods and Materials**

Data were collected at three marshes in the New Haven area to study the potential effects of human development on salt marshes, using the size and reproductive characteristics of *Spartina alterniflora* as a potential ecological indicator. The marshes for this study were selected based on the degree of human development within the vicinity of each marsh that could potentially impacting their ecology. Study sites were selected based on a gradient of potential impacts and included an area of relatively high, medium, and low human development. Comparing marshes of varying levels of human development may provide insights on impacts of human development on the growth and reproduction of *Spartina alterniflora*.

*High Human Development- Long Wharf marsh, New Haven Harbor*

The Long Wharf marsh is located at the head of New Haven Harbor and this area has experienced the most human development out of all the chosen marshes. This marsh is very narrow and small compared to the other two marshes. The size of marsh was mostly likely reduced and restricted from the construction of highways (I-95) and extensive development in this portion of the harbor's shoreline. The interstate and surrounding roads have extensive traffic, and the area is densely populated. The harbor also experiences heavy commercial and recreational boat traffic.  The dominant plant species found within this marsh are *Spartina alterniflora* and *Phragmites australis*. Most of the intertidal zone is made up of mud flats and

sand banks. One main tidal creek flows through the marsh but it was very shallow and narrow even at high tide. With the extensive development and human activity in this area, the Long Wharf marsh most likely experiences the greatest impacts by human development.


Figure 1: Aerial image of the Long Wharf marsh study site in New Haven, CT; 41°17'09.3"N 72°55'27.6"W. Yellow lines show locations of transects; Transect 1 was =15 m in length, Transect 2 was 10 m.

*Mid-range Human Development- Sandy Point Bird Sanctuary- New Haven Harbor*

The Sandy Point Bird Sanctuary was selected as the marsh system that may experience a relatively mixed level of human impacts. The surrounding area of this marsh is more residential rather than industrial. Given its location at the mouth of New Haven Harbor, it also likely experiences fewer impacts associated with harbor activities. Similar to Long Wharf, the most common species to be found in this marsh are *Spartina alterniflora* and *Phragmites australis*. The main tidal river that runs through this marsh was surrounded by large mud flats on either side, making the marsh more difficult to navigate safely. The outer edge of the marsh was

surrounded by large sandy banks which creates a point. This marsh may experience lower human impacts, but it was less protected from the wind and waves. Sand bars and sandy shores have developed from the wind and waves hitting the marsh. As such it may represent a more dynamic marsh in terms of natural environmental factors.


Figure 2: Sandy Point marsh study site in West Haven, CT; 41°16'01.0"N 72°55'39.3"W. Yellow lines indicate location of sampling transects; Transect 1 was =15 m in length, Transect 2 was =20 m.

*Low Human Development- Pine Orchard Marsh in Branford*

The Branford marsh is part of the Pine Orchard Marsh Wildlife Area. It was surrounded by vegetated headlands and forest, small residential areas, and a golf course. Train tracks, one main road, and one boardwalk cross this marsh area. These designated paths through the marsh area prevents most people from walking in the marsh itself. This marsh was designated as the least potentially affected by human activity and development. It has well developed marsh plant community including plants typical of both low marsh and high marsh habitats.


Figure 3: Branford marsh in Branford, CT; 41°16'17.2"N 72°45'31.2"W. Yellow lines show the locations of sampling transects. Transect 1 was =20 m in length, Transects 2 and 3 were = 25 m.

*Assessing Growth and Reproduction*

Sampling was conducted at low tide, when the low marsh was more easily accessible. The low marsh is submerged during high tide and cannot be easily sampled during this tidal phase. During the initial visit to each marsh, transects was used to determine the species composition of each marsh and the abundance of *Spartina alterniflora*.

At each marsh, three 10-25 m transect lines were established along different portions of the low marsh extending into the high marsh. Transect lengths varied from marsh to marsh, but each transect started in the low marsh areas where *Spartina alterniflora* is most found. At every five meters along the transect, the height of five *Spartina alterniflora* stems was measured within a 1 $m^2$ quadrat. The stem heights of *Spartina alterniflora* can also be used to determine the height forms within the marsh and the population composition for each height form.

Inflorescences of *S. alterniflora*, which contain the seeds, were cut from plants which were measured for height within each quadrat and placed into labeled bags for further examination in the lab along with the stems. The inflorescences from each site were dried and weighed after being separated from each of the stems. The weight of each inflorescence was used to indicate the reproductive output of each plant. Inflorescences with higher weights will indicate a higher reproductive output of the sampled plant. The weight of each inflorescence was compared the height of each stem to assess the relative energy plants may be putting into growth versus reproduction.

Both a wet and dry weight was taken for the stems and inflorescences for each plant. Wet weights were taken shortly after the plants were collected. After each of the plant stems and their inflorescences were weighed, they were dried in a drying oven, using metal trays to hold the plants and keep them from separated. Each plant was dried at 60° to 70° C for 24 to 48 hours depending on how dry the samples were. Most samples were dry within 24 hours. After the samples were dried, they were cooled to room temperature before taking a dry weight. Dry weights were taken for the stem and inflorescent on the same scale as the wet weight for consistency. The ratio of inflorescence weight to stem weight was used as a measure of relative contribution to reproduction for the plants.

Analysis of variance weas used to determine differences in plant characteristics among the three marshes and among the locations on transects using NCSS. Regression analyses were used to assess relationships between plant characteristics.

**Results**

*Stem Height*

Stem height varied among the three sites. Average stem heights ranged from 85 cm to 105 cm (Figure 4) and were significantly different among sites (Table 1). Long Wharf had the lowest average stem height compared to Branford and Sandy Point, but it had the highest variation. Within the sites, the shortest and tallest average height had a difference of ~20 cm, while at Branford and Sandy Point the difference in mean plant height was less than 10 cm (Figure 5). Sandy Point had the tallest recorded stem heights with the lowest height variation along the transects (Figures 4 & 5). Long Wharf also had the smallest low marsh zone, being only 15 m in length. Branford and Sandy Point both had much larger low marsh zones. The stem height for each site increased with distance and declining at 15 m before increasing in height again (Figure 5).

*Stem Dry Weight*

Stem dry weight followed a similar trend to the stem height. Long Wharf had the lowest average of 3 g while Branford and Sandy Point both had an average of ~ 5 g (Figure 6). Differences in the stem dry weight were statistically significant among sites (Table 2). The dry weights for Long Wharf had the smallest variation along the transects, ranging from 1 g to 4 g (Figure 7). The heaviest stems at 10 m at Long Wharf were only slightly heavier than the lightest stems from Sandy Point. Branford and Sandy Point had consistently heavier stems than Long Wharf along the transects (Figure 6). Dry weights were variable along the transects at Branford and Sandy Point, with greater variation at Sandy Point (Figure 6 & 7). There was a difference of 2 g at Branford between the lightest and heaviest stems whereas at Sandy Point it was 3 g. Long Wharf had a similar weight difference as Branford but there were fewer stems at Long Wharf that had similar weights (Figure 7). All sites had increasing stem weights along the transects to 15 m, where weights declined, but that slowly increased again approaching the high marsh zone.

