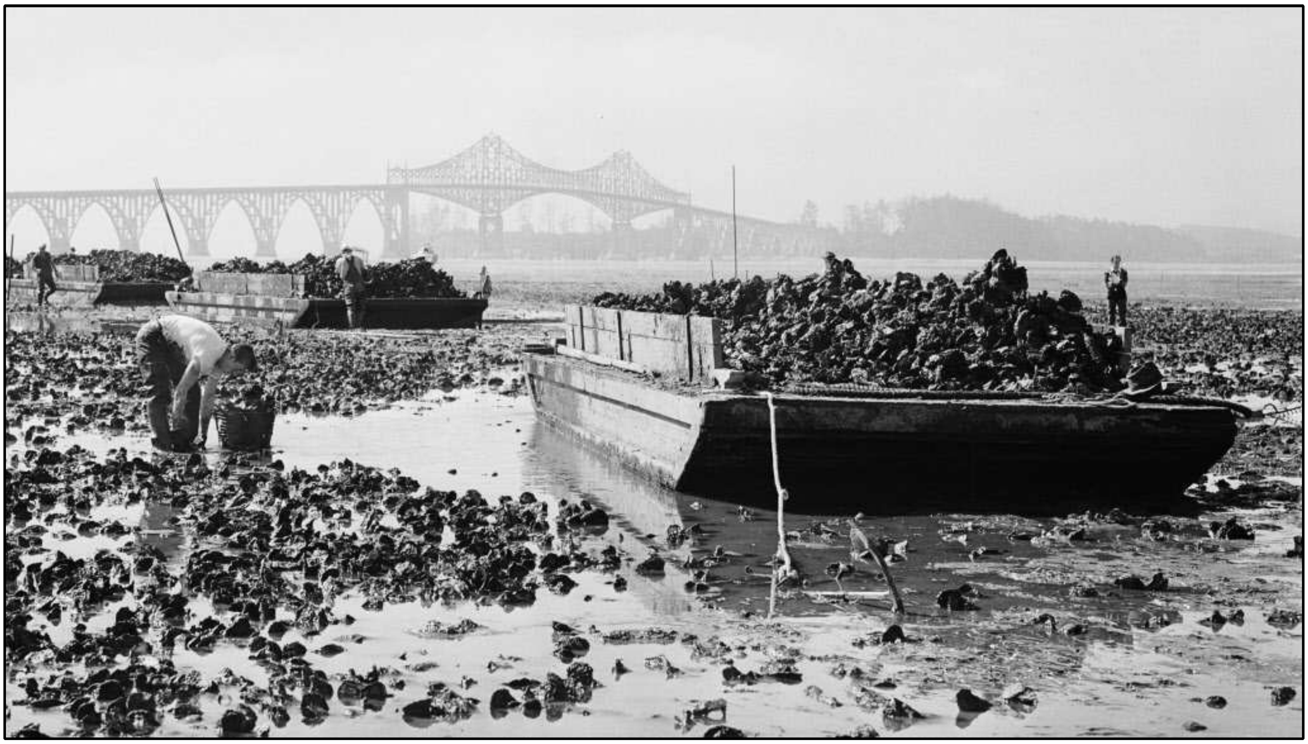
From British Columbia to Baja California Restoring The Olympia Oyster *(Ostrea lurida)*



Report of a Forum Sponsored by
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This report can be found at:
http://www.aquariumofpacific.org/mcri/info/restoring_the_olympia_oyster/forums

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Introduction

On March 16 and 17 approximately thirty people gathered at the Aquarium of the Pacific in a forum to explore the opportunities to restore the native Olymipia oyster, *Ostrea lurida,* in Southern California. The forum was stimulated by the SoCal Oyster Group of the Bren School of the University of California, Santa Barbara (UCSB), who are working on a team project for their M.S. degree. The forum was sponsored jointly by the Aquarium of the Pacific, the American Honda Motor Company, and the UCSB Bren School.

The primary goals of the Bren graduate student project are to determine:

1. Under what environmental and societal conditions is oyster restoration an effective strategy for ecosystem restoration?
2. Where are these conditions found in Southern California?
3. What are the appropriate incentives to trigger and sustain oyster restoration efforts in selected sites in Southern California?
4. What are the key metrics for measuring success?

The emphasis of their project is on goal number 3.

We invited a number of experts from around the state and the country who have had experience in oyster restoration projects not only with Olympia oysters (*Ostrea lurida),* but also with eastern oysters (*Crassostrea virginica*) and Pacific oysters (*Crassostrea gigas*). The objective was to provide context for efforts in California to restore the Olympia oyster and to provide insights from those efforts that might be applicable in California.

The participants in the forum are listed in Appendix A.

Setting the Context

Ostrea lurida, whose common name is the Olympia oyster, derives its name from Olympia, Washington, in the Puget Sound area. For thousands of years the Olympia oyster thrived in many tidal channels, estuaries, bays, and sounds of the eastern Pacific Ocean, from Southeast Alaska to Baja California. The total amount of favorable habitat on much of the West Coast of North America is naturally limited because of the paucity of estuaries, bays, and lagoons compared with the East Coast.

The Olympia oyster once supported a Native American subsistence fishery. Indian kitchen middens near San Francisco Bay contain Olympia oyster shells in sufficient quantities to establish that the animal was an important food item of coastal tribes (Barrett 1963). Indians in the southern Puget Sound region located their villages close to Olympia oyster populations (Steele 1957). The Olympia oyster was commercially exploited beginning in the 1850s in the Pacific Northwest.

The Olympia oyster declined dramatically in abundance in the 1800s in many of the estuaries in its native range because of over-harvesting, pollution, and habitat destruction. In the past decade efforts have begun to conserve, enhance, and restore Olympia oyster populations (Wasson, et. al. 2015). Throughout the 1850s and 1860s schooners laden with Olympia oysters were travelling between Oysterville, Washington, and San Francisco, heralding the start of a lucrative Pacific Northwest shellfish industry. By 1870, overharvesting had already significantly depleted oyster stocks in both Willapa Bay and Puget Sound. To augment their ailing stocks, oystermen began importing the larger and faster-growing Japanese or Pacific oyster in large numbers, which soon displaced the Olympia oyster in their cultivated beds (Pacific Biodiversity Institute).

Before their populations were decimated, Olympia oysters may have protected sections of the coastline against storm waves and storm surges and provided habitat for fish and invertebrates and food for humans and marine life. Today Olympia oysters are still present, but in discontinuous patches and in very low numbers. With a rising sea, a growing recognition of the important roles these animals could play in the future has triggered efforts to identify sites, where Olympia oysters were once abundant and remnant populations remain, that could be candidates for restoration.

A Guide to Olympia Oyster Restoration and Conservation: Environmental Conditions and Sites that Support Sustainable Populations (2015) is an important document that provides an excellent summary of the environmental conditions that affect the success of Olympia oysters. It also provides a qualitative evaluation of twenty-eight embayments along much of the native range of Olympia oysters and evaluates the risks and the stresses on existing populations and the potential for restoration.

A Look Ahead

As Southern California's coastal population continues to grow, as sea level continues to rise, and as the frequency and intensity of coastal storms increase, humans will be faced with an ever-increasing challenge of how to protect valuable natural coastal resources and their own built environment. The best management strategies will depend upon factors including: relief of the coastline, composition of coastal deposits, human population and infrastructure at risk, and natural protection. Both hard and soft solutions will have a place in the management portfolios of the future, as will managed retreat. The concept of living shorelines—shorelines fringed with salt marshes, mangroves, productive shell beds, beaches and dunes—will in many cases be a primary or secondary strategy for dealing with the "new normal." They offer many benefits, both direct and indirect, at modest cost. Over the past century or so we degraded or destroyed many of these environments before their true value was widely recognized. Now we know their value and have the knowledge and the technology to, in some cases, restore these ecosystems and, in others where no remnants remain, to create them. Oyster beds are one such ecosystem.

In this report we present several case studies of efforts underway to restore Olympia oysters (Elkhorn Slough, San Francisco Bay, Newport Bay, and San Diego Bay) and one effort that was terminated, but which we hope to restart (Alamitos Bay). We also present a case study from New York Harbor—the Billion Oyster Project (BOP). BOP, an initiative of the New York Harbor Foundation, is an ecosystem restoration and education project aimed at restoring one billion live oysters to New York Harbor and engaging hundreds of thousands of school children through restoration-based STEM education programs. Students at New York Harbor School have been growing and restoring oysters in New York Harbor for the last six years. The project was stimulated by the destruction to the greater

New York City area by Super Storm Sandy in 2012. The project had its origins in a Rebuild Design Competition. The Living Breakwaters concept was one of six winning proposals in the global competition, and the award was made to New York State.

Our hope is that this report will help stimulate further efforts to restore the Olympia oyster population at appropriate locations in California, and particularly in Southern California.

Insights from the forum

Over the course of the two-day forum, the majority of time was spent in free-form discussions. Participants brainstormed together and were struck by novel insights about Olympia oyster restoration. Below we summarize some of the insights from the forum.

Broad geographic focus: The initial emphasis of this forum was on Southern California, and some of the sponsors and participants will continue to remain focused on this region. But one clear message that emerged from the forum was that Olympia oyster restoration efforts should be united by a common vision and by shared information, along the entire range, from British Columbia to Baja California. There are very few oyster restoration scientists and practitioners along this coast, and they will find greater strength and success by working together, sharing lessons learned, and jointly developing outreach materials to engage the public and gain support from funders. So, while each individual scientist or practitioner will necessarily focus on one or a few estuaries, they will be part of a larger network of Olympia oyster restoration efforts.

Developing an inspirational vision and engaging the community: Forum participants were very moved by a presentation about the Billion Oyster Project in New York City. Murray Fisher of the New York Harbor Foundation described this initiative, and at its core was a heartfelt belief that human communities should be more engaged with their coastal environments. His example was a testament to the power of having an ambitious, simple vision. In New York City, the oyster is being used as an iconic species that inspires outreach and curriculum about coastal health. Our forum participants were inspired to try to formulate this sort of a vision for Olympia oysters along the West Coast and communicate it to our communities. The messages can be similar: Oysters everywhere are iconic coastal species that humans have interacted with for thousands of years. We want our coasts to be healthy, and one part of that is having thriving oyster populations. Fisher's advice from New York was that we don't need to worry too much about getting the details of this vision right. Just dream big and start building connections in the community.

More nuanced understanding of Olympia oyster ecosystem services: West Coast oyster populations likely provide quite different ecosystem services (benefits to humans) than oysters in other regions. In particular, there is uncertainty whether Olympia oysters ever form high profile reefs, while this is the hallmark of *Crassostrea* populations and important for shoreline protection. However, modeling suggests that even shallow beds of Olympia oysters may provide some benefits to shorelines, and if artificial reefs are built for them out of shell bags or other material, this benefit can be further enhanced. New research from San Francisco Bay suggests some species that humans care about, including crabs, sturgeon, steelhead, and wading birds, may be more abundant in living shorelines that include oysters than in adjacent mudflats. Further studies are needed to quantify which benefits Olympia oysters can provide to humans, though forum participants agreed that Olympia oysters merit restoration for their own sake, as well—we should be asking what we can do for oysters, as in the Billion Oyster Project, not just what oysters can do for us.

Complications from *Crassostrea gigas* invasions: Forum participants recognized the need for further science and policy considerations regarding the Pacific oyster, *Crassostrea gigas*. *Crassostrea* is increasing dramatically in distribution and abundance in Southern California, and, with warming waters, is likely to do so in central and Northern California. The Pacific oyster already co-occurs with Olympia oysters in numerous estuaries in the Pacific Northwest. In Southern California, restoration projects are being designed to try to optimize conditions for Olympia oysters over Pacific oysters. For example, the planned San Diego Bay project will keep living shorelines at low elevations. Such considerations may need to be incorporated more broadly across the species' range. Another complication from co-occuring Pacific oysters is the use of ecosystem services as a rationale for restoration. In many cases, Pacific oysters provide better water filtration, provision of fish habitat, and shoreline protection than Olympia oysters. So emphasis on these ecosystem services might lead to the promotion of Pacific oysters rather than Olympia oysters.

Creation of further living shorelines: Forum participants heard inspiring presentations about living shoreline projects in Southern California and San Francisco Bay. There was agreement that the living shoreline approach (creating artificial reefs to provide habitat for oyster settlement and protect adjacent shorelines) is valuable and should be replicated elsewhere along the Olympia oyster range, especially in places where such structures could serve as alternatives to shoreline armoring. In both Southern and Northern California, attempts are being made to jointly restore eelgrass and oysters as a part of living shoreline projects. New projects could be coordinated so that methods and monitoring allow for comparative analyses of restoration success and ecosystem services. In urban environments, living breakwaters might similarly provide benefits of oyster habitat and shoreline protection.

Linkage of aquaculture and Olympia oyster restoration: At some sites, Olympia oyster recruitment is high in most years, and so deployed substrates at the appropriate elevation soon are covered with oysters—"if you build it, they'll come." At other sites, recruitment is very rare in most years. Restoration at these recruitment-limited sites would benefit from linkage to aquaculture, perhaps through partnerships with commercial operations or universities. Stock from such estuaries could be raised in an aquaculture facility, and then mobile restoration units, once covered with spat, could be outplanted to the estuary. The benefit of this approach to oyster populations could be enormous and should be explored sooner rather than later. Forum participants were also interested in creating a niche market for Olympia oysters grown by commercial aquaculture operations. The species is smaller and slower growing than Pacific oysters, but could be marketed like local vegetables or grass-fed beef, for consumers willing to pay more for sustainable choices that benefit the local environment.

Action Items

- There was unanimous agreement to form an initial Executive Committee to keep the momentum of BC to Baja moving. Hunter Lenihan (UCSB) will serve as the first chair and will be joined by Chela Zabin (UC Davis), Danielle Zacherl (CSU Fullerton), and Kerstin Wasson (Elkhorn Slough Reserve, UC Santa Cruz). Others are welcome to join the group.

    - Among their first actions are to form a group to develop a proposal for a session at the next “Restore America’s Estuaries” conference, which will be held in Long Beach in December 2018.

    - Develop a Communications Toolkit. This will be a collaborative effort of the UCSB Communications Department and Honda.

    - Zacherl, Wasson, and Zabin will contact colleagues who are experts on the Olympia oyster in British Columbia, Washington, Oregon, and Baja California. The goal is to create a network of Olympia restoration sites and restoration scientists to share data, information, research needs, etc.

- We need to refine the story line of “British Columbia to Baja California” into a one- to two–page, clear, compelling document with a map. Erin Winslow of the Bren Oyster Group volunteered to create the first draft.

- October 18 to 20, 2017, Fisher will return to the Aquarium of the Pacific. He will present a public lecture on October 19, and we will hold a meeting during that period.

- In future forums, include representatives of appropriate state and federal agencies to enhance understanding of the potential beneficial uses of native oyster restoration. Agencies to include: California Coastal Commission, California Department of Fish and Wildlife, Army Corps of Engineers, National Marine Fisheries Service, and the U.S. Fish and Wildlife Service.

The Bren School Oyster Project
A Summary

Planning and Incentivizing Native Olympia Oyster Restoration in Southern California

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Client: Carpentaria Salt Marsh Reserve
Sponsor: Honda Marine Science Foundation

Abstract
The Olympia oyster, *Ostrea lurida*, is the only oyster native to the West Coast of the United States. Populations have declined over the last 150 years due to coastal development, overharvest, and pollution. Through visiting natural history museums and surveying in Southern California, we discovered that small populations of Olympia oysters still exist, though they do not resemble the historic beds they once formed. Oysters are habitat engineers that provide ecosystem benefits such as erosion control, water quality improvement, and habitat for fish and invertebrates. To incentivize oyster restoration, we quantified some of these ecosystem services through a bioeconomic model and cost-benefit analysis. Results revealed that restoring one hectare of oyster bed could increase the kelp bass fishery by 39,304 additional grams in biomass over thirty years and increase the California halibut fishery by $24,411 per cohort. Furthermore, this study suggests that restoring Olympia oysters in the Batiquitos Lagoon could decrease maintenance costs by up to $2 million. Though additional research is needed to better understand the extent of benefits provided by Olympia oysters, this project provides a framework for successful collaboration between experts, researchers, and the community to further restoration efforts.

Project Significance
According to anecdotal evidence, Olympia oysters were once prominent along the western coast of the United States to Baja, Mexico. However, due to overharvesting, pollution, and habitat modification Olympia oyster populations were reduced to a mere fraction of their once historical numbers. As a result, society today faces a shifting baseline. Olympia oysters have been absent from California's coastline since the early 1900s; thus, people no longer consider Olympia oysters to be an integral component of California's coastal ecosystems, nor do they realize the ecosystem services oysters provided. Consequently, this species is not included in most coastal restoration or management plans and is not sold for consumption in California.

As ecosystem engineers that provide a number of ecosystem services to people and wildlife, Olympia oysters serve as a model organism for estuary and wetland restoration throughout Southern California. They form beds, which create habitat for commercially and recreationally important species, help reduce wave energy and erosion rates, and improve local water quality through water filtration. Oysters are a key component of our coastal ecosystems and help maintain the quality and health of these important ecosystems.

Along the East Coast and in Washington State, numerous large-scale oyster restoration projects have been implemented to restore populations for the fishery and ecosystem services they provide. In Southern California, small-scale restoration projects have been completed and focused solely on providing hard substrate for larval settlement. Future projects and research aim to identify the bottlenecks that prevent survival and bed formation. They also plan to quantify the magnitude of these ecosystem services in Southern California. Our project's intention is to provide the necessary tools and incentives to motivate and support these future restoration efforts.

Objectives:

- Compile historic and present Olympia oyster spatial data throughout Southern California and create an online database to store this data for future use

- Provide economic incentives for Olympia oyster restoration through a shoreline stabilization cost-benefit analysis and a bioeconomic model to explore changes in fish abundance with a restored oyster bed

- Identify gaps in ecological knowledge and synthesize lessons learned from previous Olympia oyster restoration projects

- Create a network of collaboration amongst scientists, managers, and other stakeholders by organizing an Olympia oyster forum at the Aquarium of the Pacific

- Develop two short films that can be used as outreach materials to engage the public in restoration efforts

Spatial Analysis

To determine suitable locations for future Olympia oyster restoration, current and historical oyster presence need to be identified and monitored regularly.

Data Collection

We visited the Santa Barbara Museum of Natural History, Natural History Museum of Los Angeles County, and the Smithsonian Institution National Museum of Natural History to electronically catalogue previously recorded oyster survey data. These Olympia oyster specimens were collected from Morro Bay, California, to Baja, Mexico, dating from 1910 to 2010. Records included geographic coordinates, date collected, year, length, and available habitat information. Length of the specimens was measured in millimeters from the hinge with manual or digital calipers. Many specimens were collected together by the same person from one GPS location on the same day. In these cases, no more than five specimens in each group were recorded in our dataset. Presence data in San Diego Bay, Alamitos Bay, Newport Bay, and Los Angeles Harbor were also collected from Dr. Danielle Zacherl and Holly Henderson. They collected density counts and presence data from surveys between 2010 and 2014 at these sites. To fill in data gaps, our group also conducted our own surveys at Marina del Rey, Batiquitos Lagoon, San Dieguito Lagoon, and the Carpinteria Salt Marsh Reserve. One square meter quadrats were used to record densities of Olympia and Pacific oysters in the Carpinteria Salt Marsh, while only presence data was recorded in the other locations. We aggregated the data from museums and surveys to create a map of oyster presence in Southern California from 2000 to 2017.

Data Organization and Visualization

Presence data coordinates in degrees, minutes, seconds were converted to decimal degrees using an online conversion website and then loaded into ArcGIS. Extraneous data was removed because of the likelihood of recordkeeping errors. Valid data points were displayed in WGS 1984 and uploaded to ArcGIS online to create an interactive story map. Habitat, substrate, general location, and notes associated with the presence data were then sorted and also made visible in the story map. We hope this map will allow the public, restoration scientists, and managers to gain a better understanding of historical and current Olympia oyster populations in Southern California. This information can be used to prioritize restoration sites and can evolve as more spatial data is collected. This online database is viewable to the public and can be updated by approved parties (http://arcg.is/2n61DgU).

Incentives for Native Oyster Restoration

Fish Production

On the East Coast, restoring oyster beds increases taxonomic richness and the abundance of certain fishes that are limited in recruitment or growth. These complex living structures provide both nursery and foraging habitat for many important species. Data on the West Coast is limited in terms of how native oyster beds impact the surrounding aquatic communities, but preliminary studies show increases in food production of small invertebrates such as amphipods (Zacherl et al., unpublished data). We assumed species that recruit to rocky reefs would have likely recruited to these native oyster beds in bays and estuaries prior to the 1900s.

