Supporting the Development of the Santa Monica Pier Living Breakwater

Project Report

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Abstract

The Santa Monica Bay Restoration Commission's Governing Board voted unanimously to approve a work plan that would include the restoration of the Santa Monica Breakwater. With projected increases in wave action projected to strengthen due to climate change, the reconstruction would meet the goal of habitat and infrastructure protection as storm surge continues to escalate. The Bay Foundation practicum team worked with the Bay Foundation in researching case studies of previously constructed living breakwaters, making recommendations on the breakwater's design and materials, conducting research on biodiversity in the area, organizing public outreach events, and creating a visual history of how the breakwater has changed over time as well as facilitating a dialogue between the community and the project. Ultimately, the Bay Foundation Practicum Team aims to assist The Bay Foundation in initial planning stages of the breakwater renovation using field, lab, and literature review techniques while garnering public support for the project.

Introduction

The Santa Monica Breakwater was originally constructed in the 1930s in order to protect the pier and small boats from wave damage (Human Interactions with Shorelines, 2019). Since its construction, it has been rebuilt several times due to degradation. Damage to man-made structures, such as the pier and breakwater, as well as to surrounding beaches and coastal areas is expected to continue and accelerate as a result of climate related stressors.

The renovated breakwater is intended to provide protection to the coastal infrastructure and ecosystems in the Santa Monica Bay and to help support the rocky intertidal ecosystem. Most importantly, The Bay Foundation emphasizes the development of a ‘living’ breakwater, or a structure that provides physical attenuation of wave action while providing habitats for organisms living in the intertidal region. By protecting vital infrastructure and ecosystems, a restored breakwater will provide for local communities by creating economic opportunities, filtering water, sequestering carbon, and driving local food webs.

The Bay Foundation practicum team has chosen a variety of deliverables aimed at aiding in the process of revitalizing the Santa Monica Breakwater. All of those deliverables center the goals of outreach, education, and research. The outreach aspect has focused on surveying and quantifying public opinion on the project, as well as educating the public through informational videos, pamphlets, and a website. Quantifications of the breakwater’s impact on sand build up have been performed through GIS and aerial imagery, and a compilation of breakwater design choices significant to biodiversity and blocking wave action has been completed with an emphasis on innovative structural materials and design methods. Additionally, a field and lab-based assessment was carried out using eDNA and water quality analysis to determine the relative levels of biodiversity currently fostered by the breakwater.

I. Breakwater History and Timeline

History of Breakwater and Goals of Research

Built in 1934, the Santa Monica breakwater's initial purpose was to create a sheltered yacht harbor for recreational boats by acting as a barrier from onshore wave action (Gold, 1996). While no longer utilized for this purpose, this deliverable aimed at understanding the ways in which the breakwater has impacted and will continue to impact the region of the Santa Monica State beach directly onshore of the breakwater. We hope that by understanding how the breakwater has impacted the coastline since its initial construction, we can help better inform the construction of a long-lasting, coastally beneficial breakwater.

Geoprocessing Methods

To analyze these effects, we began by searching for imaging of the pier and beach region. To best analyze change, we first looked for images showing the beach before the breakwater's construction, and images from 1928 and 1931 were available from the Santa Monica Public Library. We then looked for images directly after breakwater construction, and then for every few years until the present day. A combination of sources including the Santa Monica Public Library, the USGS, the NASA AMES Research Center, the National Agriculture Imagery Program, and ESRI were sourced to create a 94 year collection of high-resolution aerial images. A table describing these data sources can be found in the appendix (Supplemental Table 1).

To compare images at different scales and taken at different angles, we then used ESRI's ArcGIS Pro to georeference each image. This process included adjusting the angle and scale of the images, and setting control points in order to align the images with their true map position. Each image was first roughly referenced in scale and position to the ESRI 2022 satellite imagery, and then adjusted using the other images to ensure continuity between structures throughout years. This georeferencing process was not free of error, with some distortions as a result of the angle at which images were taken and the limited number of physical landmarks between many of the images, however, through an iterative process of reference point adjustment we created a relatively seamless visual timeline. After this georeferencing project, we manually digitized the full visible beach extent in each image, and then clipped each beach polygon to two different study regions; both including the most northern extent shared by all images. One study area extended as far south as the north side of the Santa Monica Pier, and the second extended to the start of a parking lot constructed next to the pier at some point before 1957. These study regions can be seen in the top panel of Figure 1. We faced several difficulties in this digitization process, including the concealment of the coastline by waves, and some uncertainty in the most inland region to classify as beach. SketchUp was used to modify a 3D rendering of the Santa Monica Pier, and ArcGIS pro was used to analyze the LiDAR data provided by the UCLA Coastal Flood Lab and to create 3D visualizations (Z.R, n.d.).

Visual Timeline and Analysis of Change

This deliverable resulted in three major products. The first was a visual timeline of coastal change throughout the history of the breakwater, which can be seen in Figure 1. This product has many possible applications, including public outreach in regards to the role of the breakwater on coastal protection. This visual timeline also allowed us to analyze the lifespan and effectiveness of the breakwater qualitatively. Comparing future images to the 1928 and 1931 baseline images, we see drastic changes from the relatively narrow beach area observed over this initial period. The first post-breakwater image, taken in 1937, shows the formation of a salient, or a buildup of sediment resulting from the breakwater's construction (Williams, 2005). This salient shape is an early indication of the effectiveness of a breakwater. Throughout this timeline, external factors aside from the breakwater itself must be considered, and we combined our analysis with noted beach nourishment projects and severe weather events. The potential effect of several large beach nourishment projects, or the non-natural addition of sand, can be seen by 1950, with changes in the basic salient structure seen in 1937 (Program for the Study of Developed Shorelines at Western Carolina University, n.d.). Over the next few images, the beach appears to return to a more regular salient shape, until the 1980's where this salient structure begins to erode back to a more natural, straight shoreline. This may be due to a series of extreme storms during the early 1970s and into the 1980s, with a particularly damaging storm in 1983 with major impacts on the Santa Monica pier and likely on the breakwater itself (Baum, 1973) (The National Weather Service, 2023). By 1997 and into the present day, we saw a return to a relatively straight shoreline, similar to the pre-breakwater shape, albeit with a greater area. This progression, from a clear salient shape to an eroded salient and back to a straight shoreline, suggests the degradation of the breakwater over the study period and accompanying decreased wave attenuation ability of the breakwater.

Quantifying Beach Area and Change

The second product obtained from this collection of images was an estimate of beach area in two study regions over the study period. While these calculations should not be taken as the true beach area, due to many limitations associated with manual digitization and georeferencing, the trends and changes seen between study years helps add to the confidence in the visually observed trends and changes. Based on these area estimates, the largest beach area change occurs over the 1931 to 1937 period, or the period over which the breakwater was built. This suggests that the breakwater had a large impact on allowing for sediment buildup directly onshore of the breakwater in the area onshore of the breakwater. While the beach area continues to grow until the 1980s, this growth occurs at a decreasing rate, potentially implying a decreasing impact of the breakwater on accumulating sediment onshore of the breakwater. The results of this analysis can be seen in Figure 2.

Finally, by the early 1980s, we first observed a loss of beach area, potentially indicative of the lifespan of the breakwater's effectiveness. It is important to note the difficulty in quantifying uncertainty in these estimates of beach area. It is also difficult to understand the quantitative impact on beach area in this region as a result of beach nourishment projects, as the spatiality of this nourishment is poorly documented. Thus, this beach change analysis should be taken as a more qualitative history of the beach as opposed to a true quantitative study.

Analyzing the Current State of the Breakwater

While the resolution and visibility of the breakwater itself was low across the study period, our digitization did allow for a basic understanding of changes in the breakwater's physical structure over the study period. For example, by 1980, we started to see a more clear change in the visible extent of the breakwater even when considering the low resolution of these images, with large gaps in the exposed portions of the breakwater starting to appear. Around this time, the salient structure seen onshore of the breakwater also begins to smooth into a more 'natural' beach state. While this analysis does not provide insight on the subsurface conditions of the breakwater, the alignment of this analysis with our analysis of beach change leaves reason to believe that between the late 1970s and early 1980s, the breakwater faced severe degradation.

To better understand the current structure of the breakwater, we used a recent LiDAR mapping project undertaken by the UCLA Coastal Flood Lab in conjunction with the Santa Monica Bay Foundation. We combined the laser point cloud of the exposed sections of the breakwater along with a 3D Model of the Santa Monica pier to visualize the current extent of the breakwater. This LiDAR mapping was done during an extreme low tide (King tide) that occurred in January of 2023, and thus the above-water exposed breakwater extent was analyzed at this tide using the lowest measured elevation as 'ground level' (*LiDAR Mapping of Santa Monica Breakwater | Coastal Flood Lab*, 2023). We consider this to be the maximum above-water extent of the breakwater, as this imaging was taken during an unusually low tide. A 3D rendering of the current breakwater with a rough rendering of the Santa Monica Pier can be seen in Figure 3. This analysis may help inform the construction of a more structurally sound breakwater, as regions that are especially degraded according to this 3D imaging may require improved armoring in future breakwater designs. Further studies using this LiDAR data should look into quantifying the below water structure of the breakwater and also at quantifying the current volume and extent of the breakwater.

Figure 1a: *Images used to quantify beach area. Black line shows the digitized extent. Images were manually georeferenced using road locations and other landmarks. ESRI 2022 composite satellite image is used as a base map where aerial image frames are small.*

Figure 1b: *Digitized beach areas used in calculations.*

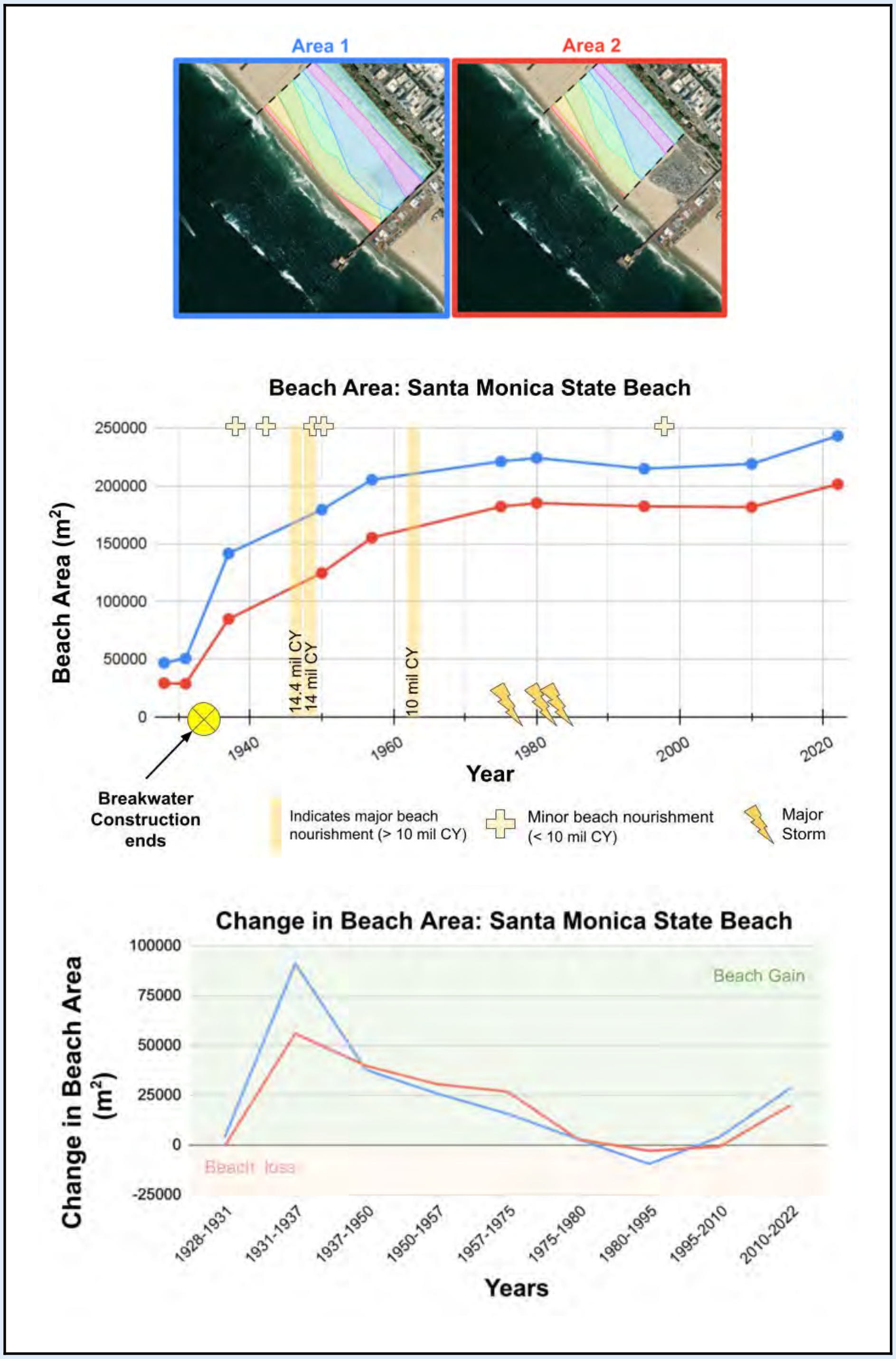


Figure 2: *Graphs of beach area and change in beach area over the study period, with red and blue lines representing the study area. Major storms and beach nourishment projects of different scales are indicated in the plot of the beach area. Shading on the plot of change in the beach area shows beach loss or beach gain.*

