San Francisco Bay Living Shorelines: Near-shore Linkages Project:

Progress and Preliminary Results

Report submitted to the San Francisco Estuary Partnership for EPA Water Quality Improvement Fund Phase II

Covering Activities September 2012- September 2013

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Table of Contents

Introduction

Brief Project Summary

The San Francisco Bay Living Shorelines: Near-shore Linkages Project is a multi-objective habitat restoration pilot project managed by the State Coastal Conservancy, in collaboration with biological and physical scientists with San Francisco State University, University of California, Davis, USGS Western Ecological Research Center, and consultants at ENVIRON Corp., Isla Arena Consulting, and ESA PWA. The basic goals are described below, and more fully described in the January 2012 final design document. The project was fully permitted in July 2012, and constructed over a three week window in July-August 2012.

General Concept

In general, Living Shorelines projects utilize a suite of bank stabilization and habitat restoration techniques to reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting, restoring, enhancing, and creating natural habitat for fish and aquatic plants and wildlife. The term “Living Shorelines” was coined because these techniques provide living space for estuarine and coastal organisms, which is accomplished via the strategic placement of native vegetation, natural materials, and reinforcing rock or shell for native shellfish settlement. The approach has been implemented primarily on the East and Gulf Coasts, where such techniques enhance habitat values and increase connectivity of wetlands and deeper intertidal and subtidal lands, while providing a measure of shoreline protection.

Living Shorelines in San Francisco Bay

While not a new concept, Living Shorelines projects are new to San Francisco Bay, where pilot restoration work on eelgrass and oyster reefs has recently led to recommendations for additional experimental testing of techniques and gradual scaling up to larger projects. The ***2010 San Francisco Bay Subtidal Habitat Goals Report*** (see www.sfbaysubtidal.org) recommended that the next generation of projects consider the possibility of integrating multiple habitat types to improve linkages among habitats and promote potential synergistic effects of different habitat features on each other as well as associated fauna. Such habitat features, if scaled up slightly beyond previous projects would have the potential to positively influence physical processes (such as sediment erosion and accretion) that influence shoreline configuration.

We have assembled an interdisciplinary team to build on previous restoration lessons and move toward integrating multiple habitats in the “San Francisco Bay Living Shorelines: Near-shore Linkages Project”. The project will further test subtidal restoration techniques, restore critical eelgrass and oyster habitat, test the individual and interactive effects of restoration techniques on habitat values, begin to evaluate connectivity between submerged areas and adjacent tidal wetlands and creeks, and test alternatives to hard/structural stabilization in a multi-objective project. Due to limited historical information on distribution and abundance of native oysters and eelgrass, we use the term “restoration” in the sense of enhancing valuable functions and services promoted by these types of features in SF Bay and elsewhere, rather than in the strict sense of replacing previously known distributions or extent.

Potential Climate Change Adaptation Approach

In addition, in developing the California (State Resources Agency) Climate Change Adaptation Strategy, state agencies have recommended the use of Living Shorelines as a potential adaptation method to reduce the need for engineered hard shoreline protection devices and to provide habitat functions and values. The State Coastal Conservancy Climate Change Policy also recommends implementation of Living Shorelines due to their ability to reduce erosion and trap sediment, allowing for both buffering of tidal wetlands and migration of habitats (“estuary rollover) – towards a goal of stronger estuarine habitat resiliency in the future due to sea level rise and other climate change related projections.

Overarching Goal

To create biologically rich and diverse subtidal and low intertidal habitats, including eelgrass and oyster reefs, as part of a self-sustaining estuary system that restores ecological function and is resilient to changing environmental conditions.

Objectives

1) Use a pilot-scale, experimental approach to establish native oysters and eelgrass at multiple locations in San Francisco Bay.

2) Compare the effectiveness of different restoration treatments in establishing these habitat-forming species.

3) Determine the extent to which restoration treatments enhance habitat for invertebrates, fish, and birds, relative to areas lacking structure and pre-treatment conditions.

4) Determine if the type of treatment (e.g., oyster reefs, eelgrass plantings, or combinations of oyster reefs and eelgrass) influences habitat values differently.

5) Begin to evaluate potential for subtidal restoration to enhance functioning of nearby intertidal mudflat, creek, and marsh habitats, e.g., by providing food resources to species that move among habitats.

6) Evaluate potential for living subtidal features to reduce water flow velocities, attenuate waves, and increase sedimentation, and assess whether different restoration treatments influence physical processes differently.

7) Determine if position in the Bay, and the specific environmental context at that location, influences foundational species establishment, habitat provision, and physical processes conferred by restoration treatments.

8) Where possible, compare the ability to establish restoration treatments, habitat functions, and physical changes along mudflats/wetlands versus armored shores.

Two Sites: San Rafael (site owned by The Nature Conservancy) and Hayward (site owned by California Department of Fish and Wildlife)

We identified two locations within the Bay that would meet our most important site selection criteria, and thus should allow us to meet many of our objectives. In 2012, we constructed one of the project sites along a portion of the San Rafael shoreline on property owned by The Nature Conservancy for a majority of our work. Hereafter, we refer to this property as **TNC**. In addition, we utilized a location offshore of Eden Landing Ecological Reserve, just south of the San Mateo Bridge on the east side of the Bay, hereafter referred to as **Eden Landing**. More detail about these sites and the surrounding watersheds, water depths, land uses, etc., are included in the final design document.

Two Experimental Designs:

Pacific Shell Bag Mounds- Larger scale experiment *to test both biological and physical effects*. This experiment includes four 32 x 10m treatment plots situated parallel to the shore, approximately 200 m from shore. This design allows us to compare the effects of Pacific oyster shell bags, eelgrass, and both together, in comparison to a control of the same size. We designed this experiment to be at a large enough scale to compare effects on physical factors such as wave attenuation and accretion as well as effects on biological properties that operate at larger scales (e.g., bird and fish utilization, water quality interactions of oysters and eelgrass). The large experiment is at the TNC site only.

"Baycrete Substrate element"- Smaller scale experiment *to examine small-scale biological effects*. This experiment consists of replicate 1x1 m substrate elements of different substrate types, intended to compare native oyster recruitment and growth parameters to inform future restoration projects. At TNC in 2012, this experiment was set up in the 30-m spaces between and on either side of the line of larger scale plots described above. At TNC, four oyster substrate types not tested in the large scale experiment (reef balls, mini reef ball stacks, layer cakes, and oyster blocks) will be replicated 5 times, for a total of 20 elements. These elements will be placed in groups (blocks) of four, with each of the four substrate types represented in each block.

A substrate element experiment will be the only project installed at Eden Landing in 2012. This is similar to that described for TNC in that it includes 1x1 m substrate elements replicated in 5 blocks and aligned parallel with the shoreline at ~200 m from shore. However, at Eden Landing, there are 5 substrate types: the 4 tested in the TNC substrate element experiment, plus the substrate type used in the larger scale project at TNC (oyster shell bags). In addition, there are 5 replicate 1x1m plots of eelgrass planted, one in each block, as well as a treatment that includes one of the oyster substrate types along with eelgrass planted directly adjacent to it. More detail about these designs is included in the final design document.

Executive Summary
Year One Monitoring Results (September 2012- September 2013)

Native oysters and invertebrate habitat

Oyster recruitment, growth and survival to date at the San Rafael site are very high, with densities at 1000-3000 oysters per m^2 on the "baycrete" elements and 10-16 per shell in the shell bags, for an overall estimate of more than two million oysters at the site. Recruitment was significantly lower at the Hayward site, where oysters are also smaller and mortality due to the non-native oyster drill (*Urosalpinx cinerea)* predation is high. Shell bags provided habitat for numerous other organisms, including crabs, shrimp and fish. The different "baycrete" elements appear to be performing more or less equally well. Across sites, tidal heights and element types, more oysters are found at lower elevations, on north vs. south faces and vertical vs. horizontal surfaces, suggesting that ameliorating heat stress is important in promoting oyster success.

Eelgrass, epibenthic invertebrates, and fish

As eelgrass originally recruited poorly in 2012, perhaps due to planting late in the season following construction delays, we replanted in April 2013. Our July 2013 monitoring showed shoot densities at ~50% (San Rafael) or 75% (Hayward) of planted densities, suggesting eelgrass has now established well at both sites. San Rafael plant heights were comparable to those in natural eelgrass beds (~130 cm), while plants are shorter at Hayward (~70 cm), perhaps due to the shallower depth of the project there. At the San Rafael site, densities of the Point Molate donor source appeared to be higher than those from Point San Pablo, while no differences were observed between donors at Hayward. So far, there are no obvious differences in eelgrass performance (densities or heights) with presence of oyster reef in the same plot, although there was a trend of greater epiphyte biomass on eelgrass with oyster reef present at San Rafael. Further, stable isotope signatures of eelgrass may also be different with oyster reef present; however, additional analysis will be needed to determine if oyster reefs influence the nutrition of eelgrass. Trapping with minnow and oval traps indicated an increased presence of species reliant on physical structure, including bay shrimp and Dungeness crab, as early as October 2012 on the oyster reefs. These patterns persisted in April and July 2013 and additional species were trapped in plots with oyster reef and eelgrass present (red rock crabs and red crabs). Both trapping and seining results suggest that eelgrass presence increases the diversity or abundance of fish and invertebrates present on the oyster shell reefs.

Birds and benthic invertebrates

The USGS Western Ecological Research Center, San Francisco Bay Estuary Field Station conducted avian and benthic invertebrate pre- (Nov 2011-April 2012) and post- installation (September 2012 – April 2013) monitoring for the Living Shorelines Near-shore Linkages project. Our primary objective was to determine species and guild specific responses to restored habitat relative to control areas and pre- installation conditions using a Before-After Control-Impact (BACI) design. Both pre- and post- installation densities were highest at

Hayward treatment and control sites where small shorebirds predominated. Wader species increased significantly post- installation in the treatment area at Hayward. At San Rafael, densities of black oystercatcher increased significantly at treatment plots in comparison to pre- installation and control densities. Bivalves predominated at Hayward and more than doubled in the treatment area during the post-installation period. The number of unique invertebrate taxa at the San Rafael site increased from 14 representing 6 classes to 22 representing 8 classes. Our preliminary results suggest that some avian and invertebrate species may be responding to oyster and eelgrass habitat restoration; however, continued monitoring as these habitats develop will be important for understanding species responses to living shoreline restoration methodologies.

Physical parameters

Understanding changes to the physical and geomorphic processes for a project area is key to evaluating the impacts to shoreline and mudflat habitats. Waves, currents, and the resultant sediment transport will cause a geomorphic response on the shoreline and bed while the morphology of the bed will affect wave shoaling and sedimentation rates. After the installation of the "baycrete" plots at San Rafael and the Pacific shell bag plots at San Rafael in summer 2012, ESA PWA began to monitor waves, currents, sedimentation/erosion rates, substrate composition, bed stability and ambient water properties. At the Hayward Shoreline site, only settlement of the elements was monitored. Preliminary results based on 12 months of data show that:

- The elements subsided on the order of 10 cm from August to December 2012 at both locations but since January 2013, the rate of change has been negligible.
- At the San Rafael site, the waves are smaller and currents confined to a narrower dominant direction in the lee of the oyster-eelgrass reef compared to the control plot. A wave model was developed to quantify the change in wave energy under varying wave and water level conditions with and without the reef. Preliminary results show that while most energy is lost on the mudflats, the reef extracts 28% more energy than a mudflat at the same location.
- The average sediment accumulation between August 2012 and July 2013 ranges from 0-5 cm for the site but the accumulation patterns are substantially different. Sediment deposits adjacent to the reef elements are on average 15 cm thick while inside the reef units, sediment thickness is closer to 24 cm. To account for different survey methods, a range of volumes was calculated. Sediment volume accumulation inside the oyster reef plots ranges from 20-40 m^3 while the background accumulation on the mudflat at the control plot of the same size is 0-17 m^3.
- The ambient water properties of temperature, salinity, dissolved oxygen (DO), and pH do not vary greatly when compared to the nearby China Camp NERR water quality data.

Section A: Measuring oyster performance and community development on restoration substrates

This group includes UC Davis, ENVIRON Corp, and Isla Arena Consulting, who are engaged in the following monitoring activities:

1. **Measuring oyster performance at both sites on the various restoration substrates**. We are measuring recruitment, survival, growth, sizes, and density of adults on the restoration substrates. We are also monitoring **oyster fecundity** at the TNC site monthly in the spring, summer, and fall.

2. **Quantifying composition and abundance of species** recruiting to restoration substrates.

3. **Measuring sediment accumulation** at the site level and on the restoration substrates.

4. **Recording temperature** at the site level and on the restoration substrates.

5. **Monitoring shoreline populations of oysters**, which can affect or be affected by the restoration project. We are collecting data on recruitment, fecundity, density, and adult sizes, as well as on drill abundance and cover of sessile organisms in the oyster zone.

6. **Determining the best time of year to deploy restoration substrates**, using tiles set out monthly beginning in May and collected in November.

Methods

We monitor oyster performance and sessile and small mobile communities on the restoration substrates three times year, in April, July and November. We use non-destructive methods to sample the substrates, collecting five replicate samples from each substrate type at each location. To sample shell bags, we retrieve from the sites monitoring bags that are 1/3 the size of the bags used to construct the shell-bag elements, bring these to the lab for processing, and return them to the sites within 24 hours. After opening each, we rinse the shells to collect and measure sediment in the bag, collect, identify, and count mesograzers (between 500 microns and 1 mm) and larger mobile organisms, count and measure oysters on subsample of shells, and track growth and mortality of individual oysters on marked shells. The shells are returned to the bags and redeployed. In addition, we collect 15-30 individual oysters monthly from the surfaces of the shell bag elements during their potential brooding period (April to November), open them with an oyster knife and record reproductive status. For the “baycrete” elements we use 10 cm^2 quadrats placed at three tidal heights to estimate oyster abundance, sizes, cover of oysters and other organisms, and sediment accumulation on vertical and horizontal faces and on the north and south sides of the elements. The interiors of some of the elements are difficult (or impossible) to measure accurately; we have made these measurements less frequently.

An estimated total of two million native oysters have settled at the San Rafael site. We used the counts of oysters from the sample shell bags to roughly estimate a total number of oysters on the shell bag elements at the San Rafael site. The mean number of oysters from sample shell bags from our most recent sampling in July 2013 was multiplied by the mean number of shells per sample bag and then by three to estimate that total number of oysters per large shell bag. Because sediment has built up on the lower layers of the shell-bag mounds, we assumed for the sake of these calculations that there were oysters only on the top layer of six shell bags, and multiplied our estimate of oysters per large bag by six to get an element estimate and by 96 to get a plot estimate. Estimates from the oyster-eelgrass and oyster-only plots were generated separately and added together for the site level estimate for the shell bags alone. To estimate the number of oysters per "baycrete" element, we estimated the dominant surface area of each element type: calculating the vertical surface area as rectangles for the oyster blocks, the vertical surface area as cylinders for the reef balls, and the horizontal surface area for layer cakes. Measurements of element dimensions were made at the high, mid- and low elevations on the elements, surface area calculated separately for each, and the mean number of oysters from the corresponding quadrats used to calculate the number of oysters per unit area for each elevation. These were added together to get element totals.

To measure the potential impact of the restoration projects on existing oyster populations and vice versa, we collect data on intertidal populations at the sites quarterly, except for fecundity measures, which are made monthly during brooding season at TNC only, EL not having a large enough population to support this type of survey. Measurements are made in 10 10 cm^2 quadrats placed along a 30 m transect in the oyster zone at each site. Measurements of existing populations began before the construction of the restoration project and are being made inshore of the restoration substrates as well as in a control plot with no project offshore.

We are using PVC poles set into the substrate to measure sediment accumulation/erosion in treatment and control plots (N=3) along the same transects used for the shoreline population measurements above. We are measuring temperature at the site level using loggers placed near the elements, set to record every hour. In July 2013, we set out additional loggers to measure small-scale differences in temperature at the element level, placing these at three tidal heights on north and south faces and on interior and exterior surfaces at both sites.

Data are being analyzed with ANOVAs and T-tests as appropriate. More complex community-level data will be analyzed using nonparametric multivariate approaches such as MDS plots and ANOSIM.

Preliminary data summary

Shell bags

Recruitment in 2012, first recorded in November that year, was much higher at the TNC site than at Eden Landing (Figure A-1). Survival was high at TNC, with large numbers of oysters still growing on shell bags throughout our most recent monitoring event in July this year. We frequently observed drill holes on the shells of dead oysters in our shell bags from Eden Landing. Initially, there was a trend of higher numbers of oysters to shell bags in the oyster-eelgrass plots than to the oyster-only plots, but this pattern was not apparent in subsequent time points (Figure A-1). Oysters at TNC were also larger than oysters at EL (Figure A-2). Our July 2013 monitoring appears to have happened before the main recruitment season for this year at TNC; we saw only a few new recruits per shell bag. However, there were many new recruits in some of the shell bags at EL. We should be able to better quantify 2013 recruitment in November this year.

We estimate that there were 2.2 million oysters on shell bags at the Nature Conservancy site in July. Total numbers of oysters were similar on the dominant surfaces of oyster blocks, large reef balls and small reef balls (between 3,300-3,800 per element). Layer cakes had far fewer, at approximately 735 oysters (Figure A-3).

In addition to oysters, the shells and shell bags are habitat for a number of mobile and sessile organisms (Table A-1). Five mobile taxa consistently inhabit shell bags at EL and are notably absent at TNC. Aside from this, species composition is similar between sites. However, species diversity at EL appears to fluctuate seasonally, while TNC species diversity changes very little over the year.

“Baycrete” elements

As with the shell bags, oysters recruited in high numbers to the test “baycrete” elements at TNC. We did not record any oysters in our quadrats at EL, although we did see oysters on the interior surfaces of the large reef balls at EL in July 2013 (~6 individuals, about 3 mm in size on average per interior).

At TNC, there were no differences in terms of number of oysters across these element types (ANOVA $F=10.7$, $P= 0.36$, $df =3$), but there were more oysters on all elements at the lower tidal heights ($F=38.1$, $P < 0.0005$, $df =2$, Figure 4). There were also more oysters on north vs. south faces across element types and tidal heights at each time point (paired T-test, $T = 4.02$, $P < 0.0005$, Figure A-5). There were also significantly more oysters on vertical vs. horizontal faces across elements and tidal heights (paired T-test, $T = 10.13$, $P < 0.0005$, Figure A-6). Taken together, these data suggest that heat stress is a major factor in oyster recruitment/survival.

Percent cover of other organisms also does not appear to vary across element types, as shown for TNC in Figure A-7. Bare space was greatest at the higher tidal heights, but decreased over time as oyster cover increased. Atlantic oyster drills seem to be an ever increasing presence across all element types at Eden Landing, with a mean of 300 ± 42 individuals/m^2.

Shoreline populations

Oysters are abundant along the shoreline at TNC, with a mean of 3,000 oysters m^2 (SE+/-250) at both the treatment and control sites. In contrast, oyster densities are low at EL, with a mean of 27.5 oysters m^2 inshore of the treatment area (SE +/-21) and 67.5 (SE+/- 20) inshore of the control area. The percent of oysters brooding on the shoreline at TNC varied month to month and between the treatment and control sites; fecundity on the shell bags appears to be generally similar to the shore populations (Figure A-8). Oyster drills are present at EL (but not TNC), although we have rarely recorded them in our transects.

Sediment accumulation

Very little sediment appears to be accumulating on the test elements, with the maximum amount ever recorded at 2 mm depth. Large amounts of sediment are accumulating on the shell bags, however. At the present, only the top layer of shell bags is above the sediment. At the site level (as measured by the sediment poles) sediment fluctuated monthly with losses in the spring months and gains in the summer; data are still being analyzed, but there does not appear to be a difference between treatment and control plots in terms of accumulation.

Next steps

Continued monitoring is planned for November 2013 and at least through 2014, which will allow us to compare three recruitment seasons, as well as the longer term survival and growth of the oysters, and any shifts in cover or use of the substrate by other organisms. This is will also allow us to assess whether there are changes to the shoreline oyster populations inshore of the project sites. Oyster recruitment data from the timing tiles from 2012 were highly variable between locations and between treatment and control plots; having additional years of data should help clarify these patterns.

Data analysis is continuing to estimate the surface area provided by the shell bags so that these can be compared to the test elements in terms of oysters per unit area. We are continuing to sort and identify mesograzers collected from the shell bags, which will add to our understanding of the communities assembling on the restoration substrates.

To better understand what appears to be a strong signal of heat stress on oyster performance, we deployed continuous temperature loggers on one of each element type at both project sites, at three tidal heights, on north and south faces and in interior and exterior portions of the elements. These data should help quantify the temperatures experienced by the oysters and improve our understanding of important temperature thresholds and how these are mediated by the various surface orientations.

Given the low recruitment and high numbers of oyster drills at Eden Landing, oyster restoration at that site might potentially be aided by the addition of seed to restoration substrates, if larger oysters are less likely than new settlers to be preyed on by drills. In fall 2013, we deployed tiles with oysters settled from Oyster Point at Eden Landing. In November, we will collect these tiles to determine whether these larger oysters survived predation by drills.

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Section B: Eelgrass, Epibenthic Invertebrates, Fish, and Water Quality Monitoring

Introduction

This report summarizes the methods and results of activity to date for the San Francisco Bay Living Shorelines: Near-Shore Linkages Project at the The Nature Conservancy ('TNC') site in San Rafael Bay and the Eden Landing Ecological Reserve ('ELER') site in south San Francisco Bay, near Hayward (Figures B-1 and B-2). Following pre-installation site assessments, San Francisco State University scientists transplanted vegetative eelgrass shoots at both TNC and ELER and conducted buoy-deployed seeding at TNC during the summer of 2012. After limited success of these transplants, perhaps due to plantings being carried out late in the growing season, SFSU repeated transplanting of vegetative shoots at both sites during the spring of 2013. The SFSU group is monitoring the effectiveness of this restoration on establishment of eelgrass, alone and in combination with oyster settlement substrate (see experimental design, Figures B-1 and B-2). We have also been working to monitor fish and invertebrate assemblages both before and after project installation as an indicator of the impacts of eelgrass and oyster substrate elements on local wildlife communities and abundances. In addition, we measure a number of other abiotic and biotic conditions in an effort to distinguish the effects of the experimental treatments.

Methods

Eelgrass planting and seed buoy installation: San Rafael (TNC site)

In July 2012 we transplanted eelgrass to the San Rafael site ('TNC') in the two large plots indicated in Figure 1 (second most northern and second most southern plots). A total of 1152 vegetative plants were collected, 576 from Point Molate ('PM'), and 576 from Point San Pablo ('PSP'). The plants were dipped in freshwater (three times for 1 minute) to remove as many invasive invertebrates as possible, and were then attached to bamboo stakes with twist-ties and burlap (to protect the shoots from abrasion). The plants were then stored in flat rectangular tanks in running bay water overnight. The eelgrass shoots were planted at TNC, in a dice formation (5 positions, as in the number five on a die) with 24 plants in each 1.5m x 1.5m unit (four patches of 5 plants in a 0.25-m^2 quadrat, and one center patch of 4; see Figure B-3). A total of 48 units of this configuration were planted at the site; 24 were planted in the eelgrass only plot (EG, second from the north) in three rows of 8 units, and 24 were planted in between units of oyster shell bag plots (the eelgrass + oyster plot = EG+O, second from the south) again in 3 rows of 8 units. Following the poor success of these transplants, we repeated the transplant effort using this same protocol in April 2013.

In conjunction with vegetative shoot collection in 2012, 740 flowering shoots were collected from the PSP donor. These shoots were placed into mesh bags (15 per bag) and held in tanks of running baywater at the Romberg Tiburon Center. Mesh bags were dipped in freshwater repeatedly to remove epifauna and were attached along with a buoy and rope to the PVC stakes within each eelgrass unit approximately two weeks after the vegetative shoots were planted, creating a seeding buoy. An extra 20 flowering shoots were collected from each donor site, to be used as a reference for recording flowering stage and seed drop within the eelgrass units. This procedure has not been repeated in 2013 due to biofouling of the seed bags limiting seed drop and potentially causing disturbance to transplanted shoot growth. We also assessed the site for seedlings prior to planting in spring 2013 and did not observe any new shoots, which indicates the seed bags did not succeed in seeding the plots.

Eelgrass planting: Hayward (ELER site)

In August 2012, we collected 200 vegetative eelgrass shoots, 100 from the shoreline adjacent to Bay Farm Island (BFI) in Alameda and 100 from eelgrass patches at Eden Landing Ecological Reserve (ELER) offshore of our study site. These shoots were dipped in freshwater carried in tubs and attached in the field to their bamboo stakes as described above. The vegetative shoots were planted in sets of 20, with five plants in a 0.25-m^2 quadrat, within 1m x 1m units (see Figure B-3). Two eelgrass units (n = 40 plants) were planted within each of the five blocks at ELER, one with eelgrass only, and one directly adjacent to an oyster shell bag mound. We also repeated the transplanting effort at Hayward in May 2013, due to low survivorship of the original plantings.

Eelgrass Monitoring

The eelgrass transplanted in July 2012 was monitored in November 2012 and January 2013. This monitoring included density counts, shoot heights, epiphyte load, epifauna abundance and diversity, and nutrient analysis. Density and shoot height monitoring were conducted concurrently, and eelgrass collections were made immediately after these measurements. We will carry out successive monitoring efforts every quarter. The monitoring of the eelgrass planted in April and May 2013 was carried out in July 2013 and will be repeated every quarter, using the same protocol as before.

All shoots within each eelgrass patch (each "dice" array) were counted to give a total shoot density per donor and treatment unit. The number of shoots per genet was also recorded. Shoot location in relation to bamboo stakes indicated which donor the shoot had originated from and the total number of shoots, including any that have emerged from clonal growth, informs the total shoot number. Additionally, the number of flowering shoots was recorded. The heights of the tallest vegetative shoot within each eelgrass patch (and of flowering shoots, if present) were measured to the nearest centimeter, from the sediment to the top, with the plant extended fully upright.

Epifauna, Epiphytes and Nutrient/Isotope Analyses

Eelgrass collections were made in November 2012 to assess epifaunal communities, epiphytic loading, and nutrient and stable isotope composition. We did not collect any samples in January 2013 as there were very few remaining at both sites.

At TNC, an "exclusion zone" has been established within each treatment plot area (Figure B-1) to reduce sediment disturbance during monitoring. We did include these areas in our density counts, by floating over the area on boogie boards when water was over the sediment, to reduce disturbance.

In fall 2012, two portions of selected shoots were collected from both sites, including the top 10 cm of the second and fourth most interior leaves ('leaf 4 and leaf 2'). This subsampling allowed us to avoid the entire shoot, to enable that shoot to continue to grow. At Eden Landing, a total of 29 portions of leaves were collected, including 13 'leaf 4' samples (seven from ELER and six from BFI) and 16 (eight from ELER and eight from BFI) 'leaf 2' samples. At TNC, only three 'leaf 4' (all from PM patches) and three 'leaf 2' samples (also all from PM patches) were collected from the eelgrass-only plot due to low shoot densities. A further 20 'leaf 4' (10 from each donor) and 18 (11 from PSP, and seven from PM patches) 'leaf 2' samples were collected from the eelgrass +oyster plots.

