Case Studies of Natural Shoreline Infrastructure in Coastal California

A COMPONENT OF *IDENTIFICATION OF NATURAL INFRASTRUCTURE OPTIONS FOR ADAPTING TO SEA LEVEL RISE*

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Cover: View of restored dunes at the Surfers' Point Managed Shoreline Retreat Project. Photo credit: Paul Jenkin

Contents

Introduction

Background and Purpose

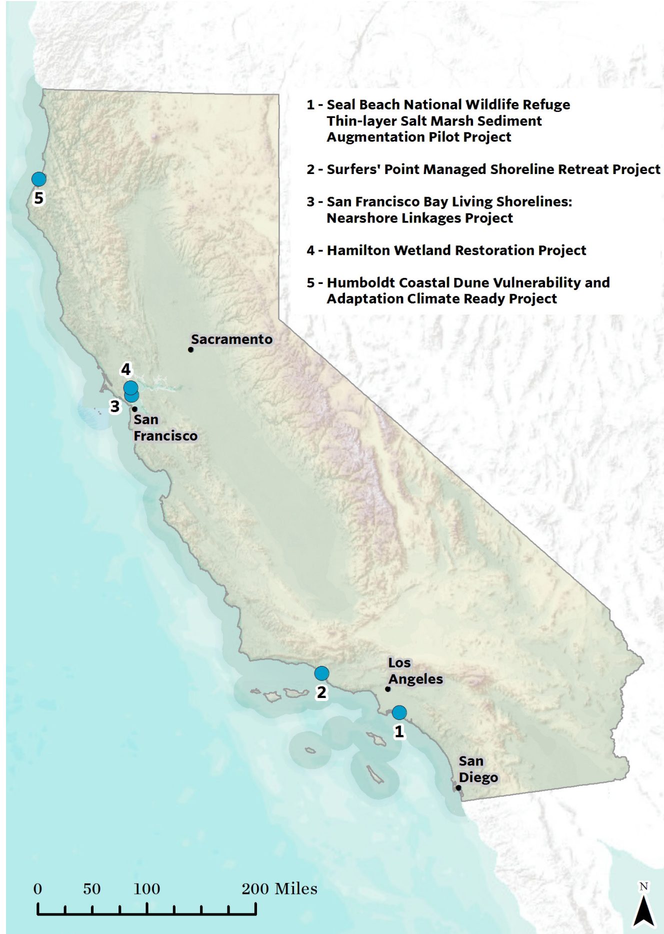
Sea level rise and erosion are major threats to California's coast, requiring solutions to preserve the many benefits a healthy coastline provides: flood protection, recreation, habitat for wildlife, water quality and more. Seawalls and other engineered structures, are commonly installed in order to hold the shoreline in place and hold back the ocean; however, they ultimately make the situation worse in most cases by increasing erosion and thus causing already vulnerable shorelines to shrink more.

Natural shoreline infrastructure is an alternative that is more likely to preserve the benefits of coastal ecosystems while also maintaining coastal access. The California coastline is very diverse, and no single solution will address all the challenges anticipated in the future. While there is a continuum of approaches to address sea level rise and coastal erosion—ranging from fully natural approaches that preserve or restore natural systems, hybrid solutions that integrate engineered aspects into restored or created natural features, and fully engineered structures like seawalls and revetments—property owners and managers don't typically consider the entire range of options when making coastal management decisions.

To address the gap in familiarity with natural infrastructure and the lack of technical guidance to aid decision-makers and engineers in the appropriate application of different strategies for different situations, this report summarizes natural infrastructure projects for a range of settings in coastal California. Each case study covers the background, permitting, planning, implementation, performance, and key lessons learned from each project in order to provide the critical information needed to implement successful adaptation strategies to address coastal issues, and inspire other communities by highlighting the lessons learned.

Case Studies Selection

A Technical Advisory Committee was charged with selecting a set of projects to highlight as case studies of natural shoreline infrastructure, and was composed of 34 representatives from local, state, and federal government agencies, non-governmental organizations (NGOs), and environmental consulting firms. Collectively, a list of 60 projects in varying stages of planning, implementation, monitoring and completion addressing a wide range of issues was compiled (Appendix 1). Most completed projects were properly categorized as restoration projects that had shoreline protection benefits; in other words, most of the projects were not driven primarily by shoreline protection objectives. However, it made sense to take shoreline management lessons from innovative restoration strategies, many of which can and should be incorporated into plans for regional coastal resilience.



Map 1: Five projects were selected to highlight a range of settings and natural shoreline infrastructure approaches in coastal California.

Case Studies

Five projects that spanned the California coast and represented different coastal settings and corresponding approaches were selected for the purposes of this report. From South to North these include:

- Seal Beach National Wildlife Refuge Thin-layer Salt Marsh Sediment Augmentation Pilot Project,
- Surfers' Point Managed Shoreline Retreat Project,
- San Francisco Bay Living Shorelines: Nearshore Linkages Project,
- Hamilton Wetland Restoration Project, and
- Humboldt Coastal Dune Vulnerability and Adaptation Climate Ready Project.

These case studies were designed to be useful examples for coastal planners, local governments, and others working on solutions and making decisions regarding climate-related coastal hazards. Summaries, key lessons learned, and project details can be found at the beginning of each case study, making it simple for readers to decide if they want to read further for a more in-depth account of project processes and outcomes. The Technical Guidance component of the *Identification of Natural Infrastructure Options for Adapting to Sea Level Rise* report is a useful companion to these case studies, and provides additional guidance and technical details to inform site selection and implementation of the strategies highlighted here.

Lessons Learned

A number of overarching lessons were identified through the process of developing the case studies and interviewing those who implemented the projects:

- Establish a multi-agency stakeholder process with long-term leadership to enhance buy-in and funding opportunities. Identify and engage champions of the project within partnering agencies.
- Coordinating with permitting agencies early in the design phase can make the process smoother. The permitting effort takes time, thoughtful discussion, and stepwise coordination, as there are multiple local, state, and federal regulations and species considerations at the land-sea interface.
- Engage with community groups to communicate the benefits of natural approaches and garner the support of local officials for approaches that improve public access and enjoyment of healthy ecosystems. Additionally, it is important to connect vulnerable communities with their shoreline, increasing understanding of risks and investment in preserving public access by using natural approaches.
- Volunteers can help with planting, monitoring, removing invasive species, which reduces project costs in addition to being community ambassadors to support more projects like these in neighboring areas.
- California has extensive experience and lessons to learn from a long history of restoration. However, funding and accomplishing significant post-project monitoring to capture and learn from those lessons are consistent challenges for restoration and adaptation projects alike. Collectively, we should support demonstration projects that collect detailed monitoring information so that they can be improved upon, tested in other areas, and applied on larger scales as part of an adaptation strategy to increase coastal resilience.

Sunset in Monterey, California. Photo credit: JacksPicks/Flickr.

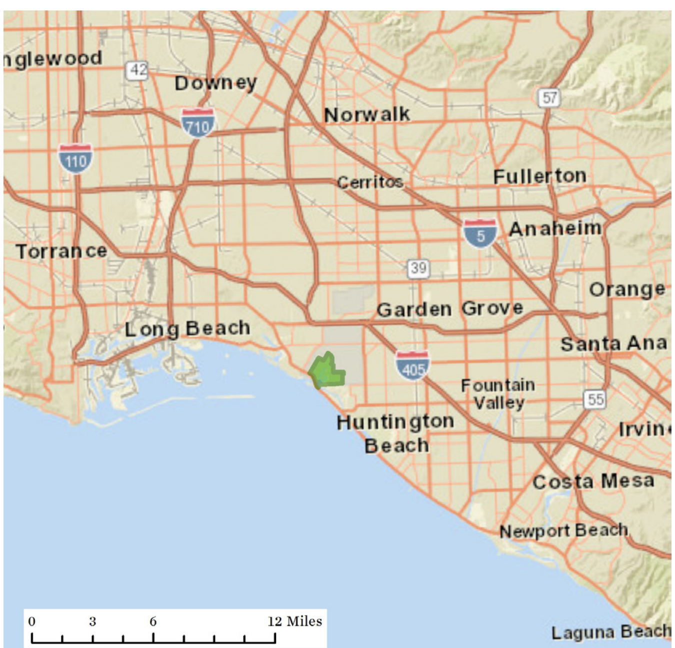
Seal Beach National Wildlife Refuge Thin-layer Salt Marsh Sediment Augmentation Pilot Project

Summary

Coastal marshes are important natural buffers to storms, high tides, and rising sea level and provide many additional benefits to numerous native and endemic species including threatened or endangered species. Extensive sea level rise modeling by U.S. Geological Survey (USGS) indicates that Seal Beach National Wildlife Refuge is an extremely vulnerable coastal marsh in California due to subsidence, a cut-off sediment supply, and sea level rise. The marsh is bounded by a Naval Weapons Base and cannot transgress landward, so U.S. Fish and Wildlife Service (USFWS) is piloting a method involving the application of a thin layer of dredge sediment on the surface of the marsh. The goals were to raise the elevation of the marsh to mitigate the impacts of subsidence and rising waters, and to enhance bird habitat. In early 2016 over the course of 4 months, the team raised the site elevation by about 8.5 inches, and vegetation and channels are already developing on the site. Although monitoring is in its early stages, this is a promising approach for the most threatened Pacific Coast marshes where other strategies like reconnecting them to their sediment supplies are not available.

KEY LESSONS FOR SUCCESS

- Complete a thorough grain-size analysis of source sediment to ensure it matches natural marsh sediment and will behave as expected when applied. Use a higher density of sampling across the source material in the planning phase when considering the use of dredge material.
- Ensure sediment cores are not consolidated, and are properly stored to enable future testing. Conduct periodic testing of the material throughout the application to track any changes.
- Consider the sediment source location and its proximity to trash-filled areas. Most of the trash transferred to the site came from sediments drawn from the boating area of the harbor.
- A 50-foot vegetated buffer around the sediment deposition area worked well except in areas with tidal channels. Hay bales can help contain sediment, but they need to be secured with rebar and held together with a natural binding rather than plastic, as the bales will degrade.
- Placing too much sediment at one time may contribute to compaction problems, burial of marsh features such as channels and ponds, and general flattening of the site.



Map 2: The project site is located at the Seal Beach National Wildlife Refuge in Orange County.

Project Details

Location: Seal Beach National Wildlife Refuge, Orange County

Setting: Marsh surrounded by development (i.e., U.S. Naval Base, Sunset Marina)

Project size: 16 acres total of which 7.87 acres was augmented; the rest was buffer

Land owners/managers: U.S. Navy/USFWS.

Project partners: USFWS, Orange County Parks, State Coastal Conservancy (SCC), California Department of Fish and Wildlife (CDFW), U.S. Navy, USGS, University of California Los Angeles (UCLA), California State University Long Beach (CSULB), Chapman University, US Army Corps of Engineers (USACE), and the Southwest Wetlands Interpretive Association.

Benefits

- Restoration and maintenance of healthy functioning coastal marsh
  - » Increased height of *Spartina* habitat for Ridgway's rail nesting and other imperiled species like California least tern
  - » Resist conversion of marsh to mudflat in the face of sea level rise
  - » Maintenance of goods and services provided by healthy coastal marsh (e.g., cleaning of water, wave attenuation, sequestering carbon, accretion of sediment)

Strategies

- Beneficial use of dredge material
- Thin-layer sediment augmentation to marsh surface

Permits, Leases, and Authorizations

- Compliance with NEPA (National Environmental Policy Act) and CEQA (California Environmental Quality Act)—because the project was supported by both federal and state funds—using an Environmental Assessment/Mitigated Negative Declaration that tiered from the Environmental Assessment prepared for the Seal Beach National Wildlife Refuge Comprehensive Conservation Plan
- Compliance with Section 7 of the Endangered Species Act involving both USFWS and NOAA (National Oceanic and Atmospheric Association)
- Consultation with NOAA Fisheries on Essential Fish Habitat (including consideration of eelgrass in the project area)
- Nationwide Permit 27 compliance—Aquatic Habitat Restoration, Establishment, and Enhancement Activities from the Corps (Section 404/Section 10)
- Section 401 (Clean Water Act) Certification from the Santa Ana Regional Water Quality Control Board
- Consistency Determination under the California Coastal Act for the California Coastal Commission
- The County of Orange provided the sediment, which was generated during a dredging project in a harbor adjacent the Refuge. The County had to obtain its own suite of permits for the dredging project and covered the costs of conducting sediment characterization needed to measure grain size and contaminant levels in the material that was to be beneficially used on the project site.

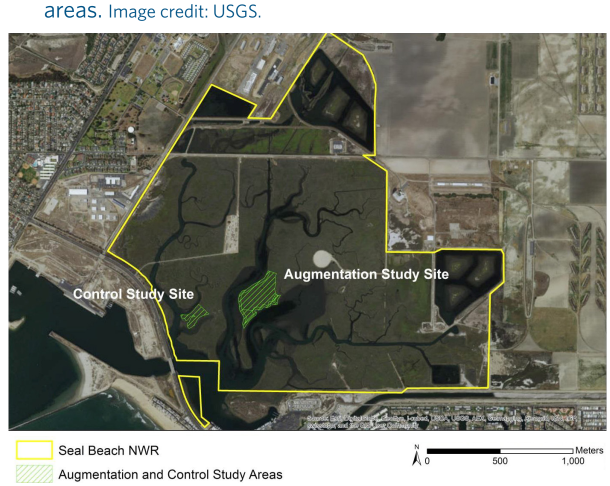
Costs

- Staff time (project design: 80 hours, NEPA/CEQA: 150 hours, grant applications: 75 hours, and permit preparation: 80 hours)
- Section 401 Certification fee: $1,097
- Dredging and sediment analyses (part of larger County dredging projects for Sunset Marina and Huntington Harbor—overall $8 M), plus $475,500 covered by grants to USFWS, for engineering design, sediment analysis (grain size/contaminants) of the dredge site and the augmentation site, permits associated with dredging, biological monitoring associated with dredging and application, and project management of the dredge operation
- Boat and motor purchase for site access: $2,750
- Pre-augmentation monitoring: $132,000 (plus 900 staff/volunteer hours)
- Construction: 1,000 hours (plus 1,000 hours post-augmentation)
- 5 years post-augmentation monitoring: $1.3 M

Timeline

- Planning and implementation initiated in 2014, construction phase completed early 2016, monitoring through 2021

▼ **Figure 1:** Study site map showing augmentation and control areas. Image credit: USGS.