Figure 3: *3D rendering of the current state of the breakwater utilizing LiDAR data. Sea-level referenced to extreme low tide (King Tide) from January of 2023.*

Future Research Avenues and Implications

As the breakwater enhancement/rebuild project continues into further planning phases, we hope that this study can help inform how a breakwater in this location will impact coastal change, as well as how the breakwater itself may change and erode over time. This, combined with an assessment of breakwater materials and construction best practices, will hopefully allow for the construction of a breakwater that better fills the coastal needs of the community, and hopefully lead to the formation of a more long-lasting structure. These results may also be important in educating the public on the role of the breakwater on maintaining and expanding beach area, as community support will become essential as the project moves towards permitting and implementation stages. Further studies of beach change should look at regions further downshore of the breakwater, as some studies suggest that breakwater structures can lead to increased erosion in down-shore regions, as understanding the potential negative impacts of the breakwater is essential to a more informed breakwater construction. Other studies should also focus on further analyzing the LiDAR data preliminarily analyzed in this project, in order to understand the full-depth structure of the breakwater and quantify certain breakwater dimensions. Our full report regarding breakwater-driven coastal change can be found here.

II. Built Materials Analysis

The addition of any coastal marine infrastructure (CMI) to coastal waters provides a hard substrate for accumulation of biofilms and the subsequent attraction of marine organisms. The use of concrete and dense terrestrial rocks, like granite, to construct CMI is common in the United States. These materials do not possess the necessary structural complexity and chemical properties of natural marine rocks. Consequently, they cannot support the same marine populations and are prone to invasive species colonization (Perkol-Finkel & Sella, 2015). Many alternative building materials that mimic the chemical and physical elements of marine rock have been manufactured to maximize the ecosystem benefits of CMI (Figure 4). If these materials are utilized correctly, the revitalization of the Santa Monica Breakwater offers a chance to cultivate a thriving coastal oasis. In addition, these bio-enhancing features are financially favorable, as they ease the permitting process and help to avoid environmental penalties. Our research aims to familiarize The Bay Foundation with the most recent bio-enhancement technologies on the market via a case study analysis of two manufacturers. We then propose a few general breakwater designs that will maximize the effect of these technologies at the new Santa Monica Breakwater.

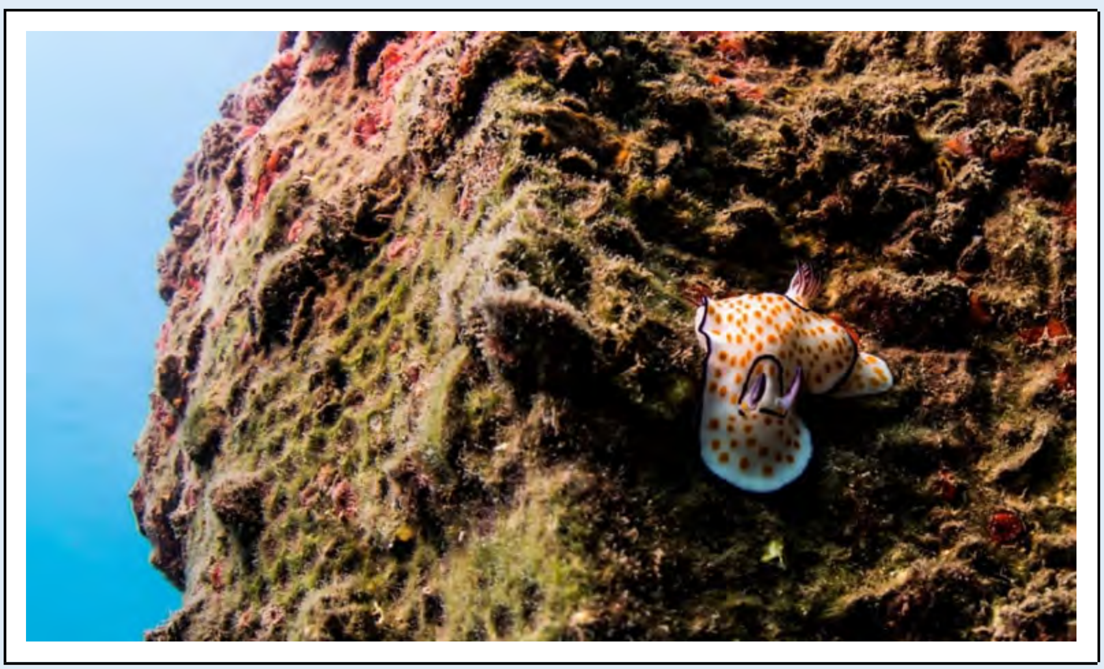


Figure 4: *Biologically enhanced non-toxic concrete from ECOncrete™. Varied textures increase surface area to allow for more marine recruitment and to create new niches. (ECOncrete, 2023)*

Living Rubble-Mound Breakwaters

Historically, offshore breakwaters have been constructed using various materials, including interlocking concrete blocks, timber, and even sunken ships. In the coastal regions of the United States, large terrestrial quarrystone rubble, or rip rap, is the most effectively used breakwater design, especially in harsh, storm-battered oceanic coasts (USACE, 1984).

The main components of a rubble-mound breakwater are as follows:

1. **Armor stones** are the visible stones that form the exterior of the breakwater. They dissipate wave energy that impacts the exterior through gaps in the stones. Multiple layers of armor stones may be laid, as in the example below. Interlocking concrete tri bars and tetra bars are also utilized for increased support.
2. **Core Stones** form the central core of the breakwater and support the armor stones above them. They are important in establishing the slope of the breakwater and are usually several magnitudes smaller in diameter than armor stones (3-4 times).
3. **Geotextiles** are reinforced fabrics used to create a layer between the soil and core stone, as well as the core and armor stone.

Because Armor stones are in contact with the marine environment, their shape and composition is critical to their impacts on the ecosystem. In addition, the size and durability of armor stones are pivotal factors in the longevity of the breakwater against currents and harsh breaking waves. It is likely that the armor stones for the new breakwater will be made from quarried granite via Catalina Island. By adding specific, bio-enhanced armor stones and other biodiversity-enhancing technologies along the granite rip rap, there will be a profound, measurable effect on the marine ecosystem, all without making major changes to the construction plan.

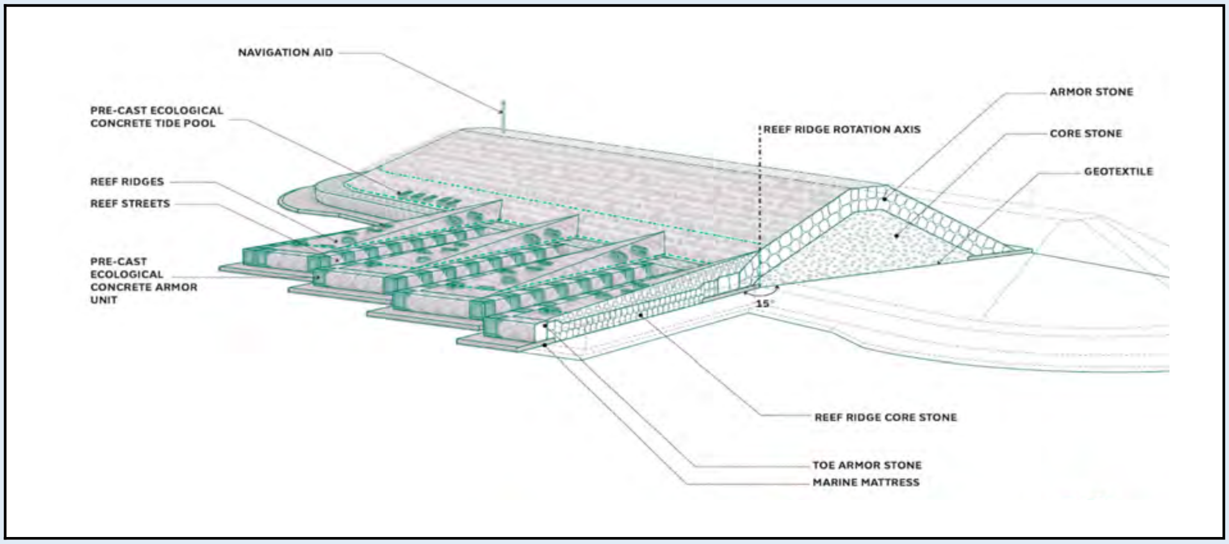


Figure 5: *A diagram showcasing the structure of a living breakwater. The three main structural components are indicated in the top right. Additional "reef" features are listed with the goal of attracting marine life. via* Scape Studio.

Living CMI Manufacturers - Case Studies

There is a small but growing market for the manufacturing of CMI bio-enhancement technology. We selected and analyzed several projects and experiments conducted by two developers at the forefront: ECOncrete™ and Reef Design Lab™. These particular developers were chosen based on the availability of published, peer reviewed results of marine life assemblage and ecosystem benefits resulting from their projects. Each case study examines a specific enhancement unit, most importantly armor stones, tide pools, and panels. Design features such as these can be incorporated into the rebuilt Santa Monica Breakwater to bolster biodiversity. We compiled 6 projects utilizing ECOncrete, and 4 utilizing Reef Design Lab. Under *Case Studies* on our website, we have included copies of the full research papers and a detailed synopsis of each, pertaining to:

1. Location of Project
2. General Climate
3. Date Installed
4. The dimensions of the structural unit of interest and the experimental design
5. The effect of the unit on marine colonization and ecosystem health

Below are general descriptions of each developer with a list of cases we compiled.

ECOncrete

ECOncrete is an Israeli startup specializing in bio-enhancing marine concrete. Their technology can be integrated into construction of breakwaters, seawalls, piers, and more. Any structural unit made of concrete, such as armor stones or pilings, can be enhanced with ECOncretes 3-layer design:

- **Composition:** A carefully engineered concrete admixture contains chemical elements that keep it porous and available for microorganism attachment. For more detailed information on the admixture, refer to *Additional Technical Documents,* on our website.
- **Microtextures:** More complicated surface textures increase surface area, allowing for recruitment of larger organisms, like oysters and tube worms.
- **Macro Textures:** Even larger shapes, like tidepools and canyons, create a structurally varied environment that resembles marine rock and retains water during intertidal shifts, supporting new niches.

Upon the attachment of calcifying organisms, like oysters, these structural units gain mass. A heavier structure is more stable, and far more likely to withstand harsh conditions. Further, ECOncrete units are cast on site and can be customized to meet different size requirements. As of now, ECOncrete is the only developer of bio-enhanced CMI structural units with published results. Our team reviewed six projects utilizing ECOncrete's technology, which can be accessed on our website.

