Upper Newport Bay Living Shorelines Project

Final Report

March 2019

Prepared for:

California State Coastal Conservancy
1515 Clay St, 10th Floor
Oakland, California 94612-1401
Contact: Evyan Borgnis Sloane, Project Manager

Prepared by:

Orange County Coastkeeper
3151 Airway Ave Suite F-110
Costa Mesa, CA 92627
Phone: (714) 850-1965 ext. 1009
Marine Restoration Director: Katie Nichols
Significant contribution from Kaylee Griffith (M.S. student, formerly at San Diego State University)

California State University Fullerton
Dept. Biological Science, Box 6850
Fullerton, CA 92834-6850
Phone: (657) 278-7510
Lead Scientist: Dr. Danielle Zacherl;
Significant contribution from Victoria Wood (M.S. student)

California State University Long Beach
Dept. Biological Sciences, 1250 Bellflower Blvd., MS 3702
Long Beach, CA 90840
Phone: (562) 985 -8878
Lead Scientist: Dr. Christine Whitcraft;
Significant contribution from Marjorie Howard (M.S. student)

TABLE OF CONTENTS

I. INTRODUCTION

Project Summary

Oyster and eelgrass beds are important habitats within California embayments, recognized for the ecosystem services they provide including habitat provision, trophic support, and shoreline protection. Despite the importance of these habitats, they have declined throughout California (CA) due to coastal development and recreational use of bays. To address this loss and explore the best methods for restoration, practitioners have restored native Olympia oysters, *Ostrea lurida*, and eelgrass, *Zostera marina*, in an innovative living shoreline approach. Orange County Coastkeeper (Coastkeeper), in partnership with California State Universities Fullerton (CSUF) and Long Beach (CSULB) installed and are continuing to monitor a restoration project in Upper Newport Bay (UNB), Newport Beach, California. Living shoreline projects utilize strategically placed native plants, reef forming animals, and natural materials to stabilize and protect shorelines while preserving valuable habitats and ecosystem services. Using funding from the State Coastal Conservancy (SCC), we initiated restoration of two key living shoreline habitats to investigate the short-term performance of living shorelines with single-habitat restoration versus multiple-habitat restoration at four unvegetated mudflats in UNB. We transplanted eelgrass to establish eight 20 m by 8 m eelgrass habitat plots (1,280 square meters) in June 2016 and installed eight 20 m by 1.5 m oyster shell plots (240 square meters) in May 2017 for a combined total restoration area of 1,520 square meters (0.4 acres). By May 2018, one year after oyster restoration and two years after eelgrass restoration, our data show significantly increased native oyster recruitment relative to controls and nearby reference locations, use of both oyster and eelgrass habitats by fish and invertebrates, and persistence and spread of eelgrass. Overall, the project goals to enhance the native Olympia oyster (*Ostrea lurida*), eelgrass (*Zostera marina*) and associated invertebrate and fish populations were met. Importantly, we have seen no evidence so far that oysters have a negative impact on either the quantity or the habitat provision function of eelgrass. However, it is premature to determine how the single-habitat versus multiple-habitat restoration affects eelgrass, adult oyster density or associated species; this will be explored in detail in future studies and as the oyster beds mature. While we generated some evidence that restored habitats retain more upshore sediment than control plots, we need more detailed metrics to be evaluated in order to determine how and to what extent the restoration affects shoreline protection; funding to do this research is currently being sought.

Goals and Objectives

The overarching purpose of this project is to enhance the native Olympia oyster (*Ostrea lurida*) and eelgrass (*Zostera marina*) populations while learning about the restoration configurations and methods that provide the greatest ecosystem benefits in terms of biodiversity and shoreline protection. We undertook a collaborative community approach in order to leverage our monitoring and restoration efforts, while informing students and the public about the benefits of conserving wetland habitats.

The specific objectives of the project are divided into three categories:

1. Species Performance

   a. Increase the abundance of oyster and eelgrass populations in UNB through single-species and integrated multiple-species restoration treatments.
   b. Determine if integrated oyster and eelgrass restoration enhances the performance of each species in terms of density, size (oysters) compared to isolated restoration of each species.
2. Habitat Value
   a. Compare the habitat value of each restoration treatment (bagged oyster shell, eelgrass beds, or integrated oyster shell and eelgrass) for invertebrate, fish and bird species compared to unstructured mudflats and pre-restoration conditions.
3. Shoreline protection
   a. Compare the effectiveness of restoration treatments (oyster shell, eelgrass beds, or integrated oyster and eelgrass restoration) in retaining sediment, attenuating waves, and reducing erosion as compared to unstructured mudflats.

Here we present work relevant to the overall ecological gains of the restoration project; some components of this report were not funded by SCC (e.g., bird surveys, USC sediment work, epifauna work by SDSU) but do address the overarching goals of the SCC-funded project and thus are included. Importantly, the project setup and collaborative nature of our work provided opportunities for external collaborations (e.g., SDSU) which expanded our scope and strengthened our investigations.

II. STUDY EXPERIMENTAL DESIGN AND RESTORATION METHODS

Overall Design

Starting in summer 2016, we constructed a series of four, 110 m X 12 m, Living Shoreline Blocks in Upper Newport Bay (UNB) (Figure 1). Within each block, we added 4 restoration treatments: 1) a restored oyster bed (20 m by 1.5 m), 2) a transplanted eelgrass bed (20 m by 8 m), 3) a restored oyster bed inshore of a restored eelgrass bed, and 4) a control treatment left un-manipulated, with 10 meters separation between each treatment (Figure 2). The four blocks were placed parallel to shore at four locations in UNB, including along DeAnza Peninsula, Shellmaker Island, and two locations on Castaways beach (PCH and Westcliff) (Figure 1). This design, with 4 replicates of each treatment, enabled comparisons of single species versus integrated restoration techniques on species performance, habitat value and shoreline protection to determine the success of combined eelgrass and oyster restoration compared to either eelgrass or oyster restoration alone.

Eelgrass Restoration Methods:

Eelgrass restoration activities took place primarily in summer of 2016 with Coastkeeper staff and 178 volunteers, including over 20 volunteer scientific divers. Eelgrass was collected from the Inner Linda Isle donor site by divers, bundled into groups of 10-12 eelgrass shoots and attached to biodegradable “anchors” made out of hemp string and wide tongue depressor sticks by land-based volunteers, and replanted by divers into transplant areas. Coastkeeper found this to be the most successful method for the area based on prior work. In each restoration plot, eelgrass bundles were transplanted into a 1 m by 1 m grid. The centers of each 1 m by 1 m square were filled with an additional eelgrass bundle, to decrease the spacing between each bundle. This required the transplantation of 349 eelgrass bundles per plot. For the 3 plots planted in June, we planted 1,047 bundles, or approximately 12,564 eelgrass shoots. For the 5 plots planted in July, we planted 1,745 bundles, or approximately 20,940 eelgrass shoots. After surveys in 2017 showed declines in eelgrass density at our Shellmaker site, this site we re-planted in the summer and fall of 2017 in the deepest areas of the plots (see results and discussion).

Oyster Restoration Methods:

To avoid the use of plastics or other non-natural materials, we utilized coconut coir, the fiber found on coconut husks, to consolidate and transport oyster shell to the restoration sites. Coir matting is manufactured using high strength bristle coir twine, which results in a semi-permanent erosion control blanket with a functional life of 4 to 6 years not submerged. Coir matting is intended for use on stream banks, on slopes as well as in channels and ditches. To our knowledge we are the first project to utilize this material with the specific goal of Olympia oyster restoration, however our project was informed by the U.S. EPA's Atlantic Ecology Division's use of the material with oyster shell for bank stabilization.

Coastkeeper planned logistics for oyster restoration and hosted several workshops in March and April to conduct outreach and prep the coconut coir oyster bag material. In April 2017, students and volunteers hand-sewed more than 500 bags using coconut coir, and filled the bags with 40,000 pounds of Pacific oyster shell to create habitat for the native Olympia oyster to settle and recruit to. On April 26-30th over 150 volunteers and the project team transported the shell and bags before dawn into four different sites in Upper Newport Bay during low tide and constructed the oyster beds.

Figure 1. Final project sites (red) in Upper Newport Bay, Newport Beach, CA: Pacific Coast Highway (PCH), Westcliff (WC), DeAnza (DA), and Shellmaker (SM). At each site, one plot of each treatment is represented (i.e. oyster bed, eelgrass bed, oyster and eelgrass bed, and control). Eelgrass was transplanted from donor eelgrass beds at Linda Isle and Harbor Island (south of PCH).

Site Locations:

Pacific Coast Highway (PCH): 33°37'9.55" N, 117°54'17.41" W to 33°37'12.53" N, 117°54'14.96" W
Westcliff: 33°37'16.81" N, 117°54'7.29"W to 33°37'17.03" N, 117°54'3.04" W
DeAnza Peninsula: 33°37'13.18" N, 117°53'54.81" W to 33°37'12.54"N, 117°53'50.65"W
Shellmaker Island: 33°37'21.60" N, 117°53'32.19" W to 33°37'18.06" N, 117°53'32.81" W

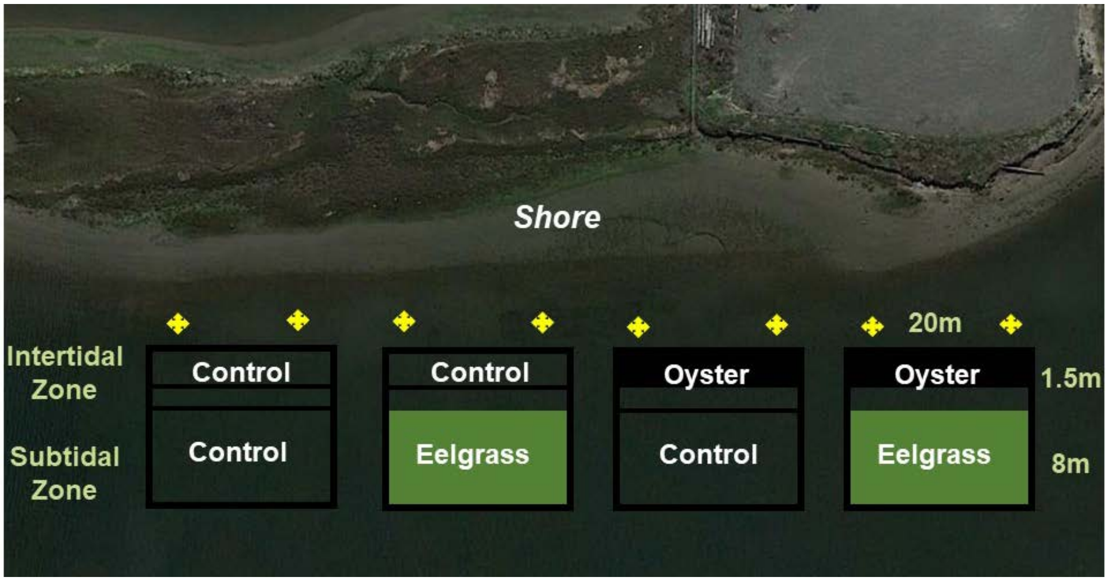

Figure 2. Example arrangement of four restoration treatments (eelgrass, oyster, combined oyster + eelgrass, and control). Treatments were randomly arranged within each site and replicated at 4 sites in Upper Newport Bay (as in Figure 1). Treatments are spaced 10 m apart from one another. Control plots were left un-manipulated for comparison to restoration plots. Yellow stars represent placement of sediment pins 5 m in from the end of each plot (5 and 15m) and 0.85 m upshore from the inshore treatments.

Figure 3. Drone photo courtesy of Nick Sadrpour, Science, Research & Policy Specialist from USC Sea Grant taken July 2017 at Westcliff site. Photo shows an oyster bed and eelgrass combined treatment (foreground) and oyster alone treatment (background).

Summary of Permits Required and Obtained for the Project:

1. Land use permit from the County of Orange # P2010-00365
2. Letter of Access to Upper Newport Bay Ecological Reserve from California Department of Fish and Wildlife
3. Army Corps of Engineers Nationwide Permit No. 27 Aquatic Habitat Restoration, Establishment, and Enhancement Activities, SPL-2016-00050-ERS
4. Santa Ana Regional Water Quality Control Board Clean Water Act Section 401 Water Quality Standards Certification, Project No. 302016-01
5. California Coastal Commission Coastal Development Permit Waiver, 9-16-0254-W
6. Letter of Authorization for the Transplanting of Eelgrass within Upper Newport Bay, City of Newport Beach, for Maintenance of Restoration Site Purposes

Monitoring Plan Overview

Our long-term monitoring surveys followed the principles of a BACI design (Before-After-Control-Impact) with all treatment plots represented at each of four field sites. We collected data in winter and spring 2016 before restoration initiation. All subsequent sampling occurred through nearly two years after restoration (See Supplementary Material – Figure 25). Importantly, our blocked design allows for our analysis to take natural variation among field sites into account.

