Accretion and Elevation Change Monitoring in a Remediated Tidal Marsh

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Abstract In response to years of pollution from a neighboring chemical company, The University of California is currently managing a remediation project at the UC Richmond Field Station Tidal Marsh. The recently excavated, cleaned, and re-graded soil on tidal marsh is being replanted. In the long term, restoration biologists hope that this area will be home to the endangered species, the California Clapper Rail and the Salt Marsh Harvest Mouse. This study will help planners to determine where to plant elevation sensitive plants by attempting to answer the following questions: 1) What is the rate of elevation change of the UC Richmond tidal marsh in the month following initial exposure to the tidal influence of the San Francisco Bay? 2) Is there a correlation between sediment accretion and the elevation change of the marsh? The change in elevation is detected at four points along six transects in the marsh using poles as reference points. Accretion is measured using small plates placed next to each pole, such that sediment captured weekly by the plate is considered to be accretion in the transect area. No significant relationship could be found between accretion and elevation change, while accretion varied significantly according to the relative elevation of the marsh. Rainfall events are shown to correlate significantly with accretion events and should be considered closely by restoration biologists.

Introduction

In the San Francisco Bay, the presence of functional tidal marsh has consistently diminished since the late 1800's, when it accounted for nearly 400,000 acres bordering the bay. Today, scientists estimate that only 8,000 acres of this tidal marsh remain (The Bay Institute 2003). The importance of tidal marsh is well-documented as a habitat for endangered species such as the California Clapper Rail and the Salt Marsh Harvest Mouse, as well as thousands of migratory birds each year (Gutstein 1989). Tidal marsh plants can also function as bioremediation tools by incorporating low levels of pollutants into their biomass and out of the soil (Cheng et al. 2002).

In response to years of pollution from a neighboring chemical company, the University of California is currently managing a remediation project at the UC Richmond Field Station, in an effort to comply with state requirements. Potential tidal marsh areas, such as those owned by the University of California, were contaminated with toxic pollutants such as mercury and arsenic by Stauffer Chemical, a company that no longer operates in the area. As part of the remediation project at the UC Richmond Field Station, contaminated soils have been moved to a toxic chemical land fill in Bakersfield and replaced with clean fill. The land has now been graded to exchange bay and marsh water through a bay inlet, and tidal marsh plants will be planted to create the area's desired habitat and restore animal life to the area (URS Corporation 2002).

In order to continue with the restoration project, the marsh's change in elevation will be evaluated due to its importance in establishing a vegetated tidal marsh habitat. The rate of accretion, defined for this paper as accumulation of sediment over time, was monitored and compared to the elevation change, to determine if a relationship can be found between accretion rate and elevation change at this site. Previous studies have shown that elevation change does not occur in direct correspondence with sediment accretion; however, compaction commonly causes marshes that have net accumulation to lower in elevation. Because the quantity of accretion in San Francisco Bay Estuaries is thought to decrease with the age of the marsh (Reed 2002), studying the newly restored and relatively vegetation-free UC Richmond site is of particular interest. The marsh's geologic age is difficult to place because new fill has been added, and its lack of vegetation indicates that it is biologically very young.

Previous studies of tidal marsh land have examined the relationship between different shoreline properties and the rate of accretion or erosion that occurs in shoreline areas. A number of predictive formulas have been established from controlled wave pool and field experiments, that consider such factors as mean sediment size, wave energy, and shoreline slope. One study predicts accretion will occur when wave heights are smaller, and also specifically warns against using predictive formulas that can lead to misrepresentations of coastal systems (Jackson 1999). Other studies have found that greater amounts of vegetation tend to decrease erosion rates, sometimes to the point of accretion (Van Eerdt 1985). Researchers have also considered the effects of storm events on accretion in salt marshes and found that greater rainfall correlates with higher rates of accretion (Fonjweng and Pfefferkorn 2001).

However, most of these studies are very site specific and are not reliable predictors of accretion on all shorelines. Similarly, the relationship between accretion and elevation change in marshland has been studied in the San Francisco Bay Estuary as well as the Mississippi Delta. In both instances it was found that accretion rates exceeded the rate of elevation rise, indicating that soil sediments are being compacted (Cahoon 1995 and Reed 2002). Because rates of accretion, erosion, and elevation change experience large variation from site to site (Gibb 1978), it is important to conduct a study specific to the UC Richmond Field Station Tidal Marsh if the UC intends to successfully remediate the marsh.