Site History

The mission of the Seal Beach National Wildlife Refuge (SBNWR) is the conservation and recovery of endangered species, migratory birds, and their habitat. Specifically, SBNWR supports the federally endangered California least tern (*Sternula antillarum browni*), light-footed Ridgway's rail (*Rallus obsoletus levipes*), and federally threatened Western snowy plover (*Charadrius alexandrinus nivosis*). (Map 2)

Due to subsidence from oil and water extraction and natural tectonics, lack of sediment accretion and rising sea levels, the marsh—including all available nest space—is now regularly flooded at high tides. (Figure 3) High rates of inundation and exposure to high salinity water stunts the growth of *Spartina,* the primary habitat-providing plant. Additionally, the Refuge is surrounded on all landward sides by roads necessary for Naval base operations, preventing migration of the marsh to higher ground. (Figure 1) SBNWR is experiencing relative sea level rise at a rate three times higher (6.23 mm/yr) than similar Southern California coastal marshes that are not experiencing subsidence.

Objective

The goal of this pilot project was to test the effectiveness of thin layer deposition of sediment to reduce inundation and improve marsh habitat at SBNWR, with the possibility of expanding to other Pacific Coast marshes. This is part of a broader effort by wetland managers, agencies, and scientists to evaluate the effectiveness of thin-layer sediment augmentation to ensure long-term sustainability of coastal marshes along the Pacific Coast. Metrics of success include: (1) achieve at least 3 inches increased elevation of the marsh plain after 2 years, (2) increase cordgrass (*Spartina*) height, (3) prevent soil carbon loss, (4) promote a biodiverse and abundant invertebrate community, and (5) increase foraging and nesting resources for Ridgway's rails and other species of interest.

Design

Within the 565-acre intertidal marsh at the refuge, a 16-acre site was selected, on which the team planned to place 10,000-13,500 cubic yards of sediment to raise the site by 10 inches (Figure 1). The 6 acres not receiving sediment were designated as buffer zone and hay bales and other sediment capture materials were placed at the border of the 10-acre site (see Figure 6). However, the plan was modified midway through because a sediment shortage prevented application to the full 10 acres. The available sediment was enough to apply 16,875 cubic yards to raise 7.87 acres by about 9 inches (see Implementation section, Figure 7). The sediment source was a maintenance-dredging project in the Sunset/Huntington Harbor conducted by Orange County Parks from which sediment was hydraulically pumped to the project site. (Figure 4) Pre-sediment application monitoring was conducted to document the existing biological and physical conditions on the site and five years of post-sediment application monitoring (Table 1). The project team hypothesized that vegetation would reestablish itself by dispersal or vegetatively from buried rhizomes, and no active planting would be necessary. Additionally, the refuge installed field cameras to produce time-lapse documentation of the site (see below for link to these videos). All activities required coordination between Refuge staff, the U.S. Navy, the County, and the sediment augmentation contractor Curtin Maritime, in addition to the researchers accessing the site for monitoring.

◄ **Figure 2:** Several bird species, like this reddish egret (*Egretta rufescens*), use the site. Photo credit: Rick Nye.

▼ **Figure 3:** Refuge before sediment augmentation at mid-tide (left) and high tide (right) showing complete tidal flooding of nesting habitat for endangered bird species. Photo credit: Rick Nye.

Implementation

The parties (see Table 1) completed pre-augmentation monitoring and surveying between October and December 2015. The site was prepared prior to sediment application by placing hay bales secured with rebar and wooden stakes around the edges of the augmentation site with a 50-foot buffer edge. The hay bales were a precaution meant to contain sediment in the intended location and reduce runoff into channels to protect water quality, especially in areas where there is eelgrass. Wooden grade stakes were placed across the site in a 10m by 10m grid, and each was marked at 10 inches above the starting grade to act as a guide for sediment depth. The Refuge sourced sediment from a nearby Orange County Parks channel-dredging project. (Figure 4) Sediment application began in January 2016 with an 8-inch diameter dredge and the sediment contractor tested several nozzle types within the test area, including round, round with deflector, oval, and spoon shaped. The sediment slurry turned out to have a much lower silt to sand ratio (expected 45% sand, 43% silt and 12% clay and got 84% sand, 8% silt, and 8% clay) than initial grain size analysis indicated. (Figure 5) The slurry ended up filling the site like a bathtub, resulting in thicker areas where there had been dips or ponds and resulting in not enough dredge sediment to cover the entire 10-acre site. Accordingly, the team reduced the overall size to 7.87 acres, prioritizing areas that contained research plots, and applying 16,875 yd^3 of sediment in total. (Figure 7) The hay bales worked well to contain sediment except in places near channels where scouring was observed and additional measures were taken to contain sediment using sand bags, and geotextile fabric. An air horn and cracker shells were used to encourage birds to leave the spray zone, however they tended to return to forage on invertebrates in the sediment slurry and were not harmed. The last day of sediment application was April 4, 2016, although there was a considerable amount of garbage transferred along with the dredge spoils, which needed to be cleaned up. Post-construction monitoring began on June 1, 2016.

▲ **Figure 4:** Pipeline route from dredge site to augmentation site at the Refuge. The Nearshore Sediment Placement site was used in the larger dredging project and not the Seal Beach project.

Table 1: Monitoring activities and responsible parties for the Seal Beach National Wildlife Refuge Thin-layer Salt Marsh Sediment Augmentation Pilot Project.

Monitoring activity	Monitoring partners
Suspended sediment in channels	USGS
Suspended sediment above marsh plain	UCLA
Precise elevation measured with RTK-GPS	USGS, USACE
Eelgrass productivity	Marine Taxonomic Services, Ltd.
Subsidence and uplift with Surface Elevation Tables	USGS
Accretion and erosion with feldspar markers	USGS, UCLA
Vegetation and benthic invertebrate biodiversity and function	CSULB
Creek morphology	UCLA
Carbon sequestration	UCLA, Chapman University
Greenhouse gas flux	Chapman University
Turbidity	USFWS, USGS
Sediment flux in the water	USGS
Bird counts	USFWS

Performance

On April 7, the applied sediment measured 10” +/- 2” over the 7.87 acres of the originally designated 10-acre site. After about 2 months, the elevation decreased to an average of 8.5 inches due to compaction, as expected by the research team. Although there was some damage to nearby eelgrass beds within the Refuge, monitoring has shown it to be recovering. On the augmentation site, pickleweed (*Salicornia*) and cordgrass (*Spartina foliosa*) are beginning to grow in patches. Most of the pickleweed is growing due to seed dispersal and most of the cordgrass present is growing from rhizomes of cordgrass that survived sediment placement. (Figure 6) Additionally, tidal channels are beginning to form at the site. The Refuge staff and science teams continue to monitor elevation, accretion/erosion, sediment flux, carbon flux, and vegetation/animals. (Figure 2) Although the site is evolving as expected, it is too early to know whether the marsh will be sustainable in the face of future sea level rise without a continued supply of sediment. The university-led research teams have produced more detailed reports, and a lessons learned report is being prepared by the SBNWR, which will be available on their website (see links below).

Resources

- SBNWR project webpage with links to reports from science teams: *https://www.fws.gov/refuge/seal_beach/what_we_do/resource_management/Sediment_Pilot_Project.html*
- Sediment Augmentation videos by Rick Nye, Refuge Manager: *https://www.youtube.com/playlist?list=PLTWKRiVML7S4ZApeslGQyOeW7DWCh0PvZ*
- K. M. Thorne, and C. M. Freeman. 2017. Thin-layer Sediment Application Pilot Project at Seal Beach National Wildlife Refuge: Elevation Change Analysis. Unpubl. Data Summary Report. U. S. Geological Survey, Western Ecological Research Center, Vallejo, CA. 92pp.

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▲ **Figure 5:** ‘Rainbow’ spray of sediment onto the augmentation site. Photo credit: Rick Nye.

▲ **Figure 6:** Cordgrass growing in augmentation site, January 2017. Photo credit: Chase Freeman.

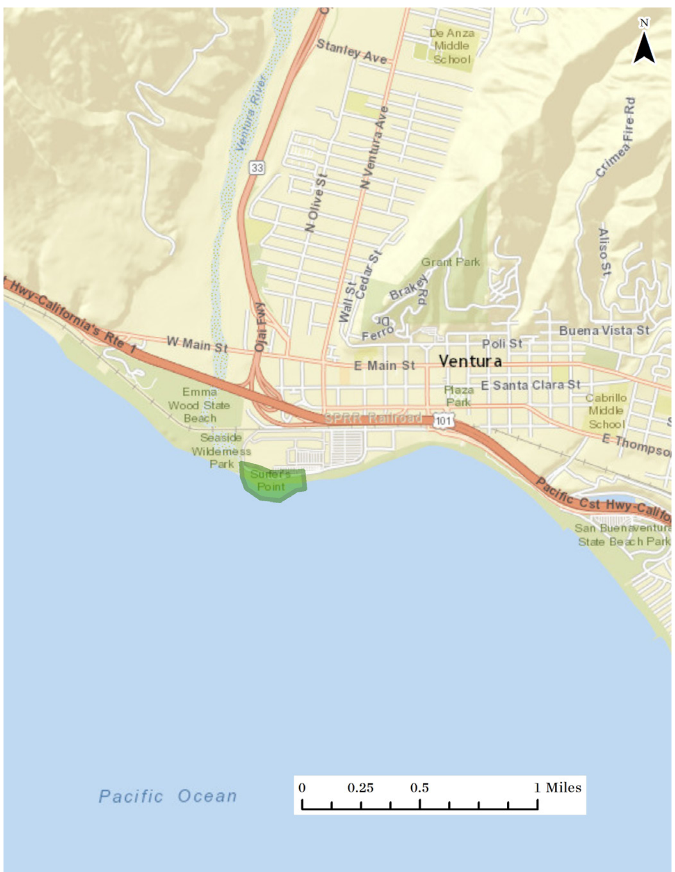
▼ **Figure 7:** Augmentation site after completion of sediment augmentation. Photo credit: Kirk Gilligan, USFWS.

Surfers' Point Managed Shoreline Retreat Project

Summary

Surfers' Point presents a case study of the combined adaptation strategies of habitat restoration, infrastructure realignment, and managed retreat in California. Strong community partnerships and a willingness to explore innovative engineering approaches led to a solution that worked with natural processes in ways that had not been attempted before. The project transformed an eroding parking lot and collapsing bike path into a cobble beach backed by dunes that has withstood strong El Niño storms and has protected the new bike path while providing continued public access to the beach. The project restored and widened the beach using native materials (cobble, sand) and dune planting by relocating infrastructure landward.

▼ **Map 3:** The project site is located at Surfers' Point in Ventura, just East of the mouth of the Ventura River. Emma Wood State Beach was the natural reference site for the project.



KEY LESSONS FOR SUCCESS

- Identify a nearby reference site that can inform the design and the interpretation of monitoring results in addition to possibly providing a source of seeds if vegetation is part of the project. Design to restore natural shore morphology and processes to the extent practicable, and identify future maintenance/ intervention/adaptation to account for un-natural and future conditions.
- Vegetated dunes effectively prevented wave overtopping and reduced maintenance associated with windblown transport of sand. Native vegetation requires no costly irrigation and volunteers can accomplish a lot of work to maintain weed-free habitat.
- Restoration of the backshore is a more effective approach to re-establishing shore morphology with desired ecology, restoration, and ecosystem services than the more traditional approach of building the shore seaward.
- Carefully design a monitoring plan that can verify design success and provide indicators of problems ahead of time. In this case, yearly beach profiles at multiple points along the shoreline indicate where erosion may be a problem, and triggers tell project managers when more cobble or sand may need to be applied.
- Look at other regional factors that may be contributing to the long-term problems of erosion and flooding. For example, an overarching problem is that the Matilija Dam has prevented transport of sediment in the Ventura Watershed to the river mouth and to the beaches. The Surfrider Foundation championed the Surfers' Point project and now they are championing the removal of Matilija Dam to restore functionality to the Ventura Watershed, including a sustainable source of sediment for the beach at Surfers' Point.
- Establish a multi-level stakeholder process engaging agencies and community groups with long-term leadership to enhance buy-in and funding opportunities.

Project Details

Location: Seaside Park (fairgrounds), City of Ventura, Ventura County

Setting: Open coast, river mouth delta, sandy beach and dunes over cobble substrate with backshore infrastructure.

Project size: 1,800 feet of shoreline

Land owners/managers: Ventura County Fairgrounds (31st Agricultural District) and City of Ventura

Project Lead: ESA (Environmental Science Associates—formerly Philip Williams and Associates or PWA), RRM Design Group, Rincon Consultants, Coastal Restoration Consultants, Surfrider Foundation

Project Partners: Working Group formed in 1995 comprised of City of Ventura, Ventura County Fairgrounds (Seaside Park), State Coastal Conservancy, California State Parks, the California Coastal Commission and Surfrider Foundation (Ventura County Bicycle Coalition and Full Sail Windsurfing Club added later)

Benefits
- Flood protection
- Recreation
- Habitat Restoration
- Water Quality
- Lower Erosion Risk
- Coastal Access
- Aesthetic Benefits

Strategies
- Managed Retreat
- Vegetated Dunes
- Cobble Berm
- Beach nourishment (sand and cobble)
- Bioswales for stormwater retention and filtration
- Permeable Parking Lot

Permits, Leases, and Authorizations
- California Coastal Commission Requirements
  - » Required Coastal Zone Management Act Consistency
  - » Sand & cobble size, color, shape, etc. w/ Engineer's Approvals
  - » Removal of fill to max extent possible
  - » Long-term monitoring: Plan, Triggers, Maintenance

▲ **Figure 8:** Restored dunes at Surfers' Point. Photo Credit: Paul Jenkin.