Both California halibut and kelp bass would likely be impacted by the restoration of native oyster beds. The California halibut has experienced a significant decline in landings throughout California, particularly in Southern California. While data are unavailable for past trends in kelp bass abundance, anecdotal evidence suggests that this species comprises a significant portion of recreational catch in Southern California. Oysters provide important intertidal and subtidal habitat in bays and estuaries that can assist these species in overcoming specific life history bottlenecks and survive into adulthood. Through this population model, the expected increases in both California halibut and kelp bass were quantified to incentivize the inclusion of native oyster restoration in future management actions.

Fish Production: Results and Implications

Through a stable age structured model, we quantified that the increase in California halibut fishery revenue increases by about $24,000 per hectare of restored oyster reef over a thirty-year period. The number of extra kelp bass that would be produced is ~1,100 individuals over a thirty-year period. These values are most likely underrepresented because we were unable to include local recruitment, reproduction, and production of additional fish and invertebrates that serve as a food source to important fish species. Further research and experimentation is needed to better understand how the restoration of oyster beds may impact our local species and fisheries. Based on the many services provided by Olympia oysters as an ecosystem engineer, we can predict that restoration of this animal could positively impact the health of California's coastlines and the many species that inhabit these critically important areas, including people and wildlife.

Shoreline Stabilization
Large-scale restoration of Olympia oyster beds could replace common costly and environmentally unfriendly means of shoreline stabilization that exist today. We analyzed Batiquitos Lagoon in San Diego County to determine how Olympia oyster beds might act as a cost-effective means for shoreline stabilization. Understanding how the costs and benefits compare at the Batiquitos Lagoon could offer an economic incentive for local entities to utilize Olympia oysters as a means of shoreline stabilization, instead of common, temporary solutions.

<u>Assumptions</u>
In order to conduct this analysis, a series of assumptions were made to simplify both the conceptual and mathematical framework. These assumptions include:

1. Olympia oysters are bed-forming invertebrates, making them an alternative to rock revetment or beach nourishment.

2. Oyster beds grow faster than the rate of sea level rise(Grabowski et al., 2012).

3. There are enough oyster larvae naturally occurring in the water column to settle on substrate and survive to sustain the bed.

4. Chosen restoration sites have suitable oyster habitat.

5. Value of property protection or damage per acre is constant among sites.

Our study covered a thirty-year time frame spanning from 2017 to 2046 and used a discount rate of 4 percent. Additionally, the net present value (NPV) of costs and benefits ignored the time cost of planning and consulting with relevant agencies for restoration. All values used were adjusted with inflation to the value of a U.S. dollar in 2016. Below are the site-specific costs and benefits used in this study.

<u>Methods</u>
Batiquitos Lagoon is located in San Diego County close to the southernmost limit of our project area. Dredging and beach nourishment occur on an as-needed basis (usually annually), and the costs are publicly available. There is some shoreline armoring in the form of rock revetment at this site. Batiquitos Lagoon was used as a comparison because of its known costs and use of stabilization methods similar to those in the Carpinteria Salt

Marsh. Our analysis calculated the NPV of the costs and benefits for Batiquitos Lagoon in two scenarios: with Olympia oyster bed restoration and without restoration.

Benefits

Without restoration, the benefits at Batiquitos Lagoon were flood control, water quality, wildlife habitat, and recreation. These benefits were taken from a California Sea Grant study conducted by Rager, Clifton, & Johnson (1995). In addition, Batiquitos Lagoon provides essential habitat for migratory waterfowl, birds, and fish species (Batiquitos Lagoon Foundation, 2017). Wetlands absorb wave energy and reduce the velocity of incoming surges. As a result, these living shorelines provide flood control to coastlines and property owners (Rager et al., 1995). The U.S. Army Corps of Engineers valued flood control provided by California's wetlands at $4,650 per acre (Allen, 1992). This value represents the amount of damages avoided with an intact wetland present. Wetlands also filter and treat water by removing nutrients, bacteria, and toxic chemicals. This water quality improvement by wetlands is valued at $6,600 per acre (Rager et al., 1995). Similarly, wetlands provide important nursery and foraging habitat to fish and invertebrates. From a survey that assessed people's willingness to pay to preserve a California wetland, this benefit is valued at $3,337 per acre for Batiquitos Lagoon (Allen, 1992). Finally, wetland ecosystems provide a recreational value to people through activities such as bird watching, hiking, and fishing. Stol et al. valued this recreational benefit at $3,347 per acre through a travel cost method in Batiquitos Lagoon (Allen, 1992). The annual dredging and beach nourishment that occur at this site maintains these benefits the wetland in Batiquitos Lagoon provides.

With restoration, our analysis examined the area of wetland habitat that would be protected by Olympia oyster bed restoration. Oyster beds would protect this essential wetland habitat and, therefore, maintain the benefits of the wetland (flood control, water quality, wildlife habitat, and recreation) without the need to dredge and nourish the beaches annually. We assumed this benefit is included in the analysis by reducing lagoon dredging and beach nourishment from annually to once every five years and is accounted for in the costs. Multiple groups would gain from these benefits including homeowners, the City of Carlsbad, recreational users of the lagoon and its wetlands, and the environment including wildlife that utilize the lagoon and restored beds as habitat. In both scenarios, the benefits of the wetland habitat are maintained; however, the costs to maintain that wetland habitat are different due to the two methods of shoreline stabilization.

Costs

With oyster restoration, the costs taken into account at Batiquitos Lagoon included restoration costs, permitting costs, and periodic costs of lagoon dredging and beach nourishment. Restoration costs were estimated at a high and low restoration cost and included shell addition, permitting, and initial construction costs (Harrison, H., Garrity, N., & Zacherl, D, 2015). The costs of shell addition were taken from the San Diego Bay Native Oyster Restoration Plan (Harrison, H., Garrity, N., & Zacherl, D, 2015). We initially used both low- and high-cost estimates, but to remain conservative in our estimates of benefits relative to costs, we used the high-end estimates for our final analysis. Shell addition costs occurred twice at Batiquitos Lagoon due to the high sedimentation rates at this site. The costs of permitting were calculated using the proposed area for restoration of 0.2 hectares. Permitting prices calculated were taken from the California Department of Fish and Wildlife Mitigated Negative Impact Permit and the Coastal Development Permits from the California Coastal Commission. Lagoon dredging and beach nourishment would need to continue on an annual basis until the restored beds become self-sustaining, no longer needing human maintenance to survive and grow. There is uncertainty as to how long it would take for oyster beds to become self-sustaining. Therefore, three restoration analyses were conducted in five-year, ten-year, and fifteen-year periods for the beds to become self-sustaining. During these periods, beach nourishment and dredging take place on an annual basis. After the beds become self-sustaining, it was assumed that dredging and beach nourishment would only need to occur every five years. Groups that would incur the costs include groups funding the restoration such as the California State Coastal Conservancy, Batiquitos Lagoon Foundation (restoration, dredging, beach nourishment), and the City of Carlsbad.

Without oyster restoration, dredging and beach nourishment would continue to occur on an annual basis. However, at the current spending rates, the Batiquitos Lagoon's dredging fund is expected to run out in thirty years (Paul Sisson, 2016). Historic dredging costs have ranged from $256,000 to $1,300,000 per year (Paul Sisson, 2016). We included the low estimated dredging cost and the exhaustion of this fund in the analysis. Without restoration, the Batiquitos Lagoon Foundation would cover the costs of the dredging and beach nourishment annually until the fund ran out. In addition, homeowners, wildlife, and recreational users of the lagoon would incur costs if the quality of the lagoon decreased over time without restoration.

Shoreline Stabilization: Results and Implications

Without oyster restoration, the NPV of the net costs (costs minus benefits) is about $1 million more expensive than the most expensive oyster restoration scenario (fifteen years until self-sustaining). This indicates that lagoon dredging without restoration is the most costly option for the lagoon foundation. If oyster restoration took place, savings to the lagoon over the next thirty years could alleviate dredging costs by $1 to $2 million. Although the costs outweigh the benefits in all scenarios, the costs associated with oyster restoration are significantly less than without restoration. These results also suggest that oyster restoration could alleviate the costs associated with annual dredging in other Southern California embayments.

Communication Tools for Restoration in Southern California

While there are many potential locations and incentives for restoration in Southern California, we need the support from coastal communities, policymakers, and environmental managers. Society today is generally unaware of the historic presence of Olympia oysters and the benefits they once provided to coastal ecosystems. This project developed communication tools that will help convey the importance of restoring Olympia oysters to the public and relevant stakeholders.

Communication Tools

Video Production

Future oyster restoration projects will benefit greatly from the input and involvement of local communities. By speaking with community members and showcasing the importance of this work through video, we can potentially get them involved in the projects through volunteering. Their effort to help lay out substrate for oyster recruitment and to monitor progress in restoration sites will greatly reduce the cost of labor for restoration and allow the volunteers to feel more connected to their environment. We will be producing videos to inform target audiences about how the restoration of native oysters can enhance the biodiversity and resiliency of the Southern California coastal ecosystem.

PSA Video (1-3 minutes)

This short public service announcement will be aimed at the coastal communities of California. It will be shared on social media to create a widespread awareness of the history of oysters in Southern California and briefly explain how restoring them can provide ecological benefits. It will incorporate footage from the work we accomplished through our research and from groups that are looking for volunteers, such as Orange County Coastkeepers, to give viewers an idea of how they can be involved in improving their coastline.

Oyster Restoration Documentary (10-15 minutes)

The goal of this documentary will be to give interested community members and stakeholders an idea of the history of Olympia oysters and the ecological and economic benefits of restoration. The film will feature oyster experts, environmental managers, and aquaculturists interested in future partnerships with restoration efforts.

Conclusion

With the right tools and incentives, Olympia oyster restoration on a large scale in Southern California can be a reality. Our project has done extensive work on gathering and compiling presence data of Olympia oysters throughout Southern California to aid in the selection of future restoration projects. In order to incentivize these projects, we have initiated an economic evaluation of restored oyster beds through a bioeconomic fish model and a cost-benefit analysis. We found that restored oyster beds have the potential to increase populations of California halibut and kelp bass and to decrease costs of wetland management through shoreline stabilization. Currently, there are several restoration projects in Southern California that aim to fill information gaps regarding Olympia oyster beds and their abilities to provide these ecosystem services. With additional outreach through a public service announcement and short documentary, we believe that these projects can incorporate increased local involvement and help to foster a relationship between coastal communities and marine ecosystems.

For our complete report, please visit the following website:
http://www.bren.ucsb.edu/research/gp_past.html

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Restoration of Native Oysters in San Francisco Bay, California

Chela Zabin, UC Davis and Smithsonian Environmental Research Center

Overview

Historical distribution and abundance

Shells of native oysters occur in the San Francisco (SF) Bay area's fossil record, including in enormous deposits of shell in the bay, and are found in Native American shell middens at various sites around the bay. These oysters were also eaten by early European settlers: Bonnot (1935) wrote that native oysters had been harvested commercially "since the days of the Spaniards." However, the actual abundance and distribution of these oysters is not well characterized, at least in part because of confusion with Olympia oysters from Washington and Oregon that were planted in San Francisco Bay as a fishery beginning in the mid-1800s.

Contemporary distribution and abundance

Currently, Olympia oysters can be found throughout San Francisco Bay, from south of the Dumbarton Bridge north to the Carquinez Bridge. During extensive drought periods, oyster populations may even extend past the Carquinez into Suisun Bay. In years of heavy rainfall, oyster populations experience massive die-offs due to lowered salinity in the northern parts of the bay and to a lesser extent in the south bay, resulting in a distribution restricted to the central portions of the bay (Chang et al. 2016; Cheng et al. 2016). During drought years, oyster populations are highly abundant in the northern portion of the SF Bay, along the Richmond shoreline and from China Camp to Pt. San Quentin. In the central bay, areas around the Berkeley Marina, Sausalito, Strawberry (Marin County), and Oyster Point also support large oyster populations in most years. In 2012 and 2013, adult oyster densities measured at eighteen sites ranged from 961 m^2 at one site in the north bay to 3 per m^2 in the southern part of the bay (Wasson et al. 2014). In the intertidal zone, oysters are typically most abundant at mean lower low water, but are also found subtidally on bridge supports and other submerged hard structures.

Proposed and current restoration efforts

The largest restoration effort in the bay is the California Coastal Conservancy's San Francisco Bay Living Shorelines Project, which constructed oyster reefs in two 10 x 32 m plots off of the San Rafael shoreline in 2012 (http://www.sfbaylivingshorelines.org). In 2013, the project supported an estimated 3 million oysters. This project used mounds of bagged Pacific oyster shell as its main restoration substrate. The project also tested several other concrete substrate types and included planting eelgrass within one of the large plots.

The Conservancy is planning a new, larger living shorelines project for the Richmond shoreline. This project is currently in the permitting stage, with construction slated for summer 2017. Three reefs are planned for oyster restoration, each consisting of large reef balls topped with a layer of shell bags. The effects of tidal elevation and the additions of rockweed (*Fucus*) on oyster recruitment and survival will also be tested. Plantings of eelgrass, native cordgrass, and other native marsh plants are also a part of this project.

Other restoration projects include The Watershed Project's deployment of 100 large reef balls in the intertidal zone at Pt. Pinole (deployed in 2012). Environ Corp also deployed large reef balls in the shallow subtidal area off Cesar Chavez Park in Berkeley in 2010. Pacific oyster shell mounds (bagged and loose) were used in a smaller, earlier project (2005-2009) at the Marin Rod and Gun Club site just north of the Richmond-San Rafael bridge. Smaller efforts aimed at testing sites and materials have been tried at Bair Island and Greco Island in South Bay in 2005-2006 and at the Eden Landing Ecological Reserve in 2012 (as part of the SF Bay Living Shorelines Project).

A fifty-year goal of restored oyster reefs over 8,000 acres was set by the 2010 Subtidal Habitat Goals document, a multi-agency planning effort for San Francisco Bay subtidal and intertidal habitats (http://www.sfbaysubtidal.org/report.html). The document also summarizes Olympia oyster research and early restoration efforts in the bay, identifies key data gaps and challenges to and opportunities for restoration, and recommends a science-based, phased approach for scaling up oyster restoration in the bay.

Wasson et al. (2014, 2015) described some of the ecological challenges to successful oyster restoration in San Francisco Bay. These include the lack of hard substrate at appropriate tidal elevations, competition with other sessile organisms (many of which are non-native), predation at some sites by a non-native predatory snail, warm air temperatures during low tides at some sites, and periodic lowered salinity during rainy years. Oysters may experience these latter two stressors more frequently under climate change. Plus, exposure to high air temperature immediately after exposure to low salinity, which can occur during minus tides in the spring, is particularly detrimental to oyster survival and growth (Bible et al. in review).

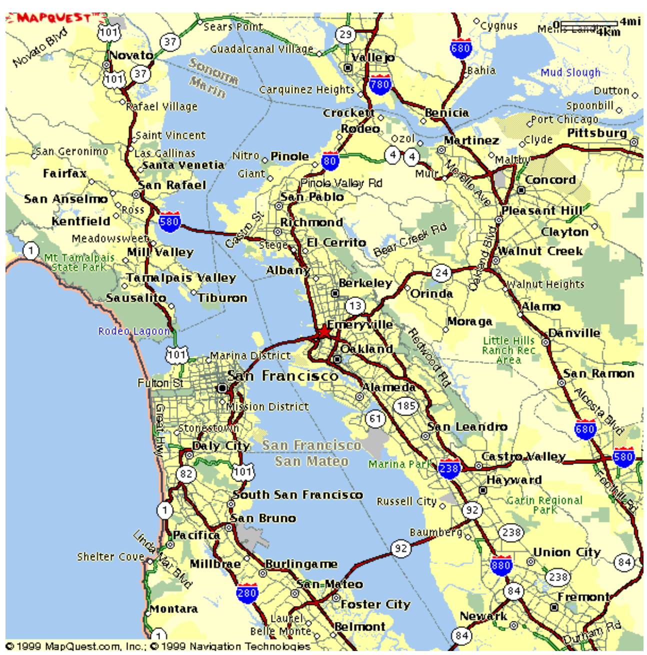
Logistical matters, including landowner permission, site access, permitting issues, funding, and conflicts with user groups may also limit oyster restoration in the bay.

Anticipated potential benefits from restoration

We anticipate that restored oyster reefs will result in greater invertebrate species diversity, mostly through the facilitative effects of the three-dimensional structure that oysters create (Kimbro & Grosholz 2006). Although data are preliminary, there were more infaunal invertebrate species post-construction at the SF Bay Living Shorelines San Rafael site compared to the pre-construction and to a control site, and the ecological community associated with oysters, which included various crab, shrimp, and small fish species, differed from that associated with the mudflat. These species as well as the oysters may represent a more diverse prey base for birds and larger fish and invertebrates. A greater diversity of bird species, including two species of special interest in the bay, were associated with the reef structures compared with pre-construction and a control site (Boyer et al. 2016). Oyster filter feeding can also contribute to improved water clarity, which may enhance eelgrass growth and contribute to nutrient cycling. These effects likely occur at very small scales given the current relatively small populations and may have been a more significant ecosystem function during times of greater oyster abundances.

Increasing oyster abundance and distribution within the bay may ensure persistence and resilience of the bay populations against extreme weather events, such as heat waves and low salinity during heavy rains (Wasson et al. 2016). Although it is unknown whether or how frequently oyster larvae from SF Bay disperse to other nearby locations (e.g. Tomales Bay or Elkhorn Slough), having multiple connected populations along a coast may help promote native oyster persistence within the region.

When oyster restoration is incorporated into a living shorelines design, shorelines can be enhanced through erosion protection and sediment accretion. These designs deliver benefits to human populations, while simultaneously providing species habitat and connectivity between multiple habitat types.



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Restoration of Native Oysters in Elkhorn Slough, Monterey Bay, Central California

Kerstin Wasson, Research Coordinator of the Elkhorn Slough National Estuarine Research Reserve

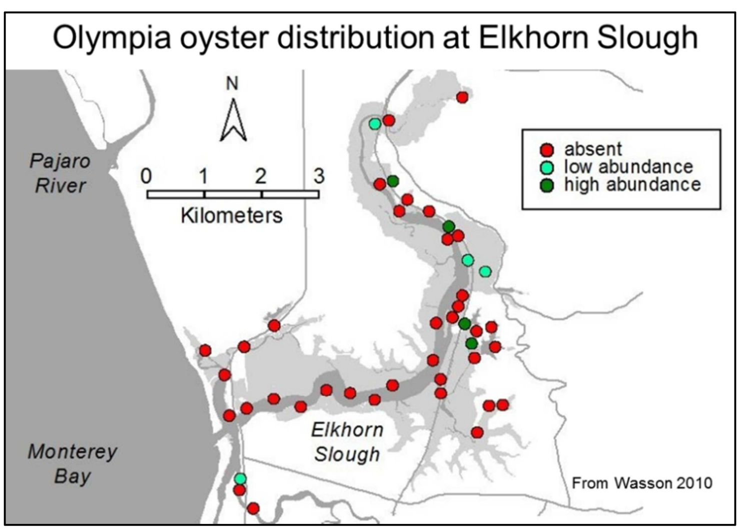
Overview

Olympia oysters have grown in Elkhorn Slough for at least 7,000 years, as evidenced by their presence in virtually every Native American midden at sites throughout the estuary from any period. Now they are extremely rare and in danger of local extinction. The Elkhorn Slough National Estuarine Research Reserve and Elkhorn Slough Foundation are committed to conducting oyster restoration to ensure that this iconic species continues to be represented in the estuary in perpetuity.

Historical distribution and abundance

At Elkhorn Slough, Native American middens reveal that native oysters were present in the estuary from sites near the mouth (e.g., Struve Pond, Moro Cojo) to the upper estuary (e.g., South Marsh), and eaten by humans, for the past 7,000 years. When George MacGinitie first studied the invertebrates of the estuary in the 1920s, he also reported oysters as being highly abundant in many sites from the mouth to the head of the estuary. But within a decade, they had been overharvested by oystermen from San Francisco Bay, and became so rare that they were not detected in surveys for many decades.

Current distribution and abundance



Today the native Olympia oyster is absent or extremely rare in most parts of the estuary, including areas where it once thrived. There are three major threats to adult oysters at Elkhorn Slough (Wasson 2010). The first is poor water quality: Oysters are absent from sites with indicators of extreme eutrophication (high nutrient concentrations, high turbidity, and low night-time oxygen levels). This includes about half of the historic estuarine network, which is behind dikes and water control structures. The second main threat is burial by sediments: In many areas, oysters are smothered by mud if they grow on the tiny bits of natural hard substrate that are available (such as shells); they only survive burial by growing on artificial hard substrates such as rip rap. The third major threat is non-native fouling species: At lower tidal heights, most available space is taken up by non-native sponges, tunicates, and tubeworms.

Today there are estimated to be about 5,000 to 10,000 Olympia oysters in Elkhorn Slough (Wasson 2010). This number seems likely to be much lower than the typical past baseline for the estuary. Recruitment failure is more common at this estuary than almost any other estuary that has been studied along the range of the species, likely because the network of adult oyster sites is so small and because larval retention is low in this very marine-influenced system (Wasson et al. 2016).