Because the University of California intends to develop a planting plan as a portion of the restoration project that will be completed at the UC Richmond Field Station, it is important to gather information that will promote such a planting plan: each species in the planting plan will flourish under specific environmental conditions that change based on the height of the marsh (Gutstein 1989), thus elevation change is a crucial factor in determining the success of the vegetation planted in the tidal marsh area.

As a result of the demands posed by the restoration project, the primary research question that will be addressed in this study is: What is the elevation change of the UC Richmond Field Station tidal marshland? In addition, this study will consider the relationship between marsh sediment accretion and elevation change, and how these effects vary by elevation, region of the marsh, and amount of rainfall. Research demonstrates that large rates of change in the elevation of a salt marsh will cause an ecosystem shift (BBL Inc. 2003). For example *Spartina foliosa* will not grow past three feet above the mean sea level, thus a drastic rise in elevation would mean that only plants with higher native ranges could habitat the area (Aquatic Outreach Institute. 2003). In contrast, a stable elevation will make easier the goals of the project to create a flourishing tidal marsh habitat. Monitoring of the tidal marsh land will extend beyond the time limits of this study, as it is predicted that increased accretion will occur as vegetation flourishes in the repaired marsh land. As a result of the need for continued monitoring, the relationship between accretion and elevation change may be a useful predictor of future elevation change in the marsh as accretion rates continue to evolve.

Study Site Located at 122°22'W longitude and 37°57'N latitude, the tidal marsh land and site for this study lies between the San Francisco Bay and the UC Richmond Field Station at the end of Egret road. On its most eastern side the marsh is 600 feet long, while the northern edge of the marsh is 400 feet long. The western side of the marsh is 300 feet long before it tapers into three 100 feet long steps, leaving the southern edge of the marsh at a length of 200 feet. The marsh has two fresh water sources, Baxter Creek and Meeker Slough that enter from the Northwest side of the marsh. A levee isolates the marsh from the tidal influence of the bay, excluding one inlet on the south side (figure one).

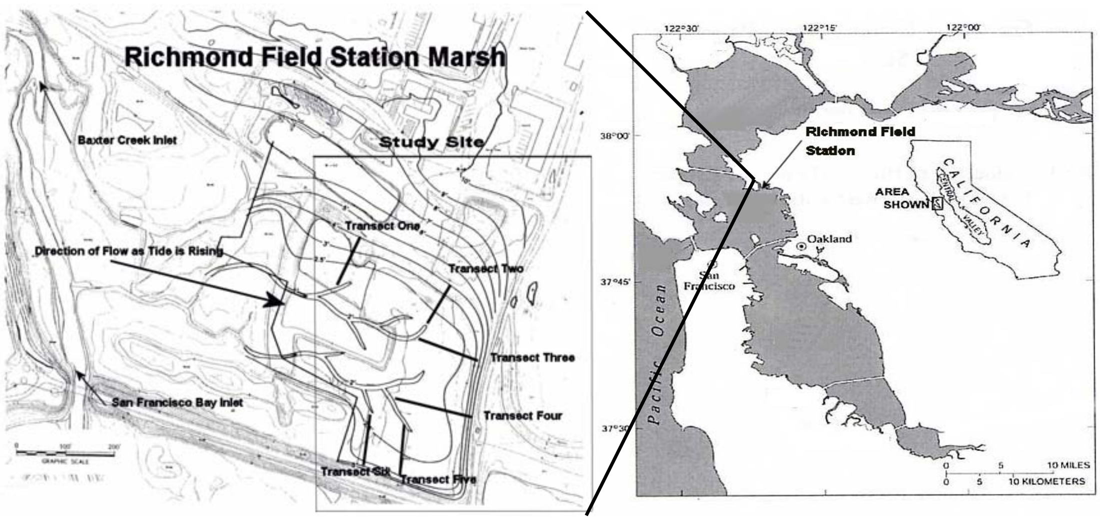

Figure 1 (Unknown and Brown 2003) is an aerial illustration of the study site and the surrounding area. Notice the two inputs of water into the marsh, Baxter Creek (a freshwater source) and a channel from the San Francisco Bay (a saltwater source). Each transect consists of a vertical pole to measure elevation change and a horizontal plate to me to measure accretion.

During high tide, salt water enters the marsh though 150 meters of channels, which flow beneath the Bay Trail levee and into the tidal marsh study area. During low tide events, water from the marsh exits to the San Francisco Bay through the same channels. The two fresh water sources, along with the salt water inlet, mix on the western side of the marsh before they move eastward toward the study site. The eastward movement of water across the marsh has been designed by the project engineers to flow through two main channels.