Cases:

1.1 Product Testing: Herzliya, Israel (Perkol-Finkel et al., 2018)

1.2 Marine Mattress: Port Everglades, Florida (Sella et al., 2022)

1.3 Classic Tidepools: Brooklyn Bridge (Perkol-Finkel et al., 2015)

1.4 Classic Armor Units: Haifa Bay, Israel (Ido et al., 2015)

1.5 Coastlock Units: San Diego (ECOncrete, 2023)

1.6 Biological Retrofitting: Staten Island Living Breakwaters Project (New York State, 2022)

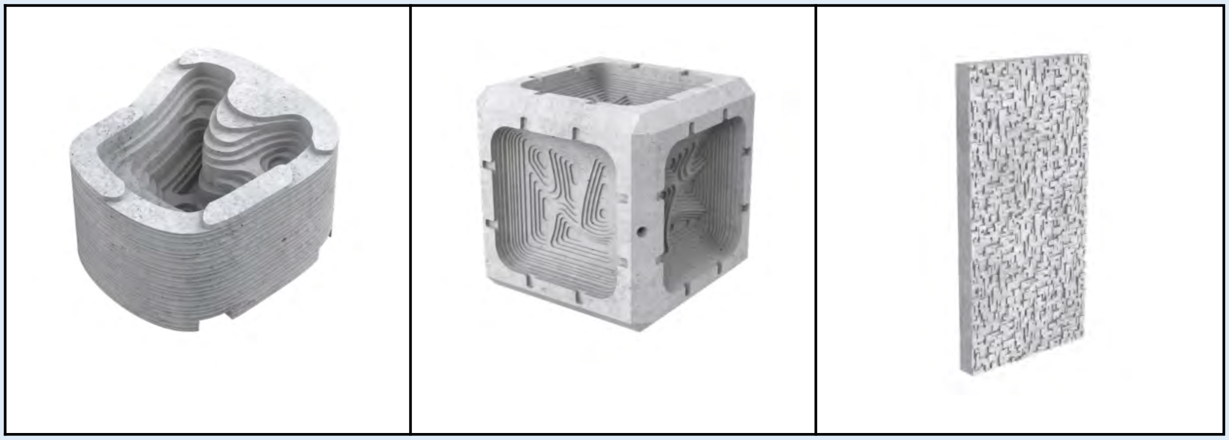


Figure 6: *Several ECOncrete units utilized in CMI. Left:A water retaining Classic Tide Pool Unit (Case 1.3). Middle:A uniquely textured Armor Stone (Case 1.4, 1.6). Right: A bio-enhancing Wall Panel (Case 1.1).*

Reef Design Lab

Reef Design Lab (RDL) is a multidisciplinary concrete design group based out of Melbourne Australia. They specialize in engineering tropical and subtropical artificial reefs, but have recently taken their technology a step further. Many of their products are designed to be attached to CMI or placed in its vicinity in order to foster a thriving reef-like ecosystem. Although these products don't serve a structural purpose, they have shown outstanding impacts on biological recruitment in many different climates.

- ❖ **Composition:** The chemical makeup of RDL's products is carefully engineered through a combination of mixing organic material with concrete and 3D printing.
- ❖ **Microtextures:** Diverse surface textures are crafted to maximize surface area and create crevices and swim-throughs to mimic a reef ecosystem.
- ❖ **Macro Textures:** Larger water retention elements are included to create an intertidal ecosystem.

Additionally, the textures on RDL's products can be quite beautiful. They draw the eye with hexagonal patterns and winding fractal grooves, offering an aesthetic appeal for marine recreation lovers and onlookers alike. RDL is one of very few developers of CMI enhancing technology with published results. Our team reviewed six projects utilizing RDL's technology, which can be accessed on our website.

Cases:

2.1 Living Sewall Panels: Sydney Harbour (Bishop et al., 2022)

2.2 Living Seawall Panels (Filtration): Sydney Harbour (Vozzo et al., 2021)

2.3 Lightweight Fish Habitat: Sydney Opera House (Reef Design Lab, 2022; Sydney Opera House, 2020; Nguyen & Russo, 2021; Been, 2020)

2.4 Complexity Panels: Global Analysis (Strain et al., 2021)

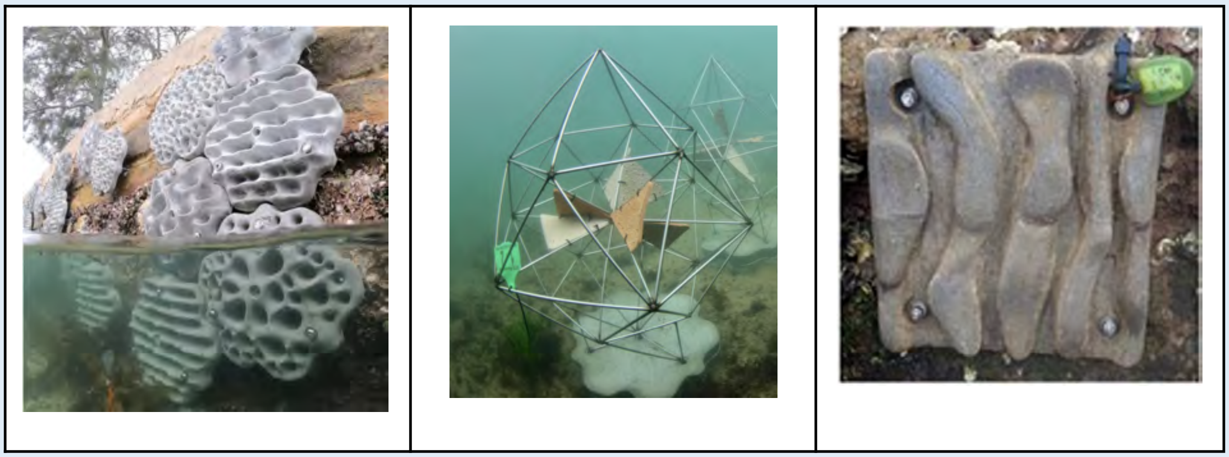


Figure 7: *Several units made by Reef Design Lab. Left: Living Seawall Panels (Case 2.1). Middle: Lightweight Fish Habitat Structures described in (Case 2.3). Right: Complexity Panels (Cases 2.2 and 2.4).*

Structural and Bio Enhancing Design Recommendations

This section explores several design options for a rebuilt breakwater that could incorporate bioenhancement features from the case studies described above. First, using guidance from the USACE Shoreline Protection Manual, our team investigated the expected dimensions and armor stone size of the new breakwater. Then, we proposed multiple "biological retrofits" that incorporate technology from the case studies to maximize the ecological effect of the rebuilt breakwater.

Structural Expectations

Maximum stability is achieved through using the largest, heaviest armor stones possible. However, it is not economically efficient to quarry and implement heavy, oversized units.

Additionally, the size of armor stones will determine which bio-enhancing technologies will fit best in the breakwater. To address armor stone size, we used the Hudson Formula (USACE, 1984) to calculate the minimum diameter of armor stones needed to withstand wave action given the slope angle of the breakwater and the layers of armor stones used. Four hypothetical structures were considered to identify the most economically and structurally ideal armor layer arrangement (Figure 8). See the full size calculations and methodology in the *Materials and Design* section of our website.

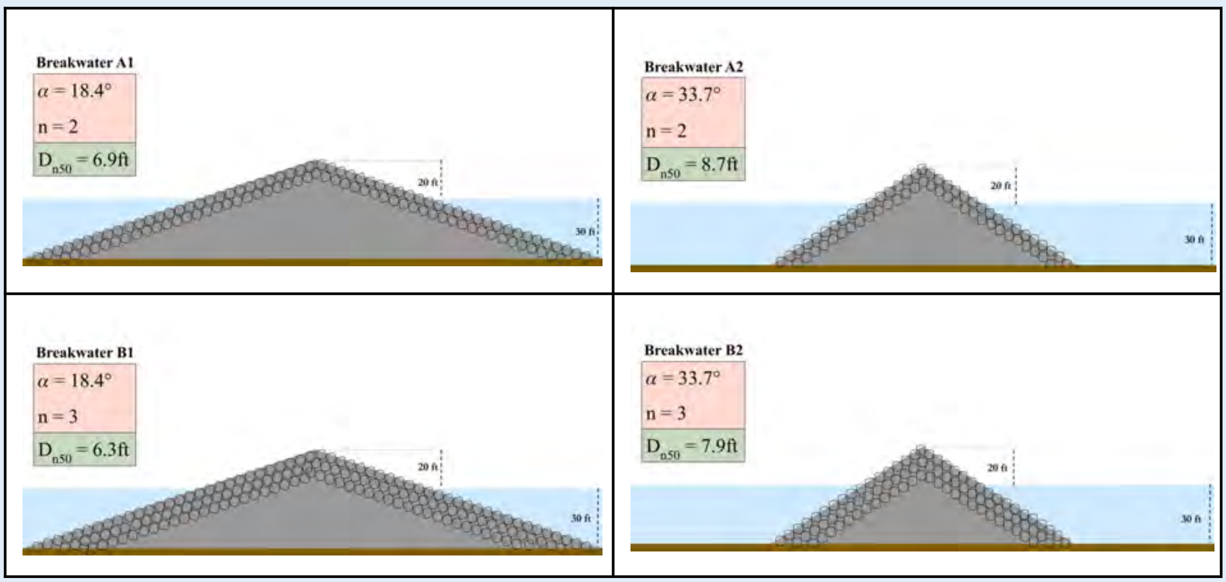
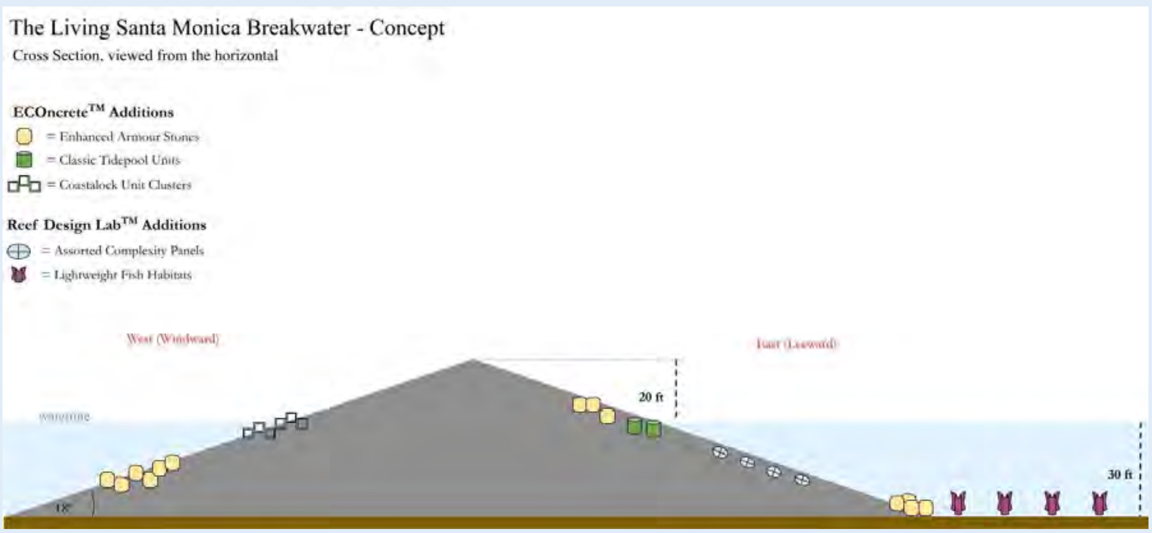


Figure 8: *Four, to-scale, hypothetical breakwater structures created with the Hudson Formula. Slope angle from the horizontal (α) and the number of armor stone layers (n) were adjusted to showcase the minimum diameter (D_{n50}) of armor stones required to withstand wave conditions in Santa Monica. Breakwater B1 (bottom left) permits the use of the smallest armor stones.*

It was concluded that Breakwater B1 (Figure 8) with three layers of armor stone and a slope angle of 18.7° permits the use of the smallest possible armor stones (6.3 ft in diameter). Overall, the calculations revealed that increasing the number of armor stone layers (n) and decreasing the slope angle (*α)* permits the use of much smaller individual stones. In addition, a lower slope angle increases the amount of riprap exposed to the intertidal zone, providing more surface area for colonization by marine organisms. As long as the breakwater rises high enough to prevent overtopping (20 ft), a low slope angle will benefit the structural integrity and biological effect of the breakwater.