Because Olympia oysters are so rare at Elkhorn Slough, and undergo many consecutive years with no recruitment (no new baby oysters join the adult populations), they are in real danger of local extinction. Olympia oysters have gone functionally extinct in the next major estuary to the south, Morro Bay, making the next closest oyster population to the south of Elkhorn Slough very far away, in Carpinteria Marsh. To the north, the nearest substantial population is in San Francisco Bay.

Olympia oyster restoration initiatives at Elkhorn Slough

The goal of oyster restoration at Elkhorn Slough is to prevent local extinction, to maintain a population that has lived in this estuary for thousands of years, and to provide a stepping stone connecting northern and southern oysters along our coast. We hope to double the numbers of adult oysters in the estuary (currently around 5,000 to 10,000) to buffer the population against local extinction.

Unlike Asian or Atlantic oysters, which often form extensive reefs, Olympia oysters tend to grow in small clusters. Our restoration efforts attempt to mimic this natural growth form. We have experimented with various small, modular reefs that provide habitat for oysters. Most of our designs use native gaper clam shells generated by sea otter foraging as the hard substrate, combined with stakes to keep the clusters out of the mud.

Elkhorn Slough Reserve staff members Kerstin Wasson and Susie Fork, together with Smithsonian Environmental Research Center scientist Chela Zabin, spent two years conducting large replicated restoration experiments on the Elkhorn Slough Reserve, with funding from CDFW's Environmental Enhancement Fund. About 200 modular reefs were deployed, including clam shell "necklaces," Reef Balls, and stakes of various types of wood. The team compared oyster success under different habitat conditions and summarized lessons learned in a scientific paper (Zabin et al. 2016). They examined effects of bottom type (gravel or mud), distance between existing adults (near/far), and tidal elevation on oysters that settled on clam-shell "necklaces." The most striking effect was tidal elevation. More oysters settled lower down, but more non-native sponges, tunicates, and bryozoans did, too. So reef placement depends on the restoration goals: to maximize oyster numbers, put them low; but to maximize oyster dominance and have virtually pure native cover, put them high. They also did some adaptive management with this concept, initially putting the reefs low to accumulate lots of newly settled oysters, then moving them high to kill off the non-natives. While using stressful conditions to enhance natives over non-natives is common in terrestrial landscapes (grazing, fire, etc.), this is perhaps the first application of this concept to marine systems, so it has some general value to practitioners working on restoration beneath the tides in other systems.

In the future, this team will continue to deploy small, modular, "artisanal" restoration units to support small clusters of oysters. They are currently seeking grant funding to do this in conjunction with eelgrass restoration at a major salt marsh restoration site on the reserve. This site is heavily used by sea otters, which may benefit from healthy oyster populations.

Elkhorn Slough also has severe shoreline erosion problems, and the team would be interested in testing the effectiveness of a "living shoreline" design to support oysters while decreasing shoreline erosion.

A new area the team would like to explore is partnership with aquaculture experts, so that restoration substrates could be “seeded” with oyster spat from Elkhorn Slough. This could greatly enhance restoration success, since natural recruitment appears to occur only about one year out of four or five in the estuary.

Benefits of Restoration
For the oyster, the anticipated benefit of the restoration work is the ability to survive and persist in this estuary where it has lived for thousands of years. Increased adult numbers within the estuary should lead to more frequent recruitment events.

Maintaining Olympia oysters at Elkhorn Slough is also important for population connectivity between Southern and Northern California, since the closest adult populations are 100 miles to the north and 250 miles to the south.

Oyster restoration at Elkhorn Slough also is meaningful for human populations. People have interacted with native oysters on these mudflats for thousands of years, and there is a real delight in continuing this long tradition. All our restoration efforts involve the community, and interactions with the oysters and their habitat are enriching experiences.

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Restoration of Native Oysters, *Ostrea lurida*, in Alamitos Bay, California

Prepared by Co-Investigator Dr. Christine Whitcraft[1]
Lead Investigator: Dr. Danielle Zacherl[2]
Additional Co-investigators: Terrance Champieux, Sara Briley, Orange County Coastkeeper

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Overview and historical distribution and abundance
Historical documents indicate the presence of oyster beds in Southern California estuaries including Alamitos Lagoon, now called Alamitos Bay (Bonnot 1935). This bay was also reported to historically contain extensive eelgrass beds. As indicated in Pleistocene fossil deposits from Northern California, there is support for the historical association between eelgrass and the Olympia oyster (Miller & Morrison, 1988). Further to the south of Alamitos Bay, researchers recently found Olympia oysters in small abundances within eelgrass beds in San Diego Bay, California (Reed & Hovel, 2006).

Current distribution and abundance
Preliminary field surveys in 2010 (Zacherl et al. unpub) in Alamitos Bay and the connected neighboring Colorado Lagoon revealed that native oysters were present in low densities on hard substrate; however, there were no natural intertidal oyster beds found anywhere in Alamitos Bay for oyster larvae to settle and grow.

Olympia oyster restoration initiatives in Alamitos Bay
In June 2012, Orange County Coastkeeper, in partnership with California State University, Fullerton, California State University, Long Beach, and KZO Education, restored oyster habitat at the Jack Dunster Marine Reserve in Alamitos Bay, California (Figure 1). Teams of researchers, students, and community volunteers laid a new oyster bed using "dead" oyster shell to facilitate future settlement of baby oysters or oyster spat. Over the next two years, we recorded significant increases in oyster settlement, survival, and growth! Details are below.

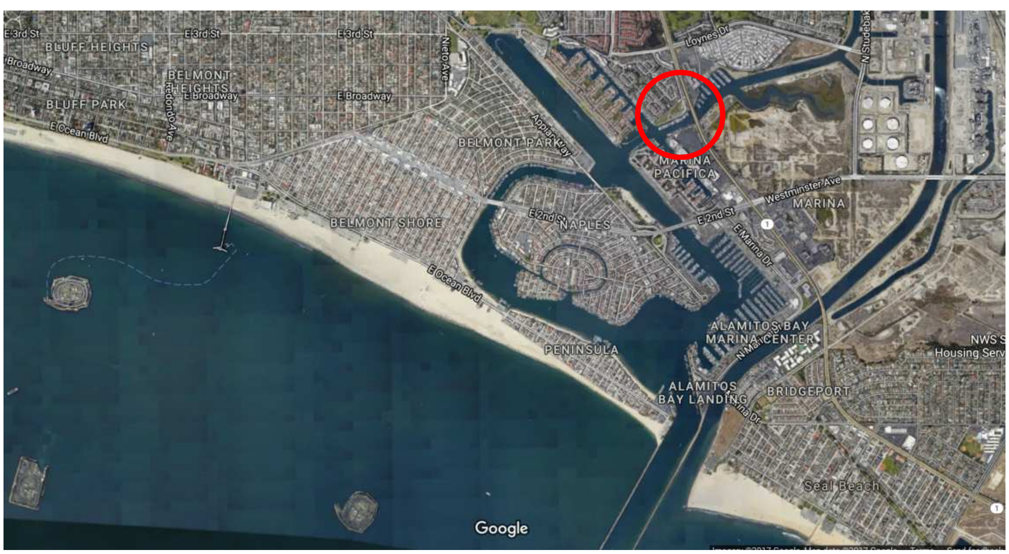

Figure 1. Google Earth image of Alamitos Bay and coastal region with location of oyster restoration circled.

Site history. Alamitos Bay is a highly urbanized estuary, surrounded by suburban neighborhoods, city parks, a city fire station, and schools. The transformation of this bay from a more natural estuary to the current highly urbanized one began in 1923 in preparation for the 1932 Los Angeles Olympics, when the tidal areas of Alamitos Bay were dredged to form Colorado Lagoon and Marine Stadium. A few years later, Colorado Street and a short culvert were installed across the connection to Colorado Lagoon. These transformations likely reduced any Olympia oyster beds in the estuary.

Current description. The study was conducted in Jack Dunster Marine Reserve (JDMR) located at the mouth of the Los Cerritos Channel in Alamitos Bay, Long Beach, California (118°7'9" N, 33°45'43" W) (Figure 1). JDMR is a 2.7-acre site containing 1.5 acres of land and 1.2 acres of wetland and subtidal habitat, which were created in 2000 as a mitigated wetland (Apodaca, 2005).

Experimental setup. The restoration area includes a created oyster bed, mudflat, and eelgrass beds where there were four treatments: one manipulated intertidal mudflat with restored oyster bed (bed) (established June 2012), one unmanipulated intertidal mudflat (control), one subtidal eelgrass bed adjacent to the oyster bed (near), and one subtidal eelgrass bed adjacent to the control (far). The oyster bed started at the southwest side of the eastern-most observation platform in JDMR and extended southwest as a 30 meter by 2 meter band (Figure 2). The near eelgrass site ran parallel, approximately 5 to 10 meters southeast, to the oyster bed and extended southwest as a 30 meter by 2 meter band (Figure 2). The far eelgrass bed continued 30 meters from the end of near and extended southwest as a 30 meter by 2 meter band (Figure 2). The control area, approximately 10 meters from bed creation site, started at the northeast side of the western-most observation platform in JDMR and extended northeast as a 30 meter by 2 meter band (Figure 2). There was one collection treatment outside of the reserve that served as a subtidal eelgrass reference: Basin-6, which was located on the opposite side of Los Cerritos Channel (118°7'7" N, 33°45'41" W) (approx. 57 meters away from JDMR). Basin-6 was included as a subtidal, eelgrass-habitat control because it was likely far enough away from the restored oyster bed to eliminate possible oyster bed effects.

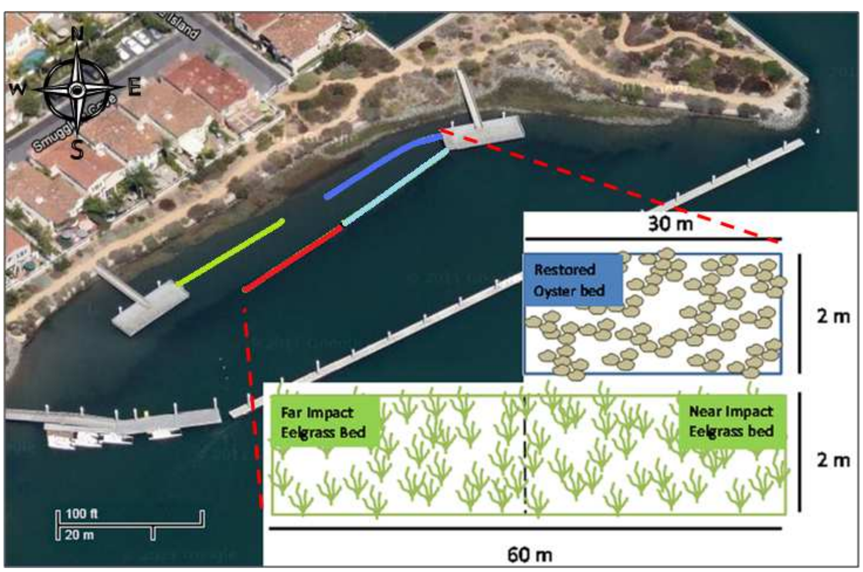

Figure 2. Schematic showing experimental design in Jack Dunster Marine Reserve.

The control location (solid green line), the oyster bed location (solid blue line), and the near and far eelgrass locations (solid light blue and red lines) are illustrated. Image credit: Google Earth.

On June 20 and 21, 2012, loose *Crassostrea gigas* oyster shell (~8 cu. yards) acquired from Carlsbad Aquafarm was used to build a bed approximately 30m long by 2m wide by 8cm deep on intertidal mudflat habitat in JDMR (approximately 60 sq meters). The shell was laid in place using manual labor from researchers and community volunteers. Sample collection for oyster settlement and growth, sediment invertebrates, and eelgrass density occurred annually, in June 2012 (pre-restoration), in January 2013 (seven months post-restoration), in June 2013 (twelve months post-restoration), and January 2014 (twenty-four months post-restoration).

Monitoring results – oyster settlement and growth. Within six months of construction, the oyster shell bed experienced significant shell loss (72 percent of original cover), most likely a result of significant sediment deposition. Oyster larval settlement occurred and adults were present, but at a very low density within the first year (June 2013: 2.29 ± 15.50 individuals m^2, Fuentes et al., unpublished data). In late June 2013, more shell was added to the mudflat to ameliorate shell loss at a lower intertidal height of 0.22 meters above MLLW and to facilitate decreased settlement by non-native *Crassostrea gigas*. In addition, the band of oyster shell was separated into several sections to increase water flow channels.

Monitoring results – invertebrates (Champieux 2015). Other oyster restoration studies throughout the U.S. have shown that restoration of oyster populations are important, but the techniques and structures used for restoration (e.g. the placement of shell on a previously bare mud habitat) could impact the soft sediment mudflat community through trampling and disruption of the sediment-water interface. Infauna and epifauna are benthic animals, such as clams, worms, and burrowing crabs, that live in and on the substrate of a body of water, especially in a soft sediment bottom. As an integral part of the consumer food chain, benthic infauna and epifauna provide important trophic support to species of commercial and intrinsic importance like crab, fish, and birds (Sacco et al., 1994; Levin et al., 1996; Moseman et al., 2004). Within the oyster bed site, invertebrate abundance and species richness were lower only under the oyster bed. The alteration in the community under the shell is driven by a reduction in species with one group of marine earthworms (*Tubificidae*) as the only remaining species under the shell. These results may be explained by the shells' action as a barrier to the mud-water interface. While significant, impacts of oyster bed construction are spatially restricted to just under the bed. In addition, the infauna results described here, we monitored benthic epifauna and are working through those data to determine if patterns are similar to the infauna.

Monitoring results – eelgrass (Briley 2015). In the eelgrass patches following restoration, we found that light was significantly lower each day in the impact site than in the control site for three months following construction. In addition, we observed denser eelgrass with shorter and narrower leaves in the control site as compared to the near impact eelgrass site; yet, the near impact bed maintained a more consistent density and mean leaf size than the far impact eelgrass site. Declines in below-ground biomass after construction of the oyster bed were observed in the impact site only, but did not translate into above-ground biomass loss. Overall, the changes observed were within the wide range of natural variation expected in this system, suggesting that oyster bed creation was not detrimental to the adjacent eelgrass bed. These findings support the potential coexistence of a constructed Olympia oyster bed and adjacent eelgrass, which is relevant to the design of future restoration efforts for both species.

Future directions. We will continue to monitor this habitat to apply the lessons learned at this site to other bays and estuaries in Southern California in an attempt to restore oyster beds to fully functioning habitats. In addition, we will add additional shell to the beds to mitigate for shell loss and sediment deposition that we have observed since the restoration. These beds will provide habitat for other fish and invertebrate species, may help improve water clarity, particularly for sunlight-loving eelgrass beds that often occur adjacent to or in and around oyster beds, and are a demonstration of the community-based restoration work that can happen in the highly urbanized landscape of Southern California.

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Restoration of Native Oysters, *Ostrea lurida*, in Newport Bay, California

Prepared by Lead Investigator Dr. Danielle Zacherl[3], Professor
Co-Investigators: Dr. Christine Whitcraft[4] Associate Professor; Orange County Coastkeeper

Overview and historical distribution and abundance
Historic documents indicate the presence of oyster beds in several Southern California estuaries, including Mugu Lagoon, Alamitos Lagoon, and Newport Bay that supported artisanal-scale harvesting and very small-scale fishery operations for at least a few decades (Bonnot 1935). Specific qualitative mention was made of several intertidal native oyster beds in Upper Newport Bay (Bonnot 1935, Gilbert 1891) north of the Hwy 1 Bridge prior to overharvest and significant habitat modification in the early to mid-1900s. The extent of those beds (size of bed, bed thickness, and oyster density) was not noted by either Bonnot (1935) or Gilbert (1891). Fossil shells recovered from two locations in the bay reveal the presence of oyster beds dating back to 600 years ago (Bonuso and Zacherl, unpublished data), and fossil deposits in nearby Coyote Hills indicate oyster presence in Orange County as far back as the Pleistocene (about 1 million years ago).

Orange County Coastkeeper and collaborator Dr. Danielle Zacherl are working to ensure that oyster bed habitat is reintroduced into Newport Bay using a science-based approach that allows them to explore the ecosystem services that oyster beds may provide and that ensures that this iconic species and the habitat it creates are re-established in perpetuity.

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Current distribution and abundance

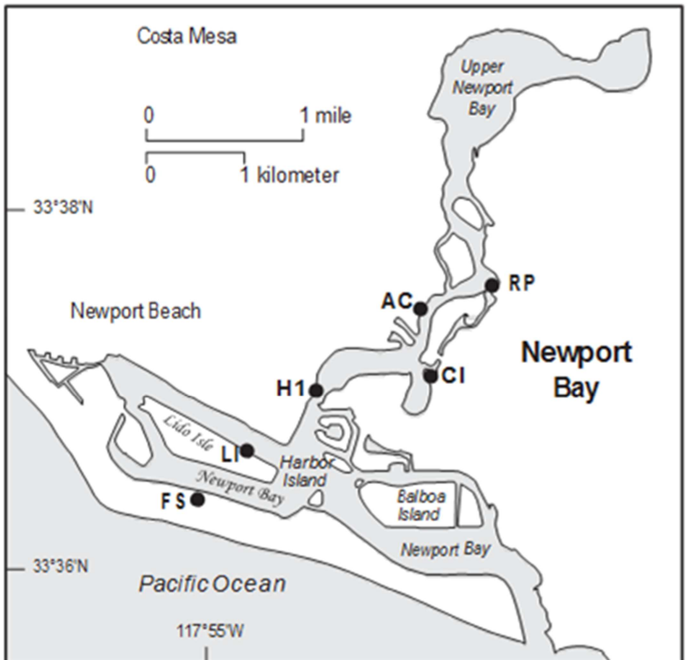

Figure 1. A subset of field sites in Newport Bay most commonly surveyed for Olympia oyster density and recruitment. FS = 15th Street, LI = Lido Island, H1= Hwy. 1, CI = Coney Island, AC = Aquatic Center, RP = Rocky

Field surveys (Polson and Zacherl 2009, Tronske, Zacherl et al., unpublished) of the entire bay (n = 30 field sites) prior to any restoration efforts revealed that while oysters ranged from present and rare to abundant, there was no natural intertidal "bed" of oysters anywhere in Newport Bay. The only location where oysters are known to be absent or where their current abundance is unknown is in the furthest reaches of Upper Newport Bay, north of Rocky Point (Figure 1), where the salinity dips below about 20 ppt and where hard substrata are absent. At highest density (Hwy 1, Figure 1), they measured ~ 54 oysters per square meter on a mudflat that was 44 percent mud and ~ 56 percent hard substrate in the form of unconsolidated gravel, shell, small, medium and large boulders (Zacherl, unpublished data, fall 2007).

Olympia oyster restoration initiatives in Newport Bay
From 2010 to 2012, Zacherl et al. (2015) initiated a pilot restoration study in Upper Newport Bay at Hwy 1 to explore which of several commonly employed oyster restoration techniques would be most successful for restoring the Olympia oyster in Newport Bay, California. Replicate (n=5) 2 meter by 2 meter shell beds were constructed of two initial shell planting thicknesses (bed thicknesses of 4 centimeters versus 12 centimeters) and two methods of deployment (bagged versus loose shell). Shell cover, oyster spatfall (settlement), oyster recruitment, and adult oyster densities were analyzed over two years;

12 centimeter-thick oyster beds maintained higher shell cover, experienced less sedimentation, and received greater numbers of oyster recruits than 4 centimeter-thick beds. There was no significant effect of shell deployment method on shell cover, recruitment, or adult density; however, spatfall was greater on loose shell beds compared to bagged shell beds in the final year of the study. Overall, augmenting mudflat habitat with oyster shell significantly increased adult *Ostrea lurida* oyster density twenty-six times, compared to un-manipulated plots and increased oyster density two to three times the average density of oysters measured elsewhere in Newport Bay. Collectively the data suggest that building thicker shell beds might increase the longevity of a constructed shell bed, and therefore this approach was recommended for future restoration activities in Southern California. This study highlighted the advantages of augmenting habitat in a manner that provides vertical relief from sedimentation.

In 2015, Orange County Coastkeeper received funding from the California Coastal Conservancy to initiate the Upper Newport Bay Living Shoreline Project. Dr. Danielle Zacherl of CSU Fullerton is a subcontractor under Orange County Coastkeeper. The team is in the midst of implementing a plan to restore native Olympia oyster (*Ostrea lurida*) and eelgrass (*Zostera marina*) habitat in Upper Newport Bay using natural structures as habitat that will also serve to buffer and protect adjacent shorelines from sea level rise and erosion. The team has been conducting baseline monitoring, implemented eelgrass restoration efforts in summer 2016, and will build oyster beds in April 2017 and monitor restoration effectiveness through April 2017.

