Correlation between Salinity, Density, and Growth Rates of Pacific Cordgrass in the Western Stege Marsh, Richmond, California

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Abstract Tidal marshes throughout the world are being depleted at an alarming rate, and especially in California. In California, and more specifically the San Francisco Bay Area, a history of diking, filling, and conversion of marsh to salt evaporation ponds has eradicated 85% of the original tidal salt marsh in San Francisco Bay. Restoration efforts are underway to help remediate these precious ecosystems. This study monitors the growth rate of Pacific cordgrass, *Spartina foliosa* and the correlation between the growth, density of the plant and the salinity of the surrounding soil. The cordgrass was found to grow at a higher rate where the density of the plant was the highest and it was found to grow at a higher rate at lower elevations where the salinity levels were lowest. This is important information for remediation work in order to restore the favored habitat of the endangered California Clapper Rail, *Rallus longirostris obsoletus* which uses the cordgrass dominated wetlands as its main habitat. As a result of the rail's habitat loss over the past few decades, numbers of the rails have declined significantly.

Introduction

During the beginning of the seventeenth century, approximately 221 million acres of wetlands could be found throughout the United States; although about 103 million acres remained as of the mid-1980's (Dahl and Johnson, 1991). In California, and more specifically the San Francisco Bay Area, a history of diking, filling, and conversion of marsh to salt evaporation ponds (Walton 1978) has eradicated 85% of the original tidal salt marsh (Marshall and Dedrick 1994). With the elimination of native tidal salt marsh plants such as Pacific cordgrass, *Spartina foliosa (Poaceae)* and Pickleweed, *Salicornia europeae (*Amaranthaceae*)* many native species populations have been declining as well. The California Clapper Rail, *Rallus longirostris obsoletus (Ridgeway, 1874*) uses the cordgrass as its main habitat, and as a result of the habitat loss numbers of the rails have declined significantly. The clapper rail population fell from about 4,000-6,000 individuals in the mid 1970s to only about 300 in 1996. (Garrison 2000). Many organizations have formed in order to restore the salt marsh habitat and protect these endangered birds. Efforts like these have been sprouting up throughout the San Francisco Bay Area. Restoration methods have included planting a wide range of native plants throughout the marsh, including Pacific cordgrass, which serves as the main habitat for the endangered California Clapper rail

In 1950, the University of California, Berkeley purchased the Richmond Field Station (RFS), a 150 acre piece of land along the Richmond shoreline of the San Francisco Bay, that was highly contaminated with pollutants (UC Regents 2007). In 2002, the University began large amounts of remediation and restoration work on the property and began trying to clean up the pollution in the salt and brackish tidal marsh that was a result of the industrial manufacturing that took place (UC Regents 2007). The University is concerned that although the marsh appears to be thriving in the diversity of native plants, there will not be enough coverage of preferable habitat for the California Clapper rail and the bird will not move into the newly renovated habitat. Therefore, they have considered altering their restoration efforts to solely focus on the expansion of Pacific cordgrass coverage and the recovery of the California Clapper rail.

S. Foliosa is the only cordgrass species native to central and southern California (Spicher and Josselyn 1985) and can be found in large patches throughout the Richmond Filed Station marsh. Spartina Foliosa rarely reproduces by seed germination, except after freshwater flooding (Ward, 2000) and instead, this species reproduces vegetatively through rhizomes in the ground (Zedler et al., 1980). Since the wetland has areas that are inundated by tide water on a daily basis and due to the fact that there are numerous topographic changes, certain areas of the marsh tend to differ in salinity. The heterogeneity of the marsh helps to create different zones that the plants can flourish in; *S. foliosa* occurs primarily at the bayward egde of the salt marsh, being farther from higher elevations that are apparent further inland (Zedler et al. 1999). Many authors suggest that this "demonstrates a type of competitive exclusion may exist in halophytic communities" (Thom 1967), including ones similar to the Richmond Field Station Marsh where strong patterns of zonation have been found (Thom 1967: MacNae 1968) and are thought to be similar to other salt marsh communities (Reed 1943; Mendelssohn and Marcellus 1976) partially due to soil salinity. In laboratory studies, growth rates of Pacific cordgrass have been found to be correlated to salinity because an increase in saline levels is found to decrease photosynthesis and carbon dioxide uptakes (Pearcy 1984). Mahall and Park (1976) also claim that *S. foliosa* is excluded from the higher parts of the marsh due to the higher salinity.