*Inflorescent Height*

Average inflorescence height was similar among sites, ranging from 20 cm to < 30 cm (Figure 8). The inflorescence height was significantly different among sites (Table 3). Sandy Point had the lowest average inflorescences height and Long Wharf had the highest average. Branford had an average that was slightly lower than Long Wharf. For each site the average remained relatively consistent across the transects, dipping slightly at 15 m (Figure 9). From 0 to 15 m, Long Wharf and Branford had similar averages. Sandy Point was lower than both Branford and Long Wharf until 15-20 m. At 10 m there was about a 10 cm difference in the inflorescent height between Long Wharf and Sandy Point (Figure 9). The variations in the averages were similar for each site with Branford having slightly more variation (Figure 8).

*Inflorescent Dry Weight*

The inflorescence dry weight varied among sites. Differences in mean inflorescence dry weight were statistically significant among sites (Table 4). Sandy Point had the lowest average at 0.2 g while Branford had the highest average at 0.5 with the highest variation in dry weight (Figure 10). Branford had a variation of 3 g, the lightest sample average being about 4 g and the heaviest being around 6 g (Figure 10 & 11). Both Long Wharf and Sandy Point had similar variation about the mean, but there was a ~0.2 g difference in their averages (Figure 10). Each location had different trends for dry weight along the transects. Branford increased and dipped at 10 m before increasing for the remaining points on the transects. (Figure 11). Long Wharf increased and dipped at 15 m, but it could not be determined if it would have increased again as there were no data points past 15 m (Figure 11). For Sandy Point the dry weights remained about the same for the first 15 m before doubling at 20 m (Figure 11).

*Relationships Among Plant Characteristics*

Two linear regression analyses were made to assess relationships among plant characteristics; one for the stem wet weight versus the stem dry weight and one for the inflorescent wet weight versus the inflorescent dry weight (Figures 12 & 13). In both cases, there was a significant positive relationship between the variables with >80% of the variation in dry weights being accounted for by the wet weights. For the stem weights many samples had a wet weight of around 10 g with a dry weight of ~4 g, with a second group of samples at ~15 g wet weight and ~5 g dry weight (Figure 12). Weights past this range were less concentrated around the regression line. Inflorescence wet weight was closely related to dry weight up to a wet weight was 1 g (Figure 13).

*Inflorescence/Stem Ratio*

The ratio of inflorescence dry weight to stem dry weight was used to assess the amounts of reproductive effort plants were making relative to stem growth among and within sites (Figure 15). Differences among the sites were significantly different (Table 5). Long Wharf had the highest ratios among the sites, at all transect positions, with a peak at 10 m. Ratios at Branford were the next largest. Sandy Point had the smallest ratios, being generally one half that found at the other sites, and especially at 10 m where the ratio was quarter of the size of Long Wharf's. There was a slight increase in the ratio with distance from the starting point of the transects (lowest position in the low marsh) at Long Wharf and Branford.

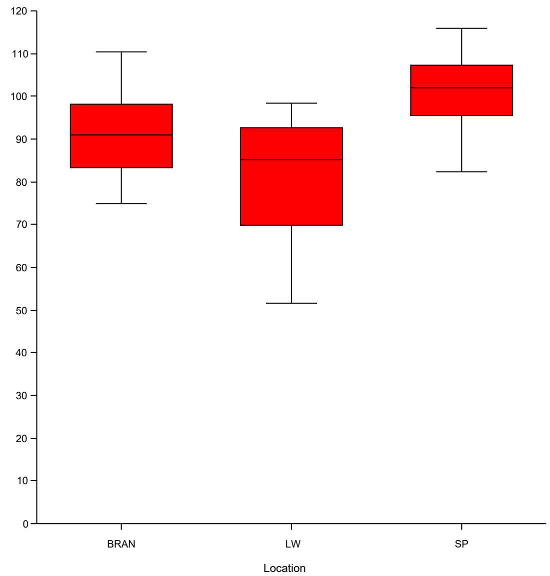


Figure 4: Box plot of *Spartina alterniflora* stem height averages; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

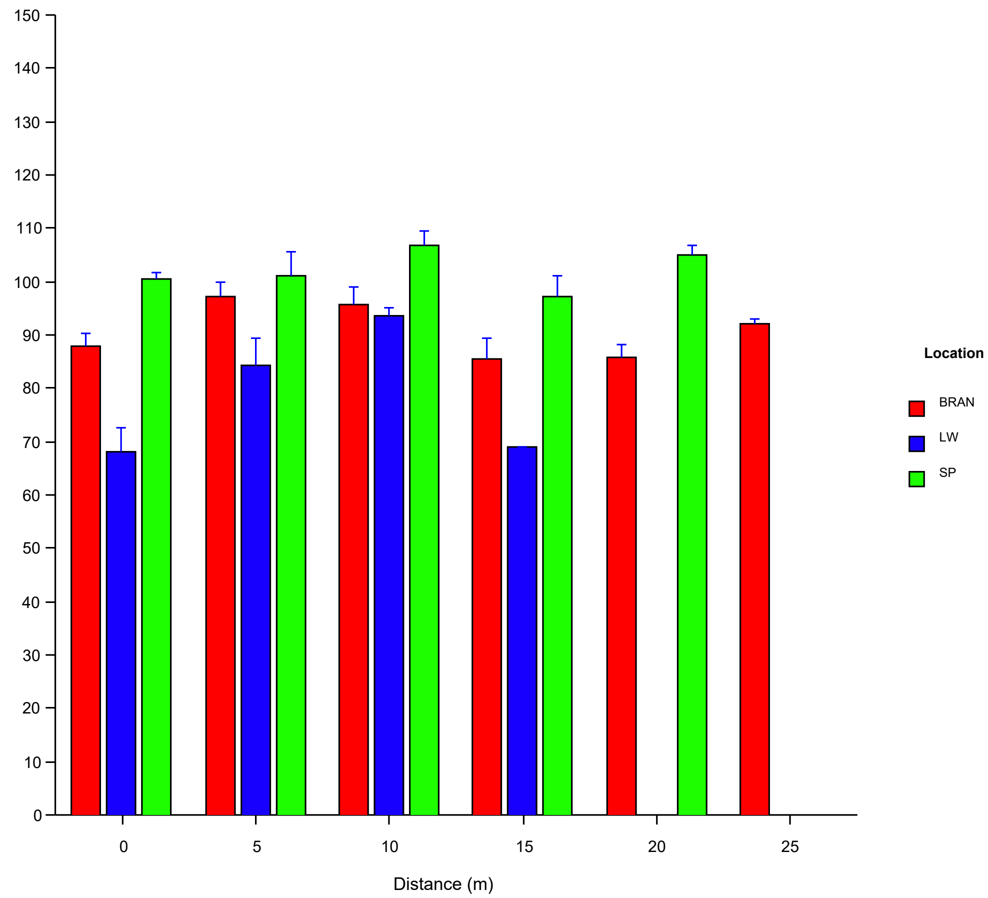


Figure 5: Stem height averages for *Spartina alterniflora* across the transects and location; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