Starting in June 2016, we constructed a series of four, 110 meter by 12 meter, Living Shoreline Blocks (Figure 2) in Upper Newport Bay. Within each block, we added one plot of four restoration treatments: 1) oyster shell bags (20 meters by 1.5 meters), 2) transplanted eelgrass bed (20 meters by 8 meters), 3) restored oyster bed above a restored eelgrass bed, and 4) a control treatment left un-manipulated, with 10 meters of separation between each treatment (Figure 3). The four blocks are parallel to shore in several locations in Upper Newport Bay, including along De Anza Peninsula, Castaways, and Shellmaker Island (Figure 2). This design, with four replicates of each treatment, will enable comparisons of single species versus integrated restoration techniques on species performance, habitat value, and shoreline protection to determine the restoration configuration offering the most benefits. Thus far the eelgrass restoration occurred in summer 2016, and oyster beds will be constructed in April 2017.

Overall, we will measure a host of parameters including environmental (temperature, salinity, dissolved oxygen, pH, and turbidity), physical (shoreline position, substrate, vessel wake height/frequency, relative current velocity, and sedimentation) and biological (native and non-native oyster abundance, density, and growth; eelgrass turion density, areal extent, growth and minimum/maximum depth ranges; and community diversity) characteristics of each site.

Figure 2. Restoration site locations: replicated 110 meter-length Living Shoreline Blocks (oyster shell and transplanted eelgrass treatments) shown in red and eelgrass donor sites shown in blue.

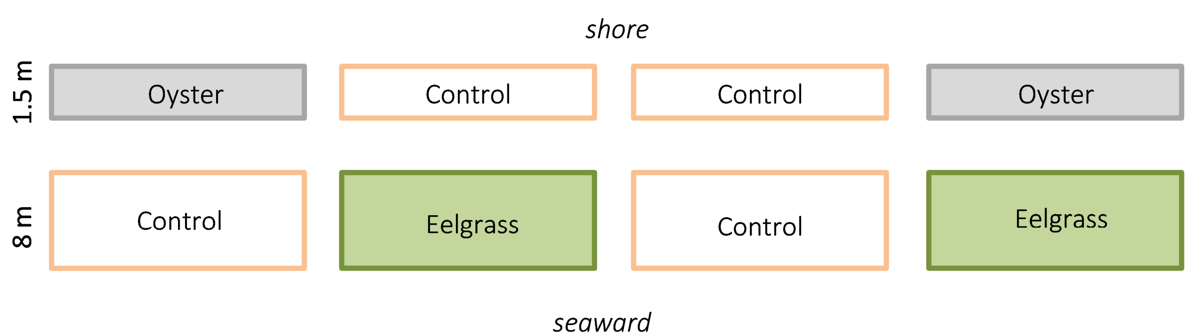

Figure 3. Example arrangement of four restoration treatments *(control, oyster, eelgrass, and* combined oyster + eelgrass) within one Living Shoreline Block. Treatments will be randomly arranged within each block and replicated at four sites in Upper Newport Bay.

Benefits of restoration

Restoration of these species is critical to the health of a resilient Newport Bay ecosystem, as both species return many ecosystem services back to our coastal wetlands. Oysters can improve water clarity and remove anthropogenic nutrient inputs from the water column, increase biodiversity through the creation of complex habitat, stabilize sediments, buffer erosion, and attenuate wave energy. Eelgrass meadows provide similar ecosystem services, including habitat and foraging grounds for many invertebrate, fish, and bird species; nutrient cycling; carbon sequestration; sediment stabilization; and water quality improvement. A primary goal of our project is to protect, enhance, and restore these habitat-forming species now that may be impacted by climate change to increase their resiliency to future change and preserve the ecosystem benefits they provide. As foundation species, oysters and eelgrass will continue to improve their environment, causing a positive feedback loop promoting future establishment and stability. To keep pace with future sea level rise and other climate related stresses, we must begin conservation and restoration of these key habitat-forming species now.

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Restoration of Native Oysters in San Diego Bay, California

Prepared by Project Team Member Dr. Danielle Zacherl[1], Professor

Co-members:
Holly Henderson, Merkel and Associates, Inc.
Nick Garrity, P.E., ESA
Megan Cooper, California State Coastal Conservancy
Eileen Maher, San Diego Unified Port District
Carolyn Lieberman, United States Fish and Wildlife Service
Mayda Winter, Southwest Wetlands Interpretive Association

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Overview
The San Diego Unified Port District teamed with the California State Coastal Conservancy and other partners (Holly Henderson, Merkel and Associates, Inc., Nick Garrity, P.E., ESA, Carolyn Lieberman, United States Fish and Wildlife Service, Mayda Winter, Southwest Wetlands Interpretive Association, and Dr. Danielle Zacherl, CSU Fullerton) to develop a proposal to implement a project in San Diego Bay that integrates intertidal shoreline stabilization with restoration of native Olympia oysters, *Ostrea lurida.* A primary goal of our project is to create a biologically rich native oyster bed in San Diego Bay as part of a complete marsh system that restores an ecological niche that was historically present, is ecologically functional and resilient to changing environmental conditions, and also protects bay tidelands and shoreline.

Historical distribution and abundance
In San Diego Bay, and Southern California estuaries in general, there is a rich history of the presence of oysters, including *Ostrea lurida,* the only remaining extant native oyster, that extends back to 23 million years ago. From fossils archived at the San Diego Museum of Natural History (SDMNH), there is extensive evidence of the presence of the genus *Ostrea* (identified as *Ostrea sp.*) from formations formed during the Pliocene epoch (5 to 2.5 million years ago) as well as several other genera that are no longer extant (e.g. the once very common *Dendostrea vespertina*, which exists in the fossil record in California from 23 to 2.5 million years ago) or now present only in the Sea of Cortez and southward (e.g. *Ostrea angelica*, now *Myrakeena angelica*).

The Holocene epoch began 11,700 years ago, and much of the evidence of continued oyster presence in the area comes from archaeological excavation of shell middens. In a review of forty-four San Diego County archaeological sites/middens, Laylander and Iversen (2008) provide evidence that *Ostrea lurida* ranged from not present to as high as 50 percent by weight of shellfish recovered; *Ostrea lurida* typically represented between 5 to 10 percent of the total shellfish by weight.

Oysters seem to have continued to play an important role as a food resource from the 1600s through the early 1900s. Davidson (1887) provides excerpts of the explorations of Cabrillo, Viscaino, and others that include mention of oysters as a food resource in San Diego Bay. In Viscaino's description of his experience in San Diego in 1602, he notes that, "in this harbor there is a great variety of fish, as oysters, mussels, lobsters…abounded." More recently, Ingersoll (1881) mentions that at La Punta on the south side of San Diego Bay, there were large enough numbers of oysters of sufficient size to have potential commercial importance (but he noted their coppery flavor). Gilbert (1889) and Bonnot (1935) described the presence of oyster beds in several Southern California estuaries, including Alamitos Bay and Newport Bay in Orange County, and Mission Bay, San Diego Bay, and the Tijuana River Estuary in San Diego County. Lastly, Hector (2002) examined the patterns of shellfish consumption of urban San Diego residents at around the turn of the century by examining the shellfish remains from two archaeological deposits—one dated at the turn of the twentieth century and the other from approximately the 1920s. These deposits indicated that *Ostrea lurida* was a food resource at the turn of the century, but it was replaced by *C. virginica* in subsequent decades. In sum, there is extensive evidence that *Ostrea lurida* was present in San Diego Bay and nearby estuaries, that it was an exploited food resource by Native American Indians prior to Spanish exploration, and it continued to be exploited through the turn of the twentieth century.

Current distribution and abundance

Density (n = 7 field sites, Tronske, Zacherl et al., unpublished) and presence/absence (Henderson, Merkel Inc.) surveys throughout the bay in 2013 and 2017 have revealed that native oysters, *Ostrea lurida*, and non-native Japanese oysters, *Crassostrea gigas*, ranged from present and rare to very abundant (up to 200 Olympia oysters per square meter and forty-five Japanese oysters per square meter). There is no natural intertidal “bed” of oysters anywhere in San Diego Bay. The only location where oysters are known to be absent are selected mudflats where hard substrata are completely absent.

Olympia oyster restoration initiative in San Diego Bay

Since 2013, the project members have been conducting preliminary studies in San Diego Bay on the physical and biological features of the bay. That, combined with modeling studies, has resulted in the formation of an extensive, large-scale restoration plan. See the document *San Diego Native Oyster Restoration Plan* for a complete description of preliminary studies and resultant study design; the overarching study objectives and a brief description of the study design are included here.

One of the primary objectives of the restoration project is to explore if constructed oyster reef arrays reduce water flow velocities, attenuate waves, and reduce rates of erosion/increase rates of deposition shoreward of the reef arrays, and whether any of these reductions result in a measurable change in shoreline morphology. In addition, the common presence of both native and non-native oysters in the bay allows a timely and unique opportunity to explore whether the tidal elevation of constructed oyster reef elements affects recruitment of native *O. lurida* and non-native *C. gigas* and other species that compete for space with native oysters. Our preliminary data indicate that the native and non-native oysters exist in San Diego Bay and elsewhere in a strong zonation pattern such that non-natives favor higher tidal elevations, and natives favor lower tidal elevations. Confirming this zonation pattern in our study will have extremely important implications for future oyster restoration study designs, especially for targeting the tidal elevation for future restoration projects that will favor native oysters.

In addition to exploring the above hypotheses, we will measure a host of other parameters to include environmental (temperature, salinity, dissolved oxygen, pH, and turbidity), physical (shoreline position, substrate, vessel wake height/frequency, relative current velocity, and sedimentation) and biological (community diversity) characteristics of each site.

The study design includes the construction of multiple oyster reef arrays (n=3 each at two tidal elevations) along the E Street Marsh. Each array is made up fifteen reef elements (basically oyster reefs) in a trapezoid shape measuring 7 feet by 7 feet at the base and 3 feet by 3 feet at the crest. The height of each element is 2 feet. Please refer to the *San*

Diego Native Oyster Restoration Plan for complete details.

Benefits of restoration

Restoration of oysters could play a critical role in stabilizing shorelines in the face of predicted climate change in San Diego Bay. Further, oysters can improve water clarity and remove anthropogenic nutrient inputs from the water column, increase biodiversity through the creation of complex habitat, stabilize sediments, buffer erosion, and attenuate wave energy.

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Billion Oyster Project:

Oyster Restoration through Public Education in New York Harbor

Peter Malinowski

The Billion Oyster Project (BOP) is based on the belief that direct engagement and interaction with wild animals and functioning ecosystems has a transformative effect on young people. As our world is increasingly urbanized, there is a growing subset of our human population that is coming of age separate from nature. Simultaneously, efforts abound aimed at increasing student engagement in school in an effort to improve outcomes for millions of young people. Too often, these interventions exist in the vacuum of school without the real-world, hands-on implementation that leads to improved self-confidence, authentic problem solving, teamwork, and the belief that anyone and everyone has the power to effect change.

BOP is an attempt to bring these too often separate issues together. It has grown from the belief that if we are to continue living, working, teaching, and learning on this planet we must fundamentally change how humans learn about and interact with nature. Our solution began in a high school aquaculture class and has grown into a region-wide initiative involving seventy restaurants, sixty-five schools, thousands of students, millions of oysters, and a dozen active restoration and research sites.

New York Harbor is a massively degraded natural system, oysters are functionally extinct, and every time it rains, billions of gallons of untreated household wastewater enter the system. The visibility is very low, often less than a foot. Currents are strong and commercial traffic is constant. To overcome these challenges, it is essential to engage the entire metropolitan community in the work of growing and restoring oysters. Community engagement has become central to the work of BOP. This work is executed through four core programs: Shell Collection, Reef Construction and Monitoring, Schools, and Citizen Science and Public Engagement. Each of these programs is designed to advance the work of growing and restoring oysters while simultaneously building a community of environmental stewards and advocates who will no longer stand for a polluted harbor that lacks its native keystone species.

The project began at the New York Harbor School, founded in 2003 by Murray Fisher and a small group of passionate educators. The Harbor School aims to prepare students for college and careers by immersing them in New York City’s maritime experience.

Students at Harbor School first began interacting with oysters as part of an oyster gardening program led by New York/New Jersey Baykeeper. For its first seven years, Harbor School was located in Bushwick, Brooklyn, New York's most land locked neighborhood. It was not until 2010 that the school relocated to Governors Island, a stone's throw from lower Manhattan and right in the center of New York Harbor. This move allowed for the development of six Career and Technical Education Programs. Through these programs students have learned to SCUBA dive safely, raise oyster larvae, operate and maintain vessels, build and maintain commercial-scaled oyster nurseries, design underwater monitoring equipment, and conduct long-term authentic research projects, all in the murky, contaminated, fast-moving waters of one of the busiest ports in the country. For these students, BOP provides a complex problem that requires them to practice the skills they are learning and collaborate with their peers from other disciplines. These students are the primary workforce for the Reef Construction and Monitoring Program. Students in individual programs work to produce the raw materials of restoration and research. Together, they plan and execute complex installation and monitoring missions throughout the harbor. These activities would not be possible without the diverse expertise of students in various programs. They are joined by a growing group of industry professionals, divers, captains, welders, advocates, scientists, and marine technicians. These BOP Professionals work alongside Harbor School teachers to facilitate the participation of students in all aspects of Reef Construction and Monitoring.

Harbor School students are now joined by students at sixty-five public middle and high schools and dozens of citizen scientists throughout the five boroughs of New York City. The work of the BOP Schools and Citizen Science Program is built around Oyster Restoration Stations. These small wire cages hold live oysters, settlement tiles, and a trap for mobile invertebrates. These components are monitored separately to assess species diversity, succession, and oyster growth and survival. Partner schools contribute by monitoring these stations and supporting breeding colonies at various locations around the harbor that add to the reproductive potential of the harbor each spring. These Oyster Restoration Stations also serve as access points that bring math and science classes out of their buildings and down to the water's edge. Through this oyster restoration and research, students learn the science of the estuary and the math of aquaculture and ecosystem restoration. In this way young people become active stewards of the harbor. The data collected by these school groups form a harbor-wide oyster growth and survival study and a growing water quality data set that together help inform future restoration work. Each year 5,000 new students participate in these programs.

A primary challenge of engaging communities and volunteers in the work of oyster restoration in New York Harbor is the physical lack of access to the water. Walk to the water's edge and more often than not, you will be met by fences and steep or vertical bulkheads. There are however a few places where access is possible. The Public Engagement Program takes advantage of these access points and is now working with community groups, schools, and volunteers in collaboration with the Reef Construction and Monitoring Program to build reefs in communities. These new reefs, for the first time, allow volunteers and schools to regularly enter the water to participate directly in oyster restoration.

All of the above programs require a consistent source of cured oyster shells. Because the oyster industry on the East Coast is dominated almost entirely by the restaurant half shell market, there is no available source of oyster shells besides those that are generated by restaurants. In New York City a full 35 tons of oyster shells are generated every week. The vast majority of these are, unfortunately, landfilled. The Shell Collection Program currently operates at seventy restaurants, five days per week, and averages four tons of shell per week. These shells are transferred to a location on Staten Island, where they spend a year out of water before they can be returned to the Harbor.

To date, through the implantation of these four programs, BOP has collected over 400,000 pounds (180 tonnes) of shells, engaged over 600 volunteers on Governors Island and at community reef sites, and worked with over 10,000 students. All of the 20 million oysters restored to date have been grown and installed by high school students. We are just at the beginning of our journey toward a recovered New York Harbor and still a long way from understanding what the best strategies are for scaling up our restoration efforts. However, if we are able to restore a sustainable oyster population and build a program that allows teachers and students to be successful in their work of restoring the natural environment, then we will have created a model that is replicable in any city in the world that happens to exist on or near a degraded natural system.

Appendix A

Forum Participants

Brooks, Andrew	UC Santa Barbara - Bren
Brumbaugh, Robert	The Nature Conservancy Chesapeake Bay
Center, Steve	American Honda Foundation
Elkin, Julia	State Coastal Conservancy
Fisher, Murray	New York Harbor Foundation
Grant, Colleen	UC Santa Barbara - Bren
Group, Brianna	UC Santa Barbara - Bren
Ho, Desmond	UC Santa Barbara - Bren
Hunter, Linda	Wild Oysters
Ishigo, Jessalyn	American Honda Foundation
Jautokas, Raminta	American Honda Foundation
Lenihan, Hunter	UC Santa Barbara - Bren
MacKay, Jonathan	Aquarium of the Pacific
Nichols, Katie	Orange County Coastkeeper
Page, Mark	UC Santa Barbara - Bren
Phillips, Teresa	American Honda Foundation
Pitton-August, Beth	UC Santa Barbara - Bren
Read, Emily	UC Santa Barbara - Bren
Schubel, Jerry	Aquarium of the Pacific
Smith, Stacie	NOAA
Thompson, Kim	Aquarium of the Pacific
Wasson, Kerstin	Elkhorn Slough Reserve/ UCSC
Windham, Diane	NOAA
Winslow, Erin	UC Santa Barbara - Bren
Zabin, Chela	UC Davis
Zacherl, Danielle	Cal State Fullerton

Appendix B

Oyster Restoration Forum Agenda

16-17 March 2017

A Forum Jointly Sponsored by American Honda Motor Co., Inc. and the Aquarium of the Pacific in partnership with the Bren School SoCal Oyster Group, University of California, Santa Barbara.

The Forum is designed to answer the following questions:

1. *Under what environmental and societal conditions is oyster restoration an effective strategy for ecosystem restoration?*
2. *Where are these conditions found in Southern California?*
3. *What are the appropriate incentives to trigger and sustain oyster restoration efforts in selected sites in Southern California?*
4. *What are the key metrics for measuring success?*

{The emphasis of the SoCal Oyster Group Project is on number 3.}

March 16, 2017

9:00 Welcome and Self Introductions
Jerry Schubel for the Aquarium
Erin Winslow for the Bren Oyster Group
Steven Center for the American Honda Motor Co., Inc.

9:15 Goals of the Forum: Desired Outputs and Outcomes
Emily Read
Jerry Schubel

9:30 A brief overview of the findings of the Bren School Oyster Project
Bren School Oyster Group

10:00 Oyster Restoration in California (Dr. Danielle Zacherl, CSU Fullerton; Bren SoCal Oyster Group). Discussion led by Bren SoCal Oyster Group

- Brief descriptions of existing restoration efforts
- Preliminary identification of areas of high potential for successful oyster restoration efforts in Southern California

10:30 BREAK

10:45 Oyster Restoration in California Discussion Continued

11:40 Summing Up the First Morning: Lessons Learned
Bren Oyster Group
Hunter Lenihan
Jerry Schubel

12:00 LUNCH - Oyster shucking demonstration and fresh oysters by Carlsbad Aquafarm; Short Video by Desmond Ho and Emily Read, Bren Oyster Group

1:00 Case Studies and Lessons Learned:
North Carolina, Professor Hunter Lenihan, UC Santa Barbara

1:30 Chesapeake Bay, Dr. Robert D. Brumbaugh, TNC The Nature Conservancy

2:00 San Francisco Bay, Chela Zabin, UC Davis

2:30 BREAK

3:00 The New York Harbor Billion Oyster Project, Murray Fisher, Founder of New York Harbor School and the Billion Oyster Project

3:45 The Southern California Situation Revisited
Panel Discussion: Where and how managers can use the lessons learned from the discussed case studies in Southern California?