Methods

Along two evenly spaced transects on the North, South, and East sides of the marsh lie the reference points for determining elevation change of the tidal marsh. Each transect contained one monitoring station at each foot contour line between one and four feet above mean sea level. Monitoring stations consisted of one twenty-four inch long PVC pipe set sixteen inches into the ground, such that eight inches of PVC pipe were visible at the beginning of the experiment. Next to each PVC pipe was a ceramic plate, three inches in diameter sitting flush with the marsh surface and held in place by a ¼ inch wooden dowel through the center of the plate, to collect sediment over time. Changes in elevation relative to the PVC pipe was considered to be the absolute elevation change of the marsh at that point and soil that collects in the plate each week is considered to be accretion. Using the vertical poles to measure absolute elevation change assumes that the poles are not sinking or rising during the study period.

Due to a number of factors implicating the installation of the monitoring equipment at the UC Richmond Field Station Tidal Marsh, it was not possible to collect preliminary data for this experiment prior to the exposure of the tidal marsh to the San Francisco Bay. In this way, baseline elevation measurements at each marker serve as preliminary data, however, because the marsh had been exposed to tidal influence, it is not possible to determine whether the data takes into account the greatest proportion of elevation change: true preliminary data may have demonstrated that the biggest change in elevation would occur the first time wave energy is introduced to the system.

The different elevations for this study were recorded at each marker and the sediment on the plate was collected, air-dried and weighed each Monday over a period of eight weeks, approximately one month after the marsh had been initially opened to the bay tides. Elevation change was measured to the nearest sixteenth of an inch and sediment weights were taken to the nearest tenth of a gram. Absolute elevations relative to the mean sea level were determined using an on onsite reference of known elevation. Rainfall data collected at the San Leandro Daily Station (http://cdec.water.ca.gov), which is 20 miles south of Richmond, was used as an estimate of the rainfall over the UC Richmond marsh. These data were used because the San Leandro Station is the closest station to Richmond where measurements are taken daily and made public online soon after. This quantitative tool allowed comparisons to be made between storm events and elevation change or accretion. The site was also analyzed qualitatively to see what geomorphologic and biological characteristics could be influencing accretion and elevation change at each monitoring station. The results of this qualitative analysis can help guide future research in the marsh toward other factors that could be influencing sedimentation process in the marsh.

The data analysis considers a number of factors and how they relate to sedimentation and elevation change in the salt marsh. On many occasions the sedimentation plates collected no sediment during a sampling period so the data set has many zeros. All of these zeros make the data set skewed toward one side, meaning that a normal distribution can not be assumed for the purposes of data analysis. A log transformation was used to normalize that data and allow accretion data to be compared using parametric methods. Weekly sedimentation was compared with weekly elevation change using linear regression and analysis of variance for the marsh as a whole, comparing each starting elevation and transect.

Results

Multiple regression analysis of the mean elevation change data compared to mean rainfall and mean sediment reveal no significant parameters (n = 8). None of the predicted controlling factors showed significant correlation with elevation change, mean sediment (P = .615) or rain fall (P = .393). A regression between elevation change and log-transformed sediment accretion (n = 192) shows P = .028, r-squared = .023. An ANOVA comparison between elevation change and starting elevation shows no difference detected between different transects (LSN = 4278, power = .07, alpha = .05) or between starting elevations (LSN = 651, power = .21, alpha= .05).

Log-transformed accretion data is compared to starting height individually using ANOVA. The Tukey-Kramer test was performed to find which groups differ significantly from each other. The means and the pooled standard errors for the non-transformed data are in table one and the tests are depicted graphically in figure two. Significant differences exist between all starting heights except between the two-foot and three-foot, and the three-foot and four-foot contours.

Starting Elevation (feet)	Sample Size	Mean (g)	Pooled Standard Error
1	48	5.57	0.58
2	48	1.9	0.58
3	48	1.51	0.58
4	48	1.5	0.58

Table 1 shows the mean sediment accumulation for each elevation contour, along with their pooled SE