Table 1: Analysis of Variance Table for stem height

| **Model Term** | **DF** | **Sum of Squares** | **Mean Square** | **F-Ratio** | **Prob Level** | **Reject Equal Means? (α = 0.05)** | **Power (α = 0.05)** |
|---|---|---|---|---|---|---|---|
| Between (Location) | 2 | 4843.246 | 2421.623 | 24.8944 | 0.00000 | Yes | 1.00000 |
| Within (Error) | 89 | 8657.536 | 97.27568 | | | | |
| Adjusted Total | 91 | 13500.78 | | | | | |
| Total | 92 | | | | | | |

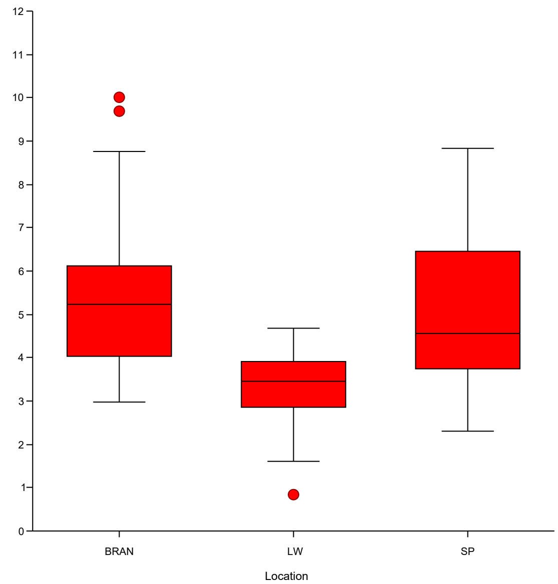


Figure 6: Box plot of *Spartina alterniflora* stem dry weight; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

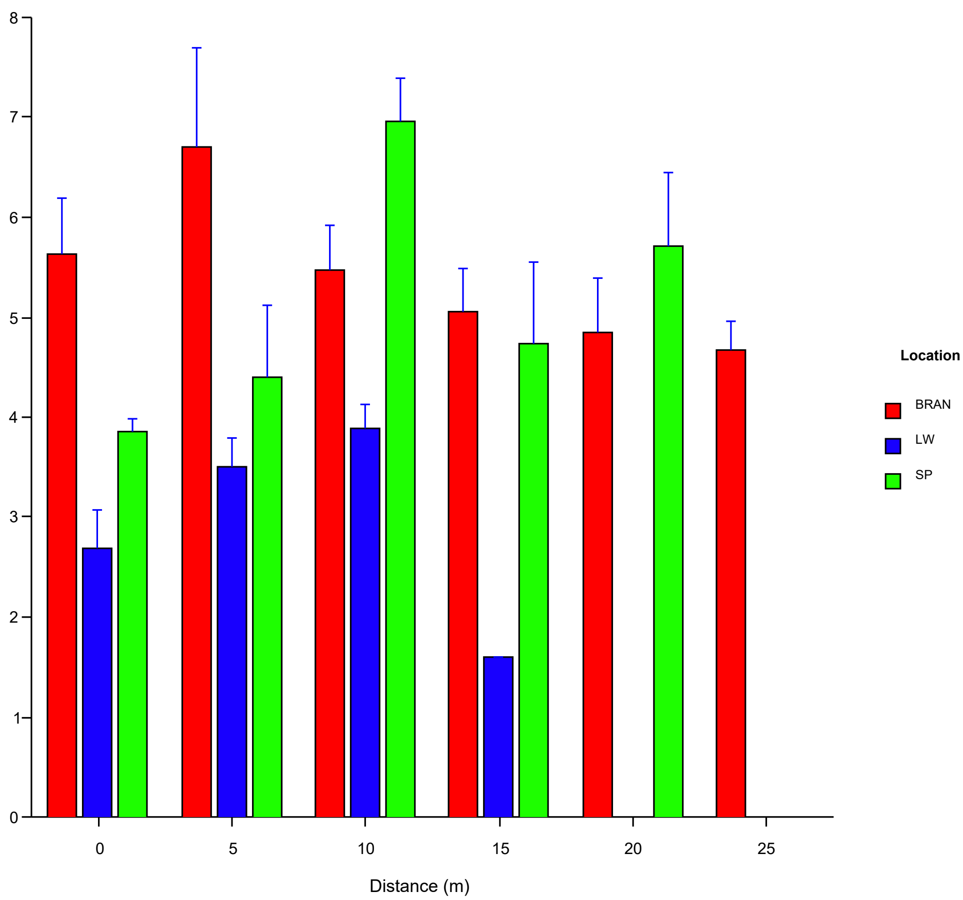

Figure 7: Stem dry weight averages of *Spartina alterniflora* among sampling sites; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

Table 2: Analysis of Variance Table for stem dry weight

| Model Term | DF | Sum of Squares | Mean Square | F-Ratio | Prob Level | Reject Equal Means? (α = 0.05) | Power (α = 0.05) |
|---|---|---|---|---|---|---|---|
| Between (Location) | 2 | 64.25969 | 32.12984 | 12.4404 | 0.00002 | Yes | 0.99533 |
| Within (Error) | 89 | 229.8612 | 2.58271 | | | | |
| Adjusted Total | 91 | 294.1209 | | | | | |
| Total | 92 | | | | | | |

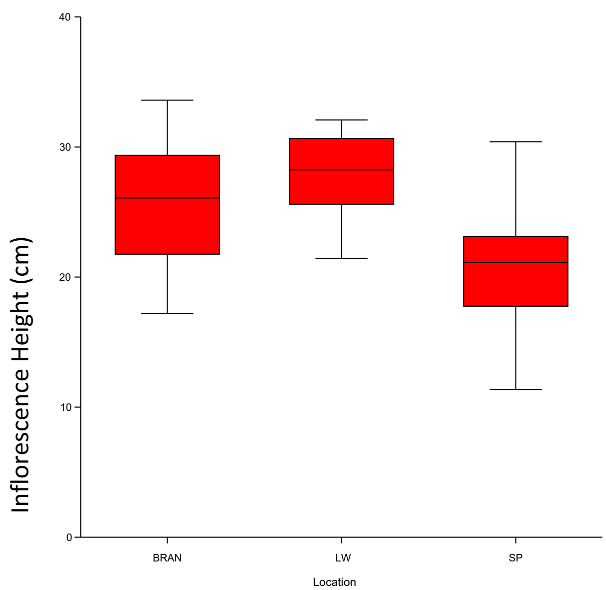


Figure 8: Box plot of *Spartina alterniflora* inflorescence height; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