Panel will be composed of all speakers plus Kerstin Watson and Mark Page, Moderated by the Oyster Group with a set of carefully crafted questions developed before the Forum and shared with Panelists)

4:30 Adjourn

5:30 Dinner at Aquarium

7:00 Public Lecture in the Ocean Theater by Bren School SoCal Oyster Group, University of California, Santa Barbara

March 17, 2017

9:00 A Brief Recap of Day 1 and An Overview of Goals for Day 2
Colleen Grant, Bren Oyster Group, Hunter Lenihan and Jerry Schubel

9:15 Continue identification of areas of high potential for oyster restoration and the qualities that give them high potential. The goal is to identify specific areas in Southern California that have high potential, and brief descriptions of why each of them has high potential for success.
Key resources—data, information, researchers, citizen groups, etc.
Discussion facilitated by the Oyster Group and Jerry Schubel

10:15 BREAK

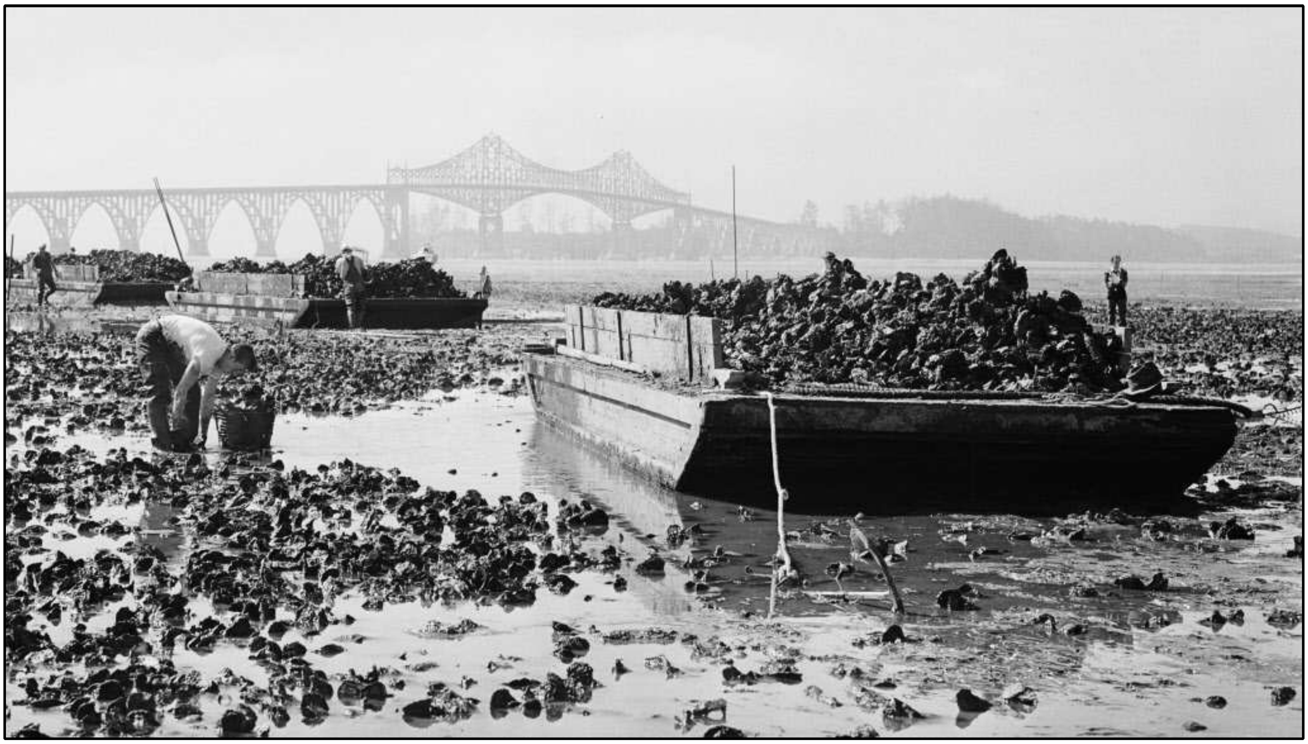
10:30 Facilitated discussion led by Professor Lenihan.

12:30 Lunch

1:30 Summary and Wrap-up and Identification of Next Steps
Oyster Group Representative, Desmond Ho
Hunter Lenihan
Jerry Schubel

3:00 Adjourn

From
British Columbia to Baja California
Restoring The Olympia Oyster *(Ostrea lurida)*



Report of a Forum Sponsored by
American Honda Motor Corporation
Aquarium of the Pacific
Bren School of the University of California, Santa Barbara

16-17 March 2017

Acknowledgements

We thank the Bren Oyster Group, all of the other presenters, and those who authored sections of this report. We thank the Bren students for acting as rapporteurs and for their excellent notes. We also thank Linda Brown for handling the logistics from start to finish and for helping assemble the sections of this report. We also thank Linda Brown and Claire Atkinson for editing the report.

Jerry R. Schubel, Aquarium of the Pacific
Steven Center, American Honda Motor Co., Inc.
Hunter Lenihan, UC Santa Barbara

This report can be found at:
http://www.aquariumofpacific.org/mcri/info/restoring_the_olympia_oyster/forums

Table of Contents

Introduction

On March 16 and 17 approximately thirty people gathered at the Aquarium of the Pacific in a forum to explore the opportunities to restore the native Olymipia oyster, *Ostrea lurida,* in Southern California. The forum was stimulated by the SoCal Oyster Group of the Bren School of the University of California, Santa Barbara (UCSB), who are working on a team project for their M.S. degree. The forum was sponsored jointly by the Aquarium of the Pacific, the American Honda Motor Company, and the UCSB Bren School.

The primary goals of the Bren graduate student project are to determine:

1. Under what environmental and societal conditions is oyster restoration an effective strategy for ecosystem restoration?
2. Where are these conditions found in Southern California?
3. What are the appropriate incentives to trigger and sustain oyster restoration efforts in selected sites in Southern California?
4. What are the key metrics for measuring success?

The emphasis of their project is on goal number 3.

We invited a number of experts from around the state and the country who have had experience in oyster restoration projects not only with Olympia oysters (*Ostrea lurida),* but also with eastern oysters (*Crassostrea virginica*) and Pacific oysters (*Crassostrea gigas*). The objective was to provide context for efforts in California to restore the Olympia oyster and to provide insights from those efforts that might be applicable in California.

The participants in the forum are listed in Appendix A.

Setting the Context

Ostrea lurida, whose common name is the Olympia oyster, derives its name from Olympia, Washington, in the Puget Sound area. For thousands of years the Olympia oyster thrived in many tidal channels, estuaries, bays, and sounds of the eastern Pacific Ocean, from Southeast Alaska to Baja California. The total amount of favorable habitat on much of the West Coast of North America is naturally limited because of the paucity of estuaries, bays, and lagoons compared with the East Coast.

The Olympia oyster once supported a Native American subsistence fishery. Indian kitchen middens near San Francisco Bay contain Olympia oyster shells in sufficient quantities to establish that the animal was an important food item of coastal tribes (Barrett 1963). Indians in the southern Puget Sound region located their villages close to Olympia oyster populations (Steele 1957). The Olympia oyster was commercially exploited beginning in the 1850s in the Pacific Northwest.

The Olympia oyster declined dramatically in abundance in the 1800s in many of the estuaries in its native range because of over-harvesting, pollution, and habitat destruction. In the past decade efforts have begun to conserve, enhance, and restore Olympia oyster populations (Wasson, et. al. 2015). Throughout the 1850s and 1860s schooners laden with Olympia oysters were travelling between Oysterville, Washington, and San Francisco, heralding the start of a lucrative Pacific Northwest shellfish industry. By 1870, overharvesting had already significantly depleted oyster stocks in both Willapa Bay and Puget Sound. To augment their ailing stocks, oystermen began importing the larger and faster-growing Japanese or Pacific oyster in large numbers, which soon displaced the Olympia oyster in their cultivated beds (Pacific Biodiversity Institute).

Before their populations were decimated, Olympia oysters may have protected sections of the coastline against storm waves and storm surges and provided habitat for fish and invertebrates and food for humans and marine life. Today Olympia oysters are still present, but in discontinuous patches and in very low numbers. With a rising sea, a growing recognition of the important roles these animals could play in the future has triggered efforts to identify sites, where Olympia oysters were once abundant and remnant populations remain, that could be candidates for restoration.

A Guide to Olympia Oyster Restoration and Conservation: Environmental Conditions and Sites that Support Sustainable Populations (2015) is an important document that provides an excellent summary of the environmental conditions that affect the success of Olympia oysters. It also provides a qualitative evaluation of twenty-eight embayments along much of the native range of Olympia oysters and evaluates the risks and the stresses on existing populations and the potential for restoration.

A Look Ahead

As Southern California's coastal population continues to grow, as sea level continues to rise, and as the frequency and intensity of coastal storms increase, humans will be faced with an ever-increasing challenge of how to protect valuable natural coastal resources and their own built environment. The best management strategies will depend upon factors including: relief of the coastline, composition of coastal deposits, human population and infrastructure at risk, and natural protection. Both hard and soft solutions will have a place in the management portfolios of the future, as will managed retreat. The concept of living shorelines—shorelines fringed with salt marshes, mangroves, productive shell beds, beaches and dunes—will in many cases be a primary or secondary strategy for dealing with the "new normal." They offer many benefits, both direct and indirect, at modest cost. Over the past century or so we degraded or destroyed many of these environments before their true value was widely recognized. Now we know their value and have the knowledge and the technology to, in some cases, restore these ecosystems and, in others where no remnants remain, to create them. Oyster beds are one such ecosystem.

In this report we present several case studies of efforts underway to restore Olympia oysters (Elkhorn Slough, San Francisco Bay, Newport Bay, and San Diego Bay) and one effort that was terminated, but which we hope to restart (Alamitos Bay). We also present a case study from New York Harbor—the Billion Oyster Project (BOP). BOP, an initiative of the New York Harbor Foundation, is an ecosystem restoration and education project aimed at restoring one billion live oysters to New York Harbor and engaging hundreds of thousands of school children through restoration-based STEM education programs. Students at New York Harbor School have been growing and restoring oysters in New York Harbor for the last six years. The project was stimulated by the destruction to the greater

New York City area by Super Storm Sandy in 2012. The project had its origins in a Rebuild Design Competition. The Living Breakwaters concept was one of six winning proposals in the global competition, and the award was made to New York State.

Our hope is that this report will help stimulate further efforts to restore the Olympia oyster population at appropriate locations in California, and particularly in Southern California.

Insights from the forum

Over the course of the two-day forum, the majority of time was spent in free-form discussions. Participants brainstormed together and were struck by novel insights about Olympia oyster restoration. Below we summarize some of the insights from the forum.

Broad geographic focus: The initial emphasis of this forum was on Southern California, and some of the sponsors and participants will continue to remain focused on this region. But one clear message that emerged from the forum was that Olympia oyster restoration efforts should be united by a common vision and by shared information, along the entire range, from British Columbia to Baja California. There are very few oyster restoration scientists and practitioners along this coast, and they will find greater strength and success by working together, sharing lessons learned, and jointly developing outreach materials to engage the public and gain support from funders. So, while each individual scientist or practitioner will necessarily focus on one or a few estuaries, they will be part of a larger network of Olympia oyster restoration efforts.

Developing an inspirational vision and engaging the community: Forum participants were very moved by a presentation about the Billion Oyster Project in New York City. Murray Fisher of the New York Harbor Foundation described this initiative, and at its core was a heartfelt belief that human communities should be more engaged with their coastal environments. His example was a testament to the power of having an ambitious, simple vision. In New York City, the oyster is being used as an iconic species that inspires outreach and curriculum about coastal health. Our forum participants were inspired to try to formulate this sort of a vision for Olympia oysters along the West Coast and communicate it to our communities. The messages can be similar: Oysters everywhere are iconic coastal species that humans have interacted with for thousands of years. We want our coasts to be healthy, and one part of that is having thriving oyster populations. Fisher's advice from New York was that we don't need to worry too much about getting the details of this vision right. Just dream big and start building connections in the community.

More nuanced understanding of Olympia oyster ecosystem services: West Coast oyster populations likely provide quite different ecosystem services (benefits to humans) than oysters in other regions. In particular, there is uncertainty whether Olympia oysters ever form high profile reefs, while this is the hallmark of *Crassostrea* populations and important for shoreline protection. However, modeling suggests that even shallow beds of Olympia oysters may provide some benefits to shorelines, and if artificial reefs are built for them out of shell bags or other material, this benefit can be further enhanced. New research from San Francisco Bay suggests some species that humans care about, including crabs, sturgeon, steelhead, and wading birds, may be more abundant in living shorelines that include oysters than in adjacent mudflats. Further studies are needed to quantify which benefits Olympia oysters can provide to humans, though forum participants agreed that Olympia oysters merit restoration for their own sake, as well—we should be asking what we can do for oysters, as in the Billion Oyster Project, not just what oysters can do for us.

Complications from *Crassostrea gigas* invasions: Forum participants recognized the need for further science and policy considerations regarding the Pacific oyster, *Crassostrea gigas*. *Crassostrea* is increasing dramatically in distribution and abundance in Southern California, and, with warming waters, is likely to do so in central and Northern California. The Pacific oyster already co-occurs with Olympia oysters in numerous estuaries in the Pacific Northwest. In Southern California, restoration projects are being designed to try to optimize conditions for Olympia oysters over Pacific oysters. For example, the planned San Diego Bay project will keep living shorelines at low elevations. Such considerations may need to be incorporated more broadly across the species' range. Another complication from co-occuring Pacific oysters is the use of ecosystem services as a rationale for restoration. In many cases, Pacific oysters provide better water filtration, provision of fish habitat, and shoreline protection than Olympia oysters. So emphasis on these ecosystem services might lead to the promotion of Pacific oysters rather than Olympia oysters.

Creation of further living shorelines: Forum participants heard inspiring presentations about living shoreline projects in Southern California and San Francisco Bay. There was agreement that the living shoreline approach (creating artificial reefs to provide habitat for oyster settlement and protect adjacent shorelines) is valuable and should be replicated elsewhere along the Olympia oyster range, especially in places where such structures could serve as alternatives to shoreline armoring. In both Southern and Northern California, attempts are being made to jointly restore eelgrass and oysters as a part of living shoreline projects. New projects could be coordinated so that methods and monitoring allow for comparative analyses of restoration success and ecosystem services. In urban environments, living breakwaters might similarly provide benefits of oyster habitat and shoreline protection.

Linkage of aquaculture and Olympia oyster restoration: At some sites, Olympia oyster recruitment is high in most years, and so deployed substrates at the appropriate elevation soon are covered with oysters—"if you build it, they'll come." At other sites, recruitment is very rare in most years. Restoration at these recruitment-limited sites would benefit from linkage to aquaculture, perhaps through partnerships with commercial operations or universities. Stock from such estuaries could be raised in an aquaculture facility, and then mobile restoration units, once covered with spat, could be outplanted to the estuary. The benefit of this approach to oyster populations could be enormous and should be explored sooner rather than later. Forum participants were also interested in creating a niche market for Olympia oysters grown by commercial aquaculture operations. The species is smaller and slower growing than Pacific oysters, but could be marketed like local vegetables or grass-fed beef, for consumers willing to pay more for sustainable choices that benefit the local environment.

Action Items

- There was unanimous agreement to form an initial Executive Committee to keep the momentum of BC to Baja moving. Hunter Lenihan (UCSB) will serve as the first chair and will be joined by Chela Zabin (UC Davis), Danielle Zacherl (CSU Fullerton), and Kerstin Wasson (Elkhorn Slough Reserve, UC Santa Cruz). Others are welcome to join the group.
    - Among their first actions are to form a group to develop a proposal for a session at the next “Restore America’s Estuaries” conference, which will be held in Long Beach in December 2018.
    - Develop a Communications Toolkit. This will be a collaborative effort of the UCSB Communications Department and Honda.
    - Zacherl, Wasson, and Zabin will contact colleagues who are experts on the Olympia oyster in British Columbia, Washington, Oregon, and Baja California. The goal is to create a network of Olympia restoration sites and restoration scientists to share data, information, research needs, etc.
- We need to refine the story line of “British Columbia to Baja California” into a one- to two–page, clear, compelling document with a map. Erin Winslow of the Bren Oyster Group volunteered to create the first draft.
- October 18 to 20, 2017, Fisher will return to the Aquarium of the Pacific. He will present a public lecture on October 19, and we will hold a meeting during that period.
- In future forums, include representatives of appropriate state and federal agencies to enhance understanding of the potential beneficial uses of native oyster restoration. Agencies to include: California Coastal Commission, California Department of Fish and Wildlife, Army Corps of Engineers, National Marine Fisheries Service, and the U.S. Fish and Wildlife Service.

The Bren School Oyster Project
A Summary

Planning and Incentivizing Native Olympia Oyster Restoration in Southern California

Prepared by: Colleen Grant, Brianna Group, Desmond Ho, Emily Read, and Erin Winslow
Faculty Advisor: Hunter Lenihan
Client: Carpentaria Salt Marsh Reserve
Sponsor: Honda Marine Science Foundation

Abstract
The Olympia oyster, *Ostrea lurida*, is the only oyster native to the West Coast of the United States. Populations have declined over the last 150 years due to coastal development, overharvest, and pollution. Through visiting natural history museums and surveying in Southern California, we discovered that small populations of Olympia oysters still exist, though they do not resemble the historic beds they once formed. Oysters are habitat engineers that provide ecosystem benefits such as erosion control, water quality improvement, and habitat for fish and invertebrates. To incentivize oyster restoration, we quantified some of these ecosystem services through a bioeconomic model and cost-benefit analysis. Results revealed that restoring one hectare of oyster bed could increase the kelp bass fishery by 39,304 additional grams in biomass over thirty years and increase the California halibut fishery by $24,411 per cohort. Furthermore, this study suggests that restoring Olympia oysters in the Batiquitos Lagoon could decrease maintenance costs by up to $2 million. Though additional research is needed to better understand the extent of benefits provided by Olympia oysters, this project provides a framework for successful collaboration between experts, researchers, and the community to further restoration efforts.

Project Significance
According to anecdotal evidence, Olympia oysters were once prominent along the western coast of the United States to Baja, Mexico. However, due to overharvesting, pollution, and habitat modification Olympia oyster populations were reduced to a mere fraction of their once historical numbers. As a result, society today faces a shifting baseline. Olympia oysters have been absent from California’s coastline since the early 1900s; thus, people no longer consider Olympia oysters to be an integral component of California’s coastal ecosystems, nor do they realize the ecosystem services oysters provided. Consequently, this species is not included in most coastal restoration or management plans and is not sold for consumption in California.

As ecosystem engineers that provide a number of ecosystem services to people and wildlife, Olympia oysters serve as a model organism for estuary and wetland restoration throughout Southern California. They form beds, which create habitat for commercially and recreationally important species, help reduce wave energy and erosion rates, and improve local water quality through water filtration. Oysters are a key component of our coastal ecosystems and help maintain the quality and health of these important ecosystems.

Along the East Coast and in Washington State, numerous large-scale oyster restoration projects have been implemented to restore populations for the fishery and ecosystem services they provide. In Southern California, small-scale restoration projects have been completed and focused solely on providing hard substrate for larval settlement. Future projects and research aim to identify the bottlenecks that prevent survival and bed formation. They also plan to quantify the magnitude of these ecosystem services in Southern California. Our project's intention is to provide the necessary tools and incentives to motivate and support these future restoration efforts.

Objectives:

- Compile historic and present Olympia oyster spatial data throughout Southern California and create an online database to store this data for future use
- Provide economic incentives for Olympia oyster restoration through a shoreline stabilization cost-benefit analysis and a bioeconomic model to explore changes in fish abundance with a restored oyster bed
- Identify gaps in ecological knowledge and synthesize lessons learned from previous Olympia oyster restoration projects
- Create a network of collaboration amongst scientists, managers, and other stakeholders by organizing an Olympia oyster forum at the Aquarium of the Pacific
- Develop two short films that can be used as outreach materials to engage the public in restoration efforts

Spatial Analysis

To determine suitable locations for future Olympia oyster restoration, current and historical oyster presence need to be identified and monitored regularly.

Data Collection

We visited the Santa Barbara Museum of Natural History, Natural History Museum of Los Angeles County, and the Smithsonian Institution National Museum of Natural History to electronically catalogue previously recorded oyster survey data. These Olympia oyster specimens were collected from Morro Bay, California, to Baja, Mexico, dating from 1910 to 2010. Records included geographic coordinates, date collected, year, length, and available habitat information. Length of the specimens was measured in millimeters from the hinge with manual or digital calipers. Many specimens were collected together by the same person from one GPS location on the same day. In these cases, no more than five specimens in each group were recorded in our dataset. Presence data in San Diego Bay, Alamitos Bay, Newport Bay, and Los Angeles Harbor were also collected from Dr. Danielle Zacherl and Holly Henderson. They collected density counts and presence data from surveys between 2010 and 2014 at these sites. To fill in data gaps, our group also conducted our own surveys at Marina del Rey, Batiquitos Lagoon, San Dieguito Lagoon, and the Carpinteria Salt Marsh Reserve. One square meter quadrats were used to record densities of Olympia and Pacific oysters in the Carpinteria Salt Marsh, while only presence data was recorded in the other locations. We aggregated the data from museums and surveys to create a map of oyster presence in Southern California from 2000 to 2017.

Data Organization and Visualization

Presence data coordinates in degrees, minutes, seconds were converted to decimal degrees using an online conversion website and then loaded into ArcGIS. Extraneous data was removed because of the likelihood of recordkeeping errors. Valid data points were displayed in WGS 1984 and uploaded to ArcGIS online to create an interactive story map. Habitat, substrate, general location, and notes associated with the presence data were then sorted and also made visible in the story map. We hope this map will allow the public, restoration scientists, and managers to gain a better understanding of historical and current Olympia oyster populations in Southern California. This information can be used to prioritize restoration sites and can evolve as more spatial data is collected. This online database is viewable to the public and can be updated by approved parties (http://arcg.is/2n61DgU).

Incentives for Native Oyster Restoration

Fish Production

On the East Coast, restoring oyster beds increases taxonomic richness and the abundance of certain fishes that are limited in recruitment or growth. These complex living structures provide both nursery and foraging habitat for many important species. Data on the West Coast is limited in terms of how native oyster beds impact the surrounding aquatic communities, but preliminary studies show increases in food production of small invertebrates such as amphipods (Zacherl et al., unpublished data). We assumed species that recruit to rocky reefs would have likely recruited to these native oyster beds in bays and estuaries prior to the 1900s.