  - » Dune restoration plan
  - » Requires construction of both Phase 1 and Phase 2
- U.S. Army Corps of Engineers
  - » Section 10 (Rivers and Harbors) & Section 404 (Clean Water Act)
  - » Beach nourishment requirements
  - » Monitoring
- CA Regional Water Quality Control Board
  - » Section 401 Certification
  - » Monitoring
  - » Construction Best Management Practices
- Additional Consultations & Permits
  - » U.S. EPA
  - » U.S. FWS
  - » Local grading permits, etc.

Costs
- Total project costs are estimated to be $5.5 M for Phase 1 and $10.9 M for the entire project (City of Ventura 2011) augmented with more recent monitoring costs. The following are estimated costs incurred to date:
  - » Planning/Design: Planning and design spanned 1998 to 2010. An EIR was completed 2000-2002. Preliminary Design, Permitting and Final Design were accomplished 2003-2009 (entire project), with a redesign for only Phase 1 competed in 2010. The total costs were approximately $2.2 M.

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Project Details *continued*

» Construction: $3.6 Million comprised of $3.4 M (2010) plus $0.2 M (2013) for dunes.

» Monitoring: $130,000 through spring 2017 (four years after dune completion, plus two years prior to dune completion and after major construction).

» Maintenance: No known maintenance costs other than weeding of dune areas completed by volunteers.

» Phase 2: Cost and timing TBD according to stakeholder consensus.

Timeline

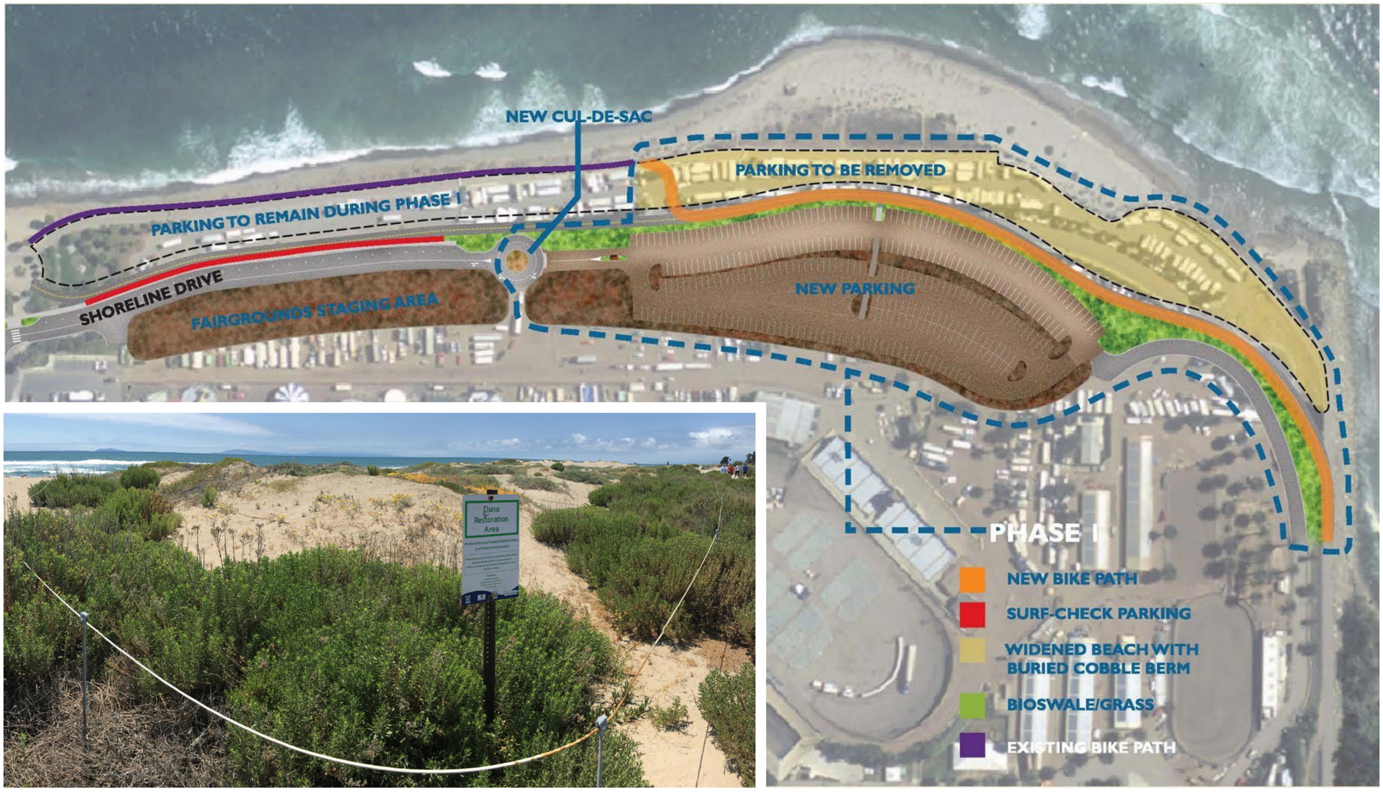
- Conceptual design introduced in 1997, EIR completed 2000-2002, design and permitting 2003-2009 (preliminary design permitting and final design construction documents for the entire project, and then redesign for only Phase 1 due to construction budget constraints), construction 2009-2010, dunes construction and vegetation 2012-2013, monitoring 2011-spring 2017. Maintenance has not been significant, comprised of volunteer weeding of planted dune area. Phase 2 still in planning/funding stage.

Site History

The project site is a river delta, with wetlands and a cobble and sand beach backed by dunes. The estuary wetlands to the east were filled and developed, and are presently used as Ventura County Fairgrounds, while the estuary to the west of the river is part of Emma Wood State Beach. (Map 3) A railway crosses the river delta, running roughly parallel to the shore and inland of the project site. In the 1940's a levee was constructed along the southeast bank of the Ventura River in response to major flooding of the City's west side. This levee constrains the river delta and wetlands from encroaching on the County Fairgrounds and associated development, much of which has been incrementally filled over the decades. The backshore was improved for public access by installation of a bike path, roadway and public parking in 1989-1990. The improvements were constructed close to the shore on imported earth and debris fill. Severe erosion and collapse of the bike path and fairground parking lot (constructed in 1989 and eroded in 1992), caused portions of it to be unusable until the managed retreat project was implemented 18 years later (Figure 9). A rock revetment was placed to limit further erosion of the backshore near the river jetty, in the location shown in Figure 9. This rock revetment was largely removed although some rocks remain and are visible, particularly during the winter when the shore recedes (see foreground of Figure 10). Note that Figure 10 is a photograph taken from a similar location as Figure 9, but located farther seaward, where the restoration project filled the previously eroded area with native materials.

▲ **Figure 9:** Project site before landward realignment of built infrastructure and restoration of the dunes and beach. The bike path and parking lot were built on fill in 1989 and eroded within 2 years. Photo credit: Paul Jenkin.

▲ **Figure 10:** Project site after managed retreat and restoration of natural processes. May 2016. Photo credit: Paul Jenkin.



▲ **Figure 11:** A schematic showing the revised design to accommodate phasing due to budget constraints. Phase 1 (blue dashed lines) was constructed 2010-2012. The remainder of the project, called Phase 2 (highlighted shore areas to the left of Phase 1), has not been constructed. 2009. Image credit: City of Ventura, RRM and PWA. Inset Photo: Restored vegetated dunes in the area labeled as 'parking to be removed' in the design schematic. Photo credit: Paul Jenkin.

Objective

The primary goals of the project were to relocate the damaged parking lot and bike path to limit exposure to erosion and wave overtopping, provide resilience and offset risk from sea level rise and storms for 50 years, and maintain access and other coastal resources without building hard structures such as seawalls. Although enhancing ecosystem function was not an explicit goal of this project, the chosen approach included restoring a natural beach backed by vegetated dunes, which inherently provides more ecosystem functionality and associated services than a seawall alternative. The project was largely driven by surfers who emphasized that natural shore conditions are more consistent with surfing and access, while armoring (e.g., seawalls) has counter-productive effects. Therefore, this is a natural infrastructure project that occurred before the term 'natural infrastructure' was widely used.

Design

Important design elements were landward realignment of infrastructure to provide adequate space for restoration of the back-shore using native materials (i.e., cobble, sand) and dune planting. (Figure 11) The reconstruction of the back-shore provided space for dissipation of waves with less wave reflection and scour, and accommodated the largely 'reversible' shore dynamics driven by the seasonal wave climate and less-regular river discharge of sediment. The setback of shore also accommodates future migration of the shore landward due to the regional sediment deficit and future sea-level rise. The landward realignment of infrastructure and back-shore restoration differs from traditional beach nourishment projects, which attempt to build the shore seaward without providing adequate space landward to achieve a more natural wave-shaped shore; hence, the setback is more resilient with less sediment placement. The second difference from a traditional beach nourishment project is the use of coarse sediment (cobble) as well as sand, and construction of dunes. Described more succinctly, the Surfers' Point project restored natural shore morphology, including materials, structure, and processes; while traditional beach nourishment is a more engineered approach, which requires higher maintenance, does not require restoration of the backshore, and is not as desirable ecologically.

▲ **Figure 12:** Emma Wood State Beach just west of Surfers' Point and the Ventura River mouth. This area was used as a reference site for the Surfers' Point design and post-construction monitoring. 2004. Photo credit: Bob Battalio.

Infrastructure design included regrading with an associated drainage system to mitigate existing water quality concerns. A bioswale and pump/filter system were incorporated to capture and/or filter parking lot runoff before discharging into the rivermouth. A new concrete bike path was designed to connect with the Ventura River Trail along the levee at the rivermouth and estuary. The California Coastal Commission issued a Coastal Development Permit to the City of Ventura to implement the project, and required a monitoring plan. The monitoring plan included identification of maintenance triggers: points along the shore that if eroded would require placement of additional cobble to maintain the protective functions of this space from wave run-up. The water-side engineering team (ESA) used a natural reference site and performed wave run-up studies and other analyses to inform their design of the project. The landside improvements (hardscape) were designed by RRM Design Group.

Emma Wood State Beach, just west of the site on the other side of the Ventura River mouth, was the reference site used to inform the elevations, slopes, and morphology of the cobble berm and back-beach design (see Figure 12).

Completed in 2005, the preliminary engineering design of the project included 0.5 feet of sea level rise, which translated to an additional 15 feet of setback landward of the calculated wave runup limits. The original setback distance of 65 feet was negotiated during the environmental review process as a balance between restoration of the shore and impact to existing land uses, which included Fairgrounds property. The City of Ventura hired ESA (then PWA) to evaluate the negotiated setback distance based on projections of existing and future runup limits to confirm that risk of damage to the new bike trail, parking and roadway would be acceptable. The analysis indicated that additional setback was needed on the western side, near the river, and this change was adopted by the City, the Fairgrounds and stakeholders, and subsequently permitted by the California Coastal Commission. This design was completed years before the State of California's interim (2010) and updated guidance (2013) and policies regarding sea-level rise, but the project design did consider sea-level rise consistent with expectations of California Coastal Commission staff, along with long-term shore recession, storm-induced erosion, and high wave runup.

Implementation

Initially, the project was designed to move the fairgrounds parking lot and bike path landward and restore cobble beach and dunes for the 1,800 feet of shoreline east of the Ventura River mouth. However, due to funding limitations, the City decided to implement the project in two phases, (see Figure 11) the first of which was constructed in 2010-2011. Phase 2 has not been constructed due to funding limitations and need for stakeholder consensus. Dunes were graded and seeded in fall/winter 2012 primarily relying on City crews for grading, and volunteers led by the Surfrider Foundation to implement planting and seeding of native dune vegetation. The City acquired the dune sand through beneficial reuse of sand that accumulated at the Pierpont Dunes, where sand was impacting residences constructed adjacent to sand dunes.

Construction began in fall of 2010 with removal of the eroding edge of the parking lot and collapsed bike path and underlying fill. The contractor excavated test pits to confirm the depth of the fill layer and to test methods for charging the cobble voids with sand. Cobble sourced from Santa Paula Creek and sand sourced from Calleguas Creek were placed on the site and some hydroseeding was done. (Figure 13) Ultimately, the beach was widened by over 60 feet. By June 2011 the new parking lot and bike path behind the restored cobble beach were completed marking the end of Phase 1. However, by February 2012, there had been significant windblown sand transport over the flat, restored beach, causing sand build-up on the new parking lot and bike path. (Figure 14) To remedy this problem, dunes were constructed using sand from Pierpont Dunes. Contractors first placed imported dune sand in linear 4-foot high berms in April 2012 and then spread the sand in May when they installed sand fencing and additional sand from Pierpont Dunes. The sand transport issue continued, requiring maintenance to remove sand from the parking lot and bike path. In November 2012, the dunes were graded into a natural hummocky pattern with more sand from Pierpont Dunes. The dune restoration was implemented during a multiple year drought 2012-2015, led by Dave Hubbard of Coastal Restoration Consultants, Inc. The dunes were planted using seeds collected from Emma Wood State Beach in December (primarily beach bur, sand verbena and beach saltbush), and no irrigation was used, saving $200k in project costs. Several methods were used to stabilize sand in the short-term while plants became established. (Figure 15) Surfrider Foundation and City of Ventura volunteers continue to weed the site each spring to remove primarily sea rocket (*Cakile spp.)* and ice plant, which is mostly eradicated but spreads quickly if not removed.