Prior to winter 2016 pre-restoration surveys, PVC pipes were placed at the start and end of each treatment to permanently mark the location of each plot so that pre-restoration monitoring would take place in the exact location of the future restoration.

To address species performance, habitat value and shoreline protection objectives we monitored the following parameters:

- Oyster monitoring: native and non-native oyster abundance, density, and size; percent shell cover
- Eelgrass monitoring: eelgrass turion density, areal extent, and minimum/maximum depth ranges
- Community parameters: diversity and abundance of epifauna, infauna, fish and birds
- Physical monitoring: sediment characteristics, shoreline profile, vessel wake height/frequency
- Water Quality: temperature, salinity, dissolved oxygen, pH

In addition to these measures, density and area of donor eelgrass beds was monitored each summer for two years post restoration to ensure no damaging impacts were caused by our collection.

For each of the metrics listed above, we briefly describe the details of each method just before presentation of each result in the Species Performance section below.

III. SPECIES PERFORMANCE

Olympia Oyster Success Metrics and Bed Integrity

CSUF was the lead in evaluating native oyster population growth and restoration unit integrity. In support of this effort, Dr. Zacherl's team conducted baseline shell cover, oyster density, and oyster settlement and recruitment surveys pre- and post-restoration. Post-restoration monitoring included measures of % shell cover (to assess bed integrity), oyster density and size, and oyster settlement and recruitment.

Density and % Shell Cover Surveys:

At each oyster or intertidal control treatment plot (n=16), we surveyed along a 20 m X 2 m transect (pre-restoration) or 20 m X 1 m transect (post-restoration) parallel to shore at approximately -0.5 Mean Lower Low Water (MLLW). We provided random X, Y coordinates for each of 10 quadrats.

Percent Shell Cover:

We used point-contact surveys to assess the amount of hard substrate habitat (and shell cover, once the beds were constructed) available for oyster settlers. Surveyors used a 50 by 50 cm gridded point-contact quadrat to note the substrate (e.g. dead shell, *Ostrea lurida, Mytilus* spp., mud) that fell under each of the 49 points. Point contact surveys were conducted in January and May 2016 to assess the amount of hard substrata (including rock, gravel, dead shell and living bivalves) available before restoration for locally produced oyster larvae, who will only settle and grow on these surfaces. In two pre-restoration surveys (January and May 2016), average percent cover of hard substrata was below 6% on all treatment plots at all study locations except at DeAnza peninsula, where the percent cover of hard substrata on the future "Oyster" treatment plot was 17.1 ± 3.3% (1 SE) in January 2016 and 15.3 ± 4.7% in May 2016. On that plot, the majority of the hard substratum was composed of dead clam and oyster shell, though living *Ostrea lurida* were present and detectable (average was ~ 2% in both Jan and May) in these quadrats. After construction of the oyster plots, shell cover was 100%. By May 2018, one year after oyster bed construction, shell cover remained high (>80%) and slightly outperformed a previous restoration effort in the bay using shell bagged in jute (Zacherl et al. 2015) on all constructed beds except the oyster treatment at PCH, which averaged 57.8 ± 4.7%. The relative instability of the PCH oyster bed may be due to the "demonic intervention" of a retiree who was encountered by our team collecting oyster shell for an art project. In addition, OCCK documented a total of 6 coir bags full of shell upshore of oyster plots on the beach in spring fall 2017, likely removed by humans via snagging on fishing hooks. In general, the PCH and Westcliff plots maintained lower % cover, likely due to increased recreational activity at these beaches. These sites are on a public beach with heavy use by dog walkers, fishermen and others. The shell cover on the control and eelgrass treatments were stable over time. Qualitatively, the coir bags were intact in November 2017, and the bags were starting to degrade by May 2018 at all sites except Shellmaker.

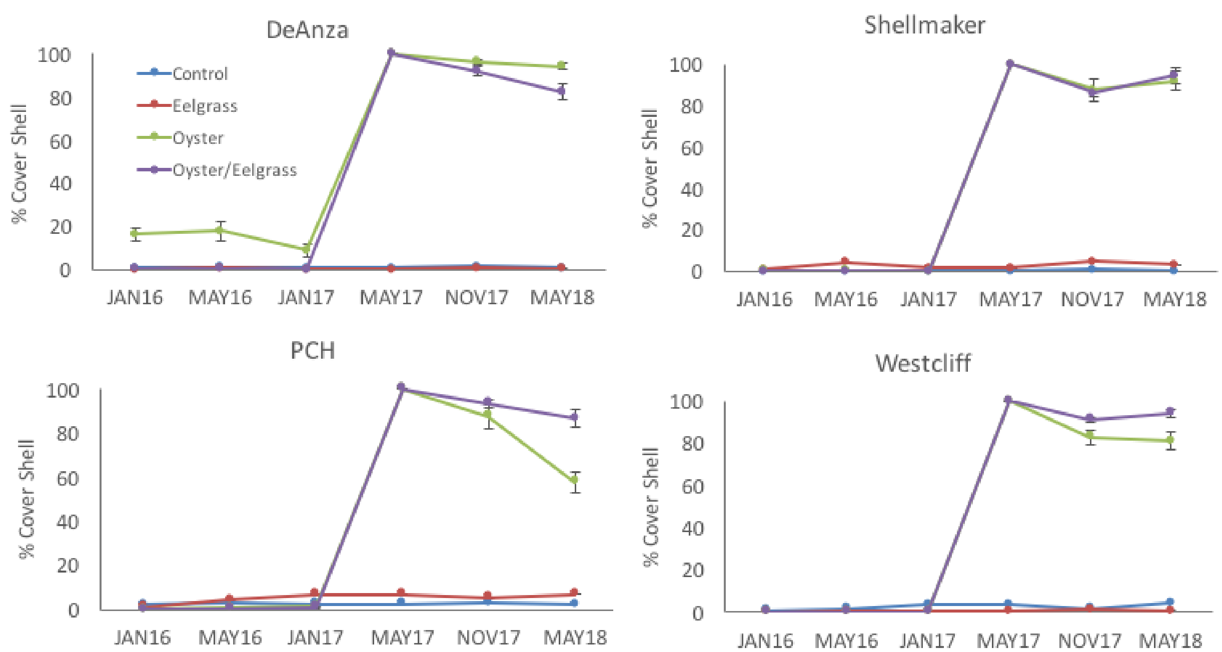

Figure 4. Time series of changes in shell percent cover on constructed oyster beds from January 2016 to May 2018, with standard error bars for all treatments at all sites in Upper Newport Bay.

Oyster Density (2016-2018):

Mean oyster density measurements (*O. lurida*/m^2) were taken within each treatment plot using 10 randomly located 20 cm X 20 cm quadrats along a 20 m X 1 m transect laid across each treatment at prior to restoration in January and May 2016, January 2017, and again six (November 2017) and twelve months (May 2018) post-oyster bed construction. Surface shell within each quadrat was excavated into a 1-gallon Zip-Loc bag for lab processing. All oysters within the quadrat were identified and counted within a 1 mm sieve. Surveyors then excavated all hard substrata within each quadrat down the mudflat surface, brought samples back to the lab and carefully identified and counted each living epibenthic bivalve, including *Ostrea lurida, Crassostrea gigas, Musculista* sp., *Mytilus galloprovincialus,* a variety of clam species, and bubble snails. Identifications and counts were double counted to ensure accuracy. Densities were converted to per m^2 for comparative purposes.

During pre-restoration surveys, we did not detect pre-existing oysters within the Shellmaker or Westcliff sites, but we did find pre-existing oysters at DeAnza and PCH. For brevity, the complete pre-restoration data are not presented here, but were reported in previous progress reports, are archived, and are available upon request. In January 2017, a few months before construction of the oyster beds, we found oysters at DeAnza, but only on the planned oyster plot at 17 oysters/m^2, and on several treatment plots at PCH, averaging about 8 oysters/m^2. Importantly, we detected none of the non-native Japanese oyster (*Crassostrea gigas)* though they were present in low abundances at all study locations, but at much higher tidal elevations than our restoration plots. Outside of oysters, Asian date mussels, (*Musculista senhousia,* non-native) and the spiny cup-and-saucer snail (*Crucibulum spinosum*) were by far the most common species detected. Bubble snails *(Bulla gouldii),* bay mussels (*Mytilu*s sp.), and a few unidentified clams (tentatively identified as *Venerupis phillipinarum*) were also detected in small numbers. Again for brevity, these data, as well as the six-month post-construction data, are not included in this final report and are available upon request.

Twelve months after oyster bed construction (May 2018), *Ostrea lurida* density ranged from 41.60 ± 12.67 oysters/m^2 to 238.4 ± 49.49 oysters/m^2 on the constructed beds. **On each bed, we recorded densities significantly higher than any measured just prior to restoration in Jan 2017, and higher than the nearest two reference locations In UNB** (Coney Island and Hwy1) (Tronske et al. 2018). At 238 oysters/m^2, density on the DeAnza oyster treatment increased 14 times relative to Jan. 2017. Importantly, of all oysters detected since bed construction, we have recorded only 1 *C. gigas*, representing less than 0.1% of total oysters detected.

At two of three sites, there was no significant difference in adult oyster density in 2018 between oyster and oyster/eelgrass but density was significantly greater on the oyster treatment compared to oyster/eelgrass treatment at DeAnza. The control and eelgrass treatment had significantly lower densities than both the oyster and oyster/eelgrass treatment at all sites (two-way ANOVA, treatment $p<0.0001$, site $p = 0.0003$, treatment*site $p = 0.0033$, Figure 5). Shellmaker was excluded from statistical analysis because the eelgrass transplant success was substantially reduced relative to the other sites, and eelgrass density was not significantly different than zero six months after oyster bed construction and only marginally denser on the oyster-eelgrass plot by one year after oyster bed construction (see discussion).

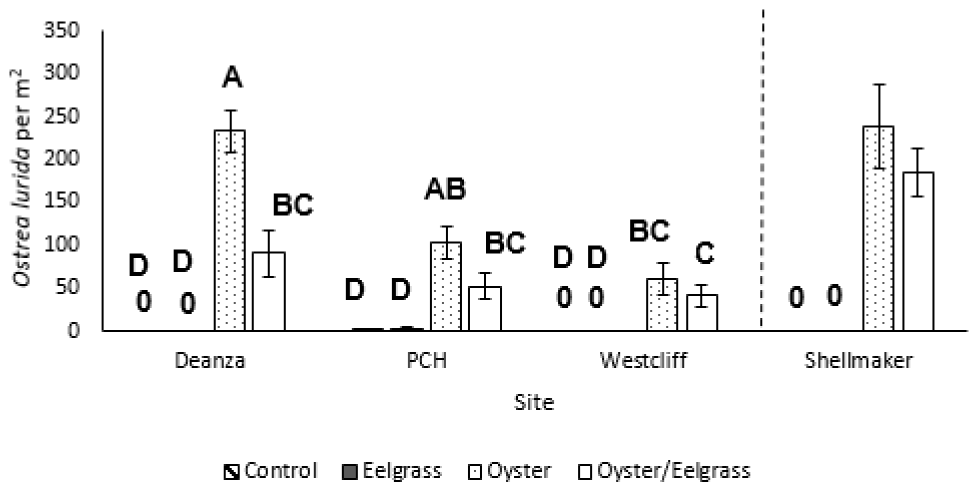

Figure 5. *Ostrea lurida* (per m^2) per site and treatment (n = 10) in May 2018, twelve months post-oyster bed construction. Error bars are ±1 SE. Variations in bold letters above bars indicate statistically significant differences among treatments and sites based upon post-hoc Tukey HSD. Shellmaker is excluded from statistical analyses but is included in graph for reference.

