# QUARTERLY PROGRESS REPORT
# As of December 31, 2017 DRAFT

Date: January 23, 2018 Dates Covered by this Report: October 1, 2017 – December 31, 2017

Agreement No.: P1496011 00 Grant Term: March 1, 2020

Project Title: Initiation of Thin-Layer Sediment Augmentation on the Pacific Coast

Grantee: U.S. Fish and Wildlife Service, San Diego NWRC

## FISCAL REPORT

| Fund Source | Amount Awarded | Amount Expended as of December 31, 2017 | Total Amount Remaining |
|---|---|---|---|
| CDFW GGRF Grant Funds | $1,055,827 | $356,044[1] | $699,783 |
| Cost Share | $1,306,048 | $1,613,334[2] | -$307,286 |
| | | | |
| Agreement Totals | $2,361,875 | $1,969,378 | $714,950[3] |

[1] Invoices covering the period 8/01/2017 – 8/31/2017 and 9/01/2017 – 9/30/2017 were submitted in the final quarter of 2017. Invoices for the period 10/01/2017 – 12/31/2017 and 5/01/2017 – 12/31/2017 will be issued in the first quarter of 2018.
[2] Includes in-kind staff time from USFWS (Refer to Attachment 1 for details.)
[3] Cost share agreements have already been achieved and are therefore not included in this total.

Invoice Submitted this Quarter: ☒ Yes (previously under separate cover) ☐ No

## PROGRAM/TECHNICAL REPORT

**Activities Performed from October 1 – December 31, 2017**:

### Monitoring

- Researchers continued post-augmentation monitoring on the augmentation site and control site and/or conducted lab work to analyze data/samples obtained at the sites.

- UCLA researchers under the direction of Dr. Rich Ambrose have been sampling feldspar/bulk density (F/B) plots and studying tidal creek accretion at the control site and on the augmentation site, involving collecting data at approximately 70 sediment stakes, 23 F/B plots, and 8 creek crossings. Photos of forming tidal creeks were taken to construct an orthomosaic that will establish the current conditions on the site. Researches can then compare future conditions with current conditions to study how tidal creeks on the site reform after hay bales are removed from the head of specific old tidal creek channels at the edge of the project's 50-foot buffer area.

- CSULB researchers under the direction of Dr. Christine Whitcraft conducted their 18 months post augmentation field work between October 13 and 16, 2017, involving plant surveys and collecting sediment samples to evaluate invertebrate abundance and diversity at both sampling sites. CSULB also conducted laboratory analysis involving sorting and identifying invertebrates collected from the sites.

- UCLA researchers under the direction of Dr. Glen MacDonald completed their analysis and prepared the final results of their assessment of pre-augmentation net sediment accretion rates, carbon stock, carbon accumulation rates, and historic sea-level rise on the Seal Beach NWR from historic sediment core data (Brown et al. 2018). The final report is provided as Attachment 2.

- Monitoring of surface elevations by USGS was performed in November 2017.

- The Refuge Manager and volunteers conducted bird surveys and general site evaluations. Time lapse photos of the site continue to be collected.

**Site Observations**

- Plant surveys conducted on October 2017 revealed that cordgrass (*Spartina foliosa*) is coming back in low-lying areas throughout the site, but is currently only present in one of the survey plots, so the numbers for statistics will not currently reflect overall site recovery.

- Numerous pickleweed seedlings were observed on the augmentation site during a site visit conducted on November 21, 2017.

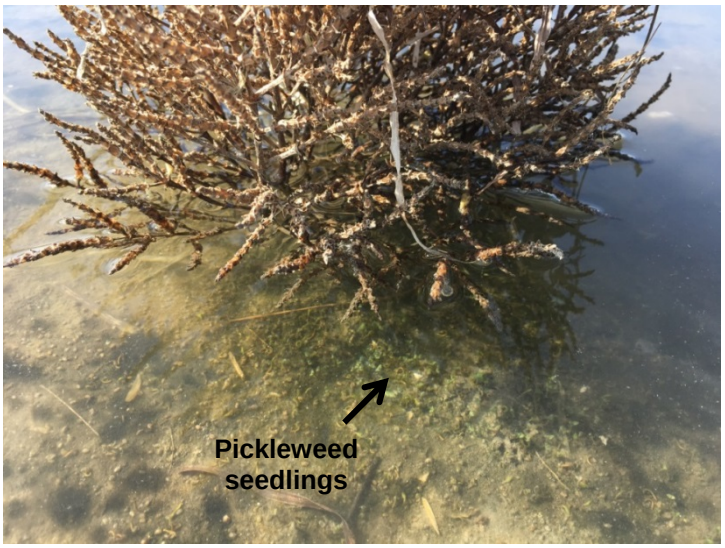


Figure 1. Annual pickleweed inundated by the tides in Fall 2017. Numerous pickleweed seedlings are present below the older plant. Photo: USFWS, R. Nye.

- Preliminary data from October 2017 related to invertebrates indicates a higher number of organisms are present on the augmentation site than were present during previous post augmentation sampling efforts.

- Shorebirds and other waterbirds were observed on the site in moderate numbers in early October, but subsequent visits in early November and early December yielded no sightings. On October 7, 2017 during a high tide survey, one great egret, five black-bellied plovers, 35 western or least sandpipers, and two unidentified gulls were observed on the site. On October 19, 2017, during a low tide survey, four black-bellied plovers were observed.

Figure 2. Taken November 2017 during a 5.5-foot high tide looking northeast from the south end of the augmentation site. Note that much of the site is inundated. Photo: USFWS, R. Nye.

No light-footed Ridgway's rails have not been observed on the augmentation site post augmentation, but they have been observed near the site. One rail was observed on a nesting platform about 300 meters south of the augmentation site during a high tide survey conducted on November 6, 2017. There are three nesting platforms at this location and none were used for nesting during the 2017 breeding season. Only one of these nesting platforms was used for nesting during the breeding season immediately preceding the augmentation process. Another group of six nesting platforms are located on the opposite side of the west channel from the augmentation site. Four of these platforms were present in 2015, when two were used for egg nests. Of the six platforms present in that location today, rails used two of the platforms during the 2017 breeding season. One was used for an egg nest and the other was used for a brood nest.

**Project Coordination**

- No full team conference calls were held during this period, but we did have a call to discuss some upcoming outreach opportunities. Richard Ambrose (UCLA), Christine Whitcraft (CSULB), and Karen Thorne (USGS) will be preparing a journal article related to the project. In addition, we discussed a recent call for abstracts for an upcoming Restoration Webinar Series sponsored by The National Oceanic and Atmospheric Administration (NOAA) and the USFWS's National Conservation Training Center.

- Refuge staff coordinated with researchers on monitoring visits to the site and quarterly and final reports.

- Researchers and monitors provided summaries of activities completed during the quarter and when available, provided relevant interim results.

**Project Outreach/Information Dissemination**

- The Refuge webpage (https://www.fws.gov/refuge/seal_beach/what_we_do/resource_management/Sediment_Pilot_Project.html) was updated to include the annual report to CDFW and new site photos.

- Evyan Sloane (California Coastal Conservancy) submitted an abstract related to our thin-layer sediment augmentation project for consideration as a possible discussion topic during the Restoration Webinar Series. This series will showcase new approaches, best management practices, and innovative restoration techniques and will provide a forum to discuss some of the biggest habitat restoration challenges facing the restoration community. If selected for inclusion in the webinar series, the discussion related to our project would likely occur sometime in mid-2018.

**Status of Ongoing Research:**

**A. UCLA (SEDIMENT CORING)** - The final report (Brown et al. 2018) describing the results of the analyses of historic sediment core data from the project site has been completed and is provided as Attachment 2. This research aimed to assess pre-augmentation net sediment accretion rates, carbon stock, carbon accumulation rates, and historic sea-level rise at the Seal Beach NWR. Presented here are the major conclusions of the analyses; the specific details are provided in the final report.

- Sediment records ranging from 380+ 78 years before present (YBP) to 1539+ 71 YBP indicate average sediment accretion rates (as determined by 137Cs and 210Pb dating) was 3.2+ 0.21 mm yr-1. This was true for both the control site and the augmentation site and for radiometric methods.
- Analysis of carbon content in the cores shows that there are approximately 73,536+ 6,635 tonnes of carbon stored at the 390 ha of active salt marsh (top 1 m) at the Seal Beach NWR. Using an estimated value of $15.17 per tonne of CO2e on the California carbon exchange (10 Jan 2018), the carbon stock at the Seal Beach NWR is worth approximately $1.1 million.
- Average CAR determined from carbon content and age-depth relationships is 116.8+ 1.6 g C m-2 yr-1, with approximately 456.3 tonnes of carbon sequestered by the salt marsh habitat at the Seal Beach NWR every year.
- A seismic event occurred ca. 1450 AD which corresponds to a previous report by Leeper et al. (2017). This event was followed by the marsh recovering from the highly sandy content.

**B. UCLA (CHANGES IN MARSH PLAIN POST-AUGMENTATION) -** Researchers at UCLA continue to collect sediment samples and measurements following the augmentation process at established sampling sites on both the control site and the augmentation site. During the last quarter, researchers conducted sampling at four creek crossings and 15 feldspar plots. Measurements were also taken at about 70 sediment stakes. The feldspar plots, which were installed in 2015 prior to augmentation, provide a method for measuring sediment accumulation on the control and augmentation site over time. Sediment stakes placed in the control and augmentation sites at a known height above the natural substrate provide a tested method for measuring sediment accretion (accumulation) or erosion, which is determined by measuring the subsequent distance from the substrate surface to the top of the stake and comparing this distance to the original distance.

Samples taken from the feldspar plots were processed for sediment bulk density (the mass of sediment in a specified volume), percent organic carbon, and grain size measurements. Processing for measuring bulk density involves drying and then weighing the core samples taken from the feldspar plots.

A major focus this quarter was establishing the current conditions of the small tidal creeks that have begun to form within the augmentation site. This data will enable researchers to document how the creeks reform over time. As addressed in our last report, tidal creek formation has been limited by the presence of hay bales placed at major pre-augmentation tidal creeks in an effort to retain the new sediment on the site and out of adjacent tidal channels supporting eelgrass. The Refuge Manager has identified several locations where removal of these hay bales will not jeopardize adjacent resources. UCLA researchers performed three site visits to take photographs of tidal creeks that will be used to create an orthomosaic. They also collected elevation data of these creek crossings. These images and measurements will form the baseline (i.e., pre hay-bale removal) from which future conditions can be compared. Similar data was collected for creek crossings on the control site to understand how tidal creeks in the marsh are influenced by tidal processes, rainfall, and any other physical factors affecting the marsh complex.

C. **CSU LONG BEACH (PLANT AND INVERTEBRATE STUDIES) -** During this quarter, researchers from CSULB conducted field work during the period October 13 – 16, 2017. This fieldwork, which was conducted on both the augmentation site and the control site, included monitoring the vegetation community, epifaunal and infaunal invertebrate populations, abiotic properties, and belowground biomass.

Invertebrate sorting and identification for the top 2 cm samples has been completed for all samples collected through summer 2017, and processing of the fall 2017 samples is underway. Sorting of the bottom 4 cm samples for all prior time periods is also underway.

Processing of belowground biomass cores is completed and the data enter. Analysis of the data is underway.

Additional colonization experiment samples, taken to evaluate any potential differences in colonization due to the high percentage of sand present in the dredged material have been sorted and identified. That experiment is now complete and the data are being analyzed for publication.

D. **CHAPMAN UNIVERSITY (GAS FLUX) -** The research team conducted sampling in October and December 2017. On each sampling trip, gas samples were collected from both the control and augmentation sites. The samples were then analyzed for carbon dioxide, methane, and nitrous oxide at Chapman University. Surface porewater was also collected and analyzed for chemical properties. Due to concerns about potential acidification of the augmentation site, pH levels in surface water and porewater collected at both sites was also measured. Redox in surface water was measured in the field.

Monitoring indicated that significant $CH_4$ fluxes continue to be minimal, but there are occasional positive fluxes. Low $CH_4$ fluxes are common from salt marsh soils.

$CO_2$ fluxes were generally lower from the control site pre-augmentation (possibly due to lower air temperatures during sampling) and were lowest from ponded communities. After the addition of sediment, the augmentation had very low $CO_2$ fluxes compared to both the control site and the pre-augmentation conditions on the augmentation site.