▲ **Figure 13:** After the eroded parking lot and bike path were excavated, cobble was imported and covered with sand to restore the cobble beach. 2011. Photo credit: City of Ventura.

▲ **Figure 14:** Wind-blown transport of sand before dunes were constructed. 2012. Photo credit: Paul Jenkin.

▲ **Figure 15:** Successful construction and vegetation of dunes, 2014. Photo credit: Louis White.

Performance

This project has performed as designed, and prevented erosion and accommodated erosion during strong El Niño storms, and has become the most visited beach in Ventura County. (Figure 16) Staff from the City of Ventura performed the beach profile monitoring, maintenance trigger points have not been reached, and the beach is behaving similarly to the reference site. While the western-most end of the site experiences greater winter erosion due to the continued presence of the Ventura River Levee and Army Corps spur groin, the summer beach profile returns due to the site's downcoast proximity to the rivermouth. Overall, the community-based volunteer project has been successful in establishing vegetated dunes with native plants and relatively low weeds, all without irrigation during drought years.

The areas of the beach backed by dunes have vegetated quickly and performed the job of protecting the space behind them from flooding during large storms. (Figure 15) Of interest, during high wave conditions in the 2015-2016 winter while other shore areas were damaged, no damage was experienced at the Surfers' Point Retreat project, and wave runup was documented to reach the bike path only where dunes were absent, in the area left flat to facilitate kite surfer activity (ESA 2016). In contrast, significant damages occurred elsewhere in the region due to these storms, including damage to Ventura Pier, erosion damage and emergency revetment at the promenade, and significant wave run-up east of the project site including overtopping and inundation in the Pierpont neighborhood.

Resources

- Ventura River Ecosystem Blog by Paul Jenkin: *http://www.venturariver.org/search/label/Surfers Point*
- Case Study on NOAA Climate.gov website: *https://www.climate.gov/news-features/climate-case-studies/restoring-surfers-point*
- Surfers' Point Monitoring Report for 2015-2016, prepared by ESA.
- PWA, 2005. Surfers' Point Managed Shoreline Retreat and Access Restoration Preliminary Design, Prepared for RRM Design Group, Prepared by Philip Williams & Associates, Ltd., August 2, 2005, PWA REF. #1708.

Contacts for Additional Information

- Paul Jenkin, Surfrider, *pjenkin@surfrider.org*
- Louis White, ESA, *LWhite@esassoc.com*
- Bob Battalio, ESA, *BBattalio@esassoc.com*

▼ **Figure 16:** Aerial view of project area after flood events, showing delivery of sediment from Ventura River and the dynamic nature of this site. March 10, 2017. Photo credit: R. Wilborn, Virtual Terrain Tours.

San Francisco Bay Living Shorelines: Nearshore Linkages Project

Summary

The multi-objective San Francisco Bay Living Shorelines project began in 2012 with the goal of examining how the creation of native ecosystems such as oyster reefs and eelgrass beds can protect the shoreline, minimize coastal erosion, and maintain coastal processes while enhancing natural habitat for fish and aquatic plants and wildlife. The project objective is to create biologically rich and diverse subtidal and low intertidal habitats, including eelgrass and oyster reefs, as part of a self-sustaining estuary system that restores ecological function and is resilient to changing environmental conditions. The project demonstrated that oyster reefs and eelgrass beds can substantially increase habitat, food resources, and biodiversity as well as reduce wave energy by 30%.

As its next phase, the Giant Marsh Living Shorelines project will incorporate current lessons learned into a design with more habitat types to test a larger scale approach linking eelgrass beds, oyster reefs, tidal marsh, and ecotone transition zones as a complete tidal system. The SF Bay Living Shorelines project raised awareness and built support and interest within the San Francisco Bay Area for living shorelines projects, and there are now multiple public and private partnerships forming to support the development of other living shoreline projects (i.e., using natural habitats to soften and protect the shoreline, and achieve both physical and biological goals). The project in San Rafael provided critical information and has led to additional living shorelines projects in San Diego Bay, Newport Bay, and Humboldt Bay, along with the growth of a statewide network of practitioners and robust exchange of ideas and lessons learned to help advance the use of natural shoreline infrastructure throughout California and the Pacific Coast.

KEY LESSONS FOR SUCCESS

- Wave energy reduction measured in the San Francisco Bay Living Shorelines site at San Rafael project is significant (30% reduction), but the project team recommends additional sites be used to determine optimal design and the need for site-specific differences in reef configuration.
- Eelgrass should be restored early in the growing season, from April to June, as there has been limited success in establishing eelgrass in late July and early August.
- Clean Pacific oyster half shell (Crassostrea gigas) bagged up and placed into mounds is an excellent material to build reefs for oyster recruitment, and the shell bag mounds provide physical shoreline protection. The bottom portion of mounds became buried in sediment, so future designs should replace the bottom portion of the mound with baycrete or other material that is less valuable than clean half shell.
- Clean oyster half shell is extremely limited in California, and shell recycling programs with restaurants and commercial shellfish growers should be established to generate more for restoration.
- Artificial structures are a great alternative to constructing reefs made of oyster half shell, which is in limited supply, but layer cakes and small reef ball stacks are not recommended.
- Restoration projects that incorporate both oyster reef and eelgrass together should be considered as preliminary evidence suggests that their co-location will maximize habitat value.

Map 4: The subtidal project site is about 1 acre in size and is located about 200 feet offshore, along the San Rafael shoreline.

Project Details

Location: San Francisco Bay, City of San Rafael shoreline, Marin County (parcel owned by The Nature Conservancy)

Setting: Deep intertidal, shallow subtidal, nearshore, soft bottom

Project size: One acre, 200 meters offshore

Project Lead: State Coastal Conservancy Project Partners: The Nature Conservancy (landowner), Environmental Protection Agency, San Francisco Estuary Partnership, CA Wildlife Conservation Board, NOAA, San Francisco State University (SFSU), UC Davis (UCD), USGS Western Ecological Research Center, ESA, CA Wildlife Foundation, Dixon Marine Services, Drakes Bay Oyster Company, Reef Innovations, and other partners.

Land owners/managers: Privately owned parcel by The Nature Conservancy, adjacent to several other public/private parcels that provide permission to access.

Benefits

- Habitat Restoration
- Food and nesting resources for aquatic and bird species
- Erosion Prevention
- Accretion of sediment
- Reduced wave energy (increased wave attenuation)

Strategies

- Eelgrass (*Zostera marina*) bed restoration
- Olympia oyster (*Ostrea lurida*) reef restoration
- Living Shorelines Approach (i.e., using natural habitats to soften and protect the shoreline, and achieve both physical and biological goals)

Permits, Leases, and Authorizations

- US Army Corps of Engineers: Nationwide Permit 27 (Aquatic Habitat Restoration, Establishment, and Enhancement Activities).
- NOAA Fisheries consultation with US Army Corps of Engineers: Section 7 consultation relative to the Endangered Species Act, Essential Fish Habitat consultation relative to the Magnuson Stevens Fishery Conservation and Management Act and Fish and Wildlife Conservation Act.
- San Francisco Bay Conservation and Development Commission (BCDC): Administrative permit.
- CDFW consultation with BCDC: Consultation to limit any impacts and maximize benefits to state-listed fish and wildlife; Scientific Collecting Permit for eelgrass donor collections; Letter of Authorization for transplanting eelgrass to restoration sites.
- San Francisco Bay Regional Water Quality Control Board: Section 404 Water quality certification.
- California Environmental Quality Act: the project was categorically exempt under Guidelines Section 15333 (14 Cal. Code Regs. §15333) as a habitat restoration project under 5 acres in size with no negative impacts anticipated.
- Letter of permission from landowner, The Nature Conservancy.

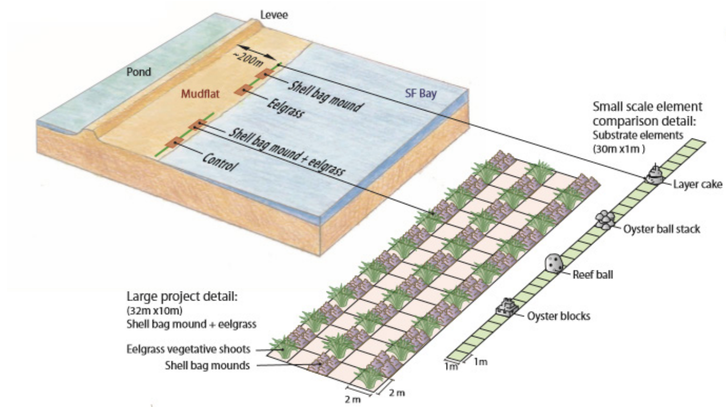
Costs

- $2.5 M for first five years ($450k for design and permitting, $350k for construction, $1.7 M for one year pre-construction and five year post-construction with high frequency monitoring)

Timeline

- Permits submitted January 2012, permits secured July 2012, installation in July-August 2012, high frequency bimonthly to quarterly monitoring through December 2017, and ongoing less frequent monitoring after that.

▲ **Figure 17:** Mounds of Pacific oyster half shell and baycrete structures off the San Rafael shoreline in San Francisco Bay. Photo credit: Sally Rae Kimmel.



▲ **Figure 18:** Schematic showing experimental design for large experiment and small experiment. Image credit: ESA.

Site History

Native Olympia oysters (*Ostrea lurida*) and eelgrass (*Zostera marina*) were once abundant in San Francisco Bay and the San Francisco Bay Subtidal Habitat Goals Report (2010) recommended protection and restoration of 8,000 acres of oyster habitat and 8,000 acres of eelgrass beds. To reach this goal, pilot studies are needed and the site offshore from the San Rafael shoreline was chosen as the first test site for larger scale restoration strategies. (Map 4) The shoreline is lined with rip-rap, a loose stone barrier which limits the interface of terrestrial and bay habitats, but does provide some habitat for Olympia oysters and other shoreline invertebrates and plants. The offshore areas of the site are shallow mudflats that are semi-protected from wave action by the Marin Islands National Wildlife Refuge. The shoreline is affected by wakes from ship traffic, wind wave energy, and tides and currents in the bay. In addition to the natural presence of native oysters in the intertidal, eelgrass test plots planted in 2006 were successful. These factors together, along with The Nature Conservancy being a willing landowner, meant this was a unique site and opportunity to test restoration approaches and their benefits for shoreline protection and ecosystem benefits.

Objective

The San Francisco Bay Living Shorelines: Near-shore Linkages Project is a pilot project designed in a thoughtful, experimental framework to answer priority science and restoration questions and meant to inform the design of larger-scale restoration projects at additional sites in San Francisco Bay or statewide in the future. The project was designed to implement key recommendations and test techniques in the Subtidal Goals Report, the San Francisco Baylands Habitat Goals Science Update (Coastal Conservancy 2015) and other regional planning documents including the San Francisco Estuary Comprehensive Conservation and Management Plan. This project aimed to test methods of eelgrass and oyster bed restoration and their effects on fostering biologically diverse invertebrate, fish, and bird communities while providing shoreline protection benefits such as increased wave attenuation and increased sediment accretion in the nearshore area. (Figure 17) These physical benefits are increasingly important to buffer shorelines against sea level rise and increased storm surge and frequency projected for San Francisco Bay.

▲ **Figure 19:** Eelgrass installation at project site. Photo credit: Sally Rae Kimmel.

Design

The State Coastal Conservancy is the lead on the project, including the lead agency on CEQA/NEPA and permitting, and provides both funding and project management. A complete package of permit application submittals, including the Joint Aquatic Resources Project Application to the agencies listed above, with Project Design, a Biological Assessment, Wetlands Delineation, Cultural Resources Report, and a detailed Monitoring Plan were submitted to regulatory agencies. There were several limitations on the project, including a lack of data (as this approach was new to the Pacific Coast), limitations on the type and amount of fill permitted, a need to plan access to the site around sensitive species windows such as salmon migration, and other site and regulatory constraints. Ultimately, the permitting agencies and landowner supported experimentation and testing of innovative new living shorelines concepts with this project, and supported it because of the habitat enhancement potential, and conservation measures and high frequency monitoring that will provide valuable data for future efforts.

To test both the biological and physical effects of oyster reefs and eelgrass beds, and the interactions between them, the design included a large experiment of four 32m by 10m plots placed roughly 200m offshore from the San Rafael shoreline, just south of the mouth of the San Rafael Canal. (Figure 18) These plots compared the effects of placing Pacific oyster shell-bag mounds, planting eelgrass, interspersing both together, and a treatment control plot. The team compared biodiversity, wave attenuation, and other attributes between experimental plots and a control plot. A small experiment was also included, to assess different substrates for oyster recruitment success. These included reef balls, mini reef ball stacks, oyster blocks, and layer cakes composed of 'baycrete', a mixture of cement, sand, shell, and rock. This material was designed to include natural materials from the bay and be more biodegradable, and is easier to permit than full concrete fill. See Figure 18 for a design schematic of both large and small experiments.

Implementation

Installation of eelgrass and oyster reef plots was completed from July to early August 2012 according to the design plans prepared by the main project team (State Coastal Conservancy, SFSU, UCD, USGS, ESA). The sourcing of materials included clean Pacific oyster half shell from Drakes Bay Oyster Company, shell and sand mined from the bay and provided by Jericho Products, and preparation of the baycrete oyster elements ahead of time by California Wildlife Foundation, Drakes Bay Oyster Company, Dixon Marine Services, and Reef Innovations. Unfortunately, permitting and construction were delayed by six weeks, resulting in late season mid-late August eelgrass plantings, as the plants had to be installed after the oyster elements were placed in July-August. (Figure 19) The initial eelgrass planting was not successful, potentially due to this late timing and less ideal tide cycles and light availability for eelgrass. The team replanted the site in April 2013. High frequency monitoring of eelgrass survival and density; oyster recruitment, survival, and density; invertebrate use, fish, and bird use; and physical parameters including bathymetry surveys, water quality monitoring, and wave monitoring was completed by the main project team from fall 2012-spring 2017 and the fifth year of required monitoring will be completed in December 2017. The project team plans to continue to monitor the project less frequently over the next five years and in the long-term.

