

SF Bay Living Shorelines: Near-shore Linkages Project

Integrating Restoration of Multiple Habitats to Increase Connectivity, Function, and Resiliency in San Francisco Bay.

Final Design, 20 January 2012 Final

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Brief Summary

The San Francisco Bay Living Shorelines: Near-shore Linkages Project is a multi-objective habitat restoration pilot project managed by the State Coastal Conservancy, in collaboration with biological and physical scientists with San Francisco State University, University of CA at Davis, ENVIRON, USGS Western Ecological Research Center, and ESA-PWA Consultants.

Following several previous iterations in which we refined the scope and scale of the project, this document provides our final plan for project design. This document incorporates feedback from agency staff and other stakeholders, and will support development of permit applications to be submitted in January 2012. The anticipated construction date for the project is June/July 2012.

General Concept

In general, Living Shorelines projects utilize a suite of bank stabilization and habitat restoration techniques to reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting, restoring, enhancing, and creating natural habitat for fish and aquatic plants and wildlife. The term “Living Shorelines” was coined because these techniques provide living space for estuarine and coastal organisms, which is accomplished via the strategic placement of native vegetation, natural materials, and reinforcing rock or shell for native shellfish settlement (Fig. 1). The approach has been implemented primarily on the East and Gulf Coasts, where such techniques enhance habitat values and increase connectivity of wetlands and deeper intertidal and subtidal lands, while providing a measure of shoreline protection.

Living Shorelines in San Francisco Bay

While not a new concept, Living Shorelines projects are new to SF Bay, where pilot restoration work on eelgrass and oyster reefs (Fig. 1) has recently led to recommendations for additional experimental testing of techniques and gradual scaling up to larger projects. The **2010 San**

Francisco Bay Subtidal Habitat Goals Report (see www.sfbaysubtidal.org) recommended that the next generation of projects consider the possibility of integrating multiple habitat types to improve linkages among habitats and promote potential synergistic effects of different habitat features on each other as well as associated fauna. Such habitat features, if scaled up slightly beyond previous projects would have the potential to positively influence physical processes (such as sediment erosion and accretion) that influence shoreline configuration.

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

Potential Climate Change Adaptation Approach

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

Overarching Goal

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

Objectives

- 1) Use a pilot-scale, experimental approach to establish native oysters and eelgrass at multiple locations in San Francisco Bay.
- 2) Compare the effectiveness of different restoration treatments in establishing these habitat-forming species.
- 3) Determine the extent to which restoration treatments enhance habitat for invertebrates, fish, and birds, relative to areas lacking structure and pre-treatment conditions.
- 4) Determine if the type of treatment (e.g., oyster reefs, eelgrass plantings, or combinations of oyster reefs and eelgrass) influences habitat values differently.

- 5) Begin to evaluate potential for subtidal restoration to enhance functioning of nearby intertidal mudflat, creek, and marsh habitats, e.g., by providing food resources to species that move among habitats.
- 6) Evaluate potential for living subtidal features to reduce water flow velocities, attenuate waves, and increase sedimentation, and assess whether different restoration treatments influence physical processes differently.
- 7) Determine if position in the Bay, and the specific environmental context at that location, influences foundational species establishment, habitat provision, and physical processes conferred by restoration treatments.
- 8) Where possible, compare the ability to establish restoration treatments, habitat functions, and physical changes along mudflats/wetlands versus armored shores.

Site selection

Given the objectives above, we began the process of identifying locations to conduct this pilot project. We found it quite challenging to achieve siting that could permit us to meet all our objectives. We decided to identify criteria most critical to conducting the project, and also secondary criteria to meet if possible:

Highest priority:

Appropriate region and depth for eelgrass and oysters (based on known distributions and/or evidence of success at proposed sites)

Appropriate substrate for oyster reefs (coarser can minimize sinking of and sedimentation on reef) and eelgrass (coarser can lead to increased light availability)

Willing landowners with expected reasonable time frame for permits/approvals

Very important, but not as critical:

Large enough shoreline, oriented so that treatment array can be placed in a line parallel to the shore and perpendicular to the direction of waves (an array that meets only the latter is less ideal)

Distance to shore amenable to shore access for ease of monitoring (e.g., a few hundred meters at most, not a mile)

To achieve if possible:

Multiple locations to provide replication and allow comparison of treatment effects in different regions

If multiple locations, then same experimental design and depth at all

Soft shoreline with paired comparison to hard shoreline nearby, if possible

We identified two locations within the Bay that would meet our most important site selection criteria, and thus should allow us to meet many of our objectives. In 2012, we propose to utilize a location along a portion of the San Rafael shoreline on property owned by The Nature Conservancy (Fig. 2) for a majority of our work. Hereafter, we refer to this property as **TNC**. In addition, we propose to utilize a location offshore of Eden Landing Ecological Reserve, just south of the San Mateo Bridge on the east side of the Bay (Fig. 2), hereafter referred to as **Eden Landing**. More detail about these sites and the surrounding watersheds, water depths, land uses, etc., are included in Appendix 1.

At **TNC**, native oysters are abundant on the lower rip-rap along the shoreline, suggesting that propagules are available. Further, the depth of the property is suitable for both eelgrass and oysters based on our previous experience (i.e., depth at the center of the property is approximately -1.5' to -2' MLLW). In addition, we have conducted successful eelgrass test plots on this property, in which plantings have persisted and spread over the last 4 years. We are also interested in this shoreline due to previous successes in restoring both eelgrass and native oysters nearby at the Marin Rod and Gun Club, and because herring spawn along this shoreline in many years and should benefit from restored subtidal habitat. The Nature Conservancy is very supportive of this project being conducted on their property. We have not been able to identify locations along this shoreline with “soft” edges that also had agreeable landowners, thus the TNC location will have one “site”, along a hardened shoreline only. At this site, we will conduct our larger-scale experiment to test both physical and biological effects of eelgrass and oyster treatments, with four 320-m² plots. In addition, among these larger plots we will place small-scale replicate “substrate elements” (each ~1m²) to test recruitment and habitat value of a number of different restoration substrates. The design of these experiments is detailed further below.

At **Eden Landing** we ultimately hope to compare physical and biological effects of our larger treatment plots (320 m² x 4) at two sites, one a soft and one a hardened shoreline. North of Mount Eden Creek, the shoreline is riprapped, and to the south, Whale’s Tale Marsh provides a softer adjacent marsh edge. However, in 2012, we propose to conduct only the “substrate element” experiment, to evaluate recruitment of native oysters and eelgrass and their associated communities in small plots of ~1m². Pending the outcome of this “Phase 1”, we would in the future conduct the larger scale experiment, repeated along both the hard and soft shorelines. Habitat appears suitable; native oysters have been found on limited hard substrate in the area in our pre-project surveys, and eelgrass occurs nearby. In addition, the South Bay Salt Pond Restoration Project includes multiple wetland restoration sites in the vicinity, and project leaders have expressed interest in the potential to integrate deeper habitats into the matrix of newly restored areas. However, this location is a shallow flat that extends for well over a mile, and the depth within a reasonable distance (from an access perspective) from shore is ~0.5' to 1' MLLW, a bit shallower than might be ideal for native oysters and eelgrass. Thus, we propose a phased approach that permits us to learn more about this location’s potential for a larger project before scaling up.