Both California halibut and kelp bass would likely be impacted by the restoration of native oyster beds. The California halibut has experienced a significant decline in landings throughout California, particularly in Southern California. While data are unavailable for past trends in kelp bass abundance, anecdotal evidence suggests that this species comprises a significant portion of recreational catch in Southern California. Oysters provide important intertidal and subtidal habitat in bays and estuaries that can assist these species in overcoming specific life history bottlenecks and survive into adulthood. Through this population model, the expected increases in both California halibut and kelp bass were quantified to incentivize the inclusion of native oyster restoration in future management actions.

Fish Production: Results and Implications

Through a stable age structured model, we quantified that the increase in California halibut fishery revenue increases by about $24,000 per hectare of restored oyster reef over a thirty-year period. The number of extra kelp bass that would be produced is ~1,100 individuals over a thirty-year period. These values are most likely underrepresented because we were unable to include local recruitment, reproduction, and production of additional fish and invertebrates that serve as a food source to important fish species. Further research and experimentation is needed to better understand how the restoration of oyster beds may impact our local species and fisheries. Based on the many services provided by Olympia oysters as an ecosystem engineer, we can predict that restoration of this animal could positively impact the health of California's coastlines and the many species that inhabit these critically important areas, including people and wildlife.

Shoreline Stabilization

Large-scale restoration of Olympia oyster beds could replace common costly and environmentally unfriendly means of shoreline stabilization that exist today. We analyzed Batiquitos Lagoon in San Diego County to determine how Olympia oyster beds might act as a cost-effective means for shoreline stabilization. Understanding how the costs and benefits compare at the Batiquitos Lagoon could offer an economic incentive for local entities to utilize Olympia oysters as a means of shoreline stabilization, instead of common, temporary solutions.

<u>Assumptions</u>

In order to conduct this analysis, a series of assumptions were made to simplify both the conceptual and mathematical framework. These assumptions include:

1. Olympia oysters are bed-forming invertebrates, making them an alternative to rock revetment or beach nourishment.
2. Oyster beds grow faster than the rate of sea level rise(Grabowski et al., 2012).
3. There are enough oyster larvae naturally occurring in the water column to settle on substrate and survive to sustain the bed.
4. Chosen restoration sites have suitable oyster habitat.
5. Value of property protection or damage per acre is constant among sites.

Our study covered a thirty-year time frame spanning from 2017 to 2046 and used a discount rate of 4 percent. Additionally, the net present value (NPV) of costs and benefits ignored the time cost of planning and consulting with relevant agencies for restoration. All values used were adjusted with inflation to the value of a U.S. dollar in 2016. Below are the site-specific costs and benefits used in this study.

<u>Methods</u>

Batiquitos Lagoon is located in San Diego County close to the southernmost limit of our project area. Dredging and beach nourishment occur on an as-needed basis (usually annually), and the costs are publicly available. There is some shoreline armoring in the form of rock revetment at this site. Batiquitos Lagoon was used as a comparison because of its known costs and use of stabilization methods similar to those in the Carpinteria Salt

Marsh. Our analysis calculated the NPV of the costs and benefits for Batiquitos Lagoon in two scenarios: with Olympia oyster bed restoration and without restoration.

Benefits
Without restoration, the benefits at Batiquitos Lagoon were flood control, water quality, wildlife habitat, and recreation. These benefits were taken from a California Sea Grant study conducted by Rager, Clifton, & Johnson (1995). In addition, Batiquitos Lagoon provides essential habitat for migratory waterfowl, birds, and fish species (Batiquitos Lagoon Foundation, 2017). Wetlands absorb wave energy and reduce the velocity of incoming surges. As a result, these living shorelines provide flood control to coastlines and property owners (Rager et al., 1995). The U.S. Army Corps of Engineers valued flood control provided by California's wetlands at $4,650 per acre (Allen, 1992). This value represents the amount of damages avoided with an intact wetland present. Wetlands also filter and treat water by removing nutrients, bacteria, and toxic chemicals. This water quality improvement by wetlands is valued at $6,600 per acre (Rager et al., 1995). Similarly, wetlands provide important nursery and foraging habitat to fish and invertebrates. From a survey that assessed people's willingness to pay to preserve a California wetland, this benefit is valued at $3,337 per acre for Batiquitos Lagoon (Allen, 1992). Finally, wetland ecosystems provide a recreational value to people through activities such as bird watching, hiking, and fishing. Stol et al. valued this recreational benefit at $3,347 per acre through a travel cost method in Batiquitos Lagoon (Allen, 1992). The annual dredging and beach nourishment that occur at this site maintains these benefits the wetland in Batiquitos Lagoon provides.

With restoration, our analysis examined the area of wetland habitat that would be protected by Olympia oyster bed restoration. Oyster beds would protect this essential wetland habitat and, therefore, maintain the benefits of the wetland (flood control, water quality, wildlife habitat, and recreation) without the need to dredge and nourish the beaches annually. We assumed this benefit is included in the analysis by reducing lagoon dredging and beach nourishment from annually to once every five years and is accounted for in the costs. Multiple groups would gain from these benefits including homeowners, the City of Carlsbad, recreational users of the lagoon and its wetlands, and the environment including wildlife that utilize the lagoon and restored beds as habitat. In both scenarios, the benefits of the wetland habitat are maintained; however, the costs to maintain that wetland habitat are different due to the two methods of shoreline stabilization.

Costs
With oyster restoration, the costs taken into account at Batiquitos Lagoon included restoration costs, permitting costs, and periodic costs of lagoon dredging and beach nourishment. Restoration costs were estimated at a high and low restoration cost and included shell addition, permitting, and initial construction costs (Harrison, H., Garrity, N., & Zacherl, D, 2015). The costs of shell addition were taken from the San Diego Bay Native Oyster Restoration Plan (Harrison, H., Garrity, N., & Zacherl, D, 2015). We initially used both low- and high-cost estimates, but to remain conservative in our estimates of benefits relative to costs, we used the high-end estimates for our final analysis. Shell addition costs occurred twice at Batiquitos Lagoon due to the high sedimentation rates at this site. The

costs of permitting were calculated using the proposed area for restoration of 0.2 hectares. Permitting prices calculated were taken from the California Department of Fish and Wildlife Mitigated Negative Impact Permit and the Coastal Development Permits from the California Coastal Commission. Lagoon dredging and beach nourishment would need to continue on an annual basis until the restored beds become self-sustaining, no longer needing human maintenance to survive and grow. There is uncertainty as to how long it would take for oyster beds to become self-sustaining. Therefore, three restoration analyses were conducted in five-year, ten-year, and fifteen-year periods for the beds to become self-sustaining. During these periods, beach nourishment and dredging take place on an annual basis. After the beds become self-sustaining, it was assumed that dredging and beach nourishment would only need to occur every five years. Groups that would incur the costs include groups funding the restoration such as the California State Coastal Conservancy, Batiquitos Lagoon Foundation (restoration, dredging, beach nourishment), and the City of Carlsbad.

Without oyster restoration, dredging and beach nourishment would continue to occur on an annual basis. However, at the current spending rates, the Batiquitos Lagoon's dredging fund is expected to run out in thirty years (Paul Sisson, 2016). Historic dredging costs have ranged from $256,000 to $1,300,000 per year (Paul Sisson, 2016). We included the low estimated dredging cost and the exhaustion of this fund in the analysis. Without restoration, the Batiquitos Lagoon Foundation would cover the costs of the dredging and beach nourishment annually until the fund ran out. In addition, homeowners, wildlife, and recreational users of the lagoon would incur costs if the quality of the lagoon decreased over time without restoration.

<u>Shoreline Stabilization: Results and Implications</u>

Without oyster restoration, the NPV of the net costs (costs minus benefits) is about $1 million more expensive than the most expensive oyster restoration scenario (fifteen years until self-sustaining). This indicates that lagoon dredging without restoration is the most costly option for the lagoon foundation. If oyster restoration took place, savings to the lagoon over the next thirty years could alleviate dredging costs by $1 to $2 million. Although the costs outweigh the benefits in all scenarios, the costs associated with oyster restoration are significantly less than without restoration. These results also suggest that oyster restoration could alleviate the costs associated with annual dredging in other Southern California embayments.

Communication Tools for Restoration in Southern California

While there are many potential locations and incentives for restoration in Southern California, we need the support from coastal communities, policymakers, and environmental managers. Society today is generally unaware of the historic presence of Olympia oysters and the benefits they once provided to coastal ecosystems. This project developed communication tools that will help convey the importance of restoring Olympia oysters to the public and relevant stakeholders.

Communication Tools

Video Production

Future oyster restoration projects will benefit greatly from the input and involvement of local communities. By speaking with community members and showcasing the importance of this work through video, we can potentially get them involved in the projects through volunteering. Their effort to help lay out substrate for oyster recruitment and to monitor progress in restoration sites will greatly reduce the cost of labor for restoration and allow the volunteers to feel more connected to their environment. We will be producing videos to inform target audiences about how the restoration of native oysters can enhance the biodiversity and resiliency of the Southern California coastal ecosystem.

PSA Video (1-3 minutes)

This short public service announcement will be aimed at the coastal communities of California. It will be shared on social media to create a widespread awareness of the history of oysters in Southern California and briefly explain how restoring them can provide ecological benefits. It will incorporate footage from the work we accomplished through our research and from groups that are looking for volunteers, such as Orange County Coastkeepers, to give viewers an idea of how they can be involved in improving their coastline.

Oyster Restoration Documentary (10-15 minutes)

The goal of this documentary will be to give interested community members and stakeholders an idea of the history of Olympia oysters and the ecological and economic benefits of restoration. The film will feature oyster experts, environmental managers, and aquaculturists interested in future partnerships with restoration efforts.

Conclusion

With the right tools and incentives, Olympia oyster restoration on a large scale in Southern California can be a reality. Our project has done extensive work on gathering and compiling presence data of Olympia oysters throughout Southern California to aid in the selection of future restoration projects. In order to incentivize these projects, we have initiated an economic evaluation of restored oyster beds through a bioeconomic fish model and a cost-benefit analysis. We found that restored oyster beds have the potential to increase populations of California halibut and kelp bass and to decrease costs of wetland management through shoreline stabilization. Currently, there are several restoration projects in Southern California that aim to fill information gaps regarding Olympia oyster beds and their abilities to provide these ecosystem services. With additional outreach through a public service announcement and short documentary, we believe that these projects can incorporate increased local involvement and help to foster a relationship between coastal communities and marine ecosystems.

For our complete report, please visit the following website:
http://www.bren.ucsb.edu/research/gp_past.html

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Restoration of Native Oysters in San Francisco Bay, California

Chela Zabin, UC Davis and Smithsonian Environmental Research Center

Overview

Historical distribution and abundance

Shells of native oysters occur in the San Francisco (SF) Bay area's fossil record, including in enormous deposits of shell in the bay, and are found in Native American shell middens at various sites around the bay. These oysters were also eaten by early European settlers: Bonnot (1935) wrote that native oysters had been harvested commercially "since the days of the Spaniards." However, the actual abundance and distribution of these oysters is not well characterized, at least in part because of confusion with Olympia oysters from Washington and Oregon that were planted in San Francisco Bay as a fishery beginning in the mid-1800s.

Contemporary distribution and abundance

Currently, Olympia oysters can be found throughout San Francisco Bay, from south of the Dumbarton Bridge north to the Carquinez Bridge. During extensive drought periods, oyster populations may even extend past the Carquinez into Suisun Bay. In years of heavy rainfall, oyster populations experience massive die-offs due to lowered salinity in the northern parts of the bay and to a lesser extent in the south bay, resulting in a distribution restricted to the central portions of the bay (Chang et al. 2016; Cheng et al. 2016). During drought years, oyster populations are highly abundant in the northern portion of the SF Bay, along the Richmond shoreline and from China Camp to Pt. San Quentin. In the central bay, areas around the Berkeley Marina, Sausalito, Strawberry (Marin County), and Oyster Point also support large oyster populations in most years. In 2012 and 2013, adult oyster densities measured at eighteen sites ranged from 961 m^2 at one site in the north bay to 3 per m^2 in the southern part of the bay (Wasson et al. 2014). In the intertidal zone, oysters are typically most abundant at mean lower low water, but are also found subtidally on bridge supports and other submerged hard structures.

Proposed and current restoration efforts

The largest restoration effort in the bay is the California Coastal Conservancy's San Francisco Bay Living Shorelines Project, which constructed oyster reefs in two 10 x 32 m plots off of the San Rafael shoreline in 2012 (http://www.sfbaylivingshorelines.org). In 2013, the project supported an estimated 3 million oysters. This project used mounds of bagged Pacific oyster shell as its main restoration substrate. The project also tested several other concrete substrate types and included planting eelgrass within one of the large plots.

The Conservancy is planning a new, larger living shorelines project for the Richmond shoreline. This project is currently in the permitting stage, with construction slated for summer 2017. Three reefs are planned for oyster restoration, each consisting of large reef balls topped with a layer of shell bags. The effects of tidal elevation and the additions of rockweed (*Fucus*) on oyster recruitment and survival will also be tested. Plantings of eelgrass, native cordgrass, and other native marsh plants are also a part of this project.

Other restoration projects include The Watershed Project's deployment of 100 large reef balls in the intertidal zone at Pt. Pinole (deployed in 2012). Environ Corp also deployed large reef balls in the shallow subtidal area off Cesar Chavez Park in Berkeley in 2010. Pacific oyster shell mounds (bagged and loose) were used in a smaller, earlier project (2005-2009) at the Marin Rod and Gun Club site just north of the Richmond-San Rafael bridge. Smaller efforts aimed at testing sites and materials have been tried at Bair Island and Greco Island in South Bay in 2005-2006 and at the Eden Landing Ecological Reserve in 2012 (as part of the SF Bay Living Shorelines Project).

A fifty-year goal of restored oyster reefs over 8,000 acres was set by the 2010 Subtidal Habitat Goals document, a multi-agency planning effort for San Francisco Bay subtidal and intertidal habitats (http://www.sfbaysubtidal.org/report.html). The document also summarizes Olympia oyster research and early restoration efforts in the bay, identifies key data gaps and challenges to and opportunities for restoration, and recommends a science-based, phased approach for scaling up oyster restoration in the bay.

Wasson et al. (2014, 2015) described some of the ecological challenges to successful oyster restoration in San Francisco Bay. These include the lack of hard substrate at appropriate tidal elevations, competition with other sessile organisms (many of which are non-native), predation at some sites by a non-native predatory snail, warm air temperatures during low tides at some sites, and periodic lowered salinity during rainy years. Oysters may experience these latter two stressors more frequently under climate change. Plus, exposure to high air temperature immediately after exposure to low salinity, which can occur during minus tides in the spring, is particularly detrimental to oyster survival and growth (Bible et al. in review).

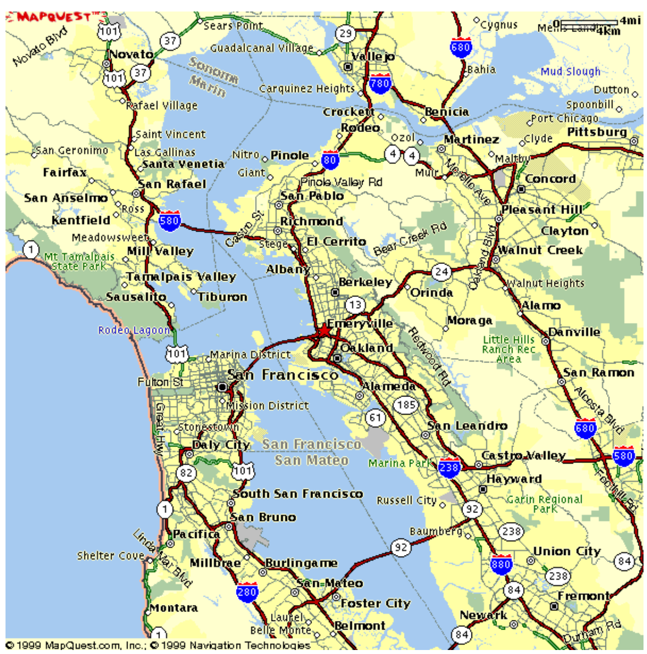
Logistical matters, including landowner permission, site access, permitting issues, funding, and conflicts with user groups may also limit oyster restoration in the bay.

Anticipated potential benefits from restoration

We anticipate that restored oyster reefs will result in greater invertebrate species diversity, mostly through the facilitative effects of the three-dimensional structure that oysters create (Kimbro & Grosholz 2006). Although data are preliminary, there were more infaunal invertebrate species post-construction at the SF Bay Living Shorelines San Rafael site compared to the pre-construction and to a control site, and the ecological community associated with oysters, which included various crab, shrimp, and small fish species, differed from that associated with the mudflat. These species as well as the oysters may represent a more diverse prey base for birds and larger fish and invertebrates. A greater diversity of bird species, including two species of special interest in the bay, were associated with the reef structures compared with pre-construction and a control site (Boyer et al. 2016). Oyster filter feeding can also contribute to improved water clarity, which may enhance eelgrass growth and contribute to nutrient cycling. These effects likely occur at very small scales given the current relatively small populations and may have been a more significant ecosystem function during times of greater oyster abundances.

Increasing oyster abundance and distribution within the bay may ensure persistence and resilience of the bay populations against extreme weather events, such as heat waves and low salinity during heavy rains (Wasson et al. 2016). Although it is unknown whether or how frequently oyster larvae from SF Bay disperse to other nearby locations (e.g. Tomales Bay or Elkhorn Slough), having multiple connected populations along a coast may help promote native oyster persistence within the region.

When oyster restoration is incorporated into a living shorelines design, shorelines can be enhanced through erosion protection and sediment accretion. These designs deliver benefits to human populations, while simultaneously providing species habitat and connectivity between multiple habitat types.



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Restoration of Native Oysters in Elkhorn Slough, Monterey Bay, Central California

Kerstin Wasson, Research Coordinator of the Elkhorn Slough National
Estuarine Research Reserve

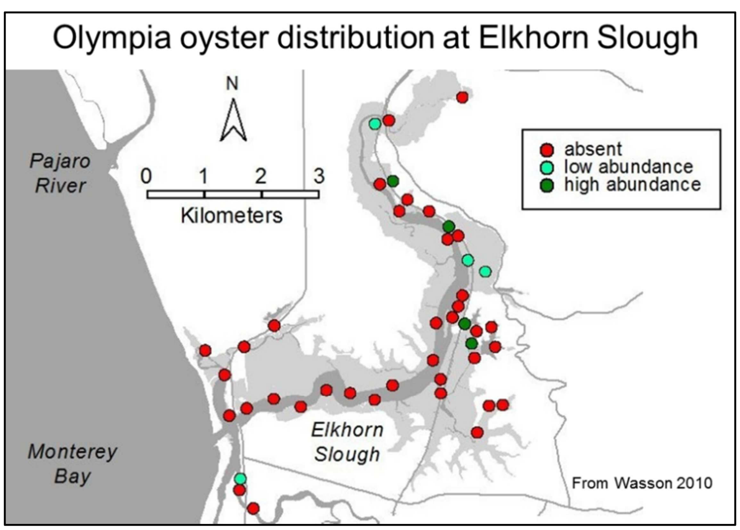
Overview

Olympia oysters have grown in Elkhorn Slough for at least 7,000 years, as evidenced by their presence in virtually every Native American midden at sites throughout the estuary from any period. Now they are extremely rare and in danger of local extinction. The Elkhorn Slough National Estuarine Research Reserve and Elkhorn Slough Foundation are committed to conducting oyster restoration to ensure that this iconic species continues to be represented in the estuary in perpetuity.

Historical distribution and abundance

At Elkhorn Slough, Native American middens reveal that native oysters were present in the estuary from sites near the mouth (e.g., Struve Pond, Moro Cojo) to the upper estuary (e.g., South Marsh), and eaten by humans, for the past 7,000 years. When George MacGinitie first studied the invertebrates of the estuary in the 1920s, he also reported oysters as being highly abundant in many sites from the mouth to the head of the estuary. But within a decade, they had been overharvested by oystermen from San Francisco Bay, and became so rare that they were not detected in surveys for many decades.

Current distribution and abundance



Today the native Olympia oyster is absent or extremely rare in most parts of the estuary, including areas where it once thrived. There are three major threats to adult oysters at Elkhorn Slough (Wasson 2010). The first is poor water quality: Oysters are absent from sites with indicators of extreme eutrophication (high nutrient concentrations, high turbidity, and low night-time oxygen levels). This includes about half of the historic estuarine network, which is behind dikes and water control structures. The second main threat is burial by sediments: In many areas, oysters are smothered by mud if they grow on the tiny bits of natural hard substrate that are available (such as shells); they only survive burial by growing on artificial hard substrates such as rip rap. The third major threat is non-native fouling species: At lower tidal heights, most available space is taken up by non-native sponges, tunicates, and tubeworms.