Oyster Abundance (2017):

We used density data and estimated bed area to provide preliminary estimates of oyster abundance. Our initial attempts at measuring the areal dimensions of the bed were unsuccessful but moving forward we have plans to record more refined estimates of changes in bed areal dimensions via mapping**.** In the meantime, we provided two estimates (one conservative, assuming 30% bed areal loss, and the other assumes no areal bed loss) of areal extent and used those to calculate abundance. In total, we calculate between 20,160 and 30,240 oysters on the restored beds as of May 2018 (Table 1).

Table 1. Oyster abundance on restored oyster beds in Upper Newport Bay in May 2018 as a function of site and treatment. Two areal estimates of bed size are provided.

Site	Treatment	Oyster Density	Oysters/30m^2	Oysters/20m^2
DA	O	233.6	7008	4672
PCH	O	104	3120	2080
SM	O	238.4	7152	4768
WC	O	60.8	1824	1216
		O total	**19104**	**12736**
DA	OE	91.2	2736	1824
PCH	OE	52.8	1584	1056
SM	OE	185.6	5568	3712
WC	OE	41.6	1248	832
		OE total	**11136**	**7424**
		Grand total	**30240**	**20160**

Oyster Settlement and Recruitment (2016-17):

We deployed settlement and recruitment tiles to assess the available larval supply dynamics at all study locations on all plots. **Settlement tiles** allow an estimate for the amount of initial oyster settlement onto hard substrata, while **recruitment tiles** serve as a longer-term estimate of larval population dynamics which accounts for post settlement mortality due to local biological interactions and disturbance. Both types of surveys used ceramic tiles (0.0225 m^2 area) suspended from polyvinyl chloride (PVC) tees 10 cm above the substratum in the middle of each treatment at -0.15 m MLLW. Oyster recruits and settlers were identified to species and counted on the underside of the tile, where they prefer to settle (Hopkins, 1935). We retrieved **settlement tiles** bimonthly from April to September, in 2016, 2017, and 2018, and monthly from September to April of each year. Settlement of *Ostrea lurida*/tile over each representative year (2016, 2017) and for each treatment at each site was summed to measure cumulative settlement for ease of statistical analyses (Zacherl et al., 2015). To additionally assay seasonal variation in oyster settlement, *Ostrea lurida*/m^2/day was averaged by treatment per sampling period from 2016 to 2017. **Recruitment tiles** were left in the field for the entirety of the summer spawning season (April to September 2016 and 2018, and March to September 2017) and retrieved and analyzed in September each year.

Before oyster bed construction in 2016, cumulative settlement (oysters/tile) of *Ostrea lurida* did not vary significantly among treatments (two-way ANOVA, treatment p = 0.241) but PCH and DeAnza received more cumulative settlement than Westcliff (two-way ANOVA, site p = 0.006). This indicated that although pre-existing differences existed among the sites, all treatments had similar potential to attract larval oysters, given the adequate habitat availability. After oyster bed construction in 2017, cumulative settlement showed a large decline in overall cumulative oyster settlement/tile compared to 2016**.** However, **in 2017, cumulative settlement of *Ostrea lurida* was significantly greater on oyster tiles than on eelgrass tiles** (two-way ANOVA, treatment p = 0.0073, site p = 0.0288, Figure 6), **and cumulative settlement continued to vary by site** (PCH received more cumulative settlement than Westcliff, and DeAnza received the same amount of cumulative settlement as PCH and Westcliff). 2018 settlement data are archived and available upon request. For more detailed data on the timing of settlement pulses throughout summers 2016 and 2017, see Fig. 24 in Supplementary Material, Woods Thesis.

Before oyster bed construction in 2016, *Ostrea lurida* recruitment did not vary significantly among treatments (two-way ANOVA, treatment p = 0.4927). Recruitment differed among sites, however: recruitment was higher at DeAnza than at PCH and Westcliff, and was higher at PCH than at WC (two-way ANOVA, site p = 0.0015). **After oyster bed construction in 2017, *Ostrea lurida* recruitment was significantly greater on the Oyster treatment than the Control treatment** (two-way ANOVA, treatment p = 0.0167), **and did not vary significantly among sites** (site p = 0.0784).

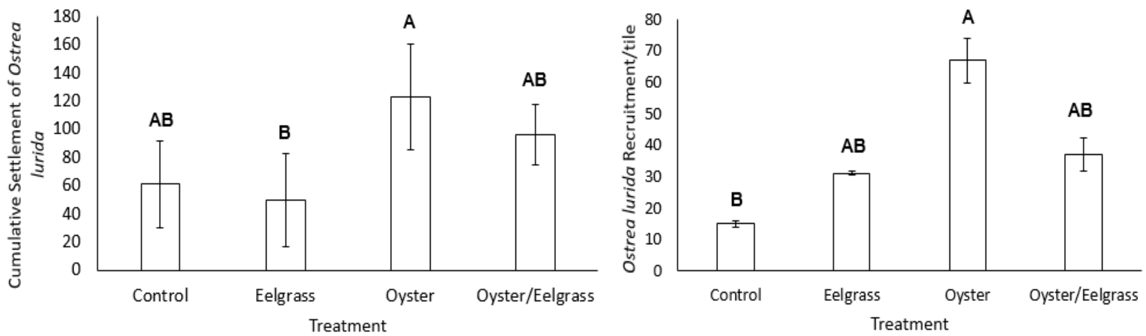

Figure 6. Total settlement (left) and recruitment (right) of *Ostrea lurida* per tile per treatment in 2017, post-oyster bed construction. Error bars are ±1 SE. Variations in bold letters above bars indicate statistically significant differences among treatments based upon post-hoc Tukey HSD. Recruitment data from 2018 are archived and available upon request.

Oyster Size (2018):

We used the size of excavated oysters one year after oyster bed construction as a proxy for growth. Oyster size measurements were taken from each oyster from each excavated quadrat at twelve months (May 2018) post-oyster bed construction. Oyster size (length) was estimated using Vernier calipers by measuring, in millimeters, the distance from the umbo to the longest point.

Twelve months after oyster bed construction in May 2018, average *Ostrea lurida* length on constructed beds ranged from 30.29 ± 4.72 mm to 34.54 ± 5.64 mm. **There was no difference in oyster length among treatments at twelve months post-oyster bed construction, but oysters were 9.9% larger at PCH compared to DeAnza** (two-way ANOVA, treatment p = 0.2115, site p = 0.0382, treatment*site p = 0.3978).

Oyster Adult Size Frequency Distribution:

We measured the length and width of all oysters excavated from the density surveys 6 and 12 months after bed construction. For brevity, these data are not presented but are archived and available.

Oyster vs. Eelgrass Density (2018):

Twelve months after oyster bed construction in May 2018, **oyster density/m^2 was negatively correlated with eelgrass density/m^2 across all eight oyster beds** (Pearson correlation, r = -0.7252, p = 0.0418). Oyster density values were log transformed prior to statistical analysis, indicating a negative exponential relationship between eelgrass density and oyster density. This finding is consistent with the trend (albeit non-significant) for higher recruitment and settlement on oyster compared to oyster/eelgrass treatments. We hypothesize that eelgrass may provide a filtering effect for oyster larvae (and possibly food and sediment, note that two of three sites with eelgrass showed more mud deposition onto oyster shells within the oyster treatments compared to oyster/eelgrass treatments). This finding should be considered preliminary as will be re-evaluated using the May 2019 (two years post-oyster bed construction) data. We have also started to analyze the condition index of bivalves on the oyster vs. oyster/eelgrass treatments to evaluate whether paired habitat restoration also affects per capita oyster physiological condition. Lastly, it is important to note that even on the oyster beds adjacent to eelgrass beds with the highest eelgrass densities, oyster density matched or exceeded the highest densities recorded to date at reference sites throughout Newport Bay (Tronske et al. 2018), and were significantly higher than pre-restoration conditions. Thus, **if eelgrass does suppress oyster density, restoration adjacent to eelgrass still results in net gains in abundance and density for oysters and re-introduces complex habitat supporting epifaunal invertebrates and fish communities.**

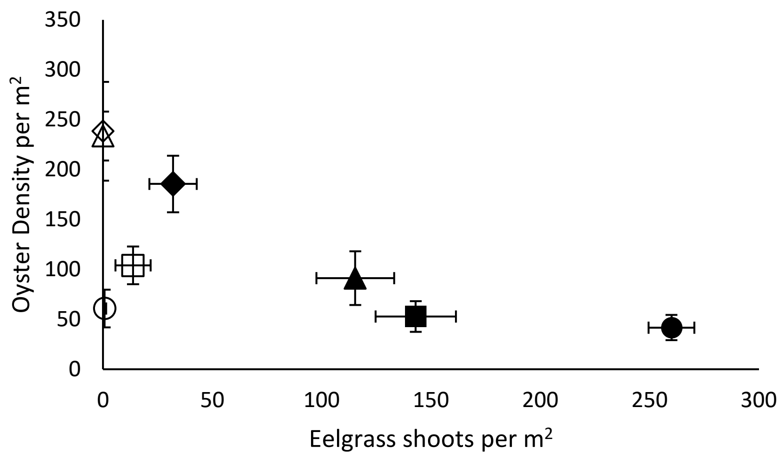

Figure 7. Relationship between mean density of adult *Ostrea lurida* as a function of mean eelgrass density in May 2018, twelve months post-oyster bed construction in Upper Newport Bay, CA. Beds were located across four sites. Error bars are ±1 SE. Triangles represent DeAnza, circles represent Westcliff, squares represent PCH, and diamonds represent Shellmaker. Unfilled symbols are Oyster treatments and filled symbols are Oyster/Eelgrass treatments.

Eelgrass

Eelgrass Density:

Eelgrass monitoring was completed underwater on SCUBA by Coastkeeper with the help of scientific divers, interns, and student volunteers. We monitored the density of turions (individual eelgrass shoots) starting in January 2016 (before restoration) through July 2018 at each of the restoration and control plots. Surveys were conducted in the winter before restoration, 1 month before restoration, and in the winter after restoration (~6 months' post restoration) and then annually in summer 2017 and 2018, 1 and 2 years post eelgrass restoration respectively with our 3-year survey planned for May 2019. Six equally spaced transects were placed perpendicular to shore, covering the entire plot length. Four quadrats (50 cm by 25 cm) were surveyed along each of the 6 transects at equally spaced intervals, for a total of 24 quadrats surveyed per plot. Within each quadrat, the total number of turions was counted, and the depth was recorded. Measurements of maximum and minimum depth limits of eelgrass within the planted eelgrass plots was also determined during eelgrass density surveys. During surveys, biologist divers also observed and took note of the depths of any eelgrass outside of the planted plot area.

Pre-restoration surveys found several relatively small pre-existing eelgrass patches within the subtidal treatment plots prior to restoration. At the PCH site, a 2 m by 2 m eelgrass patch was found, making up 2.5% of the total plot area. A 2 m by 2 m patch was found in the Westcliff site making up 2.5% of the total plot area as well. At the DeAnza site, a 2 m by 3 m patch was found in the eelgrass treatment plot, accounting for 3.75% of the total plot area and a 1 m by 1 m patch was found in the oyster/eelgrass treatment plot, accounting for 0.63% of the total plot area. No eelgrass was found in any of the Shellmaker treatment plots. Density within the eelgrass patches was measured in winter before restoration (6 months prior), 1 month before restoration, and in winter after restoration (6 months post) and ranged from **73.8 shoots/m^2** (Westcliff, oyster/eelgrass plot) **to 124.44** shoots/m2 (DeAnza, eelgrass plot).

In August 2017, approximately one year after eelgrass restoration and four months following oyster bed construction, our surveys found the highest mean eelgrass density at our DeAnza eelgrass plot with **133.67 ± 15.07 shoots per m^2** (Figure 8). Eelgrass was well-established on eelgrass and oyster/eelgrass treatments at all sites with the exception of our Shellmaker site (Figure 8). At Shellmaker, there was no detectable difference in eelgrass shoot density among any of the treatments, and density was not significantly different than zero, while at all other sites, there was significantly more eelgrass on the eelgrass and oyster/eelgrass treatments as compared to control and oyster alone treatments (two-way ANOVA, treatment*site $p<0.0001$).