**E. USGS (SEDIMENT FLUX PATTERNS AND SETS) -** Monitoring of turbidity and sediment fluxes ended in August 2017, but monitoring of post-construction marsh surface elevations with deep rod surface elevation tables (SETs) and adjacent feldspar plots continues.

Figure 3. Pickleweed growing in Plot Area SBA1, where a SET and feldspar plot is maintained. Photo: USGS.

Measurements taken on November 11, 2017 indicate that the augmentation site has continued to gradually decrease in elevation, dropping on average 3.84 mm across all fifteen SETs. The control site showed a small increase in elevation of 1.65 mm across its six SETs. A SET installed elsewhere on the Refuge several years prior to the augmentation project also showed an increase (2.49 mm), as depicted in Figure 1 of Attachment 3. Since the completion of the augmentation process, which resulted in a mean increase in elevation at the SETs of 216 mm, the elevation had a decrease of 81.25 mm between April 2016 and November 2017. The change in elevation for different time periods is depicted in Figure 2 of Attachment 3.

**F. BIRDS SURVEY RESULTS FOR THIS QUARTER -** Monthly high and low tide bird surveys continue to be conducted at the project site. The 2017 light-footed Ridgway's rail surveys have been completed. The information provided above is based on a draft of the survey report. A final survey report should be available next quarter.

**Percentage of Task Completed as of December 31, 2017:**

| | | |
|---|---|---|
| Task 1 – Project Management and Administration | | 53% |
| Task 2 – Sediment Augmentation | | 100% |
| Task 3 – Project Monitoring (overall) | | 58**%** |
| 1) Carbon Storage/Sequestration Benefits | 90% | |
| 2) Plant and Invertebrate Monitoring | 40% | |
| 3) Pacific Cordgrass Analysis | 40% | |
| 4) Site Elevations | 40% | |
| 5) Sediment Analysis (compaction, movement, bulk density) | 40% | |
| 6) Turbidity Levels | 100% | |
| 7) Bird monitoring | 40% | |
| 8) Eelgrass | 75% | |
| Task 4 – Engineering Design/Environmental Documentation (overall) | | 100% |
| 1) Engineering Plans for Sediment Augmentation Site | | 100% |
| 2) Environmental Documentation* | | 100% |
| *CEQA/NEPA has been completed by SCC/USFWS | | |
| Task 5 – Public Participation/Presentations (overall) | | 50% |
| 1) Oral/Poster Presentations | 65% | |
| 2) Workshops and/or Webinars | 35% | |
| **Overall Project** | | **80%** |

**Deliverables Completed for Each Task:**

Task 1 – Project Management and Administration

| | |
|---|---|
| 1) Quarterly Progress Report | 10 reports |
| 2) Monthly Invoices | 23 monthly invoices |
| 3) Subcontractor Selection | Orange County Parks & SWIA selected |
| 4) Data Management | preliminary data for monitoring locations |
| 5) Acknowledgement of Credit | ongoing |

Task 2 – Sediment Augmentation

| | |
|---|---|
| 1) Sediment Application | completed |
| 2) Adaptive Management | on going |
| 3) Reporting Results/Lessons Learned | in process |

Task 3 – Project Monitoring

| | |
|---|---|
| 1) Carbon Storage/Sequestration Benefits | pre-augmentation monitoring completed; long core data processing complete; post-augmentation monitoring underway; long core data final report completed |
| 2) Plant and Invertebrate Monitoring | pre-augmentation work completed; post augmentation work underway |
| 3) Pacific Cordgrass Analysis | pre-augmentation work completed; post augmentation monitoring underway |
| 4) Site Elevations | pre-augmentation RTK survey; post-augmentation photogrammetry; SET data downloads continuing; monitoring of feldspar plots continuing; seeking funding for additional aerial photography |
| 5) Sediment Analysis | initial core samples retrieved; data processing completed; grain size analysis of new sediment nearing completion |
| 6) Turbidity Levels | monitoring completed in August 2017; final report underway |
| 7) Bird Monitoring | pre-augmentation work completed; post augmentation work ongoing |
| 8) Eelgrass | pre-augmentation, post- augmentation and year one post-augmentation surveys completed |

Task 4 – Engineering Design/Environmental Documentation

| | |
|---|---|
| 1) Engineering Plans for Augmentation Site | 100% engineering plans completed |
| 2) Environmental Documentation* | CEQA/NEPA documents final; ND recorded *for USFWS and Coastal Conservancy |

Task 5 – Public Participation/Presentations

| | |
|---|---|
| 1) Oral/Poster Presentations | Presentations ongoing |
| 2) Workshops and/or Webinars | Participated in USACOE webinar; primarily results presentation planned for 2018 |

**<u>Problems/Delays Proposed Resolution:</u>**

No delays have been identified for post-augmentation monitoring. We continue to monitor eelgrass recovery, which is occurring, adjacent to the site. Another eelgrass survey will be conducted in late Spring 2018.

Revegetation of the site by Pacific cordgrass is not progressing as quickly as we had predicted, likely due to the unanticipated amount of sand present in the dredged material placed on the site. We have begun consulting with other wetland ecologists in the region who have experience with Pacific cordgrass restoration projects, such as the western salt ponds restoration project on the San Diego Bay NWR. We are considering propagating cordgrass plugs at the plant nursery on the Seal Beach NWR. Those plugs could then be planted within the augmentation site to

help accelerate revegetation of the site. We will continue to evaluate the progress of cordgrass recruitment within the site through the next growing season and provide additional input in our next quarterly report.

**Project Benefits and Results:**

Although we have not yet achieved our primary project goals, we have compiled a considerable amount of information regarding the sediment augmentation process and pre- and post-monitoring protocols. This information has benefited other land managers who are considering similar actions both on the east and west coasts of the U.S. Information related to long-term carbon sequestration at Seal Beach will benefit other land managers and those interested in carbon storage and total value of the carbon stock in southern California's coastal salt marshes.

**Summarize Benefits to Disadvantaged Communities (if applicable):**

Not applicable to this project.

**List of Proposed Activities and Tasks for the Next Quarter:**

Task 1 – Project Management and Administration
Tasks include coordination of final pre-project monitoring reports; completion of the "lessons learned" document for the thin-layer sediment augmentation process; assisting researchers with site access; preparing invoices and the next quarterly report; providing other agencies with information about the project, and all other responsibilities needed to successfully complete the project.

Task 2 – Sediment Augmentation
The sediment augmentation process has been completed.

Task 3 – Project Monitoring
Refuge staff will continue photographing and recording the locations (GPS) of cordgrass regrowth within the augmentation site. We will continue to evaluate how cordgrass reestablishment is occurring throughout the site (e.g., extension of rhizomes from the adjacent buffer area, the result of seed distribution, regrowth from buried rhizomes). Photo documentation of changes on the augmentation site over time will also continue.

USGS will continue collecting data from the SETs and feldspar plots.

Dr. Ambrose and his team at UCLA will continue compiling data from field sampling (i.e., bulk density, sediment height, feldspar cores, tidal creek cross-sections) conducted at the augmentation site and control site and continue to analyze bulk density, grain size, and carbon content (loss on ignition [LOI]) for newly collected samples, as well as conduct data entry and analysis. Photo-documenting creek formation will also continue.

Dr. Whitcraft and her team will continue invertebrate community analysis in the laboratory on both the contract samples. In addition, they will survey the site one or two times during the

next quarter to determine how plants are recovering and if there are enough growth to facilitate additional photosynthetic measurements. Data analysis will continue on belowground biomass. They will also assist the Refuge Manager in evaluating the potential for planting cordgrass plugs in various portions of the site.

Dr. Keller and his team will continue to measure greenhouse gas fluxes from the control and augmentation sites. In addition, chemical analysis of surface porewater will continue and pH levels and redox will be measured in surface water. Seasonal patterns in fluxes and their relationship to porewater chemistry will be explored as the dataset expands. Bimonthly sampling will continue in February, April, and June 2018.

MTS will be conducting the second-year post augmentation eelgrass survey in late Spring 2018.

Task 4 – Engineering Design/Environmental Documentation
This task has been completed.

Task 5 – Public Participation/Presentations
The project's lead researchers are preparing a research paper describing the relationship of land managers and ecologists in the restoration project. Members of the team may also be participating in a webinar, part of the upcoming 2018 Restoration Webinar Series sponsored by The National Oceanic and Atmospheric Administration (NOAA) and the USFWS's National Conservation Training Center.

The Refuge webpage will continue to be updated, and we will participate in conferences and webinars as opportunities arise.

## Description of Amendments and Modifications to Grant:

No amendments or modifications were made this quarter. We previously made a minor modification to the existing grant by redirecting $4,950 of unallocated research funds to additional eelgrass survey work, which was approved by CDFW on June 10, 2016.

## Attachments

1. Itemized Cost Share Accounting
2. Seal Beach National Wildlife Refuge Sediment Coring for Long-Term Carbon Sequestration and Environmental Change (Brown et al. 2018)
3. Thin-Layer Sediment Augmentation Pilot Project at Seal Beach National Wildlife Refuge: October 1 – Dec 31, 2017, Quarterly Progress Report (USGS 2018)

## References

Leeper, R., B. Rhodes, M. Kirby, K. Scharer, J. Carlin, E. Hemphill-Haley, … A. Aranda. 2017. Evidence for coseismic subsidence events in a southern California coastal saltmarsh. Scientific Reports, 7, 44615. http://doi.org/10.1038/srep44615.

# Attachment 1
# Itemized Cost Share Accounting

| Cost Share (June 1, 2015 to December 31, 2017) | | |
|---|---|---|
| Activity or Item[1] | Funding Source | Expenditure |
| Total Cost Share from June 1, 2015 to September 30, 2016 | | |
| Pre and Post-augmentation monitoring[1] | California State Coastal Conservancy | $170,776 |
| Purchase boat to access site | USFWS CRI Grant | $2,425 |
| RTK elevation survey | US Army Corps of Engineers | $50,252 |
| USFWS staff time[2] | USFWS CRI Grant | $137,592 |
| Sediment augmentation[3] | Orange County Parks | $670,500 |
| Sediment augmentation | USFWS CRI Grant | $350,000 |
| | **Subtotal** | **$1,381,545** |
| Total Cost Share from October 1, 2016 to December 31, 2016 | | |
| Post-augmentation monitoring | California State Coastal Conservancy | $45,179 |
| USFWS staff time[2] | USFWS CRI Grant | $10,575 |
| | **Subtotal** | **$55,754** |
| Cost Share from January 1 – March 31, 2017 | | |
| Post-augmentation monitoring | California State Coastal Conservancy | $38,002 |
| USFWS staff time[2] | USFWS CRI Grant and Station Funds | $1,071 |
| | **Subtotal** | **$39,073** |
| Cost Share from April 1 – June 30, 2017 | | |
| Post-augmentation monitoring | California State Coastal Conservancy | $23,885 |
| USFWS staff time[2] | USFWS CRI Grant and Station Funds | $9,201 |
| | **Subtotal** | **$33,086** |
| Cost Share from July 1 – September 30, 2017 | | |
| Post-augmentation monitoring | California State Coastal Conservancy | $101,509 |
| USFWS staff time[2] | USFWS CRI Grant[4] and Station Funds | $1,867 |
| | **Subtotal** | **$103,376** |
| Cost Share from October 1 – December 31, 2017 | | |
| Post-augmentation monitoring | California State Coastal Conservancy | $0 |
| USFWS staff time[2] | USFWS Station Funds | $500 |
| | **Subtotal** | **$500** |
| | | |
| | **Total Cost Share to Date** | **$1,613,334** |

[1] Costs associated with bird surveys and light-footed Ridgway's rail monitoring are not included.
[2] This does not include staff time accounted for on monthly invoices.
[3] The bids for sediment augmentation came is much higher than estimated by the project engineer, therefore, some of the cost for sediment augmentation was covered by the Orange County Parks.
[4] As of September 30, 2017, all USFWS CRI Grant funds have been expended and the grant is closed.