In summer 2013 however, whole shoots were collected due to higher eelgrass densities. Two shoots were collected from each unit of eelgrass (one unit = a patch of 24 plants at TNC and of 20 plants at Eden Landing, see figure 2) at both sites (except those in the exclusion zones at TNC), one from each donor giving us a total of 77 shoots from the San Rafael and 20 shoots from Eden Landing. Samples were kept cold after collection and taken back to the laboratory for processing over the following three days. Therefore, all epiphyte and epifaunal assessments from summer 2013 are in relation to the whole eelgrass shoot compared to just leaf 4 in 2012.

To assess epifaunal communities, each leaf 4 sample (in fall 2012) or whole shoot (in summer 2013) is emptied onto a 500 µm sieve and subjected to three 1-minute freshwater dips to remove clinging epifauna. Invertebrates removed during the freshwater dips were preserved in 70% ethanol and will be identified to the lowest possible taxon according to Carlton (2007), and enumerated (per shoot or sub-sample) in the winter 2013.

Then, to assess epiphytic loading, leaf 4 of the shoot samples was then gently rinsed again in bay water in a flat-bottomed tray to remove any loose sediment. Using a microscope slide, each sample was scraped in a flat bottom trap until all epiphytes had been visibly removed. The epiphytes were then transferred from the tray (and any from the collection bags) to a pre-weighed microfilter glass fiber filter using a GAST vacuum pressure pump, and filters with epiphytes dried in a 65° C oven for 48 hours to determine dry weights. Leaf 4 or whole shoot samples, with all visible epiphytes removed, were blotted dry and weighed, then dried in a 65° C oven for 48 hours.

To assess %C, %N, and C:N of eelgrass as well as the stable isotopes $\delta^{13}C$ and $\delta^{15}N$ the leaf second from the interior of the sheath ("leaf 2")was removed from each shoot, rinsed in DI water, blotted dry and weighed in a new weigh dish. The leaf 2 samples were then also dried in a 65° C oven for 48 hours. Dry weights of whole shoots and of leaf 2 sub-samples were then taken. The dried tissue samples are ground with a mortar and pestle, and sent for analysis at UC Berkeley's isotope analysis facility. Epiphytes collected will also be analyzed for $\delta^{13}C$ and $\delta^{15}N$ content determination. In addition we plan to analyze other plant, algae and animal species of interest to inform food-web dynamics.

Invertebrate Monitoring Methods

Minnow and Collapsible Traps

Six pre-construction monitoring plots (spaced approximately 66 m apart) were established along a 330-m sampling transect located 250 m offshore at each site (San Rafael and Hayward), to span the length of the current or proposed large-scale restoration treatments (n = 6). Plots were sampled once during each of the four quarterly rounds (October 2011, January, April, and July 2012) prior to the treatment implementation in July/August 2012. Plots were also sampled post-treatment in October 2012, January, April, and July/August 2013. All plots were sampled within a two-week period during each sampling round. Each sampling round consisted of three methods: 1) suction sampling (described in Section 1.4.2), 2) minnow traps, and 3) collapsible multi-species traps.

At the San Rafael (TNC) site, three post-construction monitoring plots were established in July 2012 within each of the four treatments (n = 12) distributed evenly within the 330 x 32 m sampling transect (control, eelgrass, oyster and eelgrass plus oyster) ('TNC Treatment Area'). In addition, 12 sampling plots were established in an adjacent 330 x 32 m area ('TNC Control Area') located approximately 20 m directly south of the TNC Treatment Area.

At the Hayward (ELER) site, six post-construction monitoring plots were established in July 2012, one near each set of trial elements and one at the north end of the entire treatment area ('Eden Treatment Area'). An additional six control plots were established approximately 30 m north of the Eden Treatment Area ('Eden Control Area').

These post-construction monitoring plots are sampled quarterly, post-construction. One minnow trap and one collapsible oval trap (without escape pot) are attached by rope to make one 'two-section' trap array per plot. Each trap is baited with a uniform combination of fish-based bait (1 squid plus 3 anchovies) suspended in mesh bags. Trap arrays are weighted with one half brick, attached to a labeled scientific buoy and deployed for 24 hours within each plot. Upon retrieval, all specimens are immediately identified, sexed (if possible), and measured (carapace width, or body length and body + tail length) in a wet tray to minimize harm. All trap catch is released live immediately after processing, or preserved in ethanol if additional steps are required for identification.

Epifauna by Suction

Suction sampling methods are adapted from previous invertebrate surveys within eelgrass beds conducted by the Boyer Lab. A hand-held, battery-operated aquarium gravel vacuum with a modified opening of approximately 10 mm is used to sample the epibenthic aquatic invertebrates and post-larval crabs (<10 mm) in one 0.5 x 0.25 m quadrat within each plot during low tides (<1.0 m). Suction samples are collected as pairs, with one sample collected from the vertical structure (eelgrass or oyster plot) or water column (control plot), and one sample collected from the epibenthic layer (either between the eelgrass plants or at the base of the oyster reef).

At the San Rafael site, six paired suction samples are collected from each single treatment (eelgrass only and oyster only) and each of the two control plots. An additional 12 paired suction samples are collected from the eelgrass plus oyster treatment (6 samples for both). Therefore, there were a total of 36 paired samples.

At the Hayward site, paired samples are collected within every eelgrass unit (n = 5), oyster unit (n=5), eelgrass portion of the eelgrass plus oyster units (n = 5), and oyster portion of the eelgrass plus oyster units (n=5), for a total of 20 paired samples. Additionally, 5 paired samples are collected in the control area.

A section of fine mesh pantyhose is connected to the output of the vacuum, allowing all water to pass through while trapping fine sediments and invertebrates. The mesh is then removed from the output and placed in ethanol to preserve the sample in the field. In the lab the sample is washed through a series of fine sieves (500 µm) to remove the sediment and isolate the invertebrates. The invertebrate sample is then split to ½ using a professional grade sample splitter. Invertebrates are then sorted to the most appropriate taxonomic level and counted under a light microscope.

Fish Monitoring Methods

Minnow and Collapsible Traps

Fish are monitored quarterly using the same sampling array and gear as described for invertebrates. Fish captured are identified, measured, and released.

Acoustic Monitoring Array at TNC

A comprehensive array of 27 Vemco VR2W acoustic receivers was installed at the TNC site on December 22, 2012 to continuously detect the presence and position of any acoustically tagged fish that visited the site during the winter and spring seasons. The array consisted of twenty three receivers that detect 69 kilohertz tagged fish (sturgeons, steelhead, and striped bass) and four receivers that detect 180 kilohertz tagged fish (Chinook salmon). Additionally, seven Vemco timing synchronization transmitters were installed at the site to enable precise positioning of visiting tagged fish within each plot.

On April 30, 2013 all receivers were retrieved from the site. On April 30, data was downloaded from all receivers. Preliminary review of the data suggests that eight tagged fish visited the site during the detection period. All of the detections were in the 69 kilohertz range. We are now working with the California Fish Tracking Consortium to identify these fish. The positioning analysis that will show specifically how these fish were utilizing the site is being conducted at Vemco Acoustic Telemetry. These results are expected in late October 2013.

We will re-deploy the 69 kilohertz acoustic receivers in December 2013 at the project site. Additionally we intend to deploy several 69 kilohertz acoustic receivers at a comparison oyster reef restoration site on the North Richmond Shoreline.

Seining

In May and August 2013, seining was carried out at The Nature Conservancy site in San Rafael bay. During an incoming tide, when water reached at least 2 feet in depth, 3 seine transects per treatment plot were conducted. Two people hold a seine (1m tall by 2.8 m wide) just above the sediment, at an approximate 45° angle in the water column. A third person walks towards the seine, and the seine is swept through the water column along a 30m transect. Two transects were swept on the eastern length of each plot, one directly east of the plot and one just beyond the first. A third transect was swept along the western length of each plot to give a total of 12 seine sweeps at the site.

At the end of each transect, the seine is lifted out of the water and all animals caught are enumerated, identified to species and measured. The first 10 individuals of each species are measured, and any remaining are counted but not measured to save time in the field. If any identifications are uncertain then photographs are taken, and/or vouchers are brought back to the lab for verification.

Water Quality Monitoring Methods

Temperature, Salinity, and Dissolved Oxygen

We deployed Onset HOBO U24-002 conductivity/temperature (CT) data loggers to collect continuous data on salinity and temperature at both the ELER and TNC sites. In November 2012, a total of five CT sensors were placed at the TNC site, one in each of the large-scale plots and one in the large control area (Figure B-1). Two days later, five CT sensors were placed at the ELER site, four spaced along the small-scale substrate elements installed in 2012 and one in the large control area outside the substrate element project area (Figure B-2). Each CT logger is attached vertically to a 5ft x 4in fiber reinforced plastic rectangular stake via 3/16" stainless steel screws with eyelets, with the sensor approximately three inches from the top of the stake. Copper mesh is covering the sensor panel to deter biofouling. The loggers are deployed so that the base is approximately six inches from the sediment. This mooring minimizes CT logger contact against the stakes and reduces the potential for sediment loading on the sensors. Each logger is deployed on the shore-side of each oyster structure or eelgrass unit (exact locations will be mapped with GPS), with the sensor facing the shore at both sites. At TNC, the logger in each patch is located just west of the most southern unit in the eastern row.

These sensors record conductivity and temperature continuously and are cleaned when the data are downloaded in the field using a waterproof shuttle. Cleaning and data downloads have been taken every six weeks since the beginning of December 2012. In April 2013, Onset released a product performance notification about the U24-002 data logger we are using at the sites, stating that the conductivity sensors are not functioning accurately. Due to this technical problem with the loggers, and after looking at the salinity data downloaded from them, we have decided that the salinity data is not reliable or usable. We can, however, still use the temperature data and will show this information in our next report, after our fall monitoring efforts.

In addition to these CT loggers, we have been measuring salinity, conductivity, temperature and dissolved oxygen every quarter using a handheld YSI 85 instrument. These measurements are made once in each of the treatment plots and in the large control area at

TNC, and once in the three most southern blocks and the control area at Eden Landing. Measurements are made while holding the sensor just below the surface of the water.

Water Column Chlorophyll-a

SFSU is collecting chlorophyll a data to determine if treatments influence phytoplankton abundance, thus potentially affecting competition for light and nutrients with eelgrass. Post-construction chlorophyll monitoring commenced in October 2012 and collections have been taken every quarter since then. 15 water column samples are collected from TNC, three from each treatment plot and three from the large control area. Six water column samples are collected from Eden Landing, three from the southern treatment blocks and three from the control area.

Collection vials are acid washed to sterilize before collection. In the field, each vial is rinsed with bay water before being submerged to just below the surface, upturned to remove air bubbles, then capped while still under the water. The vial is immediately placed in a cooler on ice to keep cold and dark. Back at the Romberg Tiburon Center, chlorophyll extractions follow the method of Arar and Collins (1992) followed by fluorometry analyses as described by Smith et al. (1981). The Turner Designs model 10 fluorometer used in this study is calibrated annually with a Turner primary (chlorophyll) standard that is serially diluted to obtain a standard curve and coefficients. This fluorometer is occasionally (approximately every other year) cross-calibrated with other fluorometers at RTC (e.g., RTC joint-use Turner Designs 10AU bench top fluorometer). We have not yet finished processing the water column samples collected in recent quarters but will include these results in our next report.

Light Attenuation

Photosynthetically active radiation (PAR) has been measured quarterly just below the surface and at one-meter depth using a Li-Cor underwater spherical PAR sensor. Measuring light at two depths permits calculations of light attenuation through the water column, which can then be compared among treatments and with other such measures for San Francisco Bay (Zimmerman et al. 1991, Merkel and Associates 2005). Three replicate measures within each large-scale treatment plot were taken at TNC on each sampling date. One measure in each of three of the blocks of the small-scale substrate element experiment at ELER North were also taken, along with an additional three replicate measures in the large control plot with no habitat structure at each sampling date.

Results and Discussion

Eelgrass Monitoring Results

Densities and Heights

In fall 2012 and winter 2013, densities of surviving eelgrass shoots were found to be very low at both sites. At TNC, only four shoots were observed in the eelgrass only (EG) plot (Figure B-5). Of these four shoots, three originated from PM and one from PSP. In addition, one flowering shoot from the PM donor site was observed. In the eelgrass + oyster (EG+O) plot, a total of 55 vegetative shoots were present (including shoots emerging from clonal growth), 34 from PM and 21 from PSP, no flowering shoots were observed here. In winter 2013, densities dropped again with no shoots remaining in the EG plot and only 35 vegetative shoots observed in the EG+O treatment plot, 24 from PM and 12 from PSP. No seedlings were seen in spring 2013 in either of the treatment plots. Overall, after the first round of transplants, in both treatment plots, PM plants seemed to fare better, and higher plant densities were seen in the EG+O treatment than the EG treatment in both fall 2012 and winter 2013.

After the repeated transplanting effort in spring 2013, 245 vegetative shoots were observed in the eelgrass only (EG) plot (Figure B-5) in July 2013. Of these shoots, 151 originated from PM and 94 from PSP. In addition, 31 flowering shoots were observed, 25 from PM and 6 from the PSP donor site. In the eelgrass + oyster (EG+O) plot, a total of 220 vegetative shoots were observed. Of these shoots, 128 originated from PM and 92 from PSP. Additionally, 18 flowering shoots were present, 11 from PM and 7 from PSP. Like the 2012 transplants, in both treatment plots more plants originating from PM were observed (Figure 5).

At Hayward, in fall 2012 a total of 58 vegetative shoots were observed (Figure B-6), which consisted of 31 from the ELER donor site and 27 from BFI. Three flowering shoots were also observed from the ELER donor site, and one from BFI. Eelgrass units in blocks 3 and 5 (central and most northern block respectively) had the highest densities, with 15 and 30 surviving shoots, respectively (data not shown). In winter 2013, we saw a slight decrease in vegetative shoot density with a total of 47 shoots observed. 32 of these shoots originated from BFI (a slight increase from the fall 2012 BFI shoot density) and 15 from ELER. No flowering shoots were observed.

After the repeated transplanting effort in spring 2013 at Hayward, a total of 163 vegetative shoots were observed in the plots (Figure B-6) in July 2013, which consisted of 85 from the ELER donor site and 76 from BFI. There seems to be little difference in densities between plants from the two donors. Two flowering shoots were also observed: one from the ELER donor site, and one from BFI. There seems to be a trend of slightly higher eelgrass numbers in plots at the most northern blocks versus those in southern plots (data not shown).

Figure 7a shows the mean number of shoots counted per patch of eelgrass during our monitoring efforts at TNC in July 2013. Overall there seems to be little variation in the mean number of shoots per plot, except a slightly higher mean count in the southwestern patches of the EG treatment (patch 1), which are all from Point Molate.

There seems to be very little variation in the number of shoots present per patch and donor at Hayward (Figure B-7b). On a per patch basis, there seems to be a higher density than at TNC.

Overall the transplantation effort carried out in spring and monitored in summer 2013 was far more successful than the 2012 transplants. Of the 1152 plants transplanted at TNC in summer 2012, only 35 remained by winter 2013 compared to the 465 shoots present so far relative to the 1152 shoots transplanted during spring 2013. We can calculate an establishment success indicator by comparing the number of shoots originally planted in spring 2013 in each plot with the number of shoots (including clonal growth) present in summer 2013. In the EG treatment plot at TNC, shoot densities averaged 53.9% of planted densities for the Point Molate donor and 44% for Point San Pablo. In the EG+O plot, densities were on average 49.2% of planted densities for PM plants and 49% for PSP.

Looking at Eden Landing survival, in winter 2013 only 47 shoots remained compared to the 200 planted in summer 2012. In summer 2013, however, 163 shoots were present compared to 200 transplanted in spring 2013. Thus, shoot densities were 76% of planted densities for the Bay Farm Island donor and 85% for the ELER donor.

In fall 2012, the mean maximum height of vegetative eelgrass shoots across all plots at TNC was 97.2cm (n=67). In the EG plot, mean maximum height of PM plants was 110cm (n=3), and of PSP plants was 53.2cm (n=1). In the EG+O plot, the mean maximum height of PM plants was 111.1cm (n=18) and of PSP plants was 114.5 cm (n=15, Figure B-8). In winter 2013, the mean maximum height of vegetative shoots at TNC was 34cm (n=18). No shoots were present to measure in the EG treatment. The mean maximum height of PM plants in the EG+O plot was 32.9cm (n=12) and of PSP plants was 35.14cm (n=6).Very few plants were present during these monitoring efforts so trends of heights could not reliably be made between donors or treatments, except a gradual decline in height over time.

After the replant in spring 2013, the mean maximum height of vegetative eelgrass shoots across all plots in July 2013 at San Rafael was 125.2cm (n=195). In the EG plot, maximum height of PM plants was 127.2cm (n=52), and of PSP plants was 117.4cm (n=48). In the EG+O plot, the maximum height of PM plants was 129.3cm (n=55) and of PSP plants was 126.6 cm (n=40) (Figure B-7). There does not seem to be much variation in height of plants from different donors and treatments.

In fall 2012, the mean maximum height of the tallest eelgrass shoots at Hayward was 64.8cm (n=34). The mean maximum height of shoots from the ELER donor site was 61.2cm (n=20), and from the BFI donor was 69.4 cm (n=16, Figure 9). In winter 2013, the mean maximum height dropped to 32.6cm (n=23). The mean tallest height of shoots from BFI was 32.1cm (n=13) and of those from ELER was 33.2cm (n=10).

After repeating the planting effort in spring 2013, the mean maximum height of eelgrass in July 2013 at ELER was 68.5cm (n=40). The mean maximum height of shoots from the ELER donor site was 70.4cm (n=20), and from the BFI donor site was 66.6 cm (n=20, Figure B-8). The maximum eelgrass shoot height seems not to vary between the donors at ELER, but overall the tallest plants from this site are on average smaller than those at TNC. The high density of *Ilyanassa obsoleta* (an invasive snail species) adults and eggs on the plants weigh them down and may limit the plants' ability to extend into surface waters with greater light. In addition, the shallower depth of the ELER site may negatively influence plant heights.

Epiphyte load

Summer 2013 epiphytic loading data represent the loads collected from all leaves, and so they cannot be compared directly to the loading recorded from the 2012 transplants, when only a single, older leaf was collected. Epiphyte load is expressed as a ratio of epiphyte biomass to eelgrass biomass, with higher ratios indicating a higher load.

At the San Rafael site in fall 2012, only 3 samples were collected from the EG plot (to preserve remaining shoots), thus epiphyte loading between the eelgrass and eelgrass + oyster treatment could not be compared. There was a trend toward higher epiphyte loads on Point Molate plants compared to Point San Pablo plants within the EG + O plot. In summer 2013, there was a trend of higher epiphyte loading in the EG+O plot than the EG plot, but little difference between donors in either plot. Further assessments from our quarterly monitoring efforts will help confirm trends in epiphytic loading.

At Hayward, epiphytic loads were lower in summer 2013 compared to fall 2012 also (Table B-2). Overall, though, the average dry epiphyte mass per g of samples was very similar in both years. There was not a noticeable difference in epiphyte loads between sites.

Isotope Analysis

The stable isotopes δ13C and δ15N from fall 2012 leaf 2 samples are plotted in Figure B-12. There appears to be a separation of leaf stable isotope composition with EL and BFI donors plotting similarly to each other, and the PM and PSP plants at TNC plotting separately from the ELER site. The signature of the EG+O samples at the TNC site appears to plot separately from the EG only samples, a pattern that we intend to explore further in additional samples from later quarters. Summer 2013 leaf 2 sub-samples have not been sent for analysis to UC Berkeley at the time of this report. We hope to have %N, %C of plants and epiphytes, along with ${}^{\delta}$15N and ${}^{\delta}$13C stable isotope information for several species of interest at both sites. This will give us information on food web dynamics at the two sites.

Invertebrate Monitoring Results

Minnow and Collapsible Traps: San Rafael

Overall, species richness increased throughout the treatment area in the year following project implementation. A total of three invertebrate taxa were detected in the traps during the four quarterly monitoring periods prior to project implementation (project control). These included the native mud crab/yellow shore crab (*Hemigrapsus oregonensis*), the native Dungeness crab (*Metacarcinus magister*), and shrimp species (*Crangon* sp.). In addition to these species, three more crab species were detected throughout the treatment area during the four quarterly monitoring periods following project implementation. These included the green crab (*Carcinua maenas*), California rock crab (*Romaleon antennarium*), and the red crab (*Cancer productus*). These additional species were most often detected in plots with added structure (oyster or eelgrass), with the exception of one detection of red crab in the site control plots in April 2013.

Results indicate that the addition of structure (oyster or oyster plus eelgrass) may provide habitat for juvenile Dungeness crab, shrimp, red crab, green crab and CA rock crab at the

TNC site. Both the oyster and oyster plus eelgrass plots showed a trend of increased abundance for each of these taxa relative to the plot and site controls in post implementation monitoring quarters 1, 2, and 3 (Table B-3). During the 4th quarter, these trends persisted for only the CA rock crab. The addition of structure may be having the opposite impact on the yellow shore crab. Trapping results have suggested a decrease in abundance for this species in plots with structure relative to plot and site controls during quarters 1, 2, and 4.

Minnow and Collapsible Traps: Hayward

At ELER, two taxa were observed prior to project implementation. These include the yellow shore crab and the eastern mud snail (*Illyanassa obsoleta*). After project implementation, two additional invertebrate taxa was observed on site, Dungeness crab and shrimp species. However, both taxa were observed in both control and treatment areas during the post implementation sampling (Table B-4). No trends in abundance were observed between the control and treatment areas. Some seasonal trends are apparent across the site, including the non-native, invasive eastern mud snail which has been abundant during some quarters, but appears to nearly disappear during the 2nd quarter (January).

Epifauna by Suction

Baseline (pre-project) invertebrate sampling was conducted quarterly at ELER and TNC in October 2011, February 2012, April 2012, and July 2012. Post-treatment monitoring was conducted quarterly in October 2012, February 2013, April 2013, and July 2013. Samples have been sieved and preserved in ethanol. Samples are in the process of being sorted to the most appropriate taxonomic level and counted.

Figure B-13 presents the preliminary results of multiple rounds of epibenthic suction samples from ELER. These preliminary results show the differences and similarities of community composition within each treatment, with each bar compiled from multiple samples per treatment (EEL = eelgrass blades or surrounding water column; EEL SUB = substrate at base of eelgrass; OYS = oyster shell bag mound; OYS SUB = substrate at base of oyster mound; SUB = substrate in control; WC = water column in control; -C = samples taken from oyster + eelgrass combination plots). Though these results are still preliminary (not all samples have been counted), some simple trends are visible including a larger percentage of copepods in the eelgrass samples and the presence of isopods in the oyster and oyster substrate samples. Results from TNC are still being processed and will be reported later.

Fish Monitoring Results

Minnow and Collapsible Traps

At TNC, a total of 11 individual fish of 5 species were observed during the quarterly monitoring prior to project implementation (Table B-5). Post-project quarterly monitoring detected 17 individuals of 7 species, a slight increase from pre-project monitoring. During post-project monitoring quarters 2 and 4, more fish were detected in the plots containing added structure (oyster or eelgrass). However, this trend was not apparent during quarter 3.

At ELER, a total of 14 individual fish of 5 species were observed during the quarterly monitoring prior to project implementation Table B-6). Post-project quarterly monitoring detected 12 individuals of 3 species, a decrease from pre-project monitoring. This decrease could be related to the modification of traps during post-project quarters 2-4, during which traps were adjusted to exclude large sharks which could injure themselves in the traps. One new species was detected during the post-project monitoring, a sand dab. These results do not suggest any trends of fish presence in treatment or control areas.

Seining at San Rafael

The mean number of fish and invertebrates caught, and the contributions each species made to that mean count per 30m-seine transect, per treatment is shown for May 2013 in Figure B-14. The control area at the TNC site caught the highest number of individuals (mean = 53.67 per 30m seine) in May 2013, but had the lowest diversity (3 species), with *Atherinopsis californiensis* (Jacksmelt) contributing the most to this mean count (49.67 mean individuals). The highest diversity (and second highest mean count per seine = 19) was observed in the eelgrass treatment, with 8 species (mean of 6 individuals). The next highest mean count was observed in the eelgrass + oyster treatment (mean of 8.67 individuals, 5 species). The lowest mean count per seine was seen in the oyster only treatment (4.33 individuals, 4 species). The Jacksmelt contributed the most to the mean seine count in the eelgrass and eelgrass+oyster treatments, but was not seen in the oyster treatment where the most commonly caught individual was the Bay shrimp (*Crangon franciscorum).*

In August 2013,the control area caught the highest number of individuals again (mean = 39.00 per 30m seine), with *Leptocottus armatus* (Pacific Staghorn Sculpin) contributing the most to this mean count (8.67 mean individuals) and 8 species observed in total (Figure B-15). The second highest mean count per seine was observed in the eelgrass and oyster combined treatment (mean of 32.67 individuals), and a slightly higher number of species caught (9 species) than the control. The most commonly seen species in this treatment was the Bay shrimp again (*Crangon franciscorum,* mean = 12.33). The next highest mean count was observed in the eelgrass treatment (mean = 10 individuals), with 5 species observed (less than May 2013) and the most commonly seen species being the Bay shrimp again (mean = 6.33*)*. The lowest mean count per seine and diversity, as with the May 2013 seine results, was seen in the oyster only treatment (3.67 individuals, 3 species). The Bay Goby, (*Lepidogobius lepidus*) contributed the most to the mean seine count in this treatment (mean = 3).

The results from seining indicate a lower abundance but higher diversity in some treatments in August 2013 compared to May 2013. We will repeat this seining in October 2013.

Water Quality Monitoring Results

Temperature, Salinity, and Dissolved Oxygen

Temperature (°C), dissolved oxygen (% and mg/l), conductivity (ms), and salinity (ppt) of the water column were taken every quarter from January 2013 at both sites. These readings help indicate any seasonal and inter-treatment changes in water quality and are shown in tables B-7 and B-8 for the San Rafael and Hayward site, respectively.

Water Column Chlorophyll-a

Samples from the October 2012 post-construction collections at ELER showed higher Chlorophyll-a concentrations than those from TNC (an average of 15.1 ug/L and 7.5 ug/L respectively; Table B-5), indicating somewhat higher phytoplankton abundance at ELER. At both sites, the treatment areas had higher Chlorophyll-a concentrations than the control plots. Further samples have been taken every quarter since October 2012, and we are in the process of analyzing them, which will establish whether there continue to be any trends between treatments and sites.

Light Attenuation

Tables B-10 and B-11 below show the PAR readings at both sites since October 2012. We will use these data to calculate the attenuation in the water column, which then indicates the amount of light reaching organisms at different depths. Due to equipment malfunction, there were no readings taken in the large control at TNC in April, or in 2 of the control area sample positions at TNC.