Design features

Larger scale experiment to test both biological and physical effects. This experiment includes four 32 x 10 m treatment plots situated parallel to the shore, approximately 250 m from shore. This design will permit us to compare the effects of one type of native oyster substrate, eelgrass, and both together, in comparison to a control of the same size (Fig. 3). We designed this experiment to be at a large enough scale to compare effects on physical factors such as wave attenuation and accretion as well as effects on biological properties that operate at larger scales (e.g., bird and fish utilization, water quality interactions of oysters and eelgrass). In 2012, this experimental design will only be utilized at TNC. We intend to repeat this design at two sites along Eden Landing in the future, pending the outcome of the Phase 1 “substrate element” experiment in 2012 (see below).

We will compare one type of oyster reef treatment (oyster shell bags; see below) on this larger scale, denoted as Oyster A in Figure 3. This treatment, described in detail below, has a footprint of 1 x 1 m per element. We propose to lay these out in sets of 4 elements to make larger units of 4 m² (Fig. 4). To minimize scour, our team members with expertise in physical processes recommend we have spaces of the same size (in this case, 4 m²) between these oyster reef units. We propose to install 3 rows of eight units, for a total of 24 units per plot (96 elements).

We will also plant and seed eelgrass in its own treatment plot with the same spacing as the oyster reef units. The central 1.5 x 1.5 m (2.25 m²) space within every other 4-m² space will be planted with clusters of shoots and also seeded. See details of planting methods below.

Oyster treatment A will also occur in combination with eelgrass in a separate plot. We will combine the oyster treatment with eelgrass planting/seeding using an additive design, with eelgrass placed into the central 2.25-m² of the 4-m² spaces between oyster substrate features (Fig. 5). This design permits us to maintain a spacing of oyster substrate that will minimize scour while providing enough space around eelgrass plantings to permit access for sampling.

A control plot of the same size will also be included. All four plot types will be arranged randomly in the four possible positions, with 30 m between each plot.

Adjacent to the overall treatment area, a control area of equal size will be monitored throughout the project time period.

“Substrate element” experiment to examine small-scale biological effects. This experiment consists of replicate 1 x 1 m substrate elements of different substrate types, intended to compare native oyster recruitment and growth parameters to inform future restoration projects. At TNC in 2012, this experiment will be set up in the 30-m spaces between and on either side of the line of larger scale plots described above (Fig. 6). At TNC, four oyster substrate types not tested in the large scale experiment will be replicated 5 times, for a total of 20 elements. These elements will be placed in groups (blocks) of four, with each of the four substrate types represented in each block.

A substrate element experiment will be the only project installed at Eden Landing in 2012 (Phase 1 for that location). This will be similar to that described for TNC in that it will include 1 x 1 m substrate elements replicated in 5 blocks and aligned parallel with the shoreline at ~250 m from

shore. However, at Eden Landing, there will be 5 substrate types: the 4 tested in the TNC substrate element experiment plus the substrate type used in the larger scale project at TNC (oyster shell bags; see below). In addition, there will be 5 replicate 1x1m plots of eelgrass planted, one in each block, as well as a treatment that includes one of the oyster substrate types along with eelgrass planted directly adjacent to it (Fig. 7). The layout of these replicate blocks of 7 elements will allow space for a future installation of the larger scale project pending a positive outcome of this Phase 1 experiment. Thus 32 m-long spaces will be left between substrate element blocks to accommodate the 32 m long plots of the larger scale experiment if it goes forward in a future year.

Element descriptions and rationale

Oyster treatment bases. Oyster elements all consist of a hard oyster settlement substrate of some type placed onto a supporting structure. In past projects, a wooden pallet has been used to support oyster shell or other substrates. In this project we propose a PVC base supported by legs that are sunk into the sediment (Fig. 8). This 1 x 1 m base is constructed of 4" PVC with perimeter bars and three internal cross bars. Substrates will be attached to the cross bars using large cable ties. This base design should reduce settlement into the sediment experienced in previous projects and would more easily facilitate removal of the element on its base (as opposed to a decomposing wooden pallet) if this is later deemed necessary.

Oyster and eelgrass elements. For all oyster elements, substrates will be placed onto bases as described above. Elements will be ~ 0.76 m (2.5') tall and weigh ~ 113 kg (250 lbs). "Oyster A" in the larger scale experiment could be composed of a variety of similarly sized substrates, but we propose to use Pacific oyster shell bag mounds.

Shell bag mounds: Our choice to utilize bags of Pacific oyster shells (Fig. 9) as native oyster settlement substrate is driven by their popular use on the US East and Gulf Coasts as well as previous experience in San Francisco Bay (The Marin Rod and Gun Club in San Rafael, Berkeley Marina, and Redwood City). Locally, bags nearly 7 years old are still intact and maintain a viable population of oysters, fish, and other invertebrates. Oyster density on the shell can be very high the first year (over 12 oysters per shell) then the density levels off to approximately 2 oysters per shell in about 4 years, which is equivalent to 200 oysters per bag. The amount of surface area for spat settlement and interstitial space in a bag of shells is larger than any other type of oyster substrate known to the oyster culture industry. By comparison, a Reefball (see below) at the Marin Rod and Gun Club contained up to 300 oysters per ball, but in the same space, 10 shell bags could be placed and yield over 2000 oysters. Another advantage of the shell bags is that the mesh covering affords some protection from predators while the oysters are small. In addition, shell bags are a natural substrate, easy to install and monitor. At other sites in San Francisco Bay, maintenance has been required after 3-5 years to wash out excess sediments. Alternatively, the mounds of bags can be replenished with fresh bags over time. Reef structures constructed out of bagged shell are relatively long lasting, and they can be easily removed if required either by hand or by dredge clam shell equipment.

Eelgrass will be added as whole shoot transplants using a new bamboo stake planting technique developed by SF State graduate student Stephanie Kiriakopolos. For this method, vegetative shoots are collected and attached to bamboo stakes (using paper-coated twist ties); the stakes are inserted into the sediment to hold the shoots in place until they become rooted (Fig. 1, 10). This

method has been used successfully at numerous sites around the Bay in range of soil types, thus we expect similarly consistent results across the sites in the current project. Whole shoots transplants provide the opportunity to have eelgrass and the resulting habitat and interactions right away. For each unit of eelgrass (slightly smaller than a unit of oyster substrate at 2.25 m²), a total of 25 shoots will be planted in clusters of 5 shoots each, thus a total of 1200 shoots (25 shoots x 48 units) will be planted at the TNC site within the larger scale experiment. In addition, we will supplement transplants with a seeding technique known as buoy-deployed seeding (Fig. 1, 11). This method entails collecting flowering shoots with nearly ripe seeds, placing these in a mesh bag attached to a buoy at the restoration site (temporarily secured within an eelgrass unit with a 1" PVC pipe at the center of the unit), where seeds will drop and result in seedlings. While seedlings will not emerge until the next spring, establishment from seed will increase the genetic diversity of the resulting plants at the site, which can increase resiliency to environmental stressors over time. Among choices of seeding techniques, buoy deployed seeding is relatively easy to accomplish, and has been used successfully at several previous restoration sites in the Bay. We will obtain transplant and seeding material from the nearest large bedsto each project location to minimize impacts (Point San Pablo for TNC and Bay Farm Island for Eden Landing).

Additional oyster substrates tested in small-scale “substrate elements” experiments. In addition to the larger plot experiment (at TNC in 2012 and possibly at Eden Landing at two sites in a future year), we plan to test 4 additional oyster substrates, described below, in the small-scale “substrate element” experiments at both TNC and Eden Landing.