# Attachment 2

# SEAL BEACH NATIONAL WILDLIFE REFUGE SEDIMENT CORING FOR LONG-TERM CARBON SEQUESTRATION AND ENVIRONMENTAL CHANGE

# SEAL BEACH NATIONAL WILDLIFE REFUGE SEDIMENT CORING FOR LONG-TERM CARBON SEQUESTRATION AND ENVIRONMENTAL CHANGE

10 January 2018

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# Acknowledgements

We would like to thank the Keck Radiocarbon Lab at University of California, Irvine, the Earth Sciences Lab at University of Southern California, and the Paleodlimatology and Paleotsunami Lab at California State University Fullerton for help in sample processing. We would like to acknowledge UNAVCO for the use of the DGPS equipment. We would like to thank our collaborators in the Seal Beach augmentation project, especially those from the US Fish and Wildlife Service who helped with site access and field work logistics. And finally we would like to give thanks to Scott Lydon and Elizabeth Fard for help during field work.

# Objectives

This report is a part of a larger project testing the effect of thin-layer sediment application to salt marsh surfaces with the goal of mitigating habitat loss caused by accelerated sea-level rise (SLR) through provision of additional mineral material for elevation gain. The study site is located at Seal Beach National Wildlife Refuge (NWR), which is a small marsh that supports critically endangered bird species but lacks freshwater input. Because lack of a freshwater stream means little or no terrestrial material is available to support elevation gain in Seal Beach, habitat loss is thought to be of critical concern. The artificial application of thin-layer sediment at Seal Beach marsh is one of the first attempts to maintain marsh habitat with sediment enrichment.

This section of the larger project aimed to assess pre-augmentation net sediment accretion rates, carbon stock, carbon accumulation rates (CAR), and historic SLR at Seal Beach with the use of historic sediment core data. Sediment accretion, current and past rates of SLR, and carbon storage/sequestration are some of many critical parameters for determining the viability of the marsh ecosystem at Seal Beach. This historic sediment core data adds to environmental baseline data, current monitoring, and pre-historic monitoring data to gain a more complete picture of marsh vulnerability. We estimated current C stock using loss-on-ignition (LOI), estimated historic and current CAR using age-depth models constructed from radiometric dating, and established a modern transfer function for elevation-sensitive foraminifera which has been, and can continue be, utilized in all future studies aiming to reconstruct local sea-level rise records from sediment cores dating back thousands of years.

Additionally, although not in the initial proposal, in response to concern over the unexpectedly high concentrations of sand present in sediments applied to the augmentation site, long-term, high-resolution grain size analysis was conducted on select sediment cores. Such analysis provides baseline data and an envelope of potential grainsize variability in the past.

Applications of sediment core-derived accretion rates include comparisons with monitoring of current and post-augmentation conditions being carried out by other researchers involved in the study, as well as future use in vulnerability assessments such as the WARMER model (Swanson et al., 2013; Thorne, et al., in press). Applications of carbon stock and sequestration data include estimating the ecosystem service value Seal Beach provides as a carbon sink and establishing a baseline for future monitoring of ecosystem functionality. Foraminiferal data from Seal Beach successfully aided in the creation of a Southern-California-wide transfer function (Avnaim-Katav, Roland Gehrels, Brown, Fard, & MacDonald, 2017) which can be used in all foraminifera-based SLR reconstructions going forward. Applications of grain-size also includes provision of baseline data for the augmentation study, as well as indicates these cores depict a record of historic environmental disturbance, and subsequent marsh recovery, which may prove to be a useful proxy for disturbance from thin-layer sediment application as well as from future accelerated SLR.

# Conclusions

With the collection of 18 sediment cores from the control and augmentation sites at Seal Beach, this study has looked at sediment records ranging from 380 ± 78 years before present (YPB) to 1539 ± 71 YBP. Average sediment accretion rates (as determined from $^{137}Cs$ and $^{210}Pb$ dating) was 3.2 ± 0.21 mm $yr^{-1}$, with consistency between control and augmentation sites and radiometric methods. Grain size distributions of 11% clay, 77% silt, and 10% sand from the top 5 cm of cores varies greatly from sediment applied during augmentation, consisting of 9% clay, 11% silt, and 80% on average, which is higher sand content than any sample tested in this study. A sand lens found in multiple cores is suspected

to be caused by a sudden tectonic subsidence event at 1450AD, previously identified by Leeper et al. (2017), and serves as proof of potential recovery of a salt marsh from highly sandy conditions to more typical sediment composition on the order a few decades. Analysis of carbon content in the cores collected shows that there is approximately 73,536 ± 6,635 tonnes of carbon stored in the 390 ha of active salt marsh (top 1 m) at Seal Beach. Using an estimated value of \$15.17/tonne $CO_2$e on the California carbon exchange (obtained 10 Jan 2018), this carbon stock is worth approximately \$1.1 million. Average CAR determined from carbon content and age-depth relationships is 116.8 ± 1.6 g C $m^{-2}$ $yr^{-1}$, and indicates Seal Beach sequesters \$6,922 worth of carbon each year.

# Field Collection

## Selecting Site Locations

Sediment cores were obtained for this project using a Russian Auger, which takes 1 m lengths of 2.5 cm diameter sediment cores. To ensure adequate sampling coverage, material, and replicability, 6 cores were taken on the control site and 12 cores were taken from the augmentation site. Sites were selected in the field, with an effort to obtain good geographic coverage and variation in extant plant coverage (pre-augmentation conditions) on both the control and augmentation sites while maximizing distance from marsh channels which might have impacted the long-term records due to meandering [see Fig. 1].

Field collection for modern foraminiferal analysis was conducted along a transect from high to low marsh near the Seal Beach NWR Fish and Wildlife headquarters. This site was selected as it was the best location to obtain samples from various elevations within a transect of a few hundreds of meters. Data were collected to test the effect of changing elevation, vegetation, salinity, dissolved oxygen (DO), pH, temperature, sediment bulk density, grain size, and organic content on foraminifera assemblages.

## Data Collection Procedures

At each core location of the 18 cores used for high-resolution carbon analysis, a GPS point was taken and vegetation of the surrounding area was described. Using a Russian Auger, cores extracted in meter long sections, until either intertidal or marine sediments were reached (determined by visual description of sediment, lack of tidal marsh macrofossils, or presence of marine shells) or collection was no longer physically possible (usually caused by an impenetrable basal layer or sheer stress). Meter sections were extruded in-field, described, and wrapped for transport back to UCLA where they were stored at 4°C and any remaining core samples are archived.

Along the foraminiferal transect seen in Figure 2, each of the 20 sites was GPS located to cm-level accuracy on x, y, and z planes using differential GPS, or DGPS, equipment. Pore-water was sampled, when possible, using a small tube inserted into the marsh and removed at the end of collecting (de Rijk, 1995) then tested for salinity, DO, pH, and temperature. To analyze foraminifera assemblages, a sediment sample was taken at each of the 20 station. A total of 19 sediment samples were taken using a 10 cm diameter core taken to 1 – 2 cm depth and 1 sediment sample was taken to 10 cm depth to compare live and dead assemblages (differentiated by the addition of Rose Bengal dye added after sampling) of foraminifera (Scott, Mudie, & Bradshaw, 2011). A second 1 cm depth core was taken at each of the 20 stations for analysis of sediment properties, including bulk density, organic content, and grain size.

# Methods

## Initial Core Analysis

Within 10 days of collection sediment cores underwent initial description and analysis. Cores extruded in the field were unwrapped, photographed, re-measured for any shrinkage or expansion and visually described. All cores were then analyzed for magnetic susceptibility using a Bartington MS2E hand-held reader at 1 cm resolution with Bartsoft software (Sandgren & Snowball, 2001).

Following these preliminary analyses, cores were split in half to 50 cm depth. The top 50 cm of each core was sent to California State University Long Beach for analysis of belowground biomass, while the remaining half was analyzed at UCLA for radiometric activity and carbon content.

## Chronological Control

$^{137}$Cs exhibits a distinctive 'spike' due to increased concentration of atmospheric Cs following atomic bomb testing in 1963 that was ultimately concentrated in depositional environments like the salt marsh at Seal Beach; the presence of such high concentrations of $^{137}$Cs identifies the corresponding sediment layer to the year 1963. Alternatively, $^{210}$Pb undergoes radioactive decay and serves as a chronometer for up to roughly 150 years into the past in environments with little redistribution of sediments. Similar to $^{210}$Pb dating, $^{14}$C undergoes radioactive decay but has a much longer half-life, allowing the dating of organic matter up to approximately 40 thousand years ago (kya); although it is not a reliable chronological control in the past 200 years because of human-caused increases of radioactive carbon in the atmosphere.

Both short- ($^{137}$Cs and $^{210}$Pb) and long-term ($^{14}$C) dating were used to provide the highest-resolution age-depth model possible for 6 of the 18 cores collected. A further 5 cores were radiocarbon dated to determine basal depths (and thus maximum estimated marsh age). A total of 7 cores (3 from the control site and 4 from the augmentation site) were $^{137}$Cs and $^{210}$Pb dated. While $^{137}$Cs and $^{210}$Pb provide the most accurate representation of modern sediment accretion (due to the short timescale minimizing the impact compaction has on the sediment record), testing is time consuming and expensive. Analysis of 7 cores was determined to be adequate to get a representative picture of variability in accretion without sacrificing time and budget.

Using $^{137}$Cs accretion rates of 3.4 mm yr$^{-1}$ (ranging from 2.2 – 4.6 mm yr$^{-1}$) previously obtained at Seal Beach (Brown, in preparation) to estimate locations of the $^{137}$Cs spike and depth of the $^{210}$Pb decay, we extracted a 2-4 cm$^3$ sample from each core every 2-4 cm, to a minimum of 20 cm (for low-accreting sites in the high marsh) and a maximum of 60 cm depth (for high-accreting sites in the low marsh). After samples were extracted, they were dehydrated in a drying oven at 110°C for 24 hours and then weighed to calculate bulk density (g/cm$^3$). Samples were ground, sealed in plastic tubes, reweighed, and sent to the University of Southern California for $^{137}$Cs and $^{210}$Pb analysis.

For $^{14}$C dating, organic macrofossil samples for $^{14}$C were visually identified, extracted from the core, rinsed with DI water, dehydrated in a drying oven at 110°C for at least 1 hour, weighed, wrapped in plastic, and taken to the UC Irvine Keck Radiocarbon Lab for final processing. A total of 16 samples were dated, including 14 plant macrofossils and 2 marine shells from a single hash layer (Table 2). Because any root matter will introduce erroneously young $^{14}$C ages into older sediments, all plant-matter was identified as above-ground leaves or seeds. Although plant tissue or charcoal is preferred, two intertidal shells were used. These shells were taken from a hash layer of approximately the same age and were from different species. Both shells were tested to ensure that uptake of "old" carbon ($^{14}$C which has been cycling at the bottom of the ocean for unusually long periods, brought up by upwelling, and often

introduced into marine organisms making the sample return an erroneously old age) was not an issue. All reported $^{14}C$ dates are calibrated dates. $^{14}C$ dates from plant macrofossils were calibrated using IntCal13 (Reimer, 2013); for $^{14}C$ dates obtained from marine macrofossils a mixed marine and northern hemisphere calibration curve was used with an estimated $\Delta R$ of 217 ± 129 years (Holmquist et al., 2015).

For all records with $^{14}C$ data, a Bayesian age-depth model was produced using the R software known as Bacon (Blaauw & Chrissten, 2011; R: a statistical modeling software, 2014).

## Net Sediment Accretion Rates

Net marsh sediment accretion rates for the modern period is based on total depth of marsh sediment accumulated at each core following the 1963 $^{137}Cs$ peak. Longer-term marsh sediment accretion (> 60 years) is based upon the total depth of marsh sediment accumulated in each core with the initiation of marsh sedimentation determined by $^{210}Pb$ or $^{14}C$ dating. Depths are divided by time to derive total sediment accretion rates.

*Equation 1*

$$\textit{Net Marsh Sediment Accretion Rate (mm yr}^{-1}\textit{) = Depth Marsh Sediment (mm)/Time (yr)}$$

## Grain Size Analysis

Grain size analysis allows for the identification particle size in sediment samples, often categorized into sand, silt, and clay. In a depositional environment like the salt marsh at Seal Beach, small particles such as silt and clay tend to make up the dominant portion of mineral material. These particles can remain suspended in water for longer periods of time, and only settle in low-energy environments. Larger particles, like sand, are indicative of higher-energy water movement and are often associated with higher wave action, storm, tsunami, or other disturbances in the marsh environment.