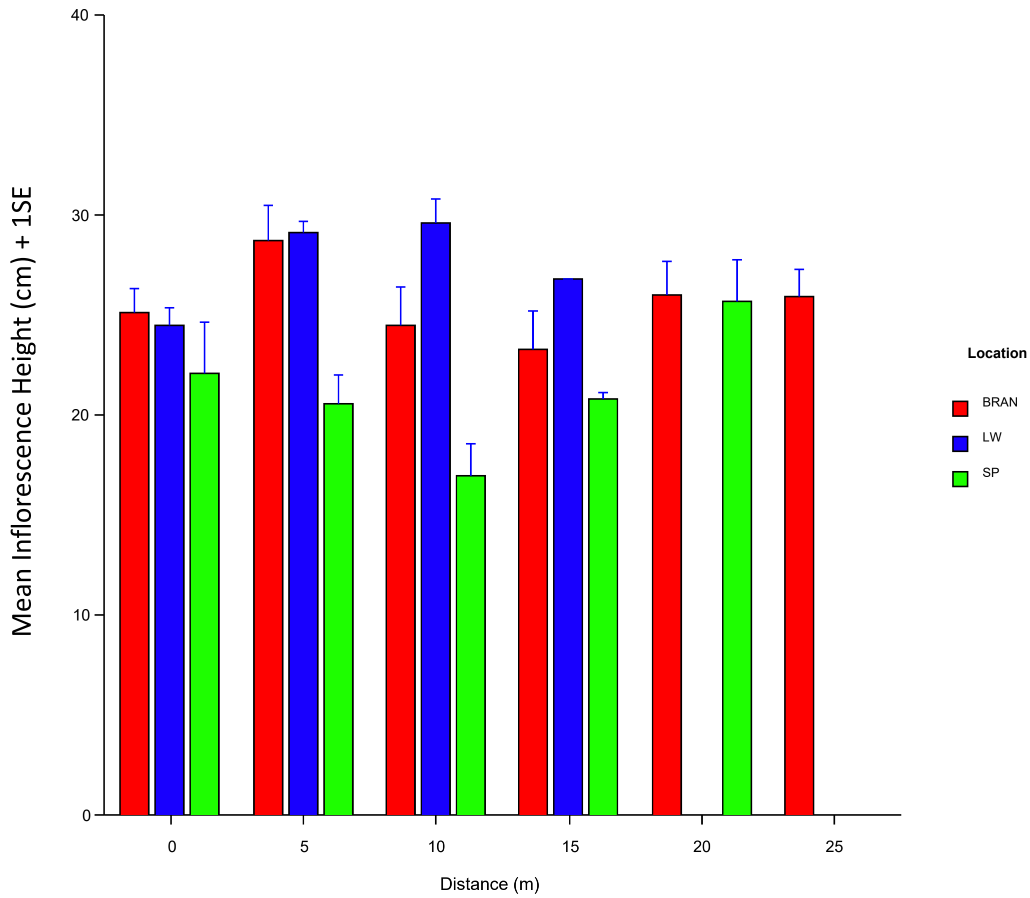


Figure 9: Inflorescence height averages of *Spartina alterniflora* among sampling sites; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

Table 3: Analysis of Variance Table for inflorescence height

| Model Term | DF | Sum of Squares | Mean Square | F-Ratio | Prob Level | Reject Equal Means? (α = 0.05) | Power (α = 0.05) |
|---|---|---|---|---|---|---|---|
| Between (Location) | 2 | 643.2925 | 321.6463 | 16.6042 | 0.00000 | Yes | 0.99959 |
| Within (Error) | 88 | 1704.683 | 19.3714 | | | | |
| Adjusted Total | 90 | 2347.976 | | | | | |
| Total | 91 | | | | | | |

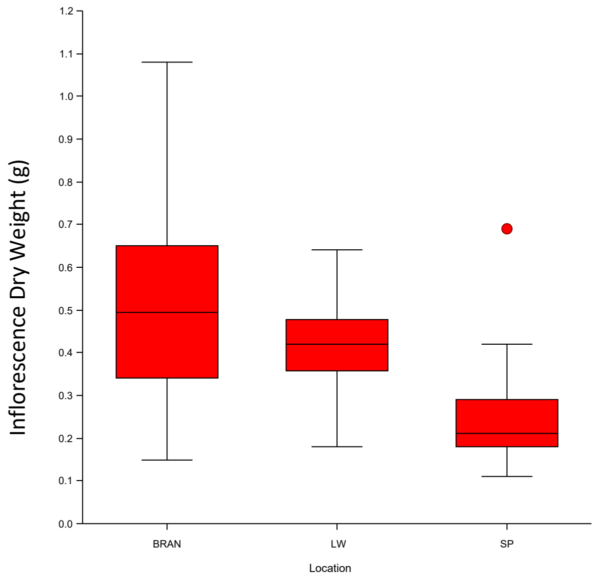


Figure 10: Box plot of *Spartina alterniflora* inflorescence dry weight; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