Biological Retrofitting

After performing the structural calculations above, we created a diagram (Figure 9) with recommendations for biological retrofits to the new breakwater utilizing technologies from the Case Studies. The arrangement and placement of the ECOncrete units specifically were verified and informed by Andre Rella, a Coastal Engineer and the Technical Director of Business Development for ECOncrete. Our team was unable to connect with Reef Design Lab.



Enhanced Armor Stones (approx. 6.3 ft in diameter) should be placed in the intertidal and subtidal zones on the leeward side of the breakwater and in the the subtidal zone on the windward side. These units are expected to increase in mass upon the recruitment of calcifying organisms, hence increasing the strength of the structure (See case 1.4).

Classic Tidepool Units (approx. 6.3 ft in diameter) should be incorporated on the leeward side of the breakwater in the intertidal zone to retain water and create new niches. These units create picturesque pools visible from the pier and beach (See case 1.3).

Coastalock Unit Clusters (each unit approx 6.3 ft in diameter) should be incorporated in the intertidal zone on the windward side of the breakwater to act as a wave "shield" during storms and retain water during calm conditions. Coatalock units are more stable than Classic Tidepool Units or Enhanced Armor stones, hence their placement only on the windward side.

Complexity Panels can be fastened to flat sections of the granite rip rap. They should be placed subtidally along the breakwater at varying positions to create marine laboratories and diving zones.

Lightweight Fish Habitats should be fastened to additional rip rap on the leeward side of the breakwater along marine laboratories and diving zones.

Figure 9: *Concept art of a new Santa Monica Breakwater retrofitted with ECOncrete and Reef Design Lab Technology.*

III. Biodiversity at the Breakwater

Introduction

Reef design of a breakwater is essential in fostering a healthy ecosystem and increasing species richness. Since there are few intertidal ecosystems along the west coast, the habitat and wildlife ensconced by a breakwater has implications for the preservation of endangered species and the health of the marine community. An effective breakwater structure cultivates a biodiverse ecosystem while slowing wave action on the shoreline and coast; revitalization of an eroding structure is essential in the wake of projected increases in storm surges due to climate change.

A healthy ecosystem can be assessed by its water quality and biodiversity. Water quality indicators include dissolved oxygen, pH, temperature, salinity, and nutrients. Though biodiversity can be assessed by a visual survey, eDNA is a method that allows for differentiation between morphologically similar species. eDNA is a collection of biomass such as cells, feces or tissue particles that come from local species. In marine ecosystems it is analyzed through taking water samples, which are then processed to extract, amplify, and sequence the DNA to reveal broad scale biodiversity.

Preliminary Analysis

To initiate our understanding of the current biodiversity of the breakwater, the team wanted to conduct preliminary surveys within the area, to help provide us with a baseline idea of what the breakwater's ecosystem looks like. It is crucial to understand the breakwater's current ecosystem in order to appropriately preserve and enhance its biodiversity during the rebuilding process. We began with obtaining some outsourced underwater footage of the breakwater from March 2023, and observed a variety of species flourishing within the area, such as:

1. Fauna
    a. Cnidaria
        i. Various corals (Anthozoa)
        ii. Gorgonians *(Alcyonacea)*
    b. Arthropods
        i. Sheep/Spider Crabs *(Loxorhynchus grandis)*
        ii. Pacific Spiny Lobsters *(Panulirus interruptus)*
    c. Echinoderms
        i. California Sea Cucumbers *(Parastichopus californicus)*

ii. Pacific Purple Sea Urchins *(Strongylocentrotus purpuratus)*
   d. Mollusks
      i. California Mussels *(Mytilus californianus)*
      ii. Scallops *(Crassadoma gigantea)*
      iii. Limpets (Archaeogastropoda)
      iv. California Barnacles *(Megabalanus californicus)*
   e. Chondrichthyes
      i. Horn shark *(Heterodontus francisci)*
   f. Osteichthyes
      i. Garibaldi *(Hypsypops rubicundus)*
      ii. Barred Sand Bass *(Paralabrax nebulifer)*
2. Flora
   a. Giant Brown Kelp *(Macrocystis pyrifera)*
   b. Sargassum (*Sargassum horneri)*
   c. Various green algaes (Chlorophyta)

Figure 10: *Fauna spotted along the breakwater – including Spiny Lobsters, Sea Cucumbers, and Garibaldi, surrounded by coral. From outsourced underwater footage.*

Sampling Justification

In order to more quantitatively gauge the effectiveness of the breakwater at fostering a healthy ecosystem and increasing species richness– since it is clear that it plays a vital role as habitat for marine species in Santa Monica Bay– the Bay Foundation Practicum Team was motivated to take samples of eDNA and water quality parameters at and around the Santa Monica Breakwater. Control samples were also obtained as a point of reference for the breakwater analysis, near the Venice Pier and further down Santa Monica Beach, beyond the breakwater. The goal is for the results to be utilized to determine whether the breakwater fosters a more biodiverse ecosystem relative to other intertidal ecosystems in the area that exist without a breakwater. Additionally, the team was interested in determining if species richness increases only proximally to the structure, or if it also increases near the pier and shoreline. These results can prove the importance of the breakwater in preserving and protecting the ecosystem especially with projected increases in storm surges due to climate change.

Site #	Description
1	Breakwater end right side
2	Breakwater end left side
3	Center of the breakwater (~317 m from either side)
4	Beach/shoreline directly parallel to center of breakwater (~330 m from breakwater, sample taken 3' into water from sand)
5	End of the Santa Monica Pier
6	Breakwater parallel to end of the pier
7	Control Sample 1 – end of Venice Pier (non-breakwater adjacent)
8	Control Sample 2 – farther down Santa Monica beach, past the length of the breakwater (634 m from the right end of the breakwater)

Figure 11: *The eight sampling locations, composed of six sites near/at the Santa Monica Breakwater, and two control samples at locations without any breakwater protection. Highlighted sites indicate those at which supplemental water quality parameters were tested.*

Santa Monica Biodiversity Sampling Sites

Control Sites (Santa Monica & Venice)

	Ideal Latitude	Ideal Longitude
Site 1	34.006145	-118.500502
Site 2	34.009996	-118.505054
Site 3	34.008439	-118.503109
Site 4	34.010123	-118.50088
Site 5	34.007433	-118.500078
Site 6	34.006824	-118.501148
Site 7	33.976512	-118.471135
Site 8	34.002889	-118.496856

	Actual Latitude	Actual Longitude
Site 1	34.004767	-118.499322
Site 2	34.009096	-118.505673
Site 3	34.006313	-118.50279
Site 4	34.008736	-118.500814
Site 5	34.00743	-118.500037
Site 6	34.005235	-118.502268
Site 7	33.974939	-118.474095
Site 8	33.999129	-118.492905

Figure 12: *Anticipated sampling coordinates plotted on a map of the breakwater, with dotted lines to show distance from actual sampling locations (from Zodiac sampling day).*

The sampling sites were picked with the goal of comparing species richness and water quality between locations away from the breakwater (Venice Pier, Lower Santa Monica Beach) with locations directly impacted by the breakwater (Santa Monica Pier, shoreline, and various areas along the structure), to assess whether the breakwater is successful at fostering a larger, healthier marine environment. The sampling sites along the breakwater were selected to observe if there is higher richness in high rubble areas in comparison to low rubble areas. By correlating the biodiversity hotspots along the breakwater with the state of the rubble structure at that location, the team hopes to determine the specific design factors that may be most essential for fostering the healthiest marine environment.

Methods

The Bay Foundation Lab Team used standard lab protocols from Eagle Laboratory for sample analysis. Detailed below are the types of samples taken as well as the manner in which analysis was performed in the lab, along with a summary of lab protocol and methods.

1. <u>*eDNA:*</u> a sample of ocean water is collected using a kangaroo bag sampler. The water sample is then passed through a filter, which traps any DNA present in the water. The DNA is then extracted from the filter and quantified to determine how much DNA is present. Then the DNA is amplified using polymerase chain reaction(PCR) and placed into gels where the DNA, which has a negative charge, is pulled through the substance by a positive charge. The area where the bar shows up in the gel can be compared to the ladder (has known strand lengths) to determine the exact size of the sample strands, which allows us to identify the DNA.
2. <u>Water Quality Parameters</u>: Chlorophyll a, dissolved inorganic carbon (DIC), and nutrient samples were collected. Chlorophyll samples are obtained in 2L carboys, and nutrient samples are collected in polypropylene Falcon tubes. DIC samples are kept in sealed glass bottles after productivity in the water is stopped by adding mercuric chloride. This kills anything living in the sample so that growth will not occur between the sampling date and lab analysis. The samples will then be analyzed through a spectrometer that measures absorbance. The samples taken are contrasted to the absorbance of samples with known nitrogen and ammonium concentrations to determine their concentrations of nitrogen and ammonium.

Results

The gel image from our eDNA analysis (Fig. 13) is labeled so that each number corresponds to a site. The sample number indicates which replicate the band is associated with. For example, “1.1” refers to Site 1, Sample 1. On the gel, the lower band is the 12S gene, which is indicative of fish/vertebrate DNA, which was the main target for our analysis of species richness (Fig. 13). Meanwhile, the upper band is another gene specific to archaea. One pitfall occurred in which some sites, including 2.1, 3.3, 6.1, and 6.2 did not have amplifiable fish DNA, which could have been an experimental error (Fig. 13). Additionally, one sample (4.2) was missing, which may have been due to missing materials or confusion on sampling day. Some of these eDNA samples also had low amounts of water due to lab errors and transport difficulties.

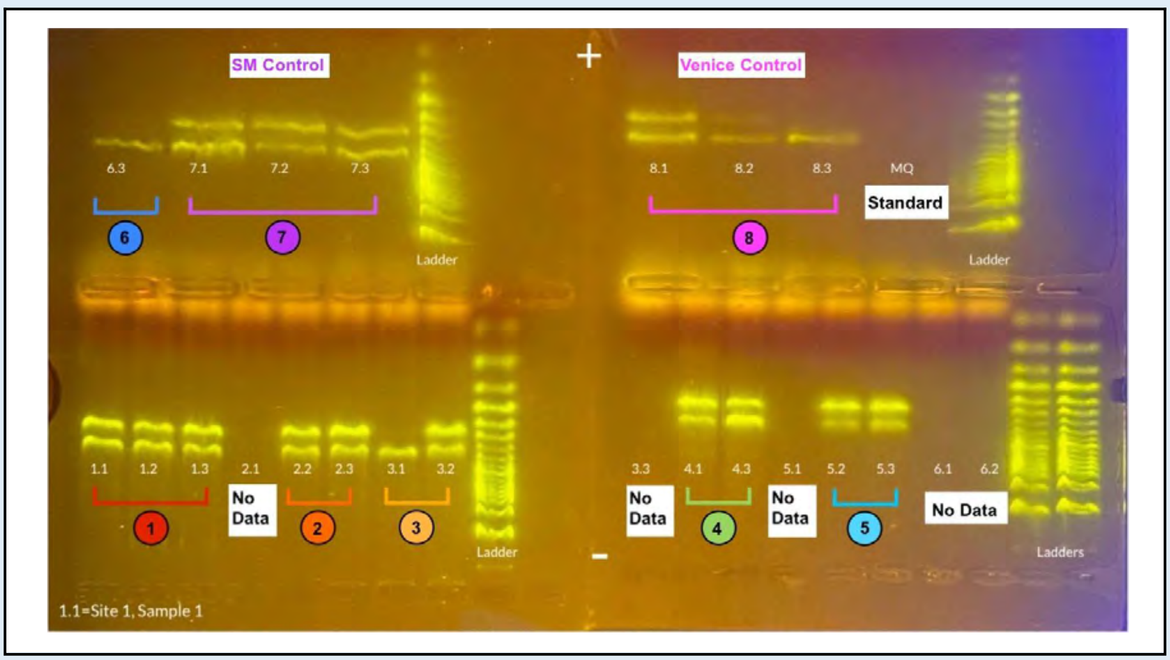


Figure 13: *Labeled PCR gel of amplified eDNA samples. Numbers indicate which site each sample was taken at, and if significant data was collected there. The lower band targets the intended 12S gene. Brighter bands indicate greater amounts of DNA than fainter ones.*