Additionally, sediment grain size has an impact on plant growth and marsh stability. For this reason, an understanding of historic salt marsh grain size will serve as a baseline understanding of not only depositional conditions at Seal Beach, but also environmental tolerances for salt marsh plant species such as *Spartina alterniflora* and *Salicornia pacifica*. Ideally, grain size added during thin layer sediment application to increase elevation should be similar to grain sizes seen in the past to mimic natural salt marsh conditions and promote plant growth.

For these reasons, grain size analysis of long-term sediment cores was determined to be a much needed addition to the original proposal. To accurately represent both study sites, three sediment cores were selected from each site in an approximate transect across the site [see Fig. 3 & 4 for exact core locations]. These three cores were also chosen to be those which had high-resolution radiometric dating previously conducted and would return the longest temporal record of grain size changes.

Sampling strategy aimed to maximize the temporal resolution in the top 1 m (approximately 100-300 ybp). Above 1m depth, a sample was taken every 2 cm; below 1m depth, samples were extracted every 5 cm. A total of 280 samples in total were successfully analyzed.

Samples were approximately 0.5 $cm^3$ when extracted. They were boiled with 25-30 mL of 30% $H_2O_2$, until reactivity ceased, indicating full removal of organic particles. Samples were then transferred to vials which were transported to California State University Fullerton to the Paleoclimatology and Paleotsunami Laboratory, where they were analyzed using a Malvern Mastersizer 2000 Laser Diffraction Particle Size Analyzer coupled to a Hydro 2000G large-volume sample dispersion unit. Laboratory procedures are further explained in Kirby et al. (2015). Particle sizes were classified as sand, silt, or clay based on the Wentworth scale.

Results were plotted using Bayesian age-depth models obtained from R software Bacon (Maarten Blaauw, 2010) where possible. For those sections of core which were analyzed for grain size, but were below the lowest $^{14}C$ date obtained (or were from a core not $^{14}C$ dated, as in the case of samples from SB15-21), a linear age-depth model was extrapolated by obtaining the average sediment accumulation rate over the Bayesian model (2.1 mm $yr^{-1}$ for SB15-09; 1.9 mm $yr^{-1}$ for SB15-11; 1.7 mm $yr^{-1}$ for SB15-20) or using the $^{137}Cs$-obtained accretion rate (2.5 mm $yr^{-1}$ for SB15-21). For sediment cores with an age-depth model, the last modeled age was used to start the linear extrapolation. Areas with a linear age-depth assumption are indicated in Fig. 8 with vertical shading.

## Carbon Stock and Sequestration

Determination of carbon content is calculated using the direct relationship between organic matter (OM) – from loss on ignition (LOI) – and carbon content (Craft, Seneca, & Broome, 1991). For LOI, a 1 $cm^3$ subsample extracted from each cm down to at least 100 cm depth, weighed, dried for bulk density (BD, g $cm^{-3}$), and fired in a 550°C furnace for 4 hours, resulting in OM (g $cm^{-3}$) (Heiri, Lotter, & Lemcke, 2001). See Equation 2 for the conversion between OM to carbon content.

*Equation 2*

$$Carbon\ Content\ (g\ cm^{-3}) = (0.40 \pm 0.01)OM + (0.0025 \pm 0.0003)OM^2$$

To tailor the relationship between carbon content and OM to California tidal marshes, we compared results from our LOI data with direct carbon content measurements for a subset of samples. The preliminary regression using our own data [Equation 3] varies slightly from the regression presented in Craft et al. (1991).

*Equation 3*

$$Carbon\ Content\ (g\ cm^{-3}) = (4.07)OM + (0.26)OM^2 + 0.50$$

With mass estimates from LOI and accretion rate estimates from age-depth modeling, the rate of carbon sequestration can be measured. Using BD, estimated carbon mass accumulation, and the age model, carbon sequestration rates (g C $m^{-2}$ $yr^{-1}$) are calculated [Equation 4] with both direct linear age-modeling (for cores with only $^{137}Cs$ and $^{210}Pb$ dating) and Bayesian age models (for cores with $^{14}C$ dates).

*Equation 4*

$$g\ C\ m^{-2} yr^{-1} = \frac{BD \times OM \times Accretion\ Rate}{0.0001}$$

## Foraminifera Transfer Function

A more complete summary of laboratory and statistical analysis of foraminifera data can be found in Avnaim-Katav et al. (2017). Foraminifera samples were dyed with rose Bengal to separate live from dead specimens. Samples were sieved and split using a wet splitter into countable units for taxonomic identification. Multivariate statistical analysis was used to identify clusters of homogenous fauna zones and test which of the environmental parameters (elevation, vegetation, salinity, DO, pH, temperature, bulk density, grain size, or organic content) caused a faunal response. These result were used to develop what is known as a transfer function, or ecological response function, which would predict habitat elevation based on foraminiferal assemblage. Results from Seal Beach sampling were combined with samples collected at Tijuana River Estuary for the final transfer function presented in Avnaim-Katav et al. (2017).

# Results

## Chronological Control

### Radiocarbon

Results from the 16 samples analyzed for $^{14}C$ returned a maximum age of 1539±71 YBP for a 2 m core taken in the augmentation site. The youngest date returned was a 1 m core from the control site which was approximate 380 ±78 YBP. By taking an average of long term accretion rates from $^{14}C$ dates (calculated using Eq. 1), estimated average sediment accretion at Seal Beach NWR is 1.55 ± 0.16 mm $yr^{-1}$, which is typical for accretion rate measurements obtained from $^{14}C$-dating in North American salt marshes, especially those on the Pacific Coast. These accretion rates are, however, low in comparison with accretion rates obtained from $^{137}Cs$, $^{210}Pb$, or modern monitoring methods such as feldspar marker horizons. This is due to the time span that analysis covers. Natural processes such as subsidence and organic decay which make these rates of accretion an underestimate of current rates, and therefore unsuitable for comparison use in modern ecosystem monitoring.

$^{14}C$ dates were critical in the establishment of age-depth models. A Bayesian model was produced for all sediment cores which have been $^{14}C$ dated. These models were used to plot grain size data by time across multiple cores.

### Radiocesium and Radiolead

Average $^{137}Cs$- and $^{210}Pb$-measured accretion for all cores was 3.2 ± .21 mm $yr^{-1}$, with average $^{137}Cs$-measurements showing slightly higher accretions rates (3.2 ± .28 mm $yr^{-1}$) compared to $^{210}Pb$-measurments (3.1 ± .33 mm $yr^{-1}$) [Table 3]. Variation in accretion rates between control and augmentation for all methods was consistently 0.5 – 1 mm $yr^{-1}$, and only significant (mean falling >2 standard errors) using $^{210}Pb$ methods, with the control site's average accretion ~ 1 mm $yr^{-1}$ higher than the accretion rate at the augmentation site (Fig. 7). The consistency between the sites indicates that these sites are suitable for comparison between vertical accretion as the augmentation study progresses.

These accretion rates are fairly typical, if on the low end, for North American salt marshes, which can see vertical accretion anywhere from 1 mm $yr^{-1-}$ to 10s of mm a year in high-accreting zones (Kirwan, Temmerman, Skeehan, Guntenspergen, & Fagherazzi, 2016). Because Seal Beach is cut off from freshwater input, all accretion must be from additions of marine sediment, intra-marsh redistribution of mineral material, or organic input. The Mediterranean climate of Southern California means precipitation and stream flow tend to be intermittent. It is possible that the accretion rates seen at Seal Beach do not show variation from rates found at other marshes, such as Tijuana River Estuary, as mineral input from terrestrial sources occupies a fairly small portion of the overall accretion budget in this climate.

## Grain Size Analysis

Grain size analysis was completed on six cores (three from the control site and three from the augmentation site), at 2 – 5 cm resolution for a total of 280 samples. Results show that grain size at the top 5 cm of the cores averages at 11% clay, 77% silt, and 10% sand. Grain size is fairly consistent across cores and between the augmentation and control sites [Fig. 8]. Maximum sand percentage in any sample analyzed was 76%, but these high levels of sand occur only in small lenses or below 1 m in depth where habitat may or may not have been salt marsh as it is today.

The above results compare to post-augmentation grain size measurement taken from Feb – Jun 2016 which averaged 9% clay, 11% silt, and 80% sand. These results show that sand concentration post augmentation greatly exceeds sand concentrations at the top of the cores in both the control and augmentation sites (pre-augmentation), as well as exceeds any sand concentration obtained in analysis of

all cores covering a history of 1500 years of accretion. While the disparity between augmentation grain size and natural grain size is concerning, this record of rapid environmental change demonstrates a potential capacity for recovery.

By plotting the grain size results by age, we can estimate that the lenses seen in cores SB15-09, 11, and 20 are an event previously identified as an abrupt subsidence event due to a tectonic event caused by the nearby Newport-Inglewood/Rose Canyon fault system (Leeper et al., 2017). Leeper et al. identify this even as having occurred from approximately 1320 AD to 1590 AD. This matches the increase in larger particle sediment seen at approximately 1450 AD in the three cores identified above. It is also possible that the lens seen in SB15-21 corresponds to this event, but because it is lacking a Bayesian age-depth model the linear age-depth model underestimates the age of this event (very probable, as accumulation rate tend to decrease with depth so using $^{137}$Cs-based accumulation rates tends to underestimate age below the cesium peak). Further $^{14}$C dates around this area would resolve this question.

However, of particular interest to the thin-layer sediment application study, it is important to note that according to the long-term grain size record obtained in this analysis, changes between a sand-dominated grain size environment and a silt-clay dominated grain size environment have occurred in the past on estimated timescales of 10 – 30 years. This indicates that although the applied augmentation sediment has a very different composition from the natural sediment seen in this record, the potential for recovery to a more typical state exists.

## Carbon

### Stock

Loss-on-ignition (LOI) was completed for all cores dated with $^{14}$C, $^{137}$Cs, and $^{210}$Pb to a depth of 100 cm. Using the conversion from LOI to estimated carbon content from Equation 3, carbon content was calculated for each cm of core to 100 cm depth for both the control and augmentation sites (pre-augmentation).

Taking the mean carbon storage for all samples tested, 0.02 g carbon cm$^{-3}$ (range: 0.0067 – 1.01 g carbon cm$^{-3}$) an estimate of total carbon storage for the top 1 m of the 390 ha salt marsh area at Seal Beach of 73,537 ± 6,635 tonnes of carbon. Using California's market price for carbon of \$15.17 / $CO_2$e (obtained 10 January 2018), this puts the estimated ecosystem service value of carbon storage at Seal Beach at 1.11 million dollars. This estimate is very likely an underestimate, as assuming a carbon storage pool of only 1 m does not account for areas of Seal Beach which likely have multiple meters of carbon storage. Based on minimum and maximum values of carbon storage seen in data from this study, value estimates vary from \$0.4m to \$6 m.

### Sequestration

The site-wide average CAR is 116.8 ± 1.6 g C m$^{-2}$ yr$^{-1}$ , consistent with rates of carbon sequestration in coastal salt marshes in California of ~100 g C m$^{-2}$ yr$^{-1}$ and global averages of approximately 220 g C m$^{-2}$ yr$^{-1}$ (Chmura, Anisfeld, Cahoon, & Lynch, 2003; Ouyang & Lee, 2014). Carbon content and sequestration are fairly consistent between control and augmentation sites, with only slightly higher carbon content in the top of the cores of the control site.

Using the estimated average CAR, approximately 456.3 tonnes of carbon are added to the 390 ha of salt marsh at Seal Beach each year. An exchange value of \$15.17 per tonne $CO_2$e indicates that yearly carbon storage at Seal Beach can be valued at \$6,922. Based on minimum and maximum levels of sequestration calculated from this data, this value could range from \$3k to \$16k.

## Foraminifera Transfer Function

This work resulted in the successful creation of a Southern California marsh transfer function for foraminiferal analysis. A robust relationship between elevation and foraminifera assemblage was seen, and can be used to reconstruct paleo-sea-levels using foraminiferal proxies with a precision of ± 0.09 m (Avnaim-Katav et al., 2017).