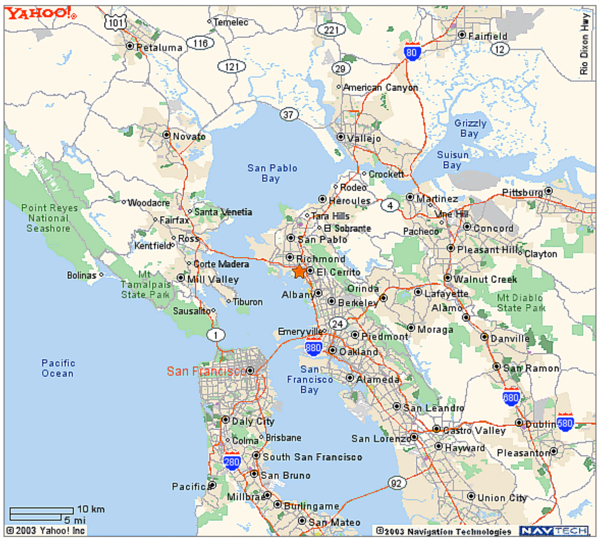
Not only does the elevation in a marsh play a large role in the plants that inhabit it, but rainfall can play an important role in the salinity of the free water contained in the soils of tidal marsh (Adams 1963) along with proximity to the bay's saline water, and finally, evaporation (Penfound and Hathaway 1938; Purer 1942). "It is of interest that a plant confined to coastal salt marshes and subjected to daily tidal inundation by sea water grows better in fresh and brackish water than in sea water" (Phleger 1971).

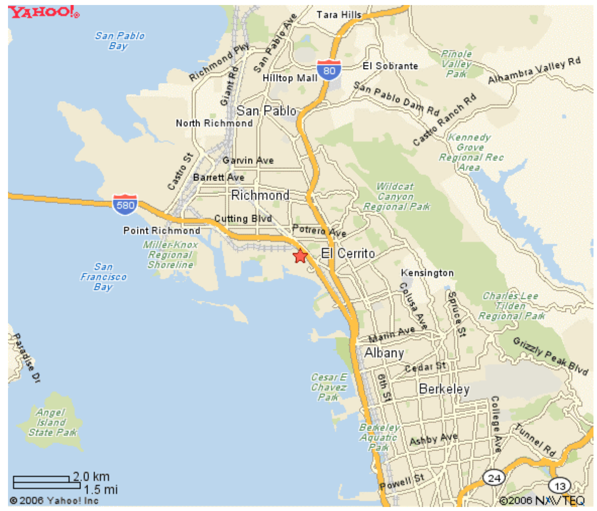
This filed study will research which areas of the Richmond Field Station marsh tend to have the greatest growth and determine if the University should alter its remediation efforts in order to maximize potential Clapper rail habitat. This study will help the university determine what action to take by answering the following question: What is the rhizomatous growth rate of the pacific cordgrass in the Richmond Field Station marsh, and is the growth rate positively correlated on density of the plant coverage and/or the salinity of the soil? My hypothesis is that Pacific cordgrass will rhizomatically grow at a higher rate in a lateral direction along the edges of the marsh, rather than toward a higher topographic elevation due to the optimal salinity levels where it currently resides. I also hypothesize that the plots with a higher density of cordgrass will have a higher percentage of growth rates per week.

Over the course of eight weeks, I monitored the amount of growth of *S. foliosa* by looking at different patches that are found at the Richmond Field Station and then ran statistical tests to see if there is any significant correlation between salinity, lateral and elevational growth and density of patches.