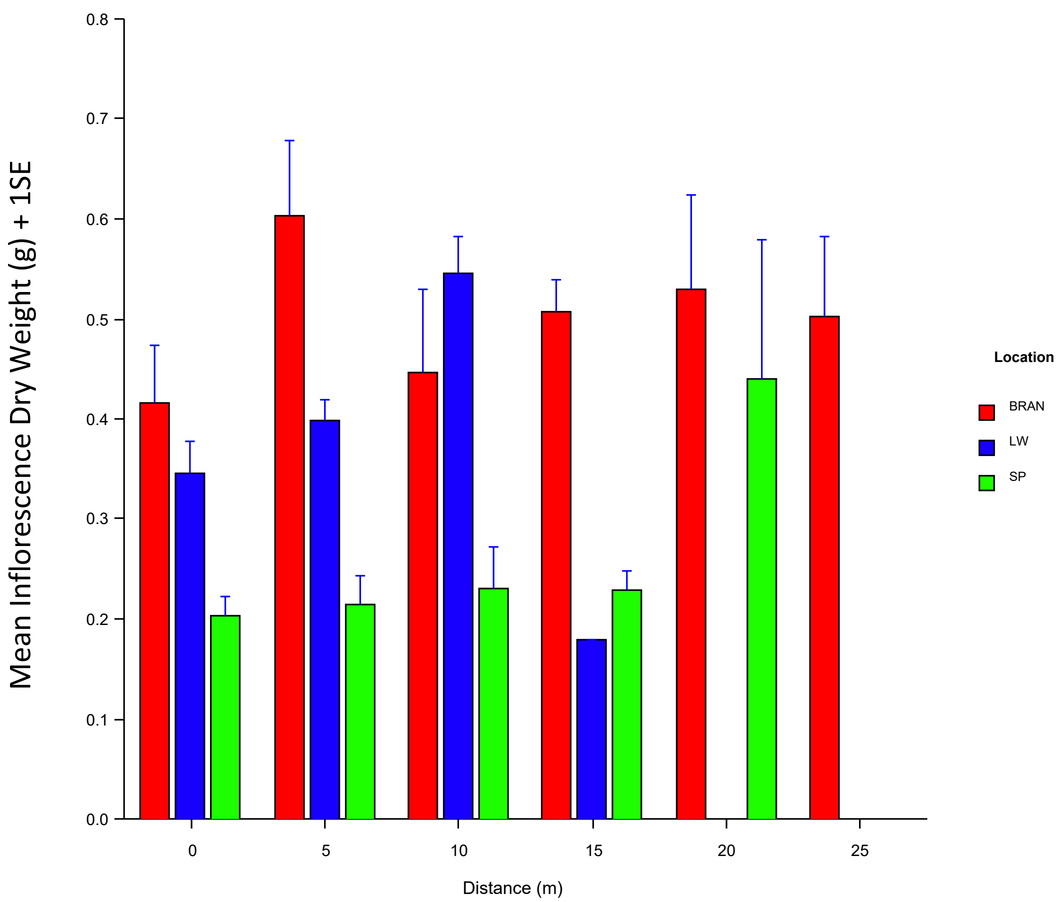

Figure 11: Inflorescence dry weight for *Spartina alterniflora* among sampling sites; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

Table 4: Analysis of Variance Table for inflorescence dry weight

| Model Term 0.05) | DF | Sum of Squares | Mean Square | F-Ratio | Prob Level | Reject Equal Means? (α = 0.05) | Power (α = |
|---|---|---|---|---|---|---|---|
| Between (Location) | 2 | 1.132044 | 0.5660222 | 19.5852 | 0.00000 | Yes | 0.99994 |
| Within (Error) | 88 | 2.543246 | 0.02890052 | | | | |
| Adjusted Total | 90 | 3.67529 | | | | | |
| Total | 91 | | | | | | |

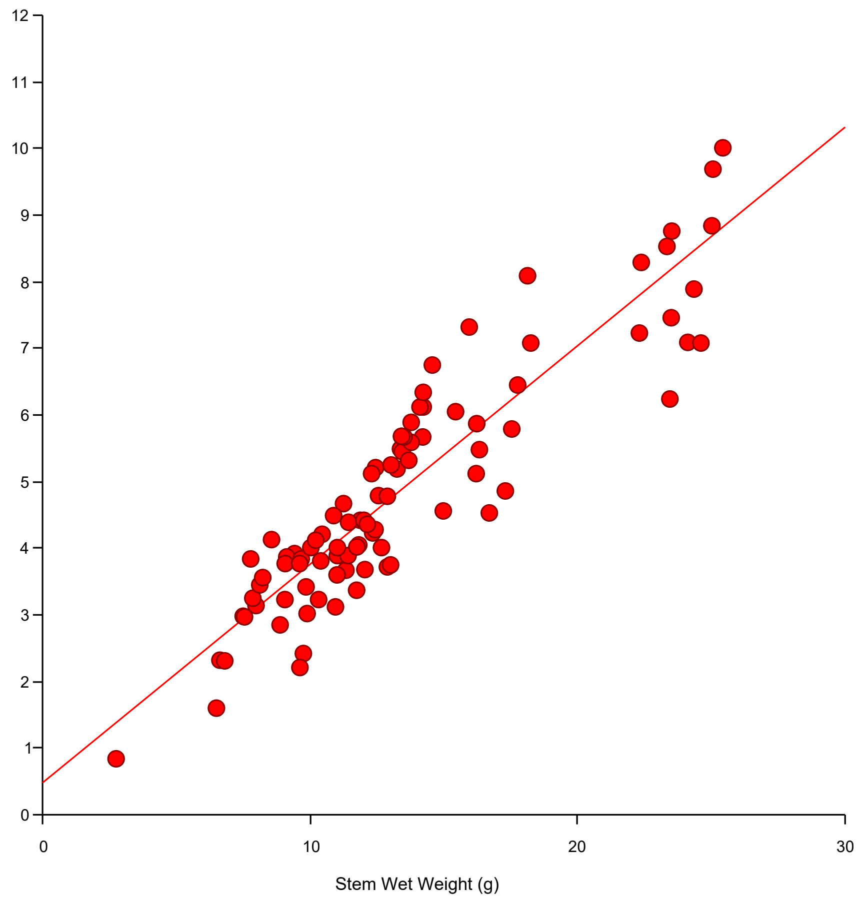


Figure 12: Stem wet weight vs stem dry weight, R-squared=0.8330, Stem dry weight (g) = (0.4723) + (0.3286*stem wet weight)

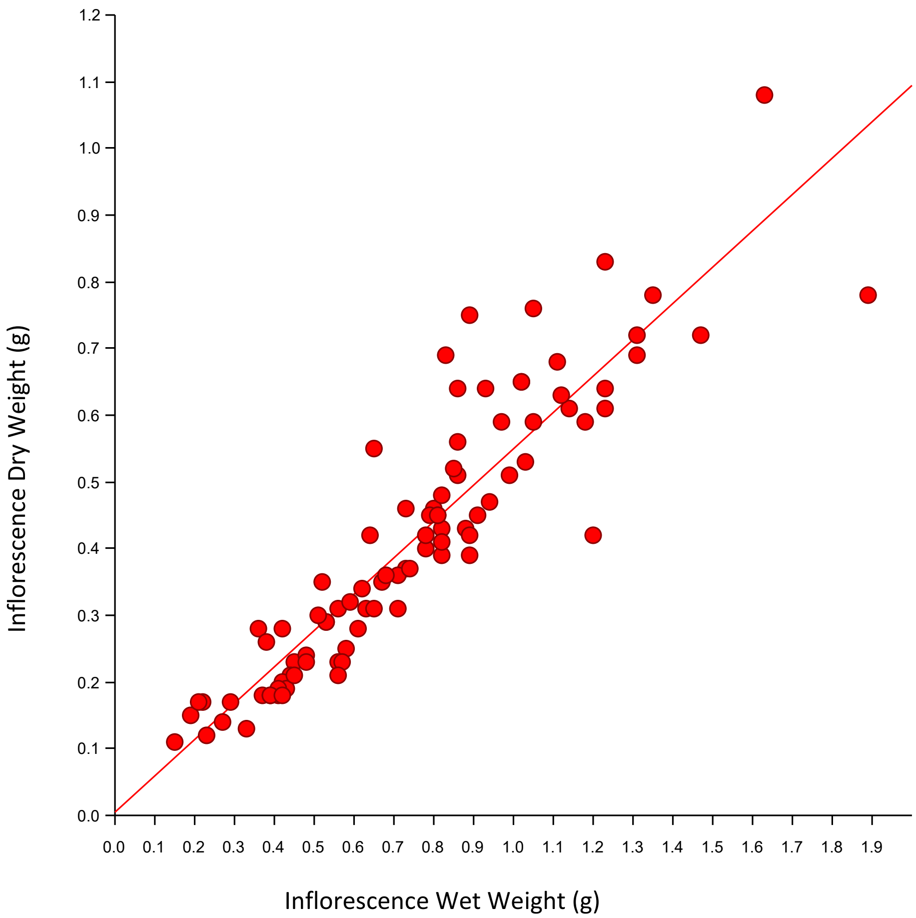


Figure 13: Inflorescent wet weight vs inflorescent dry weight, R-squared=0.8353, Inflorescence dry weight = (0.0054) + (0.5443*stem wet weight)