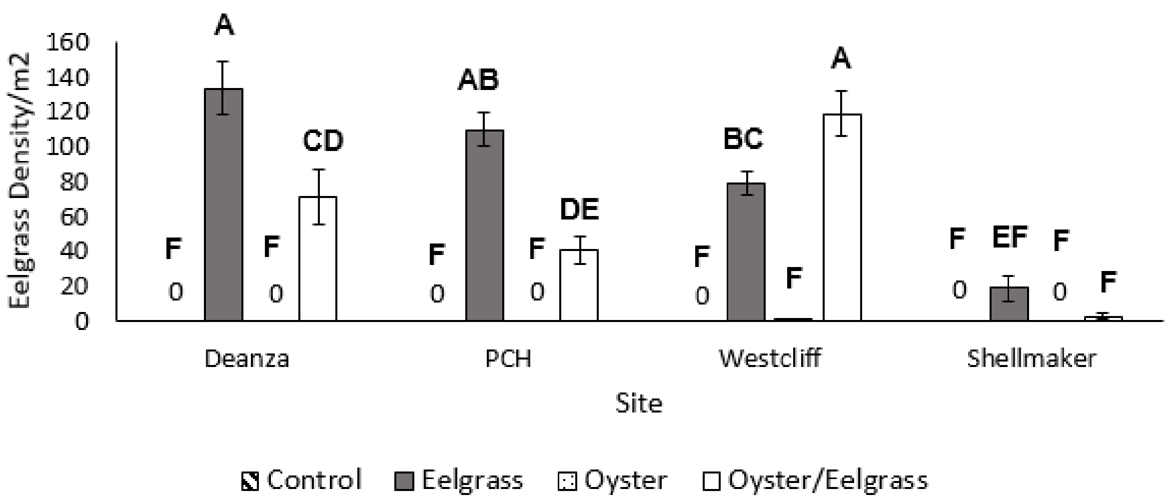

Figure 8. Eelgrass density (shoots per square meter) per treatment per site (n = 24 quadrats per treatment) in August 2017. Error bars are ±1 SE. Variations in bold letters above bars indicate statistically significant differences based upon post-hoc Tukey HSD.

In May 2018, approximately two years after eelgrass restoration our surveys found the highest mean density at our Westcliff paired oyster and eelgrass plot with a density of **260.0 ± 10.46 shoots per m^2**. In May 2018, eelgrass continued to be well-established with high shoot densities on eelgrass and oyster/eelgrass treatments at all sites with the exception of Shellmaker (Figure 9). Unlike in August 2017, by May 2018 eelgrass shoot density at Shellmaker in the eelgrass treatment was significantly higher than on the oyster and control treatments (Figure 9); however, it was substantially lower than other eelgrass treatments at other sites. In addition, the **occupancy rate of eelgrass shoots** at Shellmaker was ≤25% in August 2017, compared to >66% on all other eelgrass beds, and ≤50% by May 2018, **compared to >83% on all other eelgrass beds**. Qualitatively, the eelgrass beds on each treatment at Shellmaker only covered about half of each treatment plot, compared to the eelgrass beds at all other sites that contained nearly continuous coverage of eelgrass with only occasional small patches (<1-2 m^2) of unoccupied areas within the beds. After our summer 2017 surveys we re-planted eelgrass at Shellmaker, but unfortunately conditions at this site do not appear favorable for eelgrass persistence here (see Discussion). Depths of eelgrass ranged from 4-10 feet during our surveys.

Importantly, 1 year after oyster restoration, **there was no overall negative impact of oyster restoration on eelgrass density, the impact was site-specific**; at one site (DeAnza), eelgrass density was higher on eelgrass only compared to oyster/eelgrass, but that effect did not exist at PCH and Shellmaker, and the effect was reversed at Westcliff. Qualitatively, at all sites except Shellmaker where eelgrass performed poorly in general, we observed eelgrass encroaching across the buffer zone between oyster and eelgrass plots, directly abutting against the oyster beds (see Figure 11). Moving forward and starting with our May 2019 eelgrass surveys, we have plans to measure several other metrics of eelgrass success including reproductive output, growth, and blade morphometrics.

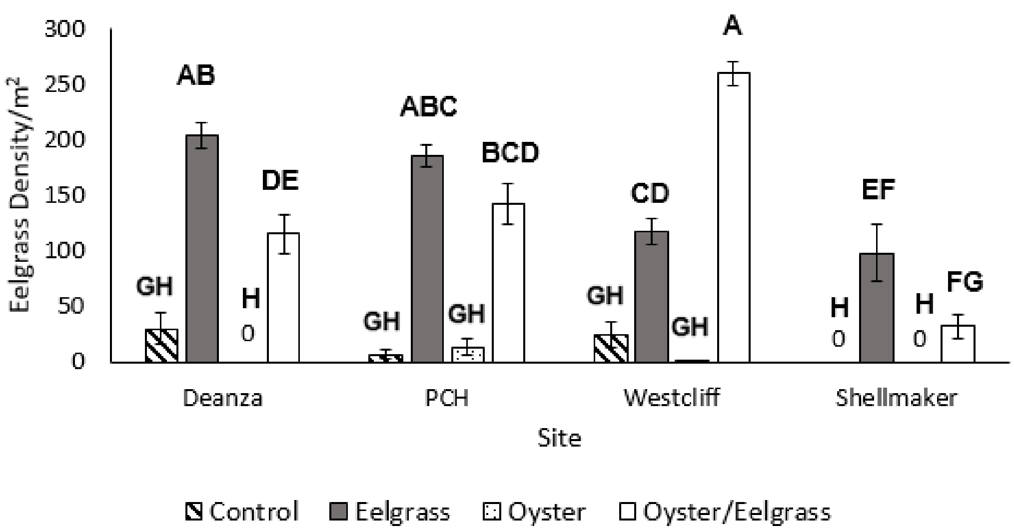

Figure 9. Eelgrass density (shoots per square meter) per treatment per site (n = 24 quadrats per treatment) in May 2018. Error bars are ±1 SE. Variations in bold letters above bars indicate statistically significant differences based upon post-hoc Tukey HSD.

Eelgrass Area:

Our experimental design called for two 8 X 20 meter eelgrass beds at each site (160 m^2 per bed with 320 m^2 total per site, see Figure 2). Areal cover of planted eelgrass plots was monitored 6 months after restoration and in June of 2018 in each of the four treatments. Divers surveyed eelgrass and control beds on SCUBA and mapped the beds using a Trimble R1 Global Navigation Satellite System receiver linked with a smartphone. This mapping was accomplished by having a single diver swim the outline of the eelgrass bed perimeter while towing a Pelican float while a second diver followed this path with the Trimble R1. This receiver, enabled with real-time Satellite-based Augmentation System correction, provides sub-meter accuracy during mapping. Data were exported to the Trimble Terraflex cloud system for review and are available as shapefiles. We are grateful to the Paua Marine Research Group for partnering with us to conduct eelgrass mapping in 2018.

Total areal extent of eelgrass in the two combined plots by site was 1,108 m^2 for PCH, 854 for Westcliff m^2 and DeAnza was the highest at 1,667.1 m^2. Shellmaker was the only site that had a lower areal extent than originally planned at 146.7 m^2**. The combined total eelgrass area was 3,775.8 m^2 in summer 2018 which is nearly 3 times our original eelgrass area target restoration goal of 1,280 m^2** (Figure 10). From a restoration perspective, the persistence and spread of eelgrass at three out of four of our sites was a great success. However, as you can note in Figure 11 the eelgrass at many sites over grew out of their intended plots and into buffer zones and control plots. While the size of these overgrowth patches was minimal overall as compared with intended eelgrass plots (i.e. a high of 70 m^2 in one PCH control as compared with a high of 833 m^2 in a DeAnza eelgrass plot) the effort required to maintain our experimental design via hand removal of eelgrass in buffer and control zones was extensive and initially unanticipated (see Discussion).

Figure 10. Results of Aerial Eelgrass Mapping Conducted in summer 2018. Bright green shows aerial extent of eelgrass overlaid on brown boxes of treatment area.

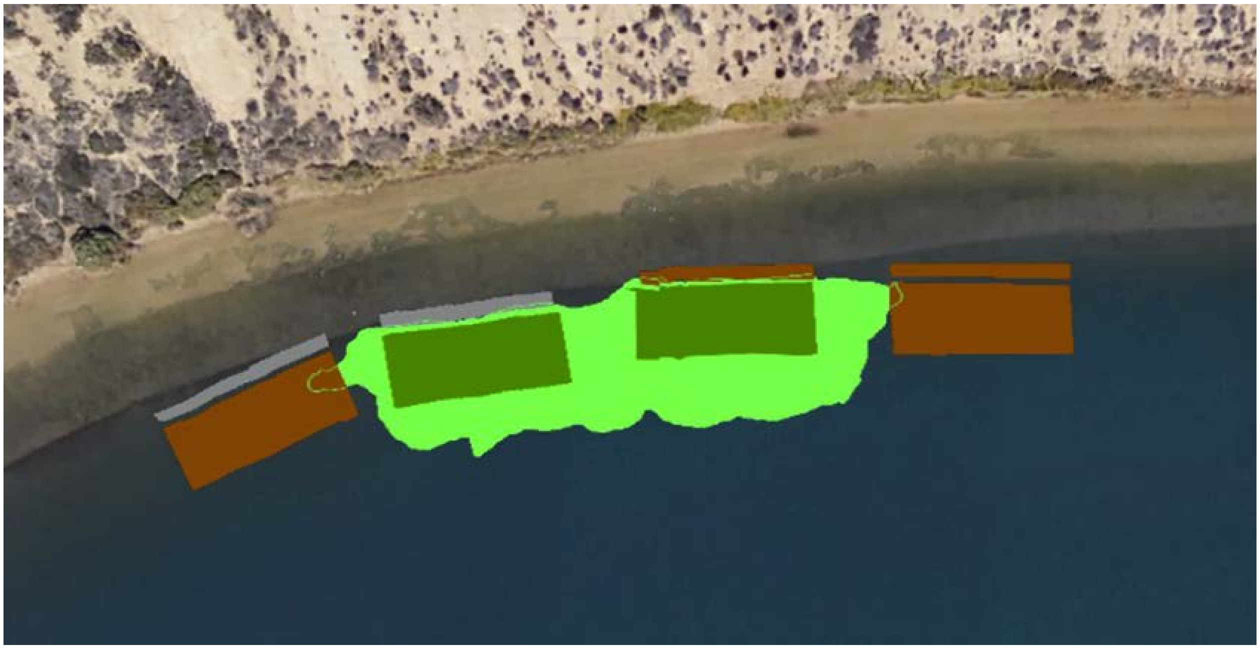

Figure 11. Results of Aerial Eelgrass Mapping Conducted in summer 2018 at Westcliff site. Bright green shows aerial extent of eelgrass overlaid on brown boxes of treatment area.

IV. HABITAT VALUE

Infaunal invertebrates and Fish

*Note that this work was partially supported by CSULB, Pacific Marine and Estuarine Fish Habitat Partnership (PMEP) and USFWS

Prior to eelgrass restoration in 2016, 80 sediment cores (18.1cm^2 by 6 cm deep) were collected to assess infaunal community composition within each of the four study sites. Five cores were collected from the intertidal portion of each restoration plot, and one core was collected from each of three subtidal plots within each site. In 2017 (one-year post-eelgrass) and 2018 (one-year post-oyster), three cores were collected from each intertidal and each subtidal plot. Sediment cores were preserved in formalin, and washed through a 300µm sieve, and infauna were identified to the lowest possible taxonomic level. Overall abundance of infauna as well as species richness were calculated for each sample. We anticipated that infauna abundance would decrease under constructed oyster beds.

As predicted, in 2018, intertidal infaunal abundance was significantly lower beneath restored oyster beds (O, O/E) relative to other intertidal plots (Figure 12, $F_{3,1}=38.76$, $p<0.001$) **and pre-oyster restoration**. Infaunal richness was also significantly lower beneath restored oyster beds relative to other intertidal plots (Figure 12, $F_{3,1}=64.47$, $p<0.001$) and pre-oyster restoration. Infaunal invertebrate communities under oyster beds were similar to each other regardless of neighboring eelgrass, as driven by lack of organisms, but among-site variation was also significant in community composition (Pseudo-F 3, 1.94, $p<0.001$). Subtidal abundance and richness were more variable within and between sites, with the only significant difference among treatments found at the PCH site (a decrease in abundance in the unpaired eelgrass treatment; $F_3=5.46$, $p=0.024$. **Increases in subtidal richness between 2016 and 2018 occurred at PCH and WC, though differences among treatments were not significant (Figure 13).**

Fish were monitored quarterly beginning in April 2017 (pre-oyster restoration), using baited video traps. GoPro cameras attached to a baited PVC T-frame were placed 1m into the subtidal plot of each treatment, at a random position along the shoreline. Video was recorded for two hours per site, twice per sampling season. Each fish entering the camera's field of view was identified, and the time entering and leaving the frame were recorded. We calculated mean abundance of fish with $MaxN_{species}$: the maximum number of each species present simultaneously in the field of view (e.g. Wakefield et al. 2013). We hypothesized that fish utilization would be enhanced at the oyster-eelgrass plots as compared to other plots because of the diversity of available habitats. **Mean abundance ($MaxN_{species}$) and community composition were highly variable among sampling periods, treatments, and sites.** In April 2018, fish community composition varied with site and treatment (Figure 14). The Shellmaker fish community had overall higher time on camera than other sites and PCH had a higher species richness than Westcliff. Based on $MaxN_{species}$, Shellmaker again had a significantly different community than DeAnza and Westcliff (Site: df=3, pseudoF=1.8631, p=0.0565). **In addition, fish communities varied between oyster and paired oyster-eelgrass treatments across sites** (df=3, pseudoF=1.7891, p=0.0733).