# Tables

*Table 1 – Core List*

Cores Taken, GPS Locations in Decimal Degrees, and Depths

| | Core Name | Site Location | Latitude (dd) | Longitude (dd) | Depth (cm) |
|---|---|---|---|---|---|
| *1* | SB15-06 | Control | 33.73495 | -118.0837 | 100 |
| *2* | SB15-07 | Control | 33.73535 | -118.0827333 | 200 |
| *3* | SB15-08 | Control | 33.73475 | -118.0831333 | 100 |
| *4* | SB15-09 | Control | 33.7359167 | -118.0822667 | 200 |
| *5* | SB15-10 | Control | 33.7355667 | -118.0824 | 200 |
| *6* | SB15-11 | Control | 33.7351833 | -118.0826667 | 181 |
| *7* | SB15-12 | Augmentation | 33.73684 | -118.07822 | 100* |
| *8* | SB15-13 | Augmentation | 33.73707 | -118.07771 | 100* |
| *9* | SB15-14 | Augmentation | 33.73672 | -118.0776 | 200* |
| *10* | SB15-15 | Augmentation | 33.73621 | -118.07757 | 100* |
| *11* | SB15-16 | Augmentation | 33.73655 | -118.07844 | 100* |
| *12* | SB15-17 | Augmentation | 33.73607 | -118.07807 | 100* |
| *13* | SB15-18 | Augmentation | 33.73624 | -118.0787 | 100* |
| *14* | SB15-19 | Augmentation | 33.7359 | -118.0785833 | 200* |
| *15* | SB15-20 | Augmentation | 33.73545 | -118.0785333 | 238 |
| *16* | SB15-21 | Augmentation | 33.7356 | -118.07954 | 210 |
| *17* | SB15-22 | Augmentation | 33.73623 | -118.0796 | 100 |
| *18* | SB15-23 | Augmentation | 33.73609 | -118.07856 | 100 |

*Table 2 – Calibrated $^{14}C$ Results*

| Core | Depth (cm) | 14C Age (BP) Uncalibrated | Error (BP) | Age (YBP) | Error (YBP) | Core |
|---|---|---|---|---|---|---|
| SB15-06 | 99 | 340 | 15 | 380 | 78 | SB15-06 |
| SB15-09 | 110 | 995 | 20 | 931 | 27 | SB15-09 |
| SB15-10 | 171 | 1440 | 15 | 1329 | 27 | SB15-10 |
| SB15-11 | 110 | 1060 | 15 | 956 | 25 | SB15-11 |
| SB15-11* | 174 | 870 | 40 | 781 | 106 | SB15-11* |
| SB15-14 | 104 | 900 | 20 | 876.5 | 32 | SB15-14 |
| SB15-14 | 107 | 1025 | 15 | 943 | 17 | SB15-14 |
| SB15-16 | 91 | 925 | 15 | 875.5 | 36 | SB15-16 |
| SB15-18 | 97 | 810 | 15 | 713 | 25 | SB15-18 |
| SB15-19 | 102 | 1065 | 15 | 957.5 | 26 | SB15-19 |
| SB15-19 | 198 | 1630 | 15 | 1539 | 71 | SB15-19 |

| | | | | | | |
|---|---|---|---|---|---|---|
| SB15-20 | 101 | 865 | 20 | 776 | 83 | SB15-20 |
| SB15-20 | 166 | 1620 | 60 | 1502 | 126 | SB15-20 |
| SB15-20* | 206 | 640 | 15 | 589 | 50 | SB15-20* |
| SB15-23 | 130 | 620 | 15 | 598 | 50 | SB15-23 |
| SB15-23 | 169 | 1505 | 15 | 1139 | 144 | SB15-23 |

* Age reversal, possible error

*Table 3 – Accretion from $^{137}Cs$ and $^{210}Pb$*

| Site | Core | 137Cs | ± | 210Pb | ± |
|---|---|---|---|---|---|
| Control | SB15-06 | 3.6 | 0.9 | 3.2 | 0.6 |
| Control | SB15-09 | 4.4 | 1.1 | 2.3 | 0.3 |
| Control | SB15-11 | 2.9 | 0.8 | 2 | 0.3 |
| Augmentation | SB15-14 | 3.6 | 0.8 | 4.4 | 2 |
| Augmentation | SB15-16 | 2.1 | 0.07 | 4 | 1.3 |
| Augmentation | SB15-20 | 3.6 | 0.8 | 3.3 | 0.8 |
| Augmentation | SB15-21 | 2.9 | 0.8 | 2.5 | 0.9 |