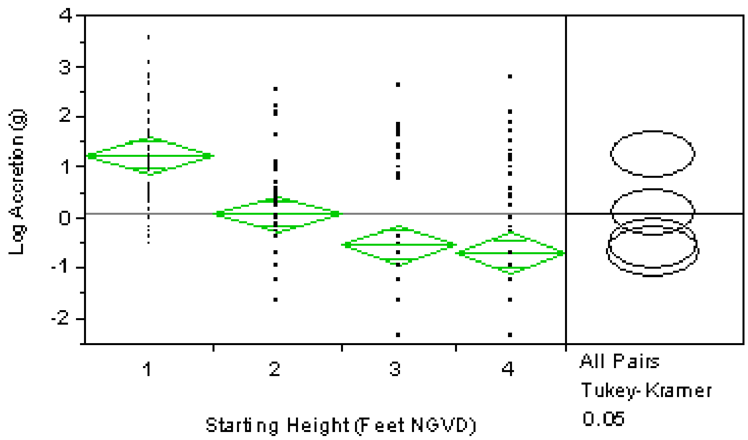

Figure 3 shows that there is a statistically significant difference in mean sediment accumulation from the one foot contour and the three other contours. The means also increase at lower heights.

ANOVA and Tukey-Kramer tests were also performed to compare the amount of rain during a sampling period to the log-transformed accretion data. Means and standard errors of the non-transformed data are reported in table two, while the log-transformed data is compared graphically in figure three. During the study accretion varied with cumulative rainfall, such that mean accretion increased as rainfall increasesd; however, rainfall events of .87 cm and 1.48 cm did not reveal a significantly different effect on accretion, nor did rainfall events of 0 cm and .47 cm differ significantly from each other. The two highest rainfall events differed significantly from the two lowest rainfall events (alpha = .05).

Rain Fall (cm)	Sample Size	Mean (g)	Std. Err. Mean
0	96	1.16	.20
1.19	24	1.38	.24
1.5	24	3.3	.62
2.21	24	3.3	.60
3.76	24	8.33	1.80

Table 2 shows that the mean sediment accumulation for the marsh increases as rain fall increases. Large standard errors are also visible in all the means.

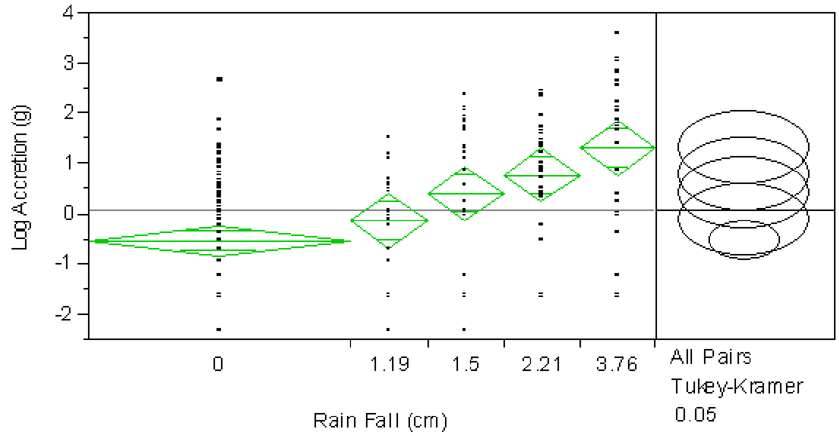

Figure 3 represents accretion for each plate every week as a function of that week's cumulative rainfall. Using ANOVA, a significant difference was found between the highest three periods of rainfall and the lowest period of rainfall. For the week when rain fall was 1.19 cm, accretion was significantly different from 0 cm and 3.76. The non-parametric Kruskal-Wallis test reveals the same differences.

The effect of rain fall events on accretion at different elevations was also examined. In figure four the axes compare rainfall's effect on accretion at the four foot contour, and the marker shapes are sorted by transect. Statistically insignificant but important trends can be seen from transect to transect. The monitoring station at transect four consistently experienced one of the highest levels of accretion and transect six consistently had one of the lowest levels of accretion. Similar analysis at other contour levels shows the same kinds of trends. Qualitative observations revealed that the monitoring station on transect six was at a steeper grade and surrounded by more vegetation than the monitoring station on the fourth transect.