Performance

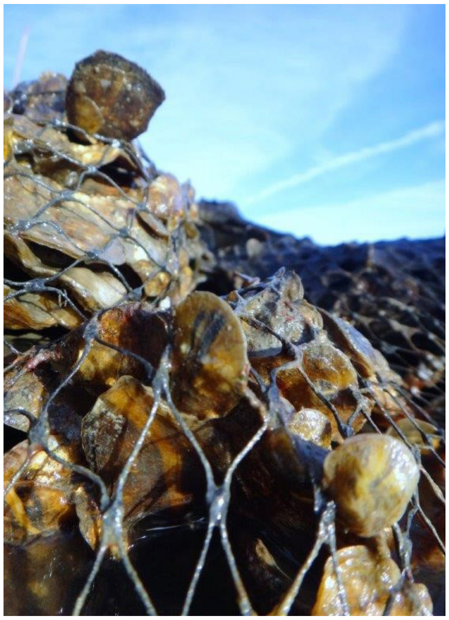
Due to a rigorous monitoring program, many lessons were learned about the process of eelgrass bed and oyster reef design, construction, monitoring, and the resulting habitat and coastal protection benefits of the project. The 2014 and 2016 hydrographic surveys revealed higher rates of erosion on the bayward side of the plots and increased accretion on the shoreward sides of the plots. According to wave modeling conducted for the project, for waves immediately offshore of the plots, the oyster–eelgrass plot dissipated approximately 30% more wave energy than the control at mean tide level. This reduction added to the wave attenuation benefits of the broad offshore mudflat, which extracted substantial energy before waves reached the plots.

Olympia oysters recruited quickly to both shell bag mounds and the baycrete structures, with an estimated peak of more than three million recruits in spring 2013, followed by a decline in recruitment and survival over the next three years to approximately 350,000 by fall 2016. (Figure 20 and 21) Control tiles on the shoreline documented a similar decline reflecting the same patterns of declines at control areas as well as the treatments. Native oyster populations are known to fluctuate over time and can be quite ephemeral, as can eelgrass populations, with fluctuating numbers both within and between years. The shell bag mounds recruited more oysters than the baycrete structures likely due to their larger size and surface area amongst and between the shells. Deeper portions of the elements and vertical surfaces tended to recruit higher densities than horizontal surfaces, potentially due to mitigation of heat stress at low tides. (Figure 20) Although there was some initial sinking (10 cm) and sediment accumulation around the bottom of the oyster shell bags, the bags were stable after 5 months.

Eelgrass density reached 200% above initial planted densities when planted alone and just under 100% density when planted amongst oyster shell mounds, which can be abrasive to shoots and restricted the available space where eelgrass could expand. The project team still recommends restoring oyster and eelgrass habitat together in the same design for highest biodiversity, but to include more space between them to allow for maximum eelgrass bed expansion. The source of the eelgrass had a minor effect on success of planting and the team recommends choosing a source site with similar sediments and habitat conditions to the planting site.

The invertebrate communities in eelgrass and oyster plots were significantly different from the control plot and attracted species that prefer a structured environment. (Figure 22) While there has been an increase of more than ten taxa on the reefs and in the sediments, as of 2016, the community composition had not completely aligned with natural mature eelgrass beds in the bay, with the native isopod (*Idotea resecata*) being absent, and native sea hare (*Phyllaplysia taylorii)* being very rare (only two individuals found). Sediment core sampling of infaunal invertebrates showed a significant increase in density where eelgrass and oyster bags were installed, potentially due to the detritus and biological material coming off the reefs and enhancing food resources for species in benthic sediments. Fish trapping, seining and acoustic monitoring indicated an increased occurrence of certain fish species, including early recruitment of eelgrass specialists such as bay pipefish (*Syngnathus leptorhynchus*). Densities of American black oystercatcher (*Haematopus bachmani*) increased in the treatment area in comparison to pre-installation and control densities, and Forster's terns (*Sterna forsteri*) and wading birds (herons and egrets) began using the treatment area after installation. Birds used the treatment area for foraging at low tide more than adjacent areas and used the oyster structures for resting or preening at high tide.

▼ **Figure 20:** Baycrete structure colonized by native Olympia oysters. Photo credit: Stephanie Kiriakopolos.



▲ **Figure 21:** Olympia oysters readily recruited to bags of clean Pacific oyster half shell. Photo credit: Stephanie Kiriakopolos.

▲ **Figure 22:** The reefs attracted many taxa that used them as habitat and a source of food, including invertebrate, fish, and avian species. A juvenile dungeness crab, Metacarcinus magister, is shown here. Photo credit: Stephanie Kiriakopolos.

Resources

- State Coastal Conservancy website: *http://scc.ca.gov/climate-change/climate-ready-program/san-francisco-bay-living-shorelines-project/*
- Project website: *http://www.sfbaylivingshorelines.org/sf_shorelines_about.html*
- San Francisco Bay Subtidal Habitat Goals Report: *http://sfbaysubtidal.org/report.html*
- Baylands Ecosystem Habitat Goals: *http://baylandsgoals.org/*
- Bay Nature article: *https://baynature.org/article/living-shorelines/*
- Annual Project Monitoring Reports at *www.sfbayliving-shorelines.org*
- Boyer, K., C. Zabin, S. De La Cruz, E. Grosholz, M. Orr, J. Lowe, M. Latta, J. Miller, S. Kiriakopolos, C. Pinnell, D. Kunz, J. Moderan, K. Stockmann, G. Ayala, R. Abbott, and R. Obernolte. 2017. San Francisco Bay Living Shorelines: Restoring Eelgrass and Olympia Oysters for Habitat and Shore Protection. Chapter 17 in D. M. Bilkovic, M. Mitchell, J. Toft, and M. La Peyre, eds., Living Shorelines: The Science and Management of Nature-Based Coastal Protection. CRC Press Marine Science Series. *https://www.amazon.com/Living-Shorelines-Management-Nature-Based-Protection/dp/1498740022*

Contacts for Additional Information

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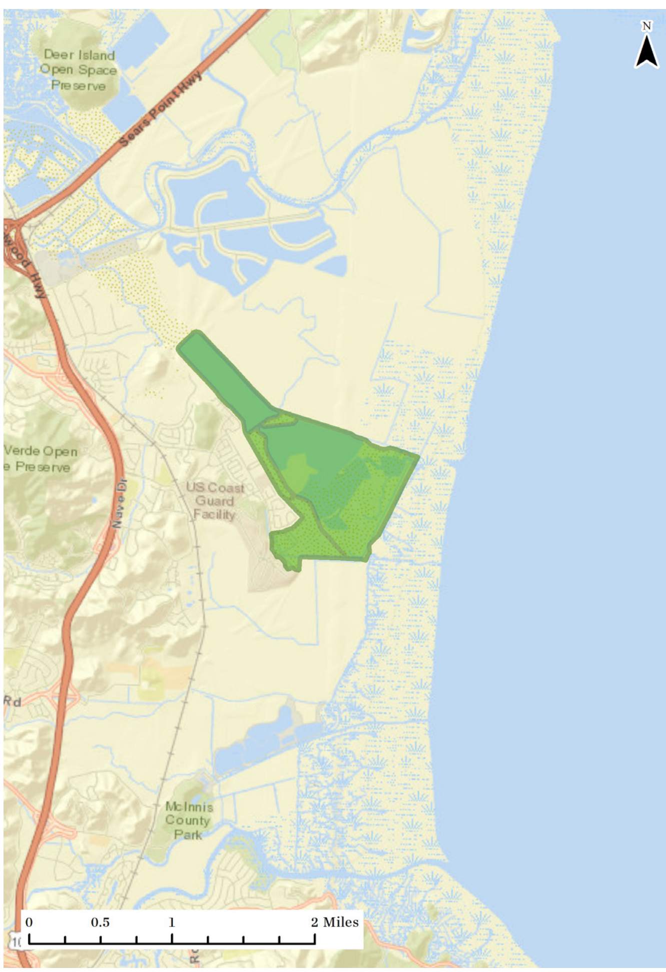
Hamilton Wetland Restoration Project

Summary

The Hamilton Wetland Restoration Project is exceptional in its restoration of a range of habitat types integrated with flood protection levees, in addition to being one of the largest examples of beneficial reuse of dredge sediment on the Pacific Coast. It follows and improves upon the restoration of Sonoma Baylands, which also used dredged sediment to restore site elevation to marsh plain. The Hamilton Project included intertidal berms to slow down wind-generated waves, and allow suspended sediment carried into the site to deposit naturally. Accordingly, this project was an early example of a horizontal levee that provides ecological benefits, such as habitat for endangered species like the Ridgway's Rail and Salt Marsh Harvest Mouse. In addition, it is the first example of seasonal wetland construction on the Pacific Coast. Although the intertidal berms compacted more than expected, the site is vegetating well and nesting shorebirds have been observed.

KEY LESSONS FOR SUCCESS

- Account for consolidation and settlement of existing and applied sediments up front.
- Consider opportunities to build in high tide refugia and additional space for habitat to migrate as sea level rises.
- Transporting dredge sediment in large quantities can be a very expensive endeavor, but regulatory agencies can encourage or require beneficial reuse of dredge sediment when large dredging projects are planned, enabling large restoration projects on subsided sites. There is no faster way to bring a subsided site up to marsh plain elevation.
- As much as possible, plan outplanting (especially in the tidal transition zone) a year or two after levee breach/ reinstating full tidal action, so that the tide lines are more developed and visible, allowing for more informed planning (locations, distribution, etc.) and a higher probability of success.
- Experiment with different planting methodologies (nursery stock, direct seeding, hydro-seeding, bulk planting of salvaged plant material, etc.). Every year, season, and site is different and different methodologies can be successful at different times.
- The incorporation of simple physical buffers to wave action, such as a lengthwise roll of plastic fencing (i.e., orange construction fencing), secured by bamboo stakes and parallel to the tide line, can allow tidal waters to flow over plantings but minimizes wave erosion by subtly minimizing wave energy.
- Careful and consistent outplanting with close attention to a sturdy 'mud cap' around the base of an outplanted seedling can significantly increase its ability to remain in place and intact, despite possible wave action.
- In upland areas, the use of burlap, mulch and/or branches (e.g., *Baccharis pilularis*) can help protect outplanted seedling and seed from desiccation, erosion, herbivory, and heat stress.



Map 5: The project site is located east of Novato, along the northwest shoreline of San Francisco Bay.

Project Details

Location: Novato, inside San Francisco Bay, Marin County

Setting: Estuarine marsh, low-energy waves

Project size: 994 acres

Land owners/managers: State Coastal Conservancy

Restoration Planning Team:

- USACE
- State Coastal Conservancy
- San Francisco Bay Conservation and Development Commission
- Philip Williams and Associates and Environmental Science Associates

Benefits

- Rapid rate of restoration through raised site elevation to marsh plain
- Habitat Restoration, including tidal marsh, seasonal wetlands, transition zones, and tidal pannes.
- Flood protection for adjacent areas while supporting complete system of tidal marsh to upland transition zone.

Strategies

- Intertidal berms
- Managed realignment/retreat
- Beneficial use of dredged sediment
- Levee breach after placing sediment to raise elevation
- Wildlife corridor—gently sloping habitat levee
- Seasonal wetland development
- Site planting through adaptive management
- Permits, Leases, and Authorizations
- National Marine Fisheries Service Biological opinion
- US Fish and Wildlife Service Biological Opinion
- San Francisco Regional Water Quality Control Board 401 Certification
- BCDC Consistency Determination for USACE
- BCDC State Permit for State Coastal Conservancy
- Lease of adjacent property from State Lands Commission

Costs

- Planning and Design: $34.9 M
- Construction on site: $32.6 M
- Offloading and placement of dredge sediment: $24.9 M
- Dredging and offloading (paid for by Port of Oakland 50-foot project ($99.3 M) and operation and maintenance costs for Oakland Harbor ($23.3 M) and Richmond Harbor ($12.4 M): $230.6M
- Planting and invasive species control: $2 M
- Monitoring (13 years): $3 M

Figure 23: Vision for the restoration of Hamilton Airfield with tidal wetlands, seasonal wetlands, and upland transition zones. Image credit: ESA (formerly PWA).

Timeline

- Project design: 1994-2006
- Dredge material placed periodically between 2007 and 2013 (multiple applications from multiple sources)
- Planting: 2012-2017 seasonally
- Levee breached: April 2014
- Monitoring of habitat development: 2014-2027

Site History

The 994-acre project area was formerly a tidal marsh that was diked and drained in the 1800s for agriculture, then subsequently converted to an Army airfield in the 1930s. (Figure 24) Over decades there was subsidence amounting to about 8-15 feet below mean lower low water. PCBs, DDT, and toxic metals had contaminated a relatively small portion of the soils (50,000 yards). In 1994, the airfield was closed through a Base Realignment and Closure process and cleaned up to Comprehensive Environmental Response, Compensation, and Liability Act standards. Over the following decade, plans were developed to restore the site to tidal marsh, seasonal wetlands, and improved levees that incorporated tidal marsh to upland transition zone habitat along the north side of the project site. (Figure 23) This represented one of the earliest on-the-ground examples of the horizontal levee concept.