Reef castles: Reef castles (Fig. 12) are modular cement structures that have been used in several oysterrestoration projects funded by Sea Grant, Audubon and the Native Conservancy on the East Coast. Created from 12" x 12" x 8" blocks, they are relatively inexpensive and easy to assemble and can be built to any dimension. A demonstration project in at the Wellfleet Bay Wildlife Sanctuary in Massachusetts found a higher per-area recruitment rate of oysters onto castles vs. Reef Balls (described below) and two types of shell cultch. Reef castles have less three-dimensional surface area than shell bags but are more complex than a number of other reef designs, which may enhance oyster recruitment through the provision of more interstitial space. The modular construction should also make monitoring during the life of the project relatively easy. It may be possible to have the castle component blocks fabricated to incorporate locally derived shell.

Reef Balls(dome style) have been used for a wide variety of intertidal and subtidal restoration projects around the world. Molds for the balls are purchased from Reef Ball International and used to create a cement dome (Fig. 13). Reef Balls are now in use in SF Bay at two restoration sites: the Marin Rod and Gun Club (San Rafael) and Berkeley Marina (north of Cesar Chavez Park). The cement for Reef Balls can be made using materials from San Francisco Bay. They are relatively easy to install and remove and have been demonstrated to be successful in recruiting oysters. Among the disadvantages of Reef Balls is that they appear to affect water movement such that scouring occurs around the base. Additionally, it is difficult to monitor oysters during the course of a project unless settlement plates or other small removal substrates are attached to the Reef Balls. Reef Ball molds comes in different sizes; we plan to use the size previously used in SF Bay (~ 2.5 ft. in diameter at the base, tapering to 1.5 ft. at the top). They are hollow; the top is open but could be capped.

Using smaller sizes of Reef Balls in a stacked configuration, a **Reef Ball Stack**, may be a way to work around some of the disadvantages of larger balls and create a variety of sizes of interstitial spaces. We propose to use basketball-sized balls, ~1 ft. in bottom diameter and height in a staggered stack with four domes per layer, to stay within the target 1x1 m dimension (Fig. 14). The domes will be anchored to one another for stability. This structure has the advantages of the single dome-style Reef Ball mentioned above, but would be easier to deploy and monitor. A drawback is our lack of expertise building and deploying this type of structure in SF Bay.

ReefballInternational, which makes the Reef Ball molds, also offers a “**Layer Cake**” design (Fig. 15), which increases the amount of interstitial space, particularly underneath, which appears to be good for oysters based on our field observations. The overall dimensions are similar to the dome-style Reef Ball described above. In addition to the provision of more settlement space, potential advantages of this method are ease of deployment and retrieval, likely less scouring than the original Reef Ball design, and the potential to modify the design for easier monitoring. Cons include our lack of experience in constructing this model and possibly increased sedimentation relative to the original Reef Ball design.

Specific locations and footprint of proposed design

Figures 16 and 17 show the proposed locations of the project at the TNC and Eden Landing sites planned for construction in 2012. Note the potential future locations of plots at two sites at Eden Landing proposed for construction in a future year pending results of the smaller scale substrate element experiment in 2012.

For the larger scale project at the TNC site, the entire project area (including the small scale substrate elements experiment) will be 278 x 10 meters, or 2780 m² (0.69 acres). The large-scale manipulated plots themselves (three 32x10 m plots containing oyster reef, eelgrass, or both, not including the control plots) will encompass 0.24 acres. The fill within these treatment plots will be considerably less, as there will be equal sized spaces between each set of oyster elements, and eelgrass plantings will have very little fill (biodegradable/removable bamboo stakes smaller than the diameter of the eelgrass shoot it temporarily holds in place). Actual fill with oyster reef elements on bases of 1 x 1 m in each treatment plot with oyster elements will be 0.024 acres, for a total of 0.048 acres across the 2 plots with oyster elements. 1200 bamboo planting stakes for the two large-scale plots with eelgrass, with a diameter of 0.25 inches each, adds only an additional 0.4 ft² of fill footprint. Twenty-four 1-inch PVC pipes to temporarily anchor the seed buoys in each plot will add an additional 0.26 ft² across the two large plots with eelgrass. In addition, the small-scale substrate element experiment at TNC will include 20 oyster elements. At TNC, the total footprint for the 20 1 x 1 m oyster elements will be 0.005 acres. Four hazard buoys (for boating safety) will each be secured by three 5-gallon buckets filled with concrete for a total of 12 buckets at the TNC site. At 12” diameter, the fill for these twelve buckets is 9.4 ft².

For the small-scale substrate element experiment at Eden Landing in Phase 1 (2012), there will be a total of 30 oyster elements of 1 x 1 m, for a total of 0.007 acres. Eelgrass planting stakes and PVC seed buoy anchors will add <0.1 ft² of fill. Two hazard buoys secured by three 5-gallon buckets of concrete each (6 total buckets) will add 4.7 ft² of fill.

Schedule

Draft Design: 11/5/11

Key Permit Agency Input Meeting: November 14, 2011

Final Design: 1/10/12

Permitting: initiate agency contact 8/1/11, final permits 4/30/12

Construction: June/July 2012

Two years of post-project monitoring through 8/30/14

Monitoring

Pre-project monitoring will include cores to assess benthic invertebrate species richness and density prior to construction. In addition, we will monitor bird, fish and epibenthic invertebrate use of the sites before any construction activities occur.

After the project is installed, biological monitoring will include various oyster and eelgrass responses to treatments and success of restoration. In addition we will use traps, suction sampling, and coring to assess fish and invertebrate responses. Waterbird and shorebird densities and behaviors will be monitored at treatment and adjacent control sites. The physical monitoring will assess changes to wave velocities, flow rates, sedimentation rates, and erosion.

Success criteria

We intend for both the larger scale project and small-scale “substrate element” projects to provide lasting habitat for numerous organisms in the high subtidal to low intertidal zone. While we expect there to be interannual variation in densities of desired organisms, the project will be deemed successful if one or more of the following criteria are met within the 5 year period following construction:

- Native oysters will recruit, with densities of >10,000 oysters per acre of substrate.
- Invertebrate species richness will increase by 15% relative to control plots with no physical structure and initial cores collected prior to construction.
- The number of visits by fish species to the larger scale project will increase by 50%, relative to pre-construction visits and the large control area with no physical structure.
- Eelgrass will establish and spread to at least twice initial planting densities.

Funding

To date, approximately \$1M has been obtained for this project (\$30K from the National Marine Fisheries Service, \$300K from US Environmental Protection Agency/San Francisco Estuary Partnership, \$300K from the State Coastal Conservancy, and \$400K from the Wildlife Conservation Board). There are additional funding needs for the monitoring aspects of the project.

Partners

The project is being managed by the State Coastal Conservancy, in collaboration with EPA/ San Francisco Estuary Partnership, Wildlife Conservation Board, NOAA Fisheries, San Francisco State University, UC Davis, ENVIRON Corporation, USGS Western Ecological Research Center, and ESA-PWA.