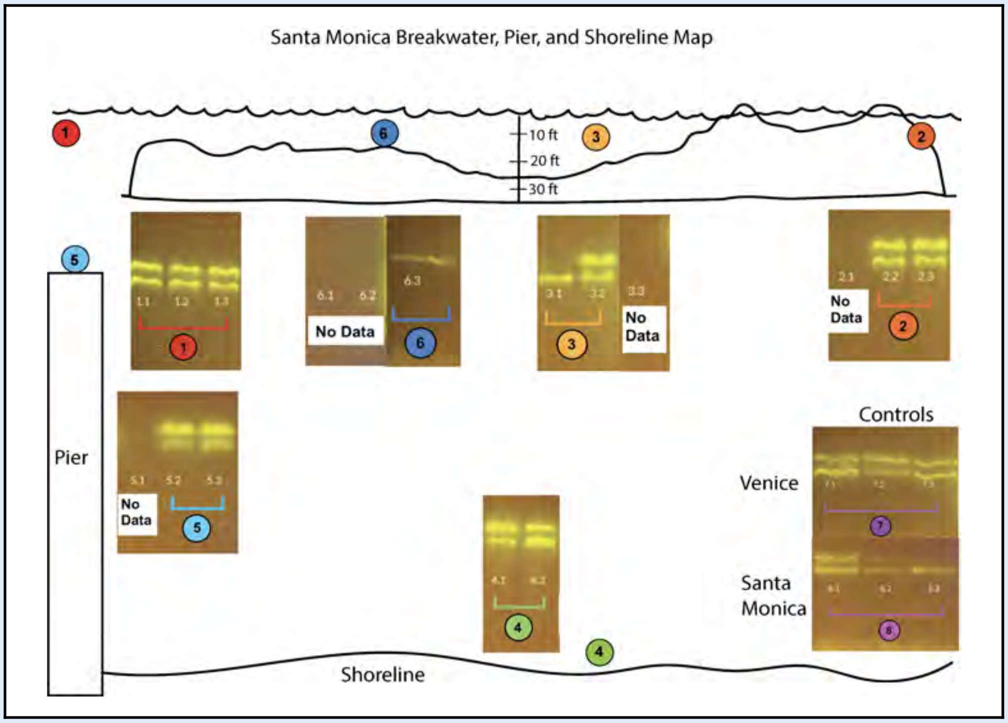


Figure 14: *PCR gels overlaid on a diagram of the Santa Monica Breakwater, to show which areas have relatively significant levels of fish species richness compared to the Venice and Lower Santa Monica control sites.*

Discussion

We hypothesized that the breakwater provides vital services for marine organisms to the extent that it has significantly increased species richness in areas proximal to the structure, relative to areas not protected from wave action further down the beach. For the most part, eDNA sequencing to prove this was successful– significant amounts of fish DNA were detected in at least one replicate of all our samples. Recall that the gels labeled “Controls" were Sampling Sites 7 (Venice Pier) and 8 (Lower Santa Monica). These sites exhibited much fainter bands– most likely because they are directly impacted by circulation from the open ocean. Thus, these bands are indicative of these areas housing lower levels of species richness relative to the sites near and adjacent to the Santa Monica breakwater. Using just species richness as our measure of diversity, these diminished levels at the control sites allowed us to draw the conclusion that the breakwater site supports higher levels of biodiversity relative to areas without a breakwater. Additionally, sites near the pier and shoreline also displayed bright bands, with the shoreline (Site 4) showing slightly brighter bands than the pier (Site 5) (Fig. 14). Therefore, higher levels of species richness seem to exist closer to the shore, and both these sites lead us to believe that the area also fosters a strengthened ecosystem on the inside of the breakwater as well. As it is protected from oncoming wave action, these bright bands are consistent with the idea that the intertidal zone on the inside of the breakwater may support a larger amount of biodiversity than areas right along the outside of the structure, which has now deteriorated quite significantly. Specifically, the areas along the middle of the breakwater (Sites 6 and 3) seem to have bands that look be a bit fainter than those near the ends (Sites 1 and 2), which would correlate to the severely deteriorated nature of the breakwater at its center (Fig. 14).

Future Research

Due to time constraints, we were unable to successfully complete the DNA quantification in order to precisely gauge species richness, as well as a majority of water quality analysis to inform how those factors might impact species distribution. So, future continuity of sample analysis should be done in order to gain a more complete understanding of both the quantitative amount of species located at the breakwater, as well as which specific species exist at both the experimental and control sites. This comparison would help assess whether the breakwater is successful at fostering a larger ecosystem and healthier environment relative to nearby intertidal ecosystems. To even further measure biodiversity, future research may find it helpful to use such data to classify the breakwater species by their abundance, size, or ecological role. Knowledge of the species (and their relative abundances) dwelling near the breakwater should inform how best to preserve and enhance the current biodiversity as plans move forward to begin reconstruction.

IV. Communications & Outreach

Justification Statement

Engaging with the public is essential when it comes to work that affects the environment, and proceeding blindly without interacting with the community to inform and address concerns could be detrimental to the progress of this project later. In order to best help The Bay Foundation, we decided to work on creating multiple forms of media that could be used on TBF's multiple social media accounts, website, or anywhere else they saw a need for our pieces. Surveys and tabling events are important in order to gauge what the public already knows about the project, assess gaps in public knowledge following this work, and address or record any concerns following the breakwater restoration. These events and surveys are two ways we decided to open up the dialogue.

Media for The Bay Foundation

Under the guidance of The Bay Foundation's Communications Committee, our own communications team created videos, video shorts, and infographics to be used by The Bay Foundation on their various social media accounts and their website.

1. Videos
   a. We produced three long videos which we uploaded to YouTube under our account, IoES TBF Practicum team. This was our best method of making our videos accessible to the public for the foreseeable future. See Web Media for full explanations; the videos can be found linked below.
      i. Coastal Change Around the Santa Monica Pier from 1928-2022
         1. https://www.youtube.com/watch?v=nzgbAGFONl0&t=3s
      ii. UCLA TBF Practicum Team's Zodiac Trip
         1. https://www.youtube.com/watch?v=D32OsoLX1Xg
      iii. The UCLA Bay Foundation Practicum Team's ROV Deployment
         1. https://www.youtube.com/watch?v=yaRHWMLc5DI

2. Video Shorts
    a. We produced a series of video shorts intended for use by The Bay Foundation's Communications Committee. Certain videos can be found on The Bay Foundation's Instagram, @thebayfoundation. Additional videos can be found on our team Instagram, @bayfoundationpracticum.
        1. Our Team's Favorite Fun Facts
            1. This short includes facts about the Santa Monica pier and its species biodiversity.
        ii. Interviewing on the Santa Monica Pier
            1. This short defines a breakwater after showing a segment of a series of interviews.
        iii. History of the Breakwater
            1. This short describes the creation and fate of the current breakwater located off of the end of the Santa Monica Pier.
        iv. What is the Heal the Bay Aquarium?
            1. This short gives information on the Heal the Bay Aquarium, which is located under the Santa Monica Pier.
    b. Instagram Reels:
        i. Did you know there's an Aquarium Under the Pier?
            1. This video describes the Heal the Bay Aquarium and how to enter the location where our outreach events were held.
        ii. Interviewing on the Santa Monica Pier
            1. This is a shortened version of the above mentioned interview video made to fit for an Instagram reel.
        iii. Field Work
            1. This Instagram reel sums up a day of field research on the UCLA Zodiac and presents it in short clips easily digestible, as a shortened field research video.
        iv. Fun Facts
            1. This is a shortened version of the previously mentioned 'Our Team's Favorite Fun Facts' video outfitted for an Instagram reel.

v. Lab Work

1. This reel discusses the work done in the lab to analyze the field collected data and eDNA analysis.

3. Infographics
   a. We produced infographics for two separate events hosted in conjunction with Heal the Bay Aquarium. The fliers can be found in the Tabling Events section.
   b. In addition to these fliers, we made an abundance of graphics detailing biodiversity facts for some of the species living around the Santa Monica Pier.

These infographics were created for a variety of reasons. Social media platforms allow for the quick dissemination of information across large areas. Aesthetics matter; bright colors and neat lines are pleasing to the eye. Using The Bay Foundation's Style Guide, we were able to create designs specific to their color scheme, typeface, and logo preferences. This guide was also used to help us create the trifolds for both tabling events. In order to best meet The Bay Foundation's needs, our Communications Team attended monthly meetings with TBF's Communications Committee. These meetings doubled in purpose; they allowed us to relay additional information about our current data and field deliverables whilst discussing future events and needed graphics.

Figure 15: *Examples of the graphics produced for media outreach. Additional examples can be found on our website and our Instagram, @bayfoundationpracticum.*

Web Media

YouTube Videos

To date, we have uploaded and published two full-length videos to our YouTube page, @IoESTBFPracticumTeam. This account was created with the purpose of publishing our longer media. This was the best way for us to circulate this sort of media and keep a permanent record of our deliverables on the internet while maintaining public access.

1. The video titled *Coastal Change Around the Santa Monica Pier from 1928-2022* details shoreline change around the Santa Monica Pier over nearly a century. To better understand the effects of the breakwater construction on the Santa Monica Beach shoreline and beach extent, we looked at archival photographs over nearly 100 years. Each image was georeferenced to its true position on a map, with the image angle and size adjusted to be consistent across years. We then digitized the beach area manually to show visually how the beach has changed in this 100 year period.
    a. Our first image is from 1928, 4 years before the construction of the breakwater. This was nine years after the construction of the first Santa Monica Pier. Here we can notice the limited beach area and the relatively straight shoreline. This is the beach’s 'natural state’, without beach nourishment or coastal infrastructure construction.
    b. The next image came from 1931. Little has changed from the previous image, with only slight fluctuations to the shape of the coastline. The completed construction of the breakwater is still a year away at this point, and thus the beach has maintained its area and fairly straight path.
    c. In 1937, we had begun to see changes caused by the breakwater construction five years earlier. The region directly behind the breakwater has transformed dramatically, gaining a significant amount of area; areas further down the beach sees less change. In beach progression, this beach gain behind the breakwater is known as a salient.
    d. In 1950, the beach had again changed, with slight erosion occuring in the center of the salient and build up on either side. This may be due to beach usage, the position of the pier, or changing currents and wave action. The increase in relative beach area both behind the breakwater and along the beach should also be noted.

e. In 1947, the Santa Monica State Beach was the location of a massive sand deposit as a result of sand removal from the future site of the El Segundo Hyperion Power Plant. Nearly 14 million cubic meters of sand were deposited along Santa Monica beaches, leading to an unnatural beach growth over this period, and some of this change in coastline shape may also be attributed to this human intervention. Several smaller beach nourishment projects also occurred in 1939, 1943, 1945, and 1949.
f. In 1957, the beach salient continued to grow, and besides a small beach nourishment project in 1950, we see a return to a more natural salient shape without significant interference in natural beach processes.
g. In 1958 a moderate beach nourishment project took place, with a larger project in 1963. We see a slight increase in beach area from the previous time step. Hurricane Hyacinth also hit Southern California in 1972.
h. In 1980, the salient was still visible, however it has smoothed since the prior photo. On August 15th, 1977, Hurricane Doreen made landfall in southern california, killing four people and causing $25 million in damages. Extreme flooding and mud flows likely caused coastal change as well as potential breakwater damage.
i. In 1978, Hurricane Norman hit California as a tropical depression and brough rain and harsh ocean conditions. The ocean conditions were strong enough to pull a 10,000 ton tanker from a mooring in Los Angeles Harbor and destroy ships across Southern California harbors, a likely source of breakwater damage. The effects of the damages had started to become visible in 1980, a few years after these major weather events.
j. By 1995, after a series of severe hurricanes, the shoreline began to flatten again, with the salient nearly disappearing. The beach began to return to a more natural shape whilst maintaining the area resulting from beach nourishment projects. In 1997, a final beach nourishment project took place. We can see a slight increase in beach area from 1995, however, the change is subtle.

    k. Finally, we see the coastline as it is today. There are limited changes from 2010, and the beach today is largely straight with no sign of the previous salient. By this point the breakwater has largely deteriorated.

