CITIZENS COMMITTEE TO COMPLETE THE REFUGE

SAN FRANCISCO BAYKEEPER®

Sent via electronic email only

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Attn: Frances Malamud-Roam, Regulatory Permit Manager
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October 4, 2022

Re: Public Notice SPN-2018-00371: West Bay Sanitary District Flow Equalization and Resource Recovery Facility Protection Project

Dear Ms. Malamud-Roam,

These comments are submitted on behalf of the Citizens Committee to Complete the Refuge (CCCR) in response to the revised Public Notice (PN) SPB-2018-00371: West Bay Sanitary District Flow Equalization and Resource Recovery Facility Protection Project. We are also resubmitting a Memorandum from Dr. Peter Baye, Coastal Ecologist, Botanist, dated March 14, 2022 regarding the proposed project.[1] This Memorandum is based upon the project description provided in the previous U.S. Army Corps of Engineers (Corps) PN dated February 14, 2022, however, many of the substantive concerns described in this Memorandum remain pertinent to the revised project description.

Thank you for the opportunity to provide comments. Our review of the proposed project is based upon information contained in the revised Corps PN, the Flow Equalization and Resource Recovery Facility Levee Improvements DEIR and FEIR and appendices of December 2020 and May 2021, the Bayfront Recycled Water Facility Project Final Report of February 2019 and the August 2022 permit application packet submitted to the Corps and San Francisco Bay Regional Water Quality Control Board (RWQCB). We appreciate the fact that the revised permit application pulls some of the previously proposed fill out of high value tidal wetlands, however, we remain extremely concerned about the potential for environmental harm that might arise from the project as proposed. Based upon our review of the PN and documents, we find that:

- The proposed levee design is inconsistent with the description and ecological function of an “ecotone” levee and precedent-setting in the proposed excavating and filling of mature high value tidal wetlands.
- In addition to the temporary and permanent fill impacts to mature, stable tidal wetlands the project has the potential to result in degradation of adjacent high value wetlands.

[1] Memorandum from Dr. Peter Baye, Coastal Ecologist, Botanist, dated March 14, 2022 to CCCR, attached hereto as Exhibit 1.

- Indirect impacts of the proposed project to adjacent high value wetlands must be taken into consideration when determining the need of a rigorous alternatives analysis and should not be based solely on the estimates of permanent impacts to waters of the U.S.
- Applicant has not adequately demonstrated that Alternative F, which could pull all the impacts out of Section 404 Clean Water Act jurisdiction, is not feasible.
- Language in the draft Adaptive Management Plan raises concerns about the potential for additional impacts to this high value wetlands complex.
- The Adaptive Management Plan as proposed is inadequate. The sources of uncertainties identified in the Adaptive Management Plan provide support for the need to expand the monitoring requirements to adjacent, high value tidal wetlands and mudflats to detect indirect impacts that might arise from the proposed project. The Adaptive Management Plan must include contingency measures for indirect impacts to adjacent high value wetlands and mudflats that result due to implementation of the proposed project.
- The impacts of the helipad on federally listed species must be considered during consultation with the U.S. Fish and Wildlife Service (USFWS).

The tidal wetlands adjacent to the West Bay Sanitary District (WBSD) Flow Equalization and Resource Recovery Facility (FERRF) are undisturbed, stable, high value tidal wetlands. In the 2020 Ridgway's Rail surveys[2], Greco Island South (the area immediately adjacent to the WBSD FERRF), part of the Don Edwards San Francisco Bay National Wildlife Refuge (Refuge), had the highest count of rails for the areas surveyed along the western shoreline of South San Francisco Bay and the highest density of rails. And in 2005, a salt marsh harvest mouse was trapped in Flood Slough.[3]

The project as proposed could result in significant direct and indirect fill impacts to stable, high value tidal wetlands and mudflats and to the Refuge. Based upon the potential direct and indirect impacts of the project and the significant degradation and destruction of special aquatic sites, we believe the project as described requires rigorous analysis of avoidance and minimization of impacts, practicable alternatives, and compensatory mitigation under the 404 (b)(1) Guidelines (40 CFR 230.1 (c-d), commensurate with the importance of these wetlands to the public interest (33CFR 320.4 (b)). These critically important Refuge wetland habitats for endangered wildlife (e.g., Ridgway's Rail (RIRA), salt marsh harvest mouse (SMHM)) meet or exceed all criteria for wetlands important to the public interest (33 CFR 320.4(b), and are likely to be altered adversely enough by the proposed project to require that *no permit be granted* (320.4(a)(4). The direct destruction and fill of extensive high tide refuge habitat in tidal wetlands bordering the Greco Island marshlands of the Refuge constitute an impermissible discharge of fill that would cause and contribute to significant degradation of wetlands and other tidal waters (40 CFR 230.10(c).

The basic project purpose of this project is to provide flood protection. The proposed project is inconsistent with the description of a horizontal/ecotone levee and ignores a fundamental standard of a horizontal levee – that the toe of the horizontal levee begins at the high tide line (HTL) and gradually slopes upward and landward from the HTL. We are extremely concerned that the use of the term "ecotone levee" in this instance, for this proposed project, in this environmental setting, sets a dangerous and negative precedent of authorizing disturbance of high value and relatively stable tidal wetlands under the guise of a nature-based solution.

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[2] Olofson Environmental, Inc. *California Ridgway's Rail Surveys for the San Francisco Estuary Invasive Spartina Project 2020*. February 1, 2021. Report to the State Coastal Conservancy. San Francisco Estuary Invasive *Spartina* Project, attached hereto as Exhibit 2

[3] *Salt Marsh Harvest Mouse Database and Maps*. San Francisco Estuary Institute & Aquatic Science Center. https://www.sfei.org/content/salt-marsh-harvest-mouse-database-and-maps accessed 3-22-2009 Figure for project location attached hereto as Exhibit 3

Horizontal levee projects within the San Francisco Bay have typically been constructed in diked baylands, in areas isolated from the tides during construction. This provides the opportunity for the ecotone slope to become vegetated prior to exposure to the tides, thereby reducing the potential for erosion of the ecotone slope. This strategy avoids the need to adversely impact high value tidal wetlands. In such situations, we have been supportive of the construction of horizontal levees.

We recognize the value of nature-based solutions in providing resilience for the natural and built environment. As an example, we wrote letters of support for the Oro Loma Sanitary District horizontal levee and have been supportive of the creation of ecotone slopes for projects such as the South Bay Salt Pond Restoration Project (SBSPRP).

Are there other instances where excavation and fill of high value tidal wetlands have been authorized for the construction of horizontal levees? The Corps has historically denied permit authorization for fills in tidal wetlands on the outboard sides of levees for the creation of benches, how does this project differ?

Commenters:

The Citizens Committee to Complete the Refuge (CCCR), with a membership of 1,800 has an ongoing history of interest in wetlands protection, wetlands restoration and wetlands acquisition. Our senior members were part of a group of citizens who became alarmed at the degradation of the Bay and its wetlands. We joined together, and with the support of Congressman Don Edwards, requested that Congress establish the Nation's first national wildlife refuge in an urban setting. The process took seven long years and in 1972, legislation was passed to form the San Francisco Bay National Wildlife Refuge (Refuge). We turned to Mr. Edwards again, and in 1988 (the first year he submitted it), his legislation to double the size of the Refuge was signed into law. The Refuge now bears his name in honor of his efforts.

CCCR has taken an active interest in Clean Water Act regulations, policies, implementation, and enforcement. We have established a record of providing information regarding possible CWA violations to both the Corps and EPA. We regularly respond to Corps public notices, and inform the public of important local CWA issues. We have responded to past proposals of reissuance and changes to the nationwide permit program. These actions demonstrate our ongoing commitment to wetland issues, toward protecting the public interest in wetlands, and in Section 404 of the CWA.

Baykeeper's mission is to defend San Francisco Bay from the biggest threats and hold polluters and government agencies accountable to create healthy communities and help wildlife thrive. Our team of scientists and lawyers investigate pollution via aerial and water patrols, strengthen regulations through science and policy advocacy, and enforce environmental laws on behalf of the public. Baykeeper and our more than 5,000 members and supporters, have an ongoing history of protecting the bed/substrate of the Bay's limited resources for the public in perpetuity. We have dedicated significant resources to ensuring commercial sand mining is conducted in a sustainable manner as well as ensuring navigational dredging is conducted in a manner protective of the Bay's water quality.

Project Description:

The proposed project is located in San Mateo County on and along lands of the West Bay Sanitary District (District) where it plans to build its Flow Equalization and Resource Recovery Facility Protection Project (FERRF). The site is adjacent to Bedwell Bayfront Park in Menlo Park, and is bounded by Flood Slough immediately to the west and Westpoint Slough to the north. Greco Island, part of the Don Edwards San Francisco Bay National Wildlife Refuge, lies immediately across Westpoint Slough from the project site.

The basic project purpose is to provide flood protection. The project lies within a Federal Emergency Management Agency (FEMA) designated flood zone. The existing levees range in elevation from 10' to 12' NAVD 88 and are not FEMA certified. The applicant is proposing to raise the elevations to 15' NAVD 88 to protect the WBSD site from potential current and future flood risk. The revised Public Notice (PN) states the applicant proposes to construct an ecotone levee and living shoreline along approximately 598 linear feet of tidal wetlands, mudflats and slough and atop 1.19 acres of waters of the U.S. including existing, high value tidal wetland habitat and tidal mudflat habitat. Temporary impacts to approximately 675 linear feet of waters of the U.S. will occur due to the installation of temporary cofferdams. A sheet pile cofferdam system would be installed during construction of the levee and would be removed at some point after the project construction is completed.

Clarification of Existing Conditions:

The August 2022 "Living Shoreline 65% Basis of Design Report" seems to suggest that the development of tidal wetlands vegetation within the project vicinity is a fairly recent development with Figure 6 of the document referencing "new tidal marsh plains," however, review of the limited Google Earth images available (A partial image of the area dating back to 1948 is available, after that the next clear image is from July 1993.) demonstrate that tidal wetlands had developed along Westpoint and Flood Slough.

These images provide documentation that the tidal wetlands and mudflats have existed at minimum for over thirty years and have been relatively stable in their extent.

The project as proposed is inconsistent with the description of an ecotone levee:

The *Adaptation Atlas*[4] describes an ecotone levee in the following manner:

> "This slope *stretches down from the crest of the flood risk management levee to tidal marsh elevation* with a gradient between 20:1 and 30:1."

An ecotone levee is also described as being "*landward of a tidal marsh*," i.e., landward of the high tide line. An ecotone levee is designed to provide lateral migration space for tidal wetlands that exist adjacent to the *toe* of the proposed levee. The proposed project differs significantly from this description. Cross Section Station 6+00 on Sheet 5 of the PN Drawings provides a visual representation of this project's departure from the description of an ecotone levee, with the proposed levee work extending bayward approximately 60-80 feet below the reported high tide line of 10.25' NAVD 88.

The proposed project proposes to disrupt through direct impacts, at minimum 1.19 acres of intact, high value tidal wetlands, mudflat and slough habitat by constructing a flood protection levee on top of the existing wetlands. Not only does this proposed action result in the temporal and potentially permanent loss of high value tidal wetlands and endangered species habitat, it also raises the concern of adverse and significant impacts of the project on the surrounding tidal slough, mudflat and tidal wetlands habitat. The actions of installing sheet pile cofferdam(s), scraping back the wetlands vegetation, and constructing a FEMA certifiable flood control levee amid high value wetlands will likely result in degradation of adjacent wetlands, mudflat, potentially alter the flows in this portion of Westpoint Slough and disturb listed and sensitive species.

The *Baylands Ecosystem Habitat Goals Update*[5] describes Greco Island as "the largest contiguous tidal marsh on the western side of the bay" that is "*relatively protected from human disturbance*" and is "one of the main population centers of centers of Ridgway's Rail in the South Bay." [emphasis added]

The whole of the impacts to waters of the U.S. must be duly considered:

The PN states that the project would place fill in 1.19 acres of waters of the U.S. for the creation of the flood control levee and oyster reef structures, with the permanent loss limited to 0.06 acres of tidal marsh habitat and conversion of 0.05 acres of mudflat habitat to tidal marsh habitat. The whole of the impacts of the proposed project must be considered in reaching a permit decision, including not only the direct and indirect impacts within the project footprint, but equally and perhaps even more important, the potential indirect impacts to high value wetlands and mudflats immediately adjacent to the project boundaries.

The *Tidal Marsh Recovery Plan*[6] describes Greco Island as an "important example of remnant pre-historical tidal marshes in the San Francisco Bay Estuary" and states:

> "These remnant pre-historical marshes are not only *critically important refuges for populations of rare species*, but they contain invaluable and irreplaceable information, preserving clues of the origin,

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[4] SFEI and SPUR. 2019. *San Francisco Bay Shoreline Adaptation Atlas: Working with Nature to Plan for Sea Level Rise Using Operational Landscape Units.* Publication #915, San Francisco Estuary Institute, Richmond, CA.

[5] Goals Project. 2015. *The Baylands and Climate Change: What We Can Do. Baylands Ecosystem Habitat Goals Science Update 2015* prepared by the San Francisco Bay Area Wetlands Ecosystem Goals Project. California State Coastal Conservancy, Oakland, CA.

[6] U.S. Fish and Wildlife Service. 2013. *Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California*. Sacramento, California. xviii + 605 pp.

development, structure, and composition of natural tidal marsh systems over several thousand years." [emphasis added]

What information has been provided to the Corps to provide assurance that the proposed project will not adversely impact surrounding wetlands, or that tidal wetlands habitat will become established on the newly created slopes? Contrary to ecotone levees authorized within San Francisco Bay to date, the proposed flood control levee will be constructed in an area that is subject to tidal currents and to wave energy.

The Adaptive Management Plan dated August 2022 acknowledges the following:

> "Given previous levels of success, moderate levels of uncertainty are associated with the project. Sources of uncertainty associated with the project include:
> • The impact of wind and waves on sediment resuspension and, in turn, the rate of site evolution and the final mix of vegetated marsh and unvegetated mudflat.
> • The effects of future sea level rise, which has the potential to affect the project outcome.
> • The impact of large storm events on erosion and shoreline position.
> • The impact of drought and/or flood events, which have the potential to affect the project outcome.
> • The extent to which the new infrastructure will perform as designed.
> • The extent to which invasive tidal salt marsh species (e.g., *Spartina* and hybrids) may establish and the extent to which they can be controlled through management."

Many of these uncertainties were discussed in detail in the March 14, 2022 Memorandum provided by Dr. Peter Baye and included as Exhibit 1 to our comment letter. These uncertainties are not restricted to the area within the project boundaries, but must be extended to the wetlands and mudflats adjacent to and outside the project boundaries – of particular concern is the consequence of ecotone slope erosion, but we are equally concerned about destabilization of the complex of high value wetlands and mudflats in the vicinity of the proposed project.

The application materials to the San Francisco Bay Regional Water Quality Control Board include the statement:

> "Sediment delivery from the primary source of sediment at the site, San Francisco Bay, will be unaffected by the project. Sediment transport capacity along Flood Slough at the northern point feature may be increased due to tidal marsh fill under certain flow conditions. <u>This increase in capacity may result in some minor, localized scour of the Flood Slough channel adjacent to the new fill relative to the existing condition</u>. This toe scour along the new project features will be mitigated by the implementation of oyster reef revetments. The relatively short extent of the proposed fill, and presence of the 150-foot-wide tidal marsh plain on the west side of Flood Slough should mitigate any risk of toe scour to the salt pond levees to the west. T<u>he tidal marsh plain to the west of the point may retreat marginally over time in response to project implementation</u>."

In addition, several of the potential contingency measures identified in the Adaptive Management Plan mention:

> "Additional management actions include, but are not limited to, adding wave breaks, placing additional fill, or removing fill."

> "Add additional wave breaks and/or implement additional erosion control methods."

The Corps must consider the potential of the proposed project to destabilize areas of high value wetlands and mudflats adjacent to the project boundaries and not just the provided estimates of temporary and permanent impacts within the project boundaries.

We appreciate the stated intent to incorporate actions that will provide resilience for the adjacent tidal wetlands. Lack of tidal wetlands migration space as sea levels continue to rise is of regional concern. However, as is so often said, "location, location, location." The siting and design of ecotone levees must be such that they will not adversely impact adjacent existing high value wetlands habitat. We urge the Corps to deny authorization of this project as currently designed.

Alternatives Analysis:

A Memorandum regarding the "Appropriate Level of Analysis Required for Evaluating Compliance with CWA Section 404 (b)(1) Guidelines Alternative Requirements" discusses the intensity of alternatives analysis and states:

> "The Guidelines do not contemplate that the same intensity of analysis will be required for all types of projects but instead envision a correlation between the scope of the evaluation and the potential extent of adverse impacts on the aquatic environment."

And:

> "Consequently, the Guidelines clearly afford flexibility to adjust the stringency of the alternatives review for projects that would have only minor impacts. <u>Minor impacts are associated with activities that generally would have little potential to degrade the aquatic environment and include one, and frequently more, of the following characteristics: are located in aquatic resources of limited natural function; are small in size and cause little direct impact; have little potential for secondary or cumulative impacts; or cause only temporary impacts</u>." [emphasis added]

However, the next sentence is crucial:

> "<u>It is important to recognize, however, that in some circumstances even small or temporary fills result in substantial impacts, and that in such cases a more detailed evaluation is necessary</u>."

We maintain that this sentence applies for the proposed flood control levee. This project will take place within high value tidal wetlands and mudflats that support federally listed species, critical habitat, and Essential Fish Habitat, that is within proximity to one of the main population centers for the Ridgway's Rail, and that will occur within a mature and stable tidal wetlands/mudflat complex. In addition, due to the construction of this levee in an area subject to tidal action and waves, there are uncertainties regarding achieving success criteria with the project footprint and of indirect impacts to adjacent high value tidal wetlands and mudflat habitat. For these reasons, a full alternatives analysis should be required despite the reported small acreages of permanent impacts to waters of the U.S.

The proposed project is not "*water dependent*," therefore, under the 404 (b) (1) Guidelines (40 C.F.R. 230.10) **the applicants must rebut the presumption that a practicable alternative exists that is less environmentally damaging.** The preamble to the Guidelines states that it is the applicant's responsibility to rebut this presumption. The Memorandum of Agreement between EPA and the Corps concerning mitigation under the Clean Water Act (CWA) 404 (b)(1) Guidelines (Mitigation MOA) states:

> 1. Section 230.10(a) allows permit issuance for only the least environmentally damaging practicable alternative. *The thrust of this section on alternatives is* *<u>avoidance of impacts</u>*. *Section 230.10(a)(1) requires that to be permittable, an alternative must be the least environmentally damaging practicable alternative (LEDPA).* [emphasis added]

The proposed project does not meet the definition of a LEDPA. The August 2022 Alternatives Analysis, identifies two potential LEDPAs, Alternatives C and Alternative F. Alternative C, the sheet pile alternative would involve the installation of 3,700 linear feet of sheet piles in limited to uplands and developed areas without disruption of special aquatic sites. The applicant provided comments rationalizing the authorization of impacts described in the PN, stating that:

> "During the meeting conducted with USACE, USFWS, NOAA Fisheries, and RWQCB on August 9, 2018, the agencies all agreed that a living shoreline concept should be evaluated as part of the project."

Clearly Alternative C would not result in the construction of a "living shoreline" for the current flood control project. That being said, implementation of Alternative C would not remove the potential to construct a "living shoreline" on this site in the future. Construction of Alternative C might however remove the potential for funding related to utilization of nature-based solutions.

Alternative F, on the other hand represents a project that is the LEDPA and meets the true definition of an ecotone levee in that the toe of the protective levee would be relocated inland, outside Section 404 Clean Water Act jurisdiction, within the footprint of the existing facility. The selection of this alternative meets the best of all conditions in that it is a LEDPA and meets the parameters of an ecotone levee, thereby potentially qualifying the project for funding currently available for the implementation of nature-based solutions.

Unfortunately, Alternative F is described, but is not analyzed further. The project applicant asserts that the capacity of Ponds 1 and 2 must be maintained, but does not address why these ponds cannot be reconfigured or deepened within the existing facility footprint. We provided similar comments in response to the PN issued in February 2022; however, the response to comments was silent as to why the storage capacity cannot be maintained by reconfiguring the location of the ponds within the facility or why capacity cannot be maintained by deepening the ponds.

The Draft Environmental Impact Report (DEIR) for this project included a "Reduced Size of Ponds to Accommodate Ecotone Levee Alternative." The DEIR acknowledged that such an alternative "...likely would reduce or avoid the placement of fill in tidal slough and wetland habitat." And,

> "The Reduced Size of Ponds Alternative would likely *avoid or substantially lessen the placement of fill in the area north of the existing northern levee within wetland and tidal habitat and would thus result in a reduced project footprint in sensitive habitat*." [emphasis added]

But then reached the incomprehensible conclusion that "The Reduced Size of Ponds to Accommodate Ecotone Levee Alternative *<u>would not eliminate any identified potentially significant environmental impacts of the proposed project</u>.*" [emphasis added]

This conclusion is unsupportable from the perspective of the 404 (b)(1) Guidelines. The proposed project will result in the fill of at least 1.19 acres of well-established, stable, high value tidal wetlands and mudflats. These habitats support listed species and have been designated as Essential Fish Habitat and critical habitat. Furthermore, it is unclear whether the impacts of the proposed project might result in impacts greater than estimated. The introduction of disturbance into a high value wetlands complex raises the potential for degradation of the adjacent wetland habitat. Tidal wetlands and mudflats are considered special aquatic sites (40 CFR 230.40-230.45). From an ecosystem and Clean Water Act perspective, filling of 1.19 acres of special aquatic habitat should be considered a significant, adverse impact. 40 CFR 230.10 (a)(3) clearly emphasizes the importance of protecting special aquatic sites:

> "(3) Where the activity associated with a discharge which is proposed for a special aquatic site (as defined in subpart E) does not require access or proximity to or siting within the special aquatic site in question to fulfill its basic purpose (i.e., is not "water dependent"), *practicable alternatives that do not involve special aquatic sites are presumed to be available*, unless clearly demonstrated otherwise. In addition, where a discharge is proposed for a special aquatic site, *all practicable alternatives to the proposed discharge which do not involve a discharge into a special aquatic site are presumed to have less adverse impact on the aquatic ecosystem, unless clearly demonstrated otherwise*." [emphasis added]

The applicant must rebut the presumption that a LEDPA exists. The fact that the applicant is describing the flood protection levee as an ecotone levee does not relieve the Corps of its responsibility to identify a less environmentally damaging practicable alternative.

Additional Concerns:

Helipad and Substantive Concerns Regarding "Take" of Federally Listed Species:

Take as defined under the ESA means "to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture, or collect, or to attempt to engage in any such conduct."

We have raised substantive concerns regarding the use of a helipad in our comments to the original PN and with respect to the potential for "take" of federally listed species to occur. We recognize that the actual helipad will be reconstructed outside of the Corps' regulatory authority, however, it should be considered within the "Action Area" under the Endangered Species Act of 1973.

50 CFR PART 402 – Interagency Cooperation – Endangered Species Act of 1973, As Amended, defines "Action" as follows:

> Action means all activities or programs of any kind authorized, funded, or carried out, in whole or in part, by Federal agencies in the United States or upon the high seas. Examples include, but are not limited to:
>
> (a) actions intended to conserve listed species or their habitat;
> (b) the promulgation of regulations;
> (c) the granting of licenses, contracts, leases, easements, rights-of-way, permits, or grants-in-aid; or
> (d) *actions directly or indirectly causing modifications to the land, water, or air.*

And "Action area means *all areas to be affected directly or indirectly* by the Federal action and not merely the immediate area involved in the action." [emphasis added]

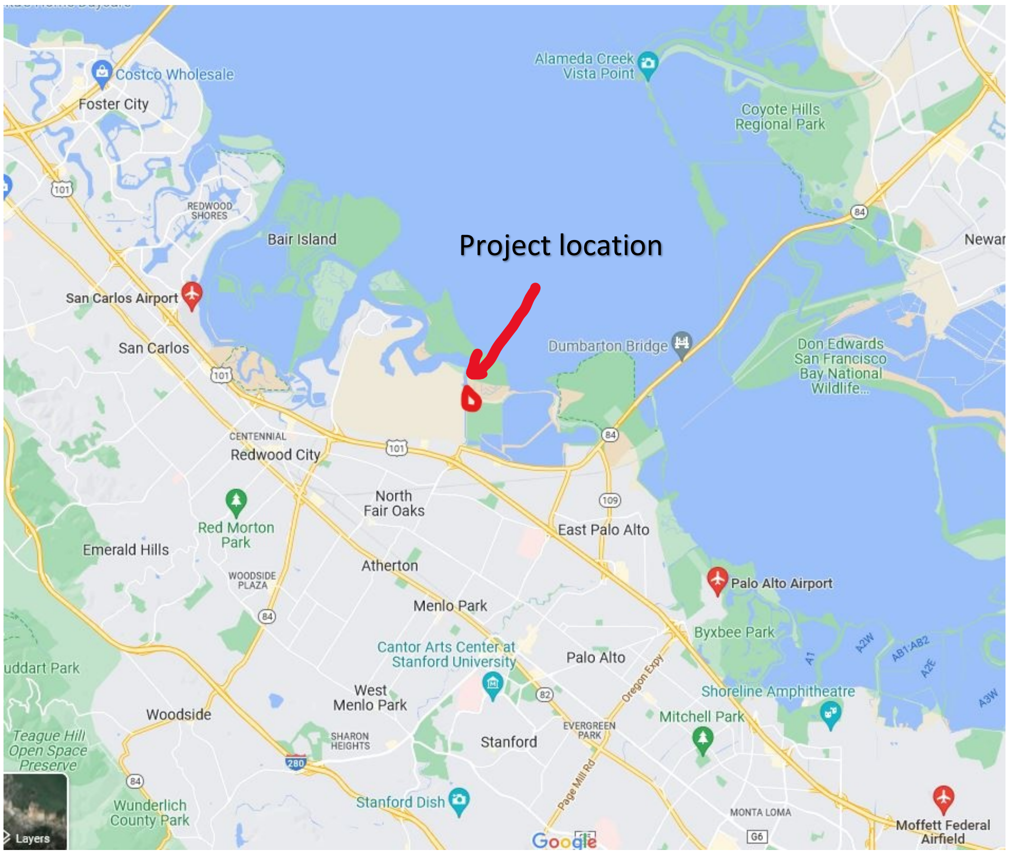
Dr. Baye's Memorandum states:

> "The uplands at the site provides "the most persistent emergent landward high tide cover available to endangered California Ridgway's rails and salt marsh harvest mice with territories located at the west half of Greco Island, during extreme high tides when all high tide cover normally available is submerged."

The helipad is immediately adjacent to Ridgway's Rail habitat. As stated earlier, Greco Island is one of the main population centers for the rail in the South Bay. The proposed helipad reconstruction is immediately adjacent to habitat that supports the Ridgway's Rail, salt marsh harvest mouse and other rare species such as the California Black Rail.

The helipad is proposed for reconstruction atop the constructed levee (as depicted on Sheets 2 and 3 of the PN drawings), therefore, this should be included in the "action area" and must be included in formal consultation with the U.S. Fish and Wildlife Service (USFWS).

This activity raises a whole suite of questions including, but not limited to, why is use of this helipad necessary given the Palo Alto and San Carlos airports are located just four miles to the south and north of the project location?



How often and what time of year would the helipad be used? Has coordination occurred with the Refuge and the USFWS due to its proximity to a high density, core area of RIRA, and what impacts would use of the helipad have on the adjacent tidal wetlands and constructed levee wetlands? The Water Board needs to consider the downwash and outwash impacts[7,8] that could occur to the adjacent tidal marsh and state and federally listed species.

[7] "Helicopter Rotor Downwash – Excessive Wind, FOD and Brownouts, What Are the Risks? - JJ Ryan Consulting." Accessed May 26, 2022. https://jjryan.com.au/index.php/helicopter-rotor-downwash-excessive-wind-fod-and-brownouts-what-are-the-risks/. Attached hereto as Exhibit 4

[8] "Preston et al. - 2014 - Rotorwash Operational Footprint Modeling Pdf." Accessed May 26, 2022. P. 10 https://apps.dtic.mil/sti/pdfs/ADA607614.pdf. Attached hereto as Exhibit 5

The response to comments to the Corps PN state:

> “The helipad is an existing feature at the project location and is currently primarily used by the County of San Mateo and the Coast Guard. The project will not change the use of the helipad from existing conditions. As a result, the use of the helipad does not need to be evaluated as part of the proposed project.”

We do not concur with this statement. Sheet 4 that provides project cross sections clearly indicates that as part of the proposed project, engineered fill would be placed in the area of the helipad.

Cofferdams:

The permit application materials submitted to the Water Board provide the following description of the use of temporary cofferdams:

> “Temporary impacts to Waters of the State will include approximately 675 linear feet associated with the temporary cofferdams placed below the verified HTL that will be used to isolate the work area from Waters of the State during construction. Temporary cofferdams will be installed at low tide to isolate the area from tidal action in Westpoint Slough. The cofferdams will consist of sheet piles installed by a pile driver operated from the top of the levee which would vibrate the sheet piles into the bay mud. Dewatering may be necessary to remove residual water from precipitation and groundwater intrusion. As a result, a dewatering plan will be drafted and submitted to the RWQCB for approval prior to construction. Dewatering pumps and generators with capacity to dewater the temporary cofferdam work area, if necessary, will be kept on site during construction. After construction of the ecotone slope/living shoreline and tidal marsh at the north point near the helipad, native plants will be installed on the ecotone slope surface. The cofferdam will be removed during low tide, allowing the tidal waters to slowly re-enter the area.”

The impacts of the proposed cofferdams are purported to be temporary in nature, but without substantive information (e.g., detailed description, drawings that indicate where cofferdams might be located, etc.) it is impossible to determine whether there could be additional direct or indirect impacts to WOTUS. The work is being proposed in an area that appears to have high value and stable wetlands. The work is being conducted in an area that is subject to the tides and waves.

How long will this cofferdam system remain in place? An email dated September 7, 2002 from consultant to Lauren Huff to permit manager Frances Malamud-Roam states the “…cofferdams are expected to stay in place until the construction is complete in order to ensure that the work area remains isolated from waters and species.” This seems to suggest the cofferdams will only be in place until construction is completed.

Will the installation of the cofferdams have adverse impacts on the adjacent wetlands or mudflats? Does the possibility of scour/erosion directly in front of vertical sheet piles resulting from reflected wave energy exist? What contingency measures have been proposed in the event such impacts occur within the high value wetlands adjacent to and surrounding the temporary sheet pile cofferdam?

Clarification Requested Regarding How the Slopes of the Levee Will be Protected from Wave Action and Scour/Erosion:

The August 2022 Compensatory Mitigation Plan states that "coir matting and coir logs shall be used as erosion control on all graded surfaces, and a September 7, 2022 from consultant Lauren Huff to permit manager Frances Malamud-Roam states:

> "Graded Soil Stabilization: Graded soils will be stabilized through a combination of salvage/placement of existing marsh vegetation, supplemental planting with containerized native plant material, seeding with a native erosion control seed mix, and erosion and sediment control Best Management Practices (BMP's), such as biodegradable straw wattles/fiber rolls or biodegradable erosion control blankets (ECB's) at higher elevations above the proposed marsh habitat. These BMP's will be selected by a Qualified SWPPP Developer (QSD) and documented in the Stormwater Pollution Prevention Plan (SWPPP) and final design plans prior to construction."

Are there known examples where these measures have been demonstrated to be effective in preventing erosion of newly graded/planted slopes in an area subject to tidal action (including perigee spring high tides/king tides) and wave energy? Dr. Baye's Memorandum provides a graphic example of the risk of "ecotone" slope wave erosion.

On the other hand, the August 2022 "Living Shoreline Draft 65% Basis of Design Report" makes the following statement:

> "Temporary erosion control measures will be deployed to mitigate the effects of wave action (and rainfall runoff) on graded slopes until vegetation can become established. The equivalent shear stress exerted by wave action on graded slopes was calculated by first using the Hudson Method to identify the weight of the median riprap particle size required to stabilize the slope, as though rock slope protection were to be used, as described in the Caltrans Highway Design Manual (Caltrans, 2020)."

Is the use of riprap really being proposed to provide protection of the newly graded slopes? If so, where will this be located? How long will it remain in place and when and how would the riprap be removed? The use of riprap raises concerns about attraction of non-native predators and competitors of the salt marsh harvest mouse.

Questions Regarding the Proposed Oyster Reef:

The "Living Shoreline" document referenced above mentions "The oyster reefs will be constructed in the lower to middle intertidal zone along the margin of existing mudflat between MLLW and MSL (-1.1 to 3.4 ft NAVD 88). However, the Adaptive Management Plan states that the oyster reef elements are "anticipated to be placed between elevations of 2 to 5 feet NAVD 88." The Corps must require clarification of the elevation at which these structures will be placed.

Boyer et al[9] provides a list of design criteria that should be considered when proposing installation of oyster reefs as nature-based solutions. In part, conclusions/recommendations pertinent to the proposed project include the following:

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[9] Boyer, Katharyn & Zabin, Chela & Cruz, Susan & Grosholz, Edwin & Orr, Michelle & Lowe, Jeremy & Latta, Marilyn & Hilton-Miller, Jay & Kiriakopolos, Stephanie & Pinnell, Cassie & Kunz, Damien & Modéran, Julien & Stockmann, Kevin & Ayala, Geana & Abbott,

- Key stressors for oysters vary with location within San Francisco Bay and may also shift over the life of a restoration project. It is unlikely that there is a single best design that can be used across estuaries or even within the Bay. Identifying potential stressors and taking these into account in project design may increase project success. For example, shell bags potentially offer protection from heat and desiccation stress and provide a lot of complex surface area for oysters and other organisms to attach to and live in, and greater recruitment and faster growth may occur at lower tidal elevations, but surfaces and tidal elevations that are more stressful in terms of exposure may provide oysters with some measure of protection from marine predators and nonnative fouling species where these species are a concern, especially over the longer term.
- Where possible, pre–site selection surveys and experimental deployments should evaluate longer term survival as well as recruitment of oysters over several tidal elevations. This might help us identify the "sweet spot" for oysters that provides the best balance between the biotic and abiotic stresses associated with different tidal elevations.
- Additional protection from oyster predators and cover of fouling species might be gained by encouraging larger mobile predators (such as cancrid crabs) and mesograzers to settle on restoration substrates. Future designs might include developing substrate types and configurations that attract large crabs and fish.
- Oyster reef designs should consider the fact that the lower portion of elements will experience sediment burial. Future designs could be elevated on materials (such as oyster blocks made of baycrete) that are less difficult to source than bags of Pacific oyster shell, which will be less available in the future.
- Results from this work and elsewhere (e.g., Trimble et al. 2009) indicate that oysters generally settle in higher numbers and grow faster at lower tidal elevations.

In addition to the findings and recommendations above, Grosholz et al[10] found that "Olympia oysters are highly sensitive to sedimentation and freshwater inputs, and moderately sensitive to excessively cold water temperature, high air temperature, food limitation, predation, and hypoxia."