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Section C: Bird and Benthic Invertebrate Monitoring

Monitoring activities: The USGS Western Ecological Research Center, San Francisco Estuary Field Station has monitored waterbird and benthic invertebrates at eelgrass and oyster restoration sites for the Living Shorelines: Near-shore Linkages project since November 2011. At the three project intertidal study sites located along the Hayward (Eden Landing North and South, ELN and ELS) and San Rafael (The Nature Conservancy, TNC) shorelines we are evaluating species and guild specific responses to restored habitat relative to control areas and pre- installation conditions using a Before-After Control-Impact (BACI) design. Each paired treatment and control study area is subdivided into zones (Fig. C-1) encompassing eelgrass and oyster treatment plots (zone B) as well as 150-m zones immediately inshore (zone A) and offshore (zone C) of the plots. This design allows us to measure potential avian and invertebrate responses both in the immediate vicinity of the treatment plots, as well as in adjacent areas that may be influenced by the restoration.

USGS WERC monitoring activities include:

- High and low tide surveys of avian densities
- Scan surveys of avian behaviors
- Focal observations on individual foraging birds from 3 guilds
- Benthic invertebrate core sampling to determine macroinvertebrate densities, biomass, and community structure

Avian Monitoring Methods – From September 2012 to April 2013, we conducted post-installation low tide and high tide surveys twice a month to monitor avian density and behavior at each site. These surveys resumed in September 2013 and will continue until project completion. During each survey, we used spotting scopes to count and identify to species all birds in each zone. Low tide surveys of each zone are conducted while the tideline is present in the zone to record the maximum number of shorebirds. After recording total numbers, we use scan sampling to randomly choose 20% of all individuals of each species and record instantaneous behaviors. In addition, we conduct focal observations on foraging individuals within each of 3 foraging guilds: benthivores, piscivores, herbivores. Foraging birds are chosen at random and observed for 3 minutes (open water birds) or 1 minute (shorebirds) to determine dive:pause durations or peck rates, measures of foraging intensity.

Benthic Invertebrate Monitoring Methods – We collected post-installation benthic invertebrate samples at all study sites during September 2012, April 2013 and September 2013. At treatment and control areas within each study site we took benthic cores (10-cm deep, 10-cm diameter) along four 500-m transects that ran perpendicular to shore (Fig. C-1). In the TNC treatment area we took cores from an additional transect (TNCTP) through a previously established eelgrass test site (Fig. C-1). Along each transect, 2 replicate samples were taken in each zone. In treatment areas, transects bisected treatment elements, and we collected cores in each of these plots. Cores were labeled to indicate sampling transect, zone and replicate (e.g. TNC01-B-1), refrigerated, and processed each within 72 hours of collection by rinsing them through 0.5-mm sieves and preserving all retained invertebrates in 70% ethanol with rose-bengal dye. Invertebrates were sorted, identified to lowest possible taxonomic class, enumerated, and measured. Ash-free dry biomass for bivalves was calculated based on length to biomass transformations taken from the literature or previously determined at USGS. Invertebrate numbers and dry biomass were summarized, and spatial distribution maps were created in ArcGIS by interpolating invertebrate biomass via Inverse Distance Weighting. We are currently processing April 2013 samples, and preliminary results from pre-installation and September 2012 cores are summarized below.

Preliminary data summary:

Avian -- Preliminary results from pre and post- installation monitoring indicate that avian densities and guilds differ greatly between TNC and EL sites. Overall, treatment and control areas at TNC were characterized by low mean densities of several species spanning 8 guilds, while high mean densities (>600 birds/ha) consisting mainly of medium and small shorebirds predominated at ELN and ELS sites. At TNC, preliminary data summary suggest that overall mean densities of birds increased inshore (zone A) of oyster and eelgrass plots, and remained similar in the vicinity (zone B) and offshore (zone C) of the plots (Fig. C-2). The number of species using zone B at TNC increased from 8 pre-restoration to 15 post-restoration (Table C-1). This includes increases in densities of black oystercatcher (*Haematopus bachmani)*, a species which was not observed prior to plot installations, but numbered as many as 18 per count on oyster elements post- installation. Over winter densities of shorebirds in zones B and C of both the treatment and control areas at ELN declined post- installation (Fig C-4). Given this trend is similar between treatment and control areas these declines do not appear related to the test elements installed at this site, but may be a consequence of the deepening channel at the mouth of Mt. Eden Creek just south of the elements or increased low-tide habitat in adjacent newly restored managed ponds. Wading bird (great (*Ardea alba)*, and snowy (*Egretta thula)* egrets) mean densities increased ($F_{1,117}$=3.52 p=0.063; Fig. 4) at ELN treatment plots in comparison to pre-treatment and control, potentially indicating increased resources for these species. Shorebird densities also decreased in all zones at ELS (Fig. C-5) post-installation, but to a lesser degree than at ELN.

Benthic Invertebrates -- Preliminary data summaries suggest the average number of individuals in TNC treatment zone B cores remained similar between pre (May 2012) and post (Sept 2012) installation periods; however the number of taxa in treatment zone B increased (Fig. C-6). Polychaetes comprised over 90% of the biomass found in post-restoration (Sept 2012) TNC cores, except bivalves predominated in control zone C (Figs C-7 & C-8). In contrast, bivalves, notably *Gemma gemma*, were found in highest densities both pre and post-restoration at ELN, with post-restoration *Gemma gemma* densities more than 2-times greater than pre-restoration cores from treatment zone B (Fig. C-9). *Gemma gemma* also dominated macroinvertebrate biomass at ELN, which was highest in treatment zone B where test elements were installed (Figs C-10 & C-11).

Implications and Next Steps

Our data to date demonstrate initial response to living shoreline treatments from some avian and invertebrate taxa; however, additional monitoring is needed as eelgrass and oyster treatments and their surrounding communities mature. Changes in prey species and accessibility as eelgrass and oyster habitat become established is likely to further influence bird use. In the near term we plan to continue avian monitoring through winter 2013-2014, as well as will finish processing benthic invertebrate cores from April and Sept 2013 over the next 2 months. In addition to on-going monitoring, our next steps will include integrating avian and invertebrate dataset in energetic models aimed at evaluating pre and post-treatment carrying capacity for avian species at Living Shoreline project sites. These models will incorporate tidal inundation to better understand how prey availability and accessibility may change with changes to elevation and other physical factors. We will also use a multivariate approach (Permanova, e.g. Toft et al. 2013) to compare pre to post-project changes in avian and invertebrate community structure. We hope to conduct future work using stable isotopes to evaluate the role of prey derived from eelgrass and oyster treatments versus other habitat types in San Francisco Bay.

For more information, please contact: Dr. Susan De La Cruz (sdelacruz@usgs.gov)

Authors of this section: USGS Western Ecological Research Station: Susan De La Cruz, John Takekawa, Laura Hollander, Ashley Smith

Section D: Physical Monitoring

All Physical Monitoring Activities Overview

Prior to the installation in summer 2012, ESA PWA conducted the following pre-project data collection:

1. Bathymetric surveys at both sites
2. Sediment composition sampling at San Rafael

After the plots were installed, ESA PWA commenced monitoring of:

1. Elevation of individual elements at both sites
2. Sediment accumulation at San Rafael
3. Waves and currents at San Rafael
4. Ambient water properties at San Rafael

Physical Monitoring Details

Element subsidence

Prior projects that installed reef elements observed significant subsidence into the bed near the San Rafael site due to the muddy substrate; some settling of the individual Living Shoreline Project units is expected as a result. To quantify this, ESA PWA is measuring the top elevation of the elements at monthly intervals and developing a trend model based on the rates of change. An initial elevation of every element in the test plots and at least one element per shell bag unit in the larger plots was collected starting in September and October 2012 at the San Rafael and the Hayward Shoreline sites using GPS and total station surveying methods. The same element within a shell bag unit was surveyed each time and was tagged to maintain consistency. Monthly surveys were continued until the subsidence appeared to level off at which point, collection shifted to bi-monthly frequency.

Dates of monitoring:

San Rafael – 2012: October 15, November 12, December 10

2013: January 23, March 7, April 16, July 11

Hayward Shoreline – 2012: September 29, November 13, December 11

2013: January 22, March 8, April 26, May 28, July 10

Findings:

To date, approximately 10 cm of subsidence has been observed across the San Rafael the site but the rate has not been constant. The average rate of subsidence site from October 2012 to January 2013 was 2.0 ±1.8 cm/month for the test plot elements and 1.7±1.6 cm/month for the treatment plot elements (Figure D-1). An important consideration is that the shell bag mounds are shorter than the other four types of elements by approximately 25 cm. The different types of elements subsided at fairly consistent rates with only the shell bag mounds showing a decreasing rate of subsidence into March. After March, the rates of change for all the elements stabilized around zero and within the estimated error of the observation approach of ±3 cm (combination of instrument accuracy and collection technique), indicating subsidence has mostly ceased.

To date, approximately 8 cm of subsidence has been observed across the Hayward Shoreline site but, similar to San Rafael, the rate has not been constant. The average rate of subsidence at the site for the test elements from September 2012 to January 2013 was 2.0± 1.3 cm/month. After January, the rates of change decrease to within the observation error similar to the San Rafael site (Figure D-2). The subsidence rates for shell bags that were placed with the eelgrass plantings were grouped with the shell bag only treatments for analysis under the assumption that the bags would settle at similar rates.

Sedimentation

Two approaches were used to track sedimentation at the San Rafael site for the project. The first involved measurement of accumulation at discrete points in and around the reefs while the second looked at volumetric changes to the bed due to sediment movement.

Sediment plate measurement

As part of the monitoring plan for sediment accumulation, ESA PWA installed 14 sediment plates placed immediately after the placement of the treatment plots at the San Rafael site. Sediment plates are flat disks placed on the substrate and held in place laterally by a threaded pole through the center of the plate. The plate is held vertically by galvanized brackets above and below the disk. Half of the plate surface was sanded to enhance sediment trapping of finer particles on a rougher surface. The sediment accumulation was measured monthly by taking 3 – 4 measurements of the observable sediment thickness on the plate surface and averaging. Biofouling and bed scouring became challenges for using sediment plates and ESA PWA discontinued using the plates as a measure of sediment accumulation.

<u>Date of installation:</u> August 31, 2012

<u>Dates of monitoring:</u> measurement - October 15

visual observations - November 12, December 10

Sedimentation volumes

The volume and depth of sediment accumulating at the reefs indicates the trapping efficiency of the structures both as units and overall. The pre-project bathymetric survey (May 2012) and a substrate and sediment survey 11 months after construction were used to calculate the sedimentation rates. While the bathymetric survey used single-beam hydrographic surveying, the post-project survey used a laser total station. For the post-project survey, four transects were measured within the oyster-only, oyster/eelgrass, and control plot: two in the N-S direction and two in the E-W direction (Figure D-3). For the oyster-only and oyster-eelgrass plots, one transect was collected through the middle of the aisles between elements while the second was collected close to the elements to capture the undulations in bed topography that occur close to the individual elements. In the oyster-only plot, data points were also collected in the middle of the units (unit = 4 individual elements), where sediment has been accumulating rapidly.

To address the uncertainty from using different survey techniques, a high and low volume estimate was calculated using (1) the elevations as measured and (2) a vertically-shifted elevation from the pre-project bathymetric survey to create no net volume change in the control plot (normalizing all the elevations by setting the pre-project elevation as 0). The second method provides a lower bound for the volume estimate and provides insight into how much sedimentation occurred in the treatment plots, independent of background processes. The oyster-only test plot was broken into sub areas to calculate the volume (Figure D-3). The volume trapped inside the oyster units was estimated using the average area (2m x 2m) and the measured depth of fill in between the individual elements.

<u>Dates of collection:</u> June 26 and July 11, 2013

<u>Findings:</u>

An average of ~5 cm of sedimentation occurred at the control plot over the year since construction (Table D-1). However, the treated plots accumulated two times as much sediment as compared to the control plot due to accumulation inside the oyster units. The average deposition inside the units was calculated to be 24 cm, as measured within the oyster-only plot. Volume within the units was assumed to be the same for the oyster-only and the oyster-eelgrass plots in order to use the same average depth of sedimentation in the sediment volume calculation. The oyster-eelgrass plot shows less accumulation, primarily due to lower sedimentation in between the oyster units. However, the difference is within the uncertainty of the survey techniques and volume calculations.

The space available on each element for oyster settlement and growth was examined by combining the average shell bag elevation and sediment accumulation. This space has decreased through time due to subsidence of the elements into the mudflat and accumulation of sediment adjacent to and inside the reef structure (Figure 4). At the start of the elevation surveys (8 weeks after deployment), an average of 65 cm was vertically available compared to an average of 30-40 cm available by July 2013, a loss of 25-35 cm.

Table D-1 – Sediment Volume Changes

		Volume Change (m^3) (+ is deposition)		
Region	Approx Area (m^2)	Oyster Only	Oyster Eelgrass	Control
inside units (between elements)	96	23.0	23.0	N/A
between units	312	3.1 to 16.1	-2.9 to 10.3	0 to 17.1
adjacent to units	*34*	*1.9 to 3.3*	*1.3 to 2.7*	*N/A*
center of aisle (N-S)	*170*	*0.3 to 7.4*	*-1.7 to 5.4*	*N/A*
center of aisle (E-W)	*108*	*0.9 to 5.4*	*-2.5 to 2.3*	*N/A*
TOTAL (m^3)	408	26.1 to 39.1	20.1 to 33.4	0 to 17.1
Average depth (cm), excluding units themselves		1 to 5.2	-0.9 to 3.3	0 to 5.5

Hydrodynamic monitoring

Wave heights, wave period, wave direction, current speeds, and current directions have been measured on both sides of the San Rafael reef structures. Two bottom-mounted Acoustic Doppler Current Profilers (ADCPs) were deployed at the San Rafael site inshore of the reefs to measure transmitted waves across the site with placements behind the oyster-eelgrass reef and at the control site; they were located 15 and 21 cm above the bed respectively. During the collection period, three large wind events occurred although because of the position of the San Rafael location, most waves propagate offshore away from the site.

Dates of collection: February 22 – April 16, 2013

Findings:

Wave height and wave period show different patterns for the two locations with fewer observations gathered for the instrument in the lee of the oyster-eelgrass plot than the one at the control plot. Wave heights ranged 6- 26 cm for both with a unimodal distribution at the control plot compared to a bimodal distribution for the one in the lee of the reef (Figure D-5). Differences were also seen in the currents in the lee of the reef. Velocities were observed to be faster and flood-dominated, with negligible ebb tide velocities. This contrasts with the current data for the control plot that shows a symmetrical distribution for the flood and ebb tides (NW-SE angle) but at slower speeds (Figure D-6).

A Boussinesq wave model was developed for the San Rafael site. This wave model is providing evaluation of wave and current interaction with the oyster reef for a wider range of possible wave events (wave height and period) and water depths (tide range). The model results are being validated with the field data. Preliminary results testing the wave height and wave energy reduction of the reefs for different wave and water level conditions show a 28% reduction of wave energy at the reef. More comprehensive analysis is underway to understand how the reef alters the waves and currents.

Ambient water properties

To collect ambient water properties (temperature, salinity, dissolved oxygen (DO), pH, and turbidity), ESA PWA deployed a Nortek Sonde on the bayside of the reef structures at the San Rafael site in spring 2013. The goal is to collect data for comparison with water properties being gathered inside the reefs and eelgrass plots.

Dates of collection: May 16-June 3, 2013

Findings:

Dissolved oxygen [DO] and pH do not vary substantially while temperature, turbidity track with tide or wind events (Figure D-7).The data were compared to the nearby China Camp NERR water quality data for quality checking, which showed close agreement for some of the parameters (temperature and DO). Turbidity varied slightly, suggesting localized suspension of sediment could be occurring. The Sonde was re-deployed for another round of monitoring at the end of September 2013.

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Authors of this section: ESA PWA: Doug George, Jeremy Lowe, Elena Vandebroek, Damien Kunz, Pablo Quiroga

San Francisco Bay Living Shorelines Project
October 2013 EPA Report

List of Figures

Section A Figures: Native Oyster Monitoring

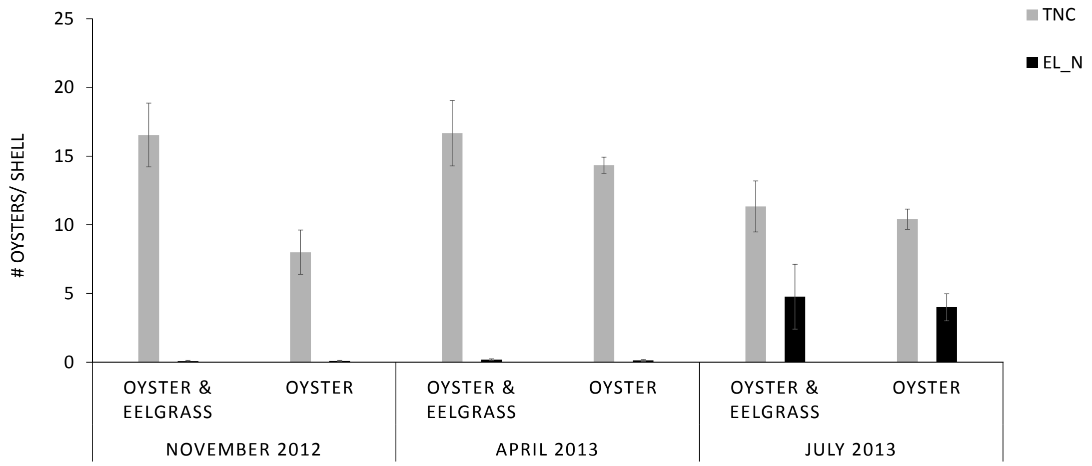


Figure A-1. Number of oysters per shell in sample shell bags for three time points, in the oyster and eelgrass plots and the oyster-only plots, for both locations. TNC = The Nature Conservancy property in San Rafael; EL_N = the Eden Landing North site, at the Hayward shoreline.

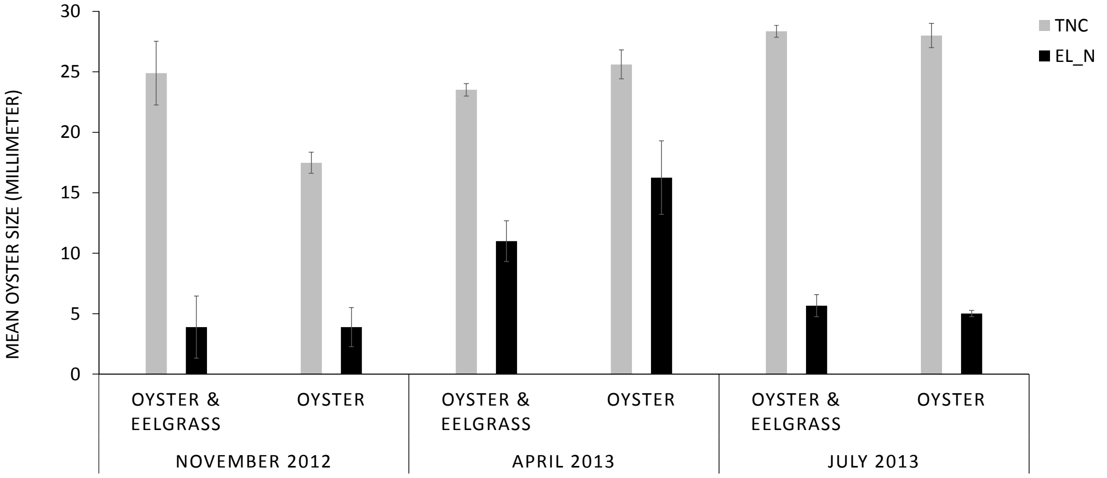


Figure A-2. Sizes of oysters sample shell bags for three time points, in the oyster and eelgrass plots and the oyster-only plots, for both locations.

TNC = The Nature Conservancy property in San Rafael; EL_N = the Eden Landing North site, at the Hayward shoreline.

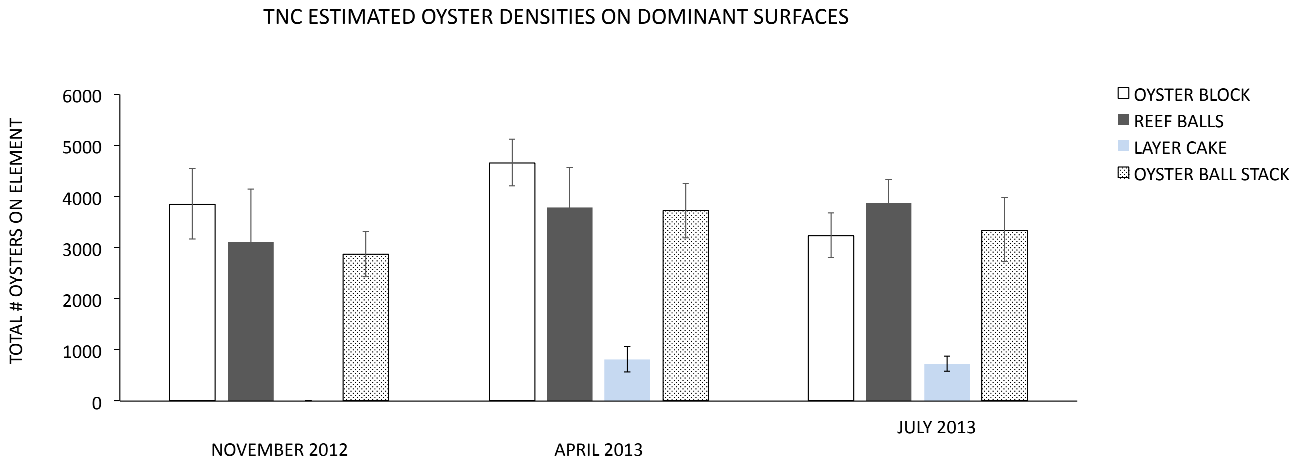


Figure A-3. Estimated numbers of oysters on the dominant surfaces of four “baycrete” element types at the TNC property. Estimates are for vertical surfaces for the oyster blocks, reef balls and oyster ball stacks and for horizontal surfaces for the layer cakes.

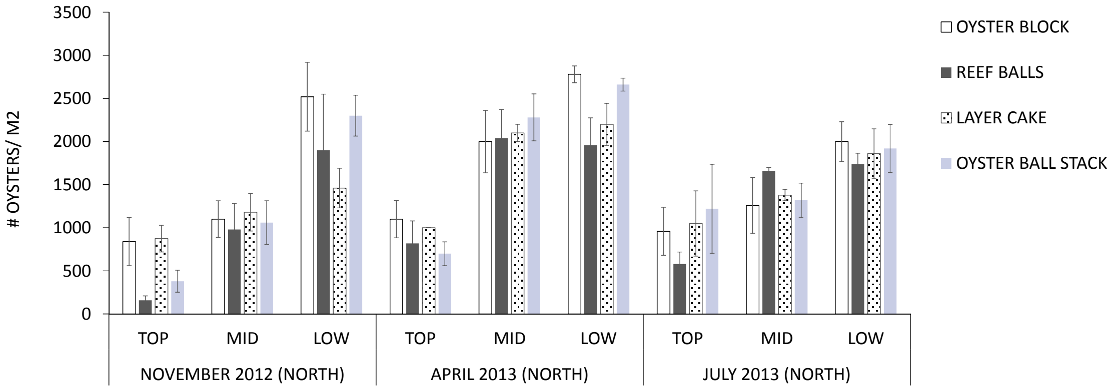


Figure A-4. Number of oysters per m^2 at TNC. Surveys were conducted on north facing vertical surfaces on three dates: November 2012, April 2013, and July 2013.

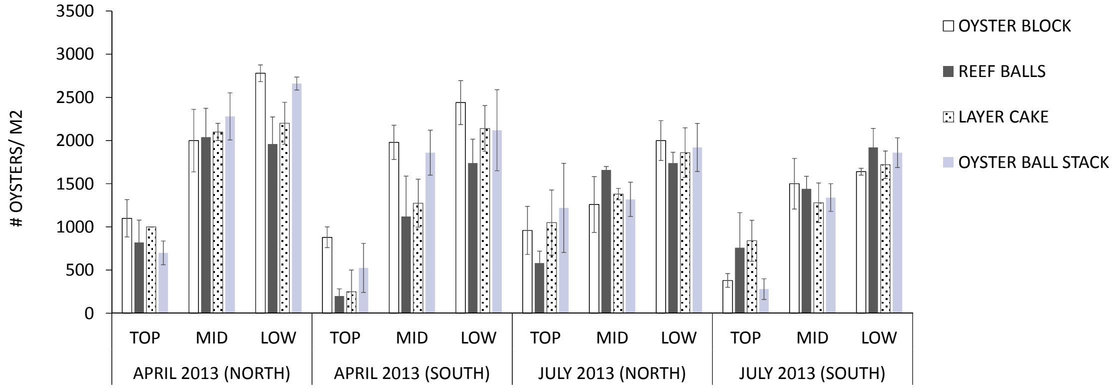


Figure 3: TNC mean north vertical surface oyster density. Surveys were conducted on north facing vertical surfaces on three dates: November 2012, April 2013, and July 2013.

Figure A-5: A comparison of the number of oysters per m at TNC, on north and south sides of elements. Surveys were conducted on north and south facing vertical surfaces on two dates: April 2013 and July 2013.

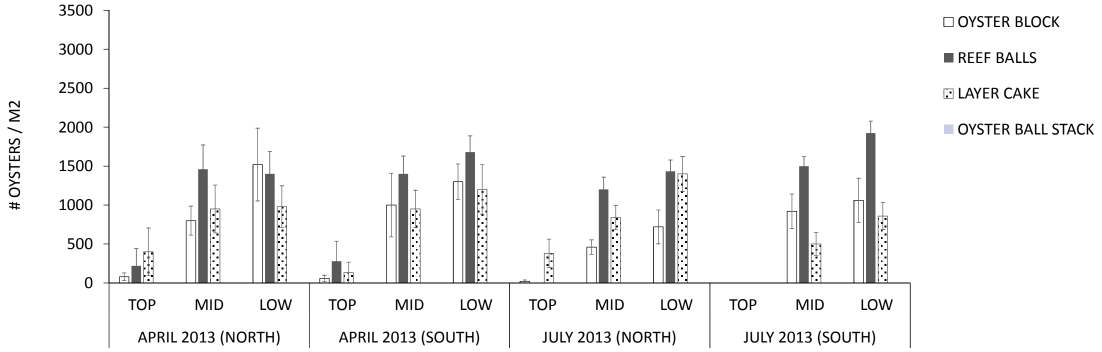


Figure A-6: Number of oysters per m^2 at TNC on horizontal surfaces. Surveys were conducted on north and south facing horizontal surfaces on two dates: April 2013 and July 2013. Oyster ball stacks do not have horizontal surfaces and thus were not surveyed. Axis are the same as for Figure A-5 (vertical surfaces) for easy comparison.