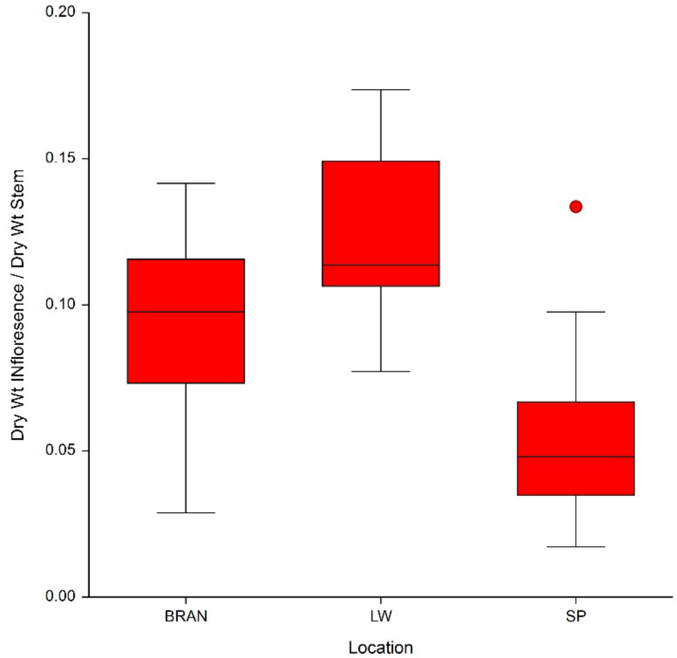


Figure 14: Box plot of *Spartina alterniflora* inflorescence dry weight vs stem dry weight; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

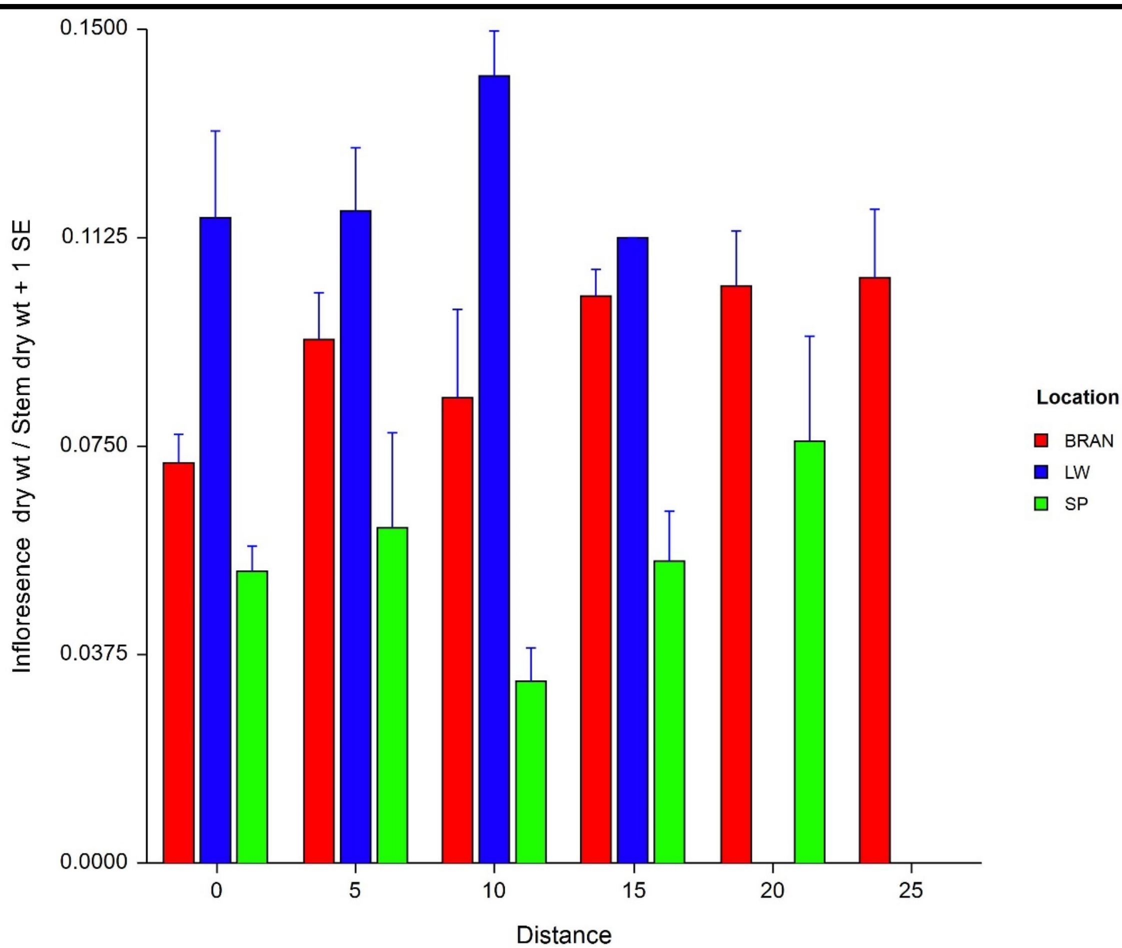


Figure 15: Stem dry weight to inflorescence dry weight ratio along sampling transects at each site; BRAN=Branford, LW=Long Wharf, SP=Sandy Point