As a result of the above information, it is vital the Corps require the applicant to provide the following information:

- Identification of the elevation at which the oyster reefs will be installed. What is the elevation that will provide the best outcome without adverse environmental impacts to the existing tidal wetlands and mudflats?
- A discussion of how the site conditions and the proposed methodology meet the ecological requirements of the Olympia oyster.
- Identification of the source of the Olympia oysters to ensure appropriate variety of the species.
- Will the reef redirect slough flow and/or sediment deposition? What has been modeled?

Robert & Obernolte, Rena. (2017). San Francisco Bay Living Shorelines: Restoring Eelgrass and Olympia Oysters for Habitat and Shore Protection. 10.1201/9781315151465-21. https://pubs.er.usgs.gov/publication/70191921 Attached hereto as Exhibit 6

[10] Grosholz, Edwin & Bible, Jillian & Ceballos, E. & Chang, Andrew & Cheng, Brian & Deck, A. & Ferner, M. & Latta, M. & Wasson, Kerstin & Zabin, Chela. (2015). UNDERSTANDING ENVIRONMENTAL CONDITIONS THAT SUPPORT SUSTAINABLE OLYMPIA OYSTER POPULATIONS: INFORMING RESTORATION AND CONSERVATION. Journal of Shellfish Research. 34. 637-637. https://www.sfbaysubtidal.org/OYSTERGUIDE-FULL-LORES.pdf Attached hereto as Exhibit 7

Multiple studies have been conducted regarding the benefits of restoring oyster reefs within San Francisco Bay and the factors that may influence the success of a project within a specific location. We urge the Corps to take advantage of the scientific expertise that exists within the Bay Area by obtaining scientific review of the proposed oyster reef installation from local experts who have developed guidance regarding the use of oyster reefs as nature-based solutions.

Adverse Impacts to Federally Listed Species:

The Corps has indicated in the PN that it has initiated Informal Consultation with the USFWS and National Marine Fisheries Service (NMFS) pursuant to Section 7(a)(2) of the Endangered Species Act of 1973.

We reiterate our concerns regarding the potential adverse impacts to listed and sensitive species. South Greco Island, in 2020, supported the highest density of RIRA within the survey area along the western shore of South San Francisco Bay and is considered core habitat for RIRA in this area of the South Bay. The proposed levee construction will result in a temporal loss of RIRA habitat and could lead to degradation of the surrounding high value tidal wetlands, mudflat and slough. The use of the helipad could result in disturbance of RIRA in the surrounding area, contributing to habitat degradation. SHMH could also be adversely impacted by the proposed project through the permanent and temporal loss of habitat.

Additional Concerns Identified by Dr. Peter Baye:

We reiterate that Dr. Baye has identified a number of substantive concerns that must be addressed including but not limited to oyster reef design feasibility and tidal elevation range, risk of adverse substrate conditions for native ecotone vegetation and deferred substrate specifications and introduction and/or facilitation of the spread of invasive non-native plant species that have yet to be adequately addressed.

Need for Requirement of a Sizeable Contingency Fee:

As we have stated, the proposed project is unprecedented in its proposal to construct a flood control levee within stable, mature, high value wetlands that support federally listed species and within an area subject to the tides and wave action. It has not been adequately demonstrated that a practicable, less environmentally damaging alternative does not exist. There are significant uncertainties regarding whether the project will achieve final success criteria, as well as concerns regarding the potential for degradation of the adjacent high value wetlands. Though we do not believe this project should be authorized, should the Corps proceed with permit authorization, a sizeable contingency fee should be required to ensure that adaptive management measures can and will be implemented in timely fashion.

Urge the Corps to Seek Scientific Peer Review of the Proposed Project:

We strongly urge the Corps to convene a Technical Advisory Committee (TAC) to conduct focused design review of the proposed project by a qualified expert panel composed of the experienced academic and professional practitioners who routinely review and advise agencies on Living Shoreline projects.

We have noted numerous uncertainties regarding the potential of this project to result in environmental harm beyond the project footprint. For this reason, we do not believe the project should be authorized. As we have repeatedly asserted throughout this comment letter, the proposed project is precedent setting in its use of the term “ecotone levee” for construction of a flood control levee within existing, stable, high value tidal wetlands and mudflats. This is an inappropriate location for experimentation of this nature, the stakes are too high. While we acknowledge the applicant has pulled back the footprint of the “permanent impacts” to high value marsh, we remain extremely concerned about the indirect impacts the proposed project will have on high value tidal wetlands and mudflats that are immediately adjacent to the project footprint. In particular, indirect impacts that could lead to the destabilization and loss of tidal wetlands and mudflats beyond those accounted for in the permit application. This tidal wetland complex supports several federal and state listed species, rare species, critical habitat and Essential Fish Habitat. We recognize that the stated permanent impacts are relatively small, but the final size of the impacts should not be the determining factor on the level of scrutiny provided for a project in this ecological setting.

Conclusion:

This project is a flood protection project. As stated previously, the proposed project design is inconsistent with the concept of an ecotone levee which is situated landward (i.e., from the high tide line and landward) of existing tidal wetlands.

We remain deeply concerned that this project will have persistent adverse impacts not only within the project footprint but also to the surrounding high value tidal wetlands, mudflat and slough and result in take of federally listed species.

The significant, unprecedented, direct, indirect, and cumulative impacts to special aquatic sites and the uncertainty of success associated with this project warrant and require rigorous alternatives analysis to identify the least environmentally damaging practicable alternative (LEDPA). To date, the applicant has failed to adequately explain why Alternative F is not practicable.

Thank you for the opportunity to provide comments. We request that we be kept informed of any future opportunities for review or comment on the proposed project. We also request that we be notified of the Corps' decision regarding the proposed permit authorization.

Respectfully submitted,

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SFBRWQCB, Keith Lichten
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USFWS, Kim Squires
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Exhibit 1

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M E M O R A N D U M

To: Citizen's Committee to Complete the Refuge (attention: Carin High)
Date: March 14, 2022
SUBJECT: West Bay Sanitary District Flow Equalization and Resource Recovery Facility Protection Project, Public Notice SPN-2018-00371, U.S. Army Corps of Engineers San Francisco District, Regulatory Division

1. Scope and Purpose. This memorandum responds to your request to provide CCCR with a technical and scientific review of the West Bay Sanitary District plans for constructing an ecotone levee within the fringing tidal salt marsh ecosystem bordering the Greco Island unit of the U.S. Fish and Wildlife Service Don Edwards San Francisco Bay National Wildlife Refuge. My scope of project review is limited to the USACE Public Notice (PN) SPN-2018-00371 and attached plans, dated February 14, 2022. My review does not cover the Environmental Impact Report (EIR) for the project pursuant to the California Environmental Quality Act, since the current USACE permit application may include modifications; review is based exclusively on the PN and supporting PN-attached documents available online during the comment period.

My review covers (a) assessment of the technical feasibility of the ecotone levee design, (b) potential short-term and long-term environmental impacts and benefits of the proposed project, considering designs, environmental setting, and proposed lack of mitigation (i.e., no compensatory mitigation or mitigation for short-term construction and post-construction impacts or erosion risks); and (c) preliminary assessment of practicable alternatives that are likely to be less environmentally damaging, pursuant to Section 404(b)(1) evaluation criteria (LEDPA). My review focuses on relatively more significant, basic environmental issues, and is not comprehensive; it does not include recommendations for project modifications, other than Corps permit and 404(b)(1) requirements for evaluation of alternatives.

The scope of my findings and assessments focuses on the following topics:

- Avoidable tidal wetland fill for ecotone slope construction:
  - net long-term wetland-upland conversion
  - temporary to persistent loss of high tide refuge habitat for federally listed wildlife species,
  - bayward encroachment of the ecotone levee toe instead of set-back from the high tide line.
- Armored wave-break "oyster reef" design feasibility and tidal elevation range.
- Risks of ecotone slope wave erosion

- Risks of adverse substrate conditions for native ecotone vegetation; deferred substrate specifications
- Native and non-native plants
    - Introduction or facilitated spread of invasive non-native plant species
    - Artificial range extended species (state native, Bay non-native)
    - Incompatible or infeasible native species assemblage
- Reintroduction of a federally listed plant with no plans or consultation with USFWS
- Incomplete project description; full and complete project alternative
- Less Environmentally Damaging Practicable Alternative design elements

2.0 Overview of findings and conclusions

The ecotone levee design is exceptional in relation to the high tide line position, and proposed construction in existing tidal marsh. The majority of the proposed ecotone levee cross-section is placed directly on an existing mature high tidal salt marsh gradient that extends to the high tide line, instead of being set back so that the bayward toe of the ecotone levee is at or above the High Tide Line, like the proposed Palo Alto Ecotone Levee demonstration project (City of Palo Alto), which minimizes or avoids fill in tidal marsh. The typical goal of ecotone (or horizontal) levees is to accommodate sea level rise like natural tidal marsh-terrestrial transition zones, which retreat landward and upward with rising sea level. Instead, this design progrades bayward, such that the tidal marsh-terrestrial ecotone and uplands encroach existing tidal marsh, converting some of it to uplands for decades. It treats the existing levee crest position as static, instead of a set-back levee crest with a set-back wide ecotone slope adapted to sea level rise during the 50 year project life.

This cross-section encroaching existing high-value tidal marsh is the core problem that causes multiple significant environmental impacts, most of which are highly significant because of the environmental setting next to Greco Island. The project as currently designed would cause significant near-term loss of the most persistent emergent landward high tide cover available to endangered California Ridgway's rails and salt marsh harvest mice with territories located at the west half of Greco Island, during extreme high tides when all high tide cover normally available is submerged. It would create disturbed salt marsh and ecotone substrates that would be susceptible to invasion by non-native species, for which no mitigation is identified. The post-construction fill substrates, partially vegetated or unvegetated after placement, would remain highly susceptible to wind-wave erosion during winter perigee spring high tides for years. The project proposes no erosion management for storm wind-wave impacts (erosion control seed mixes proposed address minor rain runoff sheetflow and rill erosion only).

The methods of salt marsh and terrestrial transition zone vegetation establishment proposed are highly unlikely to be feasible. The project proposes to salvage and translocate salt marsh vegetation in an upland nursery facility for an unstated duration and season, and replace it after construction. There is no basis for this design, and it is not feasible, especially given the acreage of salt marsh impacted. The plans also propose, incredibly, for planting an aggressive invasive non-native smooth cordgrass, *Spartina alterniflora*, in the high salt marsh zone, along with an endangered native plant, California sea-blite, with no reference to consultation with U.S. Fish and Wildlife Service or the Invasive Spartina Project. The planting specifications in plan drawings for the ecotone slope are likely to result only in weed dominance for many years, or indefinitely.

The alternatives analysis required for Clean Water Act Section 404(b)(1) compliance must evaluate alternatives that set back the ecotone slope and levee crest landward, so that the toe of the terrestrial ecotone slope remains above the high tide line, avoiding fill of tidal wetlands and important high tide refuge cover, and allows landward retreat of the salt marsh transition zone during the project life. The set-back alternative would presumably need to conserve equalization basin volume capacity by expanding equalization basins into unused fill areas (noted in the public notice project site description) that occupy roughly a quarter of the site at the south end.

3.0 Ecotone levee design and impacts

3.1. Bayward encroachment of the ecotone levee toe instead of set-back from the high tide line: high tide refuge habitat impacts

The proposed ecotone levee cross-section is placed over existing a mature high tidal salt marsh gradient spanning Westpoint Slough to the high tide line. It is located next to one of the largest high salt marsh islands remaining in San Francisco Bay, Greco Island, within the Don Edwards San Francisco Bay National Wildlife Refuge. Greco Island and the fringing tidal marsh along the project area are occupied by populations of federally listed tidal marsh wildlife species that depend on movement and access to emergent vegetative cover during high tides to avoid predation. These include the salt marsh harvest mouse (southern subspecies) and California Ridgway's rail. The tidal marsh landward shoreline includes extensive high tide refuge cover for these federally listed endangered species. Unlike most of the high tide cover available along the banks of tidal creeks within Greco Island, the landward-edge high tide cover along the project area and Bedwell Park shore retains emergent vegetation canopy above even the extreme highest tides (during Pacific sea level anomalies, significantly higher than predicted astronomic tides) that completely submerge all tidal marsh vegetation canopies on Greco Island. The landward edge high tide refuge habitat is not functionally equivalent to similar habitat on the island during these most extreme high tides, which are likely to occur more frequently and submerge most existing high salt marsh on Greco Island during accelerated sea level rise.

Figure 3.1-1. View of the fully submerged salt marsh plain of Greco Island during a perigee spring high tide and a Pacific sea level anomaly, from a kayak navigating over the island. The normal high tide cover provided by San Francisco gumplant canopies are completely submerged. January 28, 2009.

Figure 3.1-2. View of the mostly submerged salt marsh plain of Greco Island during a perigee spring high tide, showing some emergent high tide cover provided by gumplant and tall canopies on natural slough bank levees, locally emergent above the water surface This cover is available to California Ridgway's rails with territories near it; otherwise long-distance movcement to the nearest emergent cover, along the shore of Bedwell Park and the West Bay project site, is necessary to avoid avian predators.. January 1, 2014.

Figure 3.1-3. High tide cover submergence patterns, Greco Island. View of the mostly submerged salt marsh plain of Greco Island during a perigee spring high tide, showing widely dispersed emergent high tide cover provided by bushy gumplant along on natural slough bank levees, locally emergent above the water surface This cover is available to California Ridgway's rails with territories near it; otherwise long-distance movcement to the nearest emergent cover, along the shore of Bedwell Park and the West Bay project site, is necessary to avoid avian predators Jan 2, 2018.

Figure 3.1-3. Landward shore high tide cover habitat opposite Greco Island, along Bedwell Park and the West Bay project site shore, remains emergent during all high tides, and is available when the Greco Island vegetation canopy is fully submerged. Jan 2, 2018

The construction of the ecotone levee lower slope directly over the high salt marsh zone by grading imported fill over marsh vegetation would result in crushing, flattening, burial, and nearly complete mortality of high salt marsh vegetation within the project footprint. Most clonal perennial high salt marsh plant species (pickleweed, saltgrass, alkali-heath) can recover only from gradual sediment burial in increments (about 10-15 cm) that do not flatten the vegetation canopy under the burden of mechanically placed fill. The post-grading ecotone slope would therefore be bare and unconsolidated imported fill, with "salvaged" salt marsh sod stockpiled at an upland nursery (no methods or specifications cited in sheet 3 of 7; salt marsh vegetation and sod would not remain viable in an upland nursery without extraordinary and intensive cultivation in extensive, irrigated lined wetland beds).

There is effectively no chance that this unspecified and untested method (no citations given) would restore high tide vegetation cover. The most likely outcome would be winter erosion and scarping of the fill in the high tide wave uprush zone, followed by invasion and dominance of weedy non-native species in disturbed, partially eroded high salt marsh substrate. High salt marsh vegetation succession (new colonization of weedy disturbed substrate) may occur over about 5 years, but it would be unlikely to provide structural habitat equivalent to the existing mature decades-old high marsh vegetation and soil. For endangered wildlife species, this likely outcome would result in deficient refuge cover during extreme high tides that fully submerge Greco Island gumplant vegetation.

High tide cover provided by gumplant is impaired during extreme droughts that cause marsh soil hypersalinity in the high marsh transition zone below the high tide line. Gumplant dieback (reduced to bare stems) can be severe during multi-year droughts, and recruitment of gumplant seedlings and juveniles is also inhibited during severe multi-year droughts. Ecotone slope vegetation establishment in the absence of subsurface seepage irrigation is likely to be unpredictable, and therefore so is the regeneration of high tide refuge cover.

Figure 3.1-4. Gumplant dieback along the Bedwell Park-West Bay high tide shore is significant in the current multi-year drought. March 11, 2022.

3.1.3. Avoidable tidal wetland fill and net wetland-upland conversion due to ecotone slope shoreline position. The construction of the ecotone slope over existing tidal marsh, instead of setting the levee profile back (landward shift of levee and ecotone slope cross-section), would result in 3.2 acres of jurisdictional U.S. tidal waters, including 2.17 acres of salt marsh, and 1.02 acres of intertidal slough bank (mud) habitat. This is one of the largest fill proposals in intact, mature San Francisco Bay salt marsh that I have seen in over three decades. There is no justification given for the arbitrary cross-section position over tidal marsh that causes this avoidable fill. Instead, the project description alleges that because it is “a nature-based design feature to provide sea level rise resiliency for the aquatic habitats and listed species at the site” it does not need to minimize or avoid wetland fill, or compensate for (avoidable or unavoidable) impacts.

This premise is both contradictory and self-defeating. First, there is nothing inherently “nature-based” about mechanical placement of imported fill to construct an earthen slope over existing, mature, tidal marsh, just because some of it would undergo succession to high salt marsh under sea level rise in a generation or two -- assuming it doesn’t just erode first. I am professionally baffled by the proposal, because there is no state, federal, or regional wetland planning guidance that endorses placing ecotone slopes over existing tidal marsh, and there are long-established regulatory requirements to minimize and avoid fill in wetlands, which are not waived by sea level rise forecasts or entitled “nature-based feature” status. Most ecotone (horizontal) levees are proposed for construction in diked non-tidal baylands that are later restored to tidal marsh. There is no regulatory guidance or exemption that entitles self-proclaimed “nature-based features” to fill intact, high-value tidal marsh with impunity or without mitigation, without demonstrating that no less environmentally damaging practicable alternatives are available.

3.2. Risks of ecotone slope wave erosion. The project proposes placing unconsolidated earthen fill at and below the high tide line, exposing the unconsolidated fill to potential high wind-wave attack during the next perigee spring high tides of winter. Even if vegetation establishment in the salt marsh-terrestrial ecotone proceeded at optimum rates (ample rainfall, minimal storm wave impacts), the soil shear strength and vegetation roughness required to damp wave energy and resist erosion subsequently would take at least several years to develop, and much longer if severe drought or storm impacts overlapped with the post-construction period. Once wave erosion initiates a steep scarp profile that reflects high wave energy (turbulent scour zones below the scarp), positive feedback processes can intensify erosion and delay vegetation recovery. The Sears Point Wetland Restoration Project (Petaluma; San Pablo Bay National Wildlife Refuge) is a potent example, where most of the ecotone slope eroded within a few years after construction, leaving a wave-cut bench at middle marsh zone elevation range (see figures below). The project proposal includes no mitigation measures to address predictable winter storm wave erosion in the vulnerable years after construction, prior to full vegetative stabilization. The project’s inclusion of a local “wave-break” feature to protect the north end of the levee, however, provides a clear indication that the potential for significant wind-wave erosion exists at the shoreline. The feasibility of constructing an ecotone slope in a wave-exposed tidal shoreline is not indicated by the design and project location.

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Figure 3.2-1. Sears Point Wetland Restoration Project ecotone levee wind-wave erosion 3-6 years after construction. San Pablo Bay National Wildlife Refuge. Ecotone slope erosion was severe, leaving a wave-cut bench with the Mean High Water line close to the eroded scarp by 2021.

Figure 3.2-2. The newly constructed ecotone levee (Ravenswood, South Bay Salt Pond Restoration Project) at the south side of Bedwell Park is in the first growing season of revegetation after planting and seeding by Save The Bay, March 11, 2022. During this period of high vulnerability to wind-wave erosion while vegetative stabilization is incomplete, the levee is not exposed to tides and wind-waves, prior to tidal restoration. This sequence contrasts significantly with the proposed West Bay ecotone levee plans.

3.3. Risks of adverse substrate conditions for native ecotone vegetation; deferred substrate specifications. The PN states, “Using existing dredge material that is stockpiled on-site or locally sourced sand or clay, the District would place fill within existing tidal marsh for the ecotone levee along approximately 1,200 linear feet…”. Sheet 2 of 7, note 1, states “Soil specifications for all imported fill material for the ecotone levee, including structural fill, bay mud, topsoil, and upland topsoil, will be submitted to the Water board for approval prior to construction.” Read together, the only design information for the soil conditions of the ecotone

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slope is that it may range between sand and clay "locally sourced" (bayland? County?), unspecified dredge material with no textural or chemical criteria, and RWQCB review and approval some time before construction, possibly after permit review. This is an egregiously deficient and deferred substrate design for an ecotone slope. It precludes any meaningful assessment of its feasibility.

Adverse soil conditions resulting from either excessive sand or acid sulfate soils formed from sulfide-rich dredged materials may severely inhibit development of vegetation cover and height required for adequate high tide refuge habitat. Some of the existing bottom sediments in the equalization basin (bay muds) are apparently highly saline (white salt and sun-bleached algal mat crust) and hypersulfidic, due to evaporative concentration of bay mud salts and sulfates, and presence of labile organic matter from decayed algal beds. Acid sulfate soils can cause stunted vegetation height and density in high salt marsh zones, or even persistent barrens. Acid sulfate soils are difficult to treat by normal liming because of extreme low pH and metal toxicity.

Sand is a suitable substrate for estuarine beaches that evolve at the outer bay edge of salt marshes. At the landward edge, however, sand flats over low-permeability bay mud or clayey alluvium typically form playa-like barrens with prostrate vegetation that is unsuitable as high tide refuge habitat. Playa-like sandy ecotone flats are not natural ecotone types in southwest San Francisco Bay. They support specialized species assemblages that are incongruent with the assemblages proposed for revegetation of the ecotone slope.

The longer the ecotone levee vegetation establishment remains inhibited or delayed by potential adverse soil conditions, the longer the vegetative stabilization functions are delayed, and the longer the vulnerability to wind-wave erosion of the shoreline. The project should include specifications for substrate that ensure high probability of target vegetation establishment and growth, and minimal establishment of non-native vegetation.

Horizontal Levees: Adverse substrate risks

Sand playa (stratified medium sand over silty clay bay mud) – below high tide line

- Capillary salt crust ("wicking") of residual salts after perigee spring high tides
- Summer desiccation and hypersalinity
- Natural barrens
- Specialized habitat – but not high tide refuge habitat

Terrestrial transition zone above high tide line: graded bay mud
- Perennial native and non-native grasses (*Leymus triticoides* – local dominance)
- High percent cover, canopy height

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Figure 3.3-1. Sand placed in the tidal marsh ecotone below the high tide line can result in sandy playa barrens instead of dense, tall high tide cover.

Figure 3.3-2. Sand placed in the tidal marsh ecotone below the high tide line can result in sandy playa barrens instead of dense, tall high tide cover.

Figure 3.3-3. Sand placed in the tidal marsh ecotone below the high tide line can result in sandy playa barrens instead of dense, tall high tide cover.

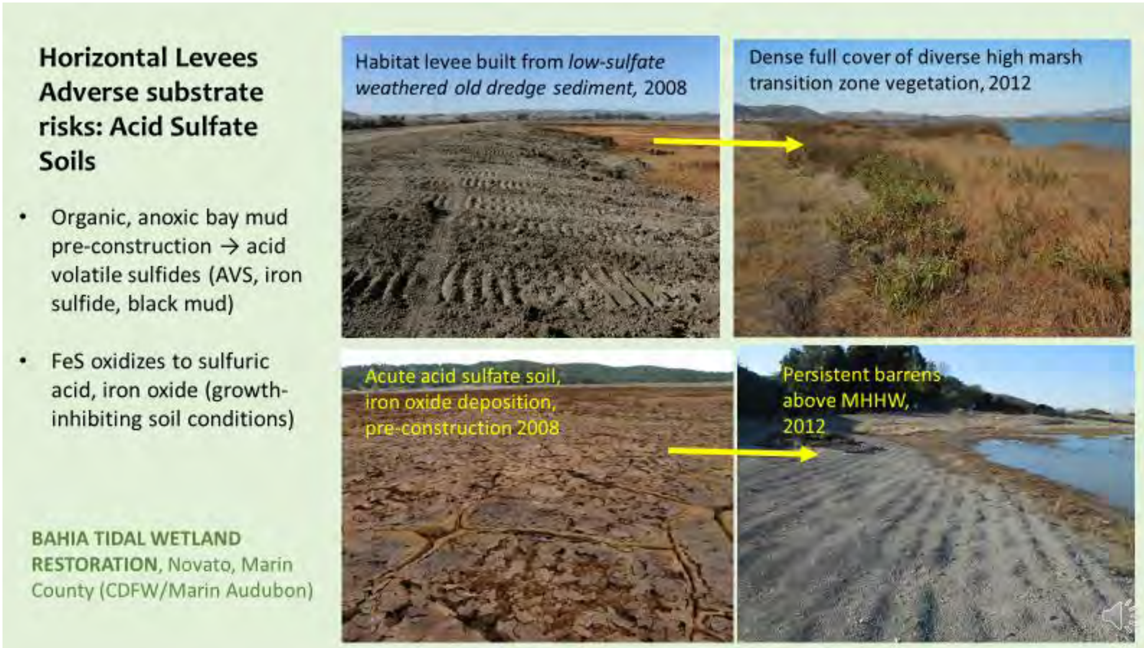

Figure 3.3-5. Acid sulfate conditions develop from drainage and oxidation of extreme high sulfide content of anoxic bay muds. Acid sulfate soils can inhibit or stunt vegetation, or cause persistent barrens in restored high salt marsh and ecotone slopes.

4.0. Native and non-native plants

The plan drawings do not refer to a vegetation management or planting plan. The planting and soil specifications in the plan drawings are insufficient to evaluate for feasibility.

4.1. Introduction or facilitated spread of invasive non-native plant species. The plan specifications for planting on sheet 3 of 7 contain an alarming recommendation for planting non-native invasive smooth cordgrass, *Spartina alterniflora*, in the high marsh zone near Mean Higher High Water elevation. This is bizarre, since native *S. foliosa* is (correctly) prescribed for the low-middle marsh zone near MHW. The California Coastal Conservancy has spent many millions of dollars to eradicate *Spartina alterniflora*, and there is no reasonable chance of resource agency approval of its planting in any salt marsh zone, even at its upper limit. It would be an unacceptable significant impact. There is no reason given for the ludicrous inclusion of this species in any revegetation plan.

4.2. **Artificial range extended species (state native, Bay non-native).** The planting scheme on sheet 3 of 7 also specifies planting of a saltbush (*Atriplex lentiformis*) species that does not naturally range to San Francisco Bay, but has been artificially planted here in the past as a wildlife habitat amenity. *A. lentiformis* is a massive sprawling shrub that smothers all species under or around it, and is incompatible with native plant community restoration and the natural grassland ecotone. It is also a risk for providing shelter for terrestrial predator dens.

4.3. Incompatible or infeasible native species assemblage. The plant species assemblage prescribed on sheet 3 of 7 includes mismatched species from dissimilar communities. Most of the species would fail or significantly underperform in sandy substrates, which are identified as a possible fill type for the ecotone. Underperformance or failure of target species would leave vegetation gaps that would be rapidly colonized by prevalent levee weeds that can tolerate sandy soils. Some species proposed, like flowering currant (*Ribes sanguineum*) are mesic riparian plants with low tolerance for extreme arid summer climates and subsaline soils. They have almost no chance of survival in a south bay ecotone unless they are permanently sub-irrigated or irrigated with non-saline water. The feasibility of this planting proposal is low.

4.4. Reintroduction of a federally listed plant with no plans or consultation with USFWS. The reintroduction of a federally listed plant, California sea-blite (*Suaeda californica*) is proposed in sheet 3 of 7, but there is no note indicating requirement for review and approval by U.S. Fish and Wildlife Service, as there is for soil on sheet 2. The PN does not identify California sea-blite as part of the Section 7 ESA consultation with U.S. Fish and Wildlife Service. The geographic location for reintroduction is suitable, but the habitat location is not. California sea-blite is associated with bay-edge, marsh-fringing estuarine barrier beaches or wave-washed shorelines sandy bluff shores with seeps. It is not adapted to clayey or sandy grassland soils with high plant competition at the dry landward edge of salt marshes. The proposal includes no reference to any recovery plan or reintroduction plan.

4.5. Lack of non-native invasive plant species management. The project site is located near Redwood City, where multiple non-native salt marsh shoreline species with very high invasion potential at the site provide seed sources for invasion. The project description and plans contain no information on early detection and control of foreseeable invasive species to the high marsh zone, such as Algerian sea-lavender (*Limonium ramosissimum*) and southeast slim aster (*Symphyotrichum subulatum* var. *squamatum*), and seaside goose-grass (*Puccinellia maritima*). Newly graded levees are highly susceptible to rapid invasion and dominance by weeds from adjacent levees and roads, as well as seed banks from imported soil. The feasibility of the ecotone levee depends on vegetation management plans, which are not cited in the PN. This omission is a predictable potential hazard for ecotone levee project planning and implementation.

5.0 Armored wave-break "oyster reef" design feasibility and tidal elevation range.
The wave-break "oyster reef" cross-sections in plan drawings show that the "oyster reef location" would be placed <u>above</u> tidal mudflat elevations at an elevation near +3 ft NAVD, where Mean Sea Level is 3.35 ft. On sheet 2 of 7, at note 2, however, it states, "Install oyster bed wave break in <u>between</u> MLLW and MSL (-1.18 to 3.35 feet-NAVD 88) to insure [*sic*] oyster growth". The notes contradict the cross-section drawing elevations indicated by a pointer arrow. The note makes no sense unless the location of the rock "reef" is actually proposed in the tidal marsh slough itself, because mudflat elevations range around MSL. The note does not make physical sense, because a wave-break crest elevation at MSL would have no more effect on wave attenuation than a mudflat at the same elevation, and much less wave damping effect than a vegetated marsh plain (high wave friction, roughness) near MHHW. It indicates a disconnect between engineered wave-break and biological oyster habitat designs.

Assuming the engineered cross-sections prevail over note 2, the nominal "oyster reef" would occupy the extreme upper end of tolerance for the tidal range of native Olympia oysters, which grow mainly below Mean Sea Level, and grow at highest densities near Mean Lower Low Water, and decline in growth and density with increasing exposure higher in the tidal frame (Wasson *et al*. 2015, 2020). The presumably rock-armored wave-break is apparently not a feasible "oyster

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reef" design, and so the rip-rap armoring above MSL is misidentified as "living shoreline" oyster reef habitat. On the other hand, if the note 2 tidal elevation range prevailed over the typical cross-section drawing, it would mean that the applicant proposes to rock armor an existing tidal salt marsh slough bank connected to the National Wildlife Refuge.

6.0 Incomplete project description and potential significant impacts of related project features
The plan drawings refer to many unexplained project features designed "by others" or for another project, but which is clearly integrated and interdependent (inseparable) from project designs. These include a helicopter pad and a storm outfall drain, in addition to main flood control levee construction. Depending on time of day and tide, the use of a helicopter pad next to a salt marsh with endangered wildlife in a National Wildlife Refuge may have significant and unacceptable impacts. Corps permit regulations require that all reasonably related activities for which a Department of Army permit is required must be included in the same permit application (33 CFR §325,1(d)(2). Impermissible "piecemealing" or project segmentation can preclude compliance with public notice regulatory requirements for providing clear understanding of information to support meaningful public comments (33 CFR §325.3) It may also preclude evaluation of a reasonable range of alternatives that may reduce project impacts.

7.0. Alternatives analysis: less environmentally damaging practicable alternative design components. Regardless of any CEQA alternatives analysis, the Corps must require a rigorous analysis of alternatives commensurate with the significance of impacts and wetland habitat values, which are both very high. The focus on evaluating less environmentally damaging practicable alternatives that avoid or minimize fill impacts to wetlands, pursuant to Section 404(b)(1) guidelines, must include a reasonable range of alternative levee configurations and positions, including set-back levees that accommodate sea level rise (marsh landward retreat) without encroaching existing high-value salt marsh. The PN refers to "Using existing dredge material that is stockpiled on-site…" and also states,

> The FERRF site also contains the decommissioned Menlo Park Wastewater Treatment Plant (WWTP; in service 1952–1980). The District currently also uses the FERRF site as extra office space and an auxiliary corporation yard for equipment and material storage, training exercises, a pump repair workshop, and a Capital Improvement Project staging area. In addition, the District provides space for Save the Bay to operate raised nursery beds for salt marsh plant propagation.

Together, these project and site description components are consistent with an alternative that excavates an expanded footprint for equalization basins to offset volume capacity lost to a set-back levee design that preserves existing salt marsh, while allowing space for an ecotone slope. In addition, alternatives that conserve equalization basin volume by excavating existing basins to stable but lower elevations, or raise levees to higher but stable elevations, should be evaluated. There is no explanation for restricting alternatives to the existing levee footprint and alignment.

Figure 7. The south end of the project site fill is free of infrastructure in January 2018. The fill areas and disused parts of the site are ripe for evaluation as basins to offset volume capacity loss from set-back levee alternatives that conserve tidal salt marsh.

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Exhibit 2

California Ridgway's Rail Surveys for the San Francisco Estuary Invasive *Spartina* Project 2020

Report to:

The State Coastal Conservancy
San Francisco Estuary Invasive *Spartina* Project
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Coastal Conservancy

This report was prepared for the California Coastal Conservancy's San Francisco Estuary Invasive *Spartina* Project

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1. Introduction

Annual monitoring for the endangered California Ridgway's rail (*Rallus obsoletus obsoletus*; formerly California clapper rail, *Rallus longirostris obsoletus*) is an essential component of the State Coastal Conservancy's Invasive *Spartina* Project (ISP). California Ridgway's rails are year-round residents of the tidal wetlands of the San Francisco Estuary and co-occur with native and non-native *Spartina*. The ISP requires information on the number of rails at each site for the planning and permitting of *Spartina* treatment. Additionally, annual breeding-season surveys provide a standardized measure of Ridgway's rail presence and distribution in *Spartina*-invaded marshes throughout the Estuary.

In collaboration with partner organizations, including Point Blue Conservation Science (PBCS), Don Edwards National Wildlife Refuge (DENWR), Avocet Research and Associates (ARA) and San Pablo Bay National Wildlife Refuge (SPBNWR), Olofson Environmental, Inc. (OEI) conducted surveys for California Ridgway's rails to inform the ISP about rail populations at sites slated for *Spartina* treatment in 2020 (Permit Number TE118356-4.2). Trained and permitted biologists performed standard-protocol surveys at 100 ISP sub-areas (made up of 109 rail "sites") between January 15 and April 15, 2020. The data were entered into the California Avian Data Center (CADC), an online database hosted by PBCS and part of the larger Avian Knowledge Network (AKN). Data were then downloaded from CADC, imported into GIS, and summarized by ISP sub-area boundaries.

Only results of surveys conducted for the ISP by OEI in 2020 are presented in this report. The ISP relies on partner organizations to conduct surveys and report results collected at other *Spartina*-invaded sites that are not surveyed by OEI. The summary data presented here represent unique detections of Ridgway's rails within the areas surveyed by OEI. These data should not be misinterpreted to be a range-wide population estimate or a comprehensive count of Ridgway's rails at all *Spartina*-invaded sites. For a complete list of ISP subareas and associated survey organizations, see **Appendix I**: Complete List of 2020 Spartina Treatment Sub-Areas and Ridgway's Rail Survey Plans.

