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Publication Date

2017

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UNIVERSITY OF CALIFORNIA

Los Angeles

The Effect of Sediment Placement for Sea Level Rise Adaptation on Suspended Sediment Concentrations in a Southern Californian Salt Marsh

A thesis submitted in partial satisfaction of the requirements for the degree Master of Science in Environmental Health Sciences

by

Amanda Julia Zhang Wagner

2017

ABSTRACT OF THE THESIS

The Effect of Sediment Placement for Sea Level Rise Adaptation on Suspended Sediment Concentrations in a Southern Californian Salt Marsh

by

Amanda Julia Zhang Wagner

Master of Science in Environmental Health Sciences

University of California, Los Angeles, 2017

Professor Richard F. Ambrose, Chair

California's coastal wetlands provide valuable ecosystem services to the environment, including sequestering carbon, improving water quality, and providing habitat for many endangered species. Yet due to sea level rise the future of coastal wetlands is in question. Sediment placement is a new and promising technique that aims to help coastal wetlands combat sea level rise. We measured suspended sediment concentrations (SSC) and volatile suspended solids (VSS) at the marsh surface of experimental and control sites one week, one month, three months, six months, and one year after sediment addition. SSC on the experimental and control sites was initially high, but then it decreased and remained low. VSS was lower at the experimental site than the control site for the first three sampling periods and similar for the remainder of the year. This is the first study to evaluate SSC and VSS changes associated with sediment placement.

The thesis of Amanda Julia Zhang Wagner is approved.

Irwin H. Suffet

Glen Michael MacDonald

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University of California, Los Angeles

2017

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ACKNOWLEDGEMENTS

I am extremely grateful for my advisor Dr. Richard Ambrose for his mentorship and guidance throughout this entire process. I would like to thank Dr. Irwin Suffet and Dr. Glen MacDonald for their expertise and guidance as my committee members. I would also like to thank Jordan Rosencranz for his expertise in field and lab research. I would also like to thank Rick Nye and Kirk Gilligan (U.S. Fish and Wildlife Service) for providing access to the site and support with logistics. This project has been supported by the California Coastal Conservancy through the Southwest Wetlands Interpretive Agency, the Environmental Health Sciences Department and UCLA Fielding School of Public Health. The Naval Weapons Station Seal Beach and the Seal Beach National Wildlife Refuge provided access to the study site. Finally, I would like to thank my fieldwork assistants: Elizabeth Gordian, Mark Trent, Joe Lazzari, and Martin Golden.

INTRODUCTION

Coastal wetlands are among the most economically and ecologically productive ecosystems. They aid in water purification, coastal protection, carbon sequestration, and support commercial fisheries (Barbier et al. 2011). Yet these valuable ecosystems are also among the most threatened due to sea level rise and human development (Bulleri and Chapman 2010, Pendleton et al. 2012, Kirwan and Megonigal 2013). In Southern California alone, around 75% of coastal wetlands have been lost since 1850 (Stein et al. 2014). With sea level predicted to rise between 1.1 and 3.6 ft. by 2100 (predicted range with 67% probability for La Jolla, California, RCP 2.6, 4.5 and 8.5 scenarios (Griggs et al. 2017)) – many coastal wetlands will likely not survive (Kirwan et al. 2010, Rosencranz 2017).

Coastal wetlands naturally accrete sediment to sustain their surface elevation while the sea level rises (Reed et al. 1999). Production of organic matter and sediment influx from upstream increases the vertical elevation of a wetland to maintain equilibrium with sea level (Morris et al. 2002). But if sea level rises too quickly, a wetland that cannot accrete fast enough will eventually become sub tidal (Stralberg et al. 2011). The wetland may be able to migrate landward, unless anthropogenic development is in the way (Donnelly and Bertness 2001). If a wetland cannot compensate and becomes sub tidal, it can no longer perform its important ecological functions. In light of this, researchers have been developing adaptation strategies to ensure the future of coastal wetlands (Ray 2007).