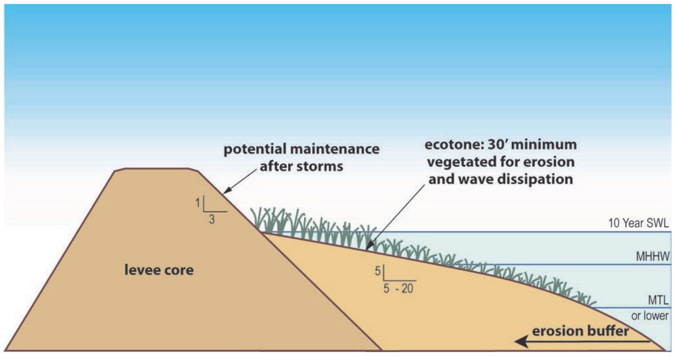
Objective

The project planned to restore a former airfield to tidal and seasonal wetlands and improve the southern flood protection levee between the adjacent neighborhood and the restoration site by raising the existing levee and incorporating a 300-foot wide sloping wildlife corridor without the use of rock armoring. (Figure 25 and 26) This approach has more recently been referred to as a horizontal levee. (Figure 27) The northern levee protects a sanitary district outfall pipe and 1600 acres of agricultural land that are proposed for restoration to wetlands as the Bel Marin Keys Unit V Restoration project. Once natural processes have fully restored the site, the project will have restored approximately 924 acres of tidal wetlands and seasonal wetlands, and 70 acres of transitional habitat (including the wildlife corridor) and created 2.66 miles of public access trails to this ecologically sensitive part of the San Francisco estuary. Due to the proximity to housing, agriculture, and wastewater treatment assets, this restoration project sought to integrate several approaches that would result in a healthy ecosystem while enhancing flood protection and recreational opportunities for the nearby communities. Lessons learned from the project will be applied to restoring the adjacent 1600-acre Bel Marin Keys property as a continuous landscape, incorporating many of the same habitat features.

▲ **Figure 24:** Hamilton Airfield prior to restoration, circa 1970. Photo credit: State Coastal Conservancy.

▼ **Figure 25:** Tidal channel entering the northern seasonal wetlands looking north in November 2012. Photo credit: Christina McWhorter.

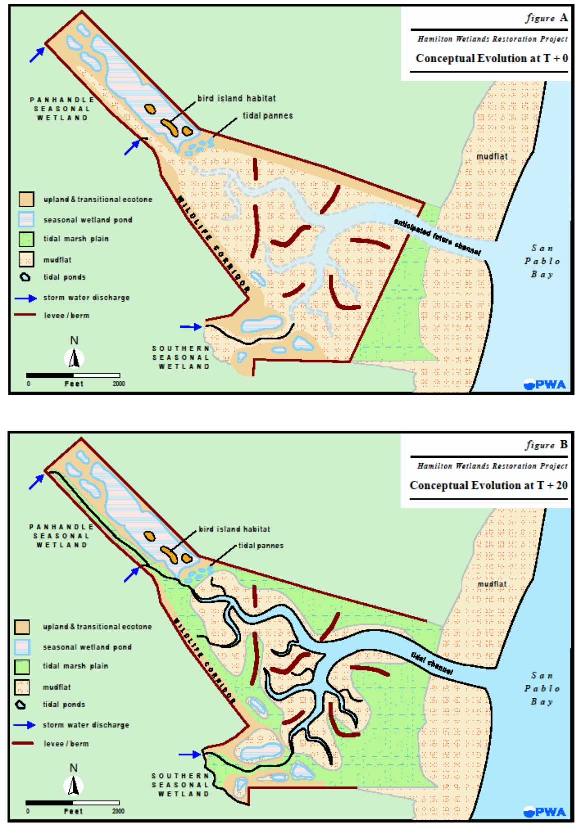
▼ **Figure 26:** Tidal channel entering the northern seasonal wetlands looking north in May 2017. Photo credit: Christina McWhorter.



▲ **Figure 27:** Wave dampening bench showing levels at 10 Year Stillwater Level (SWL), Mean Higher High Water (MHHW) and Mean Tide Level (MTL). Image credit: ESA.

Design

The project design incorporated several approaches, including (1) beneficial reuse of clean dredge sediment to raise the elevation of the site for marsh restoration, (2) realignment of flood control levees to protect housing and agricultural lands while allowing space for restored wetlands and natural tidal processes, (3) incorporation of tidal berms to break up wave energy and provide bird habitat, (4) a gently sloping wildlife corridor to support a range of vegetation types and (5) seasonal wetlands. (Figure 23 and 28) The project design incorporated feedback from a large planning committee including representation from 80 stakeholders, environmental groups, residents, and agencies. Project leaders from the Army Corps of Engineers and the State Coastal Conservancy partnered with the Bay Conservation and Development Commission, a key permitting agency in the San Francisco Bay Area, to develop permit applications.



▲ **Figure 28:** Sequence of site evolution from time of levee breach (T+0) to 20 (T+20). Habitat levee is not depicted but lies along the northern edge of the site. Image credit: ESA.

The use of dredged sediment was key to the success of the project as there is no faster way to restore a subsided site to a functional tidal marsh. This project also provided an opportunity for beneficial reuse of sediment dredged from the Bay for navigation, making use of a valuable natural resource that otherwise would have been disposed of. To allow tidal waters onto the site, the perimeter levees needed to be raised and strengthened to provide the level of flood protection required by the Federal Emergency Management Agency. During the base realignment, the adjacent community of Hamilton was developed by the City of Novato. The Hamilton Levee (formerly known as the New Hamilton Partnership levee) protects this community and lies on the western edge of the project site. Along this edge, the site design included a flatter, vegetated area transitioning from the top of the flood protection levee with a 100:1 slope. (Figure 25 and 26) This shallow slope reduced the need to armor the levee with riprap. Along the northern levee, a subtidal bench was added to the toe of the levee designed to reduce wave action on the levee itself. (Figure 27 and 29) Another important feature of the site was the addition of several intertidal berms set just below marsh plain elevation. These berms were added to the site design to reduce wind waves created on site by the long wave fetch created by the strong north bay winds and to help guide channel development. (Figure 28) The subtidal bench and intertidal berms were designed to erode naturally over time, adding to the site sediment. The design team was also interested in providing habitat connectivity between the open land on either side, so a 300-foot wildlife corridor was incorporated to accommodate the shallow slope of the transitional habitat and provide wildlife access to land from the south and along Pacheco Pond to the north. (Figure 26)

▲ **Figure 29:** The habitat-friendly levee bench on the north side of the project after 1.5 years has vegetated and resisted erosion although it has settled more than expected and may require additional sediment placement. Photo credit: Damien Kunz.

▲ **Figure 30:** Local students helping plant the northern seasonal wetlands with the STRAW Program. Photo credit: Christina McWhorter.

Implementation

The majority of the project site was restored to tidal marsh with a mosaic of upland transition zones, tidal pannes, and seasonal wetlands. This process included raising the elevation of the site with clean dredge sediment and constructing intertidal berms that would serve as wind breaks as the marsh developed. It required approximately 6 million cubic yards of sediment, most of which was sourced from the Port of Oakland's Harbor Deepening Project from 2007-2013 and pumped onto the site as it was available. Placement of the sediment required a dredged sediment offloader anchored in the Bay at depths most dredge scows could use, and construction of a 5-mile pipe and pumps to transport dredge material to the site. After constructing the perimeter levees, intertidal berms, wildlife corridor, habitat levee, and public access trail, the sediment was pumped on site and allowed to settle. The plan was to raise the site elevation to 1-1.5 feet below Mean Higher High Water (marsh plain elevation) and let natural sediments fill the site and support creation of tidal channels and sloughs after the levee breach. However, there was not enough sediment to fill the site to the desired height, and it ended up being approximately 2 feet lower than planned, thus the site will take longer than originally projected to reach an elevation that can support marsh vegetation.

The site also includes two seasonal wetlands, one in the northern panhandle, and one on the southern end of the site. A dedicated nursery was built onsite from a repurposed water treatment building to grow native plants, with a dedicated nursery manager and botanist in charge of plant production, planting, and invasive plant control. The south seasonal wetlands were not planted.

On April 25, 2014 the bayside levee was breached, restoring tidal action to the site and supporting natural sediment accretion, colonization of marsh vegetation, and use of the site by invertebrates, birds, and fish. (Figure 32) The USACE leads an adaptive management and monitoring plan and group. The nursery manager performs vegetation monitoring; bird, fish, invertebrate, sediment, wind conditions, and water drainage are monitored by ESA; and structural performance of the perimeter levee is monitored by USACE. The site is expected to reach full maturity between 2030 and 2050, although factors such as sea level rise and low levels of natural sediment accretion could delay or prevent the site from becoming fully restored.

Community Engagement

A substantial public outreach component included the planting of 35,000 plants as of summer 2017 in the northern seasonal wetland, and wildlife corridor areas. (Figure 30 and 31) The nursery manager handles all the plant related efforts on site as well as the public outreach effort. A Point Blue program called Students and Teachers Restoring a Watershed (STRAW), with funding from the State Coastal Conservancy, engages local school groups and pairs them with Point Blue and USACE biologists to participate in the planting. (Figure 30) Approximately 3,600 total hours contributed to the planting effort to establish native vegetation at the site, including 1,100 hours by community volunteers of all ages, and 2,500 hours by an AmeriCorps National Civilian Community Corps team.

▲ **Figure 31:** Wildlife corridor in May 2017. Photo credit: Christina McWhorter.

▲ **Figure 32:** Bayward levee was breached to restore site to full tidal action on April 25, 2014. Photo credit: USACE.

Performance

The Hamilton Wetland Restoration Project site is on track for full restoration of natural tidal marsh processes, according to monitoring results after the first year following the levee breach. Accretion of sediment on the future marsh plain, tidal drainage and species richness for birds, fish and invertebrates are all positive signs of the project's success. There has been a 50-75% survival rate of planted vegetation, a positive and expected result. However, the height of the berms and the perimeter levee are lower than specified, due to compaction of both the sediments underlying dredge sediment and the placed dredge sediment itself. This has resulted in erosion of the vegetated tidal bench where it ties in with the levee, especially during recent king tides and storms. The project team is determining whether the level of erosion is problematic and, if it is, will perform necessary repairs. Additionally, some areas do not fully drain when the tide goes out, but this should improve as tidal channels develop. In general, it is too early to fully assess the physical performance of the site.

Resources

- State Coastal Conservancy website: *http://hamiltonwetlands.scc.ca.gov/*
- USACE project webpage: *http://www.spn.usace.army.mil/Missions/Projects-and-Programs/Projects-by-Category/Projects-for-Ecosystem-Restoration/Hamilton-Airfield-Wetland-Restoration/*
- Bay Crossings article: *http://www.baycrossings.com/dispnews.php?id=1974*
- The Military Engineer article: *http://themilitaryengineer.com/index.php/tme-articles/tme-magazine-online/item/422-responding-in-a-crisis*

Contacts for Additional Information

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- Brenda Goeden, BCDC, *brenda.goeden@bcdc.ca.gov*
- Michelle Orr and Damien Kunz, ESA, *MOrr@esassoc.com*, *DKunz@esassoc.com*

Humboldt Coastal Dune Vulnerability and Adaptation Climate Ready Project

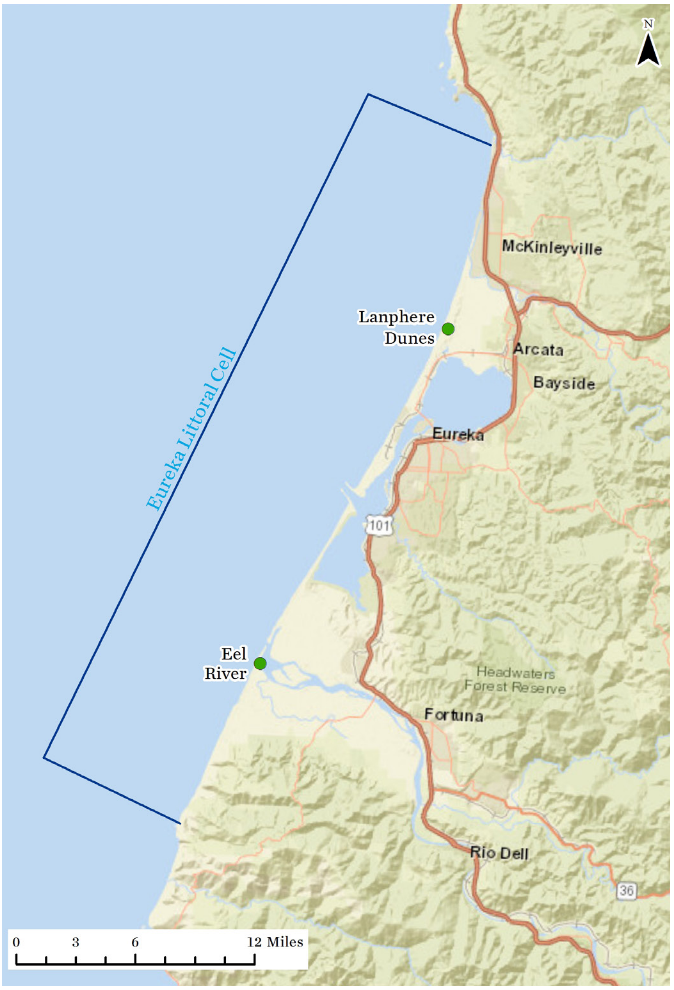
Summary

The 32 miles of beach-dune systems along the Eureka littoral cell in Humboldt County include four major barrier spits that protect the Humboldt Bay and Eel River estuaries and will be subject to sea-level rise and inland migration. (Map 6) These barrier systems support rare coastal dune ecosystems, threatened and endangered species, and important archeological sites. In addition, critical infrastructure is located in some areas including the Humboldt Bay Municipal Water District pipeline and Manila Community Service District's wastewater treatment ponds. Evidence suggests that coastal dunes dominated by native plants are better able to move inland in response to sea level rise while maintaining their integrity and protecting inland habitats and land uses.