Species Account

The California Ridgway's rail is classified as endangered by both the U.S. Fish and Wildlife Service (Federal Register 50 CFR 17.11) and the State of California (California Code of Regulations Title 14, Section 670.5). Its present range is limited to the tidal marshes of the San Francisco Estuary. California Ridgway's rails occur only in salt and brackish tidal marsh habitat and require vegetative cover suitable for both nesting and refuge during high tide events (U.S. Fish and Wildlife Service 2013). Marshes where they occur are characterized by unrestricted daily tidal flows through a network of well-developed channels. Channel density has been shown to be the most important landscape feature to positively influence Ridgway's rail density (Liu et al. 2012). Additionally, large continuous marshes with a low perimeter-area ratio support higher densities of California Ridgway's rail (Liu et al. 2012).

Habitat loss and degradation and predators are among the biggest threats to the rail (USFWS 2013).

Between 2009 to 2011, PBCS estimated that the average total population was about 1,167 individuals (Liu et al. 2012). However, the number of rails detected in 2020 by all survey organizations at the subset of marshes where surveys occurred exceeds the extrapolated population estimate from that study period, indicating that the population is likely greater now.

2. Study Area

OEI conducted surveys for California Ridgway's rail at 100 ISP sub-areas in nine reporting regions: Marin, San Francisco Peninsula, San Mateo, Dumbarton South, Union City, Hayward, San Leandro Bay, Bay Bridge North, and Suisun (**Figure 1**). The study area spanned the counties of Alameda, Contra Costa, Marin, San Francisco, San Mateo, Santa Clara, and Sonoma. Summary survey results for each site are represented within one of four maps: North Bay (**Figure 2**), West Bay (**Figure 3**), South Bay (**Figure 4**), and East Bay (**Figure 5**).

Survey effort was incomplete at 19 ISP sub-areas across 12 transects in the San Mateo and Dumbarton South Regions due to the COVID-19 pandemic (**Table 1**). All of these sub-areas were on DENWR lands. At these sub-areas, only two of three survey rounds were complete before the end of the season.

Surveys by Partner Organizations

Partner organizations surveyed an additional 27 ISP sub-areas (39 rail program sites). Rail survey data from partner organizations are not included in this report; rather, the results from those surveys are reported on by the survey organizations themselves.

For a complete list of all ISP sub-areas and associated survey organizations, see **Appendix I**: Complete List of 2020 Spartina Treatment Sub-Areas and Ridgway's Rail Survey Plans. For a complete list of OEI survey stations and their geographic coordinates in UTM, see **Appendix II**: 2020 Survey Station Coordinates.

Table 1. Survey effort was incomplete at twelve transects due to the COVID-19 pandemic.

Transect	Site Name (Sub-Area Code)
San Mateo Region	
CORK-T1	Corkscrew Slough (02b.1)
GRIN-T1	Greco Island - North (02f)
GRIS-T1	Greco Island - South (02h)
MBE-T1	Middle Bair SE (02k)
	Middle Bair N (02k)
OBEN-T1	B2 North Quadrant West (02c.1a)
	B2 North Quadrant East (02c.1b)
OBEN-T2	B2 North Quadrant South (02c.2)
OBES-T1	B2 South Quadrant West (02d.1a)
	B2 South Quadrant East (02d.1b)
	B2 South Quadrant 2 (02d.2)
	B2 South Quadrant 3 (02d.3)
Dumbarton South Region	
A21-T1	Coyote Creek - Mud Slough (05f)
	Island Ponds - A21 (05i)
CAPT-T1	Calaveras Point (05a.2)
MALA-T1	Mayhew's Landing (05e)
	Cargill Pond (W Suites Hotel) (05g)
MOWN-T1	Mowry Marsh North (05a.1)
NEWS-T1	Newark Slough East (05c.1)
	Newark Slough West (05c.2)

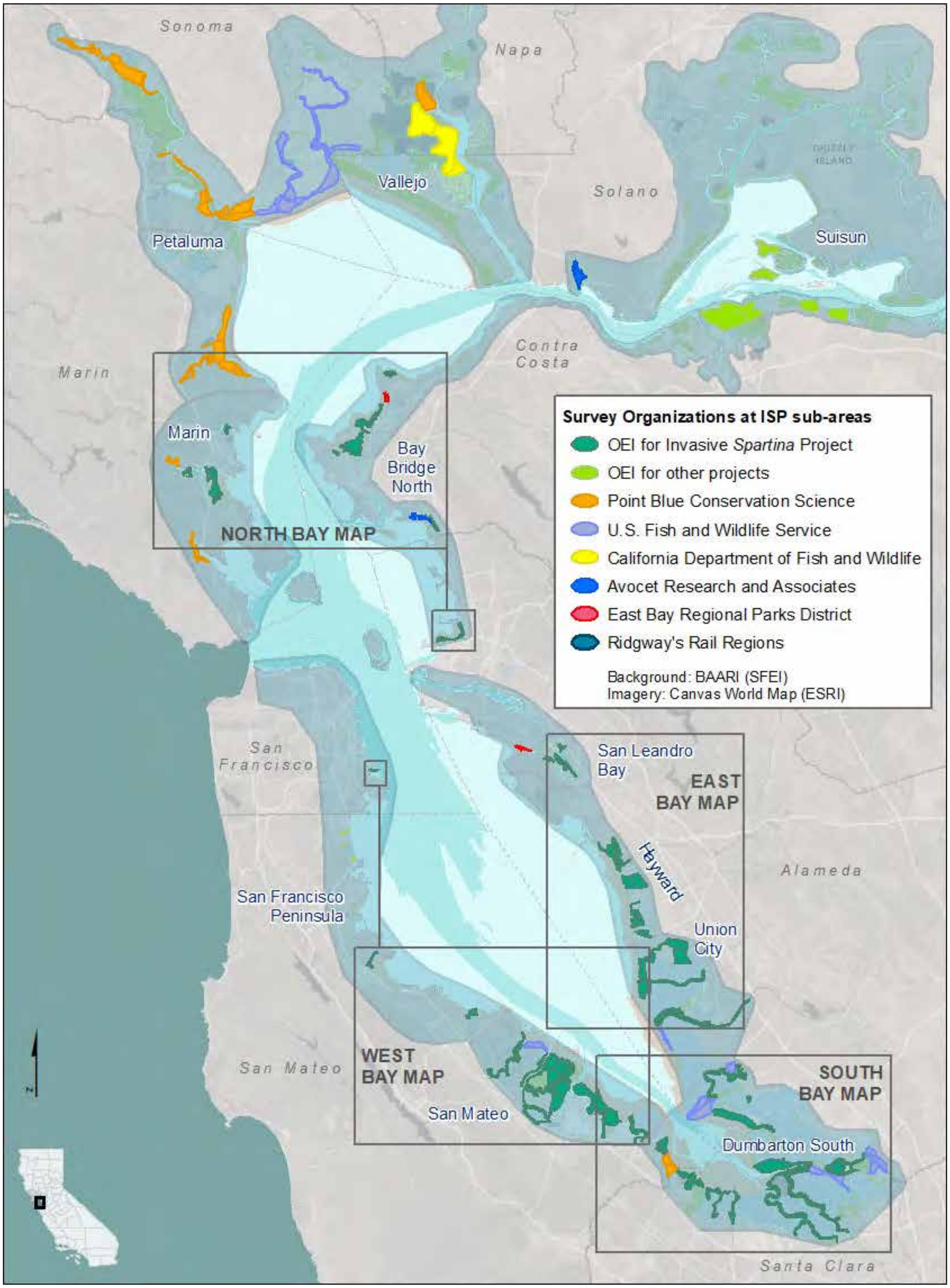

Figure 1. Regional boundaries of ISP sites surveyed for California Ridgway's rail by OEI and others in 2020.

3. Methods

Ridgway's rail surveys for the ISP were conducted using the Site-specific Protocol for Monitoring Marsh Birds (Wood et al, 2016, hereafter "NAm Protocol") based on the North American Survey Protocol (Conway 2016). Data were summarized in CADC, imported into GIS, and analyzed according to recommendations in the NAm Protocol.

3.1 Field Methods

California Ridgway's rail surveys were conducted by OEI at 100 ISP sub-areas between January 15 and April 15, 2020, using the NAm survey protocol. Surveys were conducted by the following trained and permitted field biologists at Olofson Environmental, Inc.: Jen McBroom, Jeanne Hammond, Stephanie Chen, Tobias Rohmer, Simon Gunner, Kevin Eng, Nate Deakers, Pim Laulikitnont, Brian Ort, Melanie Anderson, and Lindsay Faye.

The NAm Protocol is a transect point count survey with broadcast of vocalizations of two species of rail (black rails and Ridgway's rails) on every survey round and at every survey station. The NAm Protocol is part of the FWS Site-specific Survey Protocol (Wood, 2016) and is based on the North American Marsh Bird Monitoring Protocol. The NAm Protocol was developed to increase standardization and decrease the variance in survey results. It was first implemented in 2017 and is the standard call-count survey protocol in the Estuary.

Note: Typically three rounds of surveys are conducted using the NAm Protocol, however, due to the coronavirus pandemic, the third round of surveys was not completed at 19 sub-areas (12 transects) at Don Edwards National Wildlife Refuge (as noted in **Table 1** in the previous section).

3.2 Data Management

Data were recorded in the field on paper datasheets and GPS units were used to navigate to survey stations. Each rail observation was recorded on the datasheet with time detected, call type, number of rails, distance, and direction to the observed rail. Additionally, each rail was assigned a unique map reference identifier and the approximate location of each detected rail was recorded on a paper field map allowing for interpretation of repeat detections of any individuals. Compass and rulers were used to accurately plot rails on paper maps. At sites with overlap between other observers, birds were plotted together on a single map to determine which detections were unique. Potential predators of rail nests, young, or adults were noted.

Researchers entered data into CADC, an online database developed and hosted by PBCS in support of the NAm Protocol. By using a shared database with common tables and field headings, results can be readily shared and analyzed by partner organizations.

Each observer entered their own data into CADC and then reviewed their data for quality and accuracy. Once all data from all observers were entered into CADC, rail detections were imported into GIS in order to determine where Ridgway's rails occurred with reference to ISP sub-area boundaries.

3.3 Data Interpretation

In accordance with recommendations in the NAm Protocol, several metrics were used to evaluate Ridgway's' rails numbers at the sites presented in this report: highest minimum count; index of relative density, annual rate of change, average annual rate of change, and occupancy by black rail (BLRA), Virginia rail (VIRA), and sora (SORA). The definitions and equations used to calculate these metrics are excerpted from the site-specific survey protocol (Wood 2016) and are summarized below.

Highest Minimum Count is the minimum number of unique rails detected during the survey round with the highest count. Birds that were detected from more than one station or by more than one observer during a single round were counted only once toward the total number of rails detected in a round. Birds that were detected outside of survey time were included in the summary and counted toward the total. Once all data were summed for each round at each site, the round with the highest count was reported as the number of rails detected at each site (termed the "highest minimum count").

Index of relative density is the number of unique rails detected per unit area and is calculated as follows. For each visit, the total number of unique birds detected within 200 meters of a survey point is calculated. That count is then divided by the area of rail habitat within 200 meters of the survey stations. The area of rail habitat was calculated in GIS by buffering 200 meters around each survey station and clipping the buffered area to the marsh habitat at the site, generally excluding upland and mudflat areas. The resulting densities for each visit are then averaged. Note that previous reports used the highest of the three survey visits rather than the average of three survey visits (McBroom 2019; McBroom 2018). However, recent review of the NAm Protocol dictates that relative density should be calculated from the average of all visits rather than the max of the visits. This error in methods is corrected in this report, however direct comparison of relative density cannot be made between past reports.

As an example, assume 3, 6 and 5 unique birds are detected within 200 m of 7 survey points during three visits to a given marsh study area (assume that each point is surrounded by 100% rail habitat). The index of relative density for the study area would be calculated as 14 rails/(7 points*31 acres*3 visits) = 0.022 rails/acres. In past reports, relative density was calculated using the max of the three rounds using the following equation: 6 rails/(7 points*31 acres) = 0.028 rails/acres.

Each unique bird is only counted once (e.g., the same bird heard from two different survey points would only be counted once). The area surveyed at each point is adjusted accordingly if there is less than 100% rail habitat within the 200 meter radius.

The index of relative density was categorized into bins and displayed geographically on maps (**Figure 2 – 5**). Density bins were based on density estimates outlined in the Tidal Marsh Recovery Plan (TMRP; U.S. Fish and Wildlife Service 2013). In the TMRP, the average rail population required for rail recovery was developed by multiplying the minimum marsh acreage for each recovery unit by rail densities at calculated percentiles of observed winter populations. In this report, the highest density bin represents sub-areas where rails were detected at a density greater than the 90th percentile of observed winter densities in the South San Francisco Bay Recovery Unit, 0.45 rails/acre (or 1.11 rails/hectare). The next demarcation is 0.15 rails/acre (or 0.37 rails/hectare), which is the 60th percentile of observed winter densities; sub-areas above this demarcation are shaded dark orange and those below are shaded light orange. Below this falls sub-areas where rails were detected at a density less than 0.04 rails/acre (or 0.1 rails/hectare). Sub-areas where rails were not detected within 200 meters of the survey stations are shaded green. This category does not indicate absence; rails may have been detected beyond 200 meters and are present at the sub-area but cannot be included in the density calculation.

Table 2. Density bins developed based on density estimates outlined in the TMRP (USFWS 2013).

Density Bins	Relative Density (rails per acre)	Description
Not detected within 200m	0	Rails were not detected within 200 meters of the survey station. Note, this category does not indicate absence; rails may have been detected beyond survey area and are present at the site but cannot be included in the density calculation.
Low	< 0.04	Rails detected at a density less than 0.04 rails/acre (or 0.1 rails/hectare)
Mid	0.04 - 0.15	Rails detected at density less than the 60th percentile of observed winter densities reported in the TMRP
High	0.15 - 0.45	Rails detected at density between the 60th to 90th percentile of observed winter densities reported in the TMRP
Very high	> 0.45	Rails detected at density greater than 90th percentile of observed winter densities reported in the TMRP

Index of one-year rate of change for the total highest minimum count was calculated using the following equation:

$$m = \frac{(p2 - p1)}{p1} \times 100\%$$

where $p1$ is the total highest minimum count for the previous year and $p2$ is the total highest minimum count in the current year. For example, if the total highest minimum count for rails at DESFB was 33 birds for 2014 and 35 birds for 2015, the index of the annual rate of population change would be: ((35 – 33)/33*100%)= 6.06%.

Index of compound annual rate of change over a five-year period is a simple index of the average annual rate of change between two time points, $\overline{m}$, calculated using the total highest minimum count (summed across one or more study areas) and was obtained using the following equation:

$$\bar{m} = \left[\left(\frac{p2}{p1}\right)^{\left(1/(t2-t1)\right)} - 1\right] \times 100\%$$

where *p*1 is the total highest minimum count for the first year, *p*2 is the total highest minimum count for the last year, *t*1 is the start year, *t*2 is the end year (*t*2 - *t*1 = 5 in this five year analysis). For example, if the total highest minimum count of CA Ridgway's rails at DESFB was 28 birds for 2010 and 36 birds for 2015, the index of the average annual rate of change would be: [(36/28)^(1/[2015 – 2010])-1]*100% = 5.15% increase per year.

Index of occupancy is the maximum proportion of occupied survey points in a study area and was calculated for three other rail species: black rails (BLRA), Virginia rails (VIRA), and sora (SORA). For each visit to a study area, the total number of points occupied by each species was calculated; to be considered occupied, at least one bird of the species of interest were detected from the survey point. The maximum number of occupied points across all visits is divided by the total number of points that were surveyed in the study area to arrive at the index of occupancy. For example, assume 3, 0 and 2 points were occupied by Virginia rails at a study area with 14 points across three visits in a given year. The "index of occupancy" for the study area would be 3/14 = 0.21. This is considered a minimum occupancy index (known as "naïve" occupancy) because we know that detection probability is <1, which means the true occupancy could be >3 points. Only unique birds are considered for occupancy (the same bird detected at two points would result in only one point being occupied).

Caveats: It is important to point out that the preceding metrics of highest minimum count, relative density, population change and occupancy do not take into account factors such as detection probability, habitat covariates, etc.; thus, they should be interpreted with caution. More reliable estimates of population change will be calculated by PBCS using hierarchical models on an interval of approximately every 5 years. However, the simpler metrics provided above are easy to calculate and may allow managers to detect large changes in true abundance (assuming count indices are correlated with true abundance) over short time periods, which could be important for management interventions. The formulas for the above metrics (except for the formulas involving the index of relative density) assume that the exact same study areas are being surveyed every year. If the number of study areas or transects within study areas changes over time, e.g., the number of survey points changes, then adjustments to the analyses will be required.

4. Survey Results

The number of rails detected by OEI in 2020 was about the same as the previous year at the same subset of sub-areas, calculated as +0.25% average annual rate of change. On the longer timescale of five years, rails have increased at a rate of 4% collectively at the same subset of sub-areas since 2015 (calculated as compound 5-year rate of change). Trends show small steady increases at both timescales in the group of sub-areas where non-native *Spartina* has been treated continuously since 2012 (+3% annual change, +2% 5-year change). and slightly higher At the group of sub-areas where *Spartina* treatment is currently restricted, there is no change from the previous year (0% annual change), but a larger positive trend at the five-year timescale (+6% 5-year rate of change). Sub-areas where *Spartina* treatment was previously-restricted but where treatment is now permitted (i.e. where treatment restrictions were lifted in the 2018 Biological Opinion) show disparate one- and five-year trends; these sub-areas have declined by 9% since 2019, but are 15% greater than five years ago.

Results from each region are summarized below and analysis at each sub-area is provided in **Appendix II**. Detailed survey results from each round are included in **Appendix III**.

The Marin Region extends from the Golden Gate Bridge to the Richmond Bridge in Marin County (**Figure 2**). OEI surveyed ten sub-areas in the Marin Region in 2020 (Table 2). PBCS surveyed an additional three sub-areas in the region, including Creekside Park (04g). OEI detected a total of 84 Ridgway's rails in the Marin Region in 2020, which is the same number as detected in 2019. It is also about a 3% since 2015 at the same subset of sub-areas.

The San Francisco Peninsula Region extends from the Golden Gate Bridge to the San Mateo Bridge (**Figure 3**) and represents an urban shoreline with little marsh habitat. OEI surveyed four sub-areas in this Region in 2020. One rail was detected in each of the two sub-area splits at Seal Slough. Although no rails were detected at SFO during surveys, a rail was incidentally deteted outside of surveys at the south end of the shoreline beyond the detection threshold of our survey transect. In 2021, we recommend adding an additional station to the transect to detect rails in this portion of the marsh at SFO. Although only two rails were detected in the Region in 2020, this represents a 100% increase since 2019 when only a single rail was detected and an 11% decrease since 2015 at the same subset of sub-areas. Trends are difficult to identify at these low densities. The fragmented low-quality habitat in this Region will never support a large stable population of rails. There are few opportunities for restoration or enhancement of wetlands in this urban landscape and the creation of new habitat would likely require expensive environmental engineering.

The San Mateo Region extends from the San Mateo Bridge to the Dumbarton Bridge on the west side of the Bay (**Figure 3**). OEI surveyed 18 sub-areas within the San Mateo Region in 2020. DENWR conducted surveys at an additional sub-area, Redwood Shores (02a.3). Only two rounds of surveys were completed at seven transects in the San Mateo Region, accounting for incomplete results at eleven sub-areas. Data were summarized using only two survey rounds for those sub-areas. OEI detected a total of 145 Ridgway's rails in the San Mateo Region in 2020 (**Table 3**). This represents a 6% decrease since 2019 and a 2% decrease since 2015 at the same subset of sub-areas.

This Region contains a previously restricted sub-area where full treatment resumed in 2018: B2 North Quadrant West (02c.1a). Between 2012 to 2018, the sub-area was treated with a sub-leathal dose of herbicide to inhibit the production of seeds while maintaining vegetative growth as habitat for rails. In 2020, we detected a total of nine rails at the sub-area split, representing a 59% decrease from the previous year. However, at the two adjacent sub-area splits, B2 North Quadrant West (02c.1a) and B2 North Quadrant South (02c.2), rails increased by 180% and 500% respectively since 2019. It is likely that rails from the newly treated sub-area have moved into that adjacent habitat.

The Dumbarton South Region includes all marshes south of the Dumbarton Bridge, from Newark to Mountain View (**Figure 4**). In 2020, OEI conducted surveys at 17 sub-areas in the Dumbarton South Region. DENWR also surveyed four sub-areas: Dumbarton/Audubon (05b), LaRiviere Marsh (05d), Coyote Creek Lagoon (05f.3), and Coyote Creek South East (15a.5). PBCS surveyed one additional sub-area: Faber and Laumeister Marshes (15b). Only two rounds of surveys were completed at five transects in the Dumbarton South Region, accounting for incomplete results at eight sub-areas. Data were summarized using only two survey rounds for those sub-areas.

OEI detected a total of 135 Ridgway's rails in the Dumbarton South Region in 2020 (Table 2). This represents a decline of 10% since 2019, but a 6% increase since 2015 at the same subset of sub-areas. There are likely many more rails in the region that are not detected by surveys, since there are large tracts of tidal wetlands that are not included in the survey effort or are beyond the threshold of detection from the survey stations.

The Union City Region in Alameda County extends from the San Mateo Bridge to the Dumbarton Bridge (**Figure 5**). OEI surveyed fourteen sub-areas in the region in 2020. DENWR surveyed one additional sub-area in 2020: Ideal Marsh - North (21a). OEI detected a minimum of 46 Ridgway's rails (**Table 3**). This represents a 109% increase since 2019 and a 15% increase from 2015 detections at the same subset of sub-areas. Rails have been increasing particularly at the sub-areas where native *Spartina* has been planted by ISP: Eden Landing Reserve - South (13k) (AKA North Creek Marsh) and Eden Landing - Mt Eden Creek (13j).

The Hayward Region in Alameda County extends from the Oakland International Airport south to the San Mateo Bridge (**Figure 5**). OEI surveyed 18 sub-areas in the Hayward Region. OEI detected 221 Ridgway's rails in 2020 (**Table 3**). This represents an increase of 16% since last year and an an increase of 17% since 2015 at the same subset of sub-areas.

The Hayward Region contains six sub-areas where treatment permissions changed in 2018, including Cogswell Section B and Citation Marsh North which were divided into five sub-areas so that portions of each marsh could be fully treated. Five of the six previously restricted sub-areas were fully treated in 2020 and one was treated with a sub-lethal dose of herbicide called seed-suppression. This season was the first time that Citation Marsh Upper (20d.2a) was treated since permissions changed in 2018 and the second time that Cogswell - Sec B Bayfront (20n.1) has been treated since 2018. Changes in the rail population at these sub-areas may not be observed until two years after full treatment has resumed. Citation Marsh Central (20d.2b) and North Marsh (20f) remain restricted treatment sub-areas; no treatment will occur at this sub-area under the current Biological Opinion.

The San Leandro Bay Region in Alameda County is bounded by the cities of Oakland and Alameda (**Figure 5**) and is surrounded by commercial development, landfills, highways, and the Oakland International Airport. OEI surveyed nine sub-areas within the region, including Arrowhead Marsh, which was surveyed using the NAm protocol again this season for the third year in a row. EBRPD surveyed an additional sub-area: Elsie Roemer (17a). OEI detected 110 Ridgway's rails in San Leandro Bay in 2020. This represents a decline of 23% since last year and no change since 2015. Note that Arrowhead Marsh was surveyed using different methods in 2015, making it difficult to compare over this time period. Excluding Arrowhead from the analysis, rail detections in the region have increased by 8% since 2015.

The San Leandro Bay Region includes two previously-restricted sub-areas where treatment is now permitted: Damon Marsh (17d.4) and Fan Marsh Wings (17j.1). These two sub-areas were not treated from 2011 until 2018 and have now had three seasons of treatment of non-native *Spartina*. Treatment is still prohibited at three sub-areas in the San Leandro Bay Region: Arrowhead Marsh East (17c.2), Fan Marsh Main (17j.2), and MLK New Marsh (17h).

The two previously-restricted sub-areas are small marshes that have been highly impacted by non-native *Spartina* and have little native vegetation. As expected, rail numbers have declined with the success of non-native Spartina treatment at these sub-areas. Fan Marsh Wings (17j.1) is a marshy culvert alongside Doolittle Drive and has intermitantly supported one to two rails in the past. No rails were detected at this sub-area in 2020. Damon Marsh (17d.4) is a small marsh, occupying an area less than four acres, which has declined from 17 rails in 2019 to eight rails in 2020. Revegetation is expected to occur in the future as *Spartina* control continues successfully at this sub-area.

The Bay Bridge North Region is located in Alameda and Contra Costa Counties, extending from the Bay Bridge in Emeryville to Point Pinole north of the City of Richmond in the North Central Bay (**Figure 2**). OEI conducted surveys at six transects spanning eight sub-areas in 2020. EBRPD surveyed one additional sub-area: Giant Marsh (10c). OEI detected 55 Ridgway's rails in the region in 2020, an increase of 6% since last year and a 9% decrease since 2015 at the same subset of sub-areas. In 2020, Avocet Research and Associates (ARA) and OEI together surveyed the transect STEG-T1. OEI focused on three stations at Hoffman Marsh (22e), while ARA surveyed the five stations at Stege and Meeker Marshes (22d).

Table 3. Summary of survey results at all sub-areas surveyed by OEI for ISP in 2020, grouped by Region. Relative density is a ratio of rails per acre, calculated as the number of birds detected within 200 meters of a survey station; a zero in this column does not necessarily indicate absence from the site as birds may have been detected beyond 200 meters. Percent change cannot be calculated when a value is zero; in these instances, arrows are used to show the change from zero. Occupancy calculations are shown on a transect level, rather than sub-area level.

				RIRA Indices				Occupancy		
Sub-Area Name (Code)	**Transect**	**Area (acres)**	**% Area Surveyed**	**Highest Count**	**Relative Density (rails/acre)**	**One year Δ**	**Five year Δ**	**BLRA**	**SORA**	**VIRA**
Marin Region										
CMC Marsh Reserve (04a)	CEF-T1	77.1	96%	23	0.12	-15%	0%	0	0	0
Piper Park - East (04c)	PIPE-T1	10.1	99%	4	0.23	0%	-4%	0	0	0
Piper Park - West (04d)	PIPE-T1	13.8	100%	6	0.29	-14%	4%	0	0	0
CMC - Mouth (04j) - split into two sub-areas in 2011								0	0	0
CMC - Mouth North (04j.1)	CMCM-T1	6.0	100%	1	0.00	↑	-4%	-	-	-
CMC - Mouth South (04j.2)	CMCM-T1	12.2	92%	1	0.03	0%	↑	-	-	-
Boardwalk No. 1 (04k)	PIPE-T1	8.4	100%	1	0.00	↑	-4%	0	0	0
Pickleweed Park (09)	PIPK-T1	14.2	100%	0	0.00	-	-	0	0	0
San Rafael Canal Mouth (23d) - split into two sub-areas in 2011								0	0	0
San Rafael Canal Mouth East (23d.1)	PIPK-T1	3.6	100%	0	0.00	-	-	-	-	-
San Rafael Canal Mouth West (23d.2)	PIPK-T1	3.1	100%	0	0.00	-	-	-	-	-
Muzzi and Martas Marsh (23e) - grouped into one sub-area by ISP control program								0	0	0
Martas Marsh (23e)	MUZZ-T1	19.8	99%	10	0.25	11%	22%	-	-	-
San Clemente Creek (23e)	MUZZ-T1	18.8	50%	3	0.14	50%	↑	-	-	-
Muzzi Marsh (23e)	MUZZ-T1	138.5	55%	35	0.21	3%	1%	-	-	-
San Francisco Peninsula Region										
Pier 98/Heron's Head (12b)	HEHE-T1	10.9	93%	0	0.00	-	-	0	0	0
SFO (19h)	SFO-T1	25.1	65%	0	0.00	-100%	-100%	0	0	0
Seal Slough (19p) – split into two sub-areas in 2011								0	0	0
Seal Slough Central (19p.1)	SEAL-T1	37.8	85%	1	0.01	↑	↑	-	-	-
Seal Slough Peripheral (19p.2)	SEAL-T1	30.8	75%	1	0.01	↑	↑	-	-	-

Table 2 continued on next page

Sub-Area Name (Code)	Transect	Area (acres)	% Area Surveyed	RIRA Indices				Occupancy		
				Highest Count	Relative Density (rails/acre)	One year Δ	Five year Δ	BLRA	SORA	VIRA
San Mateo Region										
Belmont Slouth (02a) - split into three sub-areas in 2011 and 2012								0	0	0
Belmont Slough Mouth (02a.1a)	BELM-T1	51.1	75%	3	0.04	↑	4%	-	-	-
Belmont Slough South (02a.1b)	BELM-T1	17.7	81%	3	0.02	↑	-4%	-	-	-
Belmont Slough to Steinberger (02a.2)	BELM-T1	109.3	14%	0	0.00	-100%	-100%	-	-	-
Corkscrew Slough (02b.1)	CORK-T1	227.4	36%	8	0.04	-50%	-15%	0	0	0
Steinberger Slough (02b.2)	RESH-T2	105.6	37%	2	0.01	0%	↑	0	0	0
B2 North Quadrant (02c) - split into three sub-areas in 2011 and 2012								0	0	0
B2 North Quadrant West (02c.1a)	OBEN-T1	150.5	47%	14	0.09	180%	31%	-	-	-
B2 North Quadrant East (02c.1b)	OBEN-T1	146.0	47%	9	0.06	-59%	-11%	-	-	-
B2 North Quadrant South (02c.2)	OBEN-T2	226.7	26%	6	0.03	500%	20%	-	-	-
B2 South Quadrant (02d) - split into four sub-areas in 2011 and 2012								0	0	0
B2 South Quadrant West (02d.1a)	OBES-T1	38.3	75%	2	0.05	-50%	10%	-	-	-
B2 South Quadrant East (02d.1b)	OBES-T1	23.2	45%	0	0.00	-	-	-	-	-
B2 South Quadrant 2 (02d.2)	OBES-T1	58.8	73%	4	0.02	0%	-8%	-	-	-
B2 South Quadrant 3 (02d.3)	OBES-T1	67.9	22%	0	0.00	-	-	-	-	-
Greco Island - North (02f)	GRIN-T1	511.1	27%	11	0.05	57%	2%	0	0	0
West Point Slough - SW / E (02g)	WPSS-T1	39.8	65%	3	0.08	0%	↑	0	0	0
Greco Island - South (02h)	GRIS-T1	237.9	42%			-15%	4%	0	0	0
Ravenswood Slough (02i)	RAV-T1	117.8	58%	14	0.12	40%	-1%	0	0	0
Deepwater Slough (02k) - grouped into one sub-area by ISP control program								0	0	0
Middle Bair N (02k)	MBE-T1	221.6	44%	18	0.07	-31%	-17%	-	-	-
Middle Bair SE (02k)	MBE-T1	200.3	33%	2	0.02	↑	↑	-	-	-
Inner Bair Island Restoration (02l)	IBI-T1	59.6	64%	0	0.00	-	-	0	0	0

KEY TO SHADING:

- Light grey shading indicates sub-areas where treatment permissions changed from restricted to permitted through the 2018 Biological Opinion.