One potential strategy is to add a thin layer of sediment on top of coastal wetlands in order to more rapidly increase the height of the marsh surface. Studies using this technique have been done in the Gulf and Atlantic coasts of the U.S. and have shown potential for success (Croft et al. 2006, Ray 2007). The goal of thin layer sediment addition is to artificially accelerate sediment deposition and accretion by placing dredged sediment on top of marsh surfaces. The added sediment raises the surface elevation of the marsh in order to prevent submergence.

The addition of sediment to coastal wetlands has the ability to influence many ecological factors that contribute to the health of the wetland. Added sediment can influence plant density, tidal creeks, sediment flux, and other aspects of the wetland. In 1990, DeLaune et al. observed the effect of added sediment on a salt marsh along the Mississippi River Delta (Delaune et al. 1990). They found that the marsh was able to recover from the added sediment and regained its plant growth and productivity. Croft et al., in their study of the effect of sediment addition to a marsh in North Carolina, found that the marsh was able to recover and thrive after the placement of 8.5-10cm of dredged sediment (Croft et al. 2006). Several other researchers have tested the technique in other coastal wetlands with encouraging results (Ford et al. 1999, Slocum et al. 2005).

While there have been studies done on the health of wetlands after sediment addition, little is known about its effects on suspended sediment concentrations (SSC). SSC is a measurement of the sediment available for the wetland to potentially deposit over time (Reed et al. 1999). SSC can be used to predict wetland vulnerability to sea level rise, although other factors such as local storm patterns and vegetation are considered as well (Kirwan et al. 2010, Ganju et al. 2015, Hood et al. 2016). SSC is very commonly used to estimate sediment flux. SSC on the surface of a marsh indicates how much sediment is becoming re-suspended (Ganju et al. 2004). Suspended sediments at a wetland can be internal or brought in from a river upstream (Warrick and Farnsworth 2009). At our study site, a salt marsh in Seal Beach, California, there is no longer an influx of sediment coming from upstream due to redirection of streams into flood control channels that bypass the wetland. By analyzing SSC on the surface of the marsh we can determine if the added sediment is becoming re-suspended at high rates and potentially leaving the marsh surface where it was placed. SSC measurements are also part of general sediment flux patterns in a wetland (Ganju et al. 2015).

In addition to understanding how this adaptation strategy affects SSC, we do not know how it affects the organic content on the surface of the marsh. Therefore we also chose to analyze volatile suspended solids (VSS). Organic matter aids the marsh in vertical accretion (Moskalski and Sommerfield 2012), and is dependent on the vegetation on the marsh as well as influx from upstream (Chen et al. 2016). Additionally, the added sediment covered the vegetation on the experimental site, which may have also affected the organic content of the sediment on the surface of the marsh.

Since we do not understand the effects of thin layer sediment placement on SSC or VSS, we investigated the effects on SSC and VSS at a salt marsh in Seal Beach that had undergone sediment addition of dredged sediment. We compared SSC and VSS on the experimental marsh surface and control marsh surface at Seal Beach after the sediment was added for up to one year after the sediment addition. By understanding how the addition of sediment on the marsh surface can affect the nearby control site and how SSC and VSS levels change over time we can better understand how this relatively new adaptation method will affect the overall health of the salt marsh.

We hypothesized that there would be a difference in SSC and VSS between the experimental site and control site due to the addition of the sediment. We predicted that SSC would be greater on the experimental site, but that VSS would be higher on the control site. Additionally, we expect this difference to lessen as more time passes since the sediment addition. Our study tested the following hypotheses:

1) SSC will be greater on the experimental site compared to the control site at the beginning of the study.
2) VSS will be higher on the control site than the experimental site at the beginning of the study.
3) VSS and SSC differences between experimental site and the control site will decrease over time.

By understanding how SSC and VSS are affected by the addition of sediment, we can better understand the implications of this adaptation strategy. We can learn about the movement of the sediment added and the organics in the suspended sediments, which can inform managers about the potential implications of sediment placement.