Methods

The Richmond Field Station (RFS) is located approximately six miles northwest of the University of California, Berkeley campus along the San Francisco Bay shoreline in Richmond (Figure 1).





Figures 1 a,b,c: Above (a, b): Map of San Francisco Bay and location of Richmond Field Station (star). Photos courtesy of peer.berkeley.edu and eerc.berkeley.edu. Below (c): June 2006. Marsh and ecotone showing areas re-vegetated by active planting and natural recruitment of native marsh plants. Courtesy of rfs.berkeley.edu

At this location, the San Francisco Bay Trail divides the Western Stege Marsh into two different pieces of marsh and two different habitats (Gutstein 1989). The area south of the bay trail, and closer to the bay, I have defined as the "outer marsh", while the area to the north of the bay trail and farther away from the water, I have defined as the "upper or inner marsh" (Figure 2). This study takes place in the upper marsh where the University's restoration efforts can be seen.

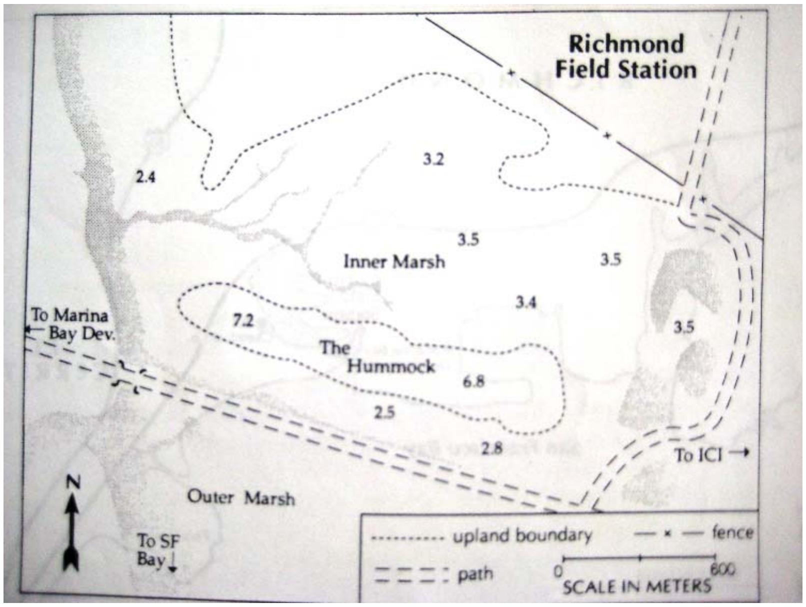


Figure 2: Map displaying division between "inner and outer" marsh. Source: Russell, 1985

To address my research question, I used an aerial GIS map provided to me by UC Berkeley with each individual and patch of cordgrass displayed on the map. This map clearly marks off patches of cordgrass that could potentially be connected through the same rhizome. Each of these patches has been classified by the density of absolute coverage (Figure 3). The density classifications were as follows: 0-15% (green), 16-25% (yellow), 26-45% (orange), and 46-75% (red). This classification is important to my research question because conclusions about how density of Pacific cordgrass affects the rhizomatous growth rate can be made.