Table 2 continued on next page

Sub-Area Name (Code)	Transect	Area (acres)	% Area Surveyed	RIRA Indices: Highest Count	Relative Density (rails/acre)	One year Δ	Five year Δ	Occupancy: BLRA	SORA	VIRA
Dumbarton South Region										
Mowry Marsh North (05a.1)	MOWN-T1	417.4	29%	21	0.04	-13%	20%	0	0	0
Calaveras Point (05a.2)	CAPT-T1	478.7	14%	5	0.04	-76%	-21%	0	0	0
Newark Slough (05c) - split into two sub-areas in 2011								0	0	0
Newark Slough West (05c.1)	NEWS-T1	167.3	15%	4	0.06	100%	↑	-	-	-
Newark Slough East (05c.2)	NEWS-T1	73.1	37%	6	0.15	-40%	10%	-	-	-
Mayhew's Landing (05e)	MALA-T1	27.9	81%	0	0.00	-	-	0	0	0
Coyote Creek - Mud Slough (05f)	A21-T1	210.2	41%	0	0.00	-100%	-	0	0	0
Cargill Pond (W Suites Hotel) (05g)	MALA-T1	18.2	99%	0	0.00	-	-	0	0	0
Plummer Creek Mitigation (05h)	PLCM-T1	16.6	97%	1	0.02	↑	↑	0	0.33	0.67
Island Ponds - A21 (05i)	A21-T1	159.2	50%	4	0.01	100%	↑	0	0.13	0.25
Palo Alto Baylands (08) – grouped into one sub-area by ISP control program								-	-	-
Palo Alto Baylands (08)	PAB-T1	116.2	74%	20	0.17	43%	2%	0	0	0.14
Palo Alto Harbor (08)	PAHA-T1	128.4	69%	28	0.20	-13%	-1%	0	0	0
Charleston to Mountain View Sl (15a.1) - grouped into one sub-area by ISP control program								0	0	0
Charleston Slough (15a.1)	MVSL-T1	36.2	73%	4	0.08	0%	2%	-	-	-
Mountain View Slough (15a.1)	MVSL-T1	74.0	30%	0	0.00	-100%	-	-	-	-
Stevens Creek to Long Point (15a.2)	STEV-T1	56.9	63%	0	0.00	-100%	-	0	0	0.33
Guadalupe Slough (15a.3)	GUSL-T1	316.2	28%	4	0.02	33%	-4%	0	0	0.13
Alviso Slough (15a.4)	ALSL-T2	459.9	17%	10	0.05	-17%	-2%	0	0	0.25
Stevens Creek (15c)	STEV-T1	27.9	75%	0	0.00	-100%	-	0.50	0.50	1.00
Cooley Landing (16) - split into two sub-areas in 2011								0	0	0
Cooley Landing Central (16.1)	COLA-T1	41.9	93%	19	0.14	138%	51%	-	-	-
Cooley Landing East (16.2)	COLA-T1	133.2	55%	9	0.05	-18%	30%	-	-	-
Union City Region										
AFCC - Mouth (01a)	AFCP-T1	23.6	60%	0	0.00	-	-100%	0	0	0
AFCC - Lower (01b)	AFCP-T2	135.4	39%	1	0.00	↑	-4%	0	0	0
AFCC - Upper (01c)	AFCC-T4	75.3	63%	0	0.00	-	-	0	0	0
AFCC - to I-880 (01d)	AFCC-T4	39.7	23%	0	0.00	-	-	0	0	0
AFCC - Pond 3 (01f)	AFCP-T1	130.9	69%	1	<0.01	↑	-23%	0.14	0	0
OAC - North Bank (13a)	OAC-T2 & OAC-T3	26.9	67%	3	0.07	50%	↑	0.11	0	0
OAC - Island (13b)	OAC-T2 & OAC-T3	93.7	68%	7	0.08	-13%	23%	0.11	0.06	0.06
OAC - South Bank (13c)	OAC-T2 & OAC-T3	24.1	61%	3	0.16	0%	↑	0.06	0	0
Whale's Tail - North (13d)	WTN-T1	140.6	46%	8	0.05	700%	27%	0	0	0
Whale's Tail - South (13e)	WTS-T1	149.3	51%	4	0.03	100%	-14%	0	0	0
Cargill Mitigation Marsh (13f)	WTS-T1	47.2	79%	0	0.00	-100%	-100%	0	0	0
Eden Landing - Mt Eden Creek (13j)	EDEN-T1	124.8	49%	11	0.03	1000%	↑	0	0	0
Eden Landing Reserve - South [AKA North Creek Marsh](13k)	ELRS-T1	239.6	36%	8	0.02	100%	↑	0	0.13	0
Eden Landing Reserve - North (13l)	ELRS-T1	229.8	18%	0	0.00	-	-	0	0	0

Table 2 continued on next page

Sub-Area Name (Code)	Transect	Area (acres)	% Area Surveyed	RIRA Indices: Highest Count	Relative Density (rails/acre)	One year Δ	Five year Δ	Occupancy: BLRA	SORA	VIRA
Hayward Region										
Oro Loma - East (07a)	ORLW-T1	197.1	54%	0	0.00	-	-100%	0	0	0
Oro Loma - West (07b)	ORLW-T3	130.7	55%	1	0.00	-50%	-4%	0	0	0
Dog Bone Marsh (20c)	NORT-T1	7.0	58%	0	0.00	-100%	-	0	0	0
Citation Marsh (20d) - - split into three sub-areas in 2012 and 2018								0.14	0.43	0
Citation Marsh South (20d.1)	CITA-T1	44.4	44%	2	0.07	-50%	↑	-	-	-
Citation Marsh Upper (20d.2a)	CITA-T1	36.0	69%	23	0.42	15%	NA	-	-	-
Citation Marsh Central (20d.2b)	CITA-T1	35.8	80%	20	0.36	5%	NA	-	-	-
East Marsh (20e)	SLRZ-T1	37.2	30%	1	0.00	-80%	↑	0	0	0
North Marsh (20f)	NORT-T1	94.2	94%	70	0.27	25%	16%	0	0.43	0.14
Bunker Marsh (20g)	BUNK-T1	35.8	95%	27	0.53	13%	30%	0	0	0
San Lorenzo Creek (20h) - split into two sub-areas in 2011								0	0	0
San Lorenzo Creek North (20h.1)	SLRZ-T1	12.0	96%	2	0.12	0%	↑	-	-	-
San Lorenzo Creek South (20h.2)	SLRZ-T1	10.4	96%	3	0.17	↑	↑	-	-	-
Cogswell - Sec A (20m)	COGS-T1	34.9	100%	5	0.09	400%	15%	0	0	0
Cogswell - Sec B (20n) – split into three sub-areas in 2018								0.14	0.14	0
Cogswell - Sec B Bayfront (20n.1)	COGS-T3	11.9	89%	7	0.00	17%	NA	-	-	-
Cogswell - Sec B South (20n.2)	COGS-T3	33.9	95%	22	0.35	47%	NA	-	-	-
Cogswell - Sec B Main (20n.3)	COGS-T3	55.5	91%	23	0.22	44%	NA	-	-	-
Cogswell - Sec C (20o)	COGS-T2	49.8	100%	14	0.15	-13%	1%	0	0	0
HARD Marsh (20s)	HARD-T1	65.9	80%	1	0.00	-67%	↑	0	0	0
Triangle Marsh - Hayward (20w)	TRMA-T1	12.4	35%	0	0.00	-	-	0	0	0
San Leandro Bay Region										
Arrowhead Marsh (17c) - split into two sub-areas in 2011								0	0	0
Arrowhead Marsh West (17c.1)	ARHE-T2	21.2	97%	5	0.23	67%	33%	-	-	-
Arrowhead Marsh East (17c.2)	ARHE-T2	22.7	90%	25	0.86	-34%	-14%	-	-	-
MLK Shoreline (17d) - split into five sub-areas in 2011								0	0	0
MLK Regional Shoreline - Damon (17d.4)	MLKS-T1	10.6	100%	8	0.44	-53%	27%	-	-	-
MLK Regional Shoreline - Damon Slough (17.5)	MLKS-T1	3.8	65%	0	0.00	-	-	-	-	-
San Leandro Creek (17e) - split into two sub-areas in 2011								0	0	0
San Leandro Creek North (17e.1)	MLKR-T1	2.0	99%	0	0.00	-100%	-100%	-	-	-
San Leandro Creek South (17e.2)	MLKR-T1	5.3	17%	0	0.00	-	-	-	-	-
MLK New Marsh (17h)	MLKR-T1	34.3	100%	55	1.27	-7%	8%	0.17	0.33	0.33
Fan Marsh (17j) – split into two sub-areas in 2018								0	0.33	0
Fan Marsh Wings (17j.1)	FANM-T1	2.4	57%	0	0.00	-100%	NA	-	-	-
Fan Marsh Main (17j.2)	FANM-T1	10.1	100%	17	1.45	-23%	NA	-	-	-

KEY TO SHADING:

- Light grey shading indicates sub-areas where treatment permissions changed from restricted to permitted through the 2018 Biological Opinion.
- Dark grey shading indicates sub-areas where treatment is still restricted.
- Medium grey shading indicates the sub-area where only seed-suppression is permitted, Cogswell Section B Main (20n.3). Seed-suppression is a sub-lethal dose of herbicide meant to halt the production of infloresences but preserve the vegetative structure of non-native *Spartina*.

Table 2 continued on next page

Sub-Area Name (Code)	Transect	Area (acres)	% Area Surveyed	RIRA Indices: Highest Count	Relative Density (rails/acre)	One year Δ	Five year Δ	Occupancy: BLRA	SORA	VIRA
Bay Bridge North Region										
Emeryville Crescent - East (06a)	EMCR-T1	54.2	7%	0	0.00	-	-	0	0	0
Emeryville Crescent - West (06b)	EMCR-T1	31.5	99%	2	0.03	100%	↑	0	0	0
Whittel Marsh (10a)	PTPN-T1	44.9	96%	0	0.00	-100%	-100%	0.75	0	0
Wildcat Marsh (22a)	WIMA-T1	333.5	40%	28	0.10	56%	-11%	0.13	0	0
San Pablo Marsh (22b) - split into two sub-areas in 2011								0.4	0	0
San Pablo Marsh East (22b.1)	RIF-T1	36.5	68%	5	0.11	-44%	-7%	-	-	-
San Pablo Marsh West (22b.2)	RIF-T1	125.6	62%	9	0.07	-36%	-15%	-	-	-
Rheem Creek Area (22c)	RCRA-T1	26.8	79%	9	0.13	13%	13%	0.50	0	0
Hoffman Marsh (22e)	STEG-T1	38.5	91%	2	0.02	↑	10%	0	0	0

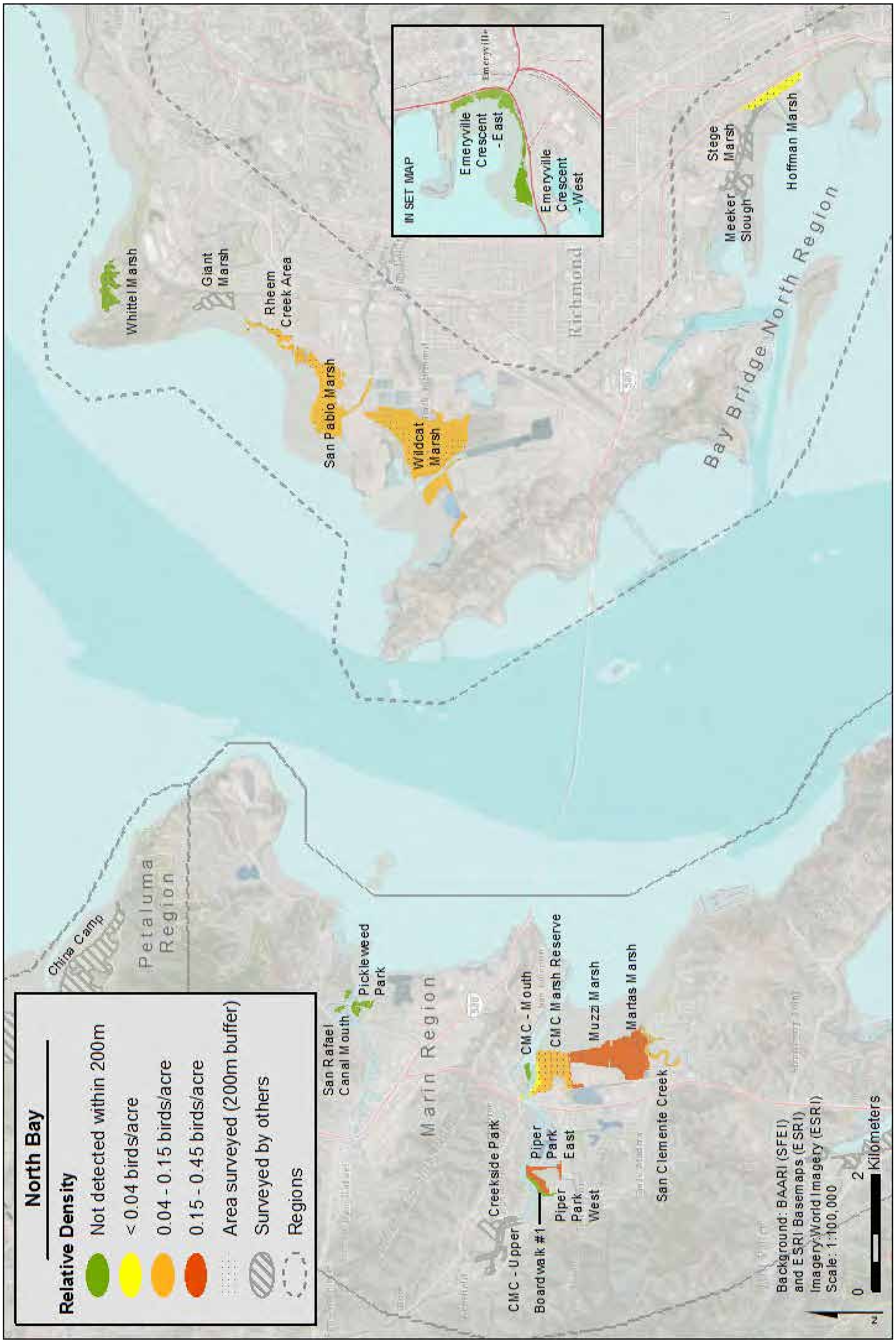

Figure 2. Overview map of North Bay, showing summary results at sub-areas in the Bay Bridge North and Marin Regions. To see survey stations and rail locations, view the map attachment named North Bay (scaled to 1:24,000 on a 24x36 poster).

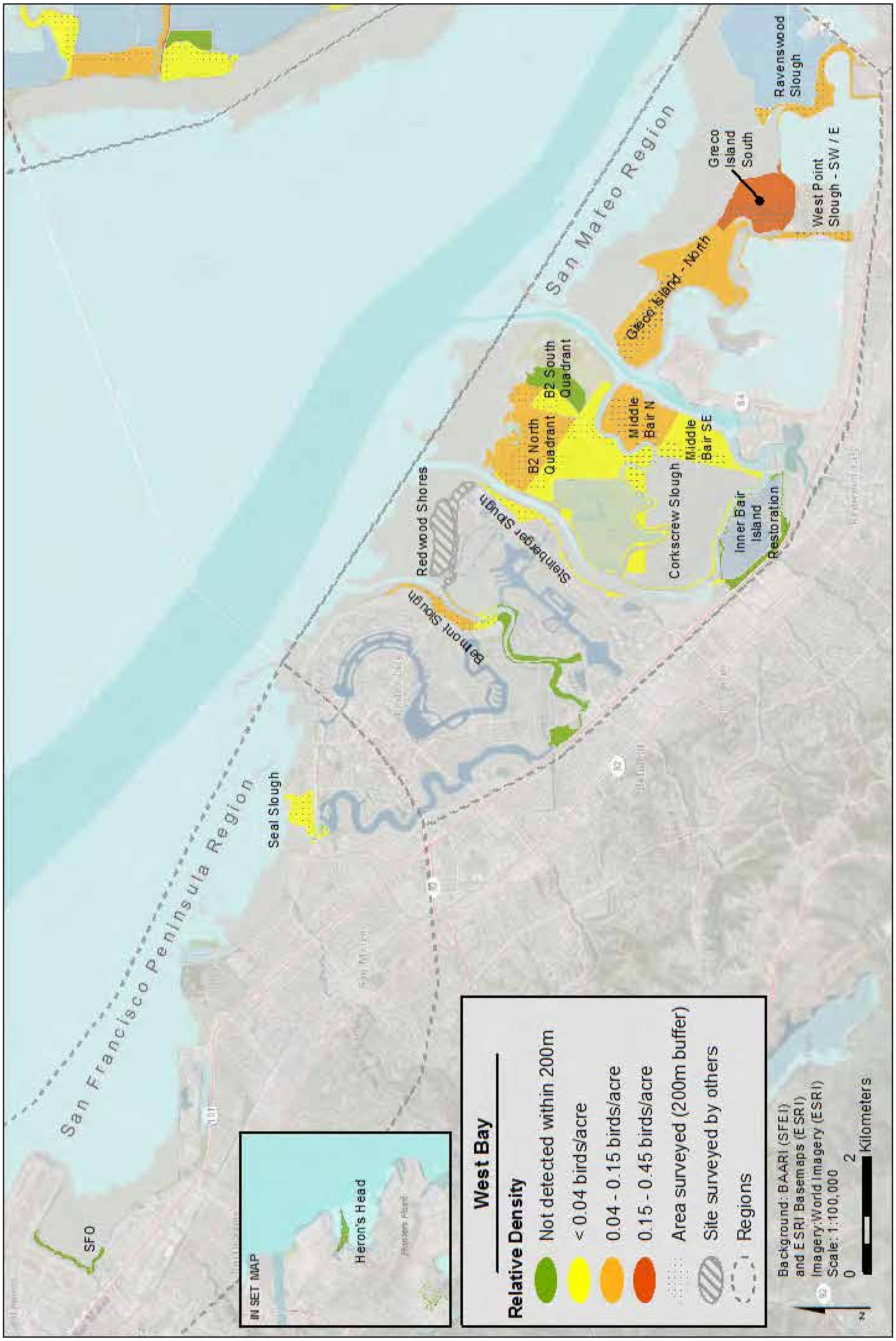

Figure 3. Overview map of West Bay, showing summary results at sub-areas in the SF Peninsula and San Mateo Regions. To see survey stations and rail locations, view the map attachment named West Bay (scaled to 1:24,000 on a 24x36 poster).

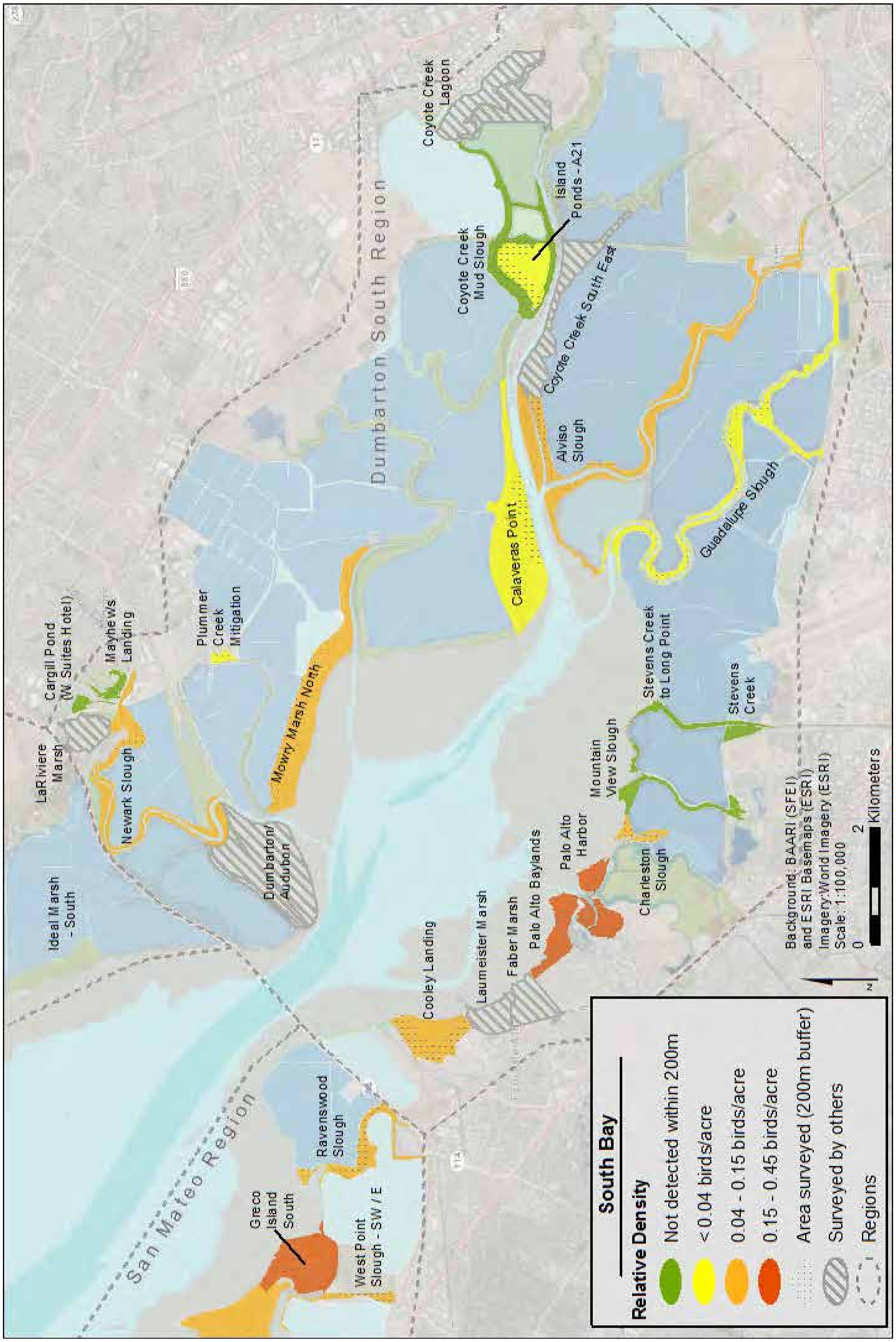

Figure 4. Overview map of South Bay, showing summary results at sub-areas in the Dumbarton South Region. To see survey stations and rail locations, view the map attachment named South Bay (scaled to 1:24,000 on a 24x36 poster).

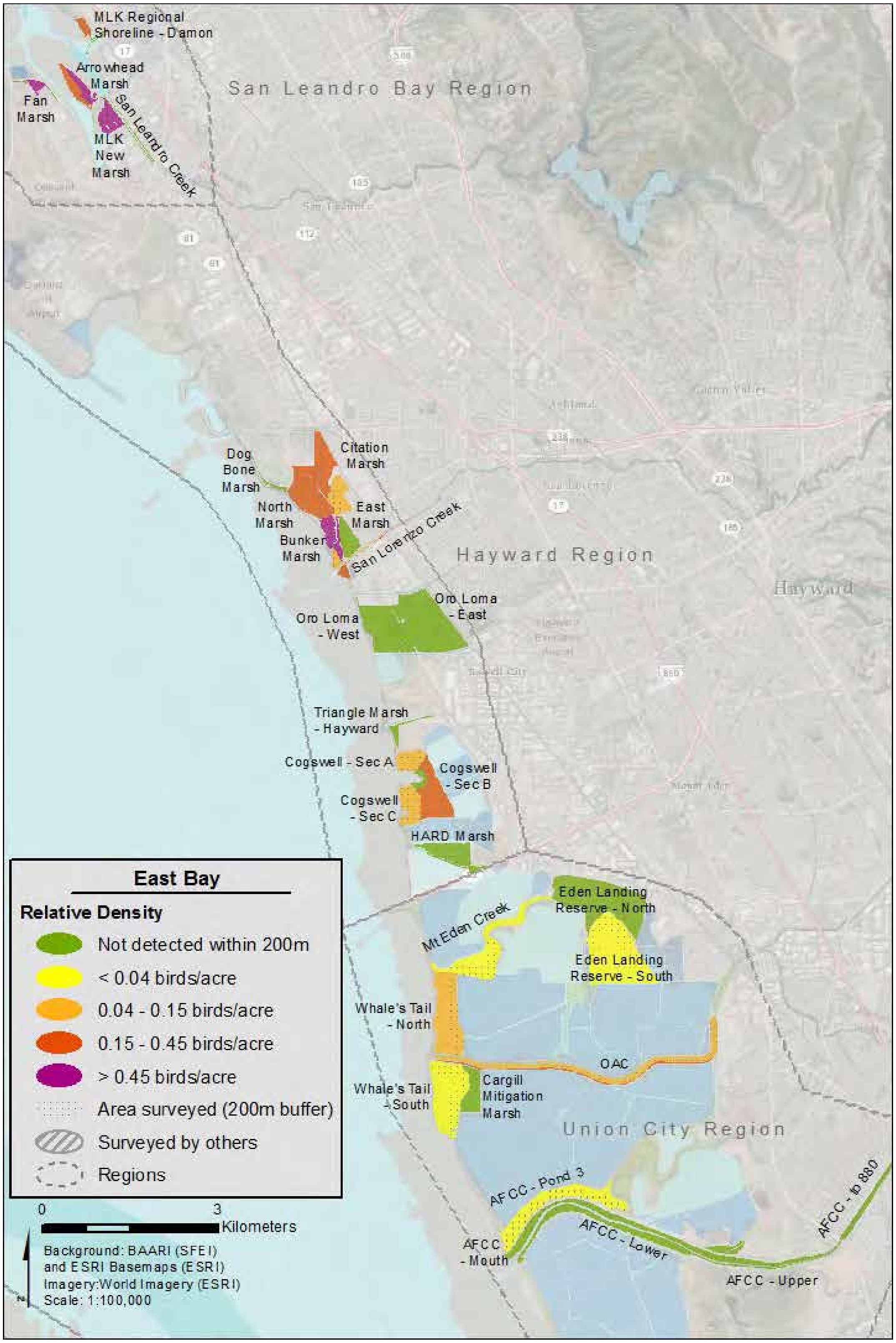

Figure 5. Overview map of East Bay, showing summary results at sub-areas in the Union City, Hayward, and San Leandro Bay Regions. To see survey stations and rail locations, view the map attachment named East Bay (scaled to 1:24,000 on a 24x36 poster).

5. Discussion

OEI detected 798 California Ridgway's rails at 70 of the 100 sub-areas surveyed by OEI for the ISP in 2020. This is nearly the same number as detected in 2019, when 796 rails were detected at the same subset of sub-areas. Good weather allowed for most surveys to be completed early in 2020, before the COVID-19 pandemic began to affect California. However, in mid-March the Bay Area announced an emergency shelter-in-place order due to the pandemic and most surveys were subsequently cancelled. Access to all National Wildlife Refuge lands and waters was restricted after March 13th and twenty (20) sub-areas in their jurisdiction were not surveyed for the third and final round. Because the round with the highest count is the only round included in the overall summary of detections, the total count from 2020 might have been higher had we been able to complete the third round of surveys on the Refuge. However, the third round of surveys is rarely the most productive survey and it is unlikely that the total number of rails detected in 2020 would have been significantly greater if the third round of surveys had been completed.

Spartina Treatment Effects

The footprint of hybrid *Spartina* has been reduced to a small fraction of the available habitat at the vast majority of ISP sub-areas where treatment has been on-going since 2012. At these sub-areas, Ridgway's rail numbers are stable and no additional treatment effects are anticipated at these sub-areas. However, at the sub-areas where treatment was restricted in 2012, hybrid *Spartina* was able to grow into large meadows, crowding out native vegetation but also providing ample cover for Ridgway's rails. Ridgway's rail numbers grew with the expansion of hybrid *Spartina* at these handful of sub-areas, which are focused along the East Bay shoreline. Through the process of consultation with the Service, treatment was allowed to resume at nine of the previously-restricted sub-areas in 2018 (six sub-areas remain restricted to treatment).

In the 2018 Biological Opinion, the Service estimated that rails inhabiting the nine previously-restricted sub-areas may be lost due to mortality or exhibit decreased reproductive success due to loss of hybrid *Spartina* cover when treatment of these sub-areas resumed. Since then, treatment has resumed at all nine previously-restricted sub-areas: B2 North Quadrant East (02c.1b), Citation Marsh Upper (20d.2a), Bunker Marsh (20g), San Lorenzo Creek North (20h.1), Cogswell - Sec B Bayfront (20n.2), Cogswell - Sec B South (20n.2), Cogswell – Sec C (20o), Damon Marsh (17d.4), and Fan Marsh Wings (17j.1).

After two years of treatment, the number or Ridgway's rails detected at these previously-restricted sub-areas have declined by 9% over the past year. Because it may take several growing seasons and treatment events to show changes in habitat, rail numbers are expected to continue to decline at these sub-areas next year. The change in rails at these sub-areas is still less than predicted in the 2018 Biological Opinion.

Recommendations

Habitat enhancement and restoration may ameliorate the effects of the temporary loss of cover due to *Spartina* removal. Additionally, the slower-paced phased treatment of the previously-restricted sub-areas will also stem declines as the habitat converts from invasive *Spartina* meadows to native marshes. The ISP is working to rapidly reestablish native vegetation and high tide refuge to support and increase the bay-wide Ridgway's rail population. These efforts include extensive revegetation of both *Grindelia stricta* and *Spartina foliosa* plantings. Additionally, the Coastal Conservancy has invested in the construction of high tide refuge islands, with ten more islands installed in the 2020 to 2021 winter season.

Ultimately, the most effective means to increase the Ridgway's rail population in the Estuary in the long term will be to increase the amount of salt marsh habitat available through the restoration of large tracts of tidal wetlands. Many of these efforts are already well on their way through the South Bay Salt Pond Restoration Project and the restoration of the Napa-Sonoma Baylands. As more of these newly-breached sites mature and become vegetated, biologists expect to see Ridgway's rails colonize and increase in numbers in response to the restored habitat. The first evidence of this positive rail response can already be seen in some recently restored sites that now support rails, including Island Ponds A21 in Coyote Creek, Eden Landing Reserve South (13k, AKA North Creek Marsh), and Sonoma Baylands Restoration at the mouth of the Petaluma River, which already supports a substantial rail population at a fairly high density. These large tracts of native marshlands are the key to the resiliency of the rail and the ecosystem in the face of an uncertain future due to climate change.

6. Permits

Surveys were conducted under the authority of U.S. Fish and Wildlife Service permit TE118356-4 and a Memorandum of Understanding with the California Department of Fish and Wildlife. Surveys were required by and conducted pursuant to conditions of the Programmatic Formal Intra-Service Endangered Species Consultation on the San Francisco Estuary Invasive *Spartina* Project and subsequent additional formal intra-Service consultations on implementation of the San Francisco Estuary Invasive *Spartina* Project. Permission for site access was granted by East Bay Regional Park District, the City of San Leandro, California Department of Fish and Wildlife, Cargill, City of Mountain View, Mid-Peninsula Regional Open Space District, Redwood City Marina, Westpoint Harbor, SFO International Airport, and Don Edwards San Francisco Bay National Wildlife Refuge.

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Appendix I: Complete List of 2020 *Spartina* Treatment Sub-Areas and Ridgway's Rail Survey Plans

KEY to Survey Organizations:

- **ARA** = Avocet Research Associates (contact Jules Evens)
- **CDFW** = California Department of Fish and Wildlife (contact Karen Taylor)
- **EBRPD** = East Bay Regional Park District (contact David Riensche)
- **ISP** = Olofson Environmental, Inc. for the Invasive *Spartina* Project (contact Jen McBroom)
- **OEI** = Olofson Environmental, Inc. for an outside agency or company (contact Jen McBroom)
- **PBCS** = Point Blue Conservation Science (contact Julian Wood)
- **DENWR** = Don Edwards National Wildlife Refuge (contact Rachel Tertes)
- **SPBNWR** = San Pablo Bay National Wildlife Refuge (contact Meg Marriott)

Appendix I: Complete list of 2019 *Spartina* treatment sub-areas and associated Ridgway's rail sites and survey plans by survey organization, survey type, and transect.

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Area 01: Alameda Flood Control Channel in Union City Region				
AFCC - Mouth (01a)	ISP	NAm	AFCP-T1	Formerly surveyed by DENWR
AFCC - Lower (01b)	ISP	NAm	AFCP-T1; AFCP-T2	Formerly surveyed by DENWR
AFCC - Upper (01c)	ISP	NAm	AFCC-T4	Formerly surveyed by DENWR
AFCC - to I-880 (01d)	ISP	NAm	AFCC-T4	Formerly surveyed by DENWR
AFCC - Strip Marsh (01e)	none	none	none	Insufficient habitat (2017)
AFCC - Pond 3 (01f)	ISP	NAm	AFCP-T1; AFCP-T2	Formerly surveyed by DENWR
Area 02: Bair and Greco Complex in San Mateo Region				
Belmont to Steinberger Slough (02a)	-	-	-	Split into five sub-areas in 2011 and 2012
Belmont Slough Mouth (02a.1a)	ISP	NAm	BELM-T1	
Belmont Slough South (02a.1b)	ISP	NAm	BELM-T1	
Belmont Slough to Steinberger (02a.2)	ISP	NAm	BELM-T1	
Redwood Shores (02a.3)	DENWR	NAm	RESH-T1	
Redwood Shores Mitigation Bank (02a.4)	none	none	none	Insufficient habitat (2017)
Steinberger to Redwood Creek (02b)	-	-	-	Split into three sub-areas in 2011
Corkscrew Slough (02b.1)	ISP	NAm	CORK-T1	
Steinberger Slough (02b.2)	ISP	NAm	RESH-T2	
Redwood Creek (02b.2)	none	none	none	Not surveyed
B2 North Quadrant (02c)	-	-	-	Split into three sub-areas in 2011 and 2012
B2 North Quadrant West (02c.1a)	ISP	NAm	OBEN-T1	
B2 North Quadrant East (02c.1b)	ISP	NAm	OBEN-T1	
B2 North Quadrant South (02c.2)	ISP	NAm	OBEN-T2	
B2 South Quadrant (02d)	-	-	-	Split into four sub-areas in 2011 and 2012
B2 South Quadrant West (02d.1a)	ISP	NAm	OBES-T1	
B2 South Quadrant East (02d.1b)	ISP	NAm	OBES-T1	
B2 South Quadrant 2 (02d.2)	ISP	NAm	OBES-T1	
B2 South Quadrant 3 (02d.3)	ISP	NAm	OBES-T1	
West Point Slough - NW (02e)	none	none	none	No site access in 2019
Greco Island - North (02f)	ISP	NAm	GRIN-T1	
West Point Slough - SW / E (02g)	ISP	NAm	WPSS-T1	
Greco Island - South (02h)	ISP	NAm	GRIS-T1	
Ravenswood Slough (02i)	ISP	NAm	RAV-T1	
Ravenswood Open Space Preserve (02j)	none	none	none	Insufficient habitat (2017)
Deepwater Slough (02k)	-	-	-	Grouped into one sub-area by ISP control program
Middle Bair N (02k)	ISP	NAm	MBE-T1	
Middle Bair SE (02k)	ISP	NAm	MBE-T1	
Inner Bair Island Restoration (02l)	ISP	NAm	IBI-T1	
Pond B3 Bair Island Restoration (02m)	none	none	none	Insufficient habitat (2018)
SF2 (02n)	none	none	none	Insufficient habitat (2017)
Middle Bair West (02o)	none	none	none	Insufficient habitat (2017)

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Area 03: Blackies Pasture and Mouth in Marin Region				
Blackie's Creek (03a)	none	none	none	Insufficient habitat (2017)
Blackie's Creek Mouth (03b)	none	none	none	Insufficient habitat (2017)
Area 04: Corte Madera Creek in Marin Region				
CMC Marsh Reserve (04a)	ISP	NAm	HEER-T1	Typically surveyed by PBCS
College of Marin (04b)	none	none	none	Insufficient habitat (2019)
Piper Park - East (04c)	ISP	NAm	PIPE-T1	Typically surveyed by PBCS
Piper Park - West (04d)	ISP	NAm	PIPE-T1	Typically surveyed by PBCS
Larkspur Ferry Landing Area (04e)	none	none	none	Insufficient habitat (2017)
Riviera Circle (04f)	none	none	none	Insufficient habitat (2017)
Creekside Park (04g)	PCBS	NAm	CSPK-T1	
CMC - Upper (04h)	PCBS	NAm*	CSPK-T1	*surveyed from adjacent site
CMC - Lower (04i)	none	none	none	Not surveyed
CMC - Mouth (04j)	-	-	-	Split into two sub-areas in 2011
CMC - Mouth North (04j.1)	ISP	NAm	CMC-T1	Not surveyed
CMC - Mouth South (04j.2)	ISP	NAm	CMC-T1	
Boardwalk No. 1 (04k)	ISP	NAm	PIPE-T1	Typically surveyed by PBCS
Murphy Creek (04l)	none	none	none	Insufficient habitat (2016)
Area 05: Coyote Creek / Mowry in Dumbarton South Region				
Mowry Marsh (05a.1)	-	-	-	Grouped into one sub-area by ISP control program
Mowry Marsh North (05a.1)	ISP	NAm	MOWN-T1	
Mowry Marsh South Bayshore (05a.1)	none	none	none	Not surveyed
Mowry Slough Upper (05a.1)	none	none	none	Not surveyed
Mowry Marsh South (05a.1)	none	none	none	Not surveyed
Calaveras Point (05a.2)	ISP	NAm	CAPT-T1	
Dumbarton/Audubon (05b)	-	-	-	Grouped into one sub-area by ISP control program
Dumbarton/Audubon (05b)	DENWR	NAm	DUMA-T2	
Dumbarton/Audubon East (05b)	none	none	none	Not surveyed
Plummer Creek (05b)	none	none	none	Not surveyed
Newark Slough (05c)	-	-	-	Split into two sub-areas in 2011
Newark Slough West (05c.1)	ISP	NAm	NEWS-T1	
Newark Slough East (05c.2)	ISP	NAm	NEWS-T1	
LaRiviere Marsh (05d)	DENWR	NAm	LARV-T1	
Mayhew's Landing (05e)	ISP	NAm	MALA-T1	Typically surveyed by DENWR
Coyote Creek - Alameda County (05f)	-	-	-	Grouped into one sub-area by ISP control program
Coyote Creek - Mud Slough (05f)	ISP	NAm*	A21-T1	*surveyed from adjacent site
Coyote Creek - North (05f)	none	none	none	Not surveyed
Coyote Creek Lagoon (05f)	DENWR	NAm	CCL-T1	
Cargill Pond (W Suites Hotel) (05g)	ISP	NAm*	MALA-T1	*surveyed from adjacent site
Plummer Creek Mitigation (05h)	ISP	NAm	PLCM-T1	
Island Ponds (05i)	-	-	-	Grouped into one sub-area by ISP control program
Island Ponds - A21 (05i)	ISP	NAm	A21-T1	
Island Ponds - A20 (05i)	none	none	none	Not surveyed
Island Ponds - A19 (05i)	none	none	none	Not surveyed