Today there are estimated to be about 5,000 to 10,000 Olympia oysters in Elkhorn Slough (Wasson 2010). This number seems likely to be much lower than the typical past baseline for the estuary. Recruitment failure is more common at this estuary than almost any other estuary that has been studied along the range of the species, likely because the network of adult oyster sites is so small and because larval retention is low in this very marine-influenced system (Wasson et al. 2016).

Because Olympia oysters are so rare at Elkhorn Slough, and undergo many consecutive years with no recruitment (no new baby oysters join the adult populations), they are in real danger of local extinction. Olympia oysters have gone functionally extinct in the next major estuary to the south, Morro Bay, making the next closest oyster population to the south of Elkhorn Slough very far away, in Carpinteria Marsh. To the north, the nearest substantial population is in San Francisco Bay.

Olympia oyster restoration initiatives at Elkhorn Slough

The goal of oyster restoration at Elkhorn Slough is to prevent local extinction, to maintain a population that has lived in this estuary for thousands of years, and to provide a stepping stone connecting northern and southern oysters along our coast. We hope to double the numbers of adult oysters in the estuary (currently around 5,000 to 10,000) to buffer the population against local extinction.

Unlike Asian or Atlantic oysters, which often form extensive reefs, Olympia oysters tend to grow in small clusters. Our restoration efforts attempt to mimic this natural growth form. We have experimented with various small, modular reefs that provide habitat for oysters. Most of our designs use native gaper clam shells generated by sea otter foraging as the hard substrate, combined with stakes to keep the clusters out of the mud.

Elkhorn Slough Reserve staff members Kerstin Wasson and Susie Fork, together with Smithsonian Environmental Research Center scientist Chela Zabin, spent two years conducting large replicated restoration experiments on the Elkhorn Slough Reserve, with funding from CDFW's Environmental Enhancement Fund. About 200 modular reefs were deployed, including clam shell "necklaces," Reef Balls, and stakes of various types of wood. The team compared oyster success under different habitat conditions and summarized lessons learned in a scientific paper (Zabin et al. 2016). They examined effects of bottom type (gravel or mud), distance between existing adults (near/far), and tidal elevation on oysters that settled on clam-shell "necklaces." The most striking effect was tidal elevation. More oysters settled lower down, but more non-native sponges, tunicates, and bryozoans did, too. So reef placement depends on the restoration goals: to maximize oyster numbers, put them low; but to maximize oyster dominance and have virtually pure native cover, put them high. They also did some adaptive management with this concept, initially putting the reefs low to accumulate lots of newly settled oysters, then moving them high to kill off the non-natives. While using stressful conditions to enhance natives over non-natives is common in terrestrial landscapes (grazing, fire, etc.), this is perhaps the first application of this concept to marine systems, so it has some general value to practitioners working on restoration beneath the tides in other systems.

In the future, this team will continue to deploy small, modular, "artisanal" restoration units to support small clusters of oysters. They are currently seeking grant funding to do this in conjunction with eelgrass restoration at a major salt marsh restoration site on the reserve. This site is heavily used by sea otters, which may benefit from healthy oyster populations.

Elkhorn Slough also has severe shoreline erosion problems, and the team would be interested in testing the effectiveness of a "living shoreline" design to support oysters while decreasing shoreline erosion.

A new area the team would like to explore is partnership with aquaculture experts, so that restoration substrates could be “seeded” with oyster spat from Elkhorn Slough. This could greatly enhance restoration success, since natural recruitment appears to occur only about one year out of four or five in the estuary.

Benefits of Restoration
For the oyster, the anticipated benefit of the restoration work is the ability to survive and persist in this estuary where it has lived for thousands of years. Increased adult numbers within the estuary should lead to more frequent recruitment events.

Maintaining Olympia oysters at Elkhorn Slough is also important for population connectivity between Southern and Northern California, since the closest adult populations are 100 miles to the north and 250 miles to the south.

Oyster restoration at Elkhorn Slough also is meaningful for human populations. People have interacted with native oysters on these mudflats for thousands of years, and there is a real delight in continuing this long tradition. All our restoration efforts involve the community, and interactions with the oysters and their habitat are enriching experiences.

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Restoration of Native Oysters, *Ostrea lurida*, in Alamitos Bay, California

Prepared by Co-Investigator Dr. Christine Whitcraft[1]
Lead Investigator: Dr. Danielle Zacherl[2]
Additional Co-investigators: Terrance Champieux, Sara Briley, Orange County Coastkeeper

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Overview and historical distribution and abundance
Historical documents indicate the presence of oyster beds in Southern California estuaries including Alamitos Lagoon, now called Alamitos Bay (Bonnot 1935). This bay was also reported to historically contain extensive eelgrass beds. As indicated in Pleistocene fossil deposits from Northern California, there is support for the historical association between eelgrass and the Olympia oyster (Miller & Morrison, 1988). Further to the south of Alamitos Bay, researchers recently found Olympia oysters in small abundances within eelgrass beds in San Diego Bay, California (Reed & Hovel, 2006).

Current distribution and abundance
Preliminary field surveys in 2010 (Zacherl et al. unpub) in Alamitos Bay and the connected neighboring Colorado Lagoon revealed that native oysters were present in low densities on hard substrate; however, there were no natural intertidal oyster beds found anywhere in Alamitos Bay for oyster larvae to settle and grow.

Olympia oyster restoration initiatives in Alamitos Bay
In June 2012, Orange County Coastkeeper, in partnership with California State University, Fullerton, California State University, Long Beach, and KZO Education, restored oyster habitat at the Jack Dunster Marine Reserve in Alamitos Bay, California (Figure 1). Teams of researchers, students, and community volunteers laid a new oyster bed using “dead” oyster shell to facilitate future settlement of baby oysters or oyster spat. Over the next two years, we recorded significant increases in oyster settlement, survival, and growth! Details are below.

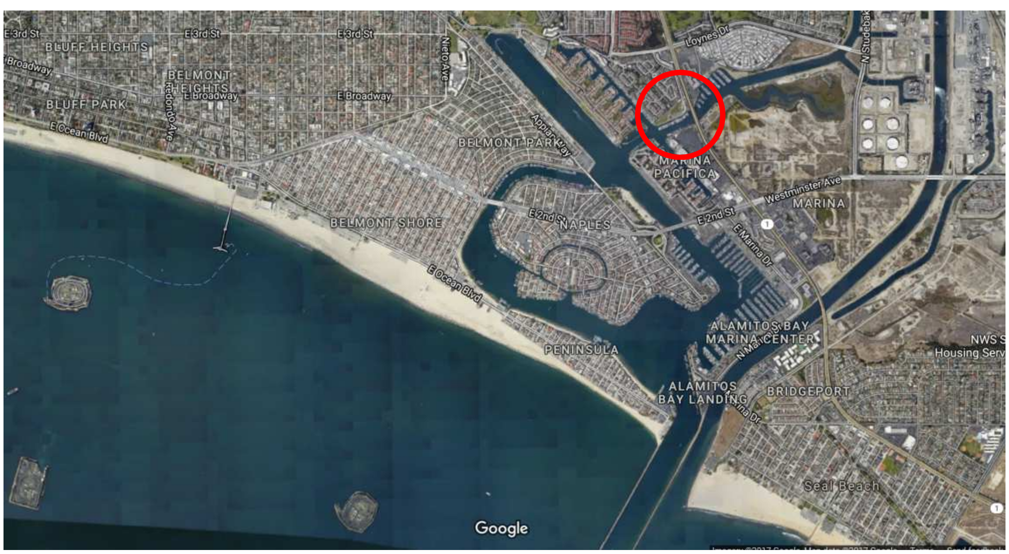

Figure 1. Google Earth image of Alamitos Bay and coastal region with location of oyster restoration circled.

Site history. Alamitos Bay is a highly urbanized estuary, surrounded by suburban neighborhoods, city parks, a city fire station, and schools. The transformation of this bay from a more natural estuary to the current highly urbanized one began in 1923 in preparation for the 1932 Los Angeles Olympics, when the tidal areas of Alamitos Bay were dredged to form Colorado Lagoon and Marine Stadium. A few years later, Colorado Street and a short culvert were installed across the connection to Colorado Lagoon. These transformations likely reduced any Olympia oyster beds in the estuary.

Current description. The study was conducted in Jack Dunster Marine Reserve (JDMR) located at the mouth of the Los Cerritos Channel in Alamitos Bay, Long Beach, California (118°7'9" N, 33°45'43" W) (Figure 1). JDMR is a 2.7-acre site containing 1.5 acres of land and 1.2 acres of wetland and subtidal habitat, which were created in 2000 as a mitigated wetland (Apodaca, 2005).

Experimental setup. The restoration area includes a created oyster bed, mudflat, and eelgrass beds where there were four treatments: one manipulated intertidal mudflat with restored oyster bed (bed) (established June 2012), one unmanipulated intertidal mudflat (control), one subtidal eelgrass bed adjacent to the oyster bed (near), and one subtidal eelgrass bed adjacent to the control (far). The oyster bed started at the southwest side of the eastern-most observation platform in JDMR and extended southwest as a 30 meter by 2 meter band (Figure 2). The near eelgrass site ran parallel, approximately 5 to 10 meters southeast, to the oyster bed and extended southwest as a 30 meter by 2 meter band (Figure 2). The far eelgrass bed continued 30 meters from the end of near and extended southwest as a 30 meter by 2 meter band (Figure 2). The control area, approximately 10 meters from bed creation site, started at the northeast side of the western-most observation platform in JDMR and extended northeast as a 30 meter by 2 meter band (Figure 2). There was one collection treatment outside of the reserve that served as a subtidal eelgrass reference: Basin-6, which was located on the opposite side of Los Cerritos Channel (118°7'7" N, 33°45'41" W) (approx. 57 meters away from JDMR). Basin-6 was included as a subtidal, eelgrass-habitat control because it was likely far enough away from the restored oyster bed to eliminate possible oyster bed effects.

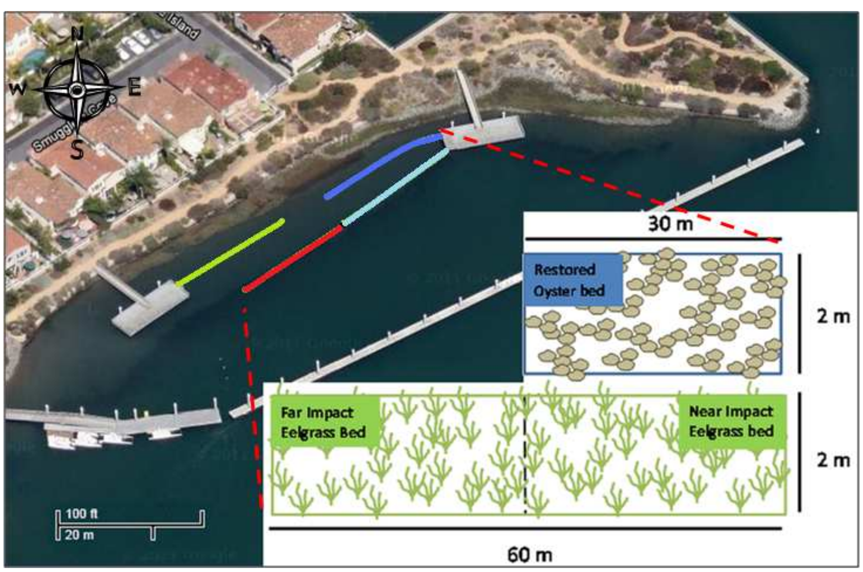

Figure 2. Schematic showing experimental design in Jack Dunster Marine Reserve.

The control location (solid green line), the oyster bed location (solid blue line), and the near and far eelgrass locations (solid light blue and red lines) are illustrated. Image credit: Google Earth.

On June 20 and 21, 2012, loose *Crassostrea gigas* oyster shell (~8 cu. yards) acquired from Carlsbad Aquafarm was used to build a bed approximately 30m long by 2m wide by 8cm deep on intertidal mudflat habitat in JDMR (approximately 60 sq meters). The shell was laid in place using manual labor from researchers and community volunteers. Sample collection for oyster settlement and growth, sediment invertebrates, and eelgrass density occurred annually, in June 2012 (pre-restoration), in January 2013 (seven months post-restoration), in June 2013 (twelve months post-restoration), and January 2014 (twenty-four months post-restoration).

Monitoring results – oyster settlement and growth. Within six months of construction, the oyster shell bed experienced significant shell loss (72 percent of original cover), most likely a result of significant sediment deposition. Oyster larval settlement occurred and adults were present, but at a very low density within the first year (June 2013: 2.29 ± 15.50 individuals m^2, Fuentes et al., unpublished data). In late June 2013, more shell was added to the mudflat to ameliorate shell loss at a lower intertidal height of 0.22 meters above MLLW and to facilitate decreased settlement by non-native *Crassostrea gigas*. In addition, the band of oyster shell was separated into several sections to increase water flow channels.

Monitoring results – invertebrates (Champieux 2015). Other oyster restoration studies throughout the U.S. have shown that restoration of oyster populations are important, but the techniques and structures used for restoration (e.g. the placement of shell on a previously bare mud habitat) could impact the soft sediment mudflat community through trampling and disruption of the sediment-water interface. Infauna and epifauna are benthic animals, such as clams, worms, and burrowing crabs, that live in and on the substrate of a body of water, especially in a soft sediment bottom. As an integral part of the consumer food chain, benthic infauna and epifauna provide important trophic support to species of commercial and intrinsic importance like crab, fish, and birds (Sacco et al., 1994; Levin et al., 1996; Moseman et al., 2004). Within the oyster bed site, invertebrate abundance and species richness were lower only under the oyster bed. The alteration in the community under the shell is driven by a reduction in species with one group of marine earthworms (*Tubificidae*) as the only remaining species under the shell. These results may be explained by the shells' action as a barrier to the mud-water interface. While significant, impacts of oyster bed construction are spatially restricted to just under the bed. In addition, the infauna results described here, we monitored benthic epifauna and are working through those data to determine if patterns are similar to the infauna.

Monitoring results – eelgrass (Briley 2015). In the eelgrass patches following restoration, we found that light was significantly lower each day in the impact site than in the control site for three months following construction. In addition, we observed denser eelgrass with shorter and narrower leaves in the control site as compared to the near impact eelgrass site; yet, the near impact bed maintained a more consistent density and mean leaf size than the far impact eelgrass site. Declines in below-ground biomass after construction of the oyster bed were observed in the impact site only, but did not translate into above-ground biomass loss. Overall, the changes observed were within the wide range of natural variation expected in this system, suggesting that oyster bed creation was not detrimental to the adjacent eelgrass bed. These findings support the potential coexistence of a constructed Olympia oyster bed and adjacent eelgrass, which is relevant to the design of future restoration efforts for both species.

Future directions. We will continue to monitor this habitat to apply the lessons learned at this site to other bays and estuaries in Southern California in an attempt to restore oyster beds to fully functioning habitats. In addition, we will add additional shell to the beds to mitigate for shell loss and sediment deposition that we have observed since the restoration. These beds will provide habitat for other fish and invertebrate species, may help improve water clarity, particularly for sunlight-loving eelgrass beds that often occur adjacent to or in and around oyster beds, and are a demonstration of the community-based restoration work that can happen in the highly urbanized landscape of Southern California.

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Restoration of Native Oysters, *Ostrea lurida*, in Newport Bay, California

Prepared by Lead Investigator Dr. Danielle Zacherl[3], Professor
Co-Investigators: Dr. Christine Whitcraft[4] Associate Professor; Orange County Coastkeeper

Overview and historical distribution and abundance
Historic documents indicate the presence of oyster beds in several Southern California estuaries, including Mugu Lagoon, Alamitos Lagoon, and Newport Bay that supported artisanal-scale harvesting and very small-scale fishery operations for at least a few decades (Bonnot 1935). Specific qualitative mention was made of several intertidal native oyster beds in Upper Newport Bay (Bonnot 1935, Gilbert 1891) north of the Hwy 1 Bridge prior to overharvest and significant habitat modification in the early to mid-1900s. The extent of those beds (size of bed, bed thickness, and oyster density) was not noted by either Bonnot (1935) or Gilbert (1891). Fossil shells recovered from two locations in the bay reveal the presence of oyster beds dating back to 600 years ago (Bonuso and Zacherl, unpublished data), and fossil deposits in nearby Coyote Hills indicate oyster presence in Orange County as far back as the Pleistocene (about 1 million years ago).

Orange County Coastkeeper and collaborator Dr. Danielle Zacherl are working to ensure that oyster bed habitat is reintroduced into Newport Bay using a science-based approach that allows them to explore the ecosystem services that oyster beds may provide and that ensures that this iconic species and the habitat it creates are re-established in perpetuity.

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Current distribution and abundance

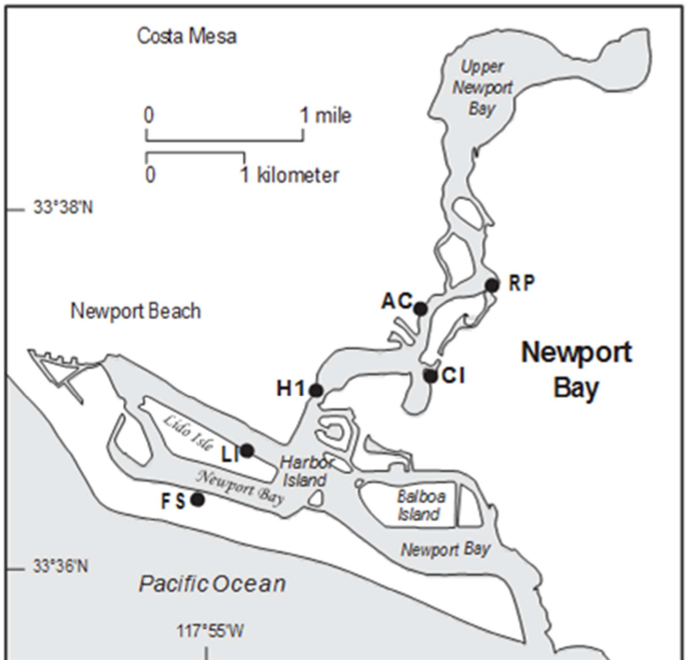

Figure 1. A subset of field sites in Newport Bay most commonly surveyed for Olympia oyster density and recruitment. FS = 15th Street, LI = Lido Island, H1= Hwy. 1, CI = Coney Island, AC = Aquatic Center, RP = Rocky

Field surveys (Polson and Zacherl 2009, Tronske, Zacherl et al., unpublished) of the entire bay (n = 30 field sites) prior to any restoration efforts revealed that while oysters ranged from present and rare to abundant, there was no natural intertidal "bed" of oysters anywhere in Newport Bay. The only location where oysters are known to be absent or where their current abundance is unknown is in the furthest reaches of Upper Newport Bay, north of Rocky Point (Figure 1), where the salinity dips below about 20 ppt and where hard substrata are absent. At highest density (Hwy 1, Figure 1), they measured ~ 54 oysters per square meter on a mudflat that was 44 percent mud and ~ 56 percent hard substrate in the form of unconsolidated gravel, shell, small, medium and large boulders (Zacherl, unpublished data, fall 2007).

Olympia oyster restoration initiatives in Newport Bay

From 2010 to 2012, Zacherl et al. (2015) initiated a pilot restoration study in Upper Newport Bay at Hwy 1 to explore which of several commonly employed oyster restoration techniques would be most successful for restoring the Olympia oyster in Newport Bay, California. Replicate (n=5) 2 meter by 2 meter shell beds were constructed of two initial shell planting thicknesses (bed thicknesses of 4 centimeters versus 12 centimeters) and two methods of deployment (bagged versus loose shell). Shell cover, oyster spatfall (settlement), oyster recruitment, and adult oyster densities were analyzed over two years;

12 centimeter-thick oyster beds maintained higher shell cover, experienced less sedimentation, and received greater numbers of oyster recruits than 4 centimeter-thick beds. There was no significant effect of shell deployment method on shell cover, recruitment, or adult density; however, spatfall was greater on loose shell beds compared to bagged shell beds in the final year of the study. Overall, augmenting mudflat habitat with oyster shell significantly increased adult *Ostrea lurida* oyster density twenty-six times, compared to un-manipulated plots and increased oyster density two to three times the average density of oysters measured elsewhere in Newport Bay. Collectively the data suggest that building thicker shell beds might increase the longevity of a constructed shell bed, and therefore this approach was recommended for future restoration activities in Southern California. This study highlighted the advantages of augmenting habitat in a manner that provides vertical relief from sedimentation.