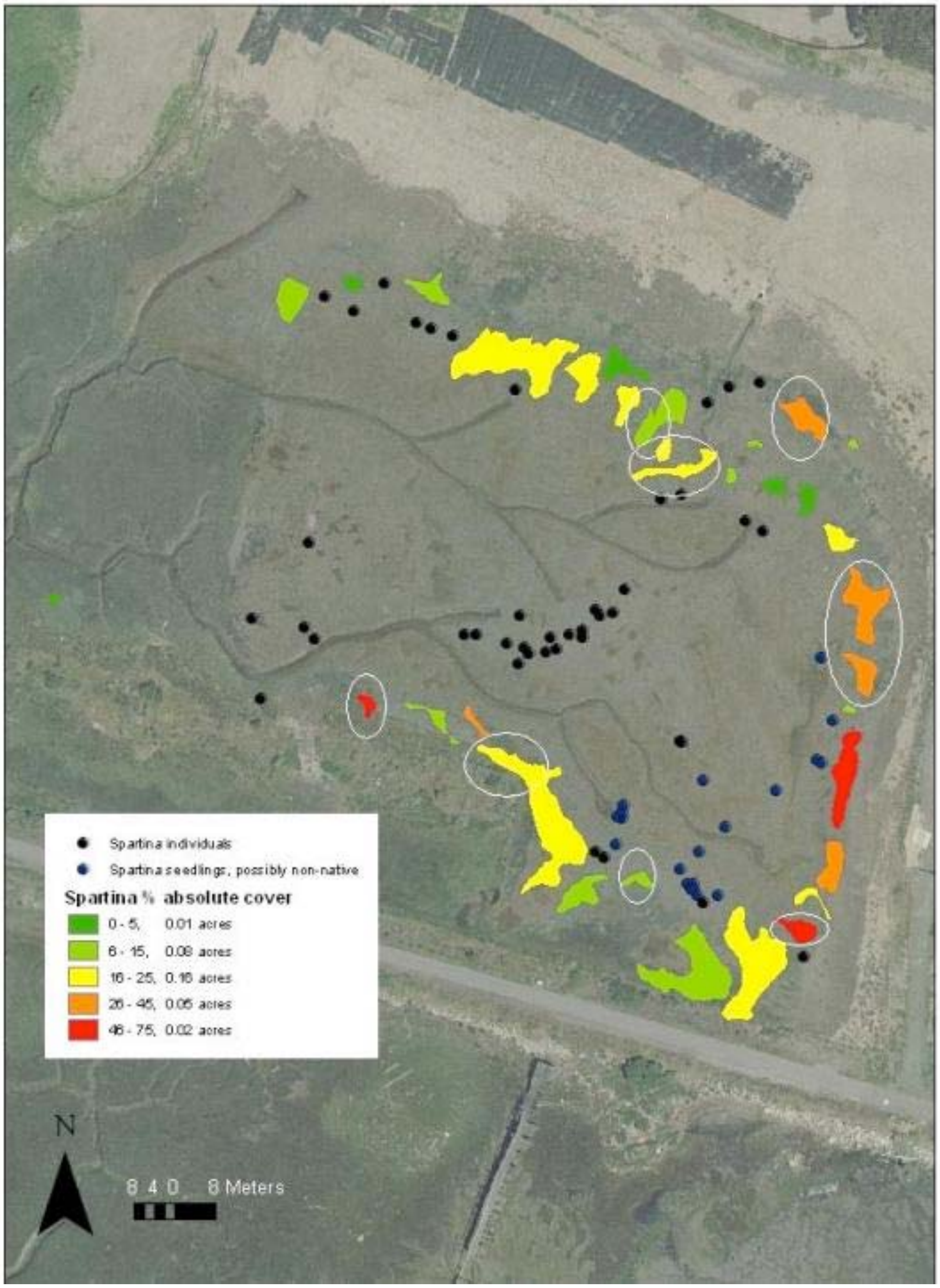


Figure 3: Distribution of Spartina Foliosa at the Richmond Field Station displayed in polygons classified by density of coverage (layout by Christina Cooker: October 18, 2007). The plots that were selected are identified by circles on the map.

I conducted a study, monitoring the growth of the pacific cordgrass at the RFS marsh, using a Stratified Random Sample Design in order to ensure that all groupings of cordgrass densities are adequately represented and completely random. After looking at the map with the different patch densities marked off, I marked off the marsh off in large transects and walked around each of the transects stopping at each of the labeled plots until I had covered the entire five acre marsh with restoration specialist, Stacy Haines. I then noted all patches of pacific cordgrass that we found and the location of these patches on the map provided by Stacy Haines. I also confirmed percent of coverage of the patch that was found to make sure that it corresponded with the density given. After all findings were recorded and compared to the GIS map, stratified random sampling was used to randomly select 2 pacific cordgrass polygons within each mapped cover class in order to monitor the growth rate (2 red, 2 orange, 2 yellow, and 2 green). The plots that were selected were noted (Figure 3).