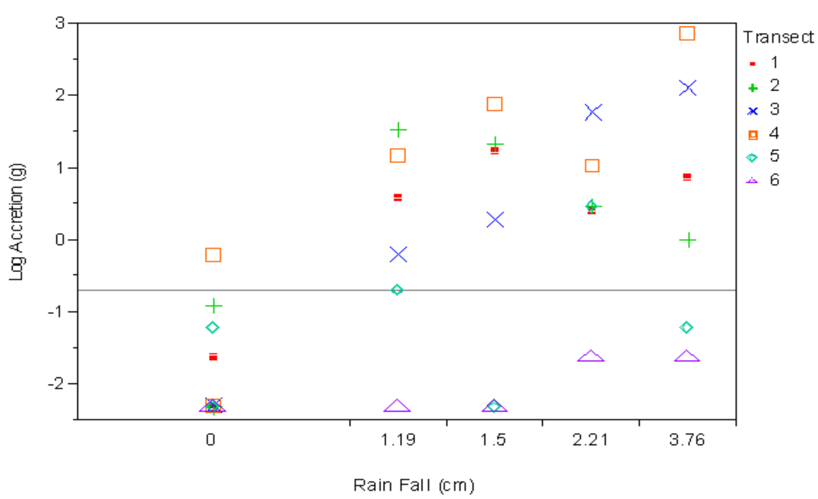

Figure 4 shows the relationship between rainfall and accretion at the four foot contour, sorted by transect. The fact that the monitoring station at transect six is nearly always the lowest accretion measurement and transect four usually has the most accretion.

Discussion

The relationship between accretion and elevation change measured by vertical poles is intriguing and somewhat counterintuitive, but not necessarily contradictory to previous studies. The same comparison has been made over a two-year time period and it was found that sites with high rates of accretion do not tend to show similarly high rates of elevation change (Reed 2002). This negative correlation is likely due to other factors that affect small changes in marsh elevations. It is possible that compaction of soil or an unknown sediment sink could account for some of the elevation changes. As described in previous marsh studies, it is possible that that the marsh is in a state of dynamic equilibrium, where sediment is transported into the marsh, then either transported out of the marsh, or compacted such that there are small detectable changes in the surface elevation at any given point, but no clear pattern in elevation change (Cahoon, Reed, Day 1995). Weekly variations in soil moisture may also account for some of the small changes detected in elevation at the monitoring poles. It is likely that there is in fact a trend in elevation change of the marsh but that the time period allotted for this study was not long enough to resolve a difference. Even though the elevation of the marsh changed very little during the course of the study, net accretion occurred for most monitoring stations every week. The UC Richmond marsh appears to be a sediment sink, over the period of this study.

Data in this experiment may also have been biased in a number of different ways during collection. Human disturbance of the marsh during and in between data collection likely had some impact on the changing elevation of the marsh: specifically noted is that the saturated areas of the marsh are prone to sinking of up to eight inches when exposed to human footsteps. Although effort was made to avoid walking in the path of the water that leads up to each vertical pole during measurement, this factor may have been influential in the collection and interpretation of the data.

Horizontal plates collected accretion over the course of a week, and were emptied after each week so that the mass of the sediment could be dried and weighed. Because of the sampling regime, each collection period was considered to be an independent event, rather than a snap-shot of interrelated events over time. This method is more accurate in quantifying the amount of accretion that occurs each week, but would not be able to measure erosion, particularly erosion immediately following a storm event, because the sediment found on each plate may have be collected right after the storm event, rather than as a result of erosion. For future studies, accretion monitoring techniques using cumulative measurements on plates is recommended (Fonjweng and Pfefferkorn 2001).

The correlation between rainfall and the amount of accretion is consistent with the literature, particularly a year long study that found 60% of accretion for that time period occurred during the largest storm event (Fonjweng and Pfefferkorn 2001). Because big storm events play a major role in the amount of accretion in this marsh, a change in weather pattern will be a major factor in the future of this marsh. The Richmond marsh appears to follow this same type of threshold model, as significant differences were found between accretion events on either side of 1.9 cm rainfall per week. Qualitative trends such as those seen in figure four suggest that much of the variance in this experiment is not due to chance but is a result of geomorphological and biological characteristics of the land. Monitoring stations that are on a steeper grade likely have less accretion then those on a flatter ground.

Future studies of marsh accretion and elevation change should have more collection points in between the two and three foot contours. The extra data points would improve the power of statistical tests and would allow researches to measure the affects of smaller differences in elevation change. A more extensive study could also include measurements of average wave height or marsh grade to help determine their affects of elevation change and accretion.

Elevation measurements should be taken of the marsh elevation using the monitoring poles installed for this study. Over a several year period, a more definite trend in marsh elevation change could potentially become clear. This data should be compared to estimates of sea level change, to give a better long term picture of how the marsh will change in the future (DeLaune and Gosselink 1983). In the future it will also be interesting to see how re-vegetation changes accretion rates and elevation change.

Only small changes in the marsh elevation were seen during this study, thus no reason has been found that the revegetation plan should not go forward as planned. A reliable predictive model has not been established by this study, but the small order of magnitude of changes in marsh elevation indicate that as long as plants are planted at or near the middle of their native range, external factors like hydrology and geomorphology should not affect the marsh elevation to the point that replanted vegetation will not be successful.

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