# Figures

*Figure 1 – Locations  Cores in Control and Augmentation Sites*

*Figure 2 – Map of Foraminifera Transect*

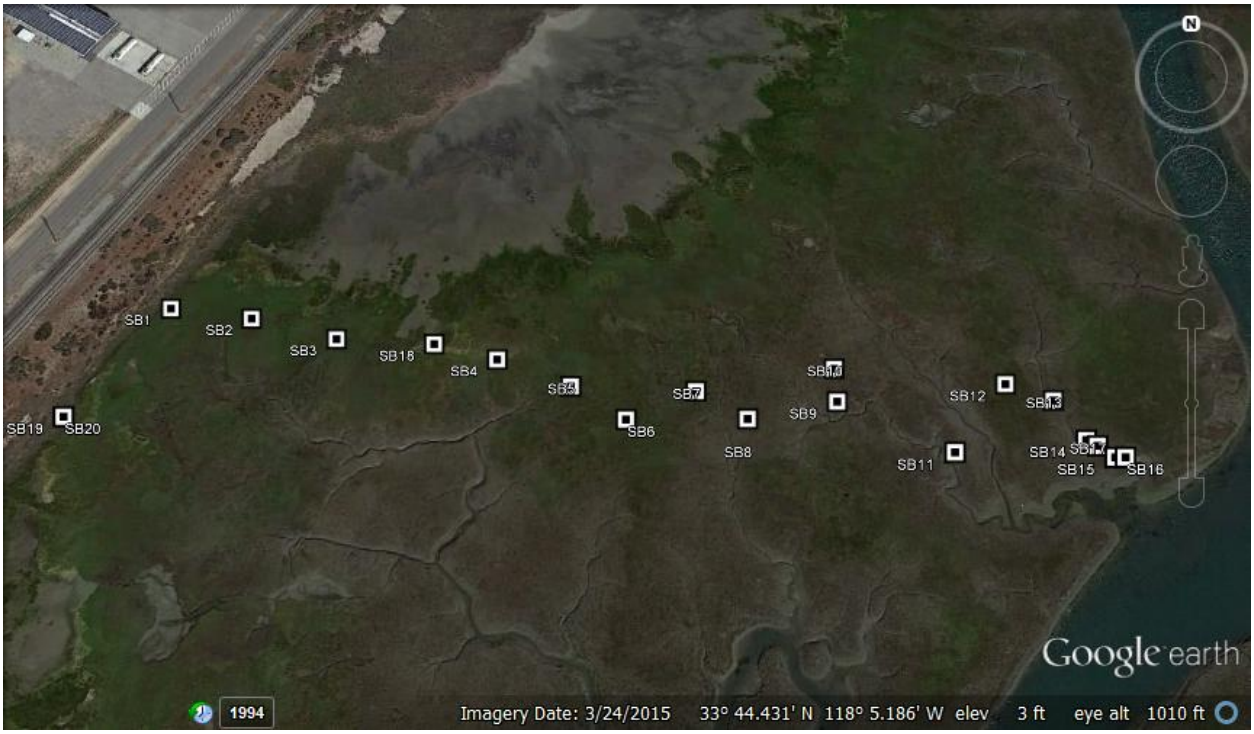


*Figure 3 – Stratigraphy Diagram: Control*

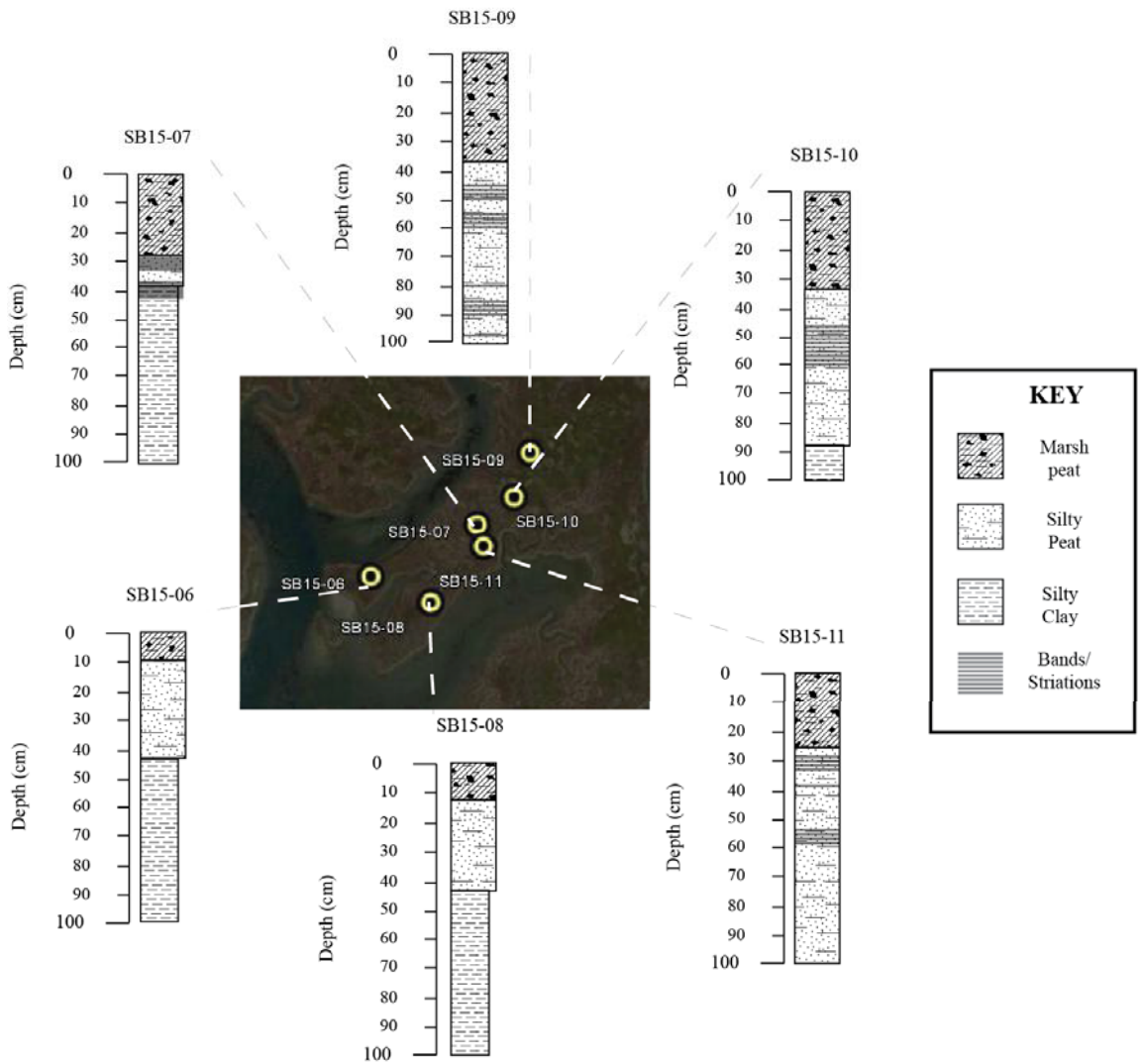



*Figure 4 –*

*Stratigraphy Diagram: Augmentation Site*

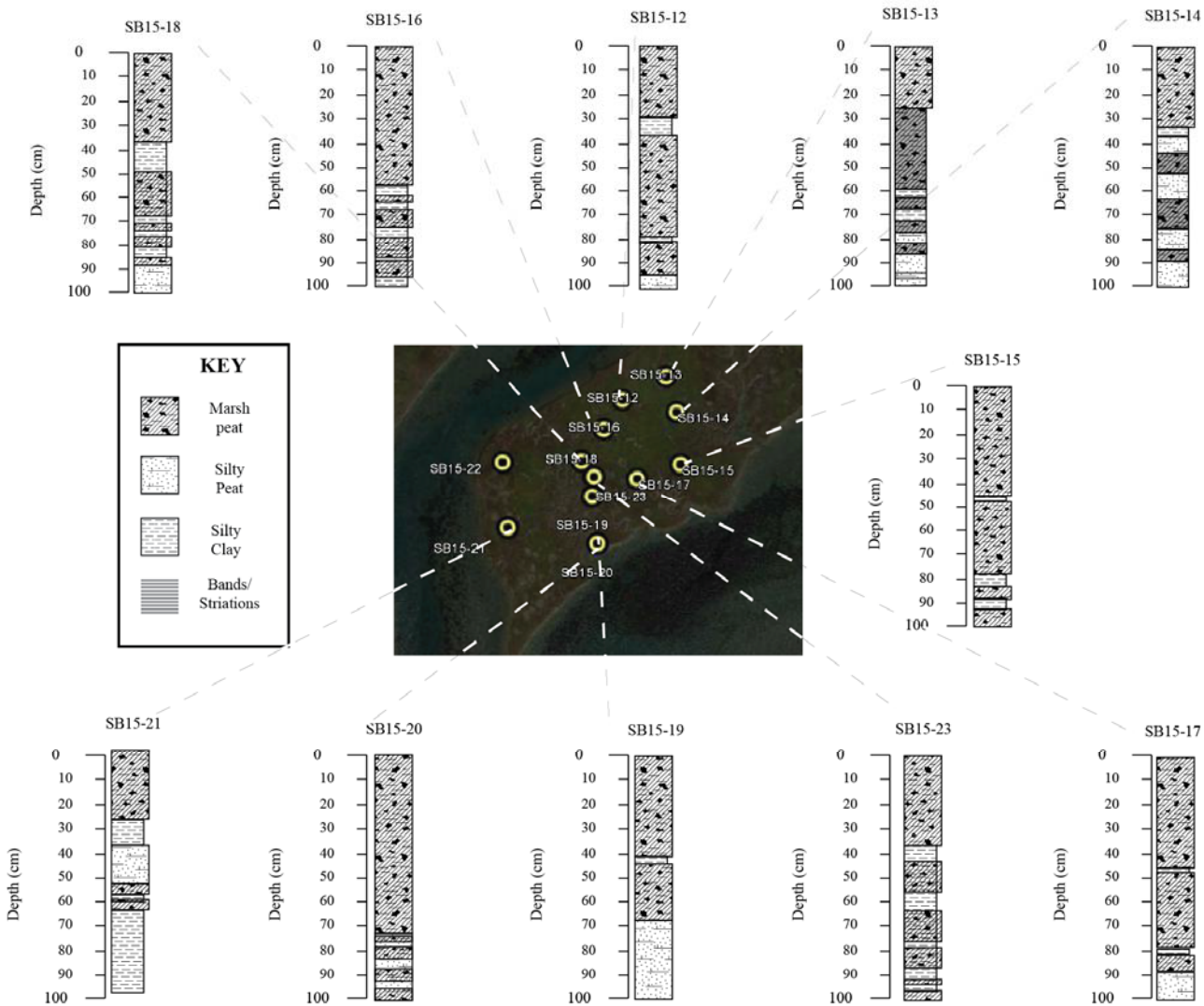



*Figure 5 – Magnetic Susceptibility*

*Profiles*

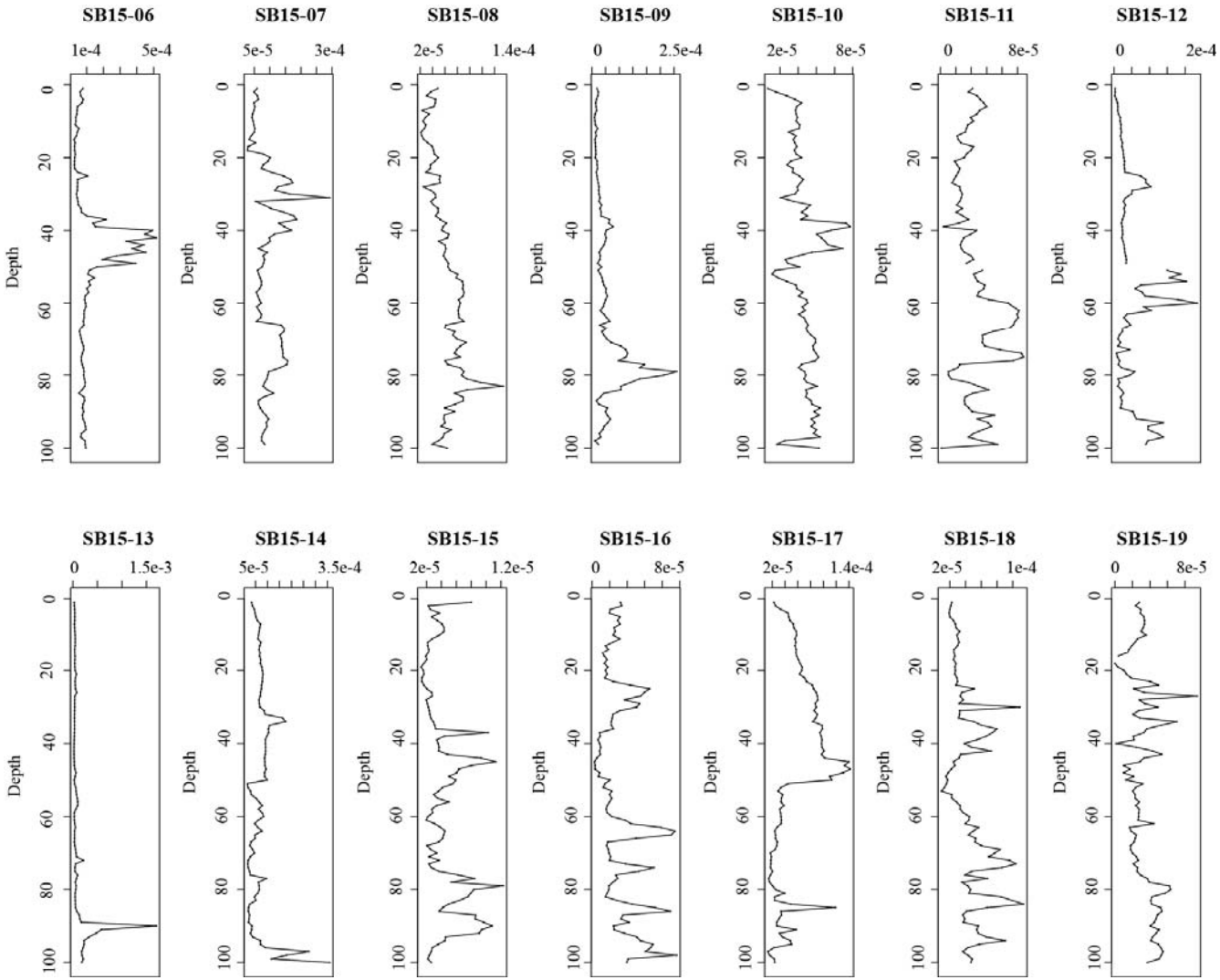

SB15-06
1e-4
5e-4
SB15-07
5e-5
3e-4
SB15-08
2e-5
1.4e-4
SB15-09
0
2.5e-4
SB15-10
2e-5
8e-5
SB15-11
0
8e-5
SB15-12
0
2e-4
SB15-13
0
1.5e-3
SB15-14
5e-5
3.5e-4
SB15-15
2e-5
1.2e-5
SB15-16
0
8e-5
SB15-17
2e-5
1.4e-4
SB15-18
2e-5
1e-4
SB15-19
0
8e-5
Depth
0
20
40
60
80
100