Once the polygons were selected, each polygon was marked off on the leading edge of vegetative growth with 3-foot bamboo stakes in the shape of a quadrilateral (square or rectangle) ensuring that each part of the polygon of cordgrass was included in the quadrilateral. By using a measuring tape, the stakes were placed 40cm apart. The corner stakes were painted for reference purposes (Figure 4)

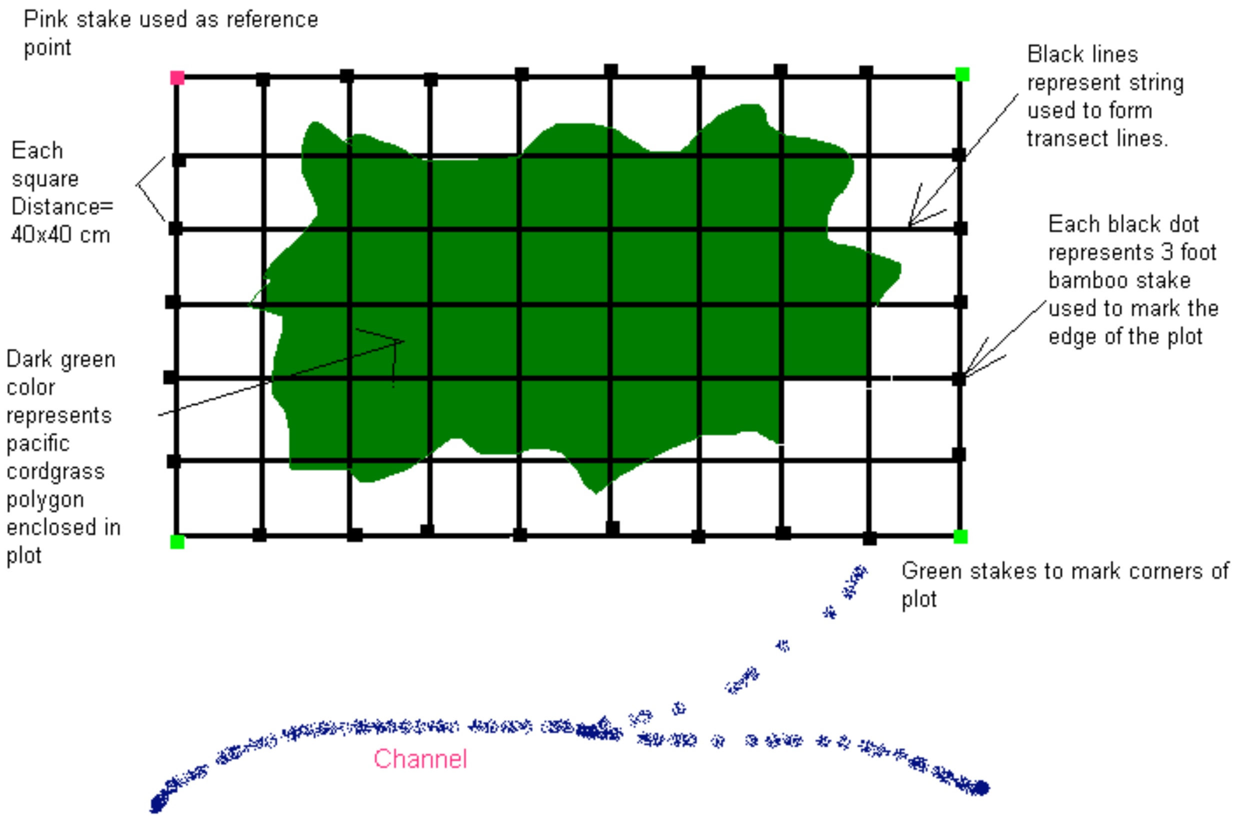


Figure 4: Example of plot set-up

When facing the center of the marsh, where numerous small channels flow, the back right stake was painted pink, while the other stakes were painted green. The lone painted pink stake was the origin and reference for the rest of the stakes, therefore I numbered it one. I then numerically labeled the rest of the stakes in both the x and y direction. Since each plot was a different size, some plots had more stakes than others. Next, a thin twin was used to connect corresponding stakes.