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Area 06: Emeryville Crescent in Bay Bridge North Region				
Emeryville Crescent - East (06a)	ISP	NAm	EMCR-T1	
Emeryville Crescent - West (06b)	ISP	NAm	EMCR-T1	
Area 07: Oro Loma in Hayward Region				
Oro Loma - East (07a)	ISP	NAm	ORLW-T1	
Oro Loma - West (07b)	ISP	NAm	ORLW-T3	
Area 08: Palo Alto Baylands in Dumbarton South Region				
Palo Alto Baylands (08)	-	-	-	Grouped into one sub-area by ISP control program
Palo Alto Baylands (08)	ISP	NAm	PAB-T1	Typically surveyed by PBCS
Palo Alto Harbor (08)	ISP	NAm	PAHA-T1	Typically surveyed by PBCS
Area 09: Pickleweed Park in Marin Region				
Pickleweed Park (09)	ISP	NAm	PIPK-T1	
Area 10: Point Pinole Marshes in Bay Bridge North Region				
Whittel Marsh (10a)	ISP	NAm	PTPN-T1	
Southern Marsh (10b)	none	none	none	Insufficient habitat (2017)
Giant Marsh (10c)	EBRPD	unknown	n/a	
Breuner Marsh Restoration (10d)	none	none	none	Insufficient habitat (2017)
Area 11: Carquinez Straits in Vallejo Region				
Southampton Marsh (11)	ARA	G	n/a	
Area 12: Southeast San Francisco in San Francisco Bay Region				
Pier 94 (12a)	none	none	none	Insufficient habitat (2016)
Pier 98/Heron's Head (12b)	ISP	NAm	HEHE-T1	Also surveyed by ESA in 2020
India Basin (12c)	none	none	none	Insufficient habitat (2014)
Hunters Point Naval Reserve (12d)	none	none	none	Insufficient habitat (2017)
Yosemite Channel (12e)	none	none	none	Insufficient habitat (2017)
Candlestick Cove (12f)	none	none	none	Insufficient habitat (2017)
Crissy Field (12g)	none	none	none	Insufficient habitat (2017)
Yerba Buena Island (12h)	none	none	none	Insufficient habitat (2017)
Mission Creek (12i)	none	none	none	Insufficient habitat (2016)
Area 13: Whales Tail Complex in Union City Region				
OAC - North Bank (13a)	ISP	NAm	OAC-T2; OAC-T3	
OAC - Island (13b)	ISP	NAm	OAC-T2; OAC-T3	
OAC - South Bank (13c)	ISP	NAm	OAC-T2; OAC-T3	
Whale's Tail - North (13d)	ISP	NAm	WTN-T1	
Whale's Tail - South (13e)	ISP	NAm	WTS-T1	
Cargill Mitigation Marsh (13f)	ISP	NAm	WTS-T1	
OAC - Upstream 20 Tide Gates (13g)	none	none	none	Insufficient habitat (2016)
Eden Landing - North Creek (13h)	none	none	none	Insufficient habitat (2017)
Eden Landing - Pond 10 (13i)	none	none	none	Insufficient habitat (2017)
Eden Landing - Mt Eden Creek (13j)	ISP	NAm	EDEN-T1	
Eden Landing Reserve - South (13k)	ISP	NAm	ELRS-T1	
Eden Landing Reserve - North (13l)	ISP	NAm*	ELRS-T1	*surveyed from adjacent site
Eden Landing - Ponds E8A, E9, E8X (13m)	none	none	none	Insufficient habitat (2017)

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Area 15: South Bay Marshes in Dumbarton South Region				
Charleston Slough to Mountain View Slough (15a.1)	-	-	-	Grouped into one sub-area by ISP control program
Charleston Slough (15a.1)	ISP	NAm	MVSL-T1	
Mountain View Slough (15a.1)	ISP	NAm	MVSL-T1	
Stevens Creek to Guadalupe Slough (15a.2)	-	-	-	Grouped into one sub-area by ISP control program
Stevens Creek to Long Point (15a.2)	ISP	NAm	STEV-T1	
Guadalupe to Stevens Bayfront (15a.2)	none	none	none	Not surveyed
Guadalupe Slough (15a.3)	ISP	NAm	GUSL-T1	
Alviso Slough (15a.4)	ISP	NAm	ALSL-T2	
Coyote Creek to Artesian Slough (15a.5)	-	-	-	Grouped into one sub-area by ISP control program
Coyote Creek South East (15a.5)	DENWR	NAm	COYE-T1	
Coyote Creek South Tributary Marsh (15a.5)	none	none	none	Not surveyed
Artesian Slough (15a.5)	none	none	none	Not surveyed
Knapp Tract (15a.6)	none	none	none	Insufficient habitat (2017)
Pond A17 (15a.7)	none	none	none	Insufficient habitat (2019)
Faber/Laumeister (15b)	-	-	-	Grouped into one sub-area by ISP control program
Faber Marsh (15b)	PBCS	NAm	FABE-T1	
Laumeister Marsh (15b)	PBCS	NAm	LAUM-T1	
Stevens Creek (15c)	ISP	NAm	STEV-T1	
Area 16: Cooley Landing in Dumbarton South Region				
Cooley Landing (16)	-	-	-	Split into two sub-areas in 2011
Cooley Landing Central (16.1)	ISP	NAm	COLA-T1	
Cooley Landing East (16.2)	ISP	NAm	COLA-T1	
Area 17: San Leandro Bay in San Leandro Bay Region				
Elsie Roemer (17a)	EBRPD	unknown	n/a	
Bay Farm Island (17b)	none	none	none	Insufficient habitat (2017)
Arrowhead Marsh (17c)	-	-	-	Split into two sub-areas in 2012
Arrowhead Marsh West (17c.1)	ISP	NAm	ARHE-T2	
Arrowhead Marsh East (17c.2)	ISP	NAm	ARHE-T2	
MLK Shoreline (17d)	-	-	-	Split into five sub-areas in 2011
Airport Channel - Fan Shore (17d.1)	none	none	none	Insufficient habitat (2017)
Airport Channel - MLK Shoreline (17d.2)	none	none	none	Insufficient habitat (2017)
East Creek - MLK Shoreline (17d.3)	none	none	none	Insufficient habitat (2017)
MLK Regional Shoreline - Damon (17d.4)	ISP	NAm	MLKS-T1	
Elmhurst Creek - MLK Shoreline (17d.5)	ISP	NAm*	MLKS-T1	*surveyed from adjacent site
San Leandro Creek (17e)	-	-	-	Split into two sub-areas in 2011
San Leandro Creek North (17e.1)	ISP	NAm*	MLKR-T1	*surveyed from adjacent site
San Leandro Creek South (17e.2)	ISP	NAm*	MLKR-T1	*surveyed from adjacent site
Oakland Inner Harbor (17f)	none	none	none	Insufficient habitat (2017)
Coast Guard Is (17g)	none	none	none	Insufficient habitat (2017)
MLK New Marsh (17h)	ISP	NAm	MLKR-T1	
Coliseum Channels (17i)	none	none	none	Insufficient habitat (2017)

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Fan Marsh (17j)	-	-	-	Split into two sub-areas in 2019
Fan Marsh Wings (17j.1)	ISP	NAm	FANM-T1	
Fan Marsh Main (17j.2)	ISP	NAm	FANM-T1	
Airport Channel (17k)	none	none	none	Insufficient habitat (2017)
Doolittle Pond (17l)	none	none	none	Insufficient habitat (2017)
Alameda Island - East (17m)	none	none	none	Insufficient habitat (2017)
Area 18: Colma Creek/ San Bruno in San Francisco Peninsula Region				
Colma Creek (18a)	none	none	none	Insufficient habitat (2017)
Navigable Slough (18b)	none	none	none	Insufficient habitat (2017)
Old Marina (18c)	none	none	none	Insufficient habitat (2014)
Inner Harbor (18d)	none	none	none	Insufficient habitat (2014)
Sam Trans Peninsula (18e)	none	none	none	Insufficient habitat (2017)
Confluence Marsh (18f)	none	none	none	Insufficient habitat (2017)
San Bruno Marsh (18g)	none	none	none	Insufficient habitat (2017)
San Bruno Creek (18h)	none	none	none	Insufficient habitat (2017)
Area 19: West San Francisco Bay in San Francisco Peninsula Region				
Brisbane Lagoon (19a)	OEI	G	n/a	surveyed by OEI for CalTrain
Sierra Point (19b)	none	none	none	Insufficient habitat (2015)
Oyster Cove (19c)	none	none	none	Insufficient habitat (2016)
Oyster Point Marina (19d)	none	none	none	Insufficient habitat (2015)
Oyster Point Park (19e)	none	none	none	Insufficient habitat (2016)
Point San Bruno (19f)	none	none	none	Insufficient habitat (2017)
Seaplane Harbor (19g)	none	none	none	Insufficient habitat (2017)
SFO (19h)	ISP	NAm	SFO-T1	
Mills Creek Mouth (19i)	none	none	none	Insufficient habitat (2017)
Easton Creek Mouth (19j)	none	none	none	Insufficient habitat (2017)
Sanchez Marsh (19k)	None	None	None	Insufficient habitat (2019)
Burlingame Lagoon (19l)	none	none	none	Insufficient habitat (2017)
Fisherman's Park (19m)	none	none	none	Insufficient habitat (2014)
Coyote Point Marina (19n)	none	none	none	Insufficient habitat (2017)
San Mateo Creek (19o)	none	none	none	Insufficient habitat (2017)
Seal Slough (19p)	-	-	-	Split into two sub-areas in 2011
Seal Slough Central (19p.1)	ISP	NAm	SEAL-T1	
Seal Slough Peripheral (19p.2)	ISP	NAm	SEAL-T1	
Foster City (19q)	none	none	none	Insufficient habitat (2017)
Anza Lagoon (19r)	none	none	none	Insufficient habitat (2016)
Maple Street Channel (19s)	none	none	none	Insufficient habitat (2017)
Area 20: San Leandro / Hayward Shoreline in Hayward Region				
Oyster Bay Regional Shoreline (20a)	none	none	none	Insufficient habitat (2017)
Oakland Golf Links (20b)	none	none	none	Insufficient habitat (2017)
Dog Bone Marsh (20c)	ISP	NAm	NORT-T1	
Citation Marsh (20d)	-	-	-	Split into three sub-areas in 2011 & 2018
Citation Marsh South (20d.1)	ISP	NAm	CITA-T1	
Citation Marsh Upper (20d.2a)	ISP	NAm	CITA-T1	Split in renegotiated in 2020
Citation Marsh Central (20d.2b)	ISP	NAm	CITA-T1	Split in renegotiated in 2020
East Marsh (20e)	ISP	NAm*	SLRZ-T1	*surveyed from adjacent site
North Marsh (20f)	ISP	NAm	NORT-T1	

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Bunker Marsh (20g)	ISP	NAm	BUNK-T1	
San Lorenzo Creek (20h)	-	-	-	Split into two sub-areas in 2012
San Lorenzo Creek North (20h.1)	ISP	NAm	SLRZ-T1	
San Lorenzo Creek South (20h.2)	ISP	NAm	SLRZ-T1	
Bockman Channel (20i)	none	none	none	Insufficient habitat (2017)
Sulphur Creek (20j)	none	none	none	Insufficient habitat (2017)
Hayward Landing (20k)	none	none	none	Insufficient habitat (2017)
Johnson's Landing (20l)	none	none	none	Insufficient habitat (2017)
Cogswell - Sec A (20m)	ISP	NAm	COGS-T1	
Cogswell - Sec B (20n)	-	-	-	Split into three sub-areas in 2018
Cogswell - Sec B Bayfront (20n.1)	ISP	NAm	COGS-T3	
Cogswell - Sec B South (20n.2)	ISP	NAm	COGS-T3	
Cogswell - Sec B Main (20n.3)	ISP	NAm	COGS-T3	
Cogswell - Sec C (20o)	ISP	NAm	COGS-T2	
Hayward Shoreline Outliers (20p)	none	none	none	Insufficient habitat (2017)
San Leandro Shoreline Outliers (20q)	none	none	none	Insufficient habitat (2017)
Oakland Airport (20r)	none	none	none	
HARD Marsh (20s)	ISP	NAm	HARD-T1	
San Leandro Marina (20t)	none	none	none	Insufficient habitat (2017)
Estudillo Creek Channel (20u)	none	none	none	Insufficient habitat (2017)
Hayward Landing Canal (20v)	none	none	none	Insufficient habitat (2017)
Triangle Marsh - Hayward (20w)	ISP	NAm	TRMA-T1	
Area 21: Ideal Marsh in Union City Region				
Ideal Marsh - North (21a)	DENWR	NAm	IMAN-T1	
Ideal Marsh - South (21b)	none	none	IMAS-T1	Not surveyed
Area 22: Two Points Complex in Bay Bridge North Region				
Wildcat Marsh (22a)	ISP	NAm	WIMA	Typically surveyed by PBCS
San Pablo Marsh (22b)	-	-	-	Split into two sub-areas in 2011
San Pablo Marsh East (22b.1)	ISP	NAm	RIF	Typically surveyed by PBCS
San Pablo Marsh West (22b.2)	ISP	NAm	RIF	Typically surveyed by PBCS
Rheem Creek Area (22c)	ISP	NAm	RCRA-T1	
Stege Marsh (22d)	-	-	-	Grouped into one sub-area by ISP control program
Stege Marsh (22d)	ARA	NAm	STEG-T1	Typically surveyed by ISP
Meeker Slough (22d)	ARA	NAm	STEG-T1	Typically surveyed by ISP
Hoffman Marsh (22e)	ISP	NAm	STEG-T1	
Albany Shoreline (22f)	none	none	none	Insufficient habitat (2017)
Area 23: Marin Outliers in Marin and Petaluma Regions				
Brickyard Cove (23a)	none	none	none	Insufficient habitat (2017)
Beach Drive (23b)	none	none	none	Insufficient habitat (2017)
Loch Lomond Marina (23c)	none	none	none	Insufficient habitat (2017)
San Rafael Canal Mouth (23d)	-	-	-	Split into two sub-areas in 2011
San Rafael Canal Mouth East (23d.1)	ISP	NAm	PIPK-T1	
San Rafael Canal Mouth West (23d.2)	ISP	NAm	PIPK-T1	

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Muzzi and Martas Marsh (23e)	-	-	-	Grouped into one sub-area by ISP control program
Martas Marsh (23e)	ISP	NAm	MUZZ	Typically surveyed by PBCS
San Clemente Creek (23e)	ISP	NAm	MUZZ	Typically surveyed by PBCS
Muzzi Marsh (23e)	ISP	NAm	MUZZ	Typically surveyed by PBCS
Paradise Cay (23f)	none	none	none	Insufficient habitat (2017)
Greenwood Beach (23g)	none	none	none	Insufficient habitat (2017)
Strawberry Point (23h)	none	none	none	Insufficient habitat (2017)
Strawberry Cove (23i)	none	none	none	Insufficient habitat (2017)
Bothin Marsh (23j)	PCBS	NAm	THF-T1	
Sausalito (23k)	none	none	none	Insufficient habitat (2015)
Starkweather Park (23l)	none	none	none	Insufficient habitat (2020)
Novato (23m)	-	-	-	Grouped into one sub-area by ISP control program
Hamilton South (23m)	PBCS	NAm	MIN-T1	
Mitchell Fragment (23m)	none	none	none	Not surveyed
Santa Venetia (23m)	PBCS	NAm	STVE-T1	
Gallinas Creek North (23m)	none	none	none	Not surveyed
McInnis Marsh (23m)	PBCS	NAm	MIM-T1	
Novato Creek Mouth (23m)	none	none	none	Not surveyed
Gallinas Creek South (23m)	PBCS	NAm	GACM-T1	Not surveyed
Hamilton North (23m)	none	none	none	Not surveyed
Novato Creek Mid Reach (23m)	none	none	none	Not surveyed
Triangle Marsh - Marin (23n)	none	None	none	Insufficient habitat (2020)
China Camp (23o)	PBCS	NAm	CCM-T1	
Petaluma River - Upper (24a)	PBCS	NAm	PDF-T1	
Grey's Field (24b)	PBCS	NAm	GRFI-T1	
Area 24: Petaluma River in Petaluma Region				
Petaluma Marsh (24c)	-	-	-	Grouped into one sub-area by ISP control program
Tule Slough (24c)	none	none	none	Not surveyed
False Slough (24c)	none	none	none	Not surveyed
Lakeville Marina (24c)	none	none	none	Not surveyed
Ellis Creek (24c)	PBCS	NAm*	GRFI-T1	*surveyed from adjacent site
Petaluma Marsh Expansion Project (24c)	none	none	none	Not surveyed
San Antonio Creek (E) (24c)	none	none	none	Not surveyed
Petaluma River (C) (24c)	none	none	none	Not surveyed
San Antonio Creek (A) (24c)	none	none	none	Not surveyed
Mira Monte Slough (B) (24c)	none	none	none	Not surveyed
Mud Hen Slough (D) (24c)	none	none	none	Not surveyed
Schultz Slough (24c)	none	none	none	Not surveyed
Gambini Marsh (24c)	none	none	none	Not surveyed
Woloki Slough (24c)	none	none	none	Not surveyed

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
Lower Petaluma River (24d)	-	-	-	Grouped into one sub-area by ISP control program
Day Island Wildlife Area (24d)	none	none	none	Not surveyed
Petaluma River - West Side (24d)	PBCS	NAm	GRPT-T1	
Carl's Marsh (24d)	none	none	none	Not surveyed
Green Point Area Marshes (24d)	PBCS	NAm	GRPT-T1	
Sonoma Marina (24d)	PBCS	NAm*	SBR-T1	*surveyed from adjacent site
Petaluma River - Lower (24d)	none	none	none	Not surveyed
Black John Slough North (24d)	none	none	none	Not surveyed
Black John Slough A (24d)	none	none	none	Not surveyed
Bahia Channel (24d)	none	none	none	Not surveyed
Black John Slough B (24d)	none	none	none	Not surveyed
Area 25: Outer Coast in Outer Coast Region				
Tom's Point, Tomales (25a)	none	none	none	Not surveyed
Limantour Estero (25b)	none	none	none	Not surveyed
Drakes Estero (25c)	none	none	none	Not surveyed
Bolinas Lagoon - North (25d)	none	none	none	Not surveyed
Bolinas Lagoon - South (25e)	none	none	none	Not surveyed
Area 26: North San Pablo Bay in Petaluma and Vallejo Regions				
Napa River (26a)	-	-	-	Grouped into one sub-area by ISP control program
Coon Island (26a)	PBCS	NAm	COIS-T1	
Fly Bay (26a)	CDFW	NAm	no data	
Napa Tract Salt Pond 5 (26a)	CDFW	NAm	no data	
Napa Tract Salt Pond 4 (26a)	CDFW	NAm	no data	
White Slough Marsh (26a)	none	none	none	Not surveyed
Fagan Slough (26a)	PBCS	NAm	FAGA-T1	
Pond 2A Restoration (26a)	none	none	none	Not surveyed
Napa Centennial Marsh (26a)	CDFW	NAm	no data	
Bull Island (26a)	none	none	none	Not surveyed
Napa Plant Site Restoration (26a)	none	none	none	Not surveyed
Skaggs Island Bridge / Napa Slough (26a)	none	none	none	Not surveyed
Dutchman Slough Mouth (26a)	none	none	none	Not surveyed
Napa Tract Salt Pond 7 (26a)	none	none	none	Not surveyed
Napa Tract Intake Pond 1A (26a)	none	none	none	Not surveyed
Hudeman Slough (26a)	none	none	none	Not surveyed
Napa Tract Intake Pond 1 (26a)	none	none	none	Not surveyed
Napa Tract Salt Pond 6A (26a)	none	none	none	Not surveyed
Napa Tract Salt Pond 6 (26a)	none	none	none	Not surveyed
Guadacanal Village (26a)	none	none	none	Not surveyed
Dutchman Slough (26a)	none	none	none	Not surveyed
Napa Tract Salt Pond 2 (26a)	none	none	none	Not surveyed
Napa Tract Salt Pond 3 (26a)	none	none	none	Not surveyed
Napa Tract Salt Pond 7A (26a)	none	none	none	Not surveyed
China Slough (26a)	none	none	none	Not surveyed
Devil's Slough (26a)	none	none	none	Not surveyed
Cullinan Ranch (26a)	none	none	none	Not surveyed

Sub-area Name (ID)	Survey Organization	Survey Type	Transect	Notes
San Pablo Bay NWR Shoreline (26b)	none	none	none	Not surveyed
Sonoma Creek (26c)	SPBNWR	NAm	SC-T1,T2	
Sonoma Baylands (26d)	-	-	-	Grouped into one sub-area by ISP control program
Lower Tubbs Island (26d)	SPBNWR	NAm	LTI-T1,T2,T3	
Tolay Creek (26d)	SPBNWR	NAm	TC-T1	
Tubbs Island Restoration (26d)	SPBNWR	NAm	TS-T1	
Petaluma River Mouth (26d)	PBCS	NAm	RMA	
Sonoma Baylands Restoration (26d)	PBCS	NAm	SBR-T1	
Sonoma Baylands East (26d)	SPBNWR	NAm	SMW-T1,T2	
Area 27: Suisun Marshes in Suisun Region				
Point Buckler (27a)	none	none	none	
MOTCO Islands (27b)	OEI	NAm	RYNW-T1, ROEI-T1	Roe and Ryer Islands
Honker Bay (27c)	none	none	none	

Appendix II: 2020 Survey Station Coordinates in UTM (NAD83, Zone 10)

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Appendix II: Survey stations by site and transect ID. Geographic coordinates are in UTM (NAD83, Zone10).

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
Marin Region					
CMCM-T1	04j	CMC - Mouth	CMCM12	542958	4199629
CMCM-T1	04j	CMC - Mouth	CMCM13	543185	4199682
CMCM-T1	04j	CMC - Mouth	CMCM14	542814	4199523
CMCM-T1	04j	CMC - Mouth	CMCM15	543007	4199427
CMCM-T1	04j	CMC - Mouth	CMCM16	543234	4199447
HEER-T1	04a	CMC Marsh Reserve	CEF01	543102	4199205
HEER-T1	04a	CMC Marsh Reserve	CEF03	543330	4199066
HEER-T1	04a	CMC Marsh Reserve	CEF05	543015	4198956
HEER-T1	04a	CMC Marsh Reserve	CEF13	543351	4199248
HEER-T1	04a	CMC Marsh Reserve	CEF16	542823	4199275
HEER-T1	04a	CMC Marsh Reserve	CEF20	543437	4199425
MUZZ-T1	23e	Muzzi Marsh	MUZZ02	543270	4198714
MUZZ-T1	23e	Muzzi Marsh	MUZZ04	543198	4198296
MUZZ-T1	23e	Muzzi Marsh	MUZZ06	543162	4198086
MUZZ-T1	23e	Muzzi Marsh	MUZZ08	543187	4197605
MUZZ-T1	23e	Muzzi Marsh	MUZZ09	543380	4197655
MUZZ-T1	23e	Muzzi Marsh	MUZZ10	543569	4197718
MUZZ-T1	23e	Muzzi Marsh	MUZZ11	543740	4197849
MUZZ-T1	23e	Muzzi Marsh	MUZZ12	543657	4197566
PIPE-T1	04c	Piper Park - East	PIF03	541478	4199615
PIPE-T1	04c	Piper Park - East	PIPE01	541484	4199149
PIPE-T1	04c	Piper Park - East	PIPE02	541459	4199364
PIPE-T1	04d	Piper Park - West	PIPE04	541308	4199419
PIPE-T1	04d	Piper Park - West	PIPE05	541136	4199313
PIPK-T1	9	Pickleweed Park	PIPK01	544265	4202286
PIPK-T1	9	Pickleweed Park	PIPK02	544239	4202484
PIPK-T1	9	Pickleweed Park	PIPK03	544183	4202641
PIPK-T1	23d	San Rafael Canal Mouth	SRCM01	544244	4202876
PIPK-T1	23d	San Rafael Canal Mouth	SRCM02	544370	4202758
San Francisco Peninsula Region					
HEHE-T1	12b	Pier 98/Heron's Head	HEHE01	555235	4176946
HEHE-T1	12b	Pier 98/Heron's Head	HEHE02	555429	4176923
SEAL-T1	19p	Seal Slough	SEAL01	562560	4158484
SEAL-T1	19p	Seal Slough	SEAL03	562728	4158450
SEAL-T1	19p	Seal Slough	SEAL04	562857	4158548
SEAL-T1	19p	Seal Slough	SEAL05	562861	4158725
SEAL-T1	19p	Seal Slough	SEAL07	562432	4158448
SFO-T1	19h	SFO	SFO04	555438	4163237
SFO-T1	19h	SFO	SFO05	555203	4162889
SFO-T1	19h	SFO	SFO06	555111	4162711
SFO-T1	19h	SFO	SFO07	555019	4162530

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
San Mateo Region					
BELM-T1	02a	Belmont Slough	BELM01	566369	4156426
BELM-T1	02a	Belmont Slough	BELM02	566069	4156168
BELM-T1	02a	Belmont Slough	BELM03	565966	4155996
BELM-T1	02a	Belmont Slough	BELM04	565882	4155814
BELM-T1	02a	Belmont Slough	BELM05	565895	4155614
BELM-T1	02a	Belmont Slough	BELM06	565938	4155419
BELM-T1	02a	Belmont Slough	BELM07	566028	4155239
BELM-T1	02a	Belmont Slough	BELM08	565828	4155213
CORK-T1	02b	Corkscrew Slough	CORK01	569367	4153611
CORK-T1	02b	Corkscrew Slough	CORK02a	569244	4153305
CORK-T1	02b	Corkscrew Slough	CORK03	568904	4152988
CORK-T1	02b	Corkscrew Slough	CORK04	568894	4152635
CORK-T1	02b	Corkscrew Slough	CORK05	568642	4152904
CORK-T1	02b	Corkscrew Slough	CORK06	568356	4153005
GRIN-T1	02f	Greco Island - North	GRIN11	570647	4153106
GRIN-T1	02f	Greco Island - North	GRIN12	570811	4152993
GRIN-T1	02f	Greco Island - North	GRIN13	570976	4152877
GRIN-T1	02f	Greco Island - North	GRIN14	571140	4152762
GRIN-T1	02f	Greco Island - North	GRIN15	571306	4152647
GRIN-T1	02f	Greco Island - North	GRIN16	571471	4152533
GRIN-T1	02f	Greco Island - North	GRIN17	571635	4152418
GRIN-T1	02f	Greco Island - North	GRIN18	571800	4152305
GRIS-T1	02h	Greco Island - South	GRIS01	573018	4150394
GRIS-T1	02h	Greco Island - South	GRIS02	573016	4150596
GRIS-T1	02h	Greco Island - South	GRIS03	573015	4150799
GRIS-T1	02h	Greco Island - South	GRIS04	573014	4150998
GRIS-T1	02h	Greco Island - South	GRIS05	572969	4151193
GRIS-T1	02h	Greco Island - South	GRIS06	572825	4151345
IBI-T1	02l	Inner Bair Island Restoration	IBI11	567713	4150454
IBI-T1	02l	Inner Bair Island Restoration	IBI13	567298	4150636
IBI-T1	02l	Inner Bair Island Restoration	IBI15	567004	4150939
IBI-T1	02l	Inner Bair Island Restoration	IBI17	566763	4151267
MBE-T1	02k	Middle Bair N	MBE01	569714	4153286
MBE-T1	02k	Middle Bair N	MBE02	569544	4153178
MBE-T1	02k	Middle Bair N	MBE03	569366	4153061
MBE-T1	02k	Middle Bair N	MBE04	569249	4152883
MBE-T1	02k	Middle Bair N	MBE05	569153	4152697
MBE-T1	02k	Middle Bair SE	MBSE02	568726	4151546
MBE-T1	02k	Middle Bair SE	MBSE04	568800	4151947
MBE-T1	02k	Middle Bair SE	MBSE06	568955	4152326
OBEN-T1	02c	B2 North Quadrant	OBE12	569256	4154869
OBEN-T1	02c	B2 North Quadrant	OBE14	569206	4154429
OBEN-T1	02c	B2 North Quadrant	OBE16	568775	4154924
OBEN-T2	02c	B2 North Quadrant	OBE06	569311	4154036
OBEN-T2	02c	B2 North Quadrant	OBE09	568814	4154381
OBEN-T2	02c	B2 North Quadrant	OBE11	568471	4154620
OBEN-T2	02c	B2 North Quadrant	OBE19	568408	4155098

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
San Mateo Region (continued)					
OBES-T1	02d	B2 South Quadrant	OBE04	569963	4154250
OBES-T1	02d	B2 South Quadrant	OBE22	569611	4154402
OBES-T1	02d	B2 South Quadrant	OBE23	569663	4154619
OBES-T1	02d	B2 South Quadrant	OBE25	569779	4155053
OBES-T1	02d	B2 South Quadrant	OBE26	569843	4154667
OBES-T1	02d	B2 South Quadrant	OBE27	569990	4154545
OBES-T1	02d	B2 South Quadrant	OBES24	569733	4154871
RAV-T1	02i	Ravenswood Slough	RAV02	575826	4149650
RAV-T1	02i	Ravenswood Slough	RAV03	575665	4149768
RAV-T1	02i	Ravenswood Slough	RAV04	575468	4149813
RAV-T1	02i	Ravenswood Slough	RAV05	575260	4149863
RAV-T1	02i	Ravenswood Slough	RAV06	574884	4150110
RAV-T1	02i	Ravenswood Slough	RAV09	574950	4149885
RAV-T1	02i	Ravenswood Slough	RAV10	574806	4150724
RESH-T2	02b	Steinberger Slough	RESH13	567756	4154757
RESH-T2	02b	Steinberger Slough	RESH14	567816	4154983
RESH-T2	02b	Steinberger Slough	RESH15	567780	4154559
RESH-T2	02b	Steinberger Slough	RESH16	567956	4155133
RESH-T2	02b	Steinberger Slough	RESH17	568105	4155282
RESH-T2	02b	Steinberger Slough	RESH18	568239	4155444
WPSS-T1	02g	West Point Slough - SW / E	WPSS09	572707	4150059
WPSS-T1	02g	West Point Slough - SW / E	WPSS10	572706	4149686
WPSS-T1	02g	West Point Slough - SW / E	WPSS11	572704	4149455
WPSS-T1	02g	West Point Slough - SW / E	WPSS12	572561	4149237
Dumbarton South Region					
A21-T1	05i	Island Ponds - A21	A21-1	589676	4146880
A21-T1	05i	Island Ponds - A21	A21-2	589848	4146987
A21-T1	05i	Island Ponds - A21	A21-3	590549	4147430
A21-T1	05i	Island Ponds - A21	A21-4	589991	4147127
A21-T1	05i	Island Ponds - A21	A21-5	590110	4147286
A21-T1	05i	Island Ponds - A21	A21-6	590276	4147430
A21-T1	05i	Island Ponds - A21	A21-7	590658	4147236
A21-T1	05i	Island Ponds - A21	A21-8	590646	4147026
ALSL-T2	15a	Alviso Slough	MAL01	586761	4146451
ALSL-T2	15a	Alviso Slough	MAL02	586668	4146281
ALSL-T2	15a	Alviso Slough	MAL04	586898	4145918
ALSL-T2	15a	Alviso Slough	MAL06	586942	4145527
ALSL-T2	15a	Alviso Slough	MAL07	587021	4146548
ALSL-T2	15a	Alviso Slough	MAL08	587328	4146607
ALSL-T2	15a	Alviso Slough	MAL09	587646	4146656
ALSL-T2	15a	Alviso Slough	MAL10	587905	4146704
CAPT-T1	05a	Calaveras Point	CAPT08	586510	4147007
CAPT-T1	05a	Calaveras Point	CAPT09	586281	4146933
CAPT-T1	05a	Calaveras Point	CAPT10	586088	4146915
CAPT-T1	05a	Calaveras Point	CAPT11	585889	4146857
CAPT-T1	05a	Calaveras Point	CAPT12	585689	4146818
CAPT-T1	05a	Calaveras Point	CAPT13	585492	4146774
CAPT-T1	05a	Calaveras Point	CAPT14a	585333	4146717

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
Dumbarton South Region (continued)					
COLA-T1	16	Cooley Landing	COLA05	576891	4148770
COLA-T1	16	Cooley Landing	COLA06	576956	4148944
COLA-T1	16	Cooley Landing	COLA07	577129	4149051
COLA-T1	16	Cooley Landing	COLA08	577293	4149164
COLA-T1	16	Cooley Landing	COLA09	576775	4148568
COLA-T1	16	Cooley Landing	COLA10	576825	4148373
COLA-T1	16	Cooley Landing	COLA11	576961	4148238
COLA-T1	16	Cooley Landing	COLA12	577112	4148090
GUSL-T1	15a	Guadalupe Slough	GUSL02	587891	4143002
GUSL-T1	15a	Guadalupe Slough	GUSL03	587773	4143515
GUSL-T1	15a	Guadalupe Slough	GUSL04	587365	4143596
GUSL-T1	15a	Guadalupe Slough	GUSL05	586585	4143375
GUSL-T1	15a	Guadalupe Slough	GUSL06	585318	4144262
GUSL-T1	15a	Guadalupe Slough	GUSL07	585019	4144717
GUSL-T1	15a	Guadalupe Slough	GUSL08	585795	4144766
GUSL-T1	15a	Guadalupe Slough	GUSL09	585184	4144825
MOWN-T1	05a	Mowry Marsh North	MOSL10	581198	4151329
MOWN-T1	05a	Mowry Marsh North	MOSL12	581587	4151341
MOWN-T1	05a	Mowry Marsh North	MOSL14	581968	4151220
MOWN-T1	05a	Mowry Marsh North	MOSL16	582349	4151098
MOWN-T1	05a	Mowry Marsh North	MOSL18	582734	4150973
MOWN-T1	05a	Mowry Marsh North	MOSL20	583117	4150850
MOWN-T1	05a	Mowry Marsh North	MOSL22	583484	4150697
MOWN-T1	05a	Mowry Marsh North	MOSL24	583816	4150474
MVSL-T1	15a	Charleston Slough	CHSL01	580426	4145106
MVSL-T1	15a	Charleston Slough	CHSL03	580657	4145153
MVSL-T1	15a	Charleston Slough	CHSL04	580414	4144826
MVSL-T1	15a	Mountain View Slough	MVSL04	581043	4145153
MVSL-T1	15a	Mountain View Slough	MVSL05	581422	4145011
NEWS-T1	05c	Newark Slough	NEW02	581705	4154094
NEWS-T1	05c	Newark Slough	NEW03	581878	4153982
NEWS-T1	05c	Newark Slough	NEW04	582059	4153878
NEWS-T1	05c	Newark Slough	NEW05	582040	4153642
NEWS-T1	05c	Newark Slough	NEW06	582159	4153474
NEWS-T1	05c	Newark Slough	NEW07	582333	4153544
NEWS-T1	05c	Newark Slough	NEW09	581635	4154254
PAB	8	Palo Alto Baylands	PAB07	578542	4146295
PAB	8	Palo Alto Baylands	PAB14	578746	4146217
PAB	8	Palo Alto Baylands	PAB16	579129	4146185
PAB	8	Palo Alto Baylands	PAB17	579308	4146093
PAB	8	Palo Alto Baylands	PAB18	579124	4146384
PAB	8	Palo Alto Baylands	PAB19	578494	4146491
PAB	8	Palo Alto Baylands	PAB20	578214	4146646
PLCM-T1	05h	Plummer Creek Mitigation	PLCM01	583615	4152372
PLCM-T1	05h	Plummer Creek Mitigation	PLCM02	583484	4152202
PLCM-T1	05h	Plummer Creek Mitigation	PLCM03	583517	4152021