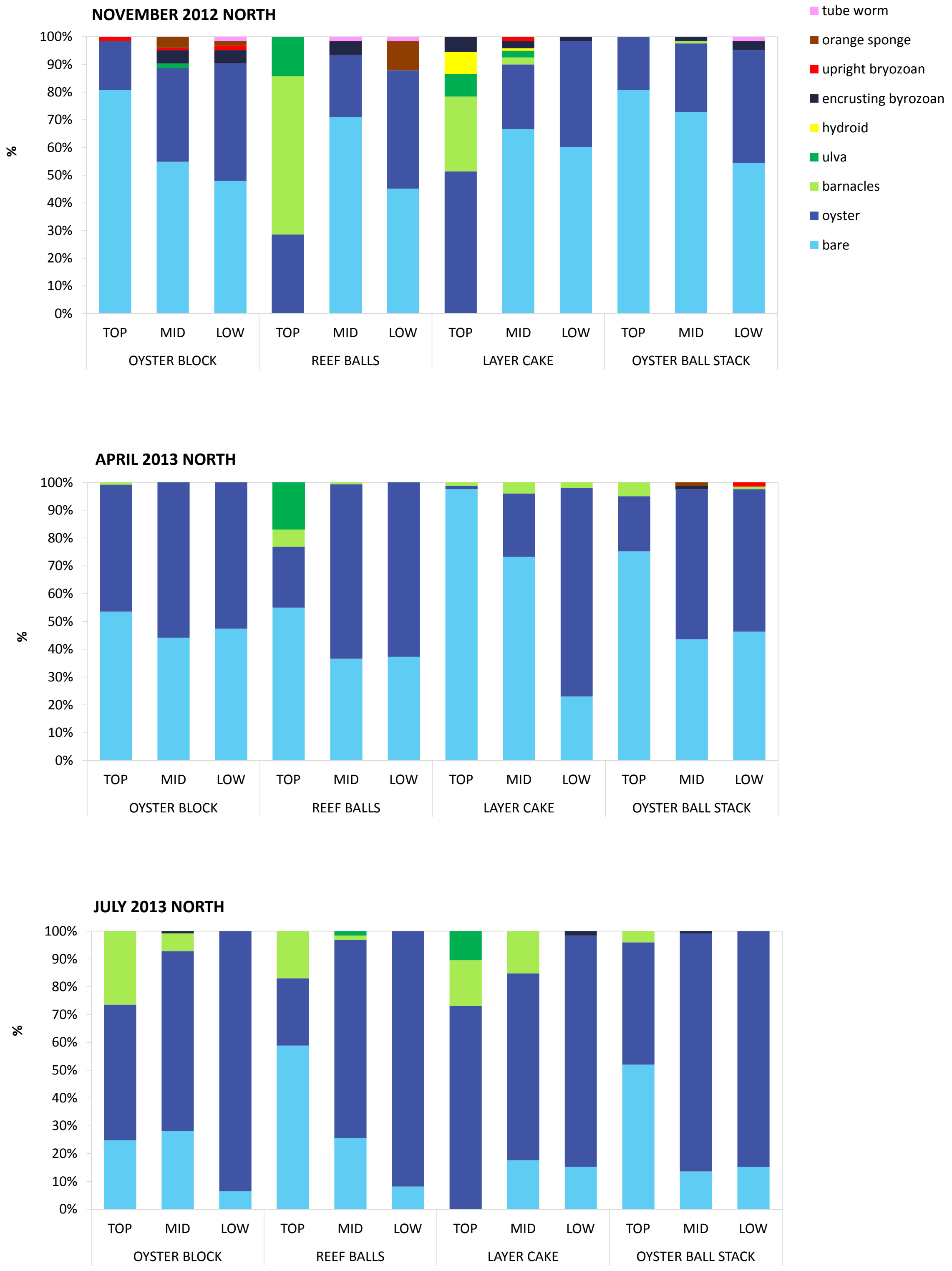


Figure A-6. Composition of sessile organisms across element types, expressed as percent cover for three time periods, November 20112, April 2013, and July 2013. Surveys were conducted on North facing vertical surfaces.

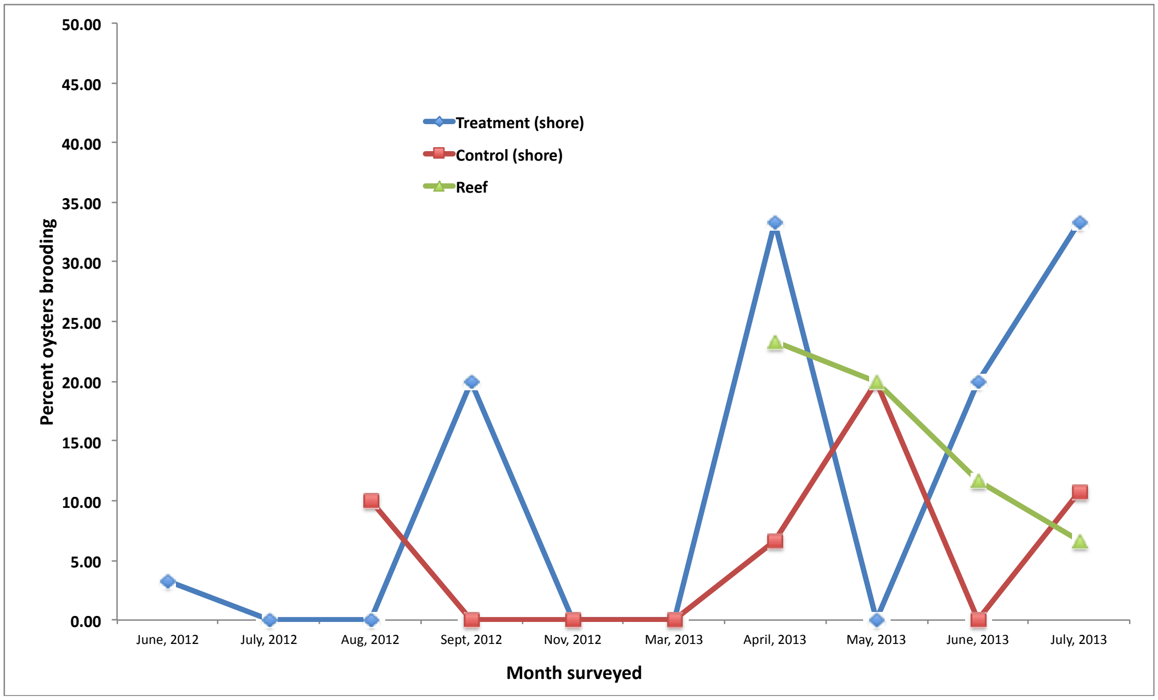


Figure A-7. Percent of oysters brooding at TNC, along the shoreline inshore of the constructed reef (Treatment), shoreline at the control site (Control) and on the shell bags (Reef). Monitoring for brooding oysters on the shell bags began in April 2013.

Section B Figures: Eelgrass, Epibenthic Invertebrate, Fish, Water Quality Monitoring

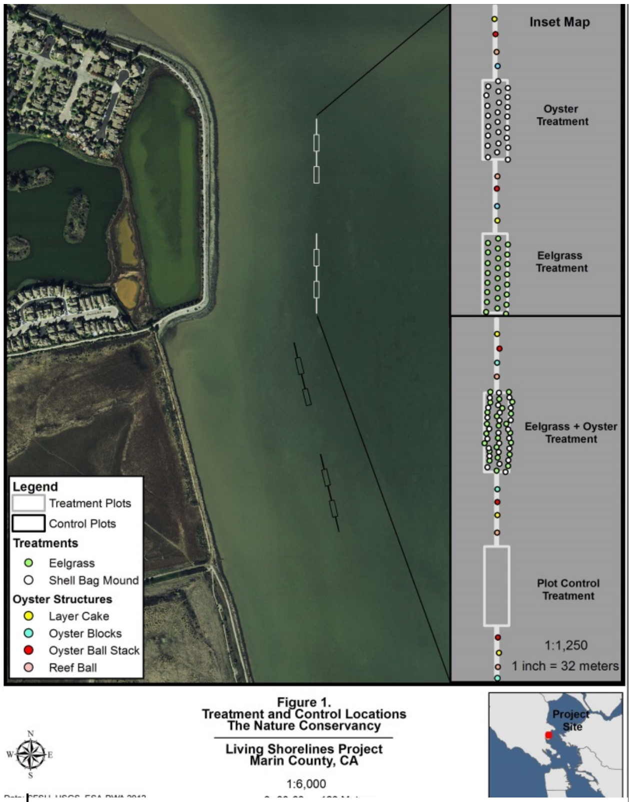


Figure B-2~~1~~ – Map showing the location and orientation of plots at The Nature Conservancy site in San Rafael bay.

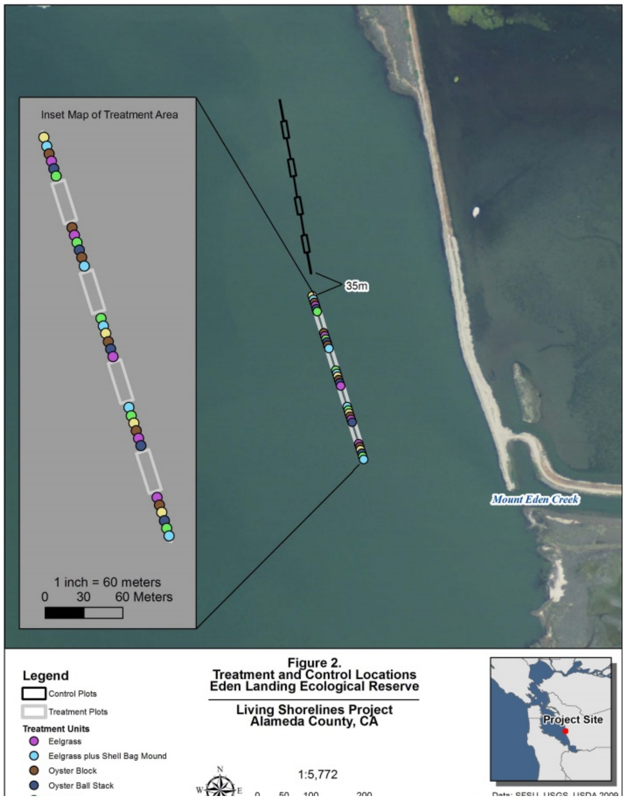


Figure B-1~~2~~ – Map showing the location and orientation of plots at the Eden Landing Ecological Reserve site in Hayward.

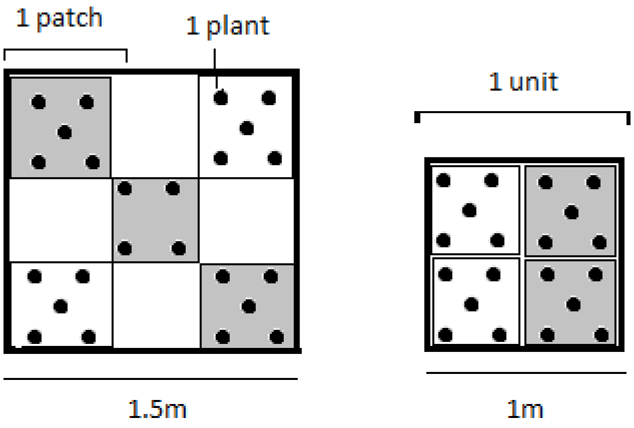
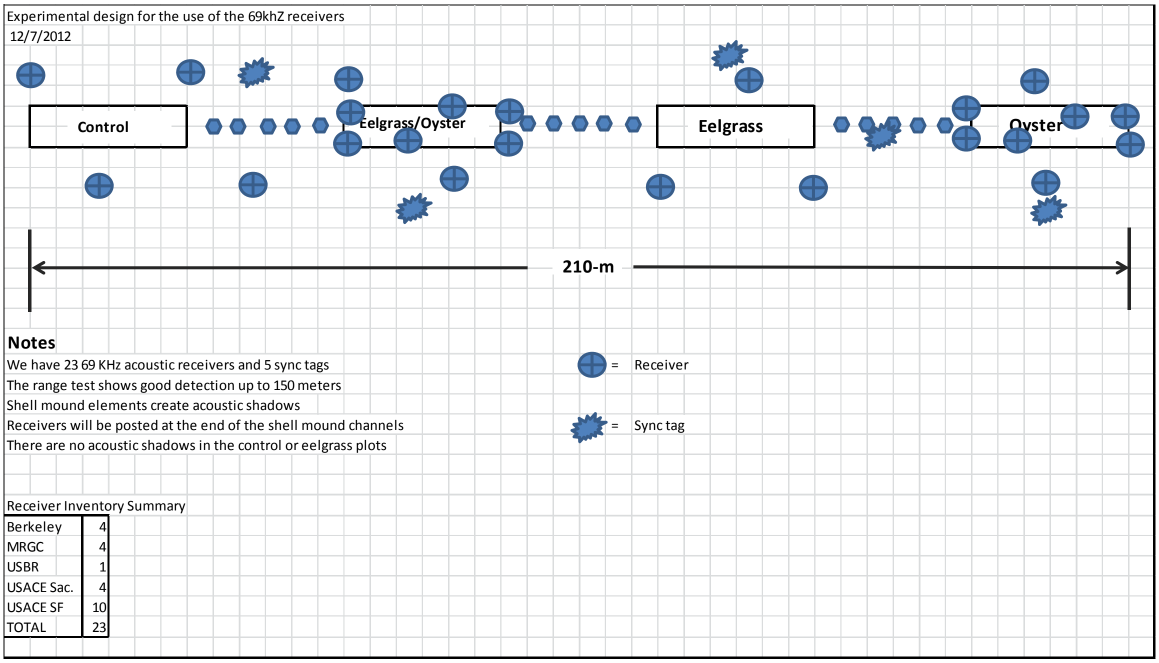


Figure B-3. Planting schematic for eelgrass units at TNC (left) and ELER (right). Shaded patches un-shaded patches indicate different donors. The central patch of eelgrass in each eelgrass unit at TNC alternated between PM and PSP donor eelgrass shoots to give 12 PM dominated and 12 PSP dominated units in each plot (24 total in both EG and EG+O treatment plots). Patches are numbered 1 to 5, ascending in a clockwise direction with 5 being the patch in the center. Each ELER unit contained 10 plants from BFI and 10 from ELER (20 total).



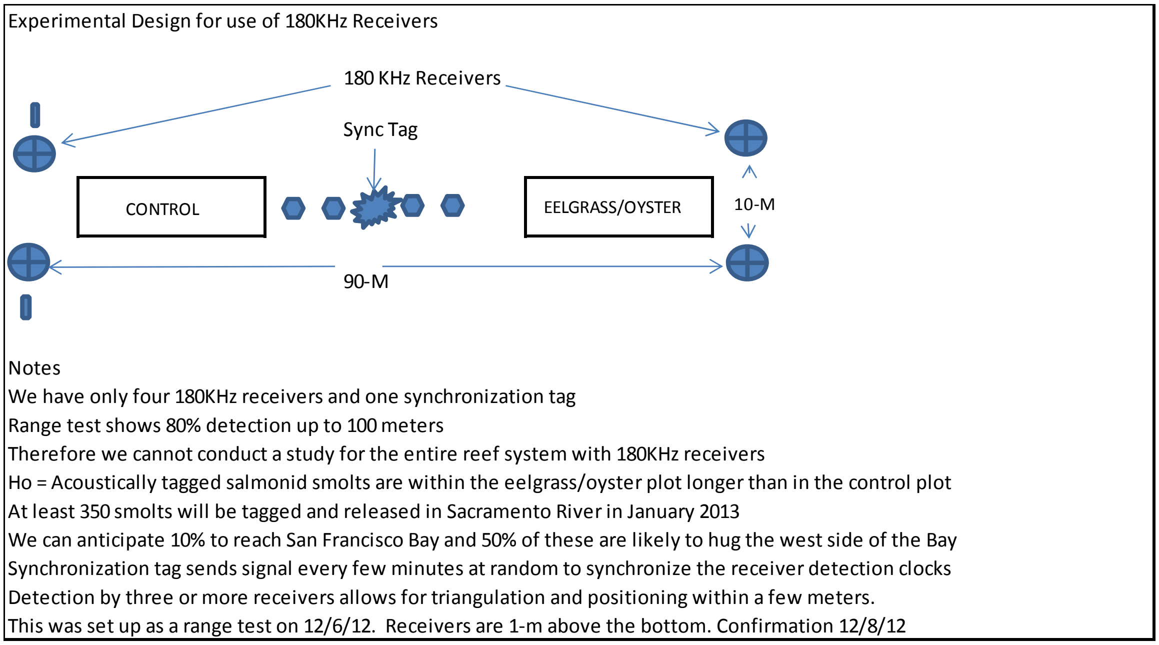
Experimental design for the use of the 69khZ receivers
12/7/2012

Notes

We have 23 69 KHz acoustic receivers and 5 sync tags
The range test shows good detection up to 150 meters
Shell mound elements create acoustic shadows
Receivers will be posted at the end of the shell mound channels
There are no acoustic shadows in the control or eelgrass plots

Receiver Inventory Summary

Berkeley	4
MRGC	4
USBR	1
USACE Sac.	4
USACE SF	10
TOTAL	23



Experimental Design for use of 180KHz Receivers

Notes
We have only four 180KHz receivers and one synchronization tag
Range test shows 80% detection up to 100 meters
Therefore we cannot conduct a study for the entire reef system with 180KHz receivers
Ho = Acoustically tagged salmonid smolts are within the eelgrass/oyster plot longer than in the control plot
At least 350 smolts will be tagged and released in Sacramento River in January 2013
We can anticipate 10% to reach San Francisco Bay and 50% of these are likely to hug the west side of the Bay
Synchronization tag sends signal every few minutes at random to synchronize the receiver detection clocks
Detection by three or more receivers allows for triangulation and positioning within a few meters.
This was set up as a range test on 12/6/12. Receivers are 1-m above the bottom. Confirmation 12/8/12

Figure B-4 – a schematic of the locations of 27 Vemco acoustic receivers for fish monitoring at the TNC site (A), and a detailed schematic of the design of sync tag and acoustic receiver layouts between the EG+O treatment and control (B). Drawings courtesy of Bud Abbott.

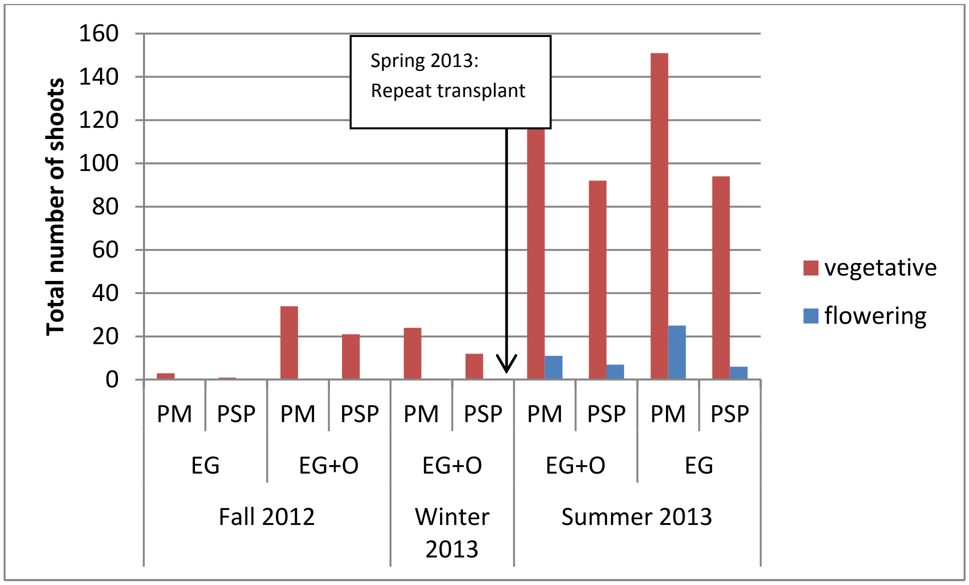


Figure B-5 – Total number of vegetative and flowering eelgrass shoots present, per donor and treatment plot at The Nature Conservancy site, San Rafael in fall 2012, winter 2013 and summer 2013. EG = eelgrass only plot, EG+O = eelgrass and oyster substrate plot, PM = plants from the Point Molate donor site and PSP = plants from the Point San Pablo donor site.

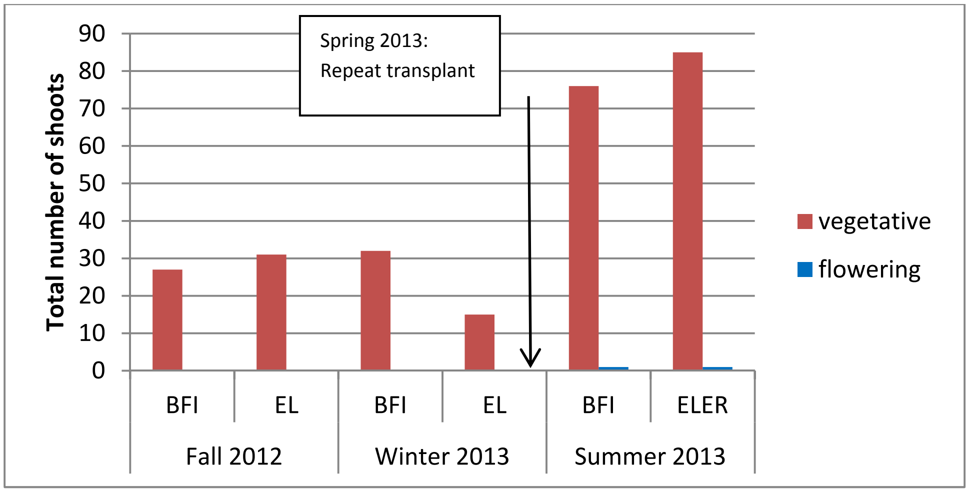


Figure B-6 - Number of vegetative and flowering shoots by donor at Eden Landing, Hayward in fall 2012, winter 2013 and summer 2013. BFI = plants from the Bay Farm Island donor site and ELER = plants from the Eden Landing Ecological Reserve site.

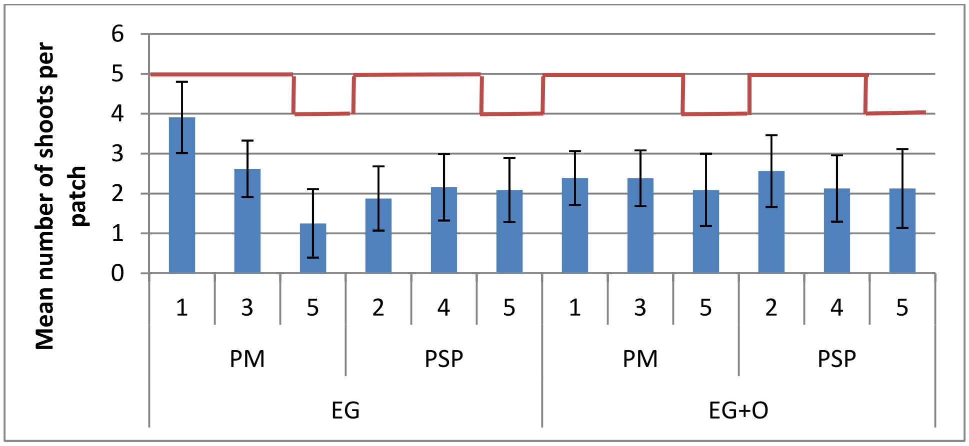


Figure B-7a – Mean number of vegetative shoots per patch, donor and treatment plot at TNC in July 2013. Horizontal axes labels 1 – 5 refer to the clockwise numbering of patches of eelgrass as shown in figure 3. Original plant numbers in each patch was 5 plants in patches 1, 2 3 and 4 and 4 plants in patch 5 making a total of 24 plants per eelgrass unit. The red line indicates the original plant numbers in each patch. EG = eelgrass only plot, EG+O = eelgrass and oyster substrate plot, PM = plants from the Point Molate donor site and PSP = plants from the Point San Pablo donor site. Error bars = 95% confidence intervals.

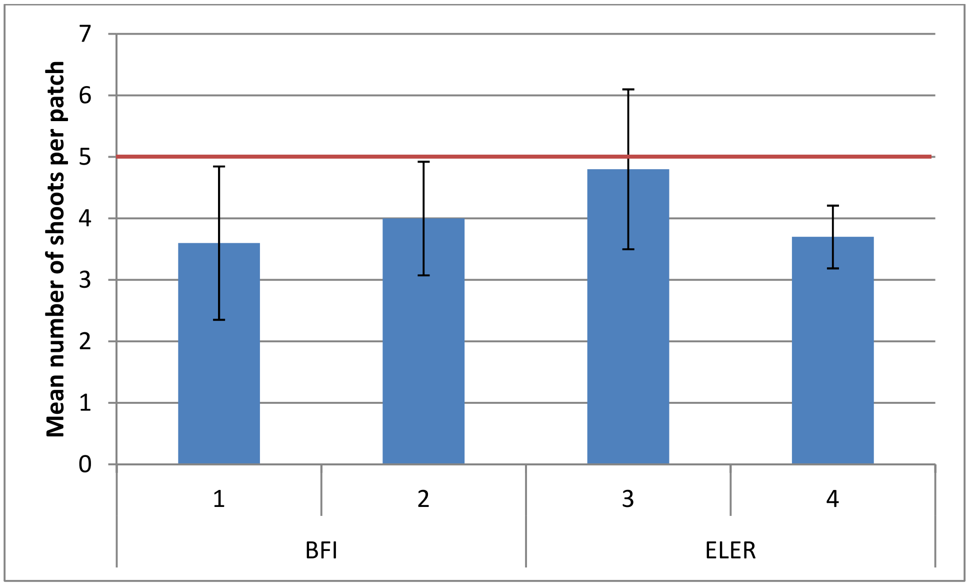


Figure B-7b – Mean number of vegetative shoots per patch and donor at Eden Landing, Hayward. Horizontal axes labels 1 – 4 refer to the clockwise numbering of patches of eelgrass as shown in figure 3. Five plants were planted in each patch making a

total of 20 plants per eelgrass unit. The red line indicates the original plant numbers in each patch. BFI = plants from Bay Farm Island, ELER = plants from Eden Landing. Error bars = 95% confidence intervals.

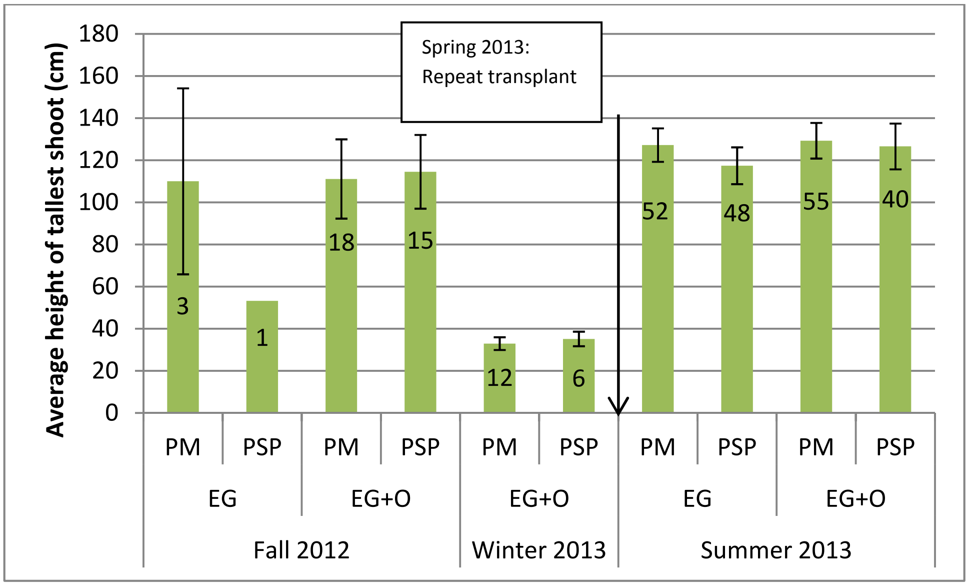


Figure B-8 - Average height of the tallest eelgrass shoot in each patch, by donor and treatment plots at The Nature Conservancy site at San Rafael in fall 2012, winter 2013 and summer 2013. EG = eelgrass only plot, EG+O = eelgrass and oyster substrate plot, PM = plants from the Point Molate donor site and PSP = plants from the Point San Pablo donor site. Numbers on columns indicate the sample size. Error bars = 95% confidence intervals.