Global Decrease in Seagrasses and Native Oysters

Worldwide declines of seagrasses, in large part related to anthropogenic activities that alter water quality or clarity, have resulted in much interest in restoration techniques to reverse this trend. Seagrasses are foundation species that support diverse communities of sediment infauna, epibenthic invertebrates, fishes, waterfowl and marine mammals, as well as providing attachment locations for algae and encrusting invertebrates. Restoring seagrass beds means restoring vital habitat, the loss of which can promote a cascading downward spiral of nearshore productivity. The only seagrass in the soft sediments of San Francisco Bay, eelgrass provides valued ecological services (Spratt 1981; Kitting and Wyllie-Echeverria 1992; Kitting 1993; Hanson 1998), yet eelgrass beds only cover <4,000 acres, or approximately 1% of submerged land in the bay (Merkel and Associates 2003, 2009). Whereas Zimmerman et al (1991) found submarine light levels in the late 1980's to be relatively low and consequently limiting for eelgrass growth and vegetative reproduction, current biophysical modeling efforts indicate that nearly 30,000 acres of bottom area may now be suitable habitat (Merkel and Associates 2004). In fact, recent surveys suggest an expansion of the bay-wide population in the last 14 years into new areas that may have recently become habitable (Wyllie-Echeverria and Rutten 1989, Merkel and Associates 2003, 2009).

Historically, native Olympia oysters *Ostreola conchaphila* were an abundant and ecologically important part of the fauna in West Coast estuaries and an important fishery (Barnett 1963, Baker 1995). Unfortunately, the popularity of the fishery that began in the 1850s and other habitat impacts resulted in the complete collapse of native oyster populations along the west coast of the U.S. during the late 19th and early 20th centuries (Barnett 1963, Baker 1995). Not only was the fishery lost, but so were the key ecosystem services provided by native oysters. Studies of oysters in estuaries in the eastern U.S. have shown that native oyster reefs (*Crassostrea virginica*) act as a "foundation species" by creating a refuge from predators and physical stress as well as a food source resulting in increased local diversity of fishes and invertebrates. In the largely unstructured, soft-sediment habitats of West Coast estuaries, aggregations of native oysters were likely to have provided similar functions and have been shown to increase invertebrate species richness (Kimbrow and Grosholz 2006).

Building on Pilot Subtidal Restoration Projects since 2004

This project will build upon pilot subtidal restoration projects that have been successfully implemented in San Francisco Bay since 2004. Small-scale eelgrass restoration projects led by Katharyn Boyer (San Francisco State University, Romberg Tiburon Center) have resulted in extensive monitoring and genetics data collected at seven eelgrass beds in the bay, and the restoration of eelgrass at two sites.

Native oyster monitoring and restoration projects implemented by Robert Abbott and Rena Obernolte (ENVIRON Corporation), Chela Zabin and Ted Grosholz (UC Davis), Marilyn Latta (Coastal Conservancy- projects implemented while working for Save The Bay), and others, have resulted in population data for more than 80 intertidal sites, data on substrate surface preferences, and successful restoration of tens of thousands of oyster recruits at the Marin Rod and Gun Club site. The funding and management of these projects has been overseen by the NOAA Restoration Center, State Coastal Conservancy/Ocean Protection Council, and other agencies; and have also had funding support and involvement from The Nature Conservancy, The National Fish and Wildlife Foundation, Restore America's Estuaries, and other foundation and community groups. NOAA, along with multiple partners, has convened three regional West Coast Native Oyster Workshops (2006, 2007, 2010), which resulted in identified recommendations for needed research and step-wise implementation project methods for native oyster monitoring and restoration in the San Francisco Estuary. NOAA and the State Coastal Conservancy convened a regional San Francisco Bay Eelgrass Workshop in 2006, which also resulted in specific recommendations for eelgrass monitoring and restoration projects.

The San Francisco Bay Subtidal Habitat Goals Project was led by the California Coastal Conservancy/Ocean Protection Council, Bay Conservation and Development Commission, NOAA Fisheries and Restoration Center, and the San Francisco Estuary Partnership. More than 75 entities contributed to the development of the 2010 report, including science advisor WimKimmerer from San Francisco State University and a broad group of consultants, scientists, resource managers, and restoration practitioners working in and around San Francisco Bay. The 50-Year Plan is non-regulatory and presents a 50-year vision for how to move forward with science-based subtidal research, protection, and restoration of submerged habitats in San Francisco Bay, through an adaptive phased project approach to learn more about subtidal ecosystem services, functions, and interactions between habitat types.

The San Francisco Bay Living Shorelines: Near-shore Linkages Project will build upon successful methods and planning to date, and take into account knowledge of constraints, timing, and design issues informed by previous efforts and recommended regional initiatives and goals.

Literature Cited

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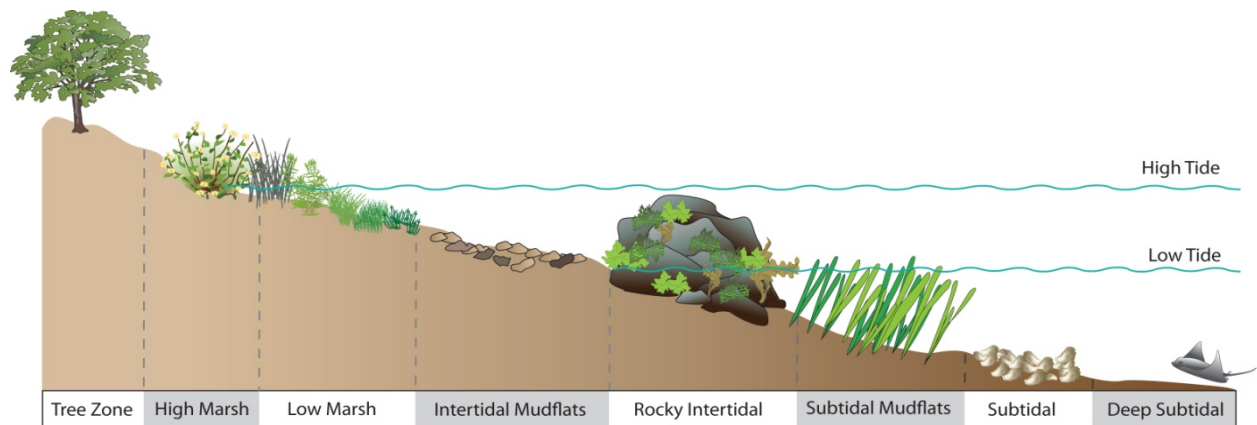


Figure 1. Top: Schematic of the Living Shorelines concept. Center left: Eelgrass restoration at the Marin Rod and Gun Club in San Rafael, using buoy-deployed seeding. Center right: Bamboo stake transplanting with whole shoots. Bottom: Oyster reef restoration with bagged Pacific oyster shell at the Marin Rod and Gun Club.