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
Dumbarton South Region (continued)					
STEV-T1	15a	Stevens Creek to Long Point	LONG09	582630	4144724
STEV-T1	15a	Stevens Creek to Long Point	LONG10	582401	4144385
STEV-T1	15a	Stevens Creek to Long Point	LONG11	582369	4144019
STEV-T1	15c	Stevens Creek	STEV01	582431	4143425
STEV-T1	15c	Stevens Creek	STEV02	582421	4143224
Union City Region					
AFCC-T1	01a	AFCC - Pond 3	AFCC02	576726	4157943
AFCC-T1	01f	AFCC - Pond 3	AFCC04	576913	4158254
AFCC-T1	01f	AFCC - Pond 3	AFCC06	577134	4158519
AFCC-T2	01f	AFCC - Pond 3	AFCC08	577453	4158695
AFCC-T2	01f	AFCC - Pond 3	AFCC10	577812	4158729
AFCC-T2	01f	AFCC - Pond 3	AFCC12	578156	4158628
AFCC-T2	01f	AFCC - Pond 3	AFCC14	578481	4158477
AFCC-T4	01c	AFCC - Upper	AFCC19	580009	4157650
AFCC-T4	01c	AFCC - Upper	AFCC21	580393	4157555
AFCC-T4	01c	AFCC - Upper	AFCC23	580793	4157508
AFCC-T4	01c	AFCC - Upper	AFCC25	581190	4157474
AFCC-T4	01c	AFCC - Upper	AFCC27	581585	4157557
AFCC-T4	01c	AFCC - Upper	AFCC29	581966	4157673
AFCC-T4	01c	AFCC - Upper	AFCC31	582309	4157863
AFCC-T4	01d	AFCC - to I-880	AFCC33	582544	4158195
EDEN-T1	13j	Eden Landing - Mt Eden Creek	EDEN01	576480	4163098
EDEN-T1	13j	Eden Landing - Mt Eden Creek	EDEN02	576489	4162896
EDEN-T1	13j	Eden Landing - Mt Eden Creek	EDEN03	576430	4162704
EDEN-T1	13j	Eden Landing - Mt Eden Creek	EDEN04	576379	4162512
EDEN-T1	13j	Eden Landing - Mt Eden Creek	EDEN05	576179	4162480
EDEN-T1	13j	Eden Landing - Mt Eden Creek	EDEN06	575980	4162529
EDEN-T1	13j	Eden Landing - Mt Eden Creek	WTN11	575778	4162563
ELRS-T1	13k	Eden Landing Reserve - South	ELRS01	578202	4163533
ELRS-T1	13k	Eden Landing Reserve - South	ELRS02	578057	4163383
ELRS-T1	13k	Eden Landing Reserve - South	ELRS03	577994	4163189
ELRS-T1	13k	Eden Landing Reserve - South	ELRS04	578001	4162988
ELRS-T1	13k	Eden Landing Reserve - South	ELRS05	578422	4163525
ELRS-T1	13k	Eden Landing Reserve - South	ELRS06	578540	4163362
ELRS-T1	13k	Eden Landing Reserve - South	ELRS07	578657	4163200
ELRS-T1	13k	Eden Landing Reserve - South	ELRS08	578777	4163039
OAC-T2	13a	OAC - North Bank	ALCK10	577579	4161047
OAC-T2	13a	OAC - North Bank	ALCK11	577774	4161008
OAC-T2	13a	OAC - North Bank	ALCK12	577954	4160949
OAC-T2	13a	OAC - North Bank	ALCK13	578133	4160880
OAC-T2	13a	OAC - North Bank	ALCK14	578290	4160821
OAC-T2	13a	OAC - North Bank	ALCK15	578491	4160791
OAC-T2	13a	OAC - North Bank	ALCK16	578684	4160842
OAC-T2	13a	OAC - North Bank	ALCK17	578837	4160946
OAC-T2	13a	OAC - North Bank	ALCK18	578983	4161058

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
		Union City Region (continued)			
OAC-T3	13a	OAC - North Bank	ALCK19	579146	4161152
OAC-T3	13a	OAC - North Bank	ALCK20	579342	4161159
OAC-T3	13a	OAC - North Bank	ALCK21	579538	4161155
OAC-T3	13a	OAC - North Bank	ALCK22	579723	4161150
OAC-T3	13a	OAC - North Bank	ALCK23	579901	4161149
OAC-T3	13a	OAC - North Bank	ALCK24	580056	4161217
OAC-T3	13a	OAC - North Bank	ALCK25	580098	4161389
OAC-T3	13a	OAC - North Bank	ALCK26	580095	4161571
OAC-T3	13a	OAC - North Bank	ALCK27	580088	4161744
WTN-T1	13d	Whale's Tail - North	WTN10	575754	4162376
WTN-T1	13d	Whale's Tail - North	WTN4	575865	4161341
WTN-T1	13d	Whale's Tail - North	WTN5	575886	4161530
WTN-T1	13d	Whale's Tail - North	WTN6	575813	4161676
WTN-T1	13d	Whale's Tail - North	WTN7	575771	4161849
WTN-T1	13d	Whale's Tail - North	WTN8	575767	4162027
WTN-T1	13d	Whale's Tail - North	WTN9	575762	4162212
WTS-T1	13e	Whale's Tail - South	WTS22	575754	4159900
WTS-T1	13e	Whale's Tail - South	WTS23	575792	4160057
WTS-T1	13e	Whale's Tail - South	WTS24	575813	4160265
WTS-T1	13e	Whale's Tail - South	WTS28	575489	4161055
WTS-T1	13e	Whale's Tail - South	WTS29	575688	4161029
WTS-T1	13e	Whale's Tail - South	WTS30	575854	4160992
WTS-T1	13e	Whale's Tail - South	WTS31	575960	4160824
WTS-T1	13e	Whale's Tail - South	WTS32	575969	4160626
WTS-T1	13e	Whale's Tail - South	WTS33	575857	4160461
		Hayward Region			
BUNK-T1	20g	Bunker Marsh	BUNK01	573456	4170331
BUNK-T1	20g	Bunker Marsh	BUNK02	573507	4170104
BUNK-T1	20g	Bunker Marsh	BUNK03	573561	4169912
BUNK-T1	20g	Bunker Marsh	BUNK04	573631	4169725
BUNK-T1	20f	Bunker Marsh	NORT08	573588	4170397
BUNK-T1	20h	Bunker Marsh	SLRZ01	573737	4169556
CITA-T1	20d	Citation Marsh	CITA01	573661	4170466
CITA-T1	20d	Citation Marsh	CITA02	573555	4170639
CITA-T1	20d	Citation Marsh	CITA03	573435	4170800
CITA-T1	20d	Citation Marsh	CITA04	573314	4170961
CITA-T1	20d	Citation Marsh	CITA05	573318	4171265
CITA-T1	20d	Citation Marsh	CITA06	573316	4171466
CITA-T1	20d	Citation Marsh	CITA07	573314	4171666
COGS-T2	20o	Cogswell - Sec C	COGS08	574984	4165788
COGS-T2	20o	Cogswell - Sec C	COGS09	575124	4165612
COGS-T2	20o	Cogswell - Sec C	COGS10	575138	4165412
COGS-T2	20o	Cogswell - Sec C	COGS11	575105	4165165
COGS-T2	20o	Cogswell - Sec C	COGS12	574791	4165248
COGS-T2	20o	Cogswell - Sec C	COGS13	574779	4165542
COGS-T2	20o	Cogswell - Sec C	COGS14	574781	4165740
COGS-T2	20o	Cogswell - Sec C	JOLA04	574909	4165104

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
Hayward Region (continued)					
COGS-T3	20n	Cogswell - Sec B	COGS15	575367	4165223
COGS-T3	20n	Cogswell - Sec B	COGS16	575572	4165228
COGS-T3	20n	Cogswell - Sec B	COGS17	575710	4165373
COGS-T3	20n	Cogswell - Sec B	COGS18	575620	4165538
COGS-T3	20n	Cogswell - Sec B	COGS19	575531	4165722
COGS-T3	20n	Cogswell - Sec B	COGS20	575436	4165912
COGS-T3	20n	Cogswell - Sec B	COGS21	575340	4166092
COGS-T4	20m	Cogswell - Sec A	COGS01	574738	4166041
COGS-T4	20m	Cogswell - Sec A	COGS02	574713	4166250
COGS-T4	20m	Cogswell - Sec A	COGS03	574862	4166363
COGS-T4	20m	Cogswell - Sec A	COGS04	575059	4166368
COGS-T4	20m	Cogswell - Sec A	COGS05	575218	4166336
COGS-T4	20m	Cogswell - Sec A	COGS06	575158	4166170
COGS-T4	20m	Cogswell - Sec A	COGS07	575043	4166004
COGS-T4	20w	Triangle Marsh - Hayward	TRMA02	574714	4166471
HARD-T1	20s	HARD Marsh	HARD01	575252	4164654
HARD-T1	20s	HARD Marsh	HARD02	575438	4164560
HARD-T1	20s	HARD Marsh	HARD03	575619	4164493
HARD-T1	20s	HARD Marsh	HARD04	575816	4164414
HARD-T1	20s	HARD Marsh	HARD05	575988	4164619
HARD-T1	20s	HARD Marsh	JOLA02	575064	4164736
NORT-T1	20c	Dogbone Marsh	DOGB01	572695	4170847
NORT-T1	20f	North Marsh	NORT01	573097	4171251
NORT-T1	20f	North Marsh	NORT02	572949	4171118
NORT-T1	20f	North Marsh	NORT03	572920	4170920
NORT-T1	20f	North Marsh	NORT04	572877	4170757
NORT-T1	20f	North Marsh	NORT05	572997	4170591
NORT-T1	20f	North Marsh	NORT06	573168	4170488
ORLW-T1	07a	Oro Loma - East	ORLW16	574840	4168558
ORLW-T1	07a	Oro Loma - East	ORLW17	574749	4168949
ORLW-T1	07a	Oro Loma - East	ORLW18	574912	4169047
ORLW-T1	07a	Oro Loma - East	ORLW19	575313	4169028
ORLW-T1	07a	Oro Loma - East	ORLW20	575474	4168815
ORLW-T1	07a	Oro Loma - East	ORLW21	575441	4168567
ORLW-T1	07a	Oro Loma - East	ORLW22	574705	4168708
ORLW-T3	07b	Oro Loma - West	ORLW01	574936	4168382
ORLW-T3	07b	Oro Loma - West	ORLW02	575023	4168204
ORLW-T3	07b	Oro Loma - West	ORLW03	574972	4168062
ORLW-T3	07b	Oro Loma - West	ORLW04	574771	4168057
ORLW-T3	07b	Oro Loma - West	ORLW05	574584	4168057
ORLW-T3	07b	Oro Loma - West	ORLW06	574382	4168054
ORLW-T3	07b	Oro Loma - West	ORLW07	574308	4168235
SLRZ-T1	20h	San Lorenzo Creek	SLRZ03	573943	4169633
SLRZ-T1	20h	San Lorenzo Creek	SLRZ04	574138	4169774
SLRZ-T1	20h	San Lorenzo Creek	SLRZ05	574277	4169889
SLRZ-T1	20h	San Lorenzo Creek	SLRZ07	573896	4169503
SLRZ-T1	20h	San Lorenzo Creek	SLRZ08	573955	4169323

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
San Leandro Bay Region					
ARHE-T2	17c	Arrowhead Marsh	ARHE01	569510	4177535
ARHE-T2	17c	Arrowhead Marsh	ARHE04	569262	4177549
ARHE-T2	17c	Arrowhead Marsh	ARHE05	569146	4177718
ARHE-T2	17c	Arrowhead Marsh	ARHE06	569063	4177898
FANM-T1	17j	Fan Marsh	FANM01	568582	4177668
FANM-T1	17j	Fan Marsh	FANM03	568635	4177820
FANM-T1	17j	Fan Marsh	FANM05	568410	4177818
MLKR-T1	17h	MLK New Marsh	MLKR01	569671	4177003
MLKR-T1	17h	MLK New Marsh	MLKR02	569622	4177196
MLKR-T1	17h	MLK New Marsh	MLKR03	569706	4177372
MLKR-T1	17h	MLK New Marsh	MLKR05	569837	4177413
MLKR-T1	17h	MLK New Marsh	MLKR06	569948	4177254
MLKR-T1	17h	MLK New Marsh	MLKR07	570046	4177104
MLKS-T1	17d	MLK Regional Shoreline - Damon	MLKS09	569336	4178901
MLKS-T1	17d	MLK Regional Shoreline - Damon	MLKS10	569456	4178741
MLKS-T1	17d	MLK Regional Shoreline - Damon	MLKS11	569515	4178546
Bay Bridge North Region					
EMCR-T1	06b	Emeryville Crescent - West	EMCR02	560250	4186896
EMCR-T1	06b	Emeryville Crescent - West	EMCR03	560177	4186720
EMCR-T1	06b	Emeryville Crescent - West	EMCR04	560358	4186670
EMCR-T1	06b	Emeryville Crescent - West	EMCR05	560565	4186723
EMCR-T1	06b	Emeryville Crescent - West	EMCR06	560742	4186744
EMCR-T1	06a	Emeryville Crescent - East	EMCR07	560954	4186746
PTPN-T1	10a	Whittel Marsh	PTPN01	556260	4206711
PTPN-T1	10a	Whittel Marsh	PTPN02	556460	4206771
PTPN-T1	10a	Whittel Marsh	PTPN03	556645	4206685
PTPN-T1	10a	Whittel Marsh	PTPN04	556830	4206771
RCRA-T1	22c	Rheem Creek Area	RCRA03	555821	4203918
RCRA-T1	22c	Rheem Creek Area	RCRA04	555895	4204106
RCRA-T1	22c	Rheem Creek Area	RCRA05	555917	4204343
RCRA-T1	22c	Rheem Creek Area	RCRA12	555741	4203735
RIF-T1	22b	San Pablo Marsh	RCRA06	555455	4203421
RIF-T1	22b	San Pablo Marsh	RIF03	555123	4202989
RIF-T1	22b	San Pablo Marsh	RIF09	554287	4203087
RIF-T1	22b	San Pablo Marsh	RIF10	554704	4203067
RIF-T1	22b	San Pablo Marsh	RIF11	555284	4203315
STEG-T1	22e	Hoffman Marsh	HOM06	559640	4195672
STEG-T1	22e	Hoffman Marsh	HOM07	559818	4195374
STEG-T1	22e	Hoffman Marsh	HOM08	560031	4195055

Transect Name	Sub-Area Code	Sub-Area Name	Point ID	X-coordinate	Y-coordinate
Bay Bridge North Region (continued)					
WIMA-T1	22a	Wildcat Marsh	WIMA02	553708	4201035
WIMA-T1	22a	Wildcat Marsh	WIMA03	553655	4201231
WIMA-T1	22a	Wildcat Marsh	WIMA04	553598	4201446
WIMA-T1	22a	Wildcat Marsh	WIMA05	553731	4201639
WIMA-T1	22a	Wildcat Marsh	WIMA06	553891	4201784
WIMA-T1	22a	Wildcat Marsh	WIMA07	554041	4201921
WIMA-T1	22a	Wildcat Marsh	WIMA08	554207	4202077
WIMA-T1	22a	Wildcat Marsh	WIMA09	553759	4200843

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Appendix III: 2020 OEI Survey Results for Each Round

The following tables describe the surveys conducted at each site including: the name of the project, the site name and ID code, the protocol used, whether broadcast was used, and the date, observer, temperature, and number of Ridgway's rails detected at the site for each round. A key to the tables is below.

Key to Protocol

- **NAm** = North American Protocol: 2-species active transect survey
- **G** = Protocol G: active stationary survey (consultant's survey)

Key to Observer

- **BO =** Brian Ort
- **JH** = Jeanne Hammond
- **JM** = Jen McBroom
- **KE** = Kevin Eng
- **LF** = Lindsay Faye
- **MA** = Melanie Anderson
- **ND** = Nate Deakers
- **PL** = Pim Laulikitnont
- **SG** = Simon Gunner
- **SC** = Stephanie Chen
- **TR** = Tobias Rohmer

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MARIN REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
CMC Marsh Reserve (04a)	NAm	1/24/2020	SC	8	0	16	2/24/2020	MA	17	4	23	3/20/2020	TR	5	2	16
Piper Park - East (04c)	NAm	1/24/2020	SG	9	2	2	2/24/2020	PL	19	1	2	3/20/2020	ND	5	2	4
Piper Park - West (04d)	NAm	1/24/2020	SG	9	2	5	2/24/2020	PL	19	1	4	3/20/2020	ND	5	2	6
CMC - Mouth North Bank (04j.1)	NAm	1/24/2020	MA	9	0	1	2/24/2020	ND	19	2	0	3/20/2020	PL	5	0	0
CMC - Mouth South Bank (04j.2)	NAm	1/24/2020	MA	9	0	0	2/24/2020	ND	19	2	0	3/20/2020	PL	5	0	1
Boardwalk No. 1 (04k)	NAm	1/24/2020	SG	9	2	1	2/24/2020	PL	19	1	0	3/20/2020	ND	5	2	0
Pickleweed Park (09)	NAm	1/24/2020	JH	18	1	0	2/18/2020	BO	14	1	0	3/10/2020	ND	6	2	0
San Rafael Canal East (23d.1)	NAm	1/24/2020	JH	18	1	0	2/18/2020	BO	14	1	0	3/10/2020	ND	6	2	0
San Rafael Canal West (23d.2)	NAm	1/24/2020	JH	18	1	0	2/18/2020	BO	14	1	0	3/10/2020	ND	6	2	0
San Clemente Creek (23e)	NAm	1/24/2020	TR	9	0	0	2/24/2020	SC	20	0	1	3/3/2020	KE	5	2	3
Martas Marsh (23e)	NAm	1/24/2020	TR	9	0	2	2/24/2020	SC	20	0	3	3/3/2020	KE	5	2	10
Muzzi Marsh (23e)	NAm	1/24/2020	TR	9	0	18	2/24/2020	SC	20	0	35	3/3/2020	KE	5	2	20

SAN FRANCISCO PENINSULA REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
Pier 98/Heron's Head (12b)	NAm	1/28/2020	TR	13	8	0	2/13/2020	PL	11	2	0	3/5/2020	PL	12	2	0
Brisbane Lagoon (19a)[1]	G[1]	1/20/2020	TR PL	13	0	0	2/4/2020	LD PL	12	3	0	2/19/2020	BO	16	0	0
SFO (19h)	NAm	1/24/2020	PL	9	1	0	2/11/2020	TR	9	3	0	3/4/2020	PL	18	8	0
Seal Slough Central (19p.1)	NAm	1/22/2020	PL	15	4	0	2/11/2020	LD	9	2	1	3/10/2020	LD	8	2	0
Seal Slough Peripheral (19p.2)	NAm	1/22/2020	PL	15	4	0	2/11/2020	LD	9	2	1	3/10/2020	LD	8	2	0

[1] Survey conducted by OEI for CalTrain. Fourth round conducted on 3/10/2020 by MA. No RIRA were detected.

SAN MATEO REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
Belmont Slough Mouth (02a.1a)	NAm	1/23/2020	PL	8	1	2	2/17/2020	LD	20	2	3	3/3/2020	KE	8	0	2
Belmont Slough South (02a.1b)	NAm	1/23/2020	PL	8	1	3	2/17/2020	LD	20	2	1	3/3/2020	KE	8	0	2
Belmont to Steinberger Slough (02a.2)	NAm	1/23/2020	PL	8	1	0	2/17/2020	LD	20	2	0	3/3/2020	KE	8	0	0
Corkscrew Slough (02b.1)[1]	NAm	1/30/2020	SC	17	2	6	2/20/2020	LD	10	1	8	-	-	-	-	-
Steinberger Slough (02b.2)	NAm	1/28/2020	TR	13	1	1	2/19/2020	TR	17	5	2	3/11/2020	LD	19	1	1
B2 North Quadrant West (02c.1a)[1]	NAm	2/6/2020	JM	6	1	14	3/5/2020	ND	12	2	0	-	-	-	-	-
B2 North Quadrant East (02c.1b)[1]	NAm	2/6/2020	JM	6	1	6	3/5/2020	ND	12	2	9	-	-	-	-	-
B2 North Quadrant South (02c.2)[1]	NAm	2/6/2020	LD	6	2	6	3/5/2020	MA	13	1	1	-	-	-	-	-
B2 South Quadrant West (02d.1a)[1]	NAm	1/30/2020	LD	17	5	1	2/20/2020	PL	7	2	2	-	-	-	-	-
B2 South Quadrant East (02d.1b)[1]	NAm	1/30/2020	LD	17	5	0	2/20/2020	PL	7	2	0	-	-	-	-	-
B2 South Quadrant 2 (02d.2)[1]	NAm	1/30/2020	LD	17	5	4	2/20/2020	PL	7	2	1	-	-	-	-	-
B2 South Quadrant 3 (02d.3)[1]	NAm	1/30/2020	LD	17	5	0	2/20/2020	PL	7	2	0	-	-	-	-	-
Greco Island - North (02f)[1]	NAm	1/30/2020	PL	16	2	11	2/20/2020	JM	6	0	9	-	-	-	-	-
West Point Slough - SW / E (02g)	NAm	1/27/2020	TR	13	3	1	2/21/2020	SG	20	1	3	3/12/2020	PL	8	2	3
Greco Island - South (02h)[1]	NAm	1/22/2020	TR	13	2	43	3/8/2020	PL	14	3	46	-	-	-	-	-
Ravenswood Slough (02i)	NAm	1/28/2020	PL	10	2	9	2/20/2020	TR	15	4	14	3/12/2020	LD	8	3	9
Middle Bair SE (02k)[1]	NAm	1/30/2020	TR	19	1	2	2/20/2020	MA	4	1	0	-	-	-	-	-
Middle Bair N (02k)[1]	NAm	1/30/2020	TR	19	1	12	2/20/2020	MA	4	1	18	-	-	-	-	-
Inner Bair Island Restoration (02l)	NAm	2/7/2020	TR	18	7	0	2/28/2020	PL	11	1	0	3/17/2020	BO	14	3	0

[1] Not surveyed round 3 due to COVID-19 Pandemic.

DUMBARTON SOUTH REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
Mowry Marsh North (05a.1)[1]	NAm	2/10/2020	ND	6	2	21	2/25/2020	SG	22	7	10	-	-	-	-	-
Calaveras Point (05a.2) [1]	NAm	2/19/2020	KE	5	3	5	1/31/2020	ND	19	2	5	-	-	-	-	-
Newark Slough East (05c.1) [1]	NAm	2/5/2020	BO	15	6	0	2/25/2020	JM	6	3	2	-	-	-	-	-
Newark Slough West (05c.2) [1]	NAm	2/5/2020	BO	15	6	6	2/25/2020	JM	6	3	5	-	-	-	-	-
Mayhew's Landing (05e) [1]	NAm	2/5/2020	SG	15	6	0	2/25/2020	BO	12	1	0	-	-	-	-	-
Coyote Creek - Mud Slough (05f) [1]	NAm	1/31/2020	SC	18	3	0	2/19/2020	PL	5	1	0	-	-	-	-	-
Cargill Pond (W Suites Hotel) (05g) [1]	NAm	2/5/2020	SG	15	6	0	2/25/2020	BO	12	1	0	-	-	-	-	-
Plummer Creek Mitigation (05h)	NAm	1/23/2020	BO	17	2	1	2/12/2020	LD	10	1	0	3/4/2020	KE	20	4	0
Island Ponds - A21 (05i) [1]	NAm	1/31/2020	SC	18	3	1	2/19/2020	PL	5	1	4	-	-	-	-	-
Palo Alto Baylands (08)	NAm	1/24/2020	KE	8	1	14	2/18/2020	LD	19	4	20	3/11/2020	TR	18	8	18
Palo Alto Harbor (08)	NAm	1/24/2020	JM	10	0	23	2/18/2020	TR	15	9	17	3/11/2020	PL	13	1	28
Mountain View Slough (15a.1)	NAm	2/4/2020	BO	11	3	0	2/18/2020	SC	18	7	0	3/5/2020	SC	16	5	0
Charleston Slough (15a.1)	NAm	2/4/2020	BO	11	3	3	2/18/2020	SC	18	7	2	3/5/2020	SC	16	5	4
Stevens Creek to Long Point (15a.2)	NAm	1/23/2020	ND	8	1	0	2/17/2020	MA	18	2	0	3/9/2020	TR	16	6	0
Guadalupe Slough (15a.3)	NAm	2/4/2020	ND	12	7	1	2/18/2020	MA	17	3	4	3/5/2020	JM	16	8	2
Alviso Slough (15a.4)	NAm	2/4/2020	SG	13	4	9	2/18/2020	ND	18	6	10	3/5/2020	KE	18	9	5
Stevens Creek (15c)	NAm	1/23/2020	ND	8	1	0	2/17/2020	MA	18	2	0	3/9/2020	TR	16	6	0
Cooley Landing Central (16.1)	NAm	2/10/2020	PL	6	1	14	2/24/2020	TR	20	5	4	3/18/2020	PL	12	3	19
Cooley Landing East (16.2)	NAm	2/10/2020	PL	6	1	7	2/24/2020	TR	20	5	9	3/18/2020	PL	12	3	6

[1] Not surveyed round 3 due to coronavirus pandemic.

UNION CITY REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
AFCC - Mouth (01a)	NAm	1/23/2020	KE	8	1	0	2/17/2020	JH	19	7	0	3/9/2020	MA	13	2	0
AFCC - Lower (01b)	NAm	1/23/2020	KE	8	1	0	2/17/2020	JH	19	7	0	3/9/2020	MA	13	2	1
AFCC - Upper (01c)	NAm	1/20/2020	SG	13	3	0	2/10/2020	KE	6	2	0	3/3/2020	ND	20	5	0
AFCC - to I-880 (01d)	NAm	1/20/2020	SG	13	3	0	2/10/2020	KE	6	2	0	3/3/2020	ND	20	5	0
AFCC - Pond 3 (01f)	NAm	1/23/2020	KE	8	1	0	2/17/2020	JH	19	7	0	3/9/2020	MA	13	2	1
OAC - North Bank (13a)	NAm	2/4/2020	JM	13	2	3	2/20/2020	SC	7	1	1	3/5/2020	BO	18	7	3
OAC - Island (13b)	NAm	2/4/2020	TR	13	9	6	2/20/2020	JH	7	0	6	3/5/2020	SG	15	6	7
OAC - South Bank (13c)	NAm	2/4/2020	TR	13	9	2	2/20/2020	JH	7	0	3	3/5/2020	SG	15	6	2
Whale's Tail - North (13d)	NAm	2/12/2020	MA	6	3	4	3/4/2020	BO	21	7	0	3/24/2020	KE	9	5	8
Whale's Tail - South (13e)	NAm	2/4/2020	SC	13	4	2	2/18/2020	SG	17	6	4	3/4/2020	JM	20	8	3
Cargill Mitigation Marsh (13f)	NAm	2/4/2020	SC	13	4	0	2/18/2020	SG	17	6	0	3/4/2020	JM	20	8	0
Eden Landing - Mt Eden Creek (13j)	NAm	1/30/2020	MA	8	2	0	2/12/2020	PL	7	2	11	3/4/2020	SG	20	6	3
Eden Landing Reserve - South (13k)	NAm	1/30/2020	JH	15	3	1	2/24/2020	SG	17	6	8	3/20/2020	SG	16	8	2
Eden Landing Reserve - North (13l)	NAm	1/30/2020	JH	15	3	0	2/24/2020	SG	17	6	0	3/20/2020	SG	16	8	0

HAYWARD REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
Oro Loma - East (07a)	NAm	2/6/2020	MA	15	0	0	2/27/2020	PL	12	1	0	3/26/2020	MA	5	0	0
Oro Loma - West (07b)	NAm	2/6/2020	BO	15	2	0	2/27/2020	MA	13	1	0	3/26/2020	SG	4	3	1
Dog Bone Marsh (20c)	NAm	2/5/2020	KE	16	1	0	2/26/2020	ND	7	0	0	3/18/2020	TR	6	1	0
Citation Marsh South (20d.1)	NAm	2/5/2020	MA	13	3	0	2/26/2020	SC	9	0	2	3/18/2020	KE	8	1	2
Citation Marsh North Channels (20d.2a)	NAm	2/5/2020	MA	13	3	19	2/26/2020	SC	9	0	33	3/18/2020	KE	8	1	12
Citation Marsh North Main (20d.2b)	NAm	2/5/2020	MA	13	3	10	2/26/2020	SC	9	0	10	3/18/2020	KE	8	1	12
East Marsh (20e)	NAm	2/5/2020	TR	12	3	1	2/26/2020	MA	9	1	0	3/25/2020	ND	7	2	0
North Marsh (20f)	NAm	2/5/2020	KE	16	1	38	2/26/2020	ND	7	0	70	3/18/2020	TR	6	1	42
Bunker Marsh (20g)	NAm	2/5/2020	JH	15	3	17	2/26/2020	BO	18	0	18	3/25/2020	BO	13	2	15
San Lorenzo Creek North (20h.1)	NAm	2/5/2020	TR	12	3	2	2/26/2020	MA	9	1	2	3/25/2020	ND	7	2	2
San Lorenzo Creek South (20h.2)	NAm	2/5/2020	TR	12	3	3	2/26/2020	MA	9	1	0	3/25/2020	ND	7	2	2
Cogswell - Sec A (20m)	NAm	1/27/2020	JM	8	1	5	2/25/2020	ND	20	6	4	3/20/2020	JH	14	8	2
Cogswell - Sec B Bayfront (20n.1)	NAm	1/27/2020	PL	8	0	2	2/25/2020	SC	23	4	4	3/19/2020	SC	14	5	7
Cogswell - Sec B South (20n.2)	NAm	1/27/2020	PL	8	0	12	2/25/2020	SC	23	4	22	3/19/2020	SC	14	5	14
Cogswell - Sec B Main (20n.3)	NAm	1/27/2020	PL	8	0	19	2/25/2020	SC	23	4	23	3/19/2020	SC	14	5	23
Cogswell - Sec C (20o)	NAm	1/27/2020	MA	7	0	13	2/25/2020	TR	19	4	14	3/19/2020	JM	13	9	6
HARD Marsh (20s)	NAm	1/27/2020	SG	7	0	0	2/26/2020	LD	22	4	1	3/19/2020	SG	13	5	0
Triangle Marsh - Hayward (20w)	NAm	1/27/2020	JM	8	1	0	2/25/2020	ND	20	6	0	3/20/2020	JH	14	8	0

SAN LEANDRO BAY REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
Arrowhead Marsh West (17c.1)	NAm	1/23/2020	TR	14	3	5	2/12/2020	SC	9	0	5	3/9/2020	JM	17	4	4
Arrowhead Marsh East (17c.2)	NAm	1/23/2020	TR	14	3	19	2/12/2020	SC	9	0	25	3/9/2020	JM	17	4	23
MLK Regional Shoreline - Damon (17d.4)	NAm	1/28/2020	JM	10	3	2	2/20/2020	ND	17	3	4	3/12/2020	SC	17	6	8
MLK Regional Shoreline - Damon Slough (17.5)	NAm	1/28/2020	JM	10	3	0	2/20/2020	ND	17	3	0	3/12/2020	SC	17	6	0
San Leandro Creek North (17e.1)	NAm	1/20/2020	JM	14	1	0	2/11/2020	SC	14	3	0	3/3/2020	TR	17	1	0
San Leandro Creek South (17e.2)	NAm	1/20/2020	JM	14	1	0	2/11/2020	SC	14	3	0	3/3/2020	TR	17	1	0
MLK New Marsh (17h)	NAm	1/20/2020	JM	14	1	46	2/11/2020	SC	14	3	55	3/3/2020	TR	17	1	45
Fan Marsh Wings (17j.1)	NAm	1/27/2020	MA	10	3	0	2/21/2020	BO	15	1	0	3/12/2020	ND	9	1	0
Fan Marsh Main (17j.2)	NAm	1/27/2020	MA	10	3	17	2/21/2020	BO	15	1	11	3/12/2020	ND	9	1	16

BAY BRIDGE NORTH REGION

Site Name (ID)	Protocol	Round 1					Round 2					Round 3				
		Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA	Date	Observer	Temp (°C)	Wind (mph)	RIRA
Emeryville Crescent - East (06a)	NAm	1/20/2020	ND	9	1	0	2/10/2020	TR	9	8	0	3/10/2020	BO	15	1	0
Emeryville Crescent - West (06b)	NAm	1/20/2020	ND	9	1	2	2/10/2020	TR	9	8	1	3/10/2020	BO	15	1	1
Whittel Marsh (10a)	NAm	1/28/2020	JH	13	5	0	2/26/2020	TR	17	1	0	3/13/2020	MA	10	3	0
Wildcat Marsh (22a)	NAm	1/23/2020	JM	14	4	20	2/10/2020	JH	5	1	28	3/3/2020	MA	18	5	7
San Pablo Marsh East (22b.1)	NAm	1/20/2020	MA	10	2	2	2/10/2020	BO	8	3	5	3/3/2020	JM	22	3	3
San Pablo Marsh West (22b.2)	NAm	1/20/2020	MA	10	2	7	2/10/2020	BO	8	3	6	3/3/2020	JM	22	3	9
Rheem Creek Area (22c)	NAm	1/22/2020	JH	13	0	3	2/11/2020	MA	9	4	9	3/3/2020	BO	19	7	3
Hoffman Marsh (22e)	NAm	1/22/2020	MA	12	3	0	2/11/2020	JM	10	2	2	3/3/2020	SC	16	4	0

SUISUN REGION

NOTE: All surveys in Suisun shown in table below were conducted by OEI in support of the Military Ocean Terminal Concord (MOTCO) Integrated National Resources Management Plans

		Round 1					Round 2					Round 3				
Site Name (ID)	**Protocol**	**Date**	**Observer**	**Temp (°C)**	**Wind (mph)**	**RIRA**	**Date**	**Observer**	**Temp (°C)**	**Wind (mph)**	**RIRA**	**Date**	**Observer**	**Temp (°C)**	**Wind (mph)**	**RIRA**
MOTCO Area 1 (27)[1]	NAm	2/12/2020	TR	15	0	0	2/27/2020	LD	23	0	0	-	-	-	-	-
MOTCO Area 2 (27)[1]	NAm	2/12/2020	ND	14	2	0	2/27/2020	SG	24	0	0	-	-	-	-	-
Point Edith Marsh (27)[1]	NAm	2/12/2020	JM	20	0	0	2/28/2020	ND	18	1	0	-	-	-	-	-
Concord Naval Weapons Station (27)[1]	NAm	2/12/2020	JM	20	0	0	2/28/2020	ND	18	1	0	-	-	-	-	-
Roe Island (27b)[1]	NAm	2/12/2020	KE	19	1	0	3/3/2020	KE	11	4	0	-	-	-	-	-
Ryer Island NW (27b)[1]	NAm	2/14/2020	KE	8	2	0	2/27/2020	SC	24	0	0	-	-	-	-	-

[1] Not surveyed round 3 due to COVID-19 Pandemic.