*Figure 6 – $^{137}$Cs and $^{210}$Pb Age Depth Models*

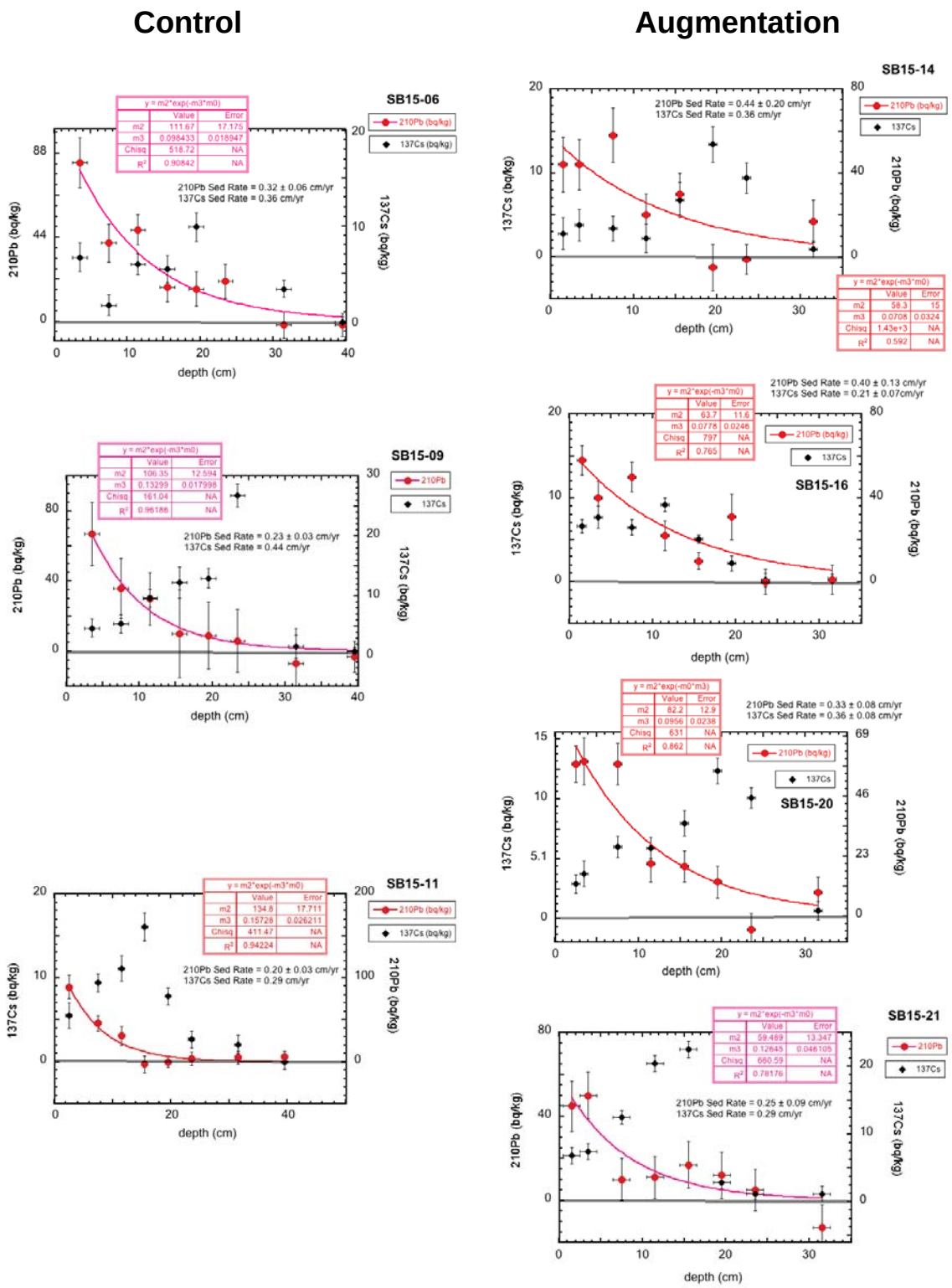



*Figure 7 – Accretion Rates for Control and Augmentation Site by Method*

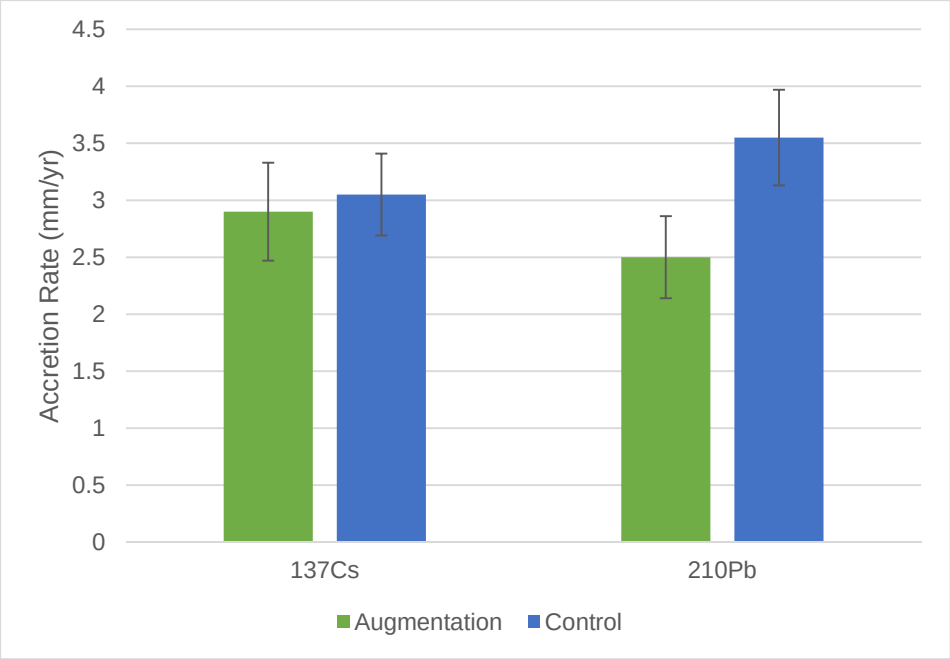
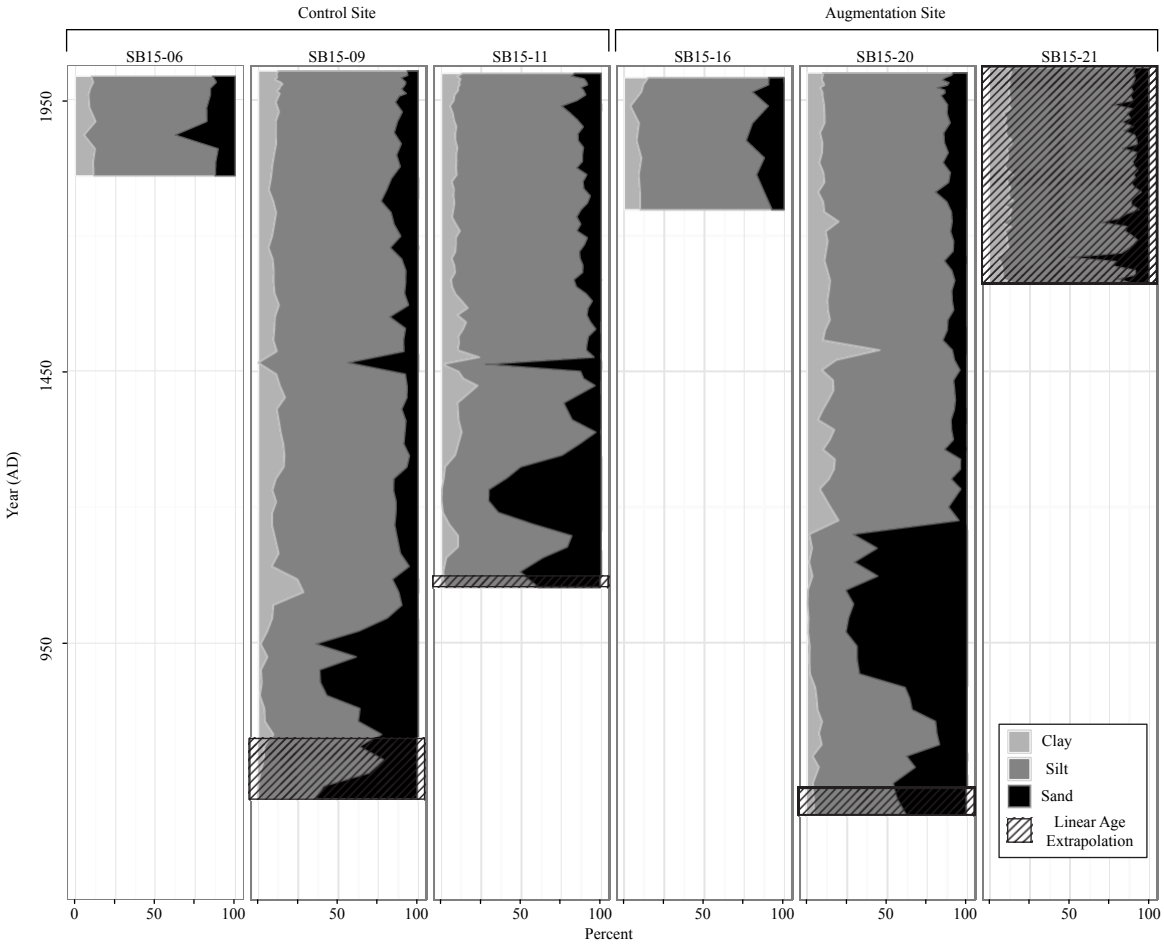

4.5
4
3.5
3
2.5
2
1.5
1
0.5
0
Accretion Rate (mm/yr)
137Cs
210Pb
Augmentation
Control

*Figure 8 - Grain Size Analysis by Time*



s

*Figure 9 – Carbon Sequestration in the Control Site*

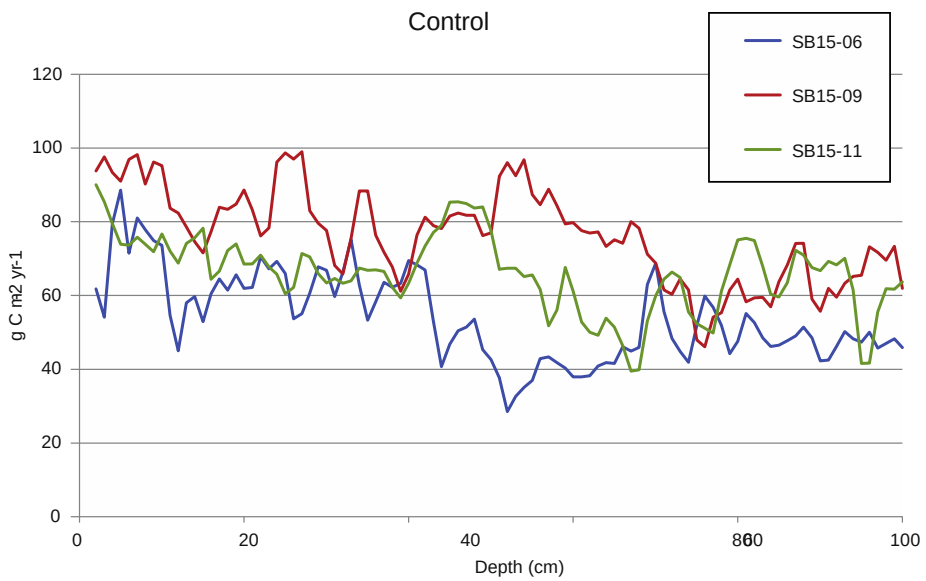
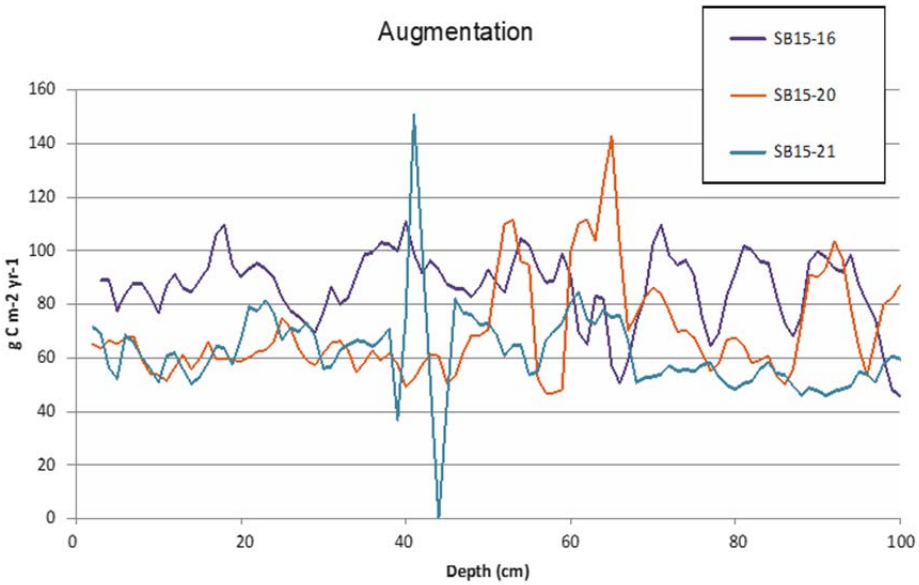


*Figure 10 - Carbon Sequestration in the Augmentation Site*

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# Attachment 3

Thin-Layer Sediment Application Pilot Project at

Seal Beach National Wildlife Refuge:

Oct 1 – Dec 31, 2017

QUARTERLY PROGRESS REPORT

# Thin-Layer Sediment Application Pilot Project at Seal Beach National Wildlife Refuge: Oct 1 – Dec 31, 2017

## QUARTERLY PROGRESS REPORT

January 10, 2018

**Principle Contact**: Dr. Karen M. Thorne[1], 916-502-2996, kthorne@usgs.gov

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Pickleweed growing into the SET SBA1 plot Area

**Summary**

- Monitoring of surface elevations continued at the augmentation site and the control site, while monitoring of sediment fluxes was ended in August of 2017 at both the sites, adjacent to the control site (deep channel site) and near the augmentation site (eelgrass site).
- Using Surface Elevation Tables (SETs) an initial surface elevation loss has been documented at the Augmentation SETs, presumably from a combination of compaction of the marsh platform and sediment being suspended during high tides and leaving the marsh.
- Surface elevation tables were measured during a November 11$^{th}$ 2017 site visit for this quarterly report time period.
- Elevation pin measurements showed that the augmentation site continued a gradual decrease in elevation dropping on average -3.84 mm across all fifteen SETs. However the control site showed a small increase of 1.65 mm across its six SETs. The original SETs (n=4) also showed an increase of 2.49 mm (Figure 1).
- Control SETs have had increase and losses of elevation since installation, but has a mean cumulative increase of 455 mm in elevation from the date of installation (Figure 2). Augmentation SETs had a mean increase in elevation of 216 mm with sediment application, but had a decrease in elevation of -81.25 mm post sediment application (April 2016-November 2017; Figure 1).
- The feldspar readings showed a larger decrease in sediment above the feldspar layer than the pin measurements for the augmentation site with a decrease of -27.40 mm. However, this is most likely due to large decreases in elevation at

platforms 2 and 4. Platforms 14 and 15 are excluded from the average since the feldspar layer is still too deep to get a reading.

- Feldspar readings at the control site showed a small decrease of -0.92 mm, whereas the original SETs showed an average increase of 4.74 mm.
- Taking into account the time period we can look at this raw data as a rate of change over time to better see the trends in the data. Currently the augmentation marsh has 62.41 mm/yr rate of change due to the sediment application. However, due to subsidence or sediment leaving the marsh the post augmentation time period has a -43.16 mm/yr rate of change. Whereas, the control site has a 1.98 mm/yr rate of change and the original SETs have a 1.90 mm/yr rate of change (Figures 2-4). These trends are similar for the feldspar data.