This project is both a science project and tests adaptation strategies at demonstration sites and is led by the U.S. Fish and Wildlife Service Humboldt Bay National Wildlife Refuge (the refuge). The science component is monitoring sediment movement and foredune morphology at the scale of the littoral cell to better understand sediment dynamics to allow for the identification of areas of vulnerability due to factors such as sediment deficiency or subsidence. Dune vegetation management strategies are tested at demonstration sites to inform regional adaptation strategies to reduce vulnerability to sea level rise and coastal storms. The current Climate Ready project will provide additional insights into the best adaptation strategies to maximize the resilience of dunes, which are the primary coastal defense infrastructure for the human communities living along Humboldt Bay.

KEY LESSONS FOR SUCCESS

- Formulate teams that include academic scientists and those doing science in a management setting to ensure dissemination through peer-reviewed publications in addition to reports required by funding agencies.
- Use a collaborative approach with both ecologists and geomorphologists on the team.
- Engage partners on the ground in data collection both on their own land (for buy in) and on their partners' land (to increase their understanding of landscape level processes). This project covered 32 miles of coast and landowners and agencies gained a deeper understanding of the entire ecosystem by working in the field together on lands they were less familiar with.
- Be proactive in presenting science-based information to the general public.
- Engage the community frequently with opportunities to ask questions about the project and participate as volunteers in data collection, invasive removal, and planting of native species.



Map 6: The project is studying sediment dynamics throughout the Eureka Littoral Cell and has two demonstration projects at the Lanphere Dunes and the mouth of the Eel River.

Double-crested Cormorants near the mouth of the Eel River in Humboldt County, CA. Photo credit: Adri/Shutterstock.

Project Details

Location: Little River to Centerville Beach, Humboldt County

Setting: Coastal dunes on barrier spits, open coastline

Project Size:

- 32 miles of shoreline for the littoral cell sediment study and historic shoreline analysis and vulnerability assessment.
- 2 demonstration sites: 935 ft (1.7 acres) of foredune at Lanphere Adaptation Site, and 165 ft (0.3 acres) at Eel River Estuary Preserve.
- Dunegrass propagation site: 600 ft (0.7 acres) of foredune at the Bureau of Land Management's (BLM) Ma-le'l Dunes South portion of the USFWS/BLM Ma-le'l Dunes Cooperative Management Area.

Project Partners: USFWS, BLM, Friends of the Dunes, California State Parks, California Department of Fish and Wildlife, The Wildlands Conservancy, City of Eureka, County of Humboldt.

Additional Climate Ready Project Team members: the Wiyot Tribe, University of Victoria's Coastal Erosion and Dune Dynamics Lab, Arizona State University, Humboldt Bay Municipal Water District, Flinders University, Humboldt Bay Harbor, Recreation and Conservation District and the consulting firm GHD.

Benefits

- Increase biodiversity through habitat restoration
- Increase resilience to sea level rise, storm surges, and high wave energy
- Facilitate decision making in areas of high vulnerability and low resilience

Strategies

- Test sea level rise adaptation in areas of positive to neutral sediment budget (wave and aeolian sand input to beach and dune system is equal to or greater than removal by waves and storms).
  - Removal of invasive over-stabilizing vegetation.
  - Planting several different configurations of native species with different morphologies and sand trapping abilities to test effectiveness in allowing sand to be transported to and over the crest of the primary foredune. Sand transport over the crest is hypothesized to be an important condition for translation (migration inland and upward in elevation) of the foredune, allowing it to maintain its integrity as a buffering feature as sea level rises. Invasive vegetation has been demonstrated to concentrate sand deposition on the front face of the foredune only.
  - Evaluate sediment budgets and morphodynamics in different vegetation treatments using Terrestrial LiDAR scanning and orthophotographs using a kite platform to evaluate the relative effectiveness of the different treatments and control (European beachgrass) in allowing translation to occur.

CONTINUED ON NEXT PAGE

Project Details *continued*

- Test foredune building as adaptation strategy in sediment-starved areas.
  - » Recontour foredunes in overwash/breach areas using native vegetation, large wood, and sand fencing.
- Quantify beach-dune sediment dynamics and identify vulnerabilities of the beach-dune system to sea level rise and extreme events along the littoral cell.
  - » Measure elevation and vegetation semiannually along beach-dune profiles distributed along littoral cell to encompass variation in latitude; barrier, beach, and dune morphology; vegetation; and nearshore processes.
  - » Analyze historic shoreline change since air photo coverage began in 1939-1941.
  - » Evaluate potential impacts of dredge disposal outside of littoral zone.
  - » Complete vulnerability assessment including cultural, ecological and infrastructure.
- Model sea level rise scenarios
  - » Based on transect data and analysis of climatic/oceanic forcing factors predict sea level rise impacts based on sediment budgets, as well as vegetation and management scenarios.

Permits, Leases, and Authorizations

- Environmental compliance: USFWS EA/FONSI (Environmental Assessment/Finding of No Significant Impact) for adaptation site; BLM Categorical Exclusion for Propagation site. No permits per California Coastal Commission needed for Eel River adaptation site as it currently exists. Technical consultation carried out with USFWS Endangered Species program to prevent impacts to endangered Western Snowy Plover (this has involved ongoing coordination with researchers at Humboldt State University who carry out nesting surveys).
- Access: Access permits were obtained from both public (i.e., Humboldt County, City of Eureka) and private landowners. Crew leaders (Research Associates) in charge of surveys were required to hold liability insurance.

Costs

- Planning and Design: $8,000
- Permitting: $6,000
- Implementation: $237,880
- Transects & Modeling: $169,395
- Planting and invasive species control: $2 M
- Monitoring: $181,190
- Outreach: $49,310

Timeline

- Research leading up to project conducted 2012-2015. Climate Ready grant started in 2015, results expected in 2019.

Aerial view of Humboldt Bay and the city of Eureka in Humboldt County. Photo credit: Creative Commons

Site History

The coastal barriers that enclose Humboldt Bay and the Eel River Estuary have historically supported expansive and diverse dune habitats. Much of the area was degraded by the intentional introduction and subsequent spread of non-native, invasive European beachgrass (*Ammophila arenaria*) and other species that overstabilize the dunes and crowd out native plants and animals. Beginning in the 1990s with the Lanphere dune restoration, land managers began collaborating to restore the dune ecosystems by removing non-native grass and, to a lesser extent, planting the native dune-building grass species. (Figure 33) Extensive dune restoration projects and monitoring have continued throughout this area since that time. To date, over 6 km of shoreline has been restored along the North and South Spits. This effort has returned the native dune species assemblage and restored dune system functions.

Since 2012, land managers have begun exploring the benefits of past restoration efforts beyond ecological benefits such as biodiversity, to determine whether restoration plays a role in promoting resilience to sea level rise and extreme events. A three-year study at Humboldt Bay National Wildlife Refuge funded by USFWS Region 8 Inventory and Monitoring program was carried out by refuge staff in collaboration with the USFWS Coastal Program. Twelve transects were established to measure changes in dune elevation and vegetation along 3 miles of coastline. Preliminary analysis of the 3-year data set revealed that invasive vegetation trapped sand strictly at the foredune seaward face, while native vegetation permitted more sand to crest and overtop the foredune, suggesting that restoration may increase resilience to sea level rise. The preliminary study was the basis for developing a demonstration adaptation project to examine different plant morphologies as a means of increasing resilience. Sediment budgets are a major determinant of resilience; however, the study was too geographically limited to assess sediment budgets beyond a very localized scale. The study has since been expanded and extended as part of the Dunes Climate Ready project.

Objective

The primary goal of the project is to prepare for climate-change-related vulnerabilities of coastal dunes and beaches along the 32-mile Eureka littoral cell. (Map 6) The USFWS have taken the scientific lead on this project with multiple partners. The study measures dune morphology changes in relation to vegetation and sediment supply using both historical imagery and collection of new data in the field. To test sea-level adaptation strategies, demonstration sites at the Lanphere Dunes are being used to compare beachgrass-dominated dunes to restored dunes to determine the vegetation scenario that optimizes sediment transport and facilitates landward and upward migration of an intact foredune. In addition, foredune-building will be tested in a second adaptation site at the Eel River mouth where sediment deficits exist. The scientific sediment supply project and adaptation demonstration projects form the basis for the vulnerability assessment and adaptation strategies in the Humboldt area. (Map 6)

▼ **Figure 33:** European beachgrass being removed from dunes (left) to allow native vegetation and natural dynamics to return (right). Photo credit: Andrea Pickart.

Design

- *Creation and monitoring of two adaptation projects*
  - » The Lanphere Dunes adaptation site will help determine the desirable planting composition that optimizes sand transport and facilitates landward and upward migration of an intact foredune (a desirable response to sea-level rise). This site compares European beachgrass (*Ammophila)*-dominated foredunes with foredunes that are restored and planted with different assemblages of native plants after removal of *Ammophila.* Native plant comparison plots included 3 treatments: American dunegrass (*Elymus mollis),* a mixture of dune mat species, and *Elymus* planted with dune mat species.
  - » The mouth of the Eel River adaptation site used a combination of native plants and driftwood to promote and monitor natural recovery of a foredune following an over-wash event.
- *Monitoring Dune Dynamics*
  - » Topographic data is being collected using RTK-GPS technology, each winter and summer, over the entire Eureka littoral cell. The data is being analyzed to better understand long and short-term beach-dune dynamics. Together with the analysis of historic shoreline changes based on air photo records, this information will be used to predict effects of sea level rise and extreme events, and to analyze vulnerabilities.
- *Native dune grass propagation site*
  - » A native dune grass propagation site has been established on the North Spit to analyze how native grass plantings affect sand movement from the beach, and to assist in future dune restoration projects along the North Spit.

Implementation

The project covers a large area between all the components and involves a high level of collaboration and participation from landowners (primarily staff from California State Parks, BLM, CDFW, and The Wildlands Conservancy), refuge staff, hired research assistants (RA), academic scientists, graduate students, and volunteers recruited by Friends of the Dunes. Each component informs the others and will inform the regional vulnerability assessment and adaptation planning. Andrea Pickart is a USFWS ecologist with the refuge who oversees the work at the adaptation sites and organizes teams for the surveys.

Adaptation Projects

The Lanphere Dunes sea level rise adaptation site had vegetation removed in fall 2015, and was planted with native vegetation in winter 2017. The California Conservation Corps (CCC) were contracted to do the beachgrass removal, assisted by CDFW and by partners and volunteers. Planting was done by CDFW, CCC donated time, RAs, USFWS staff and volunteers. (Figure 34) Vegetation monitoring is done by USFWS staff and RAs. USFWS staff conducts aerial kite surveys of the adaptation site. Vegetation monitoring through May 2017 showed high survivorship of native dune grass, with more variable success of native dune mat species. Additional planting is scheduled for fall 2017/winter 2018, however, native dune mat species have volunteered on the site in large numbers.

Geomorphic monitoring through October 2016 showed that sediment flux was greatest in the beach (generally true of beach/foredune systems) with large erosive events in winter 2016 and 2017 causing vertical scarping (cliffing) of the foredune and significant loss of elevation in the beach. Beach elevation after the first scarping interval recovered during the more depositional conditions of summer (response to winter 2017 not yet analyzed). The foredune retained volume and height in restored areas after the first year, with some translation of foredune crests eastward. Analysis of second year data is in progress, and monitoring will continue as plants become better established. All geomorphic monitoring is done by University of Victoria (now Arizona State University) students under Dr. Ian Walker's direction and with help from RAs and USFWS staff.

Work at the Eel River adaptation site has been done almost exclusively with in-kind match using labor from the landowner (The Wildlands Conservancy) and CDFW. The Eel River adaptation site (characterized by sediment deficit) experienced additional over-wash in the two subsequent winters, and is now being reevaluated as to the need to test a less passive adaptation methodology through foredune recontouring prior to planting and wood placement.

Dune Dynamics

Andrea Pickart oversees two to three funded local RAs and they are joined by up to a dozen agency partners and volunteers each season to complete the beach/dune transect surveys. The teams deploy three RTK-GPS base-station/rover pairs (provided by Dr. Ian Walker) to complete three different transects each field day. Teams are composed of a crew leader who runs the GPS, and 'veg sampler' who takes vegetation measurements. (Figure 35) The veg samplers include scientists from different disciplines among refuge partners (ranging from botanists to engineers to fishery biologists), who take a vegetation sampling training before each survey. Crews generally walk to sites carrying equipment in backpacks due to the major access logistics for ATVs. During the surveys, the crews work 40-hour weeks in the field. The partners enjoy working in the dune system and can really understand what the project is doing by participating.

▲ **Figure 34:** Restoration of native dune vegetation (*Elymus mollis*) by California Conservation Corps. Photo credit: Andrea Pickart.

Three surveys have been completed (winter 2016, summer 2015, winter 2017) and a fourth is in progress (summer 2017). Funding for two additional surveys has been secured (winter 2018 and summer 2018). Survey results have not been quantitatively analyzed, but show a trend of beach-dune recovery throughout much of the littoral cell following two extreme winters (2016 El Niño and 2017 characterized by extreme high water events). In the southern portion of the littoral cell, where a sediment deficit was presumed, recovery has not been observed, suggesting greater vulnerability.

The historic shoreline analysis is near completion, and preliminary results indicate a relatively stable to accretionary shoreline along most the littoral cell, except for an erosional hot spot north of the North Jetty of Humboldt Bay and along the entire length of the Eel River south spit. Significant accretionary trends have been exhibited over time south of the Little River, along a portion of the North and South Spits of Humboldt Bay, and the north spit of the Eel River. These data will inform the vulnerability assessment and together with the semiannual transect data will allow exploration of littoral cell dynamics and potential impacts of removal of dredge material outside of the littoral cell.