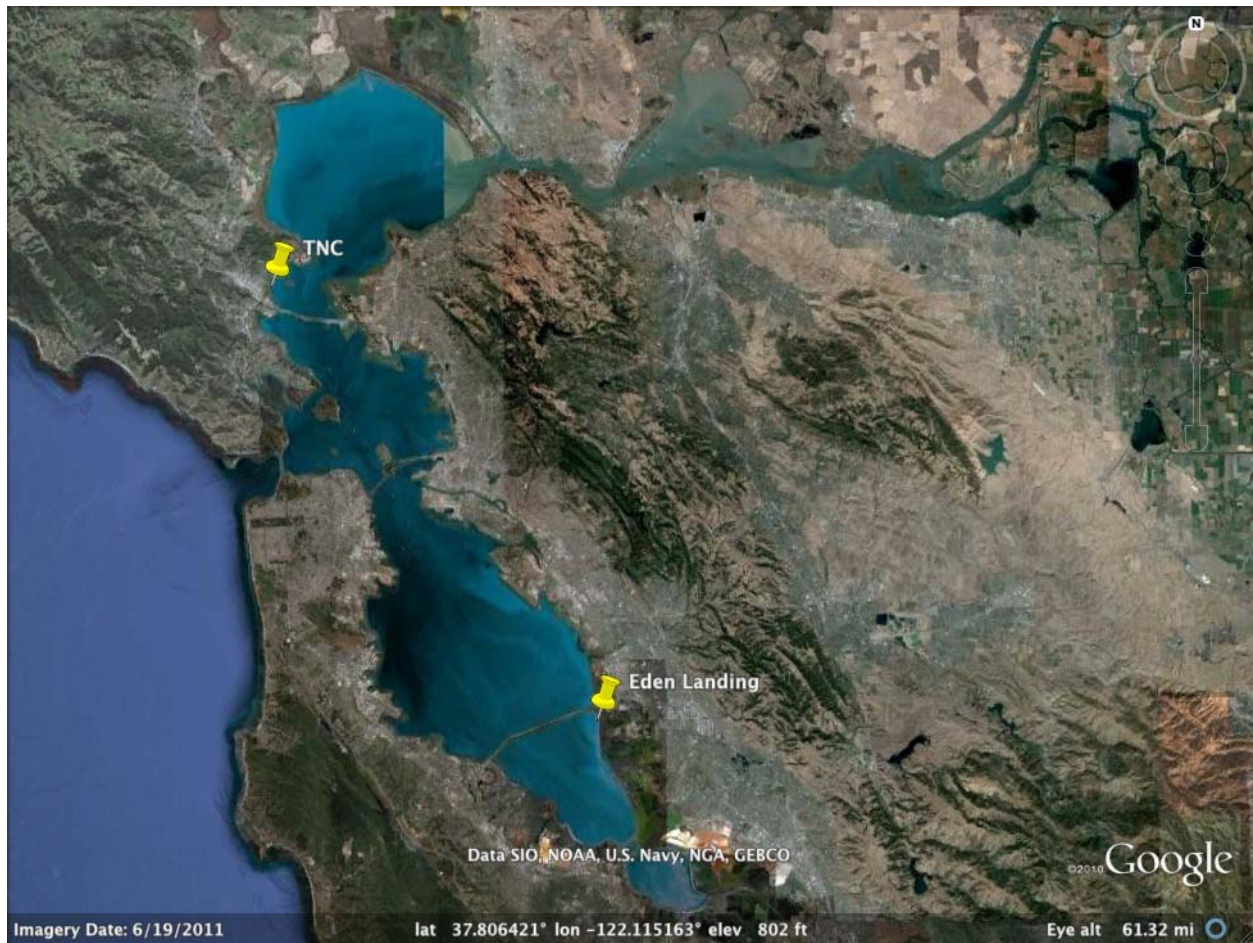


Figure 2. Proposed locations for the SF Bay Living Shorelines: Nearshore Linkages Project.

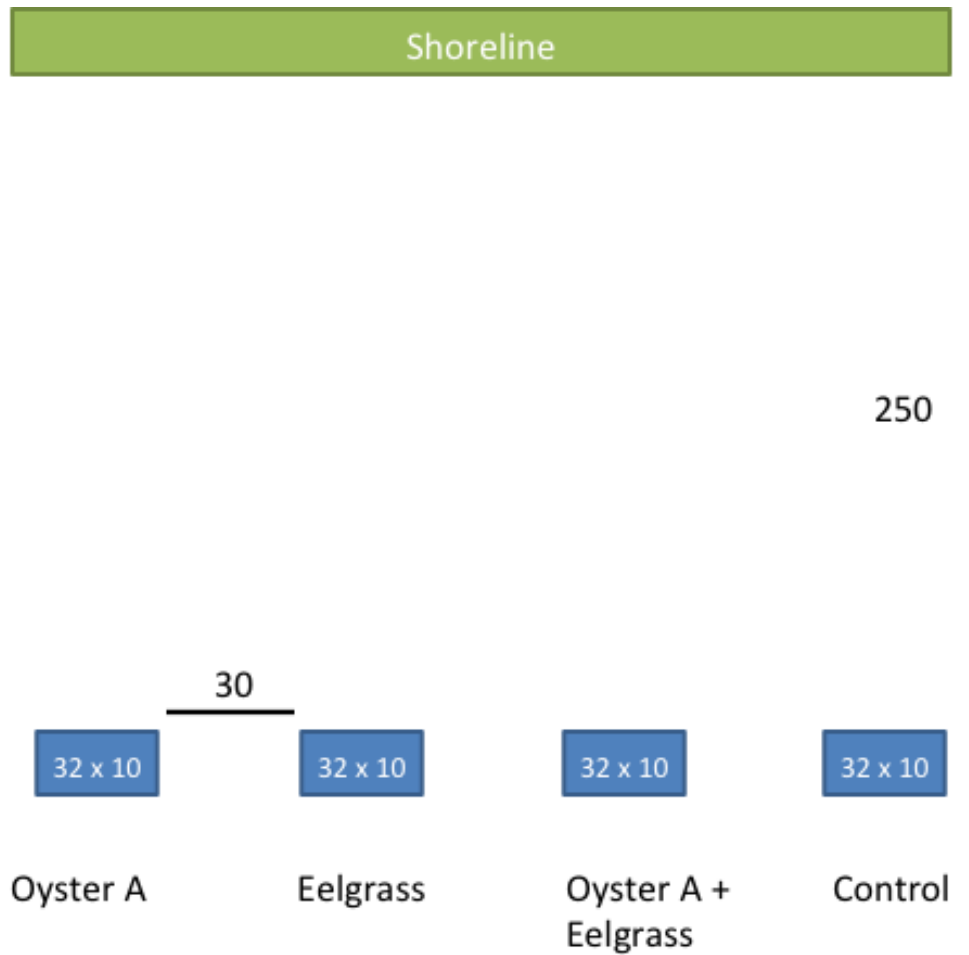


Figure 3. Proposed array of treatments in the larger scale experiment at the TNC location in San Rafael (hardened shoreline), to be installed in 2012. This design will be repeated at Eden Landing at two sites (along armored shoreline and marsh shoreline) in a future year pending the outcome of Phase 1 substrate element experiment in 2012. Dimensions are in meters.

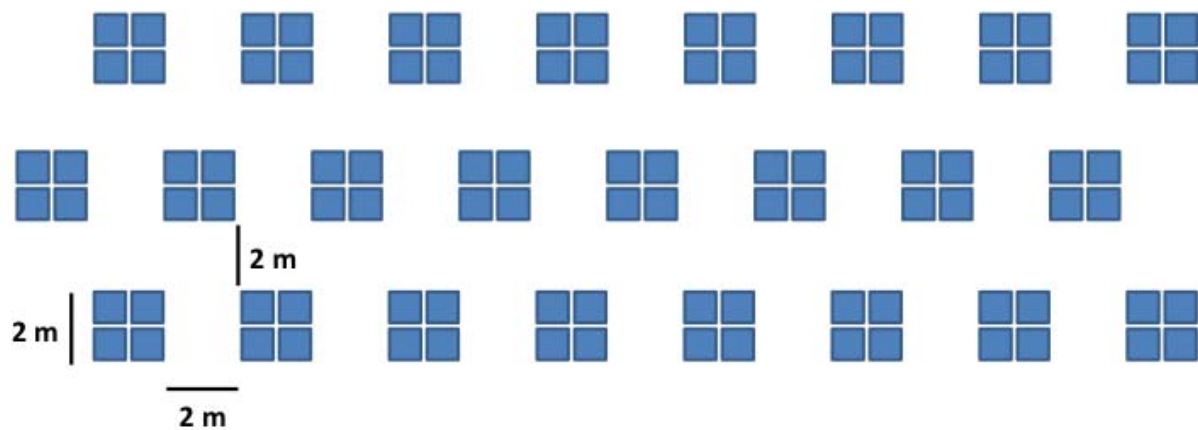


Figure 4. Configuration of oyster reef units within the oyster plot (Oyster A in Fig. 3) in the larger scale experiment to be installed at the TNC location in 2012. The eelgrass treatment will have the same layout but units will be slightly smaller ($1.5 \times 1.5 \text{ m}^2$).