Beginning on February 22, each plot was monitored for spread of rhizomatous growth (vegetative growth) for eight weeks. A sample was collected and recorded every other week, the last recordings taking place on April 4.

Each week, the procedure for observing growth remained consistent. Visual observations were recorded noting the outer most growths on each piece of twine. These outer most shoots of cordgrass were marked with a small flag. This was completed in the lateral direction (left-right in Figure 4) and also in the elevational direction (up-down in Figure 4). By taking both lateral and elevational growth measurements, comparisons can be completed more easily.

After the course of eight weeks, I used excel to test my results through the use of statistics. To test the first part of my hypothesis, to test whether there was significantly more rhizomatic growth in the lateral direction (along the edge of the marsh) or if there was more growth in the elevational direction (toward or away from the channels) I input my findings into excel. For each plot the total number of recorded growths was divided by three in order to find and average number of growths per week. This average was then divided by the total number of growths that were possible in order to find a percentage.

Results

Observed lateral and elevational growth rates of the Pacific cordgrass differed significantly. There was considerably less growth (as visually observed increase in outer most rhizomes) in the elevational direction and remarkably more growth in the lateral direction (Table 1).

Table 1: Average proportion (%) of sample points showing positive growth in the lateral and elevational direction for each of the eight plots

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5	Plot 6	Plot 7	Plot 8
Elevational	8.3%	3.5%	13.3%	5.6%	6.5%	13.3%	6.6%	5.9%
Lateral	18%	16%	14.3%	12.4%	15%	17%	14%	15.4%

The average proportion (%) of sample points showing positive growth in both the lateral and elevation directions represented by one average clearly demonstrate the significant correlation between lateral and elevational growth. The mean for the elevational growth was 7.875 with a standard error of + 1.273. The mean for the lateral growth was found to be 15.263 with a standard error of + 0.625. It was also found that P(T<=t) two-tail= 0.00068712 and that t Stat= -5.765883059. (Figure 5)

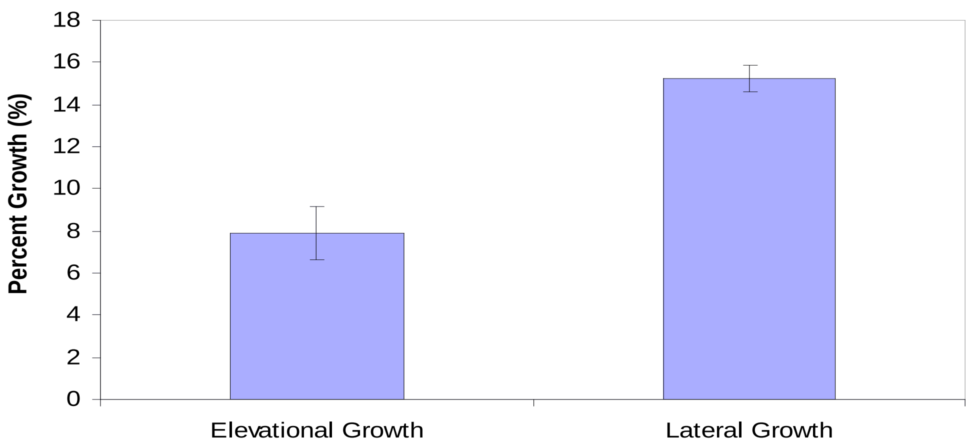


Figure 5: Average proportion (%) of sample points showing positive growth in the lateral and elevational direction. Lateral growth measuring 15.2625 $\pm$ .62478 and elevational growth measuring 7.875 $\pm$ 1.2732