2. The video titled *UCLA TBF Practicum Team's Zodiac Trip* shows a montage of our data collection and sampling while using UCLA's research vessel, The Zodiac. We recorded different environmental factors at eight test sights around the Santa Monica region; pacific locations and environmental markers can be found in the Sampling Justification section. In addition to capturing the methodology behind our approach to collecting data, this video will be used to continue the funding offered to the UCLA Zodiac.
3. The video titled *The UCLA Bay Foundation Practicum Team's ROV Deployment* details the testing and planning done prior to the deployment of the ROV on the UCLA Zodiac research vessel. The video includes live camera footage from the ROV with an explanation behind its function.

Instagram Account

Our Instagram account can be found @bayfoundationpracticum via the application or with the link, https://www.instagram.com/bayfoundationpracticum/ . We posted many graphics, videos, visuals, and information on this account. These videos were created with the intention for use on The Bay Foundation's own account. These posts were made using photos taken by team members. Other graphics were uniquely designed for each specific post. The account houses reels, informational posts, photos from tabling events, photos from data collection, and story archives featuring fliers. This account is public; these videos and posts will remain accessible to the general public. The Bay Foundation has plans to post additional graphics created by our own communications committee in the coming months.

UCLA Radio

A select few members of our team spoke about this project and The Bay Foundation on UCLA's student-run media organization, UCLA Radio. The episode aired May 17th from 1 PM to 2 PM. The team spoke about the history and the presence of the Santa Monica Breakwater, different marine species inhabiting the area, highs and lows of the project thus far, and goals we were working towards before the end of the year. We also advertised our second tabling event which occurred the following Sunday.

Interviews

Santa Monica Pier

We conducted a set of video interviews on Saturday, March 4th at the Santa Monica Pier. We began by asking pier-goers if they would be able to answer a few short interview questions for a University of California, Los Angeles senior project involving the Institute of the Environment and Sustainability. If their answer was yes, we asked them if we had permission to film their responses. We asked them a set of three questions. These questions were used to establish locality to the area and to establish an idea of the individual's understanding of a breakwater. After these questions were asked, we explained the significance of the breakwater to the participant.

1. Where are you from?
2. Do you know what a breakwater is?
3. Do you know that there is a breakwater at the end of the Santa Monica Pier?

These questions were designed to help us understand the extent at which individuals understand a breakwater's significance. The responses to these questions allowed us to design our next educational videos and photos for the subsequent outreach events. Additionally, these interviews helped us create an informational video detailing a definition of a breakwater. This video short was intended for use on The Bay Foundation's newest social media outlet, Tik Tok. After a series of interviews, the definition of a breakwater is discussed. We spoke with respondents after the interviews to further their understanding of the numerous functions of a breakwater.

Tabling Events

Two tabling events were hosted in order to provide awareness and information about this project, as well as gauge public knowledge and feelings on breakwater restoration. Both tabling events were hosted by the Heal the Bay Aquarium that is located under the Santa Monica Pier. Methods for the event included synthesizing interactive materials to present, both informational and engaging, meeting with the team to discuss goals for the event, preparing surveys to distribute, and creating and publishing content to promote the events. After the events, data was synthesized and discussed in order to address concerns and improve for following events.

Tabling Event #1

The first event at the Heal the Bay Aquarium took place both inside of the aquarium with a booth and table as well as outside, with team members outside speaking to pier-goers about the project, passing out pamphlets (Fig. 19), and distributing the survey (see Survey section for survey questions and results). The trifold pamphlet informs about the project, breakwater history, and Santa Monica Bay biodiversity. We also created a flier to advertise for this event which is also seen below. The tabling event had two interactive aspects, the first being the aquarium animal biodiversity scavenger hunt in the pamphlet which participants could complete for prizes. The second interactive aspect was a survey, further explained in the following section. Team members described the project, answered questions, and informed visitors about the importance of the breakwater.

Figure 16: *The Bay Foundation Practicum Team at the first Heal the Bay tabling event.*

Tabling Event #2

The second tabling event was also hosted at the Heal the Bay Aquarium under the Santa Monica Pier, this time with the booth set up near the entrance to speak with visitors as they entered and to encourage those walking by to enter the aquarium. The same trifold and scavenger hunt were distributed with a second survey described in the following section. Prizes were also available for filling out the survey or completing the scavenger hunt. We included more interactive aspects for this event including abalone shells and a species guide to look through, with more information on the rocky intertidal zone and an interactive model of the beach area. We created this model using aerial images of the beach area that our GIS/Aerial imaging team synthesized by year and important events in order to demonstrate the way that Santa Monica Beach has changed over the last hundred years and the breakwater's role in this, noting important weather and sand dumping events in the model as well (Fig. 17). Visitors could flip through the sand area for the years ranging from 1928 until present day with stickers marking important events in these years like hurricanes and sand being added. There is also a demonstration of the original breakwater in this model next to a modeling of the current state of the breakwater for the sake of comparison.

Figure 17: *The booth (left) with its numerous fliers, stickers, shells, pamphlets, and interactive breakwater diagram (right). This diagram simulates the coastal change that has taken place at the Santa Monica Beach over time.*

Figure 18: *Fliers Created for tabling event #1 (left) and tabling event #2 (right).*

Figure 19: *Trifold pamphlet handed out at both tabling events.*

Surveys

One survey, distributed through Google Forms, was formulated for each tabling event at the aquarium– totaling two (one for each event). Survey questions were meant to gauge public knowledge and sentiments towards the Santa Monica breakwater improvement project. The first tabling survey included the following questions:

1. What is your zip code?
2. Do you know what a breakwater is?
3. Did you have prior knowledge that there is a breakwater off of the Santa Monica pier?
4. How concerned are you with coastal restoration? 1-Not at all concerned, 5-Very Concerned
5. Would you verbally support a project to potentially improve the water quality around the pier?
6. How familiar are you with marine ecosystems? 1- I know nothing, 5- I am very familiar
7. Do you have any questions or concerns about the breakwater restoration project?

Our survey collected 82 responses. A powerpoint presentation with this data is in the appendix: (Survey #1 Results). Around 58.5% of respondents did not not know what a breakwater was before speaking to us, 74.4% of respondents did not have prior knowledge that there is a breakwater off of the Santa Monica Pier, 46.3% of respondents were very concerned with coastal restoration, 84.1% were willing to verbally support a project to potentially improve the water quality around the pier, 19.5% were very familiar with marine ecosystems, and many questions and concerns were raised in the comments section. Some response concerns included the following:

1. How will the breakwater affect recreation around the pier?
2. Isn't the breakwater itself a major disruption to the natural ecosystem and water cycle?
3. What would a breakwater restoration project look like?
4. What are the details of how it will be constructed and how will it be funded?

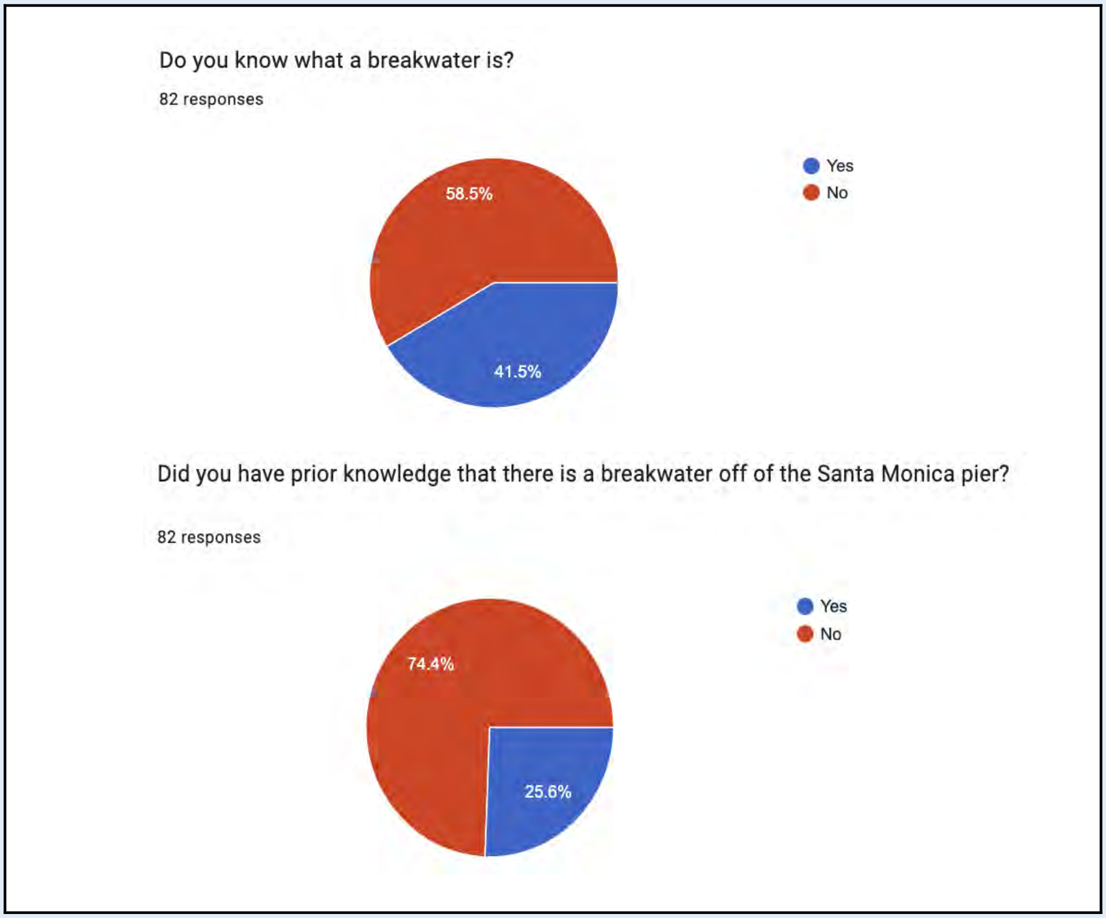


Figure 20: *Two graphs created using data from the first survey.*

The second tabling event survey was unsuccessful in its number of responses, receiving only 15, likely due to excessive length. It was aimed more at demographics of visitors the second time, with the same idea of gauging public knowledge on the project before and after speaking with our team at the tabling event. Due to the lack of responses, survey data will not be included for this study.

Website Materials

Our work can be found archived on our website. Our web address is: https://bayfoundationpracticum.wordpress.com/. The intention behind the website was to create a space to archive the team's work publicly so it can continue to be accessed. On the website, users can find information about the intended purposes of the breakwater renovation. These purposes outline the importance of this revitalization project. They include damage prevention from future natural disasters and storms, increasing the area's ability to sequester carbon and cycle nutrients, and providing overall support to the rocky intertidal ecosystem. Additionally, you can find another link to our work on the Institute of the Environment and Sustainability's website. This web address is: https://www.ioes.ucla.edu/project/the-bay-foundation-restoring-the-santa-monica-breakwater-rocky-intertidal-preserve/.

Outreach Conclusions

Through outreach, both digital and event based, visitors and residents of the Santa Monica Bay were informed of the project while having the opportunity to raise concerns. This way, the project team was informed of the aforementioned comments. Through the use of web media, outreach extended beyond those we could speak to face to face, thus opening up interactions with hundreds more. This allowed for the creation of room for dialogue centered around the project. These conversations, both online and in person, will formulate future steps and information to include when interacting with the public. Moving forward, future events can address the questions raised in the survey from the first tabling event via material or display as well as any other web media created. This can allow The Bay Foundation to create a clear perception of their overall project and clear up any misconceptions. It will also aid in informing the public of the background needed to properly appreciate the importance and relevance of breakwater restoration.