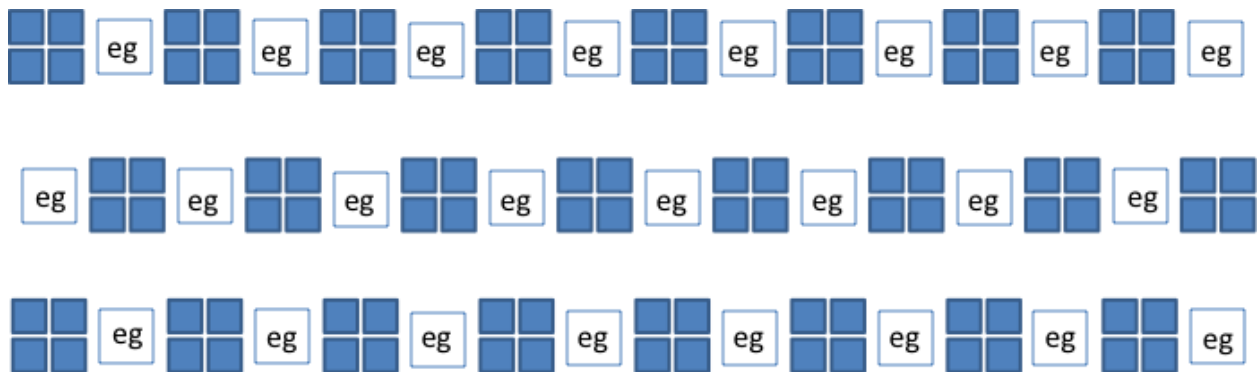


Figure 5. Array of oyster and eelgrass treatments (Oyster A + Eelgrass in Fig. 3) when combined in an additive design to test interactive effects in the larger scale experiment to be installed at the TNC location in 2012. Unit sizes are the same as in Fig. 4. There will be a 0.25 m space on either side of each eelgrass unit to permit monitoring access between plots.

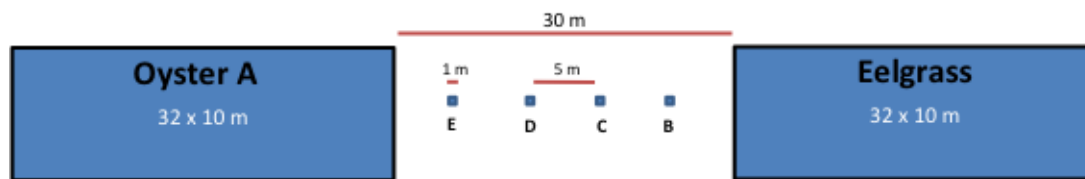


Figure 6. Schematic of additional oyster substrate types (“substrate elements”), to be tested at TNC among the larger treatment plots (e.g., Oyster A and Eelgrass treatments). This set of 4 oyster substrate elements (a block) will be replicated 5 times in the three spaces in between and on either side of the larger scale plots.

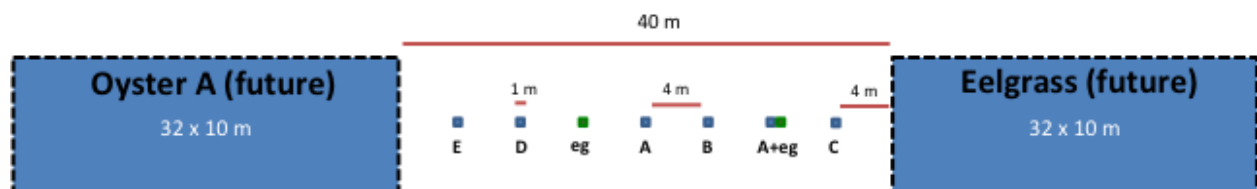


Figure 7. Schematic of “substrate elements” to be tested at Eden Landing, leaving space for potential future installation of larger treatment plots (e.g., Oyster A and Eelgrass treatments). This set (block) of 7 oyster (A-E) and eelgrass (eg) elements will be replicated 5 times in between and on either side of the four spaces reserved for future larger scale plots. These 35 substrate elements will be installed at one of the two large scale sites, the one to the north of Mount Eden Creek, along the hard shoreline edge, due to easier access at this site than along Whale’s Tale marsh (See Fig. 16).

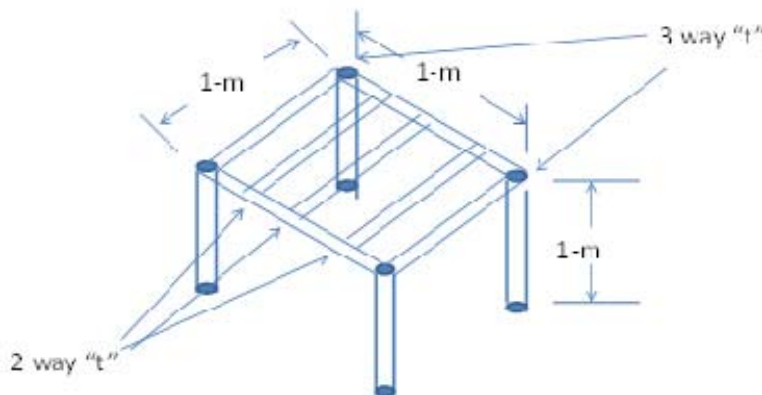


Figure 8. Conceptual illustration of a base constructed of 4” PVC pipe, to be sunk into the sediment to one meter depth. The top of the base cross bars will be at sediment level. Substrate elements will be secured to the base by large cable ties.



Figure 9. Shell bag mounds ready for deployment at the Marin Rod and Gun Club, a restoration site in San Rafael, just north of the Richmond-San Rafael Bridge. In the proposed project, there will not be a central pvc pipe.

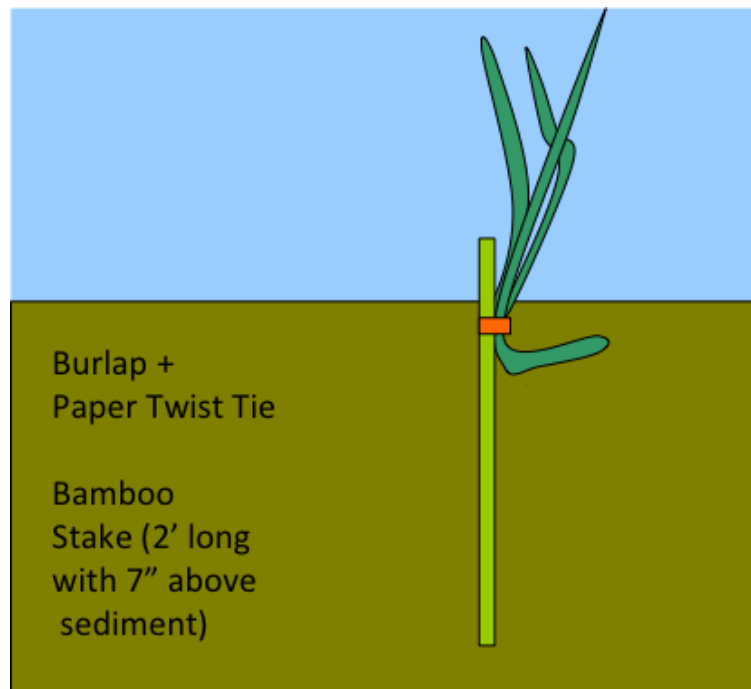


Figure 10. Bamboo-stake transplanting method for eelgrass vegetative shoots.