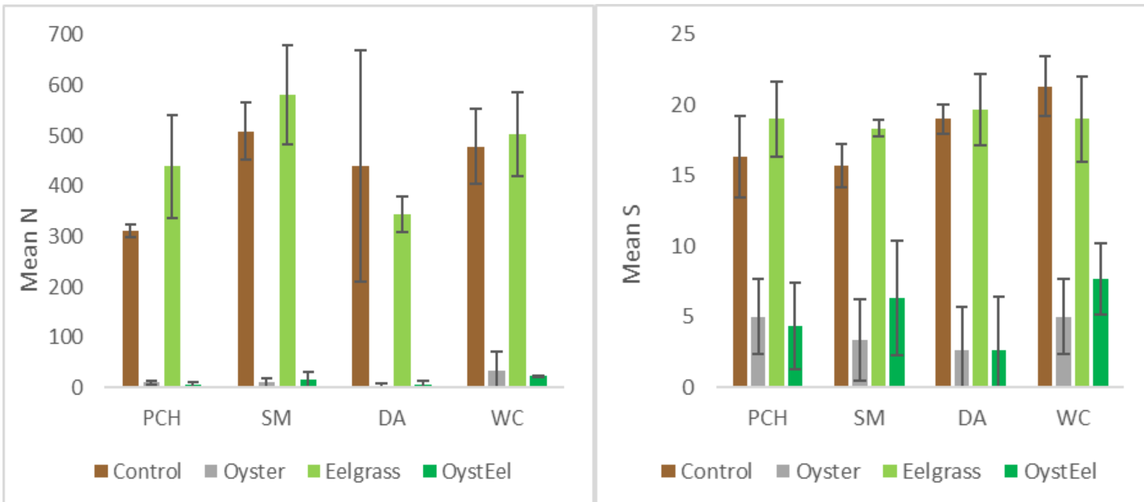

Figure 12. Abundance (N/ 18.1 cm^2, left) and species richness (S /18.1 cm^2, right) of intertidal infauna collected in May 2018.

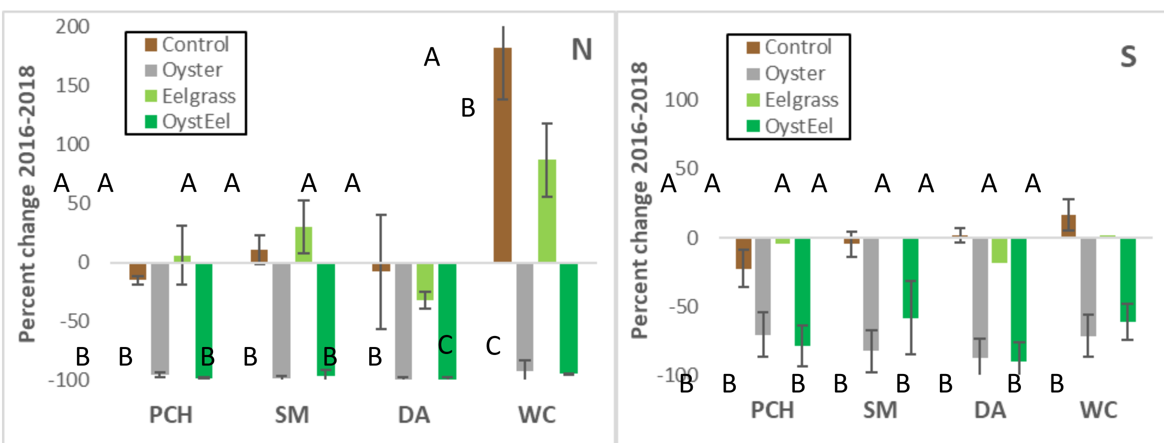

Figure 13. Percent change in intertidal infaunal abundance (N, left) and richness (S, right) from 2016 to 2018, pre- to post-oyster restoration. Significant differences between treatments, as determined by Tukey's test within site, are indicated with letters.

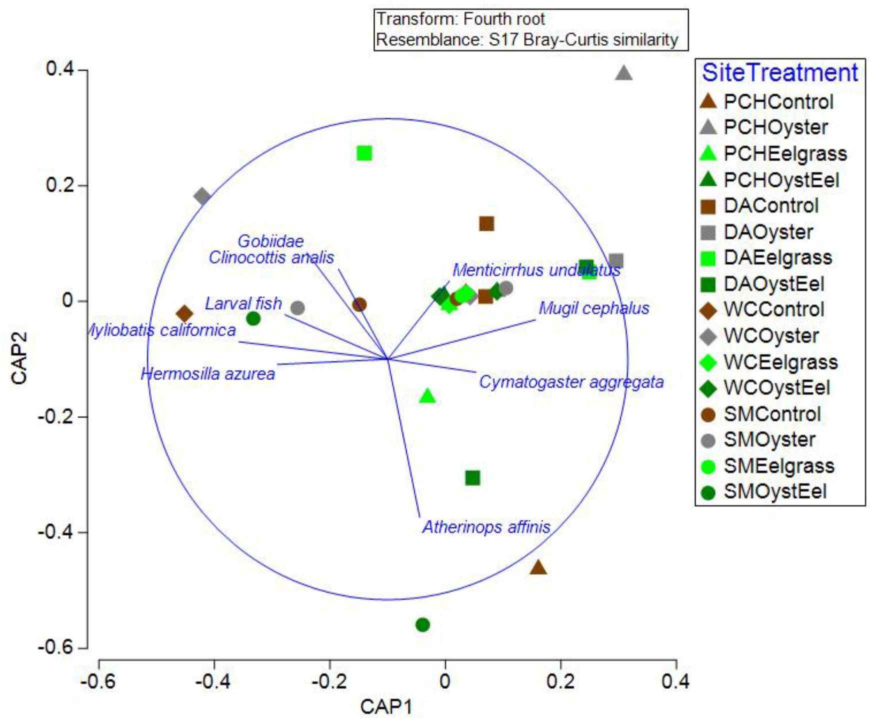

Figure 14. CAP multivariate plot of fish communities among treatments and locations. Each point represents a sampling point and all of the fish seen in the associated video. Distance between points corresponds to differences among community composition. The overlaid vectors indicated which species drive any observed differences.

<u>*Eelgrass Epifaunal Invertebrates*</u>

*Note that this work was supported by COAST, PADI Foundation and SDSU

We used invertebrate field collections to understand if eelgrass epifaunal community structure varied with adjacent habitat type (Olympia oysters or unvegetated sediment) and edge proximity (edge or interior), and whether variability was mediated by mechanisms such as resource availability and shoot density. We also utilized tethering experiments to estimate how proximity to edges and edge type influenced relative survival of a common eelgrass epifaunal species (grass shrimp) please see Griffith thesis in the Supplementary Information for more detail. We predicted that architecturally complex and low contrast eelgrass-oyster edges would result in greater richness than the high contrast but structurally simpler eelgrass-sediment edges.

Eelgrass epifauna (500 µm and 3 cm) were collected at the edge and interior of each eelgrass bed with an airlift suction sampler immediately prior to oyster restoration (April 2017), six months' post-oyster restoration (November 2017) and one-year post-oyster restoration (May 2018). We estimated eelgrass structural complexity from the sampled area with seagrass shoot counts within a 0.062 m^2 quadrat which were standardized to shoots m^{-2}. We repeated this process three times at the shallow eelgrass bed edge (0-1 m from the border) and interior (≥3 m from any edge), at both eelgrass treatments (n = 2) at all sites (n = 3), totaling 36 epifaunal collections per sampling period. We sieved samples at 500 µm, and subsequently counted and identified all mobile epifauna to the lowest practical taxon (species for most taxa, gammarid amphipods to suborder Gammaridea).

One year after oyster restoration (May 2018), restored eelgrass beds supported a diverse and abundant epifaunal community: beds supported an average of 10,540 individuals per m^2 and included 34 taxa (Table 2). The most common group (peracarid crustaceans) represented 94% of total invertebrates, with gammarid amphipods accounting for 83% of all organisms counted. Epifauna density varied widely among sites; 47% of all epifauna counted were from DeAnza (DA), 32% were from PCH, and 21% were from Westcliff (WC) (Table 2). **All sites had increased density and rarefied richness in May 2018, but overall decreased Simpson's diversity compared to April 2017** (Figure 15). The decrease in diversity indicates that species evenness decreased and communities are dominated by a few taxa (i.e. gammarids).

We sampled epifauna communities at the eelgrass edge and interior to investigate if these sub-habitats responded uniquely to restoration treatments. **Neighboring oysters and proximity to eelgrass edges appeared to influence epifauna richness and diversity at DA only and epifauna density did not vary by treatment at any site**. Oysters elevated eelgrass epifauna richness and diversity in the DA Oyster-Eelgrass eelgrass bed compared to the DA Eelgrass bed. Our proposed mechanisms shoot density and epiphyte food resources did not appear to explain community patterns, but the uniform and somewhat low-density plantings of eelgrass (compared to natural beds) may explain why strong edge effects were not found.

Table 2. Taxon abundance in all eelgrass epifauna samples one year after adjacent habitat restoration (May 2018). Each taxa listed made up at least 1% of the total sampled.

Taxon		PCH	WC	DA	Total	%
Gammaridea	peracarid	19986	12838	29814	62638	82.6
Synaptotanais notabilis	peracarid	981	602	1124	2707	3.6
Caprella sp.	peracarid	509	355	1757	2621	3.4
Paracerceis sculpta	peracarid	991	512	1098	2601	3.4
Postasterope barnesi	ostracod	625	206	254	1085	1.4
Nereis sp.	polychaete	134	584	217	935	1.2
Assiminea californica	gastropod	460	187	104	751	1
Hippolyte californiensis	shrimp	190	237	306	733	1
Others	--	412	533	858	1803	2.4
Totals		24288	16054	35532	75874	100

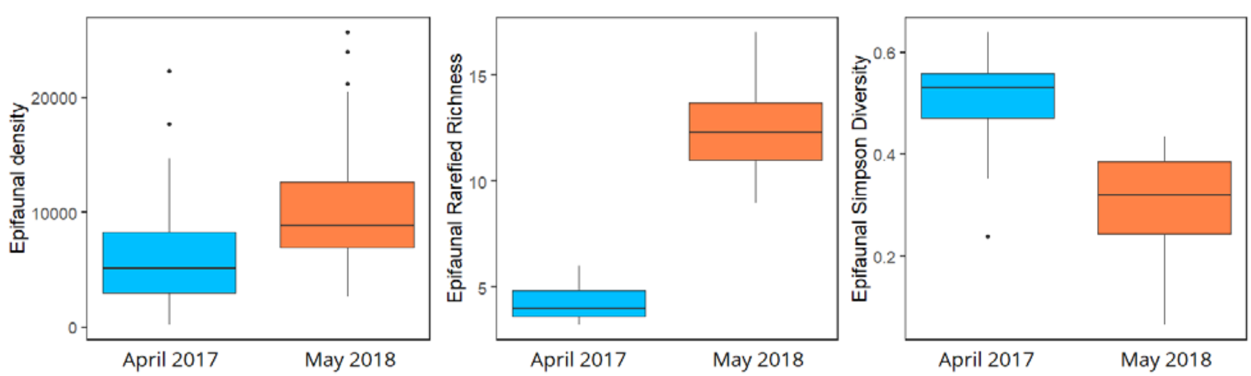

Figure 15. Boxplots for eelgrass epifaunal community responses before oyster shell addition (April 2017, blue) and one year after (May 2018, orange). This set represents untransformed responses of epifaunal density (A), rarefied richness (B), and Simpson index of diversity (C). Each box represents 36 samples (treatments and sites pooled).