The suggested steps moving forward for outreach include the continuation of the production of web media through Instagram posts and videos, the creation of new YouTube videos, the creation of video shorts, and the occurrence of more tabling events. It is also advised that future fliers, posts, and other infographics be created in multiple versions featuring languages other than English. As of 2019, around 54% of the population (age five and older) speak a language other than English at home, with the top five languages spoken being Spanish, Tagalong, Chinese, Vietnamese, and Korean (IPUMS USA, 2020). This would greatly increase accessibility to communities local to the Santa Monica area, thus allowing for The Bay Foundation and other organizations to continue the dialogue on the importance of the pier, breakwater, residents, and biodiversity all taking refuge around the Santa Monica Bay.

Final Conclusions

While we produced a variety of deliverables that differed greatly in scope, these deliverables were unified in their pursuit of informing a long-lasting, coastally beneficial breakwater that supports diverse habitats and public interests. In their most simple form, these deliverables informed us of the following;

1. The breakwater has had an immense impact on the Santa Monica coastline, however, its effects have diminished over the breakwater's lifespan.
2. A combination of local materials and built structures aimed at providing habitats for intertidal organisms has been proven effective across a range of case studies, and implementing such processes may allow for a breakwater with a long-lasting and ecosystem-sustaining structure.
3. Preliminary analysis of eDNA suggests that the breakwater supports diverse marine life, and further analysis may inform what kind of marine life is supported. This understanding will allow for the development of a breakwater that maintains current biodiversity and possibly that allows for increased recruitment.
4. The public is uninformed about the role and presence of a breakwater off the Santa Monica Pier. Public outreach about the breakwater and the proposed revitalization will be essential as this project moves into permitting and planning stages.

We hope that taken together, these deliverables will provide the basis for a holistic approach at the breakwater revitalization project. These findings are just the beginning, and over the next few years extensive work will be necessary to put these findings into practice.

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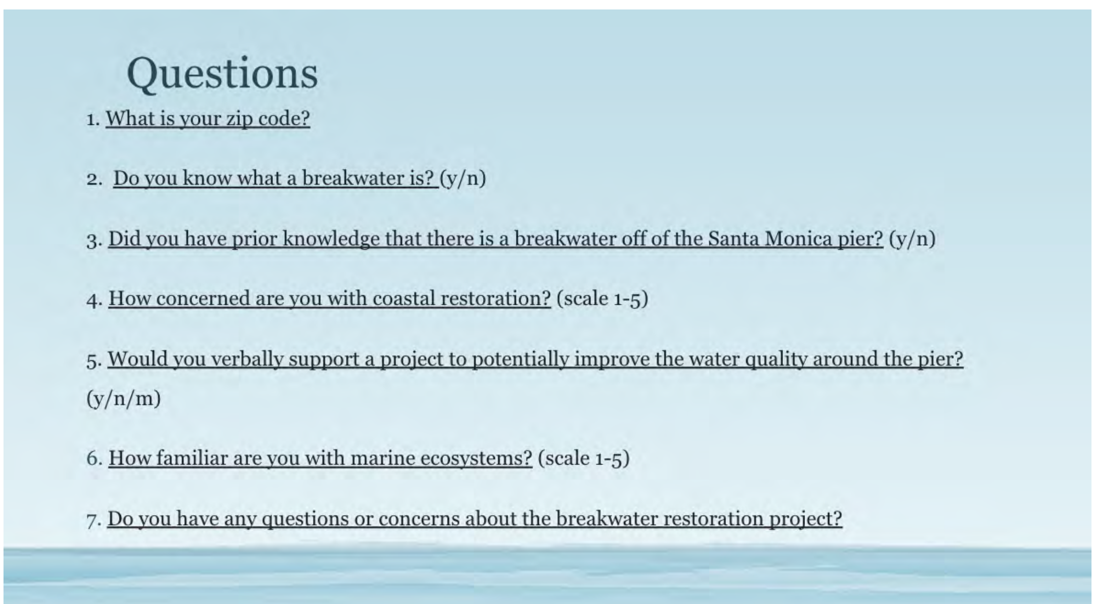
Appendix I

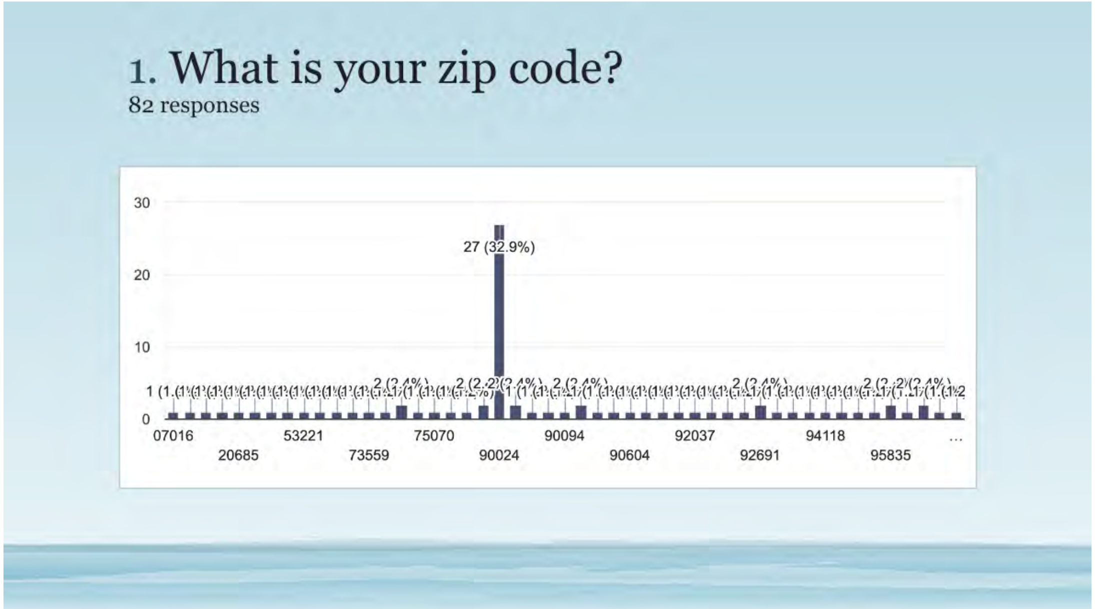
Image	Collection Date	Creator/ author	Identifier	Image Hosting Organization
a	01/ 1928	(Fairchild Aerial Surveys, 1928)	Job #C164-4	SMHIA *
b	07/20/1931	(Fairchild Aerial Surveys, 1931)	Job# C1270 Section 5	SMHIA *
c	02/20/1937	(Fairchild Aerial Surveys, 1937)	Job # 4915, Section 6	SMHIA *
d	04/01/1950	(Pacific Air Industries, 1950)	Image C245	SMHIA *
e	11/22/1957	(Fairchild Aerial Surveys, 1957)	Job# VII LA 12	SMHIA *
f	01/12/1975	(National Aero Mappers (Colton, Calif.), 1975)	Image #6	SMHIA*
g	10/20/1980	(USGS, n.d.)	Entity ID: AR1VRZS00020054	USGS Earth Explorer
h	05/ 26/1995	(NASA AMES Research Center, 1995)	Entity ID: AR5950049294886	USGS Earth Explorer
i	04/30/2010	(National Agriculture Imagery Program, 1995)	Entity ID: M_3411860_SE_11_1_20100430, M_3411861_SE_11_1_20100430	USGS Earth Explorer
j	2018- 2023	(ESRI, n.d.)	-	ESRI

Supplemental Table 1: Aerial Image Data Sources. * *Santa Monica Historic Image Archive*

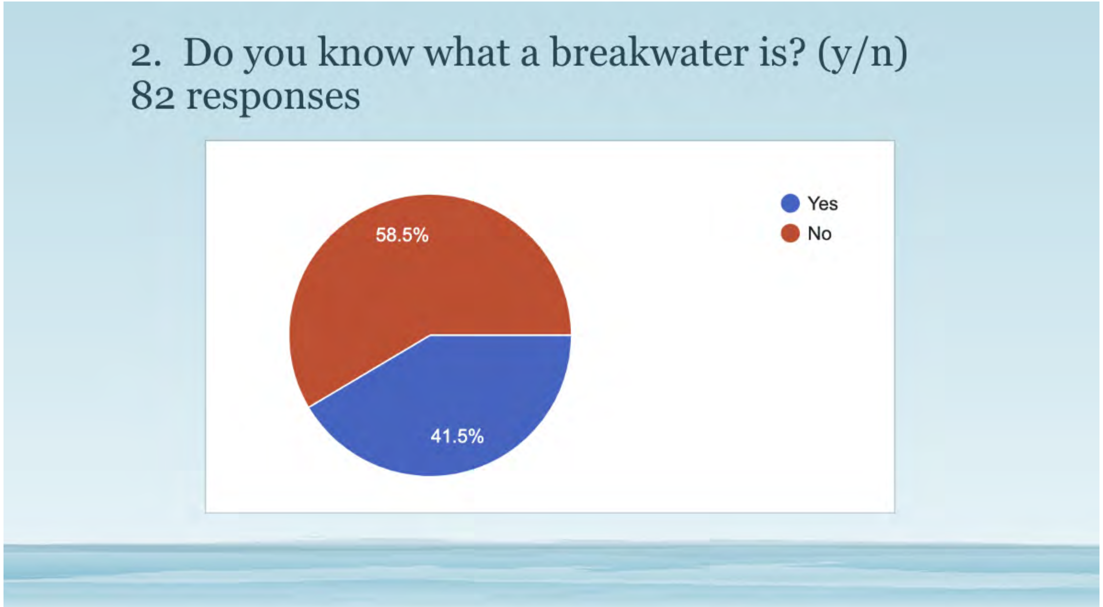
Appendix II

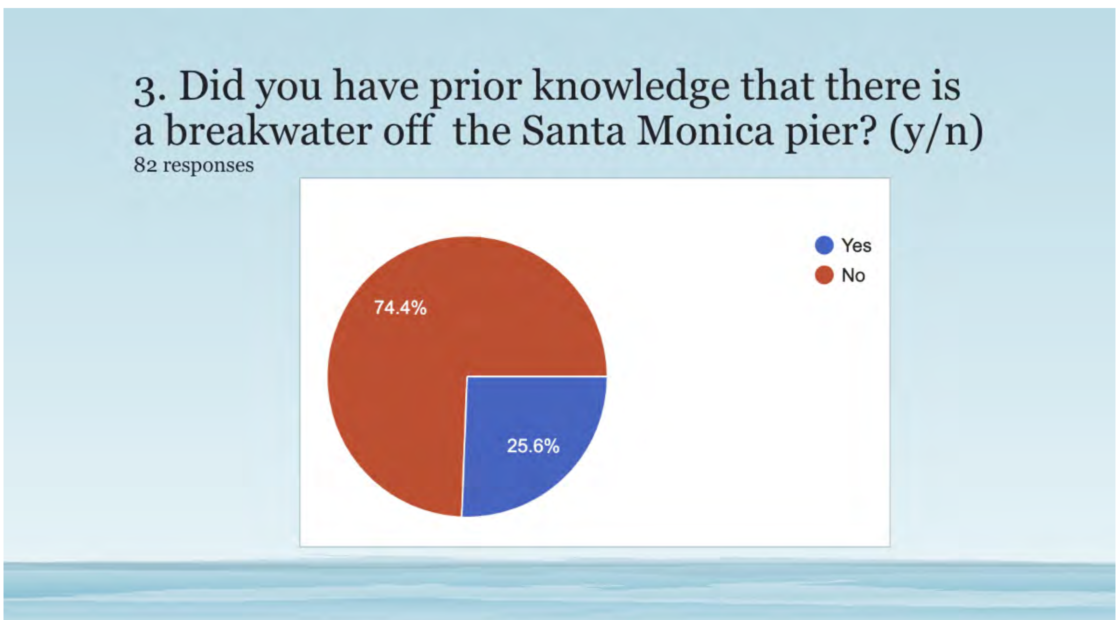
Powerpoint of first survey results:

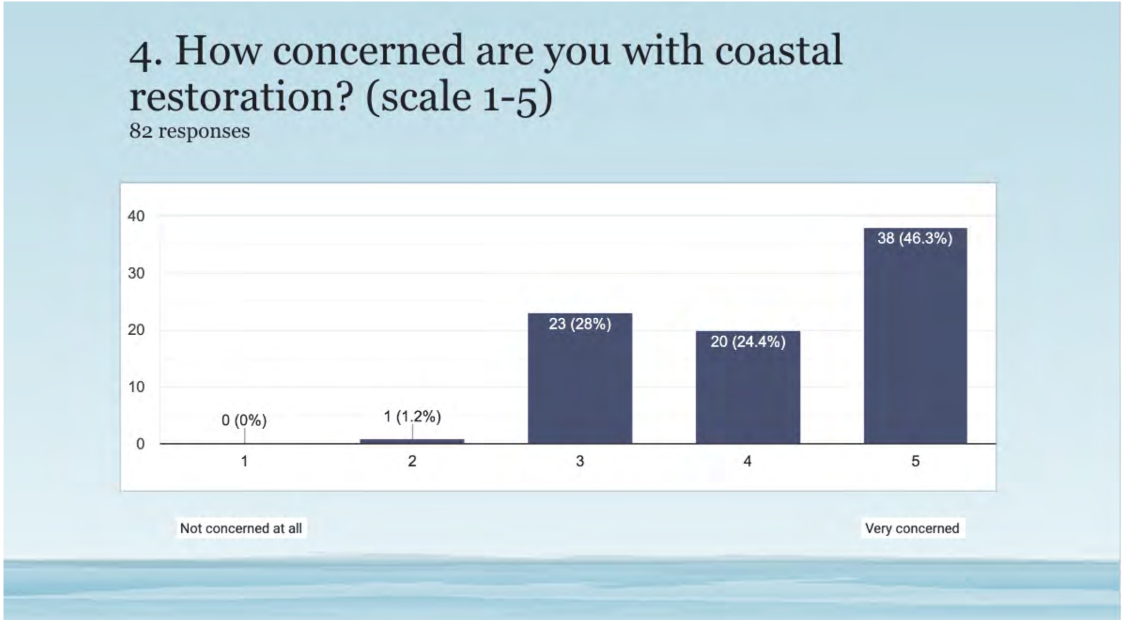


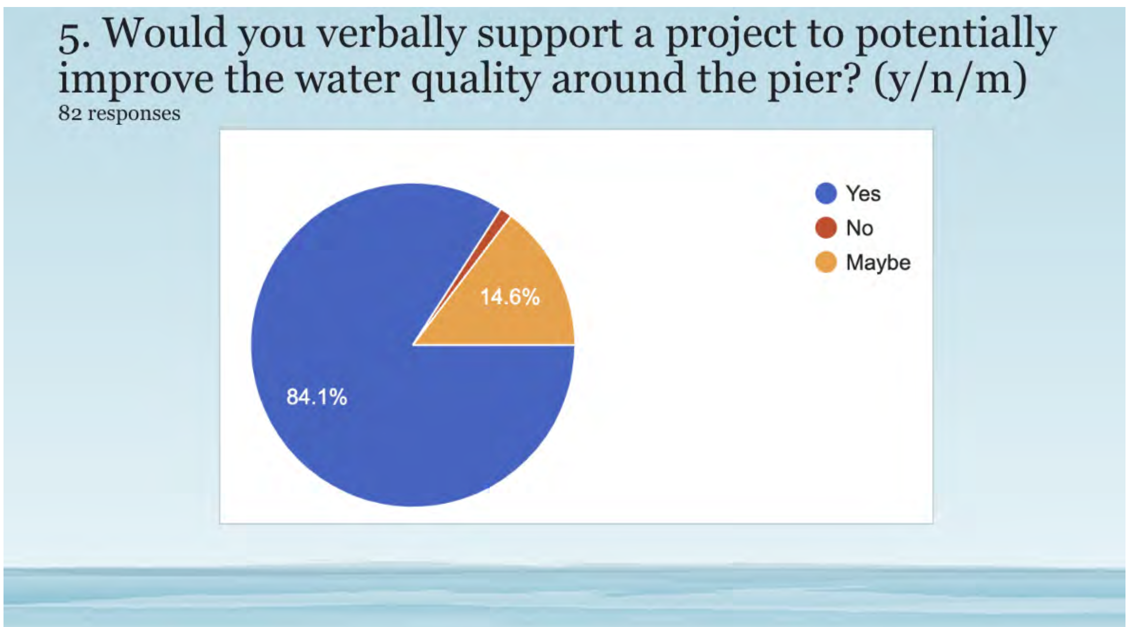

1. What is your zip code?
82 responses
27 (32.9%)
30
20
10
0
07016
20685
53221
73559
75070
90024
90094
90604
92037
92691
94118
95835

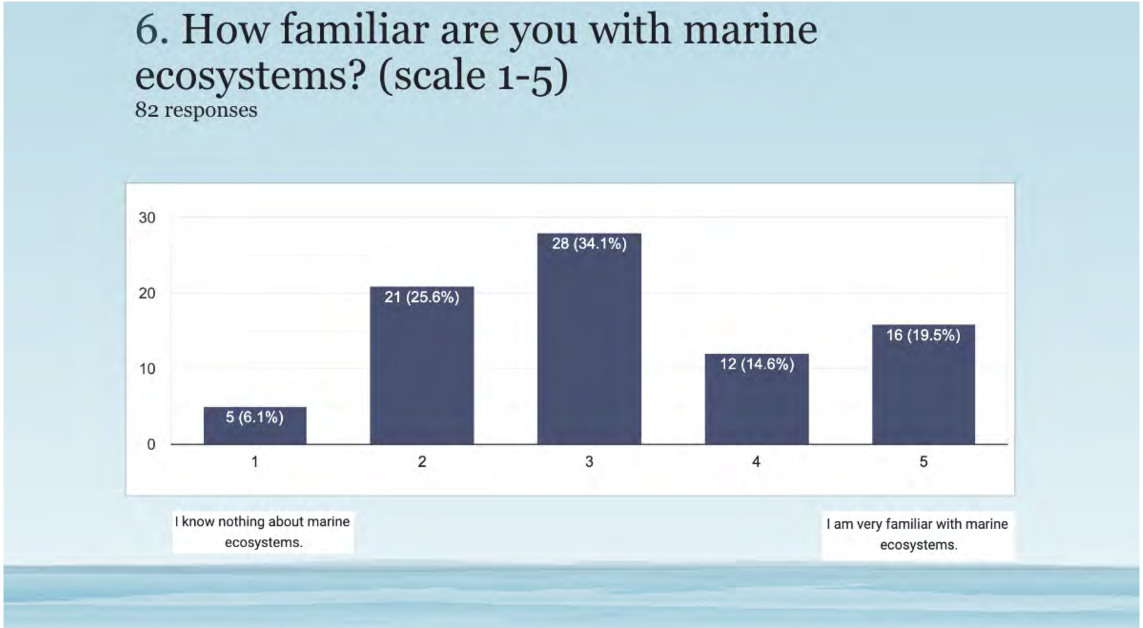

CANADA
Edmonton
Calgary
Vancouver
Seattle
UNITED STATES
Great Plains
Denver
San Francisco
Los Angeles
Dallas
Houston
Chicago
St Louis
Detroit
Toronto
Montreal
Boston
New York
Washington
Atlanta
Miami
Havana
CUBA
MÉXICO
Monterrey
Guadalajara
Mexico City
Port-au-Prince

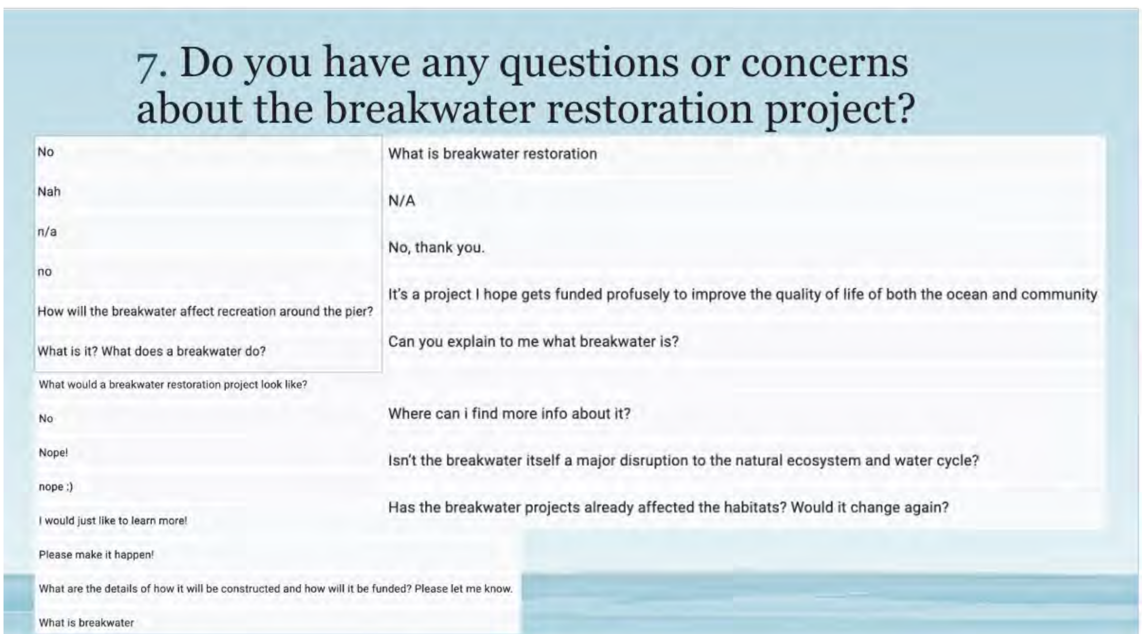

2. Do you know what a breakwater is? (y/n)
82 responses
Yes
No
58.5%
41.5%


3. Did you have prior knowledge that there is a breakwater off the Santa Monica pier? (y/n)
82 responses
Yes
No
74.4%
25.6%


4. How concerned are you with coastal restoration? (scale 1-5)
82 responses
40
30
20
10
0
0 (0%)
1 (1.2%)
23 (28%)
20 (24.4%)
38 (46.3%)
1
2
3
4
5
Not concerned at all
Very concerned


5. Would you verbally support a project to potentially improve the water quality around the pier? (y/n/m)
82 responses
Yes
No
Maybe
14.6%
84.1%


6. How familiar are you with marine ecosystems? (scale 1-5)
82 responses
30
20
10
0
5 (6.1%)
21 (25.6%)
28 (34.1%)
12 (14.6%)
16 (19.5%)
1
2
3
4
5
I know nothing about marine ecosystems.
I am very familiar with marine ecosystems.


7. Do you have any questions or concerns about the breakwater restoration project?
No
Nah
n/a
no
How will the breakwater affect recreation around the pier?
What is it? What does a breakwater do?
What would a breakwater restoration project look like?
No
Nope!
nope ;)
I would just like to learn more!
Please make it happen!
What are the details of how it will be constructed and how will it be funded? Please let me know.
What is breakwater
What is breakwater restoration
N/A
No, thank you.
It's a project I hope gets funded profusely to improve the quality of life of both the ocean and community
Can you explain to me what breakwater is?
Where can i find more info about it?
Isn't the breakwater itself a major disruption to the natural ecosystem and water cycle?
Has the breakwater projects already affected the habitats? Would it change again?

Moving Forward

- Update our communications efforts with the collected information
  - factor in that at time of survey response we have not yet shared project with respondents
  - have a post project introduction/event survey to fill out as well so that we can see the effect of outreach
  - suggestions section for after events from the public
  - give more information on the history of the Santa Monica Breakwater in terms of updating survey
  - Go into next event planning based off of these responses
    - lots of out of town zip codes so sharing more of locational history could be helpful
    - getting bios/ interviews from the people that responded to the survey could also be useful

  survey 2: https://docs.google.com/document/d/1RHwHsnlFfUi9WGMzJjEqFI1OfuV4wv2CQuvPBghYQu8/edit