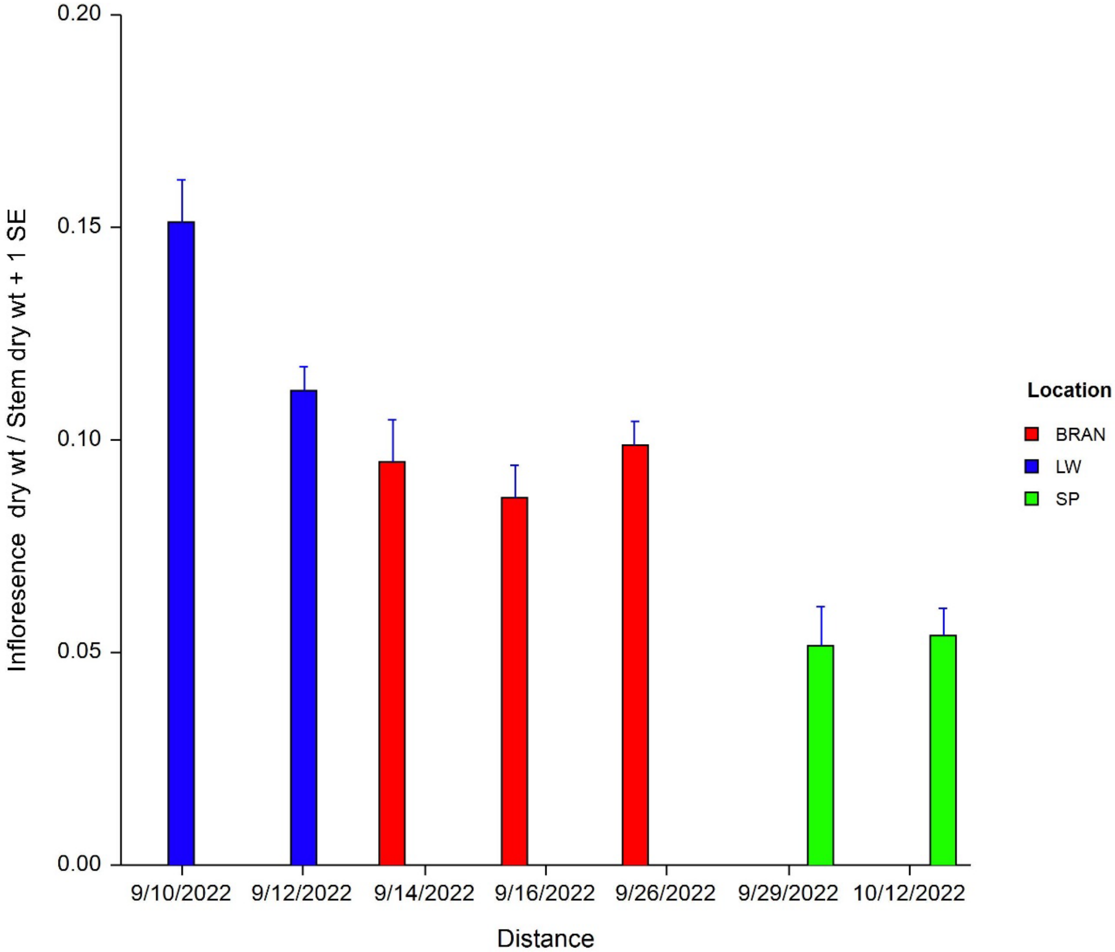


Figure 16: Inflorescence dry weight vs stem dry weight for each site and time of data collection.

Table 5: Analysis of Variance Table for stem/inflorescence ratio

| **Model Term** | **DF** | **Sum of Squares** | **Mean Square** | **F-Ratio** | **Prob Level** | **Reject Equal Means? (α = 0.05)** | **Power (α = 0.05)** |
|---|---|---|---|---|---|---|---|
| Between (Location) | 2 | 0.05881616 | 0.02940808 | 36.3292 | 0.00000 | Yes | 1.00000 |
| Within (Error) | 88 | 0.07123503 | 0.0008094889 | | | | |
| Adjusted Total | 90 | 0.1300512 | | | | | |
| Total | 91 | | | | | | |

## Discussion

*Comparing Plant Growth (Size) and Reproduction*

*Stems*

The study sites were statistically different from each other, suggesting that each site had been impacted differently (Tables 1 & 2). Long Wharf had the lowest stem heights and dry weights (Figures 5 & 7). The samples collected from Long Wharf were noticeably thinner and shorter than samples at the other sites. Many of the plants were thinner than a pencil. Branford consistently had much thicker stems. This made them much harder to cut and contributed to the higher dry weight. The stems collected from Branford were slightly higher, but were heavier than Long Wharf. Sandy Point was very similar to Branford in both stem height and dry weight (Figures 5 & 7).

Each of the study sites varied from each other differently, but all followed a similar trend for stem height and dry weight along the transect. Generally, for both the stem height and dry weight at each site increased along the transects until about 10 m (Figures 5 & 7). The stem height and dry weight was lower at 10 m for each site. After 10 m both the stem height and dry weight increased again. Branford and Sandy Point did not have as big of a shift in the stem height compared to Long Wharf. Branford showed evidence of higher tidal inundation into the low marsh the high marsh transition. Multiple patches of taller *Spartina alterniflora* were found in the higher parts of the marsh that is normally dominated by the short form and *Spartina patens*. With Long Wharf having the shortest stem heights and dry weights, this suggest that the influence of human activities made an impact on the growth of the plants in this location. Being in a less developed area, plants at the Sandy Point and Branford sites may have been less impacted and were able to grow larger compared to Long Wharf.

*Inflorescences*

The height and dry weight of the inflorescences for each site varied. Branford was the most consistent for both the height and dry weight (Figures 9 & 11). Long Wharf had similar inflorescence heights and dry weights to Branford. Observations during sampling correlated with the data to show that these sites were similar, but still statistically different from each other. In the field the inflorescences collected from these two sites were similar in size, but Branford appeared to have more seed pods on its inflorescences contributing to its dry weight being higher. Sandy Point had much smaller inflorescences and lower dry weights than both Branford and Long Wharf (Figures 9 & 11). Many of the inflorescences at Sandy Point had been damaged or missing entirely. Many of the collected samples appeared to be missing at least half of the length of the inflorescence. Inflorescences that had not broken partially or entirely where missing most of their seed pods. The seed pods had either fallen off after drying out or possibly eaten by the local birds. Many birds could be seen at Sandy Point as it was also a bird sanctuary. The inflorescences and even some of the stems had also been damaged by the wind. Sandy Point was highly exposed to the wind and storms, and many bent and broken plants were observed. Locations that are exposed like Sandy Point are more likely to face to decline in size from naturally caused damages (Kennish et al. 2014). Being at the tallest part of the plants, the inflorescences faced the full force of the wind.