Birds

*Note this work was not supported by SCC funds

Pre-restoration bird surveys were conducted between the months of January – June of 2016; post-restoration (of both eelgrass and oysters) surveys were conducted between April 2017 – March 2018. Each bird survey was conducted at -0.5 MLLW or lower, which represents the tidal height of the oyster beds. Each survey consisted of four focal and scan samples. For each scan sample, the location and identity of all birds was determined at the site for 3 minutes. For each focal sample, 1 – 2 birds were randomly selected to collect behavioral data. The birds were then observed for 4 minutes, recording instantaneous observations of their behaviors every 30 seconds. Since the timing of the low tides varied throughout the year, the data was separated into two tide seasons: the afternoon low tide season (January – March) and the morning low tide season (April – June). Two-way ANOVAs were used to test for effects of treatment and pre vs. post restoration, plus their interactions on bird density and richness using JMP data analysis software. One survey site, Shellmaker, was excluded from analysis due to lack of eelgrass over a portion of the sampling period.

Across both morning and afternoon tides for pre and post-restoration, we observed 41 species and 421 total birds on all treatments. The bird species observed most consistently throughout pre and post-restoration surveys were the Willet (*Tringa semipalmata*), Marbled Godwit (*Limosa fedoa*, Figure 16), and Western and Least Sandpipers (*Calidris mauri, Calidris minutilla*). Birds spent 70% of observed time foraging as opposed to other behaviors. The amount of birds seen during the tide season differed greatly with a density of 80 bird/ha seen during the afternoon tides compared to 6 birds/ha during the morning tides. This large difference in presence during afternoon tides appears to coincide with migratory patterns common in birds. **Based on morning tide bird surveys, there was no difference in bird density and bird richness among the sites and treatments during pre- and post-restoration surveys** (Two-way ANOVA, $p>0.05$ for all other effects and interactions). **However, on control treatments during the afternoon tide season, density and richness both declined after restoration** (Two-way ANOVA, Treatment*Pre- or post-interaction, $p<0.05$). All other treatments, besides control, had no difference in density or richness, pre- or post-restoration. **This provides some indication that restored habitats may serve as a buffer for regional bird declines, maintaining local density and species richness.**

Figure 16. Marbled godwit's utilizing restored eelgrass bed (Photo taken by Kiarra Lyons).

V. PHYSICAL MONITORING

With the help of environmental engineers from Anchor QEA and students from USC and CSU Fullerton, Coastkeeper monitored several aspects of the beach upland of the restoration plots to determine if the living shoreline elements (restored oyster and eelgrass beds) aid in shoreline protection. These include: inshore and intertidal sediment characteristics, intertidal sediment accumulation, and shoreline profile. We also monitored water quality.

Sediment Characteristics

Intertidal sediment:

Grain size was assessed at each treatment plot across all sites prior to oyster bed construction (March-April 2017), and twelve months (May 2018) after construction. Grain size measurements were taken 0.85 m upshore of each treatment and centered at 10 m. Each representative core was 3 cm deep within a 10 X 10 cm area. We analyzed grain size by category (clay, silt, and sand) with univariate and multivariate tests.

Site differences in grain size were found pre-oyster bed construction (March 2017, ANOSIM, site $p = 0.015$, $Rho = 0.657$, treatment $p = 0.126$, $Rho = 0.417$) continued to be prevalent one-year post oyster construction. In 2017, Westcliff was characterized by relatively high percent silt, while PCH was sandier. **In May 2018, one year post-oyster bed construction, grain size differed by site, but no significant difference was detected among treatments**. Representative treatments were more similar to one another in grain size characteristics than site-level characteristics, with a marginally significant treatment effect (ANOSIM, treatment $p = 0.055$, $Rho = 0.41$, site $p = 0.276$, $Rho = 0.25$) (see Wood's thesis in Supplementary Materials). In general, Oyster and Oyster/Eelgrass treatments were characterized by higher percentages of silt and clay, while Eelgrass and Control treatments had higher % sand.

Inshore Sediment:

*Note this work was not supported by SCC funds

Three undergraduate students at the University of Southern California (Jeremy Smith and Corryn Knapp, Suriya Tanjasiri) took on an independent student research project to analyze inshore sediment characteristics of the restoration sites. Two 50 ml syringe sediment cores were taken at +0.5 m MLLW (mean lower low water) inshore of each treatment plot at each of the four sites. Collections were taken bimonthly at PCH, WC, and DA before restoration in May 2016 through April 2018. Once back at the lab, sediments were analyzed for grain size (via sieving methods from the University of Twente's ISRIC protocol) and organic carbon content (loss on ignition/ash free dry weight).

High variability made it difficult to discern the influence of treatments on inshore grain size within each site. However, on average, in-shore sediments at plots with restored eelgrass retained a greater proportion of finer particles than plots without eelgrass. DA is the site with the finest sediments and WC has a greater proportion of larger sediments. Preliminary data from 2017 through May 2018 (one year after oyster restoration) suggest that at PCH inshore finer sediments (<250 µm) have accumulated most at the oyster-eelgrass treatment. More analyses incorporating variability across sites is necessary to confidently conclude these differences are attributable to the treatments.

Percent Mud Coverage and Mud Deposition on Hard Substrata:

Percent substratum cover measurements were taken within each treatment plot using 10 randomly-placed 0.5 X 0.5 m gridded quadrats pre-oyster bed construction (January 2017), six months (November 2017), and twelve months post-oyster bed construction (May 2018) using point-contact techniques (n = 49 points per quadrat). At each point, we used a probe to assess not only the substratum but also mud or sand burial upon it. If the mud/sand depth was >9 mm at a representative point, then the substratum was scored as mud or sand. The hard substratum was recorded as well as the depth of mud (or sand) when <9 mm of sediment was measured upon the hard substratum. Indicating the potential burial height of our shell beds is a crucial factor in oyster mortality as survival decreases significantly once an oyster's body is 90% covered by sediment (Colden and Lipcius, 2015). The point contact technique, therefore, allowed us to simultaneously track the conversion of shell habitat back into mud (i.e., changes in % mud cover over time) while also scoring the extent of sedimentation occurring on habitat that we continued to score as "shell".

During pre-oyster bed construction in January 2017, mud coverage was more than 90% at all treatments. Six months post-oyster bed construction in November 2017, mud coverage on Oyster and Oyster/Eelgrass treatment dropped precipitously relative to pre-restoration because of the placement of 100% cover of dead oyster shell during oyster bed construction. Nonetheless, some mud deposited onto the oyster beds in subsequent months, slightly reducing shell cover and returning a small percentage of the constructed oyster bed habitat back into mud habitat. Mud cover ranged from a mean of 2.24 ± 0.83% to 13.47 ± 3.51% on constructed oyster bed treatments while the Control and Eelgrass treatments ranged from a mean of 92.65 ± 1.56% to 99.59 ± 0.27%. **There was no significant difference in mud coverage at the Oyster versus Oyster/Eelgrass treatments across all sites in November 2017**. **Six months post-oyster bed construction, sediment deposition onto hard substrata (including coir, rock, and shells) on oyster beds was significantly higher on the Oyster treatments than at Oyster/Eelgrass treatments** (two-way ANOVA, treatment p = 0.0450, site p = 0.7494, treatment*site p = 0.7911).

Twelve months' post-oyster bed construction in May 2018, percent mud coverage was significantly higher at the Oyster treatment compared to Oyster/Eelgrass treatment at PCH and Westcliff, but there was no difference in percent mud coverage at DeAnza between the Oyster and Oyster/Eelgrass treatment (two-way ANOVA, treatment p<0.0001, site p = 0.0092, treatment*site p<0.0001). Mud coverage on all constructed oyster beds (a proxy for conversion back to mudflat habitat) was below 17% except on the PCH Oyster treatment. **Twelve months post-oyster bed construction, sediment deposition onto hard substrata (including coir, rock, and shells) on the oyster beds remained significantly higher on Oyster treatments compared to Oyster/Eelgrass treatments only at PCH, with no differences in sedimentation detected at other sites among treatments** (two-way ANOVA, treatment p = 0.0003, site p = 0.1492, treatment*site p<0.0001).

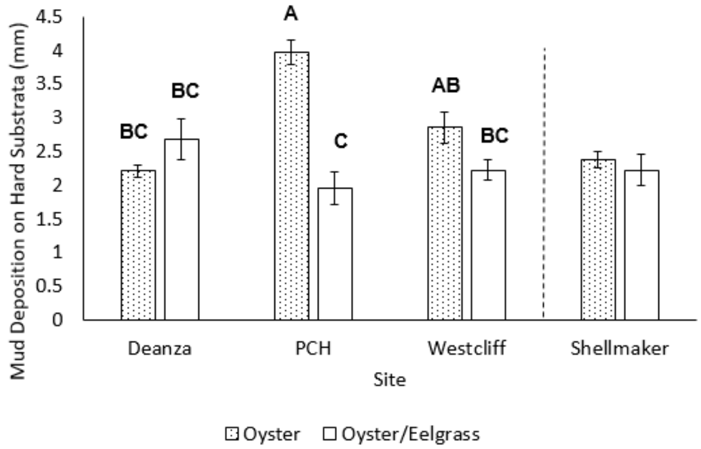

Figure 17. Mud deposition (mm) on hard substrata per treatment per site in May 2018, twelve months after oyster bed construction. Error bars are ±1 SE. Variations in bold letters above bars indicate differences among treatments based upon post-hoc Tukey HSD. Shellmaker is excluded from analyses but is included in graph.

Sediment Retention

Sedimentation immediately upshore of each treatment plot (0.85 m) was calculated using sedimentation pins (US Geological Survey, 2012). Two sedimentation pins were hammered into the sediment at every treatment, located at the 5 m mark and at the 15 m mark across the 20 m total treatment width. Sedimentation pins were 1.5 m tall, with 0.9 m hammered into the sediment, and 0.6 m of pin exposed. Every month, we measured changes in elevation in sediment height (in mm) on each sedimentation pin on the north, south, east, and west side and the height of pins were averaged together to get a representation of sedimentation occurring throughout the upshore area of each treatment plot (US Geological Survey, 2012). Upstream and downstream sediment pin effects were also visually inspected to ensure averaging sediment pins was appropriate. There was no detectable upstream or downstream effect on sedimentation among pins within treatments via visual inspection and therefore sedimentation was averaged across the two sediment pins at each treatment.

A year after the oyster beds were constructed, in May 2018, sedimentation did not differ by site or up-shore of treatment (two-way ANOVA, treatment p = 0.0865, site p = 0.3726, Table 3, Figure 18). There was, however, **a trend towards net sedimentation upshore of the Oyster, Oyster/Eelgrass, and Eelgrass treatments compared to the erosional Control treatments** (Figure 18).

Table 3. Two-Way ANOVA for Effects of Site and Treatment on Upshore Sedimentation Measured with Sediment Pins Twelve Months after Oyster Bed Construction (May 2018) in Newport Bay, CA.

Source	SS	DF	MS	F ratio	Prob > F
Site	1.79	2	0.90	1.17	0.3726
Treatment	8.22	3	2.74	3.57	0.0865
Model	10.02	5	2.00	2.61	0.1372
Error	4.61	6	0.77		
Total	14.62	11			

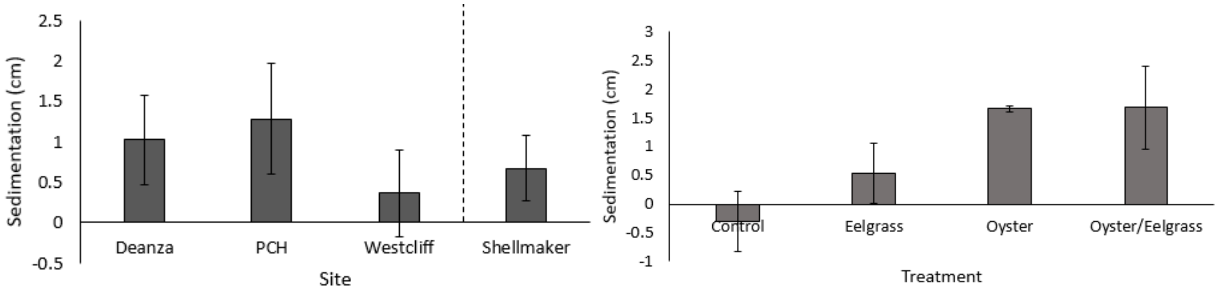

Figure 18. Total sedimentation (cm) across sites (significant, left) and treatments (not significant, right) in May 2018 one-year post oyster bed construction. Error bars are ±1 SE.