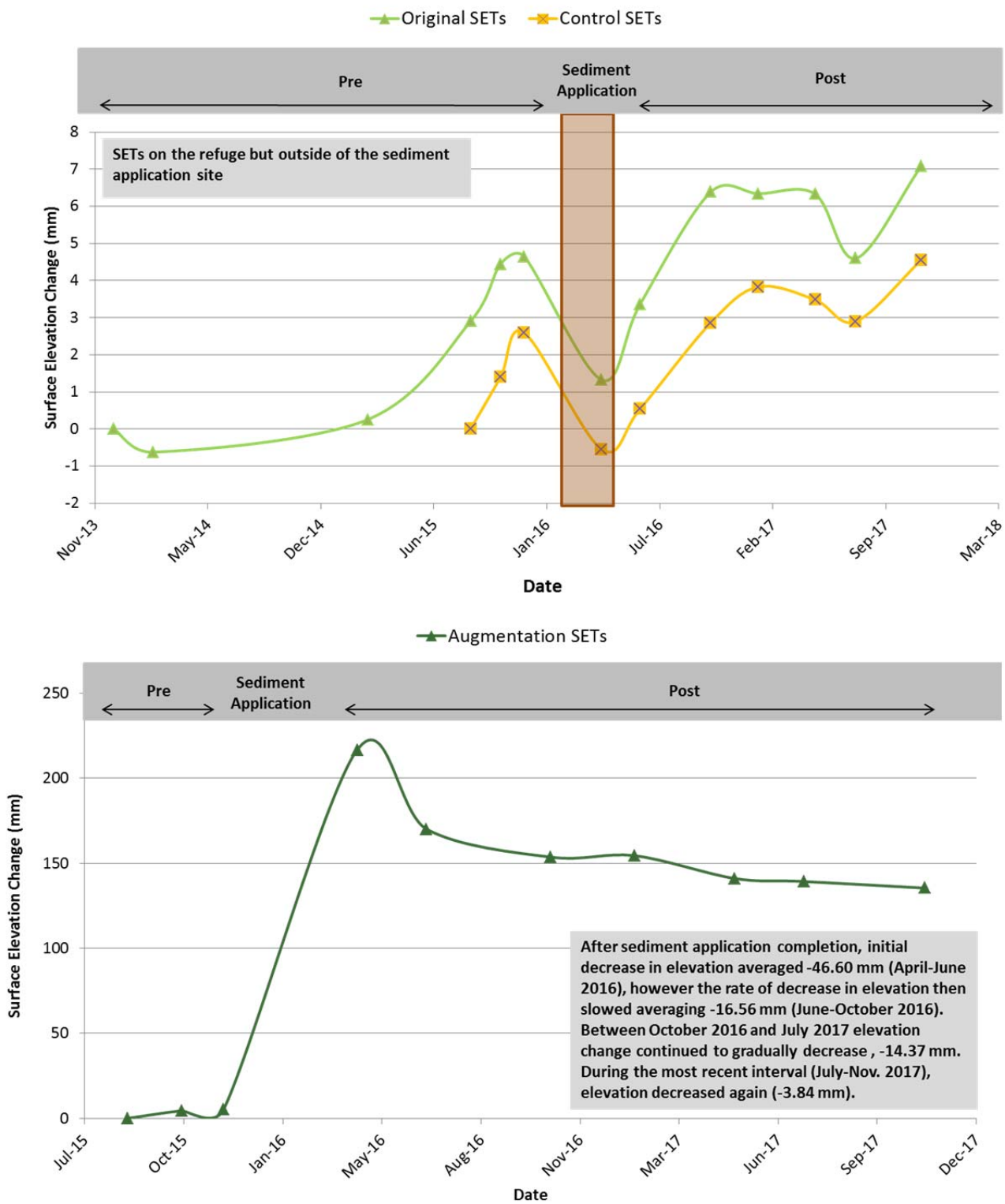


**Figure 1.** Mean surface elevation change at control site (above) and augmentation site (below).

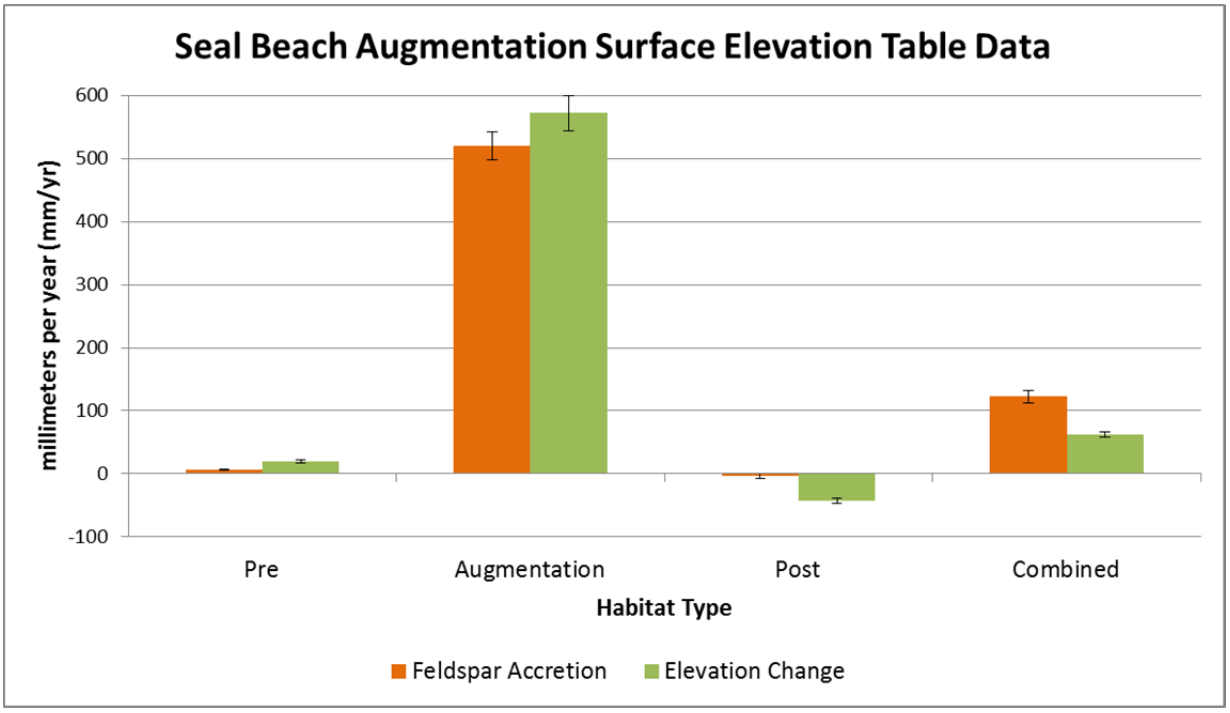


**Figure 2.** Sediment augmentation site rates of change in millimeter per year (mm/yr) calculated from pin measurements (elevation change) and feldspar measurements (feldspar accretion) for different time periods of the augmentation project.

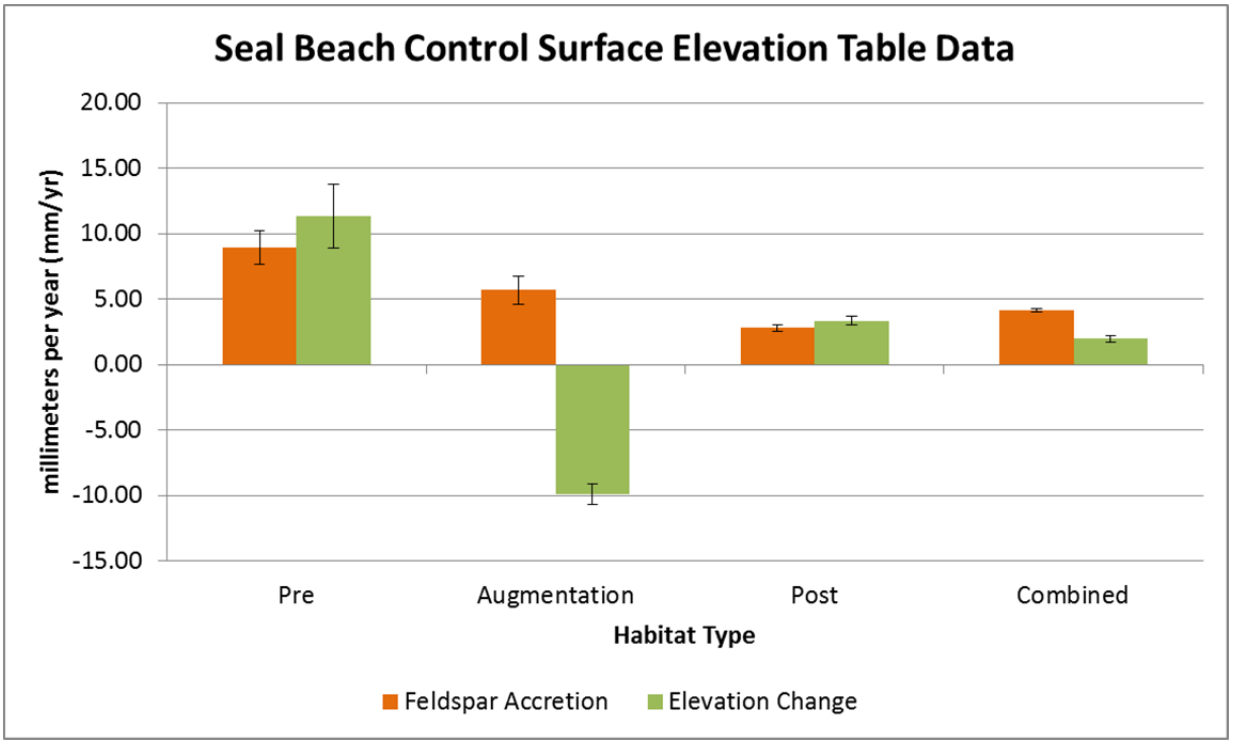


**Figure 3.** Control site rates of change in millimeter per year (mm/yr) calculated from pin measurements (elevation change) and feldspar measurements (feldspar accretion) for different time periods of the augmentation project.

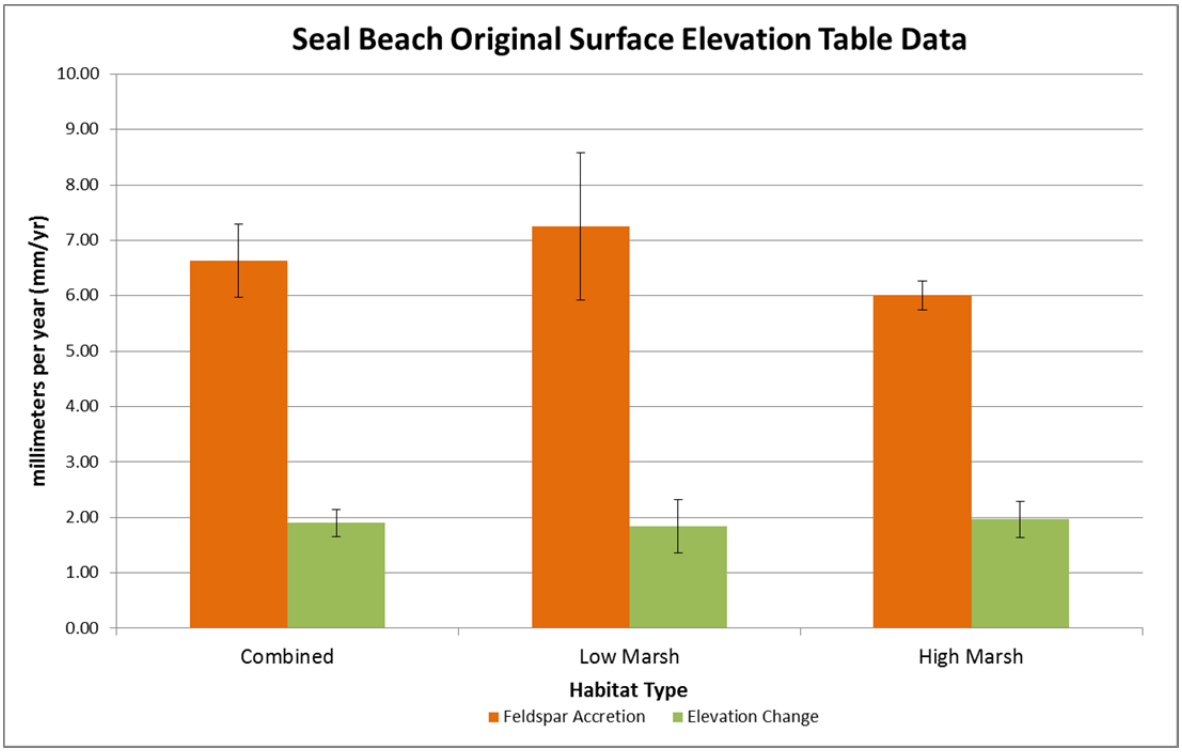


**Figure 4.** Original Seal Beach SETs rates of change in millimeter per year (mm/yr) calculated from pin measurements (elevation change) and feldspar measurements (feldspar accretion).