METHODS

Study Site

The Seal Beach National Wildlife Refuge is 391 hectare of protected land within the Naval Weapons Station Seal Beach in southern California, thirty miles south of Los Angeles (33^0 73'N, 118^0 07'W). This salt marsh is dominated by *Spartina folisa* (cordgrass) and supports a variety of wildlife, including the federally endangered *Rallus obsoletus levipes* (Light-footed Ridgway's rail) and *Sterna antillarum browni* (California Least Tern). From December 2015 to April 2016 the U.S. Fish and Wildlife Service applied a layer of sediment over approximately 8.5 acres of the low salt marsh in order to evaluate the elevation change and health of the wetland over a period of about five years; a control site was established across the channel.

Figure 1: Map of sampling locations, experimental site on the right and control site on the left. Pink circles indicate SET plots and green circles indicate UCLA and CSU Long Beach plots.

Sampling Design

We used established sampling locations, marked with PVC poles, which were representative of the entire experimental and control site. A total of 38 sampling locations were on the experimental site and 21 on the control site (Figure 1). Twenty-three of the sampling locations on the experimental site and 15 of the sampling locations on the control site were stratified based on two types of vegetation, *Spartina foliosa* (cordgrass) and *Batis maritima* (saltwort), and ponds on the marsh surface and established with PVC poles by UCLA and CSU Long Beach researchers. Fifteen of the sampling locations on the experimental site and 6 on the control site were established by the U.S. Geological Survey for Surface Elevation Tables (SETs) and are relatively evenly spaced over the length of the sites. The exact number of samples varied slightly for each of the sampling periods due to complications with the plots and problems with the sampler bottle device. One sampling location on the experimental site was buried when the sediment was sprayed on the site. We were unable to relocate it so another sampling location was established in a similar location but were unable to sample that location until it was re established 2 months after the sediment addition. Additionally, the sampler bottles used occasionally did not fill with water when they turned sideways. One possible explanation is that they were not properly zip-tied to the PVC pole and where therefore dislodged from their location as the tide came in. Also, some of the tops of the sampler bottles came off, possibly due to the movement of the tide or weak attachment of the tops.

Samples were taken 1 week, 1 month, 3 months, 6 months, and 1-year after completion of the sediment placement in order to evaluate the change in SSC and VSS over time. We expected the most rapid change in SSC and VSS to occur soon after the sediment addition was completed so we initially sampled more frequently.

Suspended Sediment Concentrations and Volatile Suspended Solids

In order to evaluate the influence of sediment addition on sediment movement over the marsh surface we used SSC, which is a more reliable measurement than total suspended solids (TSS) (Gray et al. 2000). Additionally, we measured VSS from the same samples to examine the organic content of the suspended sediment above the marsh surface.

In order to collect SSC and VSS data from the surface of the experimental and control site, we used 250ml single-stage, siphon sampler bottles (Braatz 1961). The sampler bottles have an intake nozzle that collects a sample of the water as the tide rises at the salt marsh (Figure 2). The sampler bottles were zip-tied to the PVC poles of the aforementioned plots the day before a

6ft tide. The 6ft tide was necessary for the sampler bottles to completely fill due to the height of the experimental site. The following day the samplers were collected and placed in a refrigerator at 4°C for no longer than one month before analysis.

For analysis of SSC and VSS we followed the ESS Method 340.2 (1993). 50-52mm A/E glass fiber filters were rinsed with 60ml of distilled water and placed for 30 minutes at 550°C in a muffle furnace. The filters were then washed with 60ml of distilled water and placed in an oven at 103-105°C for a minimum of one hour. After being cooled in a desiccator, they were weighed, and then placed on a vacuum filtration system. The contents of the 250ml sampler bottle were poured into a graduated cylinder. The remaining sediment on the bottom of the sampler bottle was rinsed into the graduated cylinder using a small amount of distilled water. Slowly, the graduated cylinder was poured into the vacuum filtration system. Any sediment remaining at the bottom of the graduated cylinder was rinsed into the filtration system using a small amount of distilled water. After filtering onto the glass fiber filter, the samples were placed in an oven at 103-105°C for one hour, cooled in a desiccator, and weighed. For each set of samples, a minimum of 6 blanks were processed with approximately 300ml of distilled water. After weighing the samples, they were placed in a muffle furnace at 550°C for 30 minutes, cooled in a desiccator, and then weighed to determine volatile suspended solids.