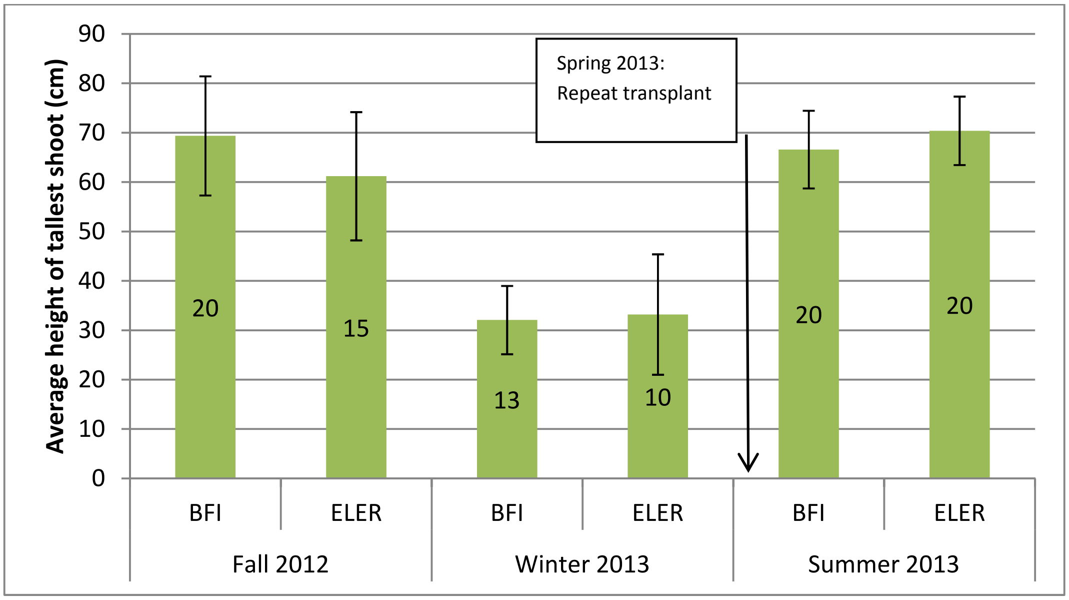


Figure B-9 - Average height of the tallest eelgrass shoot in each patch, by donor at Eden Landing, Hayward. BFI = plants from the Bay Farm Island donor site and ELER = plants from the Eden Landing Ecological Reserve site in fall 2012, winter 2013 and summer 2013. Numbers in columns indicate the sample size. Error bars = %95 confidence interval.

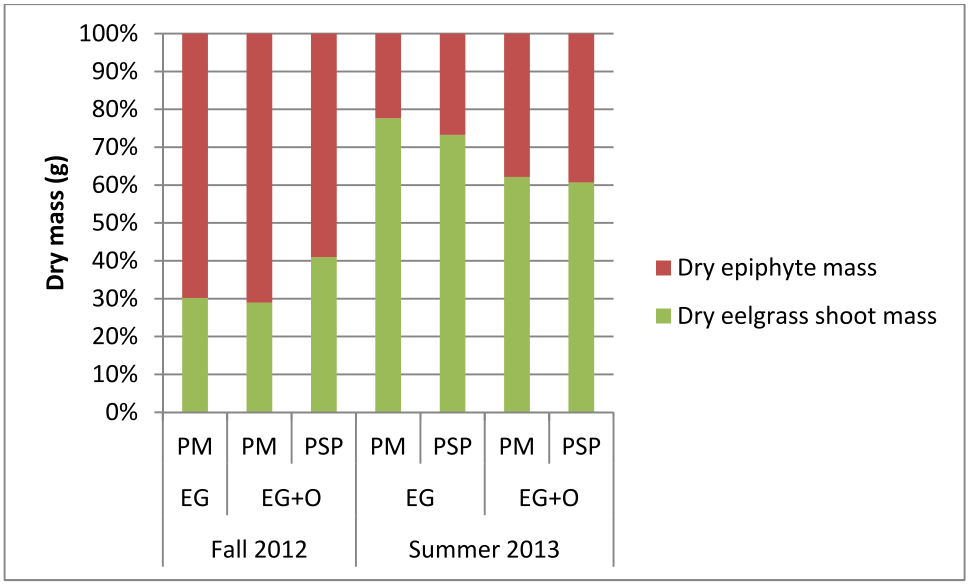


Figure B-10 –Mean epiphyte load, shown as a percent of dry mass, collected at The Nature Conservancy site in fall 2012 and summer 2013. EG = eelgrass only plot, EG+O = eelgrass + oyster substrate plot, PM = plants from the Point Molate donor site and PSP = plants from the Point San Pablo donor site. Note that Fall 2012 samples included only leaf #4 to avoid removing whole plants when there were few. Leaf #4 is an older leaf and likely to have proportionally greater epiphyte biomass per g of eelgrass biomass than would whole shoots, as were collected in summer 2013.

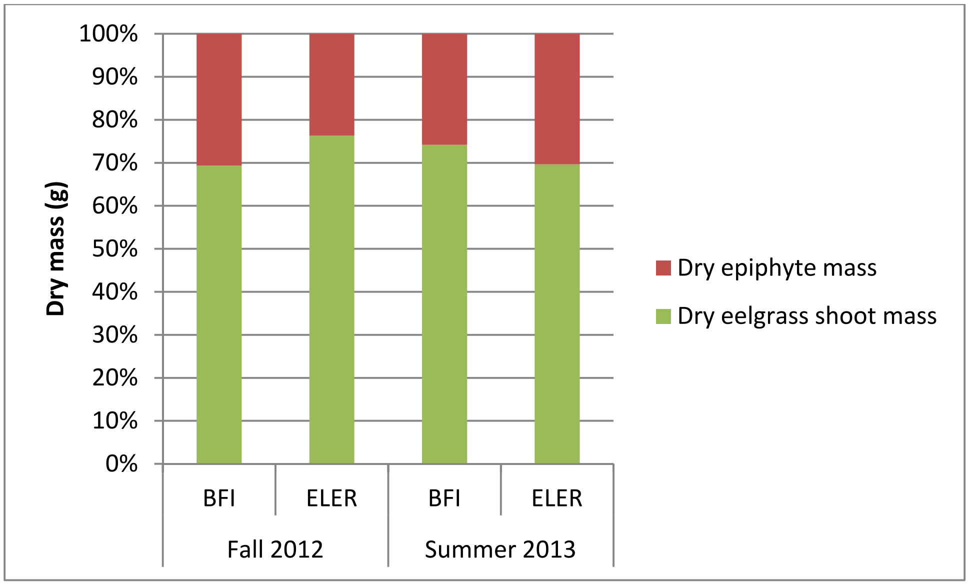


Figure B-11 - Mean epiphyte load, shown as a proportion of the total sample weight from samples at Eden Landing, Hayward, in fall 2012 and summer 2013. BFI = plants from the Bay Farm Island donor site and ELER = plants from the Eden Landing Ecological Reserve site. Note that Fall 2012 samples included only leaf #4 to avoid removing whole plants when there were few. Leaf #4 is an older leaf and likely to have proportionally greater epiphyte biomass per g of eelgrass biomass than would whole shoots, as were collected in summer 2013.

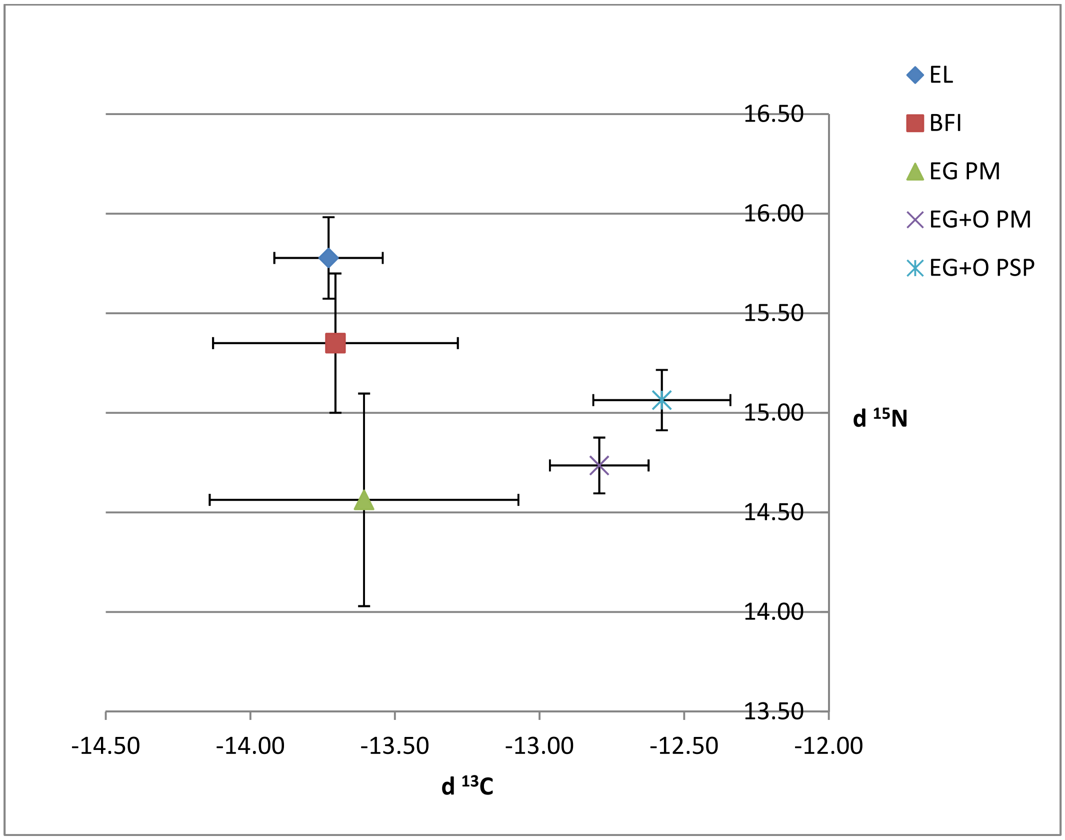


Figure B-12 – d^{13}C plotted against d^{15}N for leaf 2 subsamples, collected in fall 2012. Error bars = 95% confidence intervals.

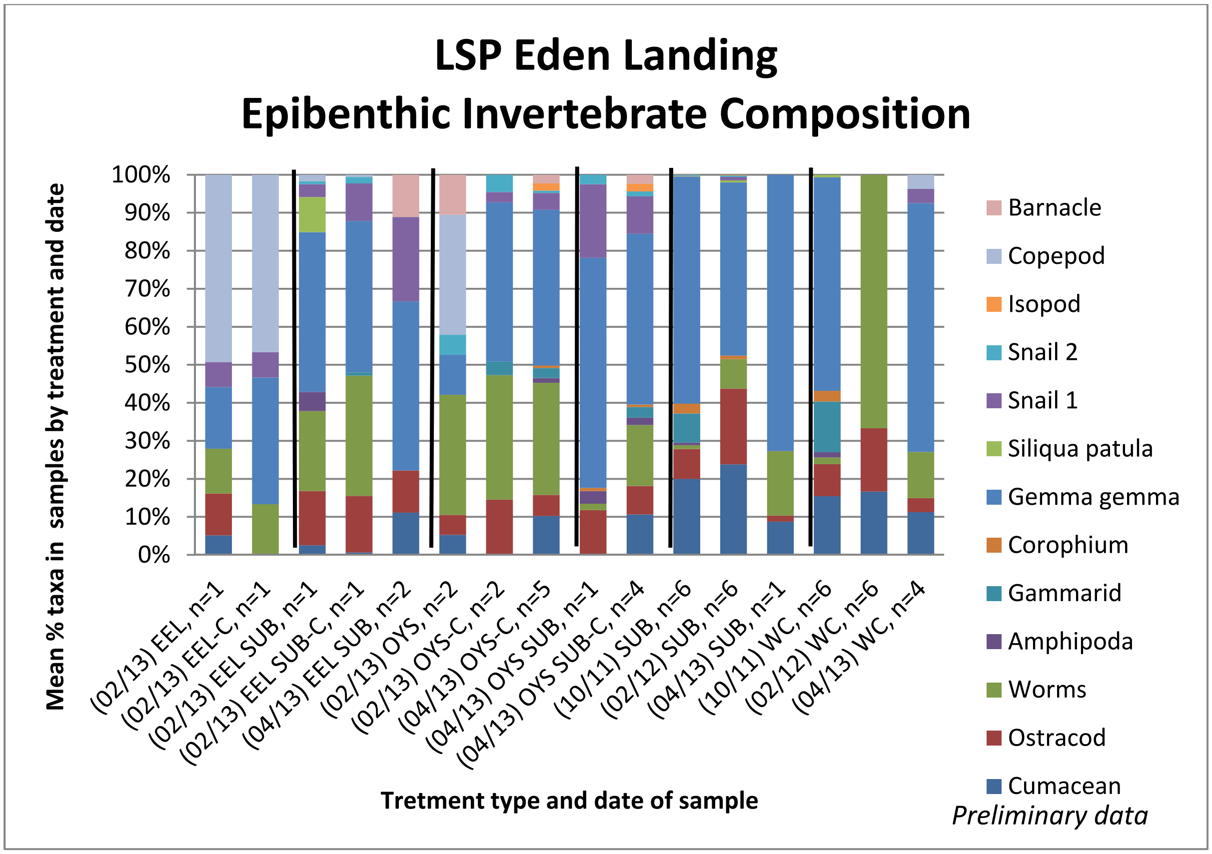


Figure B-13. Preliminary mean aquatic invertebrate abundance data (sample sizes vary) collected by suction sampling in 0.25m x 0.25m quadrat during baseline sampling (October 2011, February 2012) and post-treatment sampling (February 2013 and April 2013) at the ELER site. Data collected and compiled by SFSU 2011-2013.

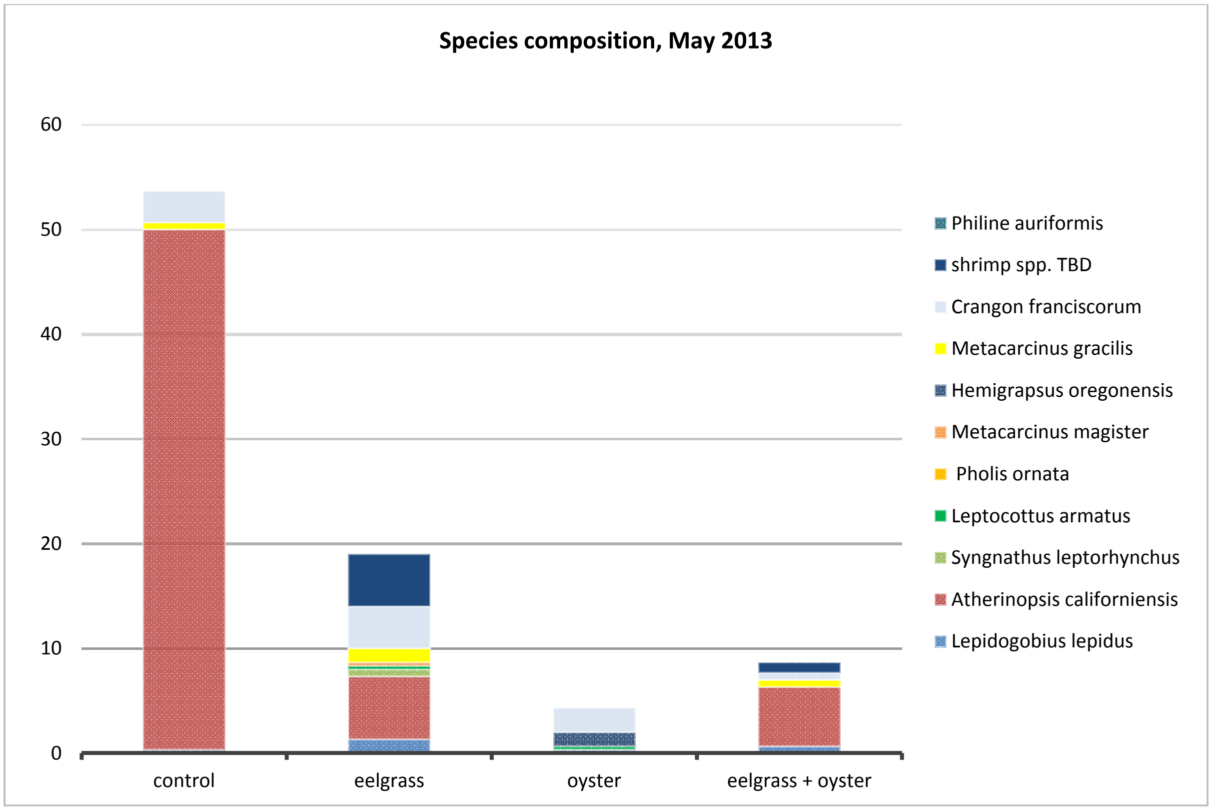


Figure B-14 – Mean number of individuals caught per 30m seine sweep in each treatment at The Nature Conservancy site in San Rafael, in May 2013. Contributions made by different species to the mean seine count are indicated by different colours.

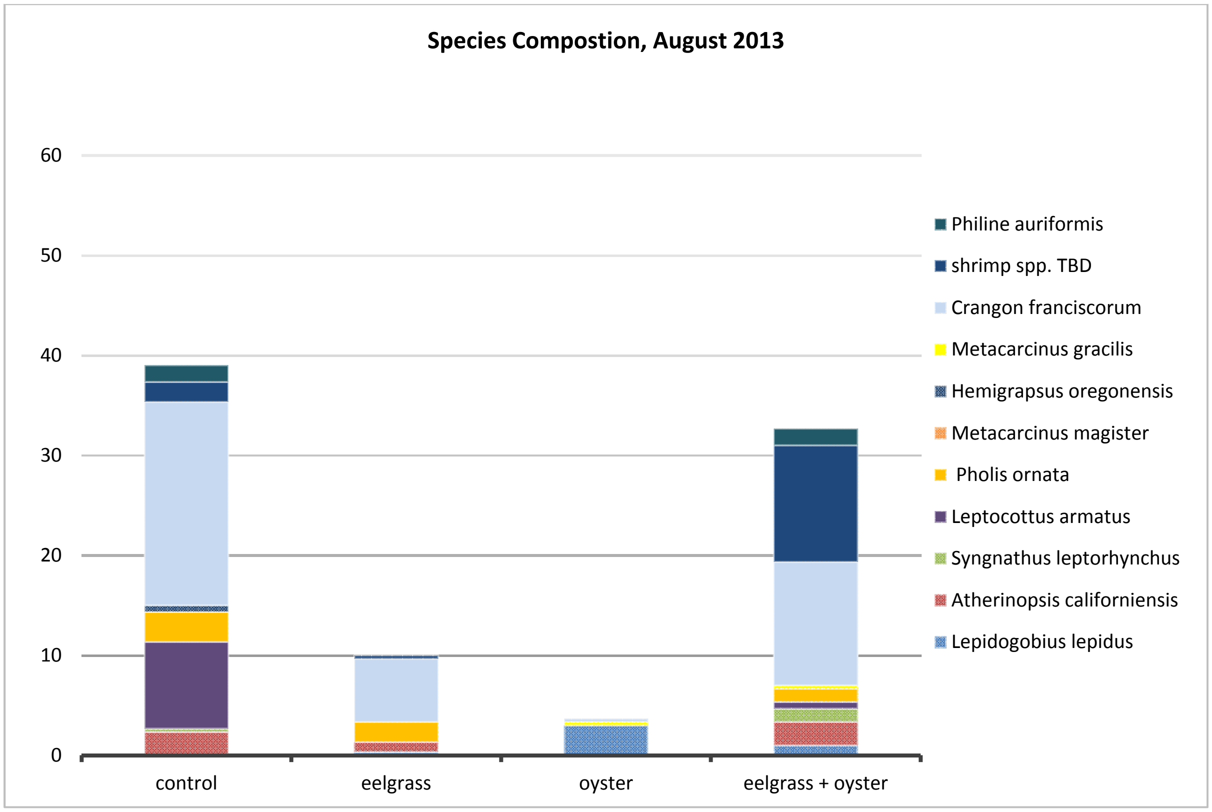


Figure B-15 - Mean number of individuals caught per 30m seine sweep in each treatment at The Nature Conservancy site in San Rafael, in August 2013. Contributions made by different species to the mean seine count are indicated by different colours.

Tables: SFSU October 2013 report

Table B-1- Average biomass (g) of dry eelgrass, dry epiphyte [plus 95% confidence intervals (95% CI)] and average dry mass of epiphytes per 1g of dry eelgrass, by donor and treatment at TNC. Data are from the fall 2012 and summer 2013 samples. Note that Fall 2012 sampling was of a single, older leaf per sampled shoot, while summer 2013 was of whole shoots; thus, comparisons should be made among treatments within dates only.

Treatment	Donor	Fall 2012			Summer 2013		
		Average dry mass of eelgrass leaf #4 (g) [95% CI]	Average dry mass of epiphyte (g) [95% CI]	Average dry mass of epiphyte per g of dry eelgrass tissue (g)	Average dry mass of eelgrass shoot (g) [95% CI]	Average dry mass of epiphyte (g) [95% CI]	Average dry mass of epiphyte per g of dry eelgrass tissue (g)
EG	PM	0.34[+/-0.15]	0.79[+/-0.64]	2.31	1.8 [+/- 0.81]	0.52 [+/-0.08]	0.29
	PSP	N/A	N/A	N/A	1.3 [+/-0.77]	0.47 [+/-0.06]	0.36
	Both donors	N/A	N/A	N/A	1.5 [+/-0.81]	0.49 [+/-0.05]	0.33
EG+O	PM	0.14[+/-0.07]	0.35 [+/-0.14]	2.45	1.3 [+/-0.59]	0.76 [+/-0.45]	0.61
	PSP	0.14[+/-0.06]	0.20 [+/-0.06]	1.44	1.4 [+/-0.86]	0.94 [+/-0.51]	0.65
	Both donors	0.14[+/-0.10]	0.27[+/-0.21]	1.95	1.4 [+/-0.74]	0.85 [+/-0.51]	0.63
	All treatments	0.17[+/-0.11]	0.34[+/-0.07]	2.05	1.4 [+/-0.77]	0. 67[+/-0.19]	0.46

Table B-2 - Epiphyte: eelgrass biomass (g) ratios by donor at Eden Landing, Hayward.

Donor	Fall 2012			Summer 2013		
	Average dry mass of eelgrass shoot (g) [95% CI]	Average dry mass of epiphyte (g) [95% CI]	Average dry mass of epiphyte per g of dry eelgrass tissue (g)	Average dry mass of eelgrass shoot (g) [95% CI]	Average dry mass of epiphyte (g) [95% CI]	Average dry mass of epiphyte per g of dry eelgrass tissue (g)
BFI	0.13[+/-0.02]	0.06[+/-0.02]	0.44	0.52 [+/- 0.17]	0.17 [+/-0.01]	0.34
ELER	0.15[+/-0.05]	0.05[+/-0.01]	0.31	0.41[+/-0.13]	0.18[+/-0.01]	0.44
Both donors	0.14 [+/-0.03]	0.05[+/-0.01]	0.37	0.46[+/-0.11]	0.18[+/-0.01]	0.39

Table B-3. Mean trap abundance and SD of aquatic invertebrates at the TNC site, Living Shorelines Project. Data collected and compiled by SFSU, 2011-2013.

	Pre/Post				mean abundance ± SD[2]					
Sample Quarter	Date	n	Plot[1]	Soak Hours	HEMORE	METMAG	CRsp	CANMAE	CANPRO	ROMANT
1	Pre: Oct '11	6	Proj Control	24	1.83±1.47	0.50±0.84	0.67±0.52	0	0	0
	Post: Oct '12	3	Plot Control	24	17.00±15.87	0.33±0.58	1.67±1.53	0	0	0
		3	Eelgrass[3]	24	8.67±3.79	0.67±0.58	0.67±1.15	0	0	0
		3	Oys+Eel[3]	24	2.33±3.21	2.33±2.08	3.00±2.00	0	0	0
		3	Oyster	24	0.67±0.58	2.33±4.04	2.67±0.58	0	0	0
		12	Site Control	24	1.83±1.37	0.17±0.19	0.25±0.17	0	0	0
2	Pre: Jan '12	6	Proj Control	6	0.33±0.52	3.20±2.17	0	0	0	0
	Post: Jan '13	3	Plot Control	24	0	0	3.00±1.73	0	0	0
		3	Eelgrass[3]	24	0	0	0	0	0	0
		3	Oys+Eel[3]	24	0	0.33±0.58	16.33±9.24	0.33±0.58	0	0
		3	Oyster	24	1.33±1.53	0	12.33±6.81	0	0	0
		12	Site Control	24	0.17±0.19	0.00	1.25±1.62	0	0	0
3	Pre: May '12	6	Project Control	24	1.00±0.63	0	0.17±0.41	0	0	0
	Post: Apr '13	3	Plot Control	24	5.67±3.51	0	3.67±2.08	0	0	0
		3	Eelgrass[3]	24	0.67±1.15	0	3.33±1.15	0	0	0
		3	Oys+Eel[3]	24	1.33±1.53	0.33±0.58	14.67±12.22	0	1.67±0.58	0
		3	Oyster	24	2.50±2.12	0.50±0.71	7.00±1.41	0	0	0
		12	Site Control	24	3.58±1.93	0.08±0.17	3.41±1.81	0	0.08±0.17	0
4	Pre: Jul '12	6	Proj Control	24	70.33 ±20.69	0	1.67±1.86	0	0	0
	Post: Jul/Aug '13	3	Plot Control	24	0.33±0.58	2.00±1.73	4.00±2.65	0	0	0
		3	Eelgrass	24	0.33±0.58	0.67±0.58	3.00±1.00	0	0	0.33±0.58
		3	Oys+Eel	24	0	0	6.00±1.00	0	0	1.00±1.73
		3	Oyster	24	0	0	2.33±2.52	0	0	0.33±0.58
		12	Site Control	24	1.00±0.82	1.92±0.83	2.67±1.74	0	0	0

1. Proj Control= Project Control (Mudflat pre-restoration); Plot Control = 32mx10m control plot within treatment area; Eelgrass= 32mx10m eelgrass treatment plot; Oys+Eel= 32mx10m control plot combined oyster and eelgrass treatment plot; Oyster = 32mx10m oyster treatment plot; Site Control= Control area outside of treatment area (4 control plots in same arrangement of treatment plots)
2. HEMORE- *Hemigrapsus oregonensis;* METMAG- *Metacarcinus magister;* CANPRO- *Cancer productus;* ROMANT- *Romaleon antennarium;* CRsp- *Crangon* sp.; CANMAE- *Carcinus maenas.*
3. Eelgrass very sparse until July 2013. Eelgrass treatments more representative of mudflat than eelgrass. Oyster + Eelgrass (Oys+Eel) treatments more representative of oyster treatment than combined.