Community Engagement

This project included over a dozen partners ranging from federal, state, and local agencies to universities, NGOs, tribes, special districts, a consulting firm and even private landowners. Landowners and agencies that manage land worked together along the 32-mile dune system and in the process broadened their perspective and understanding of the entire ecosystem. In addition to engaging a high diversity of partners in the actual work, the public is actively engaged through Friends of the Dunes. Friends of the Dunes maintains a page on their website to keep the public updated quarterly about the project (*http://www.friendsofthedunes.org/science/climate-ready/*). They have also sponsored public presentations and field trips to provide opportunities for dialogue between the public, scientists, and land managers.

▲ **Figure 35:** Vegetation and RTK-GPS elevation surveys. Photo credit: Andrea Pickart.

Resources

- Climate Ready Project: *http://www.friendsofthedunes.org/science/climate-ready*
- Humboldt Bay Refuge: *https://www.fws.gov/refuge/Humboldt_Bay/wildlife_and_habitat/DunesRestoration.html*
- Friends of the Dunes: *http://www.friendsofthedunes.org/science/FAQ-November-17-2015.pdf*

Contacts for Additional Information

- Andrea Pickart, Humboldt Bay National Wildlife Refuge, *andrea_pickart@fws.gov*

Appendix 1

Compiled list of projects generated by Technical Advisory Committee

NAME	LOCATION	WEBSITE
SOUTH COAST		
Bolsa Chica Wetland Restoration	Orange County	*http://www.amigosdebolsachica.org/bolsa_chica_restoration/default.php*
Cardiff State Beach Living Shoreline Project	Encinitas	*http://www.cityofencinitas.org/Government/Departments/Public-Works/Environmental-Management/Coastal-Zone-Management*
Imperial Beach Nourishment Project	Imperial Beach	*http://www.sandag.org/index.asp?projectid=358&fuseaction=projects.detail*
Malibu Lagoon State Beach Restoration Project	Malibu	*http://www.santamonicabay.org/explore/wetlands-rivers-streams/malibu-lagoon/*
Regional Beach Restoration Project I & II	San Diego	*http://www.sandag.org/index.asp?subclassid=32&fuseaction=home.subclasshome*
San Diego Bay Native Oyster Living Shoreline Project	San Diego Bay	*http://scc.ca.gov/2015/07/03/san-diego-bay-native-oyster-conceptual-restoration-plan/*
Santa Monica Bay Dune Restoration Project	Los Angeles County	*http://www.santamonicabay.org/santa-monica-beach-restoration-pilot/*
Seal Beach thin layer marsh sediment augmentation	San Diego	*https://www.fws.gov/refuge/seal_beach/what_we_do/resource_management/Sediment_Pilot_Project.html*
South San Diego Bay Coastal Wetland restoration	South San Diego Bay	*http://scwrp.org/projects/south-san-diego-bay-restoration/*
Surfers Point Shore Enhancement	Ventura	*http://surferspoint.org/*
Tijuana River Estuary Tidal Restoration Project (TETRP)	South San Diego	*http://trnerr.org/tijuana-estuary-tidal-restoration-program/*
Upper Newport Bay Living Shorelines Project	Orange County	*https://www.coastkeeper.org/restoration/eelgrass-restoration-upper-newport-bay/*

NAME	LOCATION	WEBSITE
CENTRAL COAST		
Ocean Beach Master Plan	San Francisco	*http://www.spur.org/featured-project/ocean-beach-master-plan*
Elkhorn Slough Tidal Wetland Restoration Project	Moss Landing	*http://www.elkhornslough.org/tidal-wetland-program/*
Restoration and Managed Retreat of Pacifica State Beach	Pacifica	*http://www.cakex.org/case-studies/restoration-and-managed-retreat-pacifica-state-beach*
Salinas River State Beach Dune Restoration	Moss Landing/ Monterey Bay/ Monterey County	*https://ccwg.mlml.calstate.edu/sites/default/files/documents/SRSB_DuneRestorationandManagementPlan.pdf*
Upper Pajaro River Floodplain Restoration Project	Santa Clara Valley	*http://www.baeccc.org/pdf/Upper%20Pajaro%20River%20Floodplain%20Restoration.pdf*
Window on the Bay un-development	Monterey	*http://monterey.org/Services/Parks-and-Beaches/Window-on-the-Bay*
SAN FRANCISCO BAY		
Albany Bulb	Alameda County	*http://www.albanybulb.com/*
Aramburu Island	Richardson Bay/ San Francisco Bay	*http://richardsonbay.audubon.org/conservation/aramburu-island*
Bel Marin Keys/Hamilton Wetland Restoration	Novato	*http://hamiltonwetlands.scc.ca.gov/*
Dotson Family (Breuner) Marsh	Point Pinole Regional Shoreline	*http://www.ebparks.org/about/planning#breuner*
Creosote Removal/ Living Shorelines	Richmond/ SF Bay	*https://baynature.org/article/pilot-project-remove-350/*
Hamilton Wetlands Restoration Project	Novato / San Francisco Bay	*http://hamiltonwetlands.scc.ca.gov/*
Heron's Head	San Francisco County, San Francisco	*http://sfport.com/herons-head-park*

NAME	LOCATION	WEBSITE
Integrated Restoration in San Francisco Bay: Maximizing Ecological Function and Shoreline Protection through a Multi-habitat Living Shoreline Approach	Giant Marsh, Pinole	*http://www.sfbayjv.org/project-integrated-restoration-in-san-francisco-bay.php*
Invasive Spartina Project -Revegetation & High Tide Refuge Islands	San Francisco Bay	*http://www.spartina.org/project.htm*
Miller-Knox Regional Shoreline Enhancement	Contra Costa County	*http://www.ebparks.org/parks/miller_knox*
Novato Creek Vision (Flood Control 2.0)	Novato	*http://www.sfei.org/sites/default/files/biblio_files/NovatoCkBaylandsVision_FC2pt0_SFEI_2015.pdf*
Oro Loma Horizontal Levee Project (Ecotone Slope)	San Lorenzo	*http://oroloma.org/horizontal-levee-project/*
Petaluma Marsh Restoration	Novato	*http://www.swampthing.org/projects/applied-conservation-science/item/150-petaluma-river-marsh-restoration*
San Francisco Bay Living Shorelines	San Rafael	*http://www.sfbaylivingshorelines.org/sf_shorelines_about.html*
Sears Point Wetland and Watershed Restoration Project	South of Hwy 37, north SF Bay	*https://sonomalandtrust.org/publications/plans_reports.html*
Sonoma Creek Enhancement Project	mouth of Sonoma Creek, South of Hwy 37	*http://ca.audubon.org/conservation/conservation/seas-shores/san-francisco-bay/sonoma-creek-restoration*
South Bay Salt Pond Restoration Project	Alameda, San Mateo, and Santa Clara Counties	*http://www.southbayshoreline.org/*
Walnut Creek Vision (FC 2.0)	Walnut Creek	*http://www.sfei.org/flood-control-20*
Yosemite Slough - Candlestick Point SRA General Plan	San Francisco Bay	*http://www.parks.ca.gov/?page_id=28024*

NAME	LOCATION	WEBSITE
NORTH COAST		
Bodega Water Conservation Pilot Program	Salmon Creek	*https://oaec.org/our-work/projects-and-partnerships/water-institute/bodega-pilot-program/*
Bolinas Lagoon: north end restoration and invasive management	Bolinas	*http://www.marincountyparks.org/depts/pk/our-work/os-main-projects/bolinas*
City of Arcata Living Shoreline Project	Arcata	*http://www.madriverunion.com/arcata-will-protect-accommodate-and-retreat-from-rising-sea-waters/*
Giacomini Wetland Restoration Project	Point Reyes National Seashore	*http://cakex.org/case-studies/restoring-giacomini-wetlands-agricultural-lands-point-reyes-national-seashore*
Humboldt Bay Dune Restoration Project	Humboldt Bay	*https://www.fws.gov/refuge/Humboldt_Bay/wildlife_and_habitat/DunesRestoration.html*
Humboldt Bay Tidal Salt Marsh Restoration Project	Humboldt County	*https://www.fws.gov/fieldnotes/regmap.cfm?arskey=36946*
Humboldt Coastal Dune Vulnerability and Adaptation Project	Humboldt County	*http://www.friendsofthedunes.org/science/climate-ready/*
Kent Island Restoration Project	West Marin, Bolinas	*https://www.marincountyparks.org/depts/pk/our-work/os-main-projects/bolinas*
MacKerricher State Park Dune Rehabilitation Project	Mendocino County	*http://www.parks.ca.gov/pages/980/files/final%20addendum%20-%20mackerricher%20dune%20rehabilitation%20mnd%20with%20signature.pdf*
Point Reyes National Seashore Dune Restoration Project	Marin County	*http://www.sfnps.org/dunes/resource_briefs*
Redwood Creek Restoration at Muir Beach	Muir Beach	*http://www.baeccc.org/pdf/Redwood%20Creek%20Restoration.pdf*
Salt River Ecosystem Restoration	Eel River Delta, Humboldt Co.	*http://humboldtrcd.org/index_files/salt_river_ecosystem_restoration_project.htm*
Tomales Bay eelgrass restoration	Tomales Bay	*https://farallones.noaa.gov/eco/tomales/seagrass.html*

Appendix 2

Permit Applications and Approvals

- *National Environmental Policy Act (NEPA):* Overarching federal environmental review process triggered by federal actions (permits, funding, etc.) required for any projects that don't have an exemption (such as small projects, projects with a research focus, etc.). Can include National Historic Preservation Act cultural resources review and other consultations.
- *US Army Corps of Engineers:* Clean Water Act Section 401 for placement of fill in navigable waters, Endangered Species Act consultation to ensure minimal impact. Mechanisms can include the Individual Permit, Nationwide Permit 27 (Aquatic Habitat Restoration, Establishment, and Enhancement Activities), Nationwide Permit 13 (Shoreline stabilization). New Nationwide Permit 54 (Construction of Living Shorelines) took effect in March 2017, but has a 500-linear foot limit so is most appropriate for small projects.
- *NOAA Fisheries consultation with US Army Corps of Engineers:* Section 7 consultation relative to the Endangered Species Act (aquatic species), Essential Fish Habitat consultation relative to the Magnuson Stevens Fishery Conservation and Management Act and Fish and Wildlife Conservation Act. Mechanisms can include informal (for project actions that are not likely to adversely affect habitat) or formal consultation (for projects that are likely to affect habitat or species).
- USFWS consultation with US Army Corps of Engineers: Federal review of habitats within USFWS jurisdiction, including Section 7 consultation relative to the Endangered Species Act (terrestrial species), Mountain Lion Initiative consultation, and others.
- California Environmental Quality Act (CEQA): Required for any projects that don't have an exemption (such as small projects, projects with a research focus, etc.) Requires examination of multiple environmental considerations in a broader context beyond the project footprint.
- California Coastal Commission: The California Coastal Commission implements the California Coastal Act of 1976 and has regulatory authority over development along the coast in balance with the protection of coastal resources, environmentally sensitive habitats, and public access. This work is carried out through land use planning and permitting. The Commission also has the responsibility to work with local governments to establish Local Coastal Programs (LCPs) which, when certified by the Commission, becomes the land use plan basis for coastal permitting at the local level. More specifically, Coastal Development Permits (CDP) are typically required for living shoreline projects. CDP is the regulatory mechanism by which proposed developments in the coastal zone are brought into compliance with the policies of Chapter 3 of the Coastal Act. After the Commission certifies a LCP most coastal development permit authority is delegated and coastal development permit applications are then reviewed and acted on by cities and counties.
- *San Francisco Bay Conservation and Development Commission:* State regulatory agency with jurisdiction of the San Francisco Bay shoreline and lands 100' inland from the shoreline, currently undergoing review of their existing mandate and any changes necessary to allow the appropriate use of beneficial fill, and allow experimental climate adaptation approaches such as living shorelines. Coastal Zone Management Agency. Consultation relative to the McAteer-Petris Act, which limits placement of fill and addresses other considerations in San Francisco Bay. Administrative Permit (smaller footprint, minimal impacts) or Individual Permit (larger footprint, impacts).
- California Department of Fish and Wildlife consultation with the California Coastal Commission or the Bay Conservation and Development Commission: Consultation to limit any impacts and maximize benefits to state-listed fish and wildlife; Scientific Collecting Permit for eelgrass donor, native oyster, and other native species collections; Letter of Authorization for transplanting eelgrass to restoration sites.
- *State and Regional Water Quality Control Boards:* State regulatory agency with jurisdiction in riparian, estuarine, and coastal waters. Section 404 Water Quality certification to address issues associated with placement of fill, turbidity, minimizing construction impacts to water quality.
- *California State Lands Commission:* Coordination to confirm whether the project is on state-owned or leased lands, and to confirm CEQA compliance. Projects proposed on land under State Lands Commission ownership require Commission Approval and a Lease Agreement.
- *Letter of Permission and consultation with local jurisdiction (county, city, municipality):* This may include approval by City Council or other local jurisdictional body such as a Major Use Permit.
- *License Agreements or other permission mechanisms with landowner(s):* This may include agreements with (private, local, state, or federal) landowner(s) such as a Right of Entry Permit that provide permission to access or Encroachment Permit that provides permission to construct. Note that many coastal and estuarine shoreline and nearshore subtidal areas can have multiple landowners/parcels even in a small area.

For inquiries regarding the case studies included in this report, please contact Jenna Judge at jenna.judge@noaa.gov. For inquiries regarding *Identification of Natural Infrastructure Options for Adapting to Sea Level Rise*, please contact Sarah Newkirk at snewkirk@tnc.org.