*Inflorescence versus Stem Weights*

Plants for each site distributed their energy for growth and reproduction differently from each other. Plants at Long Wharf and Branford appeared to be putting more of their energy into inflorescences and reproduction relative to stem growth (Figure 14). Long Wharf had a higher ratio than Branford in the lower parts of the low marsh, but past 15 m Branford had a similar ratio for reproduction. Long Wharf appeared to be putting more energy into reproduction relative

to growth compared to the other marshes. This is a small marsh in area and limited on how much it could spread through asexual selection given the significant human development surrounding the marsh. Reproducing through sexual selection may be a better strategy for the Long Wharf *Spartina* population as new plants would be able colonize areas that were less impacted by human development. The Branford marsh is much larger and not limited in size like Long Wharf and could successfully reproduce sexually or asexually. *Spartina alterniflora* was not limited to a particular part of the marsh and could spread through root systems and cloning (Crosby et al. 2015). Evidence of new patches of *Spartina alterniflora* was observed at Branford and not the other marshes. Being able to spread through asexual reproduction, Branford did not have to spend as much energy as Long Wharf on creating inflorescences to reproduce sexually. Sandy Point appeared to extend the least amount of energy on creating inflorescences relative to stem growth (Figure 14). Along the transects, Sandy Point had a ratio between the inflorescence dry weight and stem dry weight that was about half of the ratio for Long Wharf. As stated previously many of the inflorescences for Sandy Point had been damaged. This suggests that this site is exposed to much greater extremes in terms of natural disturbance. Long Wharf at the head of New Haven harbor is much more protected than Sandy Point, and the Branford site is very well protected being located along a relatively quiescent tidal creek. Thus, plants at Sandy Point may be putting more energy into growth (i.e., stem height) and perhaps through asexual reproduction in order to maintain their population, relative to expending energy on sexual reproduction in the production of seed pods. Multiple strong storms and flooding in the fall likely impacted the marsh. Damage to many of the inflorescences may have led to lower heights and weights in some samples. The inflorescence data for Sandy Point may have been inaccurate due to this damage.

**Obstacles and Errors**

No major obstacles or errors impacted the data significantly. The one main issue that arose during the data collection was being able to access Sandy Point. Sandy Point during the summer and early fall has limited access, only local residents in West Haven can access the area regularly. As a result, I had to wait a bit longer to be able to access the marshes here as I was not local to the area at the time of data collection. Many of the plants had already past bloom and some plants were missing their inflorescence.

**Conclusion**

Different levels of human impact may have had an impact on the growth and reproduction of *Spartina alterniflora*. Plants and marshes that are limited in size and are potentially most impacted by human development, such as Long Wharf, may put more available energy into reproduction to ensure population maintenance. Marshes that are more protected from natural disturbances and from human development, such as the Branford marsh appeared to put more relative energy into reproduction as well. In contrast, marshes, such as that at Sandy Point, which may be somewhat affected by human development but also be more prone to the effects of natural disturbances, may put more energy into growth as opposed to reproduction. This study shows that the interplay between human and natural disturbances may be quite complex in terms of their overall impacts on *Spartina populations*. The results from this study can help protect marshes from current and future human development.

**Future Directions**

Future studies should expand on the information and data collected in this study. the sampling for this study was conducted during the fall, and as such the data collected are limited

to this season. Collecting data starting in the spring when *Spartina altneriflora* begins to grow and for its whole growing season would provide a more complete data set that can be analyzed to assess both natural and human impacts. Growth analyses could be done, measuring the growth of plants on a weekly or bi-weekly basis. This could provide more complete data as to whether more energy is being spent on growth or reproduction. Secondly, measuring the width of the stems may provide further insights into these interrelationships. Observations of the samples showed that some sites had thicker stems than others.

In addition, I think it would be beneficial to increase the number of study sites and sample more transects in different locations within each site. By collecting more data in different areas, once could then assess if the results from an expanded study as suggested would be consistent with results conclusions presented in this thesis. At each of the sites that I did do I would have liked to test some of the parameters to see if there was anything variation between the sites. Variations in the parameters for each site may be an additional explanation for why each site was statistically different from each other. My main goal in the future is to expand on this research and learn more about how the actions of human impact vital ecosystems like salt marshes.

## References


Anderson C, Treshow M. 1980. A Review of Environmental and Genetic Factors That Affect Height in *Spartina alterniflora* Loisel. (Salt Marsh Cord Grass). Estuaries. 3(3): 168-176.

Bertness M. 1985. Fiddler Crab Regulation of *Spartina alterniflora* Production on a New England Salt Marsh. Ecology. 66(3): 1042-1055.

Bortolus A, Adam P, Adams J.B., Ainouche M.L., Ayers D, Bertness M.D., Bouma T.J., Bruno J.F., Cacador I, Carlton J.T., Castillo J.M. 2019. Supporting Spartina interdisciplinary perspective shows *Spartina* as a distinct solid genus. Ecology. 100(11) e0 e02.

Crosby S, Ivens-Duran M, Bertness M, Davey E, Deegan L, Leslie H. 2015. Flowering and Biomass Allocation in U.S. Atlantic Coast *Spartina alterniflora*. American Journal of Botany. 102(5): 669-676.

Donnelly J, Bertness M. 2001. Rapid shoreward encroachment of salt marsh cordgrass in response to accelerated sea-level rise. PNAS. 98(25): 14218-14223.

Franz D. 1997. Resource Allocation in the Intertidal Salt-Marsh Mussel *Geukensia demissa* in Relation to Shore Level. Estuaries. 20(1): 134-148.

Hartig E, Gornitz V, Kolker, Mushacke F, Fallon D. 2002. Anthropogenic and Climate-change Impact on Salt Marshes of Jamaica Bay, New York City. Wetlands. 22(1): 71-89.

Jia M, Wang Z, Liu D, Ren C, Tang X, Dong Z. 2015. Monitoring Loss and Recovery of Salt Marshes in the Liao River Delta, China. Journal of Coastal Research. 31(2): 371-377.

Kearney M, Turner R. 2016. Microtidal Marshes: Can These Widespread and Fragile Marshes Survive Increasing Climate-Sea Level Variability and Human Action? Journal of Coastal Research. 32(3): 686-699.

Kennish M, Meixler M, Petruzzelli G, Fertig B. 2014. Tuckerton Peninsula Salt Marsh System: A Sentinel Site for Assessing Climate Change Effects. New Jersey Academy of Science. 59(2): 1-5.

McKee K, Patrick Jr. W. 1988. The Relationship of Smooth Cordgrass (*Spartina alterniflora*) to Tidal Datums: A Review. Estuaries. 11(3): 143-151.

Steever E, Warren R, Niering W. 1976. Tidal Energy Subsidy and Standing Crop Production of *Spartina alterniflora*. Estuarine and Coastal Marine Science. 4: 473-478.

Wan H, Wang Q, Jiang D, Fu J, Yang Y, Liu X. 2014. Monitoring the Invasion of *Spartina alterniflora* Using Very High Resolution Unmanned Aerial Vehicle Imagery in Beihai, Guangxi (China). The Scientific World Journal. 1-7.

Warren R, Niering W. 1993. Vegetation Change on a Northeast Tidal Marsh: Interaction of Sea-Level Rise and Marsh Accretion. Ecology. 74(1): 96-103.

Zhan Y, Aarninkhof S, Wang Z, Qian W, Zhou Y. 2020. Daily Topographic Change Patterns of Tidal Flats in Response to Anthropogenic Activities: Analysis through Coastal Video Imagery. Journal of Coastal Research. 36(1): 103-115.