Table B-4. Mean trap abundance and SD of aquatic invertebrates at the Eden Landing (ELER) site, Living Shorelines Project. Data collected and compiled by SFSU, 2011-2013.

	Pre/Post				mean abundance ± SD[2]			
Sample Quarter	**Date**	**n**	**Plot[1]**	**Soak Hours**	**HEMORE**	**METMAG**	**CRsp**	**ILYOBS**
1	Pre: Oct 2011	6	Proj Control		2.83±1.72	0	0	37.50±29.45
	Post: Oct 2012	6	Site Control	24	0.17 ± 0.41	0	0	27.67 ± 32.55
		6	Treatment	24	2.83 ± 1.17	0	0.33 ± 0.52	33.83 ± 40.53
2	Pre: Jan 2012	6	Proj Control	3	0.17 ±0.41	0	0	0
	Post: Jan 2013	6	Site Control	24	0.17±0.45	0	0.17±0.41	1.67±1.86
		6	Treatment	24	0.83±1.41	0	0	1.00±1.10
3	Pre: Apr 2012	6	Proj Control	6	0	0	0	0
	Post: Apr 2013	6	Site Control	24	0.17±0.41	1.00±0.89	0.17±0.41	143.50±81.11
		6	Treatment	24	1.40±1.67	0.40±0.89	0	277.40±75.42
4	Pre: Sep 2012	6	Proj Control	24	1.00±1.10	0	0	215.00±203.42
	Post: July 2013	6	Site Control	24	2.00±1.26	0	0.17±0.41	86.67±89.28
		4[3]	Treatment	24	6.00±5.83	0	1.50±1.73	39.50±65.29

1. Proj Control= Project Control (Mudflat pre-restoration); Site Control = mudflat adjacent to treatment area post-restoration; Treatment=Treatment area
2. HEMORE- *Hemigrapsus oregonensis;* METMAG- *Metacarcinus magister;* CRsp- *Crangon* sp.; ILYOBS- *Illyanassa obsoleta*
3. Sample size is reduced due to drifting, open, or damaged traps.

Table B-5 – Fish species and numbers caught in Minnow and Collapsible traps at TNC prior to project implementation (October 2011, January, April and July 2012) and post-project (October 2012, January, April and July 2013).

TNC	**Pre-project**	**Post-project**												
	4 Quarters Oct'11-Jul'12	**Quarter 1 Oct '12**	**Quarter 2 Jan '13**				**Quarter 3 Apr '13**				**Quarter 4 Jul '13**			
		(All plots)	**O**	**E**	**OE**	**C**	**O**	**E**	**OE**	**C**	**O**	**E**	**OE**	**C**
Bay Pipefish		1						1	1					
Jacksmelt	6		1							1	1			
Leopard Shark	1									2	1			
Pacific Staghorn Sculpin	1													
Shimofuri Goby	2								2	2			1	
Shiner Surfperch	1													
Black Surfperch										1			1	1
Total	**11**	**1**	**1**	**0**	**0**	**0**	**0**	**1**	**3**	**6**	**2**	**0**	**2**	**1**

O= Oyster Treatment; E= Eelgrass Treatment; OE= Combination Oyster plus Eelgrass Treatment; C= Control (both plot control and site control combined)

Table B-6 – Fish species and numbers caught in Minnow and Collapsible traps at ELER prior to project implementation (October 2011, January, April and July 2012) and post-project (October 2012, January, April and July 2013).

ELER	**Pre-project**	**Post-project**						
	4 Quarters Oct’11-Jul’12	**Quarter 1 Oct ‘12**	**Quarter 2 Jan ‘13**		**Quarter 3 Apr ‘13**		**Quarter 4 Jul ‘13**	
	C	(T+C)	**T**	**C**	**T**	**C**	**T**	**C**
Barred Surfperch	1	1						
Leopard Shark*	9	7			1			2
Pacific Staghorn Sculpin	1							
Sevengill Shark	2							
Topsmelt	1							
Sand dab						1		
Total	**14**	**8**	**0**	**0**	**1**	**1**	**0**	**2**

*From quarters 2-4, traps were modified to exclude large sharks

T= Treatment; C= Control

Table B-7 - temperature (temp, °C), dissolved oxygen (DO), conductivity and salinity) from The Nature Conservancy site, San Rafael. OY = oyster shell bag elements plot, EG = eelgrass only plot, OE = oyster shell bag and eelgrass combined plot, SC = small control, LC = large control (North of other plots). Due to equipment malfunction, we were unable to take readings in the large control during April 2013.

	January 2013				
	OY	**EG**	**OE**	**SC**	**LC**
Temp (°C)	11.3 C	10.9 C	10.9 C	10.9 C	10.9 C
DO %	94.8	93.5	88.9	90	86.1
DO mg/l	9.05	8.95	8.5	8.59	8.22
Salinity	22.5	22.9	23	22.9	23
	April 2013				
	OY	**EG**	**OE**	**SC**	**LC**
Temp (°C)	18.2	18.2	17.9	18.2	Not taken
DO %	85.2	90.6	83.9	78.2	
DO mg/l	6.962	7.22	6.78	6.53	
Conductivity (ms)	32.26	32.45	32.2	33.03	
Salinity (ppt)	23.6	23.6	23.6	23.6	
	July 2013				
	OY	**EG**	**OE**	**SC**	**LC**
Temp (°C)	24.1	23.6	24.1	24.41	25
DO %	90.2	87.6	92	85.2	91.3
DO mg/l	7.34	7.14	8.12	6.78	7.48
Conductivity (ms)	33.1	32.98	33.45	33.15	32.95
Salinity (ppt)	24.2	24.2	24.3	24.2	24.2

Table B-8 - temperature (temp, °C), dissolved oxygen (DO), conductivity and salinity measured from treatment blocks 1, 2 and 3 (1 being the most southern) and the control area of Eden Landing Ecological Reserve site, in Hayward.

	January 2013			
	Block 1	**Block 2**	**Block 3**	**Control Area**
Temp (°C)	12.4	12.1	12.3	12.2
DO (%)	100.9	101.4	100.6	103.3
DO (mg/l)	9.95	9.95	9.80	9.55
Conductivity (ms)	26.54	26.57	26.65	26.97
Salinity (ppt)	22.2	22.2	22.3	22.3
	April 2013			
	Block 1	**Block 2**	**Block 3**	**Control Area**
Temp (°C)	18.6	20.3	19.2	19.5
DO (%)	93.4	91.5	90.1	92.5
DO (mg/l)	7.21	7.15	7.05	7.24
Conductivity (ms)	31.79	35.8	33.2	32.5
Salinity (ppt)	23	25.1	24	23
	July 2013			
	Block 1	**Block 2**	**Block 3**	**Control Area**
Temp (°C)	24.8	24.9	25.1	25.3
DO (%)	91.4	90.3	88.6	89.7
DO (mg/l)	7.09	7.06	6.98	7.01
Conductivity (ms)	34.8	33.6	32.9	33.5
Salinity (ppt)	24	25	24.9	25

Table B-9 – Chlorophyll-a extractions from water column samples in treatment and control areas at both ELER and TNC.

Location	Chlorophyll-a (ug/L)	Standard Deviation
ELER Elements	13.4	3.6
ELER Large Control	16.8	1.1
TNC Large Control	5.8	1.1
TNC Small Control	9.5	2.1
TNC Oysters / Eelgrass	6.8	0.4
TNC Eelgrass	7.8	2.1
TNC Oysters	8.0	1.2

Table B-10 – PAR measured at the Nature Conservancy site in San Rafael every quarter since October 2012. Units are micromoles of photons per second per square meter (μmol s^{-1} m^{-2}).

Treatment	Depth	Oct-12	Jan-13	Apr-13	Jul-13
Oyster	Air	1079	2730.667	2843.667	3014
	Surface	497.6667	1775.667	2123	2175
	1m	147.6667	430	113.75	178.5
Eelgrass	Air	1171.667	2607.333	2980.667	2896
	Surface	502	1788.667	2569.667	2150
	1m	125.3333	341	173.9	144
Oyster+ eelgrass	Air	1853.333	2643.333	2963.667	2758
	Surface	783.3333	1489	2106.667	2056
	1m	214.6667	341	71.12	157.6
Small control	Air	2011.667	2675.333	2941.667	2985
	Surface	1101.333	1425	2249	2001
	1m	282	409	73.29667	98.4
Large control	Air	1029.667	2642.333	Not taken	2984
	Surface	443	1796		2067
	1m	125.3333	325.3333		168

Table B-11 - PAR measured at Eden Landing, Hayward every quarter since October 2012. Units are micromoles of photons per second per square meter (μmol s^{-1} m^{-2}).

Treatment	Depth	Oct-12	Jan-13	Apr-13	Jul-13
Block 1	Air	2475	2587	2966	3014
	Surface	2020	1283	1986	1875
	1m	105	233	314	126
Block 2	Air	2568	3000	3958	3450
	Surface	1980	2182	2008	1745
	1m	211	123	163	116
Block 3	Air	2486	3981	3457	3004
	Surface	2018	2056	1658	1896
	1m	273	554	199	175
Control 1	Air	2555	3970	3015	2965
	Surface	1995	1850	1895	1846
	1m	173	Not taken	96	103.5
Control 2	Air	2645		3742	3014
	Surface	2050		2561	1963
	1m	202		189	142
Control 3	Air	2640		3566	3057
	Surface	1836		2154	2045
	1m	269		158	128

Section C Figures: Bird and Benthic Invertebrate Monitoring

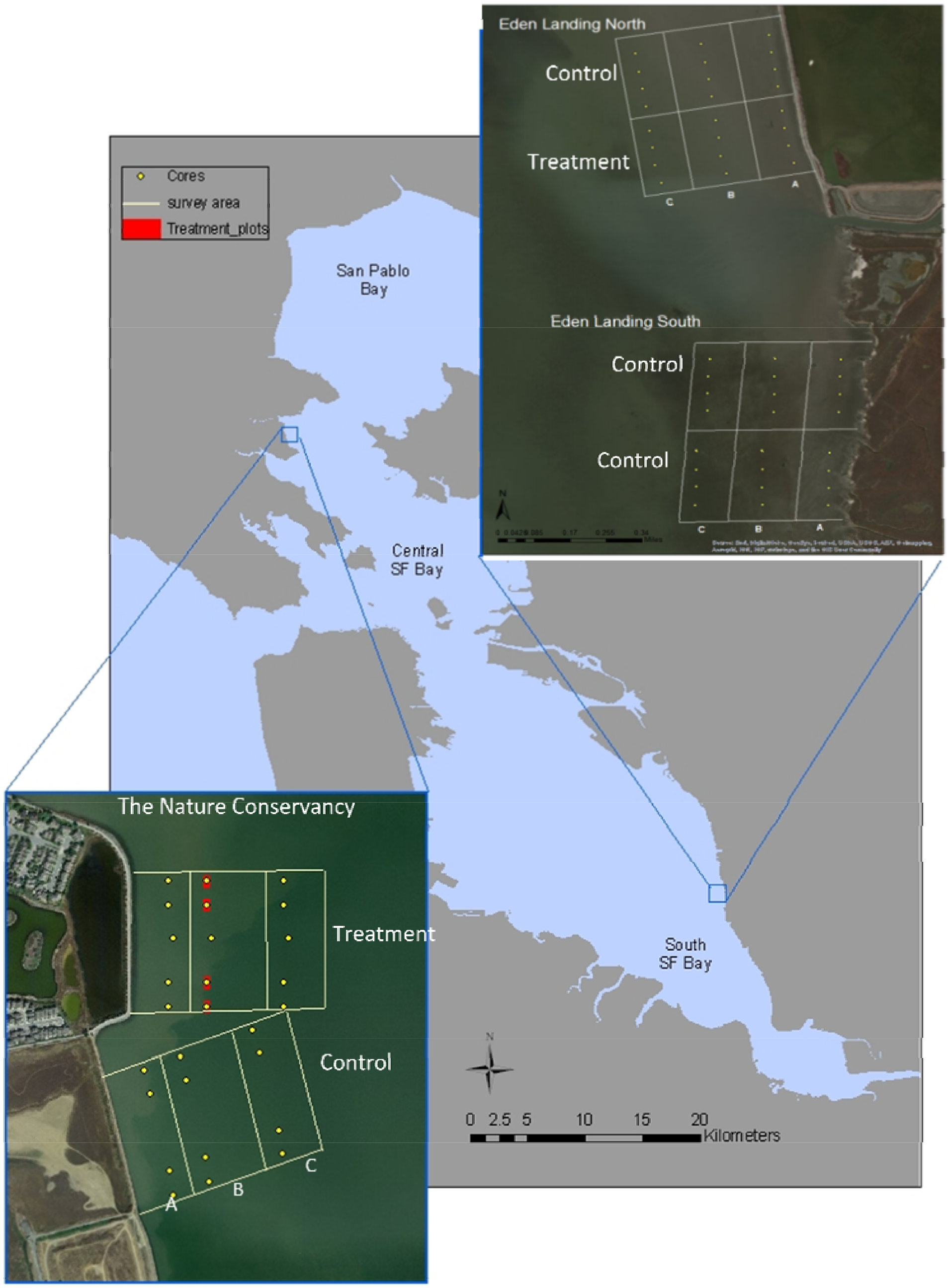


Figure C-1. Living Shorelines study sites including avian survey areas, planned eelgrass and oyster treatment plots, and sampling locations for benthic cores.

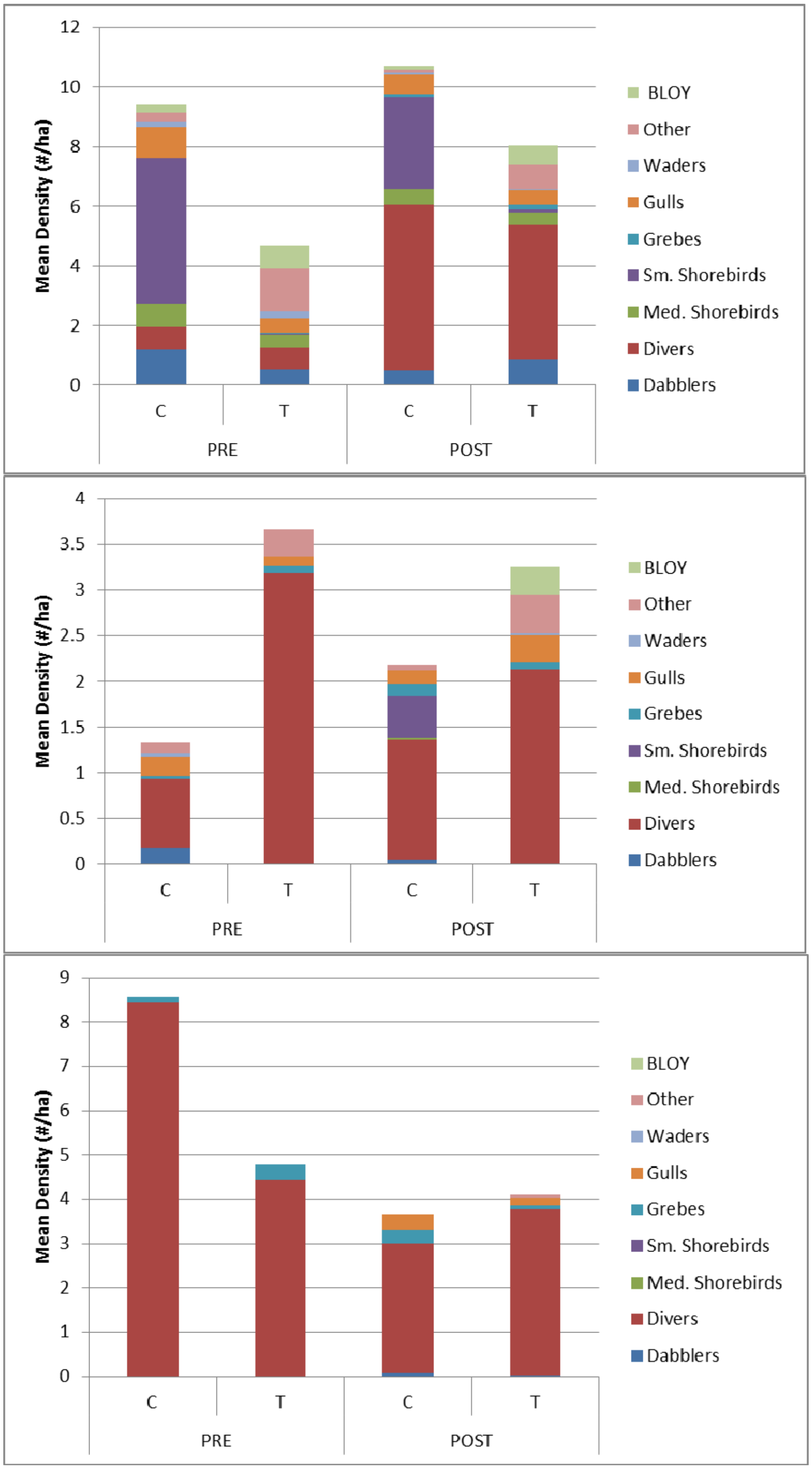


Figure C-2. Mean pre- (2011-2012) and post-installation (2012-2013) avian guild densities during low tide surveys in control and treatment plots for zones A, B, and C (top to bottom) at TNC. Note y-axes are not the same among graphs. Black oystercatcher (BLOY) is included to show the post-treatment increase in this species in Zone B.

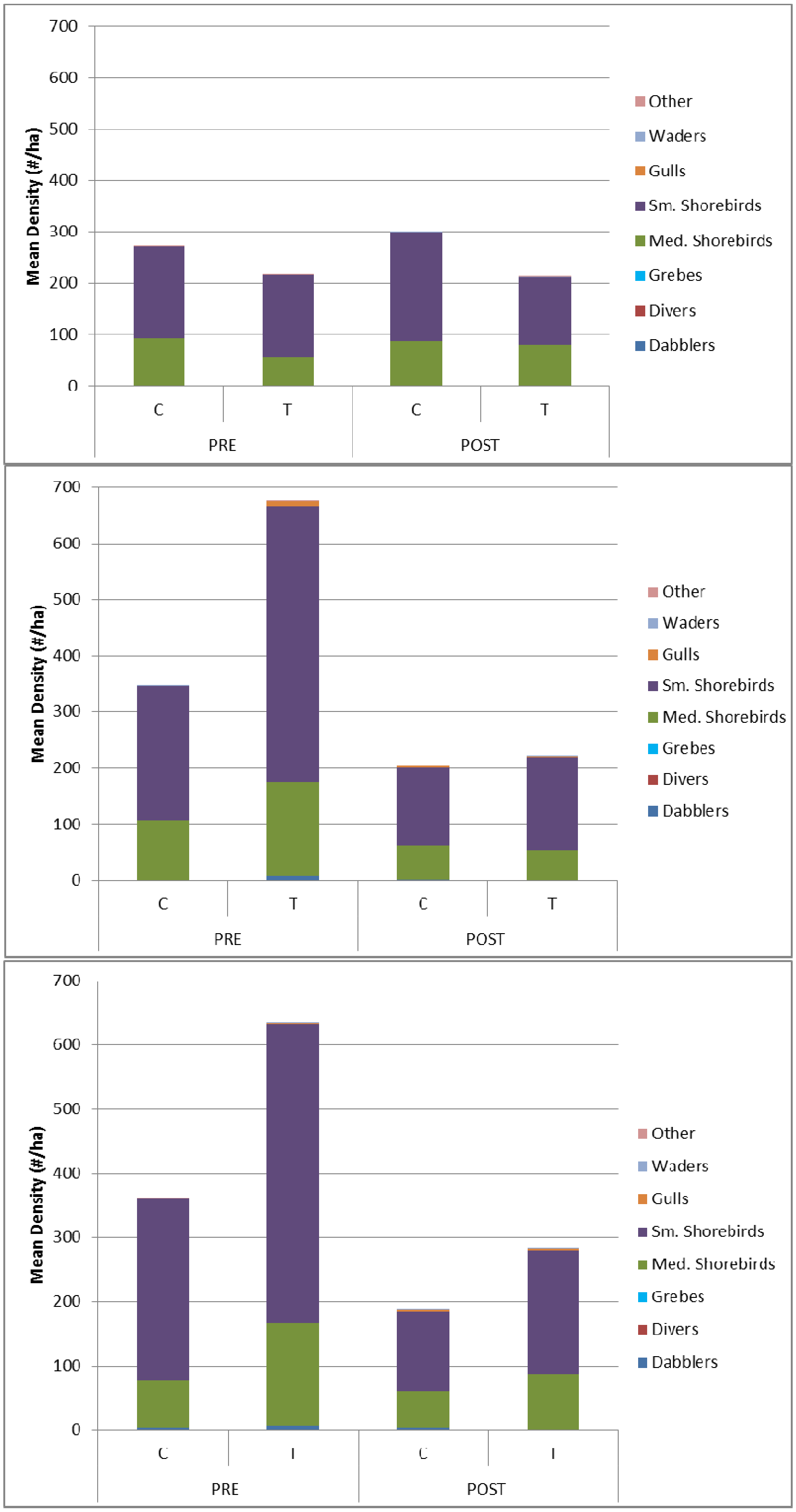


Figure C-3. Mean pre- (2011-2012) and post-installation (2012-2013) avian guild densities during low tide surveys in control and treatment plots for zones A, B, and C (top to bottom) at ELN.

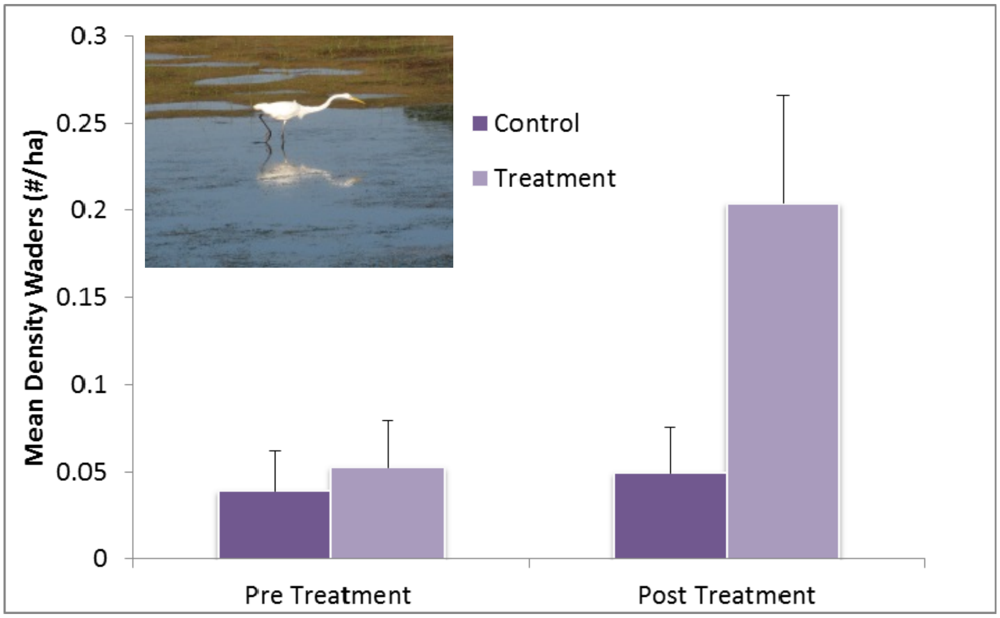


Figure C-4. Mean pre- (2011-2012) and post-installation (2012-2013) wader densities during low tide surveys in control and treatment plots for at ELN.

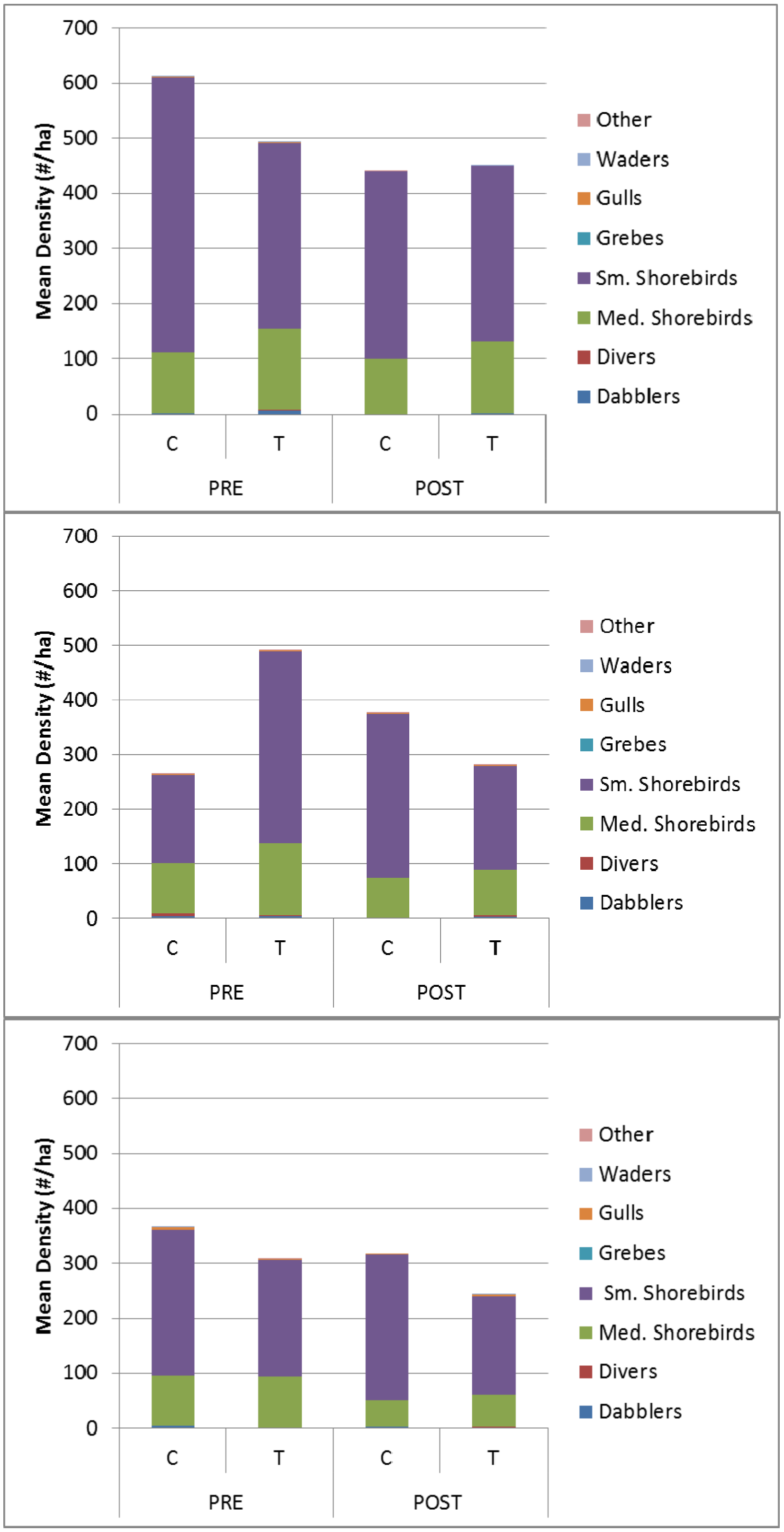


Figure C-5. Mean pre- (2011-2012) and post-installation (2012-2013) avian guild densities during low tide surveys in control and treatment plots for zones A, B, and C (top to bottom) at ELS.