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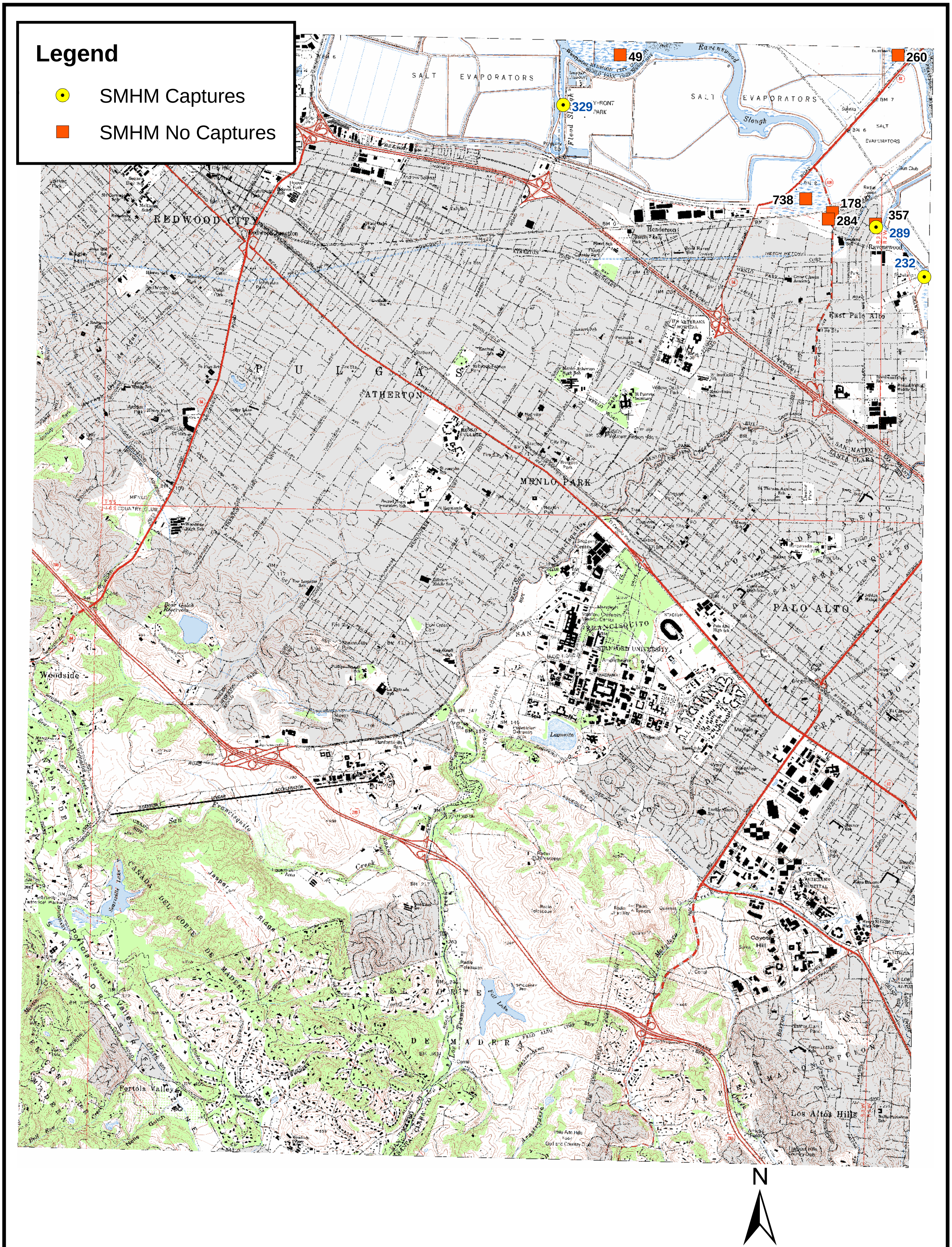
Exhibit 3 https://www.sfei.org/content/salt-marsh-harvest-mouse-database-and-maps



Trapping Locations on the Palo Alto Quad

Exhibit 4

JJ RYAN CONSULTING PTY LTD (https://jjryan.com.au)

BUILDING THE FUTURE TOGETHER

Helicopter Rotor Downwash – Excessive wind, FOD and brownouts, what are the risks?

What is helicopter rotor downwash?

Rotor downwash is a commonly ignored phenomenon that occurs during helicopter hover in close proximity to a ground surface. It has the potential to cause significant damage to nearby vehicles and objects, as well as people. Figure 1 shows the impact of helicopter rotor downwash while hovering over water and while landing in a dusty environment.

Figure 1 – Examples of helicopter rotor downwash impacts

What are the potential risks due to rotor downwash?

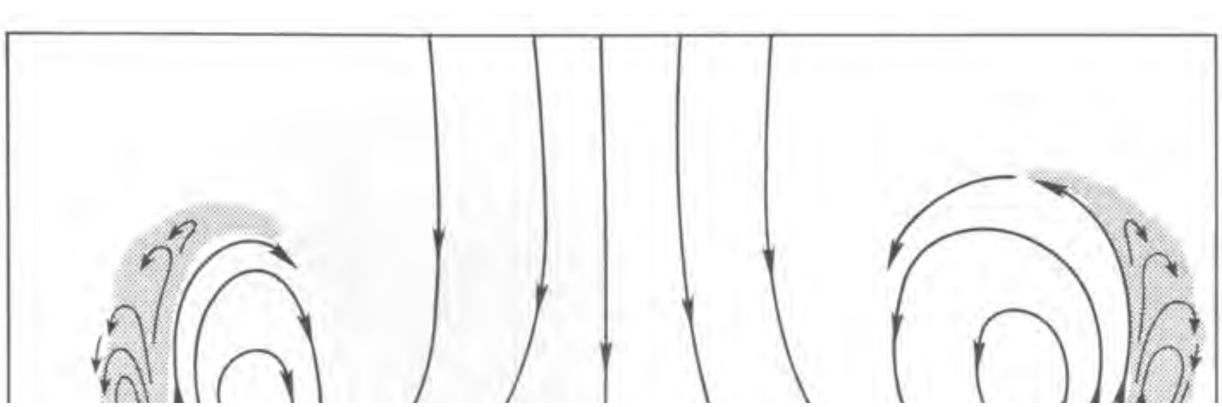
There are a variety of risks associated with helicopter rotor downwash, as summarised in Table 1.

Table 1 – Summary of potential risks to people, buildings, aircraft and helicopters

Risk Element	Risk Description	Risk Mitigation
People	Secondary effects of Foreign Object Debris (FOD) such as dust and sand or other objects becoming airborne causing injury	Ensuring that the helicopter movement areas have an appropriate surface and designing helicopter movement areas away from people
Buildings	Operational effects on hangars and other building structures resulting in damage to cladding or other structure elements exceeding wind design loads	Designing the helicopter movement areas away from buildings or ensuring buildings are designed to withstand additional load
Light aircraft	Impact on light (recreational or general aviation) aircraft while taxiing or in aircraft parking zones	Ensuring sufficient separation between helicopters taxiing or in aircraft parking zones
Helicopters	Brownouts during landing procedures causing loss of spatial awareness and resulting in a hard landing or helicopter crash	Ensuring effects of the zone of influence related to downwash is understood to allow an appropriate landing surface to be constructed

What are acceptable limits on downwash velocities?

There is limited guidance on maximum helicopter rotor downwash velocities. By calculating the downward force from the helicopter rotors, it has been assumed that the horizontal component causing a ground affect conservatively equal the vertical wind speed, as shown in Figure 2.



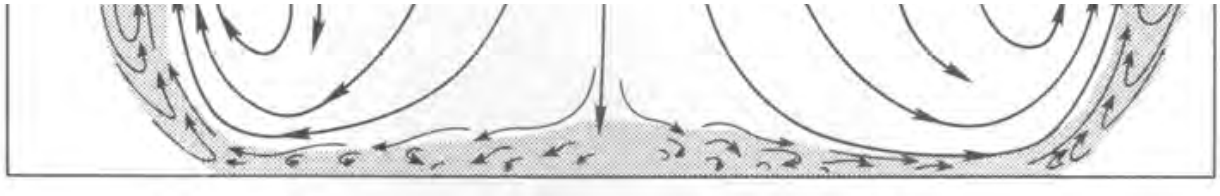


Figure 2 – Wind vortices forming helicopter downwash

While not directly related to helicopter rotor downwash, Australia's Civil Aviation Safety Authority (CASA) currently defines the recommended maximum wind velocities affecting people, objects and buildings in the vicinity of an aeroplane in the Manual of Standards (MOS) Part 139, as summarised in Table 1.

Table 1 – Maximum wind velocity for specific objects and activities (adapted: CASA, MOS Part 139)

Affected object	Maximum wind velocity
Passengers and main public areas	60 km/h
Minor public areas	80 km/h
Public roads	50 km/h where vehicle speed < 80 km/h 60 km/h where vehicle speed > 80 km/h
Personnel working near an aeroplane	80 km/h
Apron equipment	80 km/h
Light aeroplane parking areas	Desirably 60 km/h, not greater than 80 km/h
Buildings and other structures	Not exceeding 100 km/h

How is helicopter rotor downwash currently modelled?

A variety of research has been undertaken in the United States of America by both the US Army regarding the ground effects of helicopter downwash. Helicopter downwash is most significantly influenced by the mass of the helicopter and the diameter of the helicopter rotor.

Modelling the impacts of helicopter downwash at final approach and take-off area (FATO) as well as hover-taxi locations can allow for better planning for helicopter operations. This can benefit both airport and helicopter operators by identifying 'areas of significant wind velocity' to improve safety and reduce the impacts on people and property.

A typical rule of thumb requires a distance of 2 to 3 times the rotor diameter, from the rotor hub to allow the downwash velocity to dissipate to acceptable levels. The calculated downwash velocities for a helicopter with a 22m rotor diameter with a mass of 13t and 18t is shown in Figure 3 where it can be seen that the 80km/h wind velocities are exceeded at up to 40m from the rotor diameter (this would require an 80m wide corridor).

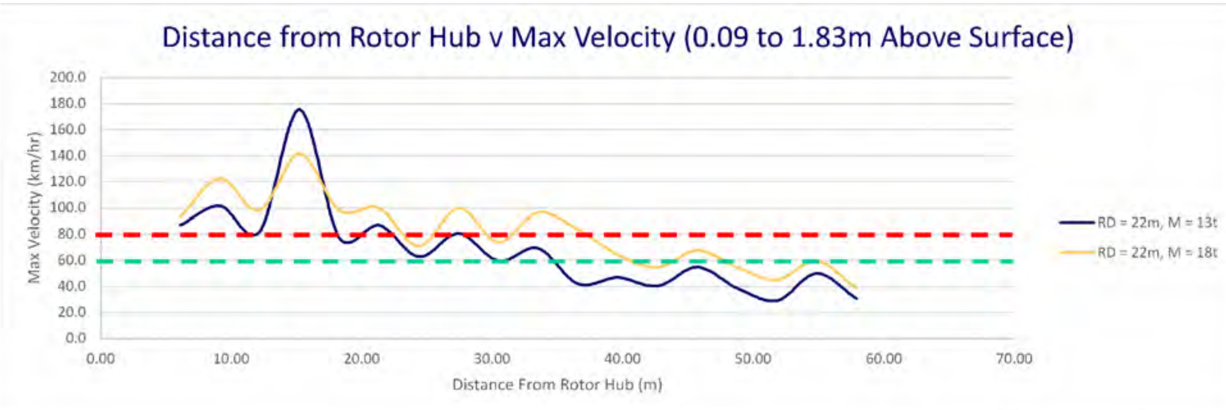


Figure 3 – Distance from rotor hub versus maximum downwash velocity

How could the helicopter downwash be more modelled better?

JJ Ryan Consulting have developed a helicopter downwash model based on US Army and NASA research coupled with aeronautical engineering calculations for aerofoils.

The model ultimately produced a downwash velocity heat-map, as shown in Figure 4 to allow the impacts of helicopter downwash to be modelled for three conditions, specifically helicopter take-off, hovering and hover-taxiing.

Potential Risk Legend	
Low risk to safety	≤ 60km/hr
Potentially acceptable	60 - 80 km/hr
Higher risk to safety	80-100 km/hr
Potentially unsafe	≥ 100km/hr

Horizontal Distance from Rotor Hub(s), m	Velocity Point Height Above Ground, m	Downwash Velocities, km/hr, at Indicated Headings, deg											
		0°	30°	60°	90°	120°	150°	180°	210°	240°	270°	300°	330°
6.10	0.09	-	-	78.9	-	46.7	38.6	-	59.5	25.7	35.4	51.5	48.3
9.14	0.09	-	82.1	115.9	69.2	120.7	119.1	38.6	119.1	109.4	99.8	109.4	101.4
	0.30	-	-	101.4	-	99.8	111.0	-	91.7	82.1	75.6	82.1	78.9
	0.61	-	-	120.7	-	120.7	122.3	-	119.1	112.7	104.6	109.4	112.7
	0.91	-	-	95.0	-	95.0	103.0	-	125.5	96.6	99.8	99.8	103.0
	1.22	-	-	74.0	-	64.4	83.7	-	120.7	112.7	123.9	112.7	120.7
	1.52	-	-	33.8	-	14.5	19.3	-	83.7	103.0	109.4	86.9	101.4
	1.83	-	-	-	-	-	-	-	35.4	72.4	66.0	61.2	38.6
12.19	0.09	-	114.3	107.8	114.3	112.7	112.7	96.6	109.4	119.1	114.3	115.9	115.9
	0.30	-	88.5	-	99.8	-	-	78.9	-	-	-	-	-
	0.61	-	115.9	-	119.1	-	-	103.0	-	-	-	-	-
	0.91	-	82.1	-	88.5	-	-	69.2	-	-	-	-	-
	1.22	-	82.1	-	53.1	-	-	59.5	-	-	-	-	-
	1.52	-	46.7	-	16.1	-	-	33.8	-	-	-	-	-
	1.83	-	14.5	-	-	-	-	24.1	-	-	-	-	-
15.24	0.09	103.0	101.4	64.4	103.0	59.5	62.8	91.7	64.4	78.9	74.0	70.8	78.9
	0.30	-	-	112.7	-	104.6	107.8	-	111.0	119.1	119.1	114.3	120.7
	0.61	-	-	62.8	-	64.4	66.0	-	49.9	70.8	77.2	74.0	75.6

	0.91	-	-	80.5	-	67.6	69.2	-	72.4	88.5	95.0	95.0	82.1
	1.22	-	-	35.4	-	25.7	29.0	-	38.6	45.1	53.1	48.3	43.5
	1.52	-	-	30.6	-	16.1	35.4	-	45.1	49.9	57.9	45.1	46.7
	1.83	-	-	8.0	-	-	8.0	-	19.3	29.0	45.1	25.7	22.5

Figure 4 – Heat map showing the helicopter downwash velocities for a specific type of helicopter

The velocities are then translated into computer aided design packages to allow detailed planning and design of helicopter movement areas.

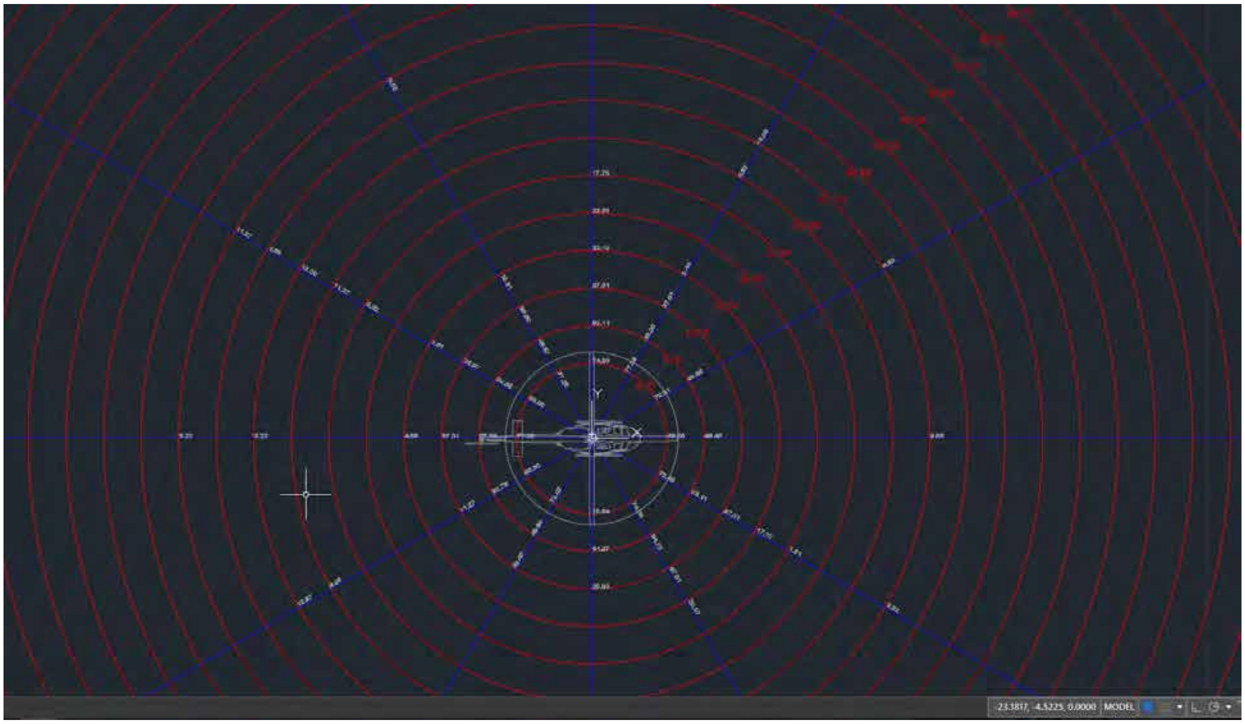


Figure 5 – Helicopter modelled in AutoCAD based on the heat map model

What is the future of helicopter downwash modelling?

In the future, JJ Ryan Consulting will conduct further research and analysis of the ground effects of rotor downwash. This will lead to better planning and design of FATO's and hover taxi locations which will assist in improving aviation safety by allowing the impacts on people, buildings to be mitigated.

JJ Ryan Consulting's model has limitations because it is based on theoretical calculations derived from aeronautical engineering formulas. In the future, JJ Ryan Consulting intends to undertake further testing with scale models and anemometers calibrate the model with our theoretical model. It should also be noted that the effects of cross-wind can also change (exacerbate or reduce) the impacts of the helicopter downwash in a particular direction.

Aviation (https://jjryan.com.au/index.php/category/aviation/)

(HTTP://TWITTER.COM/INTENT/TWEET?STATUS=HELICOPTER ROTOR DOWNWASH – EXCESSIVE WIND, FOD AND BROWNOUTS, WHAT ARE THE RISKS?+»+HTTPS://TINYURL.COM/Y6SEE7ZZ) (HTTP://WWW.FACEBOOK.COM/SHARER/SHARER.PHP?U=HTTPS://JJRYAN.COM.AU/INDEX.PHP/HELICOPTER-ROTOR-DOWNWASH-EXCESSIVE-WIND-FOD-AND-BROWNOUTS-WHAT-ARE-THE-RISKS/&T=HELICOPTER ROTOR DOWNWASH – EXCESSIVE WIND, FOD AND BROWNOUTS, WHAT ARE THE RISKS?) (HTTPS://PLUS.GOOGLE.COM/SHARE?URL=HTTPS://JJRYAN.COM.AU/INDEX.PHP/HELICOPTER-ROTOR-DOWNWASH-EXCESSIVE-WIND-FOD-AND-BROWNOUTS-WHAT-ARE-THE-RISKS/) (HTTP://PINTEREST.COM/PIN/CREATE/BUTTON/?URL=HTTPS://JJRYAN.COM.AU/INDEX.PHP/HELICOPTER-ROTOR-DOWNWASH-EXCESSIVE-WIND-FOD-AND-BROWNOUTS-WHAT-ARE-THE-RISKS/) (HTTP://WWW.ADDTOANY.COM/EMAIL?LINKURL=HTTPS://JJRYAN.COM.AU/INDEX.PHP/HELICOPTER-ROTOR-DOWNWASH-EXCESSIVE-WIND-FOD-AND-BROWNOUTS-WHAT-ARE-THE-RISKS/&LINKNAME=HELICOPTER ROTOR DOWNWASH – EXCESSIVE WIND, FOD AND BROWNOUTS, WHAT ARE THE RISKS?) (HTTP://WWW.ADDTOANY.COM/SHARE_SAVE#URL=HTTPS://JJRYAN.COM.AU/INDEX.PHP/HELICOPTER-ROTOR-DOWNWASH-EXCESSIVE-WIND-FOD-AND-BROWNOUTS-WHAT-ARE-THE-RISKS/&LINKNAME=HELICOPTER ROTOR DOWNWASH – EXCESSIVE WIND, FOD AND BROWNOUTS, WHAT ARE THE RISKS?)

BIM – Past, present and future.. what is 6D? (https://jjryan.com.au/index.php/bim-past-present-future/)

Is that a bird? Is it a plane? No… it's JJR's drone inspecting sports light poles! (https://jjryan.com.au/index.php/is-that-a-bird-is-it-a-plane-no-its-jjrs-drone-inspecting-sports-light-poles/)

Exhibit 5

1.0 Introduction

Utilization of Vertical Takeoff and Landing (VTOL) aircraft may be limited by their impact on the surrounding environment. The wake produced by a thrust-generating rotor can have nuisance to hazardous level effects on ground personnel, structures, and equipment as well as negatively affect airborne operations.

Rotorwash is defined as the overall velocity flow field produced by a rotor or other thrust generating device. Regions within the rotorwash include “downwash,” “transition,” and “outwash.” Downwash is the vertical component of the rotorwash flow field under the rotor(s). In the transition region, the downwash contacts the ground plane, turns, and becomes outwash. Outwash is the horizontal component of the rotorwash flow field outside of the area under the rotor(s). Figure 1-1 graphically displays the rotorwash under both a hovering single- and twin-rotor aircraft.

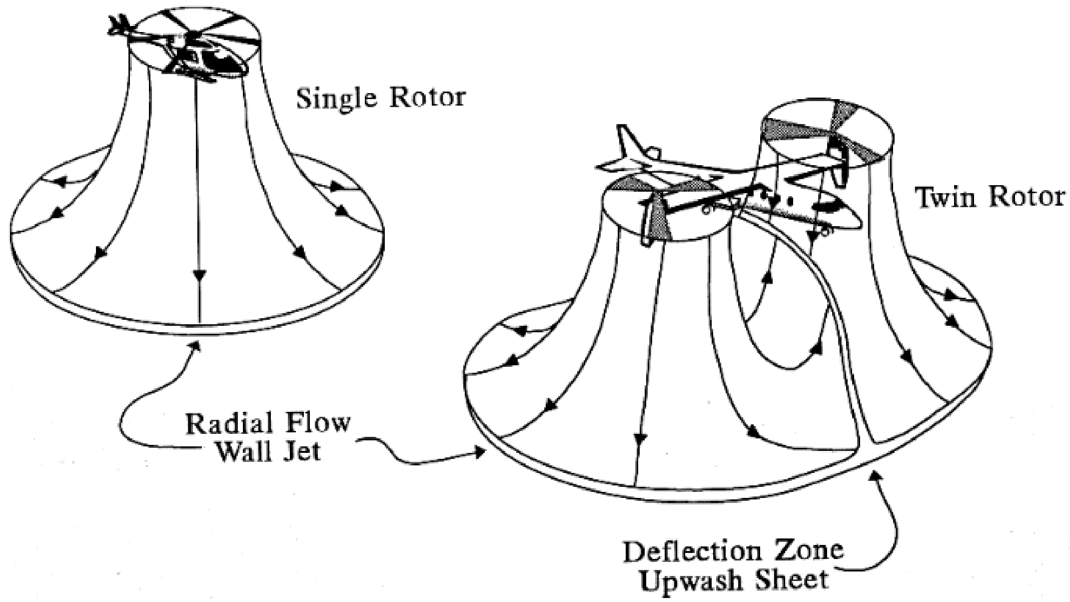


Figure 1-1 Rotorwash Flow Fields of Single- and Twin-Rotor Configurations Operating in Close Proximity to Ground (Reference 1)

The downwash primarily impacts operations directly under the aircraft such as airborne operations. Outwash primarily impacts the ground area surrounding the aircraft. Impact of the outwash on the surrounding environment can be represented as an operational footprint. This footprint defines the landing zone clearance needs, such as separation from structures, unprotected people, other aircraft, and shipboard equipment, as well as displaying the ability of ground personnel to approach and depart the aircraft.

Exhibit 6

San Francisco Bay Living Shorelines: Restoring Eelgrass and Olympia Oysters for Habitat and Shore Protection

Chapter · March 2017

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CHAPTER 17

San Francisco Bay Living Shorelines

Restoring Eelgrass and Olympia Oysters for Habitat and Shore Protection

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CONTENTS

17.1 INTRODUCTION

Living shorelines projects utilize a suite of sediment stabilization and habitat restoration techniques to maintain or build the shoreline, while creating habitat for a variety of species, including invertebrates, fish, and birds (see National Oceanic and Atmospheric Administration [NOAA] 2015 for an overview). The term "living shorelines" denotes provision of living space and support for estuarine and coastal organisms through the strategic placement of native vegetation and natural materials. This green coastal infrastructure can serve as an alternative to bulkheads and other engineering solutions that provide little to no habitat in comparison (Arkema et al. 2013; Gittman et al. 2014; Scyphers et al. 2011). In the United States, the living shorelines approach has been implemented primarily on the East and Gulf Coasts, where it has been shown to enhance habitat values and increase connectivity between wetlands, mudflats, and subtidal lands, while reducing shoreline erosion during storms and even hurricanes (Currin et al. 2015; Gittman et al. 2014, 2015).

There have been fewer living shorelines projects along the US West Coast, with most occurring on small private parcels along Puget Sound in Washington state; however, recognition of the many potential benefits of this approach is growing in the region, in part because of increasing concerns about sea level rise and storm surge and the need to protect valuable residential, commercial, and industrial assets (Gallien et al. 2011; Heberger et al. 2011; McGranahan et al. 2007). In developing the California State Resources Agency Climate Change Adaptation Strategy (Natural Resources Agency 2015), California state agencies recommended the use of living shorelines as a climate change adaptation strategy to reduce the need for engineered hard shoreline protection while enhancing habitat functions as sea level rises. The California State Coastal Conservancy Climate Change Policy (State Coastal Conservancy 2011) and the California Coastal Commission Sea Level Rise Guidance (California Coastal Commission 2015) also recommended implementation of living shorelines because of their potential to reduce erosion and trap sediment while providing intertidal and subtidal habitat and helping to maintain and protect adjacent tidal wetlands. Further, the San Francisco Bay Subtidal Habitat Goals Project proposed piloting of living shorelines projects that test the roles and potential synergy of integrating restoration of multiple species for both habitat and shoreline protection benefits (State Coastal Conservancy 2010). In addition, a 2015 climate change update to the Baylands Ecosystem Habitat Goals Report (Goals Project 2015) recommended multihabitat, multiobjective approaches and living shorelines in order to increase resiliency of San Francisco Bay tidal wetlands and associated habitats to climate changes such as sea level rise.

Concordant with these recommendations, the San Francisco Bay Living Shorelines: Near-shore Linkages Project was implemented in 2012 by the State Coastal Conservancy and an interdisciplinary team of biological and physical scientists. In this chapter, we review our objectives and project design, and evaluate outcomes 3 years after installation, concluding with an assessment of early lessons learned and design criteria for future projects in San Francisco Bay and elsewhere.

17.2 FOCUS ON EELGRASS AND OLYMPIA OYSTERS

Although there are numerous options for species and materials to be utilized in living shorelines designs, this first living shorelines project in San Francisco Bay focused on restoration of two native species, eelgrass (*Zostera marina*) and Olympia oysters (*Ostrea lurida*). We selected these two species for several reasons. First, worldwide declines in both seagrasses and native shellfish species have made their restoration a major priority (Beck et al. 2009; Cunha et al. 2012; Kirby 2004; NOAA Fisheries National Shellfish Initiative 2011; Orth et al. 2006, 2010; Waycott et al. 2009), in part to recover the many associated species that utilize them as primary or critically important habitat (Coen et al. 2007; Hughes et al. 2009; Luckenbach et al. 1995; Ramsey 2012; Scyphers et al. 2011). Second, both seagrasses and shellfish have been shown to attenuate waves and accrete sediments, making them desirable for use in shoreline protection (Fonseca et al. 1982; La Peyre et al. 2015; Lenihan 1999; Meyer 1977; Piazza et al. 2005; Scyphers et al. 2011). Third, within San Francisco Bay, *Z. marina* and *O. lurida* have been identified as major targets for restoration, with increases of 3200 ha of each proposed over 50 years (State Coastal Conservancy 2010). Finally, incorporation of these two species together in a living shorelines design was of interest because of the potential for positive interactions that could enhance establishment or growth of either species or increase the variety of organisms attracted to the complex habitat structure (e.g., Kimbro and Grosholz 2007; Wall et al. 2008).

Eelgrass provides valued ecological functions and services in San Francisco Bay (De La Cruz et al. 2014; Hanson 1998; Kitting 1993; Kitting and Wyllie-Echeverria 1992; Spratt 1981) but covers only ~1200 ha, or approximately 1% of submerged lands (Merkel and Associates 2004, 2009, 2015). Historic coverage and distribution are not well known (a few locations were noted by Setchell 1922, 1927, 1929), but many shallow areas that were likely to have been suitable for eelgrass growth were filled or dredged as commercial shipping and infrastructure around the bay developed. Although submarine light levels in the bay are relatively low and consequently limiting for eelgrass growth (Zimmerman et al. 1991), biophysical modeling indicates that 9490 ha of bottom area may be suitable habitat (Merkel and Associates 2005). Recent studies on restoration methodologies and donor source selection (Boyer et al. 2010), genetic diversity (Ort et al. 2012, 2014), invertebrate usage (Carr et al. 2011), trophic dynamics (Carr and Boyer 2014; Kiriakopolos 2013; Lewis and Boyer 2014; Reynolds et al. 2012), and abiotic effects on eelgrass (Santos 2013) have contributed to an understanding of the opportunities for eelgrass restoration within the bay (reviewed in Boyer and Wyllie-Echeverria 2010). Further, declines in suspended sediment concentrations measured in the last decade indicate improving water clarity (Schoellhamer 2011); restoration measures could proactively advance population expansion in San Francisco Bay, taking advantage of improvements in water quality conditions.

Olympia oysters were historically an abundant part of the fauna in West Coast estuaries (Baker 1995); however, the popularity of the fishery that began in the 1850s as well as other impacts resulted in a collapse of native oyster populations in the region by the early 20th century (Baker 1995; Barnett 1963; Kirby 2004; Zu Ermgassen 2012). Little is known about the pre-European contact distribution and abundance of oysters in San Francisco Bay, much less the ecosystem services they provided; however, aggregations of native oysters were likely to have been habitat for numerous sessile and mobile animals (Ramsey 2012); they are known today to increase invertebrate species richness even at small scales (Kimbro and Grosholz 2007). Because it has not been an important fishery since Gold Rush days, the Olympia oyster has been poorly studied compared to its larger cousins, the Atlantic (*Crassostrea virginica*) and Pacific oyster (*Crassostrea gigas*). Restoration of Olympia oysters, which began in Puget Sound in 1999, is still relatively new compared with efforts in the Atlantic and Gulf coasts and much remains to be learned about effective restoration for these oysters. Lessons learned from restoration on the East and Gulf Coasts are not directly transferrable for several reasons, including differences (1) between the species in terms of life history and ecology; (2) in key limiting factors (such as disease, which is a major issue in many East Coast systems, but not on the West Coast); (3) in restoration goals, which, on the East and Gulf Coasts, frequently include restoring the commercial and recreational fishery as well as habitat, while West Coast restoration efforts have focused solely on oyster population and habitat enhancement; and (4) in the use of hatchery-reared oysters for population enhancement, which has not been used widely in West Coast projects to date.

Monitoring of oysters in SF Bay has resulted in detailed population data for more than 20 intertidal sites (presence/absence data for more than 80 sites), and an increased understanding of the factors that limit oyster populations today (e.g., A. Chang, unpublished data; Deck 2011; Grosholz et al. 2008; Harris 2004; Polson and Zacherl 2009; Wasson et al. 2014; Zabin et al. 2010). This research, along with earlier recruitment studies and small-scale restoration projects, indicates the potential to restore oysters in many areas of the bay through the placement of hard substrate at appropriate tidal elevations, relying entirely on naturally occurring recruitment (Abbott et al. 2012; Grosholz et al. 2008; Wasson et al. 2014; Welaratna 2008; Zabin et al. 2010), although enhancement with hatchery-reared oysters may improve success at some sites.

With these advances in our understanding of the dynamics of eelgrass and Olympia oyster populations and their restoration in San Francisco Bay, the timing was appropriate to increase the scale of restoration of both of these species to acreages large enough to permit evaluation of their effects on physical processes as well as habitat usage by highly mobile bird and fish species. The San Francisco Bay Living Shorelines: Near-shore Linkages Project further tests restoration techniques, restores critical eelgrass and oyster habitat, examines the individual and interactive effects of restoration techniques on habitat values, and tests alternatives to hard/structural stabilization in a multiobjective pilot climate adaptation and restoration project.

17.3 PROJECT GOAL AND OBJECTIVES

The overarching goal of the project 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 objectives of the project are as follows:

1. Use a pilot-scale, experimental approach to establish native oysters and eelgrass at multiple locations in San Francisco Bay.
2. Compare the effectiveness of different restoration treatments in establishing these habitat-forming species.

3. Determine the extent to which restoration treatments enhance habitat for invertebrates, fish, and birds, relative to areas lacking structure and pretreatment conditions.
4. Determine if the type of treatment (e.g., oyster reefs, eelgrass plantings, or combinations of oyster reefs and eelgrass) influences habitat values differently.
5. Begin to evaluate potential for subtidal restoration to enhance functioning of nearby intertidal mudflat, creek, and marsh habitats, for example, by providing food resources to species that move among habitats.
6. Evaluate potential for living subtidal features intended for habitat to also reduce water flow velocities, attenuate waves, and increase sedimentation, and assess whether different restoration treatments influence physical processes differently.
7. Determine if position in the Bay, and the specific environmental context at that location, influences foundational species establishment, habitat provision, and physical processes conferred by restoration treatments.
8. Where possible, compare the ability to establish restoration treatments, habitat functions, and physical changes along mudflats/wetlands versus armored shores.

17.4 SITING AND DESIGN

The two locations for the project (Figure 17.1) were the San Rafael shoreline (parcel owned by The Nature Conservancy) and the Eden Landing Ecological Reserve in Hayward (owned by the California Department of Fish and Wildlife). The San Rafael site included a larger-scale and a small-scale study, while the Hayward site included only a small-scale study, as described below. Oyster treatments were constructed and eelgrass plantings were installed in late July through early August 2012.

17.4.1 Larger-Scale Experiment to Test both Biological and Physical Effects (San Rafael Only)

This portion of the project included a larger-scale experimental design with four 32 × 10 m treatment plots situated parallel to the shore, approximately 200 m from shore. The scale of these four plots allowed for evaluation of the effects of native oyster substrate (mounds of bagged Pacific oyster shell), eelgrass, and both together, in comparison to a control plot of the same size (Figures 17.1 and 17.2). The experiment was designed to be large enough in scale to compare effects on physical factors such as wave attenuation and sediment accretion, as well as effects on biological properties that operate at larger scales (e.g., highly mobile invertebrate, bird, and fish utilization).