In 2015, Orange County Coastkeeper received funding from the California Coastal Conservancy to initiate the Upper Newport Bay Living Shoreline Project. Dr. Danielle Zacherl of CSU Fullerton is a subcontractor under Orange County Coastkeeper. The team is in the midst of implementing a plan to restore native Olympia oyster (*Ostrea lurida*) and eelgrass (*Zostera marina*) habitat in Upper Newport Bay using natural structures as habitat that will also serve to buffer and protect adjacent shorelines from sea level rise and erosion. The team has been conducting baseline monitoring, implemented eelgrass restoration efforts in summer 2016, and will build oyster beds in April 2017 and monitor restoration effectiveness through April 2017.

Starting in June 2016, we constructed a series of four, 110 meter by 12 meter, Living Shoreline Blocks (Figure 2) in Upper Newport Bay. Within each block, we added one plot of four restoration treatments: 1) oyster shell bags (20 meters by 1.5 meters), 2) transplanted eelgrass bed (20 meters by 8 meters), 3) restored oyster bed above a restored eelgrass bed, and 4) a control treatment left un-manipulated, with 10 meters of separation between each treatment (Figure 3). The four blocks are parallel to shore in several locations in Upper Newport Bay, including along De Anza Peninsula, Castaways, and Shellmaker Island (Figure 2). This design, with four replicates of each treatment, will enable comparisons of single species versus integrated restoration techniques on species performance, habitat value, and shoreline protection to determine the restoration configuration offering the most benefits. Thus far the eelgrass restoration occurred in summer 2016, and oyster beds will be constructed in April 2017.

Overall, we will measure a host of parameters including environmental (temperature, salinity, dissolved oxygen, pH, and turbidity), physical (shoreline position, substrate, vessel wake height/frequency, relative current velocity, and sedimentation) and biological (native and non-native oyster abundance, density, and growth; eelgrass turion density, areal extent, growth and minimum/maximum depth ranges; and community diversity) characteristics of each site.

Figure 2. Restoration site locations: replicated 110 meter-length Living Shoreline Blocks (oyster shell and transplanted eelgrass treatments) shown in red and eelgrass donor sites shown in blue.

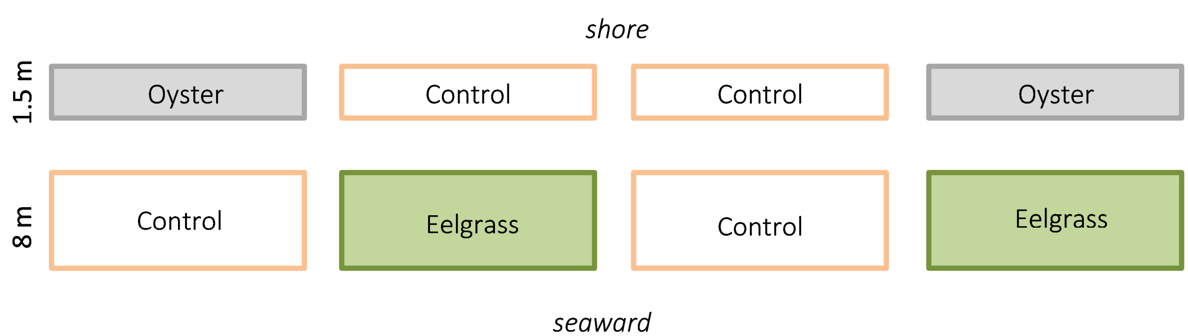

Figure 3. Example arrangement of four restoration treatments *(control, oyster, eelgrass, and* combined oyster + eelgrass) within one Living Shoreline Block. Treatments will be randomly arranged within each block and replicated at four sites in Upper Newport Bay.

Benefits of restoration

Restoration of these species is critical to the health of a resilient Newport Bay ecosystem, as both species return many ecosystem services back to our coastal wetlands. Oysters can improve water clarity and remove anthropogenic nutrient inputs from the water column, increase biodiversity through the creation of complex habitat, stabilize sediments, buffer erosion, and attenuate wave energy. Eelgrass meadows provide similar ecosystem services, including habitat and foraging grounds for many invertebrate, fish, and bird species; nutrient cycling; carbon sequestration; sediment stabilization; and water quality improvement. A primary goal of our project is to protect, enhance, and restore these habitat-forming species now that may be impacted by climate change to increase their resiliency to future change and preserve the ecosystem benefits they provide. As foundation species, oysters and eelgrass will continue to improve their environment, causing a positive feedback loop promoting future establishment and stability. To keep pace with future sea level rise and other climate related stresses, we must begin conservation and restoration of these key habitat-forming species now.

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Restoration of Native Oysters in San Diego Bay, California

Prepared by Project Team Member Dr. Danielle Zacherl[1], Professor

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Holly Henderson, Merkel and Associates, Inc.
Nick Garrity, P.E., ESA
Megan Cooper, California State Coastal Conservancy
Eileen Maher, San Diego Unified Port District
Carolyn Lieberman, United States Fish and Wildlife Service
Mayda Winter, Southwest Wetlands Interpretive Association

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Overview

The San Diego Unified Port District teamed with the California State Coastal Conservancy and other partners (Holly Henderson, Merkel and Associates, Inc., Nick Garrity, P.E., ESA, Carolyn Lieberman, United States Fish and Wildlife Service, Mayda Winter, Southwest Wetlands Interpretive Association, and Dr. Danielle Zacherl, CSU Fullerton) to develop a proposal to implement a project in San Diego Bay that integrates intertidal shoreline stabilization with restoration of native Olympia oysters, *Ostrea lurida.* A primary goal of our project is to create a biologically rich native oyster bed in San Diego Bay as part of a complete marsh system that restores an ecological niche that was historically present, is ecologically functional and resilient to changing environmental conditions, and also protects bay tidelands and shoreline.

Historical distribution and abundance

In San Diego Bay, and Southern California estuaries in general, there is a rich history of the presence of oysters, including *Ostrea lurida,* the only remaining extant native oyster, that extends back to 23 million years ago. From fossils archived at the San Diego Museum of Natural History (SDMNH), there is extensive evidence of the presence of the genus *Ostrea* (identified as *Ostrea sp.*) from formations formed during the Pliocene epoch (5 to 2.5 million years ago) as well as several other genera that are no longer extant (e.g. the once very common *Dendostrea vespertina*, which exists in the fossil record in California from 23 to 2.5 million years ago) or now present only in the Sea of Cortez and southward (e.g. *Ostrea angelica*, now *Myrakeena angelica*).

The Holocene epoch began 11,700 years ago, and much of the evidence of continued oyster presence in the area comes from archaeological excavation of shell middens. In a review of forty-four San Diego County archaeological sites/middens, Laylander and Iversen (2008) provide evidence that *Ostrea lurida* ranged from not present to as high as 50 percent by weight of shellfish recovered; *Ostrea lurida* typically represented between 5 to 10 percent of the total shellfish by weight.

Oysters seem to have continued to play an important role as a food resource from the 1600s through the early 1900s. Davidson (1887) provides excerpts of the explorations of Cabrillo, Viscaino, and others that include mention of oysters as a food resource in San Diego Bay. In Viscaino's description of his experience in San Diego in 1602, he notes that, "in this harbor there is a great variety of fish, as oysters, mussels, lobsters…abounded." More recently, Ingersoll (1881) mentions that at La Punta on the south side of San Diego Bay, there were large enough numbers of oysters of sufficient size to have potential commercial importance (but he noted their coppery flavor). Gilbert (1889) and Bonnot (1935) described the presence of oyster beds in several Southern California estuaries, including Alamitos Bay and Newport Bay in Orange County, and Mission Bay, San Diego Bay, and the Tijuana River Estuary in San Diego County. Lastly, Hector (2002) examined the patterns of shellfish consumption of urban San Diego residents at around the turn of the century by examining the shellfish remains from two archaeological deposits—one dated at the turn of the twentieth century and the other from approximately the 1920s. These deposits indicated that *Ostrea lurida* was a food resource at the turn of the century, but it was replaced by *C. virginica* in subsequent decades. In sum, there is extensive evidence that *Ostrea lurida* was present in San Diego Bay and nearby estuaries, that it was an exploited food resource by Native American Indians prior to Spanish exploration, and it continued to be exploited through the turn of the twentieth century.

Current distribution and abundance

Density (n = 7 field sites, Tronske, Zacherl et al., unpublished) and presence/absence (Henderson, Merkel Inc.) surveys throughout the bay in 2013 and 2017 have revealed that native oysters, *Ostrea lurida*, and non-native Japanese oysters, *Crassostrea gigas*, ranged from present and rare to very abundant (up to 200 Olympia oysters per square meter and forty-five Japanese oysters per square meter). There is no natural intertidal "bed" of oysters anywhere in San Diego Bay. The only location where oysters are known to be absent are selected mudflats where hard substrata are completely absent.

Olympia oyster restoration initiative in San Diego Bay

Since 2013, the project members have been conducting preliminary studies in San Diego Bay on the physical and biological features of the bay. That, combined with modeling studies, has resulted in the formation of an extensive, large-scale restoration plan. See the document *San Diego Native Oyster Restoration Plan* for a complete description of preliminary studies and resultant study design; the overarching study objectives and a brief description of the study design are included here.

One of the primary objectives of the restoration project is to explore if constructed oyster reef arrays reduce water flow velocities, attenuate waves, and reduce rates of erosion/increase rates of deposition shoreward of the reef arrays, and whether any of these reductions result in a measurable change in shoreline morphology. In addition, the common presence of both native and non-native oysters in the bay allows a timely and unique opportunity to explore whether the tidal elevation of constructed oyster reef elements affects recruitment of native *O. lurida* and non-native *C. gigas* and other species that compete for space with native oysters. Our preliminary data indicate that the native and non-native oysters exist in San Diego Bay and elsewhere in a strong zonation pattern such that non-natives favor higher tidal elevations, and natives favor lower tidal elevations. Confirming this zonation pattern in our study will have extremely important implications for future oyster restoration study designs, especially for targeting the tidal elevation for future restoration projects that will favor native oysters.

In addition to exploring the above hypotheses, we will measure a host of other parameters to include environmental (temperature, salinity, dissolved oxygen, pH, and turbidity), physical (shoreline position, substrate, vessel wake height/frequency, relative current velocity, and sedimentation) and biological (community diversity) characteristics of each site.

The study design includes the construction of multiple oyster reef arrays (n=3 each at two tidal elevations) along the E Street Marsh. Each array is made up fifteen reef elements (basically oyster reefs) in a trapezoid shape measuring 7 feet by 7 feet at the base and 3 feet by 3 feet at the crest. The height of each element is 2 feet. Please refer to the *San*

Diego Native Oyster Restoration Plan for complete details.

Benefits of restoration

Restoration of oysters could play a critical role in stabilizing shorelines in the face of predicted climate change in San Diego Bay. Further, oysters can improve water clarity and remove anthropogenic nutrient inputs from the water column, increase biodiversity through the creation of complex habitat, stabilize sediments, buffer erosion, and attenuate wave energy.

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Billion Oyster Project:

Oyster Restoration through Public Education in New York Harbor

Peter Malinowski

The Billion Oyster Project (BOP) is based on the belief that direct engagement and interaction with wild animals and functioning ecosystems has a transformative effect on young people. As our world is increasingly urbanized, there is a growing subset of our human population that is coming of age separate from nature. Simultaneously, efforts abound aimed at increasing student engagement in school in an effort to improve outcomes for millions of young people. Too often, these interventions exist in the vacuum of school without the real-world, hands-on implementation that leads to improved self-confidence, authentic problem solving, teamwork, and the belief that anyone and everyone has the power to effect change.

BOP is an attempt to bring these too often separate issues together. It has grown from the belief that if we are to continue living, working, teaching, and learning on this planet we must fundamentally change how humans learn about and interact with nature. Our solution began in a high school aquaculture class and has grown into a region-wide initiative involving seventy restaurants, sixty-five schools, thousands of students, millions of oysters, and a dozen active restoration and research sites.

New York Harbor is a massively degraded natural system, oysters are functionally extinct, and every time it rains, billions of gallons of untreated household wastewater enter the system. The visibility is very low, often less than a foot. Currents are strong and commercial traffic is constant. To overcome these challenges, it is essential to engage the entire metropolitan community in the work of growing and restoring oysters. Community engagement has become central to the work of BOP. This work is executed through four core programs: Shell Collection, Reef Construction and Monitoring, Schools, and Citizen Science and Public Engagement. Each of these programs is designed to advance the work of growing and restoring oysters while simultaneously building a community of environmental stewards and advocates who will no longer stand for a polluted harbor that lacks its native keystone species.

The project began at the New York Harbor School, founded in 2003 by Murray Fisher and a small group of passionate educators. The Harbor School aims to prepare students for college and careers by immersing them in New York City's maritime experience.

Students at Harbor School first began interacting with oysters as part of an oyster gardening program led by New York/New Jersey Baykeeper. For its first seven years, Harbor School was located in Bushwick, Brooklyn, New York's most land locked neighborhood. It was not until 2010 that the school relocated to Governors Island, a stone's throw from lower Manhattan and right in the center of New York Harbor. This move allowed for the development of six Career and Technical Education Programs. Through these programs students have learned to SCUBA dive safely, raise oyster larvae, operate and maintain vessels, build and maintain commercial-scaled oyster nurseries, design underwater monitoring equipment, and conduct long-term authentic research projects, all in the murky, contaminated, fast-moving waters of one of the busiest ports in the country. For these students, BOP provides a complex problem that requires them to practice the skills they are learning and collaborate with their peers from other disciplines. These students are the primary workforce for the Reef Construction and Monitoring Program. Students in individual programs work to produce the raw materials of restoration and research. Together, they plan and execute complex installation and monitoring missions throughout the harbor. These activities would not be possible without the diverse expertise of students in various programs. They are joined by a growing group of industry professionals, divers, captains, welders, advocates, scientists, and marine technicians. These BOP Professionals work alongside Harbor School teachers to facilitate the participation of students in all aspects of Reef Construction and Monitoring.

Harbor School students are now joined by students at sixty-five public middle and high schools and dozens of citizen scientists throughout the five boroughs of New York City. The work of the BOP Schools and Citizen Science Program is built around Oyster Restoration Stations. These small wire cages hold live oysters, settlement tiles, and a trap for mobile invertebrates. These components are monitored separately to assess species diversity, succession, and oyster growth and survival. Partner schools contribute by monitoring these stations and supporting breeding colonies at various locations around the harbor that add to the reproductive potential of the harbor each spring. These Oyster Restoration Stations also serve as access points that bring math and science classes out of their buildings and down to the water's edge. Through this oyster restoration and research, students learn the science of the estuary and the math of aquaculture and ecosystem restoration. In this way young people become active stewards of the harbor. The data collected by these school groups form a harbor-wide oyster growth and survival study and a growing water quality data set that together help inform future restoration work. Each year 5,000 new students participate in these programs.

A primary challenge of engaging communities and volunteers in the work of oyster restoration in New York Harbor is the physical lack of access to the water. Walk to the water's edge and more often than not, you will be met by fences and steep or vertical bulkheads. There are however a few places where access is possible. The Public Engagement Program takes advantage of these access points and is now working with community groups, schools, and volunteers in collaboration with the Reef Construction and Monitoring Program to build reefs in communities. These new reefs, for the first time, allow volunteers and schools to regularly enter the water to participate directly in oyster restoration.

All of the above programs require a consistent source of cured oyster shells. Because the oyster industry on the East Coast is dominated almost entirely by the restaurant half shell market, there is no available source of oyster shells besides those that are generated by restaurants. In New York City a full 35 tons of oyster shells are generated every week. The vast majority of these are, unfortunately, landfilled. The Shell Collection Program currently operates at seventy restaurants, five days per week, and averages four tons of shell per week. These shells are transferred to a location on Staten Island, where they spend a year out of water before they can be returned to the Harbor.

To date, through the implantation of these four programs, BOP has collected over 400,000 pounds (180 tonnes) of shells, engaged over 600 volunteers on Governors Island and at community reef sites, and worked with over 10,000 students. All of the 20 million oysters restored to date have been grown and installed by high school students. We are just at the beginning of our journey toward a recovered New York Harbor and still a long way from understanding what the best strategies are for scaling up our restoration efforts. However, if we are able to restore a sustainable oyster population and build a program that allows teachers and students to be successful in their work of restoring the natural environment, then we will have created a model that is replicable in any city in the world that happens to exist on or near a degraded natural system.

Appendix A

Forum Participants

Brooks, Andrew	UC Santa Barbara - Bren
Brumbaugh, Robert	The Nature Conservancy Chesapeake Bay
Center, Steve	American Honda Foundation
Elkin, Julia	State Coastal Conservancy
Fisher, Murray	New York Harbor Foundation
Grant, Colleen	UC Santa Barbara - Bren
Group, Brianna	UC Santa Barbara - Bren
Ho, Desmond	UC Santa Barbara - Bren
Hunter, Linda	Wild Oysters
Ishigo, Jessalyn	American Honda Foundation
Jautokas, Raminta	American Honda Foundation
Lenihan, Hunter	UC Santa Barbara - Bren
MacKay, Jonathan	Aquarium of the Pacific
Nichols, Katie	Orange County Coastkeeper
Page, Mark	UC Santa Barbara - Bren
Phillips, Teresa	American Honda Foundation
Pitton-August, Beth	UC Santa Barbara - Bren
Read, Emily	UC Santa Barbara - Bren
Schubel, Jerry	Aquarium of the Pacific
Smith, Stacie	NOAA
Thompson, Kim	Aquarium of the Pacific
Wasson, Kerstin	Elkhorn Slough Reserve/ UCSC
Windham, Diane	NOAA
Winslow, Erin	UC Santa Barbara - Bren
Zabin, Chela	UC Davis
Zacherl, Danielle	Cal State Fullerton

Appendix B

Oyster Restoration Forum Agenda

16-17 March 2017

A Forum Jointly Sponsored by American Honda Motor Co., Inc. and the Aquarium of the Pacific in partnership with the Bren School SoCal Oyster Group, University of California, Santa Barbara.

<u>The Forum is designed to answer the following questions</u>:

1. *Under what environmental and societal conditions is oyster restoration an effective strategy for ecosystem restoration?*
2. *Where are these conditions found in Southern California?*
3. *What are the appropriate incentives to trigger and sustain oyster restoration efforts in selected sites in Southern California?*
4. *What are the key metrics for measuring success?*

{The emphasis of the SoCal Oyster Group Project is on number 3.}

<u>March 16, 2017</u>

9:00 Welcome and Self Introductions
Jerry Schubel for the Aquarium
Erin Winslow for the Bren Oyster Group
Steven Center for the American Honda Motor Co., Inc.

9:15 Goals of the Forum: Desired Outputs and Outcomes
Emily Read
Jerry Schubel

9:30 A brief overview of the findings of the Bren School Oyster Project
Bren School Oyster Group

10:00 Oyster Restoration in California (Dr. Danielle Zacherl, CSU Fullerton; Bren SoCal Oyster Group). Discussion led by Bren SoCal Oyster Group

- Brief descriptions of existing restoration efforts
- Preliminary identification of areas of high potential for successful oyster restoration efforts in Southern California

10:30 BREAK

10:45 Oyster Restoration in California Discussion Continued

11:40 Summing Up the First Morning: Lessons Learned
Bren Oyster Group
Hunter Lenihan
Jerry Schubel

12:00 LUNCH - Oyster shucking demonstration and fresh oysters by Carlsbad Aquafarm; Short Video by Desmond Ho and Emily Read, Bren Oyster Group

1:00 Case Studies and Lessons Learned:
North Carolina, Professor Hunter Lenihan, UC Santa Barbara

1:30 Chesapeake Bay, Dr. Robert D. Brumbaugh, TNC The Nature Conservancy

2:00 San Francisco Bay, Chela Zabin, UC Davis

2:30 BREAK

3:00 The New York Harbor Billion Oyster Project, Murray Fisher, Founder of New York Harbor School and the Billion Oyster Project

3:45 The Southern California Situation Revisited
Panel Discussion: Where and how managers can use the lessons learned from the discussed case studies in Southern California?

Panel will be composed of all speakers plus Kerstin Watson and Mark Page, Moderated by the Oyster Group with a set of carefully crafted questions developed before the Forum and shared with Panelists)

4:30 Adjourn

5:30 Dinner at Aquarium

7:00 Public Lecture in the Ocean Theater by Bren School SoCal Oyster Group, University of California, Santa Barbara

March 17, 2017

9:00 A Brief Recap of Day 1 and An Overview of Goals for Day 2
Colleen Grant, Bren Oyster Group, Hunter Lenihan and Jerry Schubel

9:15 Continue identification of areas of high potential for oyster restoration and the qualities that give them high potential. The goal is to identify specific areas in Southern California that have high potential, and brief descriptions of why each of them has high potential for success.
Key resources—data, information, researchers, citizen groups, etc.
Discussion facilitated by the Oyster Group and Jerry Schubel

10:15 BREAK

10:30 Facilitated discussion led by Professor Lenihan.

12:30 Lunch

1:30 Summary and Wrap-up and Identification of Next Steps
Oyster Group Representative, Desmond Ho
Hunter Lenihan
Jerry Schubel

3:00 Adjourn