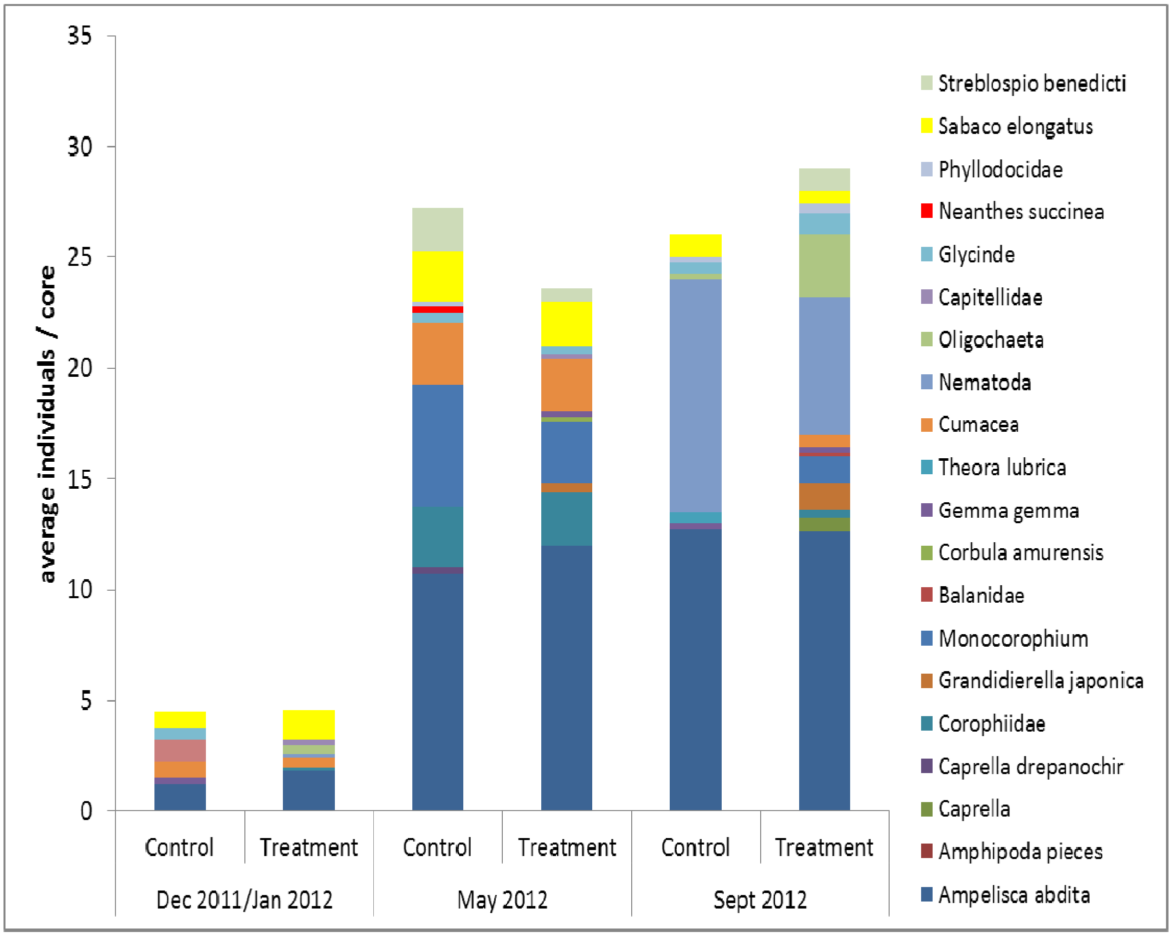


Figure C-6. Mean pre (Dec2011/Jan2012 and May 2012) and post-installation (2012-2013) number of invertebrate individuals found in zone B cores only at TNC.

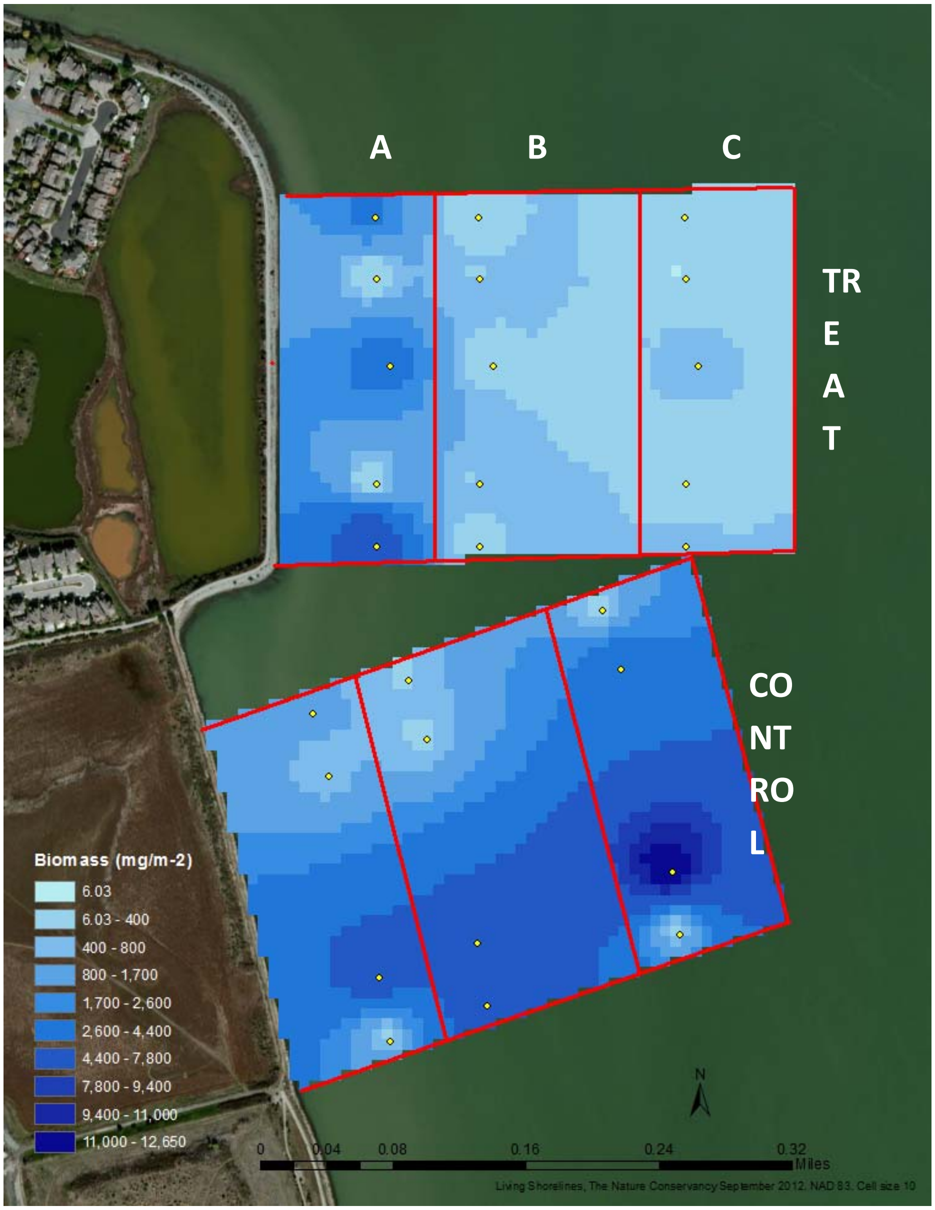
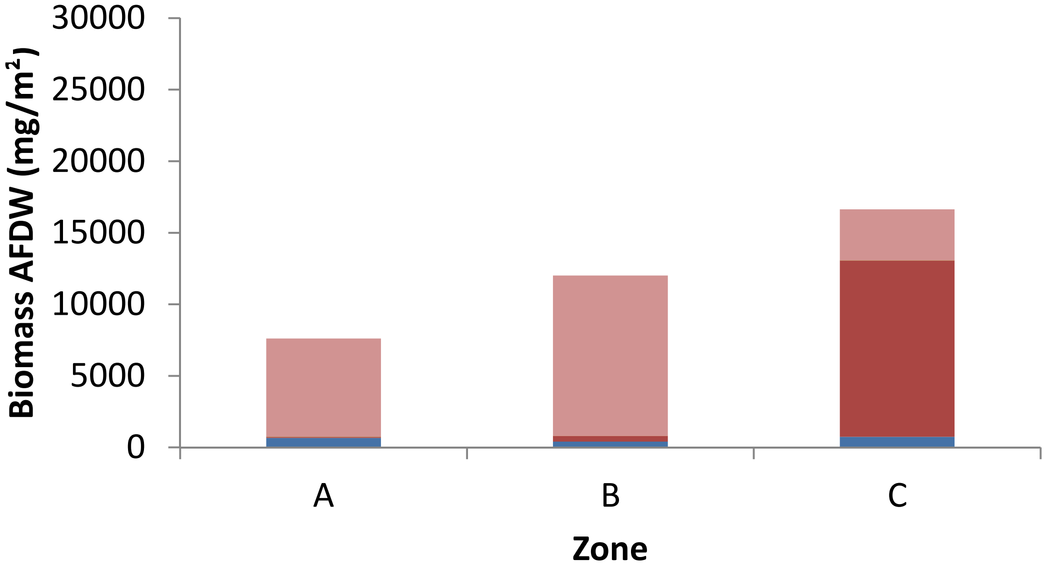
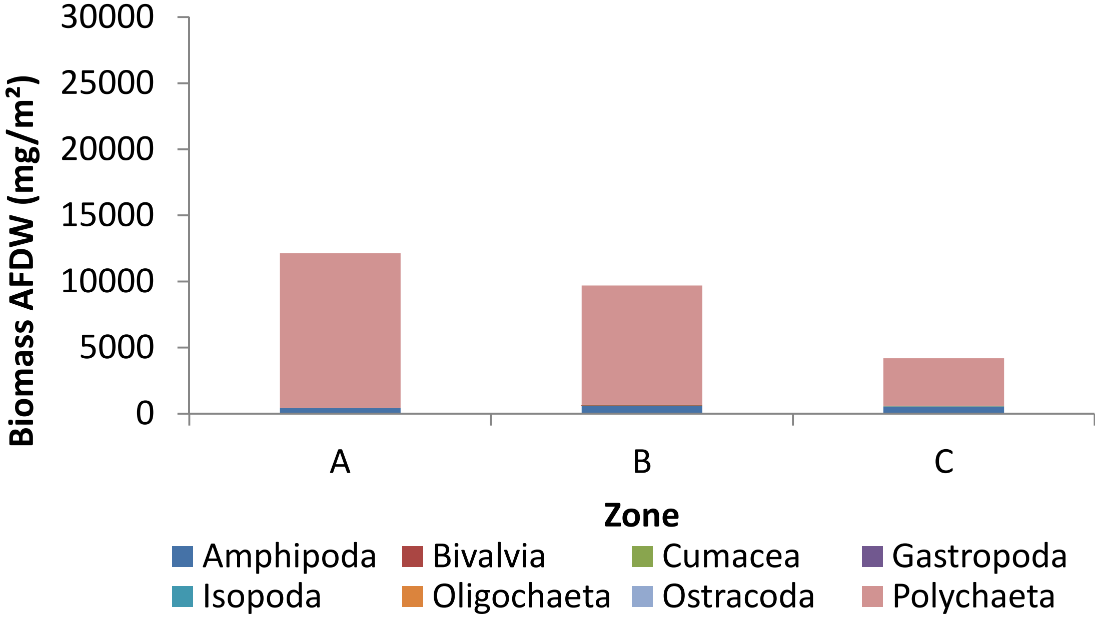


Figure C-7. Interpolated map of invertebrate biomass (AFDM mg m^{-2}) at paired control and treatment areas at TNC in Sept 2012.



Biomass AFDW (mg/m²)
30000
25000
20000
15000
10000
5000
0
A
B
C
Zone



Biomass AFDW (mg/m²)
30000
25000
20000
15000
10000
5000
0
A
B
C
Zone
Amphipoda
Bivalvia
Cumacea
Gastropoda
Isopoda
Oligochaeta
Ostracoda
Polychaeta

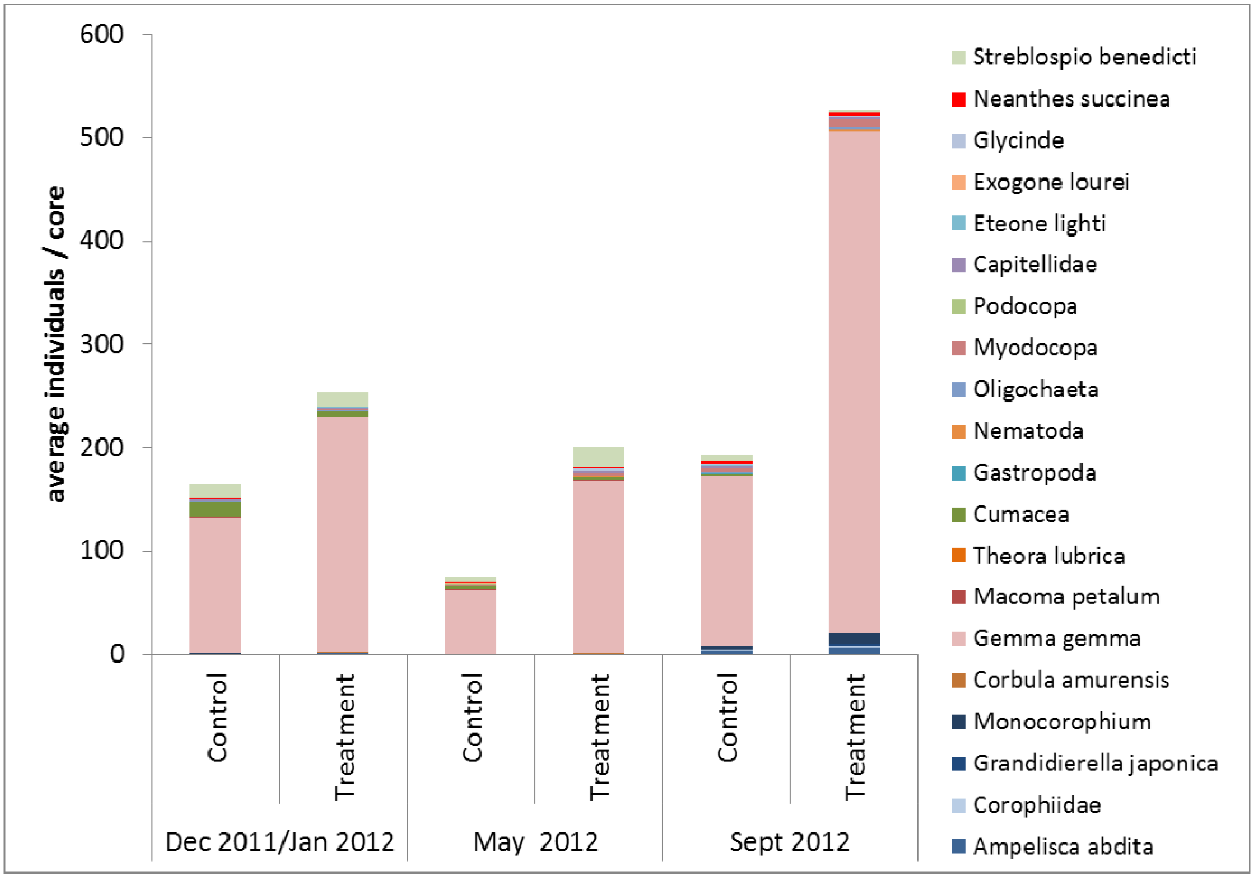


Figure C-9. Mean pre (Dec2011/Jan2012 and May 2012) and post-installation (2012-2013) number of invertebrate individuals found in zone B cores only at ELN.

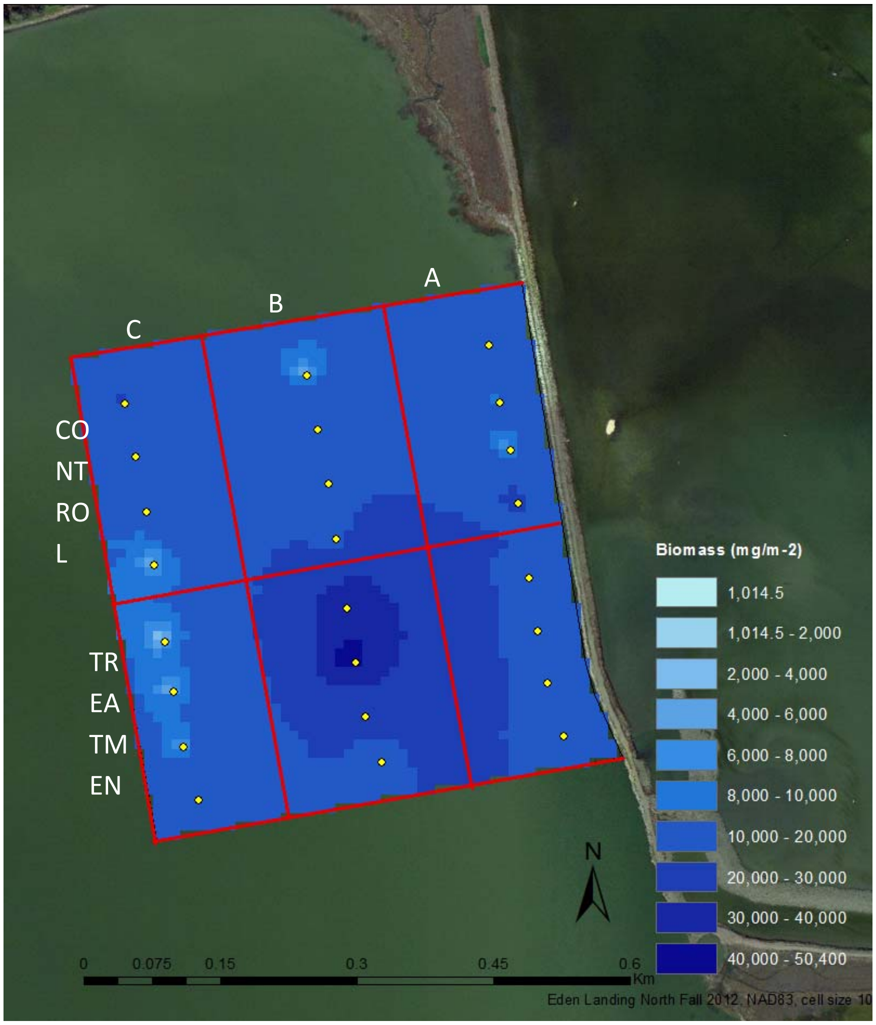


Figure C-10. Interpolated map of invertebrate biomass (AFDM mg m^{-2}) at paired control and treatment areas at ELN in Sept 2012.

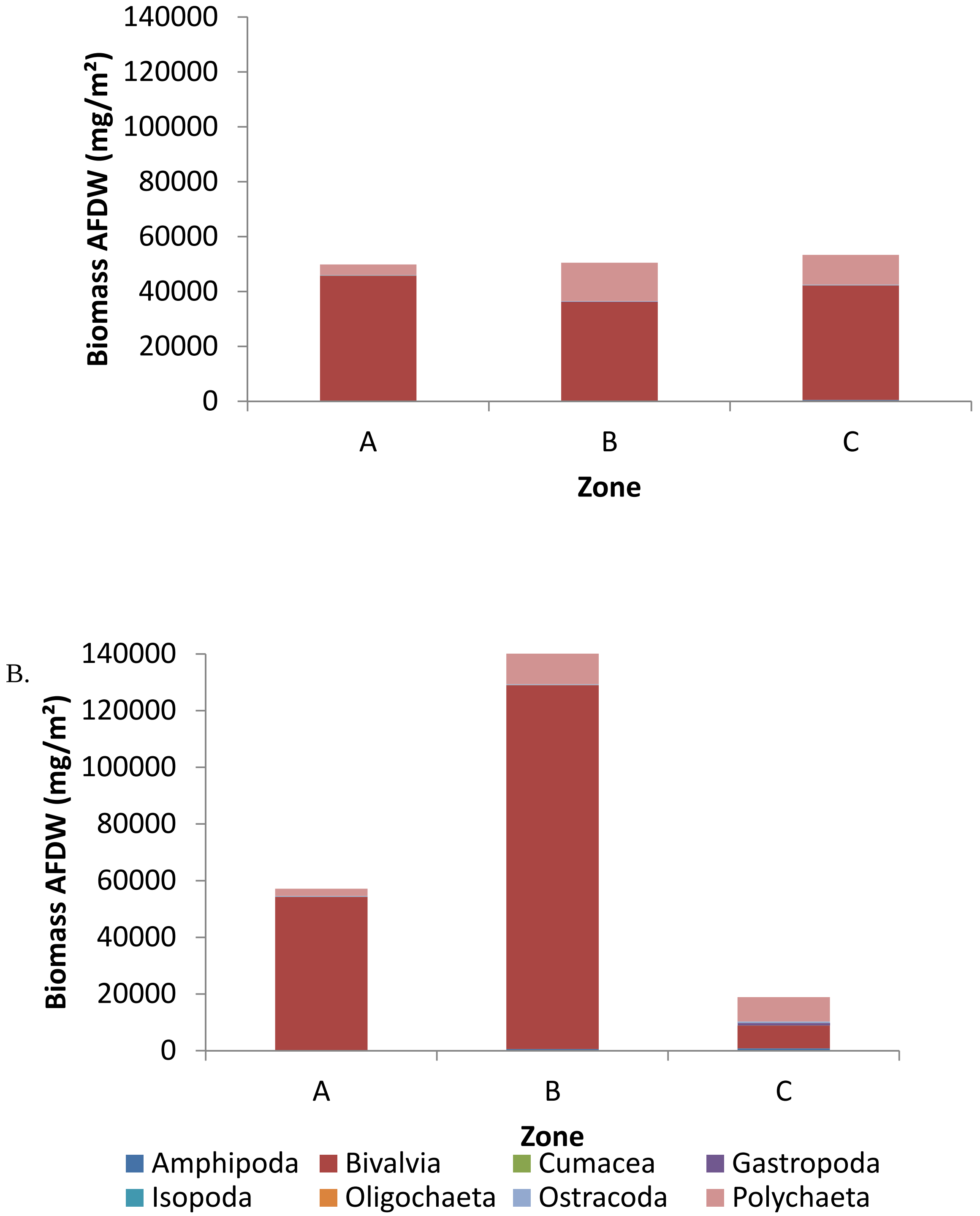
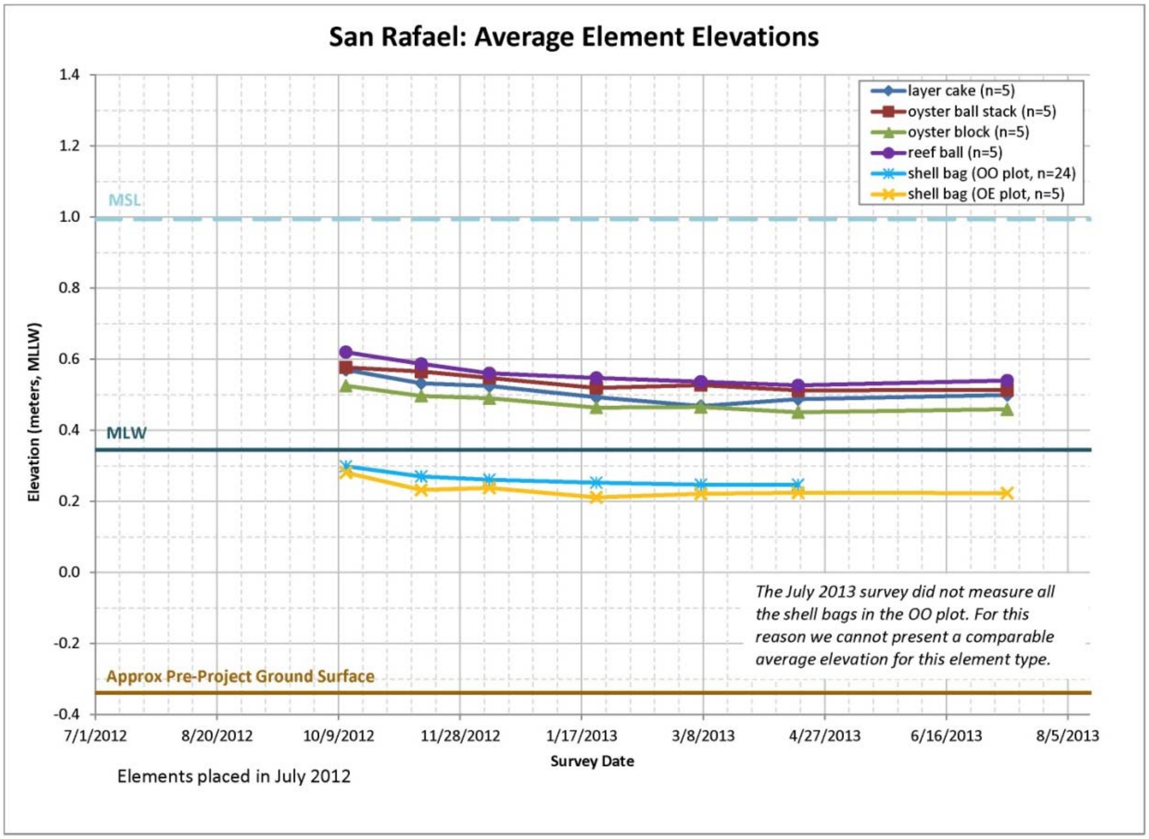


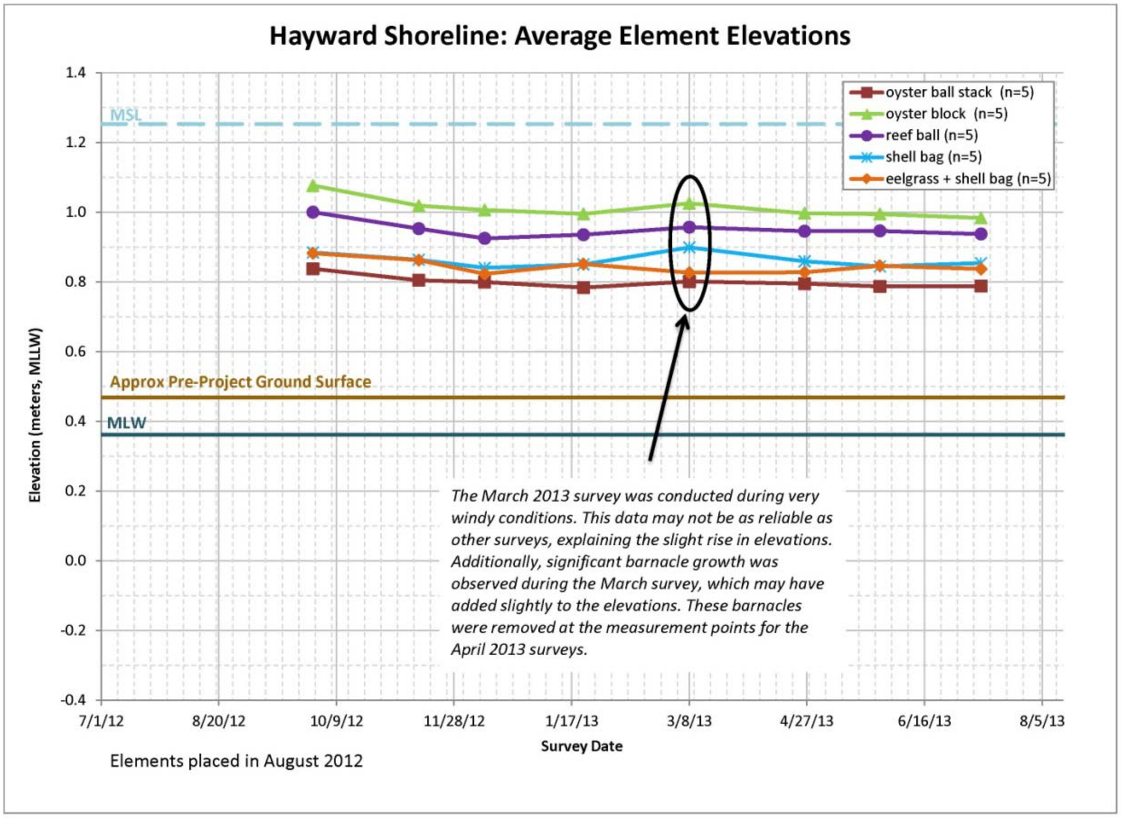
Figure C-11. Invertebrate biomass (AFDM mg m^{-2}) by taxa at paired control (A) and treatment (B) areas at ELN in Sept 2012.