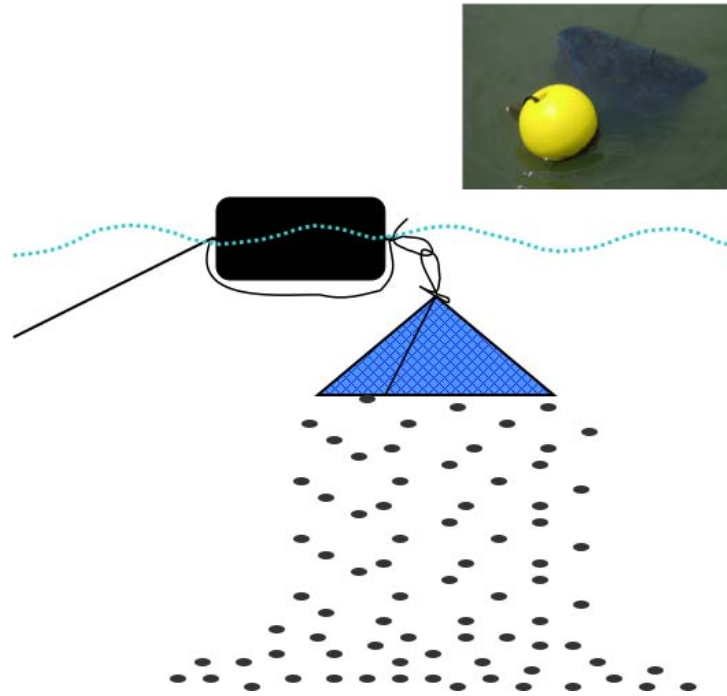


Figure 11. Buoy-deployed seeding of eelgrass.

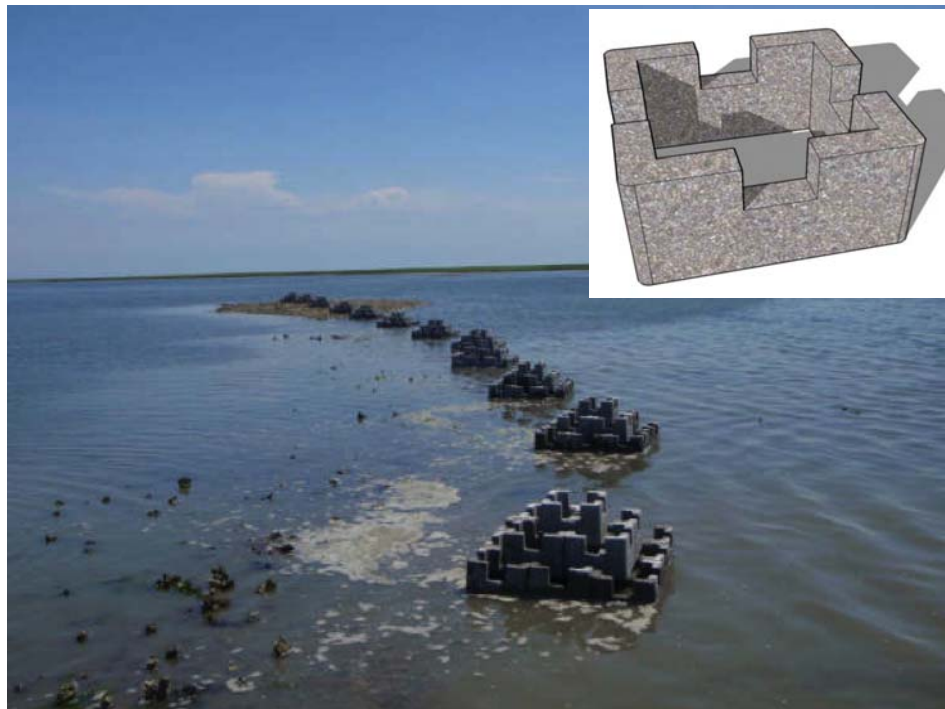


Figure 12. Reef castles built by The Nature Conservancy. Inset shows the configuration of a single castle block.



Figure 13. Reef ball on a pallet at the Marin Rod and Gun Club, San Rafael.

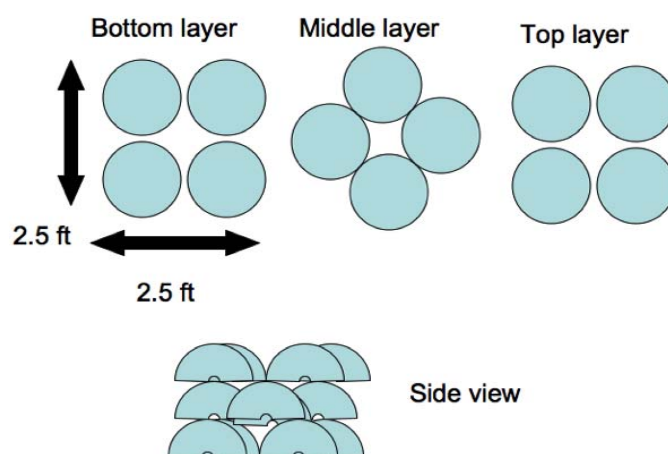


Figure 14. Schematic of a Reef Ball Stack using basketball-sized domes.



Figure 15. The “layer cake” modification of the original Reef Ball.