Data Analysis

All data analysis was performed with R Studio (version 0.98.1062). We transformed all SSC data using a square root transformation to obtain normal distributions. We tested for homoscedasticity using the Fligner-Killeen test of homogeneity of variances. A two way ANOVA was used to compare SSC data over time for the experimental site and the control site; followed post-hoc tests. We were unable to normalize VSS data so a Kruskal-Wallis rank sum test and Wilcoxon rank sum test was used to analyze the differences over time and between the experimental and control site.

Figure 2: Single Stage Sampler Bottle zip tied to PVC pipe on experimental site.

RESULTS

Suspended Sediment Concentrations

During the first sampling period, one week after the sediment was added we saw high SSC on both the experimental site and control site (Figure 3). The SSC leveled out as time went on.

For the samples analyzed one week after the sediment was added there was an outlier on the control site that was 3.41 standard deviations above the mean. The SSC for the control site with the outlier changes from 69.8±13.6 mg/L to 57.1±5.0 mg/L without the outlier. The outlying sample appeared to have large clumps of sediment, making it heavier. Six months after the addition of sediment on the control site there was another outlier 4.28 standard deviations above the mean. The mean SSC for the control site with the outlier is 54.2±23.2 mg/L and 31.4±4.6mg/L without the outlier. The outlier for the six month sampling period appeared to be very sandy.

There was a significant interaction between site and time since completion of the experimental site (Two-way ANOVA, time: P=<0.001, site: P=0.55, time*site: P=0.04), indicating that the relationship between sites was not consistent overtime. Excluding the two outliers, the control site was higher than the experimental site three months and six months after sediment was added, the experimental site was higher than the control site one week, one month, and one year after the addition of the sediment.