Shoreline Profile

We monitored shoreline loss/gain (change in shoreline position) and shoreline profile/elevation changes to evaluate the degree to which oyster and eelgrass habitats abate shoreline erosion or enhance sediment accretion. Prior to restoration we conducted topographic surveys by measuring elevation of at least three points along each treatment plot using a laser level standardized to a known tidal elevation. Shoreline surveys were conducted in summer and winter of 2016, and again in the winter of 2017. Permanent markers were installed prior to restoration and were unfortunately lost one-year post restoration thus results from these surveys were inconclusive and are not presented here.

Coastkeeper and partners at USC (Dr. Jill Sohm and students) and USC Sea Grant also explored the use of drone aerial imaging to provide digital elevation models of the shoreline. We explored the potential for aerial imaging to provide a precise and holistic understanding of shoreline changes (see Figure 19). The spatial accuracy of our current data was not precise enough for analysis but there is potential to develop this work further and we intend to explore other methods to address the physical aspects of our project more completely (See discussion for future plans).

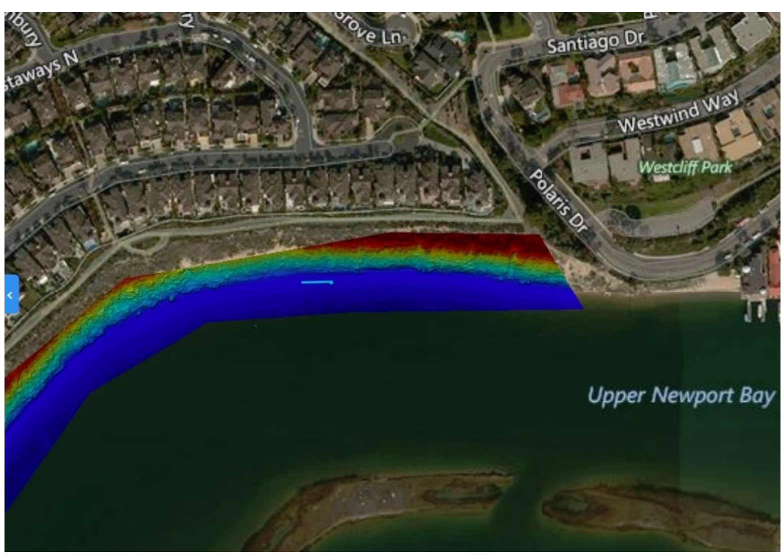

Figure 19. Example image captured November 7, 2018 and viewed through DroneDeploy to explore the potential to create fine scale elevation maps.

Water Quality Monitoring

Temperature, dissolved oxygen, pH, and salinity were measured at each site at least annually using an YSI 556 Multi-Probe System. **We did not detect strong differences among the four sites in these point trials and thus also examined a longer time series.** While continuous water quality sampling during the duration of the project would have been ideal, time and funding forced us to prioritize some aspects of our initial monitoring plan. Weekly water sampling was conducted during a 24-week period from September to March 2019, during some substantial rain events, with a few exceptions. Shellmaker was sampled 22 times, DeAnza was sampled 24 times, Westcliff was sampled 24 times, and PCH was sampled 23 times. See Figure 20 for results of the 2019 water quality monitoring.

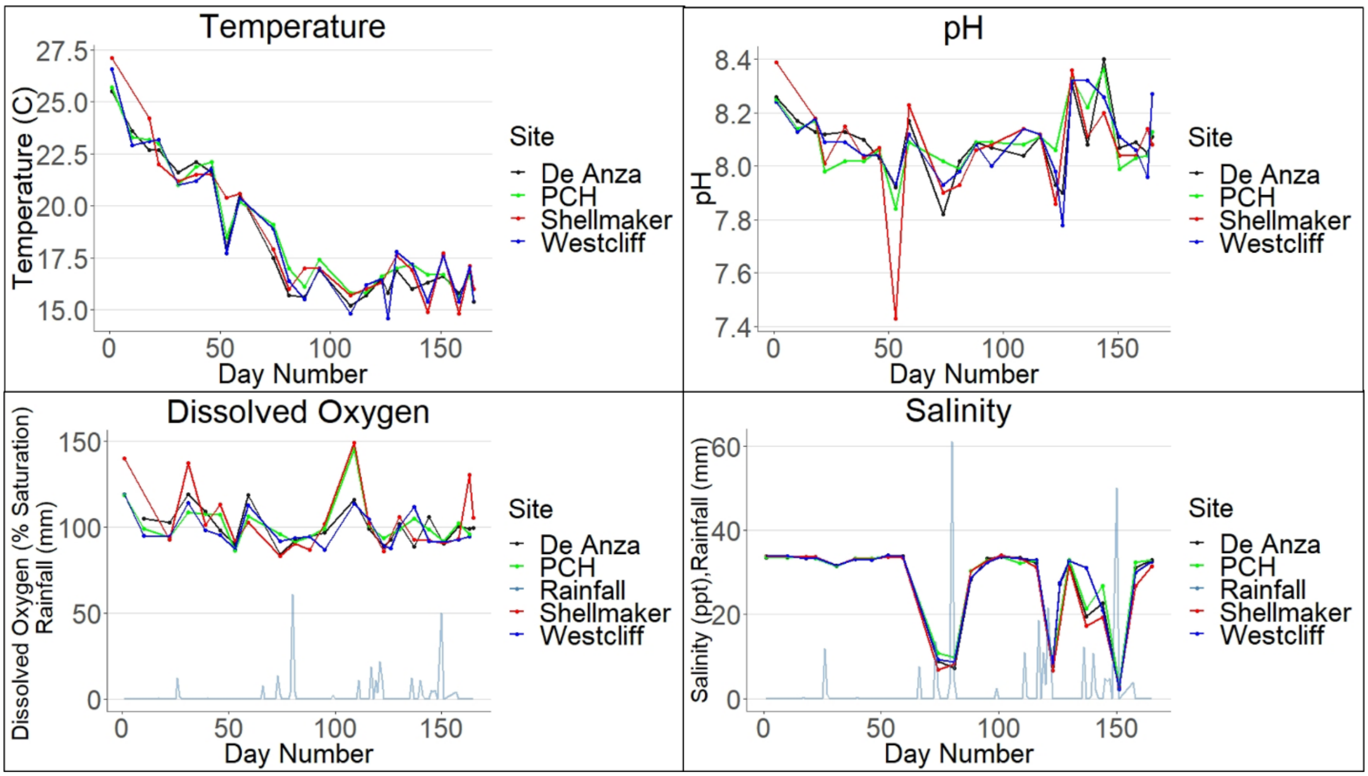

Figure 20. Results of 24-week water sampling over two substantial rain events.

Wave Attenuation

In summer of 2017 we conducted replicated trials at our DeAnza site to ascertain whether we could detect the effects of our paired treatments vs single restoration or control sites on their ability to attenuate waves. We utilized HOBO U20L Water Level Loggers to gauge pressure and conducted several trials monitoring during times of heavy wakes from nearby boats. Results showed pressure changes, but were ultimately inconclusive. Additional follow up and future research is needed to address this question (see discussion).

VI. EDUCATION AND COMMUNITY OUTREACH

It is critically important to engage the public in an understanding of how living shorelines may benefit their community. By specifically involving community volunteers directly in our habitat restoration, maintenance, and monitoring, our goals were to increase awareness about the threats to coastal habitats and promote the local desire to protect these habitats. This project has maintained an extensive volunteer effort of over 569 individuals spanning close to 3,000 volunteer hours. Three M.S. students completed or will soon complete their thesis research on this project, which will result in at least 3 scientific manuscripts. In addition, numerous OCCK interns and undergraduates at SDSU, CSULB, and CSUF were involved in the research and monitoring.

We have integrated the living shoreline concept and this project into Coastkeeper's website, monthly e-newsletters, social media, and press releases to local media. By involving volunteers directly in eelgrass restoration, oyster bed building and in our scientific monitoring, we facilitated experiential, hands-on opportunities in conservation for the public. Through our monitoring activities and ongoing education activities at the Back Bay Science Center, we will continue to make eelgrass and native oyster restoration and conservation a priority for Newport Bay.

Recreational fisherman regularly visit three of our four restoration sites. In January 2018, one of our restored oyster beds was significantly compromised by an individual collecting shells in the State Marine Conservation Area. Through the creation of pamphlets and direct conversations at the beach we are working to build awareness about the benefits of conserving these habitats for recreational fisheries. Further, we have increased awareness about conservation of wetland habitats through numerous public presentations and media efforts as detailed below.

Select list of Media:

"Coastkeeper seeks to replenish Southern California oyster reefs" The Log, 10/1/2015
http://www.thelog.com/Article/Coastkeeper-seeks-to-replenish-Southern-Calfornia-oyster-reefs2015-09-22T12-59-00

"Eelgrass gets a transplant in Newport Bay restoration project" The Daily Pilot, 6/12/2015
https://www.latimes.com/tn-dpt-me-0613-eelgrass-restoration-20150612-story.html

"Coastkeeper Creates a Living Shoreline" The Newport Beach Independent, 7/7/2017
https://www.newportbeachindy.com/coastkeeper-creates-a-living-shoreline/

Videos:

OCCK Eelgrass Restoration: https://www.youtube.com/watch?v=aFXGDTjW8Qg

OC Coastkeeper Living Shorelines Olympia Oyster Restoration: - Oyster restoration documentary project collaborating with students at UC Santa Barbara's Bren School.
https://www.youtube.com/watch?time_continue=3&v=Wag9ne60baY

Also featured in their Shelling out Solutions video:
https://www.youtube.com/watch?time_continue=2&v=i403l3zUsfA

Presentations were given in the Community at the following locations/with the following groups:
Orange County Natural History Lecture Series, Ocean Institute's Girls in Ocean Science Teen Conference, Saddleback Canyon College, Climate and Coastal Water Protection Forum and Workshop, South Orange County

Dive Club, Newport Bay Watershed Executive Committee, Concordia University, Sea and Sage Audubon, Newport Bay Fecal Coliform TMDL Stakeholder group, Girl Scouts, Newport Bay Harbor Commission, Back Bay Science Center, San Diego State University Marine Science Day, CSULB Faculty Fellows group, Long Beach Yacht Club

Scientific Presentations and Posters

Howard, M.E., Picciano N., & Whitcraft, C.R. (2018, December). Impacts of living shorelines restoration on fish and infaunal communities in Newport Bay, CA. Poster presented at the Restore America's Estuaries Summit Meeting in Long Beach, California.

Howard, M.E., Picciano N., & Whitcraft, C.R. (2018, December). Impacts of living shorelines restoration on fish and infaunal communities in Newport Bay, CA. Poster presented at the California Estuarine Research Society Meeting in Long Beach, California.

Howard, M.E., Whitcraft, C.R., & Zacherl, D.C. (2018, November). Effects of paired Olympia oyster (Ostrea lurida) and eelgrass (Zostera marina) restoration on fish and invertebrate communities in Newport Bay, California. Oral presentation given at the Western Society of Naturalists Meeting, Tacoma, Washington.

Howard, M.E., Whitcraft, C.R., & Zacherl, D.C. (2018, March). Impacts of paired Olympia oyster (Ostrea lurida) and eelgrass (Zostera marina) restoration on fish and invertebrate communities in Newport Bay, California. Poster presented at the National Shellfisheries Association Annual Meeting, Seattle, Washington.

Griffith, K.R., Hovel, K.A. (2017, November). Seagrass edge effects: the influence of patch edge type on epifaunal communities in restored eelgrass habitat. Poster presentation given at the Western Society of Naturalists Meeting, Pasadena, California.

Griffith, K.R. (2018, March) Living Shorelines: integrating science and habitat restoration. Oral presentation given to the public at the San Diego State University Marine Ecology and Biology Student Association's Marine Science Day, San Diego, California.

Griffith, K.R., Hovel, K.A. (2018, November). Edge effects in estuarine habitat mosaics: an experimental test using restored eelgrass beds. Oral presentation given at the Western Society of Naturalists Meeting, Tacoma, Washington.