Next, in order to test my hypothesis that density of the plot is correlated to growth, I used my collected data and put it into chi-squared test. This would allow me to see if the correlations between the gathered results were significant (Figures 6 and 7). After completing the chi-squared tests, I found that my results were not significantly correlated to density of the plot. In Figure 6, the two plots with 26-45% coverage are represented by a data label A*. This is because in the lateral direction, Plots 1 and 3 (26-45% coverage) had a two-tailed P value that equaled 0.0808. The association between rows (groups) and columns (outcomes) was considered to be not quite statistically significant in comparison to the rest which were not statistically significant (Figures 6 and 7).

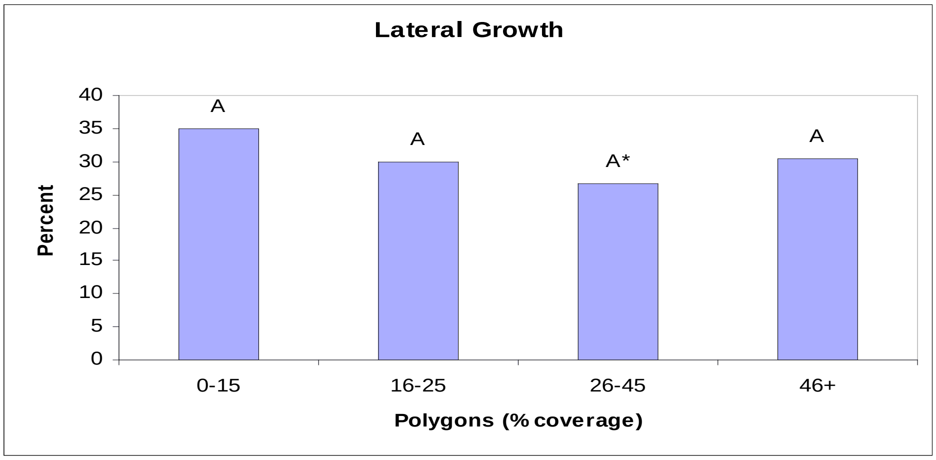


Figure 6: Letters above each bar represent significance groups based on chi-squared analysis of actual observed growth or non-growth (not the %)

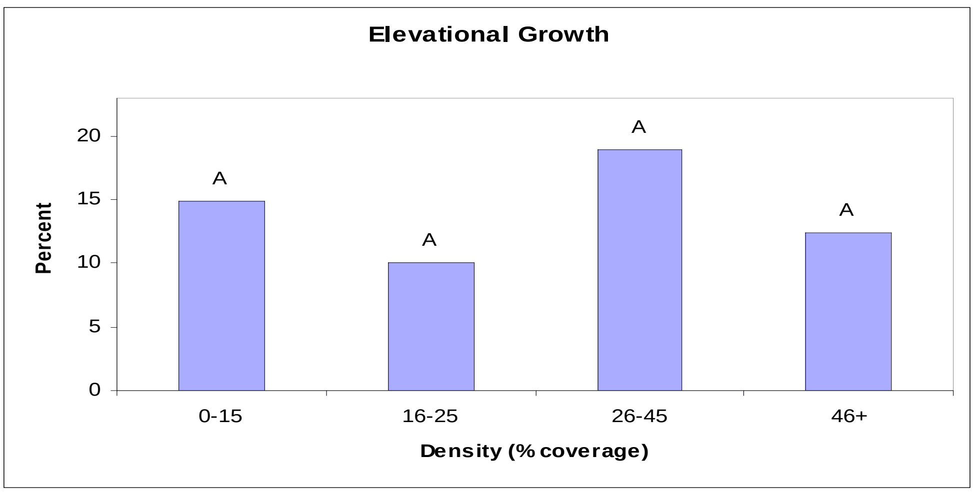


Figure 7: Letters above each bar represent significance groups based on chi-squared analysis of actual observed growth or non-growth (not the %)