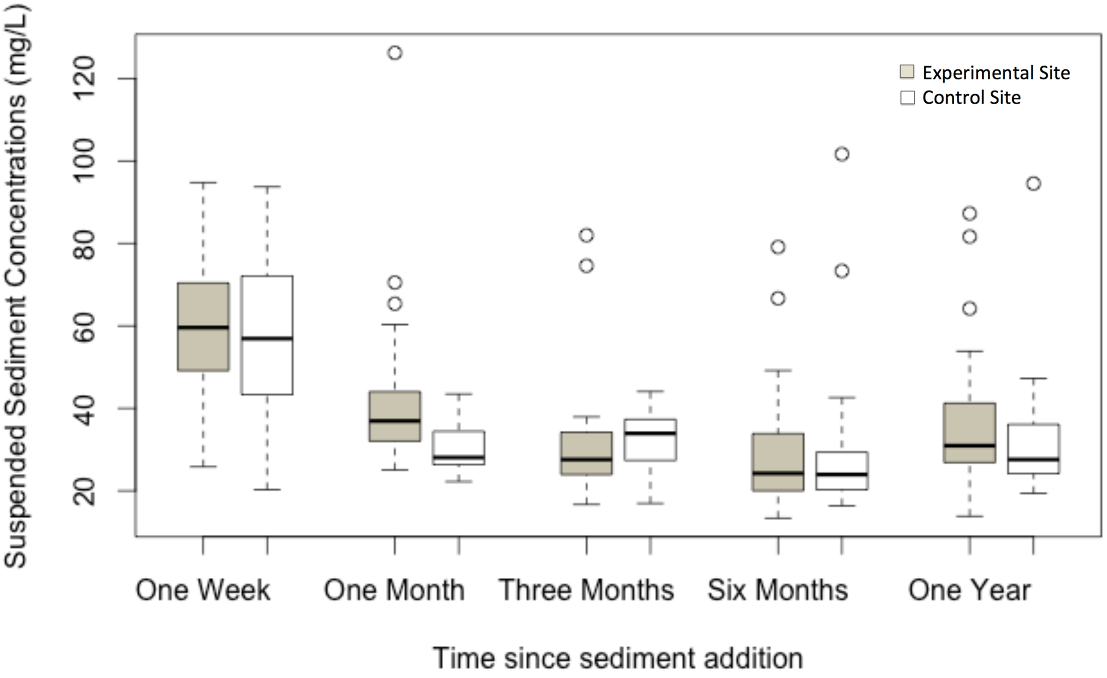

Figure 3: Suspended sediment concentrations in the control and experimental site over time since sediment addition. Two outliers have been excluded from the figure: 299.3 mg/L from One Week Control Site and 509.4 mg/L from Six Months Control Site. The box represents the 25th and 75th percentiles, and the band in the middle is the median. The upper whisker is the upper quartile plus 1.5 times the interquartile range (IQR). The lower whisker is the lower quartile minus 1.5 times the IQR. Open circles represent data points outside this range.

Volatile Suspended Solids

For the one month and three month post sediment addition sampling periods, the median of the control site was higher than the experimental site (Wilcoxon rank sum test P=0.03, P=0.005, respectively). For the one week, six month and one year sampling periods, the experimental site and control site had similar medians. VSS did not change significantly over the course of the year on both the experimental site and the control site (Kruskal-Wallis: P=0.1255, P=0.1386, respectively, Figure 4).

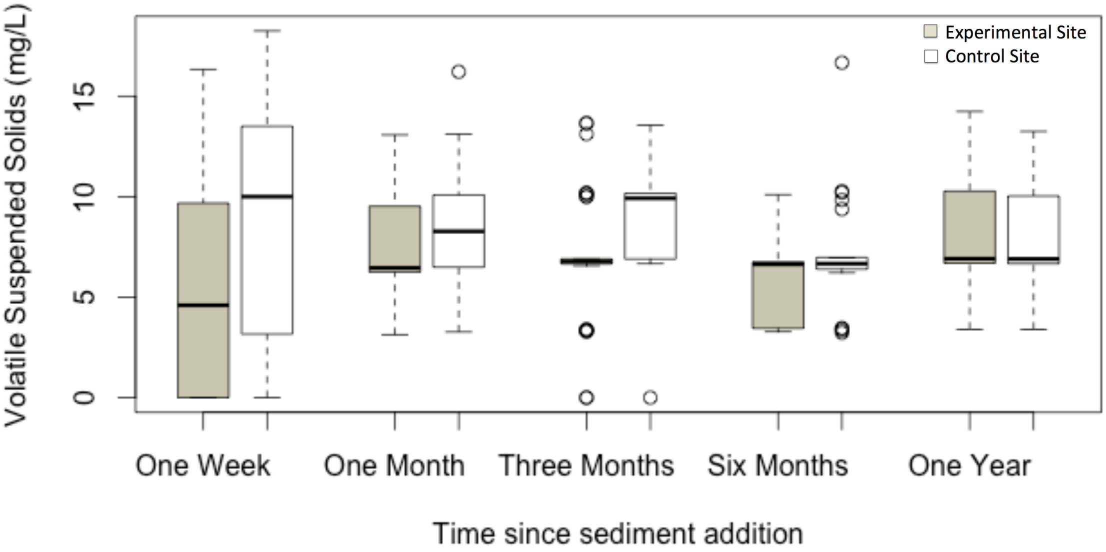

Figure 4: Volatile suspended solids from the experimental and control site over time since completion of the experimental site. Boxplot notation is the same as in Figure 3.

DISCUSSION

Our data shows that the addition of sediment to the experimental site caused a temporary increase in SSC on both the experimental and control site. The high SSC concentrations at the experimental and control site that occurred one week after the addition of the sediment were higher than those found in the literature for the same site (Rosencranz et al. 2016). Rosencranz et al. measured SSC at the same Seal Beach salt marsh during their study of sediment flux and found that it was at most 39 mg/L (2016). Additionally, the one-year post sediment addition sampling occurred 17 days after the latest rainfall during a particularly stormy southern California winter, when SSC might be expected to be relatively high. However, we did not see the same high levels of SSC that we did during the one-week post sediment addition data. Although we did not measure SSC before the addition of sediment, the one-week post sediment addition data was higher than the rest of the year. This indicates that the added sediment caused the increase in SSC on both the experimental and control site.