Section D: Physical Monitoring



The July 2013 survey did not measure all the shell bags in the OO plot. For this reason we cannot present a comparable average elevation for this element type.

Figure D-1: Average element elevations relative to MLLW at the San Rafael site from deployment in July 2012 to July 2013. After an initial settling period, all of the reef structures have stabilized at a consistent height. Oscillations in elevation now appear to be within the collection error of ±5 cm (combination of instrument accuracy and collection technique), indicating the rate of change has become negligible.



The March 2013 survey was conducted during very windy conditions. This data may not be as reliable as other surveys, explaining the slight rise in elevations. Additionally, significant barnacle growth was observed during the March survey, which may have added slightly to the elevations. These barnacles were removed at the measurement points for the April 2013 surveys.

Figure D-2: Average element elevations relative to MLLW at the Hayward Shoreline site from deployment in August 2012 to July 2013. After an initial settling period, all of the reef structures have stabilized at a consistent height. Oscillations in elevation now appear to be within the collection error of ±5 cm (combination of instrument accuracy and collection technique), indicating the rate of change has become negligible.

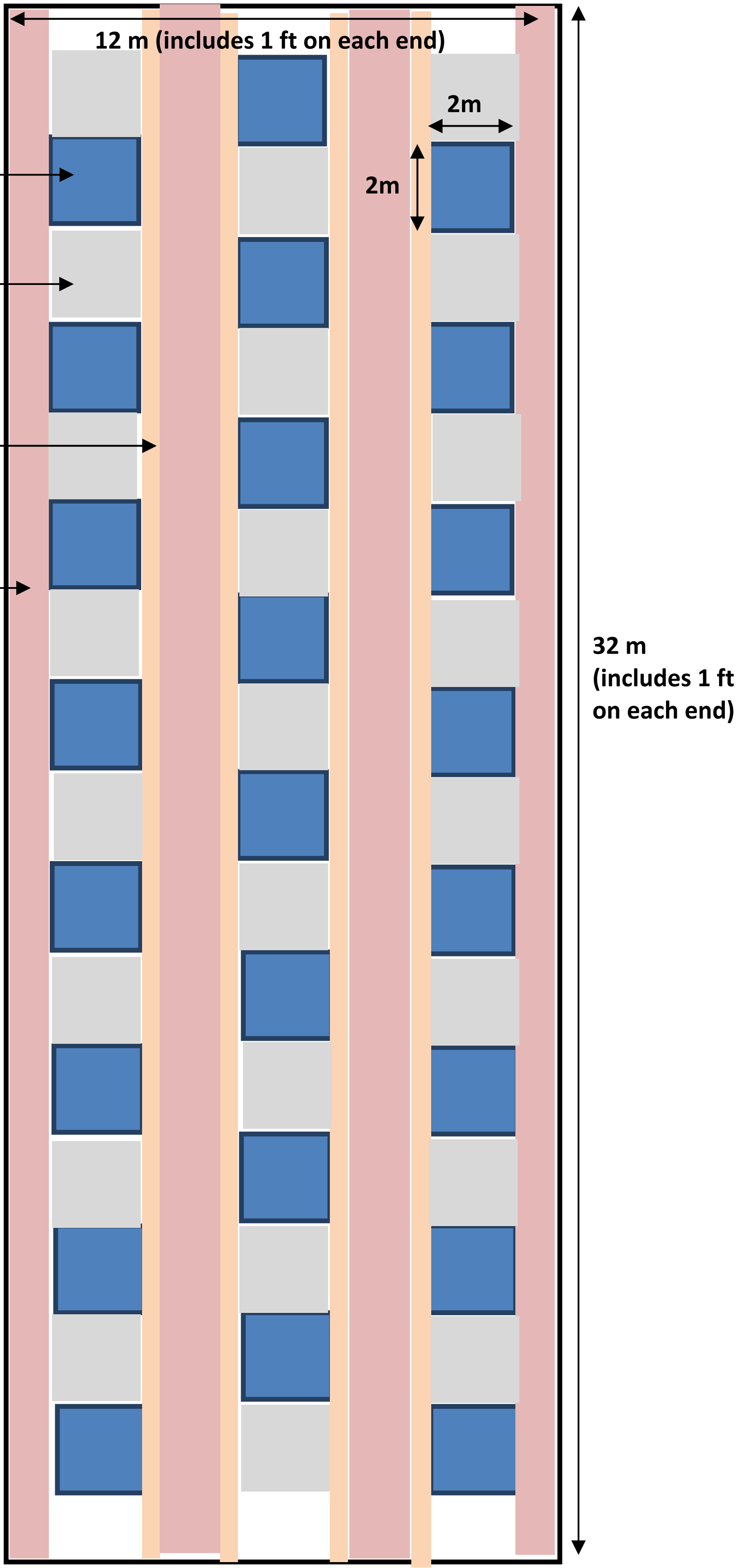
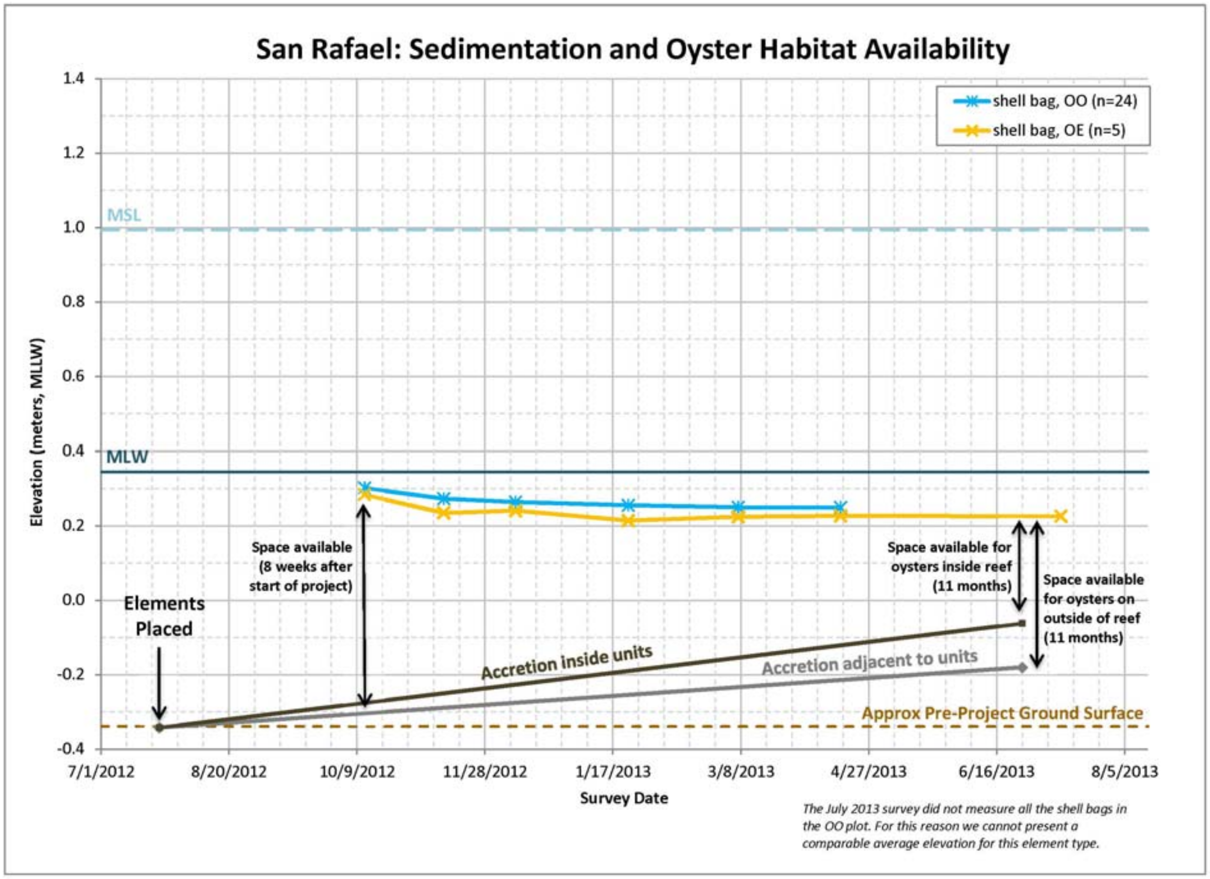
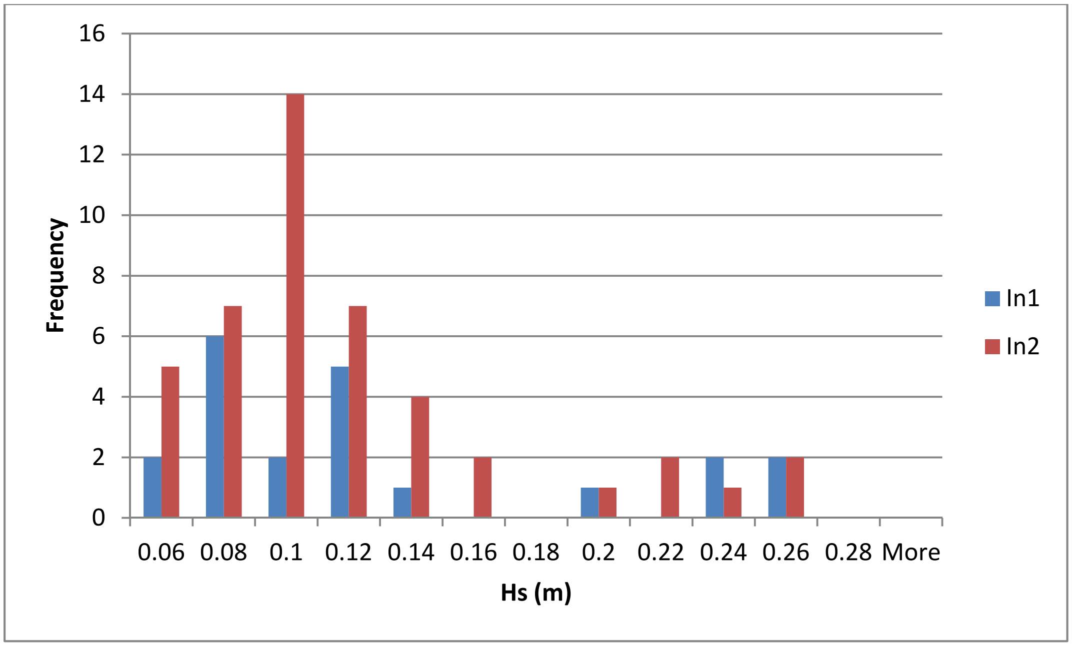


Figure D-3: Schematic for determining sediment volume changes inside the oyster reefs. The volume trapped inside the oyster units was estimated using the average area (2m x 2m) and the measured depth of fill in between the individual elements. An average deposition of 24 cm was used for all units. In the middle of the vertical aisles between oyster units (pink stripes, assumed to be 75% of the aisle width), the "center of aisle" transect was used. The "edge of element" transect was used along the remaining edges of the channels inside the plot (orange stripes). Cross-sections were used for the northern and southern halves of the plot for the spaces between the units.


San Rafael: Sedimentation and Oyster Habitat Availability

The July 2013 survey did not measure all the shell bags in the OO plot. For this reason we cannot present a comparable average elevation for this element type.

Figure D-4: Average shell bag elevation and sediment accretion affecting the San Rafael site. The exposed surface area of the element available for oyster settlement and growth has decreased through time due to subsidence of the elements into the mudflat and accumulation of sediment adjacent to and inside the reef structure. At the start of the project, 0.65 m was exposed compared to 0.3-0.4 m exposed by July 2013, a loss of 0.25-0.35 m



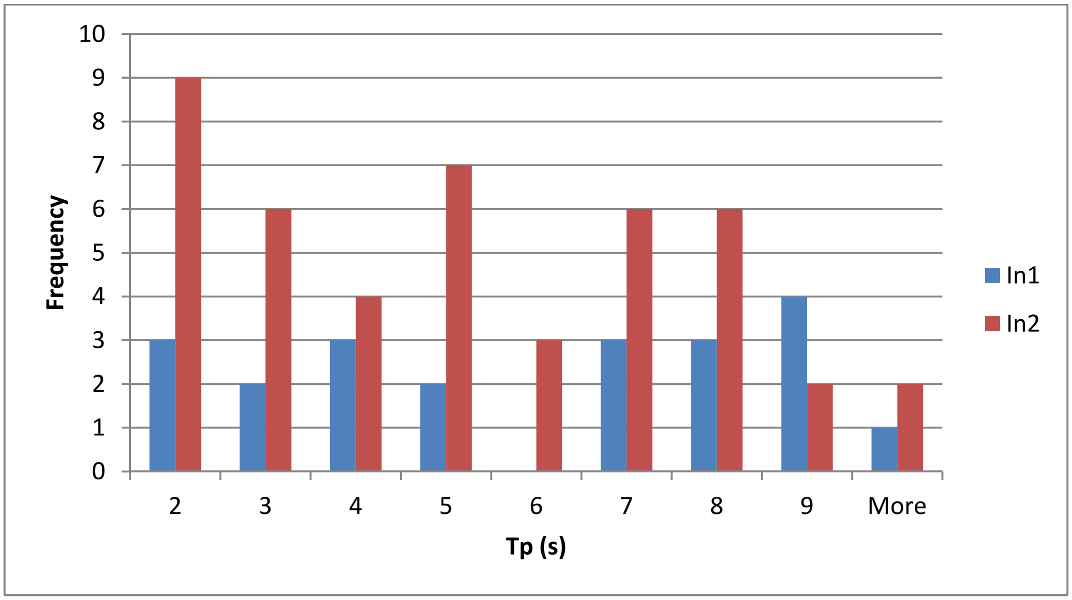


Figure D-5: Wave data collected by the ADCP for the two inshore instruments at the San Rafael site from February 26-April 16, 2013 with In1 behind the oyster-eelgrass reef and In2 at the control plot. Wave height (top) and wave period (bottom) show different patterns for the two locations. Fewer observations were gathered for In1 than In2 overall with In2 showing a unimodal distribution of wave heights compared to a bimodal distribution for In1.

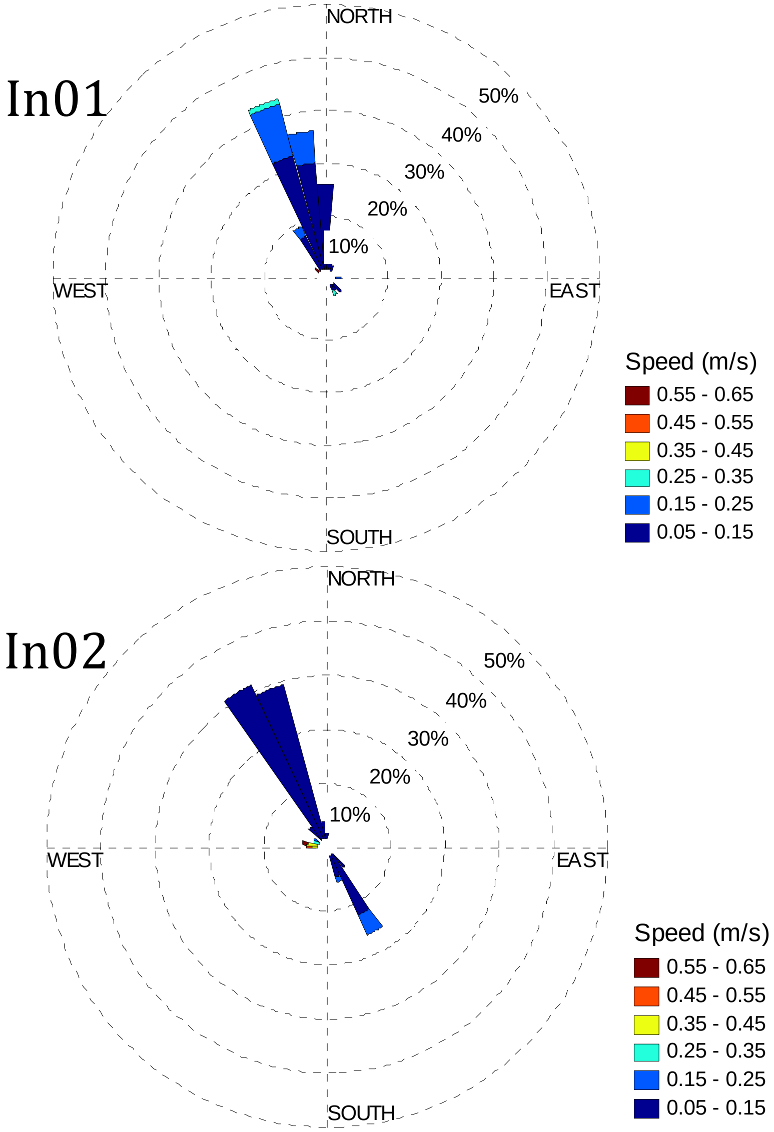


Figure D-6: Current data collected by the ADCP for the two inshore instruments at the San Rafael site from February 26-April 16, 2013 with In1 behind the oyster-eelgrass reef and In2 at the control plot. Currents behind the reef (In1) were observed to be faster in general but flood only. This contrasts with the current data for the control plot (In2) that shows a symmetrical distribution from NW-SE at slower speeds than at In1.

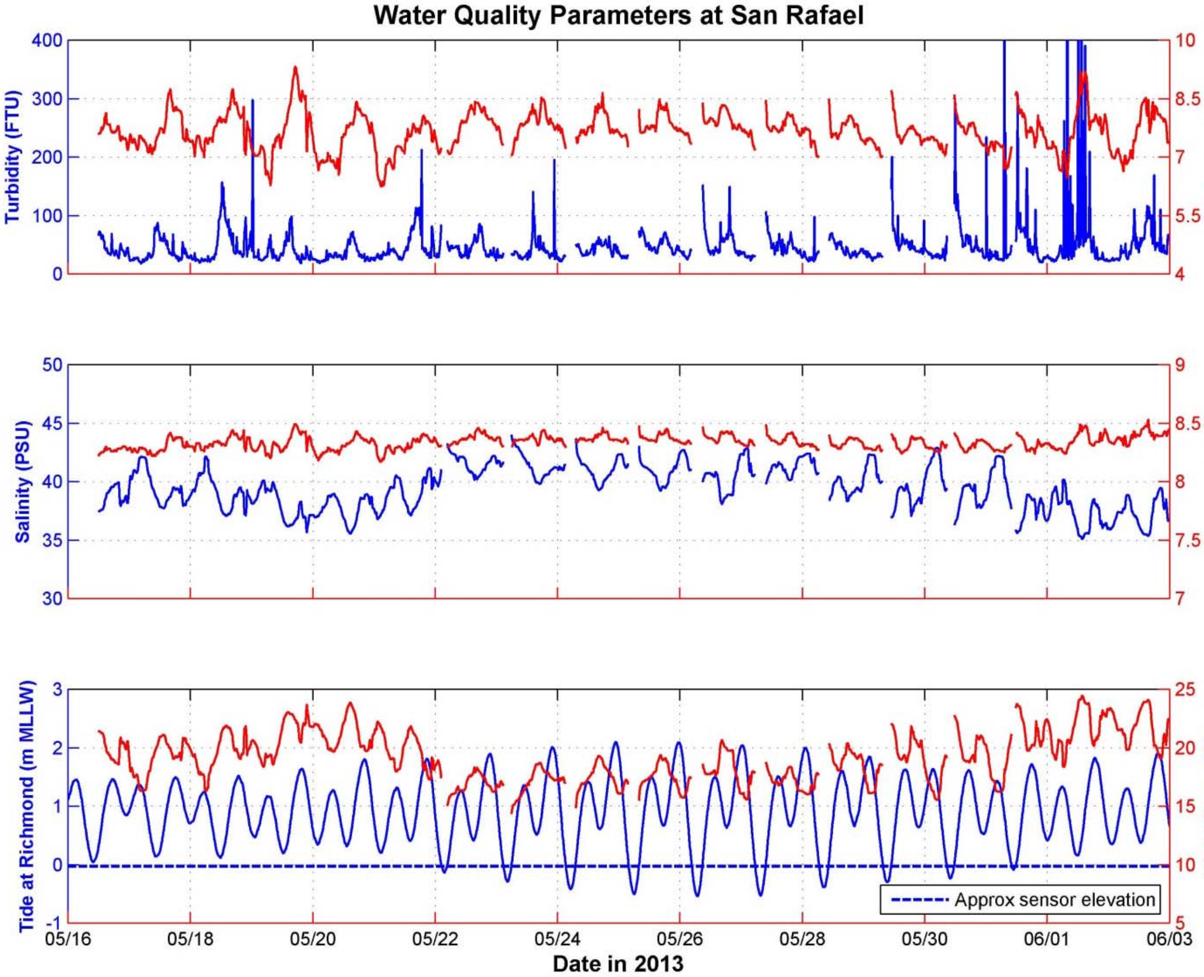


Figure D-7: Ambient water quality data for the San Rafael site from May 16-June 3, 2013. Breaks in the record indicate when the instrument was exposed during low tide (blue line in bottom panel). Some parameters are fairly conservative and do not vary substantially (pH, dissolved oxygen) while others track with tide or wind events (temperature, turbidity). A problem with the salinity sensor skewed the results above what is normal for the San Francisco Bay.

San Rafael site- Pacific shell bag mounds

San Rafael site- “baycrete” elements

San Rafael site- native oysters settled on Pacific shell bag mounds

San Rafael site- native oysters settled on “baycrete” elements- oyster blocks (top picture) and mini reef ball stacks (bottom picture).

San Rafael site- gravid shrimp (top picture), nudibranch (bottom picture).

San Rafael site- juvenile Dungeness crab


USGS, Piotter

Avian monitoring at Eden Landing South (ELS), January 2013


USGS, Staff

Benthic invertebrate coring

Acoustic Doppler Current Profiler (ADCP) deployment inshore of oyster-eelgrass plot. In picture, Eddie Divita of ESA PWA.

Photo: Doug George

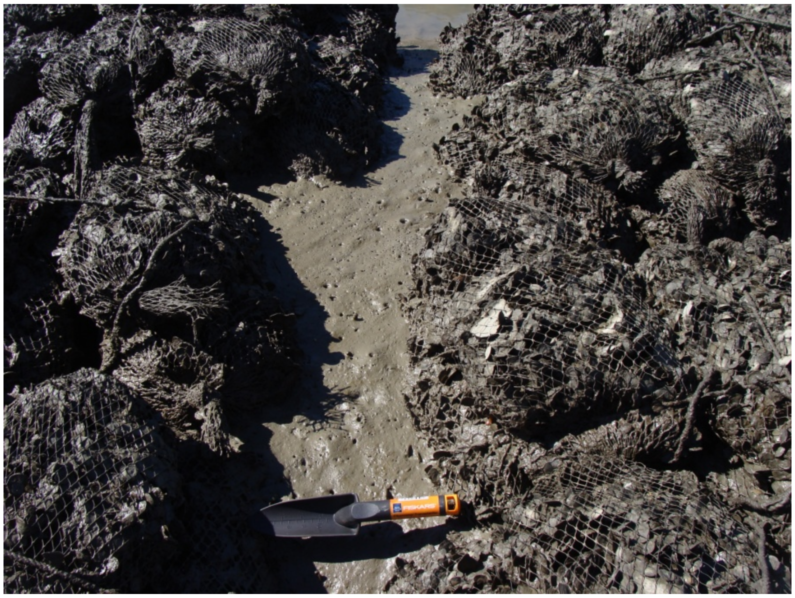
2-26-2013

Installation of ambient water properties instrument, a Nortek Sonde to measure temperature, salinity, pH, dissolved oxygen and turbidity. The Sonde is mounted on the stake in the foreground. In picture, Elena Vandebroek of ESA PWA.

Photo: Damien Kunz

5-16-2013

Oyster-Only plot at San Rafael, facing south, looking at the sediment accretion patterns along the edges of the units. Note sediment accretion in the lee of the units. Elevation surveys of the bed were gathered immediately adjacent to the units and then down the centerline of the aisles to determine sediment volume changes.



Sediment accumulation in between oyster elements after a little more than 10 months, view from above. The sediment accreted since placement is 20-25 cm thick from the bottom layer of shell bags to the sediment surface.

SOURCE: Doug George, June 26, 2013

ESA PWA oceanographer Doug George and coastal engineering Elena Vandebroek surveying the elements on Eden Landing and measuring sediment accumulation.

Photo: Elena Vandebroek

9-28-2012

ESA PWA field services manager Damien Kunz collecting sediment cores at the San Rafael site prior to construction of reefs to establish baseline sediment grain size distribution.

Photo: Doug George

7-6-2012