Griffith, K.R., Hovel, K.A. (2018, December). Edge effects in estuarine habitat mosaics: an experimental test using restored eelgrass beds. Oral presentation given at the California Estuarine Research Society Meeting, Long Beach, California.

Nichols, K. D. (2017, May) Integrated oyster and eelgrass restoration in Newport Bay. Headwaters to Oceans Conference.

Nichols, K. D. (2018, December). Integrated oyster and eelgrass restoration in Newport Bay. Restore America's Estuaries.

Wood, V.R., Carlin, J., Stapp, P., Zacherl, D.C. (2018, November). The effect of sedimentation on oysters adjacent to eelgrass meadows. Poster presentation given at the Western Society of Naturalists Meeting, Tacoma, Washington.

Zacherl, DC. (2017). Restoration of Olympia oysters, *Ostrea lurida*, in southern California. Talk presented at Honda Foundation and Aquarium of the Americas Oyster Forum. Long Beach, CA.

Zacherl, DC (2018, December). HOW LOW CAN THEY GO? Tidal distributions of native and Pacific oysters in so CAL and implications for restoration. Lightning Talk presented at Restore America's Estuaries. Long Beach, CA.

VII. DISCUSSION AND OUTLOOK

Discussion

Overall, the project goals to enhance the native Olympia oyster (*Ostrea lurida*) and eelgrass (*Zostera marina*) populations were met. In the two years since this project began, we have increased the available oyster habitat by placing shell in various configurations on the bare mudflat and exceeded our eelgrass acreage goals by nearly three times. Importantly, we have seen no evidence so far that oysters have a negative impact on either the quantity or the habitat provision function of eelgrass. Preliminary results indicate a potential and relatively small negative impact of eelgrass on adult oyster density; this will be explored in detail in future studies and as the oyster bed itself matures. Even in the presence of the highest eelgrass densities, adult oyster density was higher than prior to restoration and equal to or higher than reference sites throughout Upper Newport Bay.

In addition to understanding oyster recruitment and eelgrass habitat creation, we have evaluated associated ecosystem benefits, specifically invertebrate and fish biodiversity and shoreline protection. We see early signs that integrated oyster and eelgrass restoration mitigates the reduction in invertebrates under the oyster beds be increasing the overall abundance and richness of the entire plot (e.g. eelgrass habitat compensates for loss of invertebrates under the oyster beds). Habitat value of the restored habitats for fish appears to have increased marginally as a result of the restoration, but it is not yet possible to tease out differences between oyster/eelgrass and eelgrass treatments. In summary, our results across multiple metrics are preliminary and are site-specific, and therefore one preliminary conclusion we can reach is that site can influence restoration success and associated benefits. As oyster abundances continue to increase on the beds and the habitat matures, we will be better poised to determine the specific habitat value associated with oysters versus paired oyster-eelgrass habitat.

Site-specific differences, such as grain size, may influence the success of eelgrass restoration and should be carefully considered in restoration planning, as demonstrated further in the variable success of eelgrass restoration. After several planting attempts at our Shellmaker site, it appears that this site is not ideal for the persistence and spread of eelgrass. The fact that there was no preexisting eelgrass here prior to restoration suggests that abiotic factors at this site such as sediment type, fresh water input or hydrodynamics may not be conducive to eelgrass growth. Further investigation is needed to examine these factors in more detail. The tidal height of restoration at this site was also slightly higher than our other sites while the mudflat slope was shallower, and during re-planting we focused on transplanting to the deeper sections of the plots.

Qualitatively, it is worth noting that a large patch of eelgrass within 100 m of our control plot at Shellmaker seems to be persisting.

When considering eelgrass restoration, it is important to consider the effort required to maintain controls in an experimental design. Over time, our planted eelgrass grew substantially and hand removal to maintain buffers and control zones was extensive. Larger buffer zones and increased distances between treatment plots could be utilized as intertidal space allows for future designs to mitigate this issue.

We have also learned valuable lessons and best practices about restoration materials. First, the coconut coir we utilized is a welcome alternative to plastic mesh. The coir held up underwater over time and worked well for transporting shell to the sites. On surveys, we even saw oysters (and diverse other bivalves) recruiting to the coir itself. The coir took longer than anticipated to break down underwater and kept the shell consolidated for at least a year. A drawback of using the coir was that material prep was labor-intensive; hand-sewing bags took a lot of man hours. Additionally, OCCK recorded the removal of at least 7 coir bags full of shell from our Castaways sites; ostensibly these were caught by fishermen and dragged shoreward. When found, we returned them to just adjacent to the beds.

As a portion of this project, we used a collaborative community-based approach for construction, monitoring and restoration efforts. This was successful in informing the general public and students about the benefits of conserving and restoring wetland habitats. For example, the project involved over 569 volunteers spanning close to 3,000 hours and over 25 presentations were given on the project for a variety of audiences.

Finally, our preliminary data indicate that the oyster beds are assisting with sediment retention upshore of the beds as compared to unstructured mudflats. Because shoreline protection elements are a key portion of this project, we have significantly increased our efforts on this project component and are actively seeking funding to enhance this aspect of the monitoring for this project. In the near future, we will expand our sedimentation sampling, measure changes in oyster bed height and integrity, use LiDAR technology to evaluate upshore elevation changes, and use more advanced pressure transducer wave gauges and tilt current meters over a longer trial period to resolve whether oyster beds reduce locally generated wave energy. We will convert the pressure readings we did take to wave parameters using both wave-by-wave and spectral methods (Karimpour et al. 2017). While current literature emphasizes the ability of seagrass to stabilize sediment in situ and attenuate wave energy when the plant is at a depth not greater than double the mean leaf length (Fonseca and Calahan, 1992), the complexity of the interactions between the sediments and wave energy with the addition of variable bathymetry and tidal flux potentially make the effects of this eelgrass restoration variable. Further analysis should include the mean elevation of seagrass and bathymetry of each site to determine ideal conditions for sediment stabilization.

Summary

In summary, as related to specific performance goals, the project increased the abundance of oyster and eelgrass populations in Upper Newport Bay. Through our single-species and integrated multiple-species restoration treatments, we see early signs that integrated oyster and eelgrass restoration can compensate for losses of species associated with lost mudflat habitat. Cities such as Newport Beach are extremely vulnerable to economic damages caused from sea level rise because of the amount of property at risk of increased erosion from rising sea levels and increased wave energy from storms. Southern California has an important tourism economy that is sensitive to the quality of its coasts and beaches. Because of this, the development of efficient coastal infrastructure is key to the resilience of the region

VIII. ACKNOWLEDGEMENTS

Thanks to City of Newport Beach, CA Dept. of Fish and Wildlife, Orange County Parks, The Bayside Village and Marina for permission to access the sites. Thanks to the staff at the Back Bay Science Center for their support and use of facilities. SCUBA tanks were provided in kind by Beach Cities Scuba. We are grateful for advice we received from the US EPA's Office of Research and Development's Atlantic Ecology Division, and colleagues that participated in the San Francisco Living Shorelines Project. Thank you to the Paua Marine Group, Anchor QEA, USC and USC Sea Grant and S. Briley. Special thanks all of our hardworking OC Coastkeeper, Whitcraft and Zacherl lab volunteers, technicians, students and interns. Funds were provided by CA State Coastal Conservancy. Additional funding was provided by the Honda Marine Science Foundation (monitoring) and the U.S. Fish and Wildlife Service through the Pacific Marine and Estuarine Partnership (fish and infauna work).

IX. REFERENCES

Fonseca, M. & Calahan, J. (1992). A preliminary evaluation of wave attenuation by four species of seagrass. Estuarine, Coastal and Shelf Science, 35(6), 565-576. http://dx.doi.org/10.1016/s0272-7714(05)80039-3

Hopkins, A. E. 1935. Attachment of larvae of the Olympia oyster,*Ostrea lurida*, to plane surfaces.Ecology16:82–87

Karimpour, A, Chen Q, Twilley R. (2017) Wind Wave Behavior in Fetch and Depth Limited Estuaries. *Scientific Reports* volume 7, Article number: 40654

Tronske NB, Parker TA, Henderson HD, Burnaford JL, Zacherl DC. (2018) Densities and Zonation Patterns of Native and Non-Indigenous Oysters in Southern California Bays. Wetlands:1-14.

Wakefield CB, Lewis PD, Coutts TB, Fairclough DV, Langlois TJ (2013) Fish Assemblages Associated with Natural and Anthropogenically-Modified Habitats in a Marine Embayment: Comparison of Baited Videos and Opera-House Traps. PLoS ONE 8(3): e59959. doi:10.1371/journal.pone.0059959

Wood V (2018) The Effect of sedimentation on oysters (*Ostrea lurida*) adjacent to eelgrass beds (*Zostera marina*). California State University, Fullerton

Zacherl DC, Moreno A, Crossen S. (2015) Exploring Restoration Methods for the Olympia Oyster, *Ostrea lurida* Carpenter, 1864: Effects of Shell Bed Thickness and Shell Deployment Methods on Shell Cover, Oyster Recruitment, and Oyster Density. Journal of Shellfish Research 34(3): 819-830.
.

X. SUPPLEMENTARY MATERIAL

<u>Completed Theses (to be emailed with final report)</u>

K.R. Griffith. Edge effects in estuarine habitat mosaics: an experimental test using restored eelgrass beds. M.S. Thesis SDSU 2019.

V. Wood. The Effect of Sedimentation on Oysters Adjacent to Eelgrass Beds. M.S. Thesis CSUF 2019.

<u>Additional Photos</u>

Figure 21. Community volunteers hand sewing coir bags for deployment.

Figure 22. a) Photo of initial oyster bags post restoration at Shellmaker site in April 2017 and b) Photo of restored oyster bed taken at Shellmaker site in Winter 2019 (photo: D. Zacherl)

Figure 23. Volunteer line during oyster restoration at DaAnza site, April 2017.

Figure 24. a) CSULB Graduate Student Marjorie Howard taking a sediment core from an Oyster Restoration Plot (photo: K. Nichols), b) SDSU Graduate Student Kaylee Griffith and CSUF Graduate Student Victoria Wood Measuring Sediment Pins (photo: K. Nichols), c) Round Ray captured during Go-Pro Fish video surveys (photo: M. Howard)

Timeline

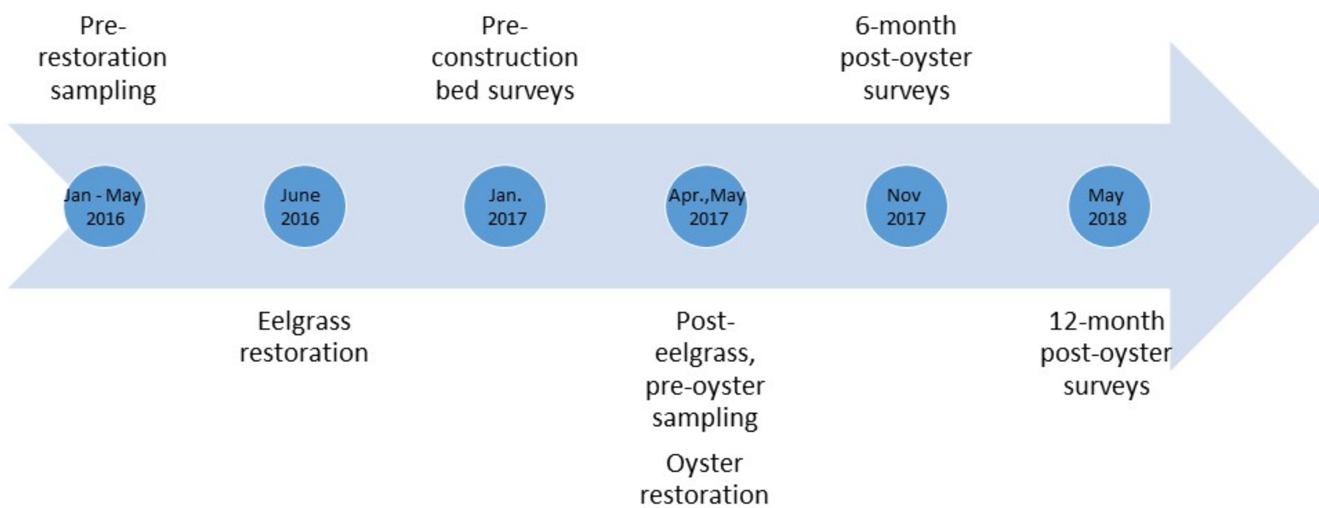

Figure 25. Timeline of restoration and monitoring