Discussion:

Because the endangered California Clapper Rail utilizes *S. Foliosa* for its main nesting habitat and as protection from predators, and because there few marshes left along the California coast that support this plant and bird, there is both a dire need to preserve the best nesting sites, including the Richmond Field Station, as well as create new marshes with Pacific cordgrass (Trnka). Plant distribution within salt marshes has been correlated with a variety of factors including, but not limited to salinity (Phleger 1971). Plants that are found inhabiting salt marshes and are therefore subject to the daily tidal inundation by sea water grow better in water that is lower in salinity than higher salinity (Phleger 1971). I have found that cordgrass grows best at a lower elevation where the salinity levels are the least. This is apparent in my data because there was proportionally less growth in the elevational direction, and proportionally more growths recorded in the lateral direction along the edge of the marsh (Figure 5).

According to Clarke and Hannon (1969), soil salinity increases landward to a "maximum at or just above the mean high water level" and then gradually decreases toward the tidal salt marsh. In 1984, research was conducted by Robert Peacy and Susan Ustin correlating salinity to the growth and photosynthesis of the Pacific cordgrass. Peacy and Ustin found that in lower elevational portions of the marsh where the salinity level was the lowest, *Spartina foliosa* had the highest photosynthesis and growth rates.

The data that I collected agrees with the past findings and supports my hypothesis. Lowered salinity increases growth rates of *S. foliosa* (Phleger 1971). The Richmond Field Station *Spartina foliosa* rhyzomatically grew more laterally along the border of the marsh rather than toward higher elevations (Figure 5). Not only did it have more new shoots, but I believe that it had proportionally longer distance of growth. This would be interesting to look at in the future and possibly do more research on the length of growths. *S. Foliosa* encounters no competition from other plants in the area where its growth is most dense (at the lowest fringe of the marsh) (Phleger 1971)

Phleger (1971) found that plants differed markedly with respect to growth and differed in their survival in various salinities. There was considerably less growth at higher concentrations. In a lab setting, the plant survival rate was greatest in fresh water, whereas the rate was lowest in the highest salt concentration tested. (Phleger 1971)

There is much future research that needs to be conducted at the Richmond Field Station in order to fully monitor the growth rates of pacific cordgrass. I would be interested in finding out more about the soil composition and deposition around each of the plots. I would like to learn if certain soil material (examples include: clay, sand, silt, etc) inhibit rhizomatous growth. There are numerous factors that could be considered including: tidal inundation, soil type, drainage and competition by other species (Phleger 1971). I think that viable information for the future of this study would be the significance of varying sediment load after each incoming and outgoing tide and how it plays a role on the growth rates of the pacific cordgrass. "Sedimentation was apparently the only geological process affecting the position of the ecotone" (Mahall 1976). "Tidal flushing modifies soil conditions by increasing the amount of oxygen content in the soil" (Linthurst 1979) and by minimizing the accumulation deposition of toxic compounds (Wiegert 1983). An increase in tidal flushing increases the growth rates of *S. foliosa* (Cain and Harvey 1983) which may be explained by increased amount of oxygen in the soil (Howes et al. 1981; Mendelssohn et al. 1981), and a reduction of the accumulation of toxics (Mendelssohn and Seneca 1980; King et al. 1982). I believe these components could determine if the cordgrass increases or decreases the growth rate in a specific direction.

The purpose of this study was to compile information on the growth rates of Pacific cordgrass in the Richmond Field Station marsh in order to assess the potential habitat for the California Clapper Rail. These findings could potentially influence other restoration projects throughout the San Francisco Bay area and determine what action steps need to be taken in order to restore the native habitat as fast as possible for this endangered bird. With my findings I hope to have demonstrated the optimal elevation to transplant the native cordgrass and how far apart these plants should be spaced in order to save time to ensure that the plants could have rhizomatically spread to cover the entire marsh. If the transplant of pacific cordgrass is successful over a short period of time, the clapper rail could have chance to not only survive, but to flourish.

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