Interestingly, the control site was influenced by the sediment addition even though it is 259 meters away from the edge of the experimental site. It is therefore difficult to evaluate our hypotheses because it appears that the added sediment reached the control site. The control site was initially chosen as a control for comparing vegetation, natural accretion rates, and invertebrates with the experimental site, not SSC or VSS. While we did expect some turbidity in the nearby channel, we did not expect the added sediment to influence the SSC of the control site. However, our results show that the sediment addition had an influence on the marsh surface and increased SSC at first. Over time this effect disappeared and SSC stabilized both at the experimental site and control site. More stable SSC may indicate that the sediment placed on the experimental site was not re-suspending as readily as when it was first placed. The effect the sediment addition had on the control site was unexpected and provides valuable insight into thin-layer sediment addition and how it effects nearby environments. For example, the increase in SSC on the experimental site and control site may indicate potential negative impacts on aquatic life in nearby channels (Wilber and Clarke 2001).

Since the added sediment was dredged from a nearby channel, we were expecting the VSS on the experimental site to be lower than the control site. Since there is no influx of sediment from upland, we expect the organic matter on the control site to come from within the salt marsh (Ganju et al. 2015) or carried in with the tide. We found that the organic content of the suspended sediment, VSS, was low on the experimental site when compared to the control site one week to three months after the sediment was added. This is likely due to the addition of the sediment and the lack of vegetation because the sediment covered all the plants. The added sediment may have had lower organic content since it was very sandy (unpublished data). Later in the study, six months after the addition of the sediment, the VSS on the experimental site was comparable to the control site. Perhaps the VSS measured was comparable to the control site and the marsh surface in general because the added sediment was not re-suspending as readily. When Croft et al. conducted a sediment placement study in North Carolina they suggested that incremental addition of sediment over time may be most beneficial for plant biomass (2006). Had this been done at Seal Beach, rather than a single addition of sediment, the plant biomass may have been preserved and resulted in higher VSS on the experimental site.

The potential for this adaptation strategy is evident (Ray 2007); however, we must learn more about its impacts to the health of the marsh and its potential for long term success. Our data suggests that sediment placement has consequences on sediment flux and organic content on the surface of the marsh. This is the first time these impacts have been studied and our results indicate that although the sediment and organic content is affected, both can quickly return to stable levels. Managers should be aware that SSC may increase over the marsh surface where the sediment was added and on nearby marsh surfaces, as seen in our control site. This increased SSC may result in more rapid deposition and accretion in areas where sediment addition has not already increased the marsh surface elevation. Also the increased SSC may result in negative ecological impacts to aquatic biota (Newcombe and MacDonald 1991). Managers should be aware of the potential negative ecological impacts of this adaptation strategy due to increased SSC.

If we want to help coastal wetlands adapt to climate change using anthropogenic strategies, we must understand more about the impacts the adaptations strategies have to the ecosystem. In the future, we should evaluate the change in sediment flux caused by sediment addition by looking at SSC and VSS on the surface of the marsh in addition to SSC and VSS in the tidal creeks and channels. For example, if SSC were high for a long period of time we would expect that to indicate that the added sediment is being re-suspended and moving off the marsh surface where it was placed, reducing the long-term success of sediment addition. The SSC and VSS impacts seen in this study may be due in large part to the very sandy dredged sediment. Other sites where this adaptation strategy is being applied should measure SSC and VSS to see if similar effects occur if the added sediment is not as sandy. By understanding the SSC and VSS associated with sediment addition we can better understand the potential that sediment addition has for success.

The future of coastal wetlands in the face of sea level rise is uncertain (Kirwan et al. 2010, Rosencranz 2017); but techniques like sediment addition are promising to help them become more resilient in the face of climate change (Delaune et al. 1990, Croft et al. 2006). For salt marshes like Seal Beach with no influx of sediment from an upstream source, sediment placement is a crucial adaptation strategy for its long-term survival. We must continue to explore these adaptation strategies so we can successfully assist coastal wetlands in combating the impending rapid sea level rise.

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