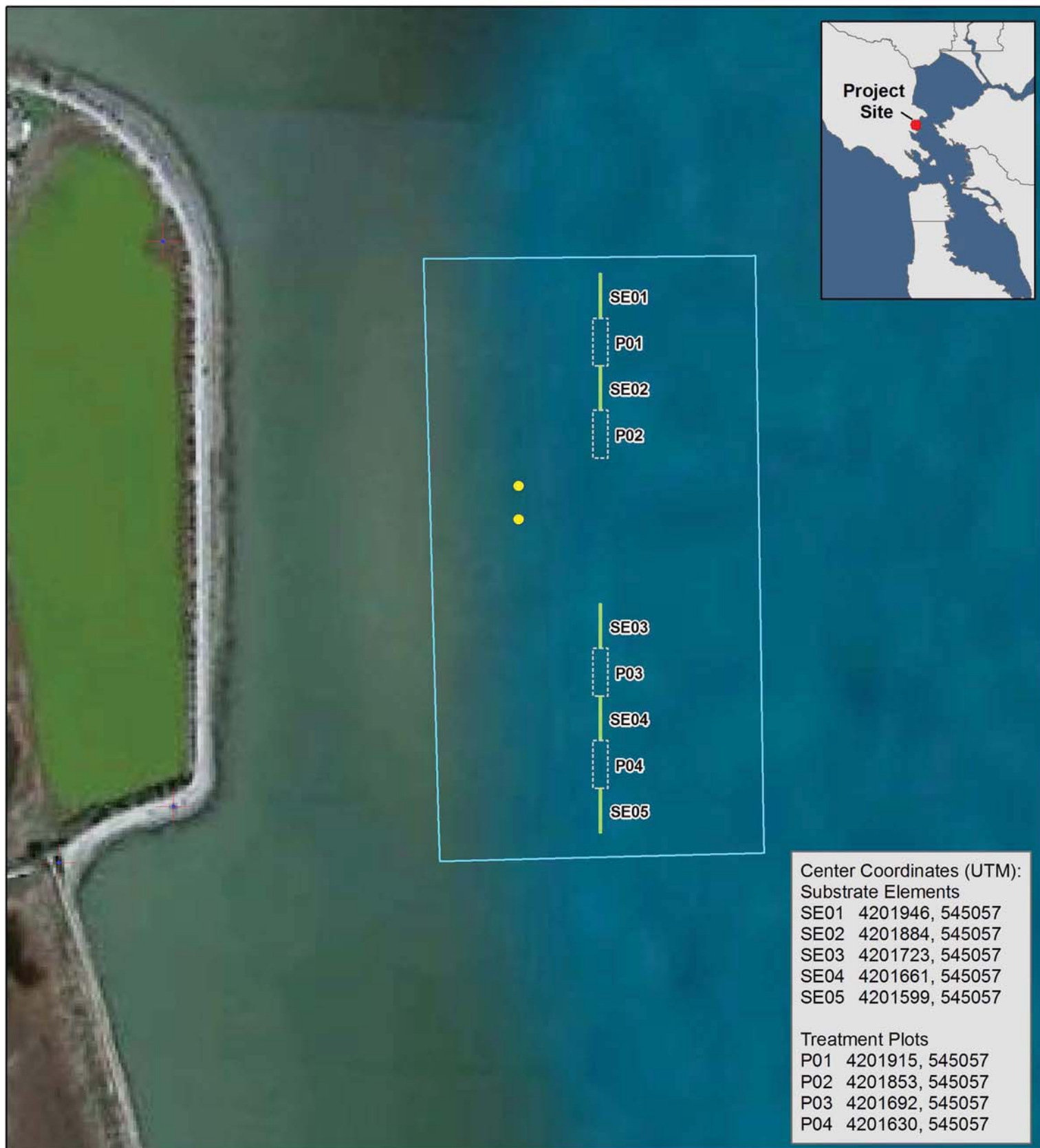


Figure 2. TNC Site
 SF Bay Living Shorelines:
 Near-shore Linkages Project

Marin County, CA

1:3,500

0 30 60 120 Meters



Legend

- 2008 Test Plots
- Treatment Plot (32m x 10m)
- Substrate Element (30m x 1m)
- TNC Property

Data: SFSU, USGS, TetraMetrics2012
 Map produced by C. Pinnell, Jan 2012
 TNC_2012-0124.mxd

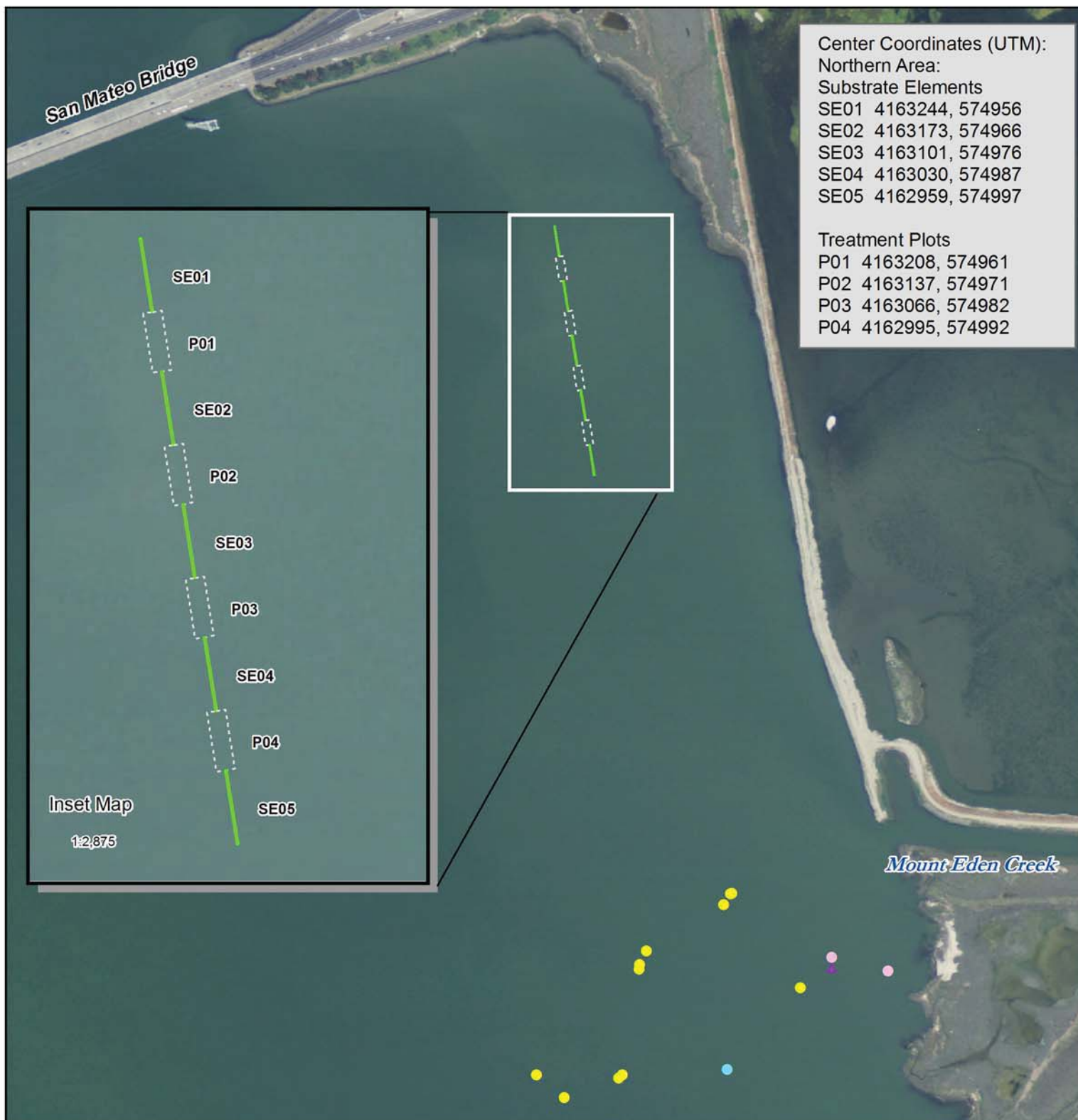


Figure 4a. ELER Site - North
 SF Bay Living Shorelines:
 Near-shore Linkages Project

Alameda County, CA

Legend

- Phase 1 Substrate Element (40m x 1m)
- Phase 2 Treatment Plot (32m x 10m)

BioResources

- ▲ Oyster Test Plot
- Eelgrass Location (Boyer)
- Eelgrass Location (Merkel)
- Eelgrass Test Plot

1:7,000

0 130 260 Meters



Data: SFSU, USGS, USDA 2009
 Merkel and Associates 2008-2010
 Map produced by C. Pinnell, Jan 2012
 ELN_2012-0124.mxd