The Pacific oyster shell mound treatment plot, described in detail below, had a footprint of 1 × 1 m per element. These were laid out in sets of four elements to make larger units of 4 m^2 (Figures 17.2 and 17.3). To minimize scour, the design included spaces of the same size (4 m^2) between these oyster shell mound units. There were 3 rows of 8 units, for a total of 24 units per plot (96 elements).

Eelgrass was planted and seeded in the eelgrass treatment plot with the same spacing as the oyster reef units. The central 1.5 × 1.5 m (2.25 m^2) space within every other 4-m^2 space was planted with clusters of shoots and also seeded. The planting technique entailed using a bamboo stake to anchor each shoot in place until rooted (Figure 17.3). Two donor beds were used for transplant material at each site: Point San Pablo and Point Molate (both on the Richmond shoreline) were the sources at San Rafael, while Eden Landing Ecological Reserve in Hayward (small patches offshore) and Bay Farm Island near Alameda were the sources planted at the Hayward small-scale project site (Figure 17.1). Flowering shoots were only available from Point San Pablo at the time of project implementation in late summer 2012 and were collected for use in buoy-deployed seeding (Pickerell et al. 2005) at the San Rafael site only, with a seed bag anchored by a PVC pipe at the center of each unit.

The combined oyster and eelgrass plot was based on an additive design, with eelgrass placed into the central 2.25 m^2 of the 4-m^2 spaces between oyster substrate features (Figure 17.2). This

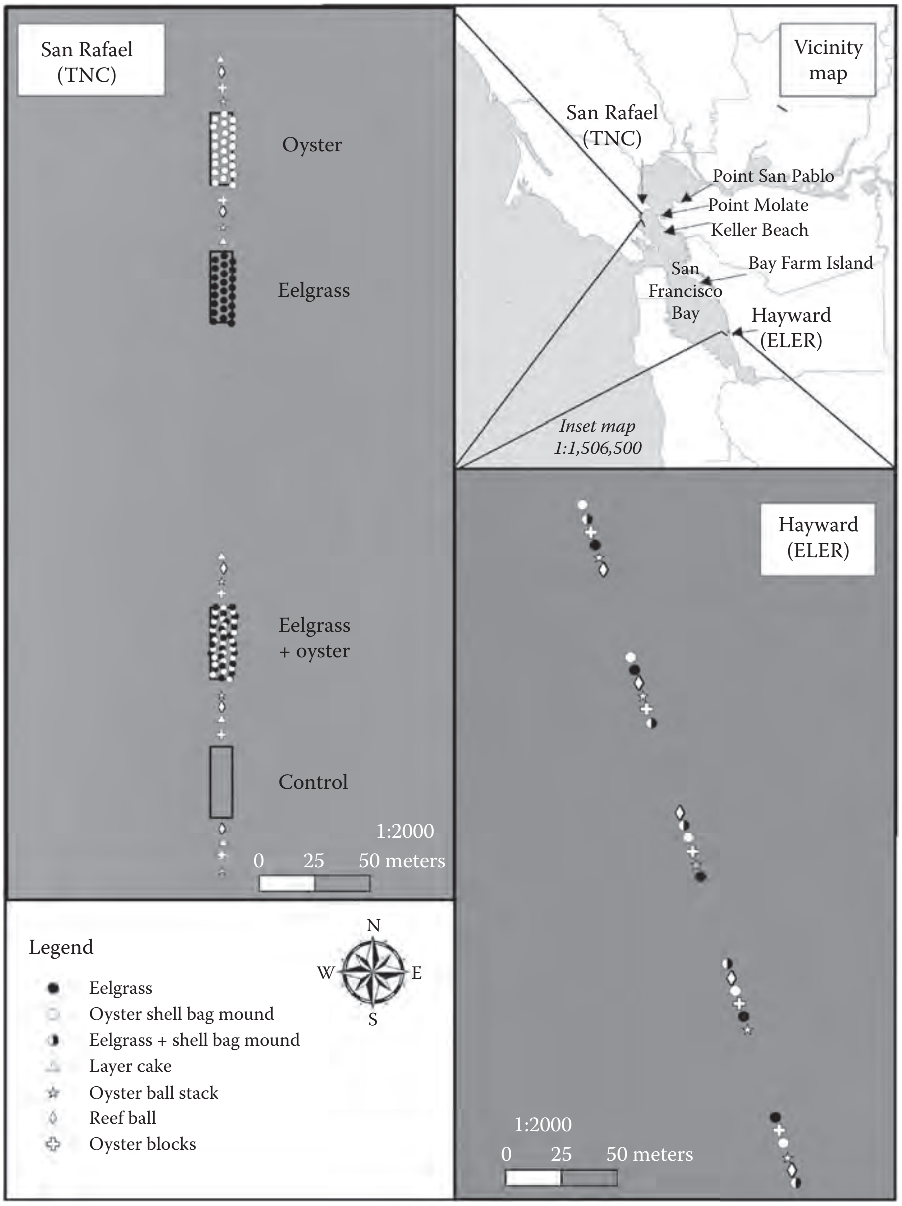
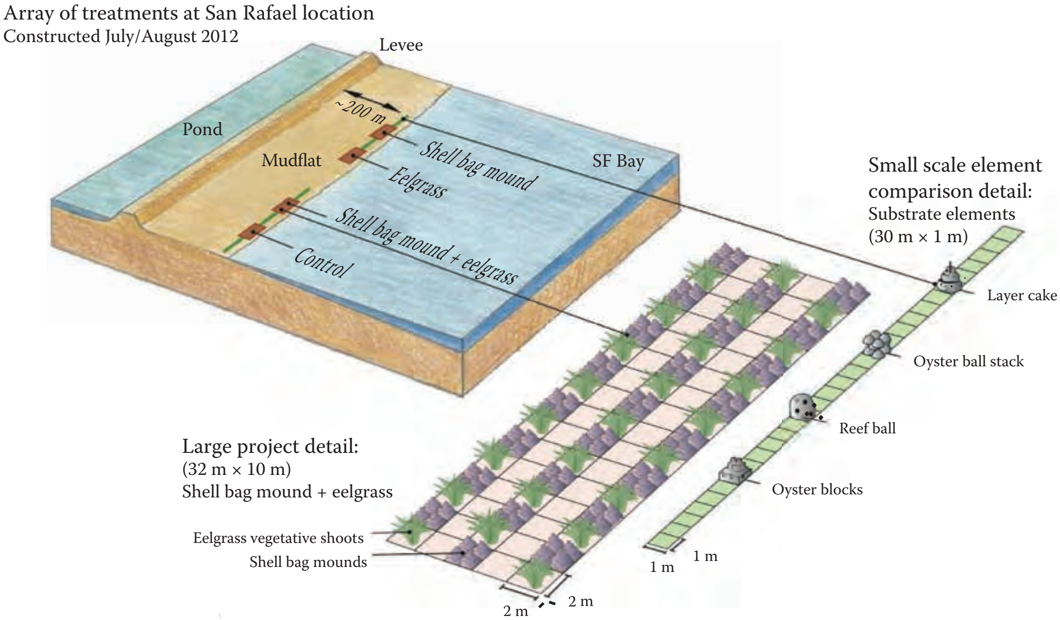


Figure 17.1 Maps showing the location and configuration of (left) the larger-scale and small-scale experiment designs at San Rafael (property of The Nature Conservancy [TNC]) and (right) the small-scale design at Hayward (offshore of Eden Landing Ecological Reserve [ELER]). Space was left at the center of the San Rafael project for preexisting test plots of eelgrass. Eelgrass transplants were collected from Point San Pablo and Point Molate for the San Rafael site and from Bay Farm Island and offshore of ELER for the Hayward site (top right map). Point Molate and Keller Beach eelgrass beds were used as reference sites for epibenthic invertebrate community development at San Rafael.



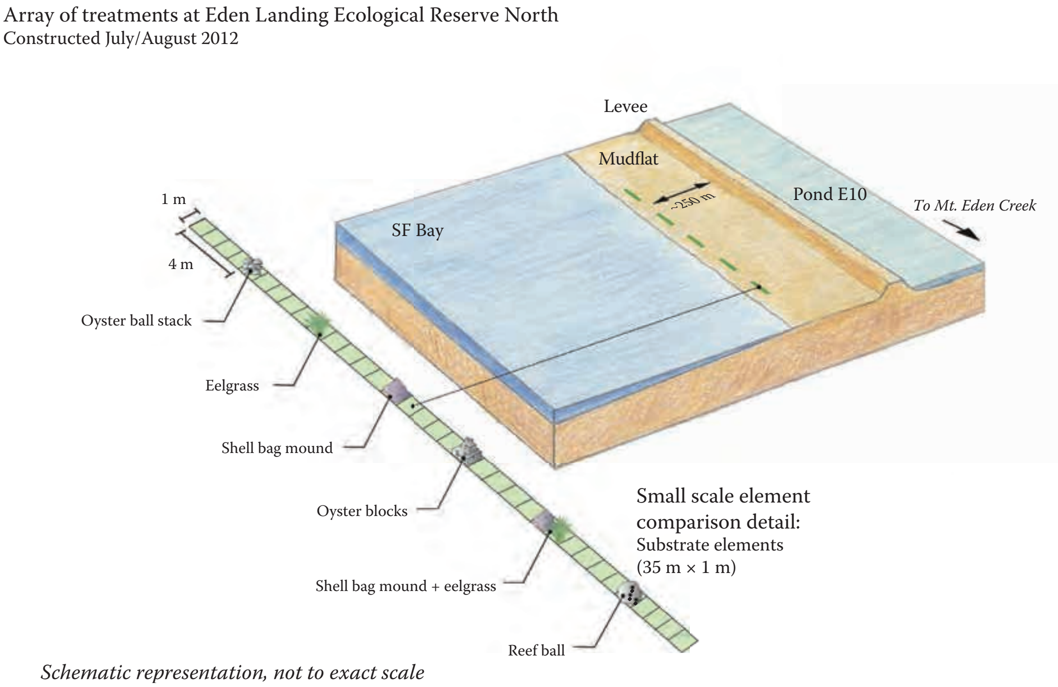


Figure 17.2 Schematic of the Living Shorelines: Nearshore Linkages project. Top: the larger-scale project design, as placed at the San Rafael site, with the four types of baycrete elements (the small-scale substrate design) in rows between the four large plots. Bottom: the small-scale substrate design as planned for the Hayward site; note that ultimately the layer cake was not used at Hayward due to concerns about structural integrity with higher wave action. Shell bag mounds were placed as single elements for comparison to baycrete at the Hayward site, and small eelgrass plots, alone and adjacent to oyster elements, were included. (Drawings courtesy Environmental Science Associates.)

Figure 17.3 Top: Photos of treatments used in the project. Bottom: Eelgrass planting using bamboo stake technique, including, on the right, a schematic of planting design within an eelgrass unit at San Rafael and Hayward. Two donors were used to plant each site, as indicated by shading in the schematic. For San Rafael, the donor in the center alternated in each patch.

design permitted us to maintain a spacing of oyster substrate that would minimize scour, while providing enough space around eelgrass plantings to permit access for sampling.

A treatment control plot of the same size was also included (Figures 17.1 and 17.2). The four treatments were arranged randomly in the four possible positions, with 30 m between each plot. Adjacent to the overall treatment area, a large project control area of equal size to the four plots was monitored throughout the project period for certain measures (e.g., bird use of completely unstructured habitat relative to the whole treatment area containing structure).

17.4.2 "Substrate Element" Experiment to Examine Small-Scale Biological Effects (San Rafael and Hayward)

This smaller-scale experiment consisted of five replicate elements of different substrate (surface) types, intended to compare native oyster recruitment, growth, and survival to inform future restoration projects. At the San Rafael site, this experiment was situated in the 30-m spaces between and on either side of the line of larger-scale plots described above (Figures 17.1 through 17.3). At San Rafael, the elements included reef balls, oyster ball stacks, oyster blocks, and a layer cake design all made of "baycrete," a mixture of roughly 20% marine-grade cement and a high proportion of materials (roughly 80%) derived from the Bay including dredged sand and shell (Figure 17.3). These substrate types were replicated five times, for a total of 20 elements placed in groups (blocks), with each of the four substrate types represented in each block.

The Hayward site also included 1-m^2 substrate elements made of baycrete, replicated in five blocks and aligned parallel with the shoreline at ~200 m from shore (Figures 17.1 through 17.3). However, there were five treatments (substrate types): reef balls, oyster ball stacks, oyster blocks, Pacific oyster shell mounds alone, and the latter placed along with adjacent eelgrass plantings. The layer cakes were ultimately not included at this site because of concerns about structural integrity under higher wave action, and the oyster shell mounds were added since there was no large-scale project to test their effectiveness at this site as at San Rafael.

17.5 BRIEF PERMITTING REVIEW

The State Coastal Conservancy coordinated with permit agencies before permit application submittals to discuss draft designs and regulatory mechanisms. Permitting discussions focused on project methods and resulting effects on bay species, seasonal windows for the work, and issues regarding the placement of clean Pacific oyster shell and baycrete structures as beneficial fill to create habitat. Permit applications were submitted in February 2012, and numerous follow-up meetings and correspondence occurred on particular aspects of each agency's requirements. Final permits were secured in July 2012, just before construction in late July and August 2012. Permit applications and approvals included the following:

- 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.
- California Department of Fish and Wildlife 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 State Lands Commission: Coordination to confirm that the project is not on state-leased lands.
- California Environmental Quality Act: the project was categorically exempt under Guidelines Section 15333 (14 Cal. Code Regs. §15333) as a small habitat restoration project, not exceeding 5 acres, to restore and enhance habitat for fish, plants, or wildlife and with no significant adverse impact on endangered, rare, or threatened species or their habitat, no known hazardous materials at or around the project site and, given the scale and methodology, no potential for cumulatively significant effects.

In addition to permits, agreements and letters of permission with the landowners (The Nature Conservancy for the San Rafael site and the California Department of Fish and Wildlife for the Hayward site) and local government (City of San Rafael) were obtained.

17.6 KEY FINDINGS, 3 YEARS AFTER INSTALLATION (THROUGH SUMMER 2015)

17.6.1 San Rafael Site

17.6.1.1 Eelgrass

After replanting eelgrass in April 2013 (as the original late-summer planting in 2012 did not succeed), plants at the larger-scale San Rafael project site performed well, reaching 50% of planted densities on average by summer 2013 and 124% by summer 2014 (Figure 17.4). By summer 2015, vegetative shoot counts had reached more than 200% of planted densities in the eelgrass-only plot and just more than 100% in the eelgrass + oyster plot. Although we did not detect seedlings from of buoy-deployed seeding effort in 2012, flowering shoots developed in the plots by summer each year (data not shown), suggesting the possibility of additional recruitment from seed. Maximum plant heights typically reached 160 cm or more during spring–fall, with a marked decrease in height during winter (Figure 17.5). Vegetative shoot density was significantly higher in the eelgrass-only plot starting in spring 2014 (Kruskal-Wallis $\chi^2 = 13.73$, df = 1, $p < 0.001$). Vegetative shoot heights also tended to be shorter in the eelgrass + oyster plot (Kruskal-Wallis $\chi^2 = 11.31$, df = 1, $p = 0.0008$). The trend of lower overall densities and heights in the eelgrass + oyster plot compared to the eelgrass-only plot may have been attributed to abrasion of plants against the oyster shells, limited space for spread within the matrix of the mixed habitat plot, or somewhat higher epiphytic algal loads on leaves (unpublished data). During the period when the two donors could still be tracked (through summer 2014), plants originating from Point Molate produced significantly higher numbers of shoots than those from Point San Pablo (Kruskal-Wallis, $\chi^2 = 18.21$, df = 1, $p < 0.0001$), perhaps owing to better matching of site conditions between the Point Molate and San Rafael sites (finer sediments than Point San Pablo; Boyer and Wyllie-Echeverria 2010).

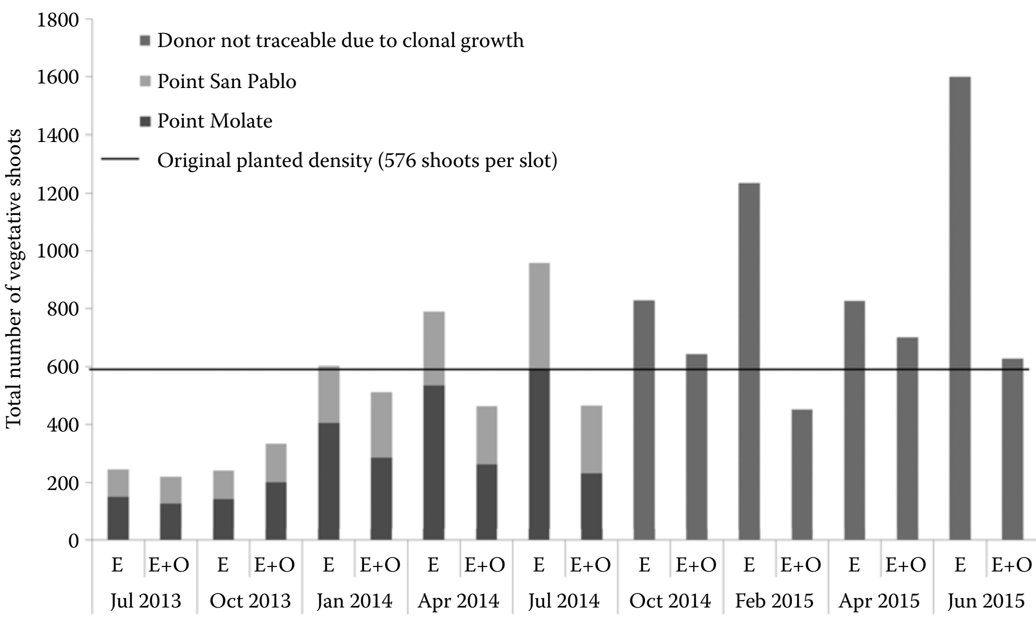


Figure 17.4 Total number of vegetative eelgrass shoots present, per donor and treatment plot at the San Rafael site, quarterly through summer 2015. E = eelgrass plot, E+O = eelgrass and oyster plot. Plants originating from the Point Molate and Point San Pablo donor sites could only be distinguished through July 2014 and were pooled thereafter.

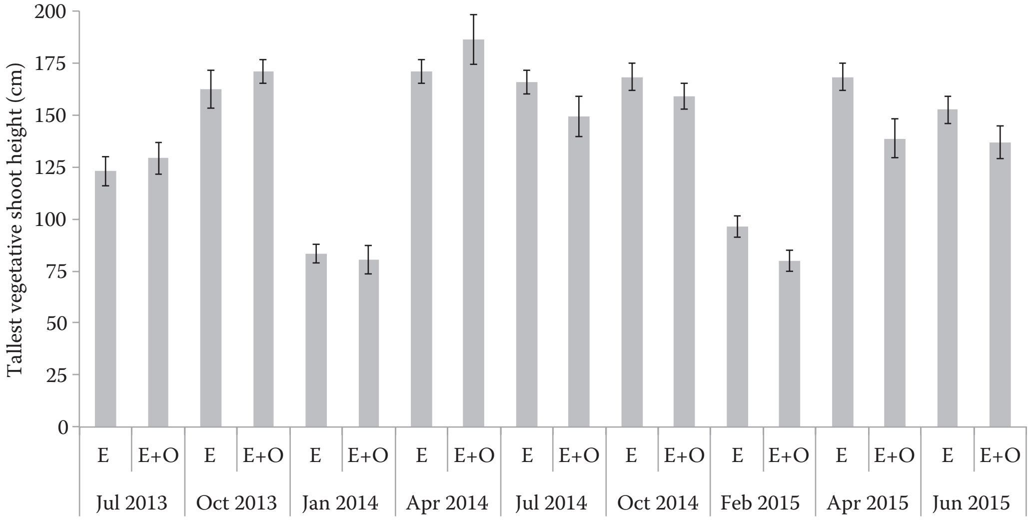


Figure 17.5 Mean height of the tallest vegetative eelgrass shoot in each unit (n = 24; ±95% CI), by treatment at the San Rafael site for each quarterly monitoring effort through summer 2015. E = eelgrass plot, E+O = eelgrass + oyster plot. The Point Molate and Point San Pablo donors did not differ in height on any date and were pooled here.

17.6.1.2 Olympia Oysters

Olympia oysters quickly recruited to the shell mound structures (by the first fall), with an estimate of more than 2 million present in the first year (Figure 17.6). To be conservative, the population estimates included only the top layer of the oyster shell mounds (the upper third of the 1-m-tall structures), as the lower layers have accumulated sediment and may not support living oysters. The total population reached an estimated peak of 3 million in spring 2013, but has declined since fall that year, with the current population (as of summer 2015) estimated at 750,000 (Figure 17.6). This decline does not appear to be attributed to space competition among growing oysters, but may be the result of (expected) mortality of some of the oysters that settled in the first 2 years as the oysters increased in size, combined with lower recruitment of oysters to the site in 2014 and 2015, as determined by recruitment tiles placed along the shoreline (unpublished data). No differences in oyster numbers or sizes were obvious between the oyster only and eelgrass + oyster treatment.

Oysters also recruited readily to the small "baycrete" structures. Measures of these structures in small quadrats (100 cm^2) early in the project indicated that twice as many oysters were present at lower and mid-level elevations (approximately −20 cm and 0 cm MLLW, respectively) than at the high elevation (~+50 cm MLLW) and on vertical than on horizontal faces; north sides of the elements also typically had 50% more oysters than did south sides. Elevational and directional differences in densities decreased over time, however. There were no differences in oyster sizes across these various surfaces or element types.

There were no differences in oyster densities between the various baycrete element structure types, with the exception of the layer cake configuration, which has more horizontal surface area, on which there were fewer oysters (Figure 17.7). In addition, the stacked small oyster balls tended to collapse; hence, the larger reef balls and oyster blocks have performed best overall among the baycrete structures. Overall, baycrete structures did not support as many oysters as the shell bag elements (Figure 17.7), attributed at least in part to the greater surface area provided by the shells and perhaps also to the lower tidal elevation of the shell bags (the tops of which are at ~+25 cm MLLW).

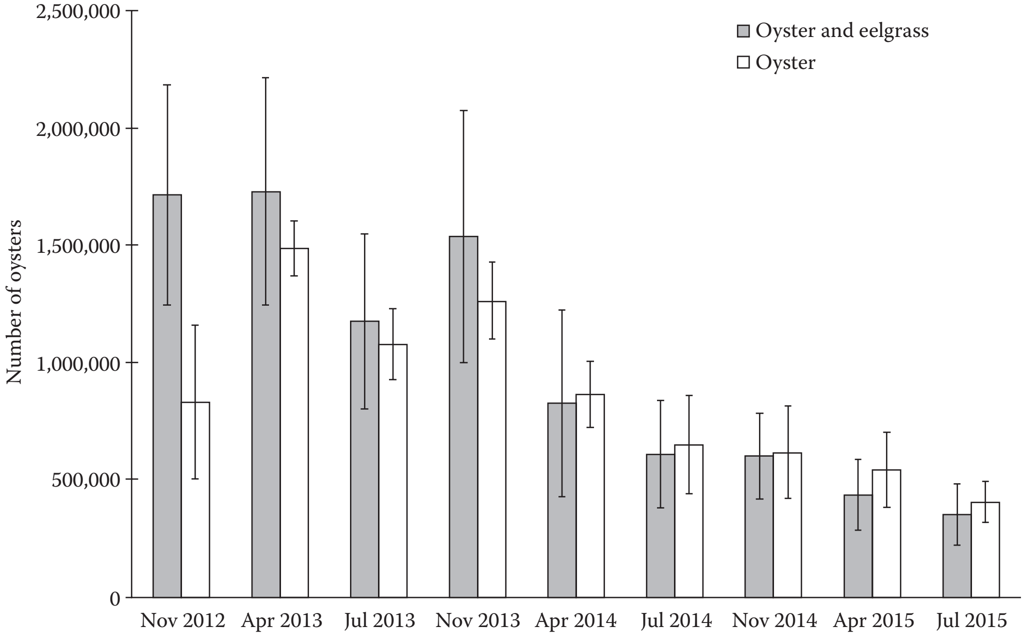


Figure 17.6 Estimated total number of native oysters on shell bag mounds at the San Rafael site over time in the oyster-only plot and oyster + eelgrass plot. To be conservative, only the upper portion of the mounds is included here. Means (±95% CI) were calculated from five replicate shell bags removed from the mounds for oyster counts on each date, which were then scaled up to estimate oyster numbers at the plot level.

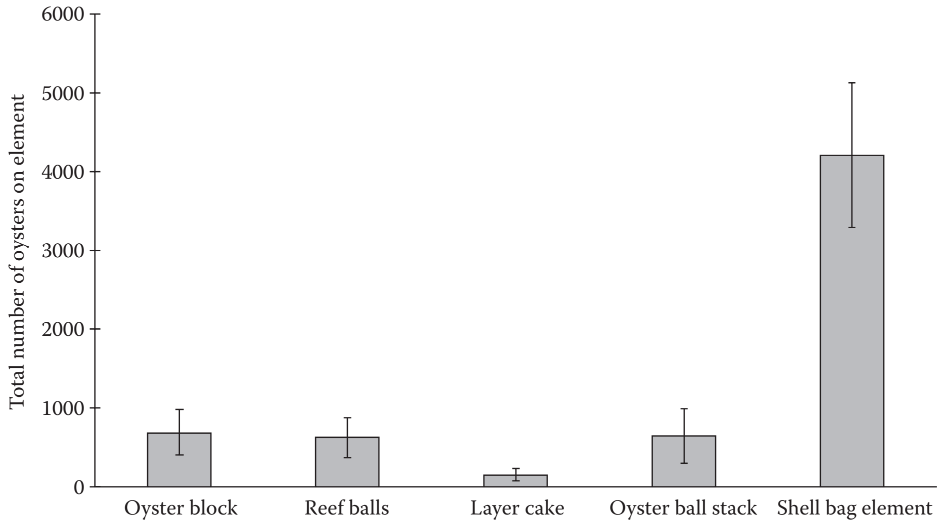


Figure 17.7 Estimated native oyster abundance per baycrete or shell bag element, July 2015. Means (±95% CI) were generated by scaling up from 10 small replicate shell bags (five each from oyster-only and oyster–eelgrass treatment plots) or from six 100-cm^2 quadrats placed on each of five replicate baycrete elements at the San Rafael site.

17.6.1.3 Epibenthic Invertebrate Response

Epibenthic invertebrates were assessed quarterly using baited minnow and oval traps, suction sampling, and shoot collection (for detailed methods, see Pinnell 2016). Trapping with minnow and oval traps for 24 h each quarter indicated an early response of species reliant on physical structure, including shrimp (bay shrimp *Crangon franciscorum* and oriental shrimp *Palaemon macrodactylus*), seen in higher abundance in all treatment plots compared to pretreatment (Kruskal-Wallis $\chi^2 = 24.85$, df = 4, $p < 0.0001$), and Pacific rock crab (*Romaleon antennarium*), which was significantly more abundant in the oyster plots than pretreatment levels (Kruskal-Wallis $\chi^2 = 26.51$, df = 4, $p < 0.0001$). Additional species known to be attracted to physical structure have been trapped in plots with oyster reef or eelgrass present, including native red rock crabs (*Cancer productus*) and northern kelp crabs (*Pugettia producta*), as well as a few nonnative green crabs (*Carcinus maenas*). Suction sampling of epibenthic invertebrates (using a battery-powered aquarium pump on each type of structure or the sediment in the control or pretreatment sampling) showed that community composition was distinct in the plots with oyster reefs present, relative to the control plot and preconstruction conditions (PERMANOVA [Bray Curtis], $p < 0.001$), with the eelgrass-only assemblage in between (Figure 17.8a; Appendix). Further, the invertebrate assemblage in the eelgrass + oyster plot was intermediate between that in the eelgrass-only and oyster-only plots (although more similar to the oyster-only plot). Similarly, freshwater dips of eelgrass shoots to assess epifauna communities (Carr et al. 2011) showed slight differences if oyster reef was present along with eelgrass (Figure 17.8b). Epifauna assemblages on eelgrass at the San Rafael site have not converged with those at Point Molate and Keller Beach, two natural beds just across the bay (Figure 17.8b). Notably, two native species known to remove epiphytes from eelgrass leaves to the benefit of eelgrass growth (Lewis and Boyer 2014) continue to be absent (the isopod *Pendidotea resecata*) or very rare (the sea hare *Phyllaplysia taylori*) at the restored site (only two individuals found during July 2014).

17.6.1.4 Fish Response

Trapping of fish (the same oval and minnow traps described above for invertebrates, with deployment for 24 h once each quarter) showed much overlap in species composition among the treatments; however, a pattern of black surfperch and bay pipefish (*Syngnathus leptorhynchus*) having a greater association with eelgrass habitat emerged. Seining results indicated early recruitment to eelgrass by bay pipefish (within 1 month of the April 2013 replant) and that eelgrass presence increased the occurrence of certain fish species among oyster reef structures, including bay pipefish, shiner surfperch (*Cymatogaster aggregata*) and saddleback gunnel (*Pholis ornata*). Acoustic monitoring using an array of 69-kHz receivers to detect tagged fish showed that individuals of several species visited the site, including two white sturgeon (*Acipenser transmontanus*), a green sturgeon (*Acipenser medirostris*, a threatened species), a leopard shark (*Triakis semifasciata*), a steelhead smolt, and a striped bass (*Morone saxatilis*). Positional analysis, currently underway, will help determine the degree to which the fish were lingering at the site.

17.6.1.5 Bird and Infaunal Invertebrate Response

To evaluate bird and infaunal invertebrate responses, the treatment area at San Rafael was subdivided into a zone encompassing the eelgrass and oyster treatment plots (zone B) as well as 150-m zones immediately inshore (zone A) and offshore (zone C) of the plots, and a nearby control (unmanipulated) area was divided in the same way; here, we focus on zone B. Avian density and behavior were surveyed at high tide (>0.8 m MLLW) and low tide (<0.25 m) from shore two times a month during the fall (September, October, and November), winter (December, January, and February), and spring (March, April, and May). Benthic cores were collected (10 cm diameter)

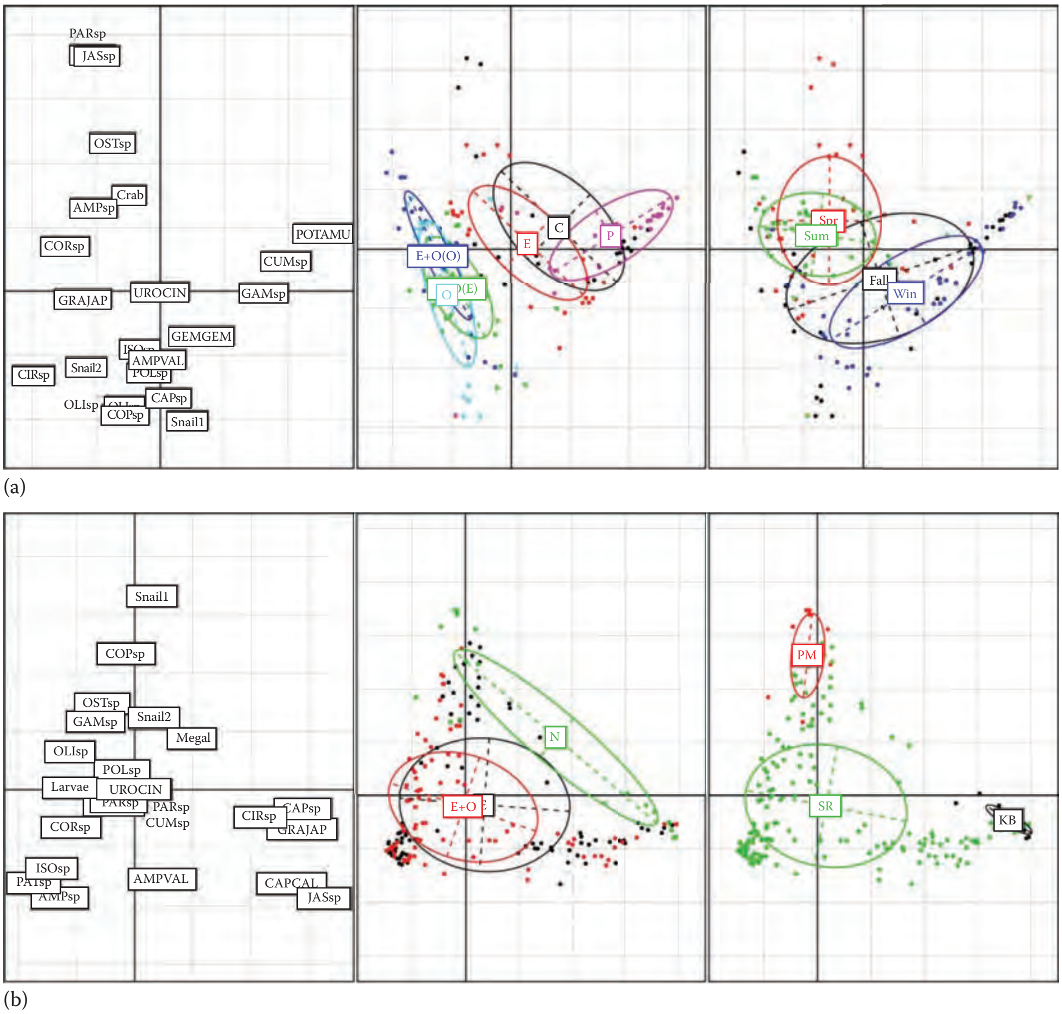


Figure 17.8 Correspondence analysis of epiphytic invertebrates: (a) San Rafael suction sampling patterns by taxa, treatment, and season, fall 2013 through summer 2014 (Year 2 of the project), in comparison to pretreatment (P) samples. C = control, E = eelgrass, O = oyster, E+O(E) = eelgrass from E+O plot, and E+O(O) = oyster from E+O plot. (b) Eelgrass shoot collection patterns in spring 2014 comparing assemblages at the San Rafael (SR) plots from the E or E+O plots to that of two natural (N) beds at Keller Beach (KB) and Point Molate (PM). Two species, *Phyllaplysia taylori* (Taylor's sea hare) and *Pentidotea resecata* (an isopod), were absent or rare at San Rafael and were removed from b owing to their presence obscuring differences produced by other parts of the assemblage. Taxa abbreviations as in Appendix.

during September and May of each year to sample infaunal invertebrates along transects that bisected each zone. Densities of American black oystercatcher (*Haematopus bachmani*) increased in the treatment area in comparison to preinstallation and control densities, and Forster's terns (*Sterna forsteri*) and wading birds (herons and egrets) began using the treatment area after installation (Figure 17.9). Comparing behavior of all bird species during low tide, the treatment area was used more for foraging than was the control area (Figure 17.10); nonforaging (resting, preening, etc.) behaviors were predominant at high tide. Overall benthic invertebrate densities and biomass increased from preinstallation (spring 2012) to year 2 postinstallation (spring 2014) in oyster,

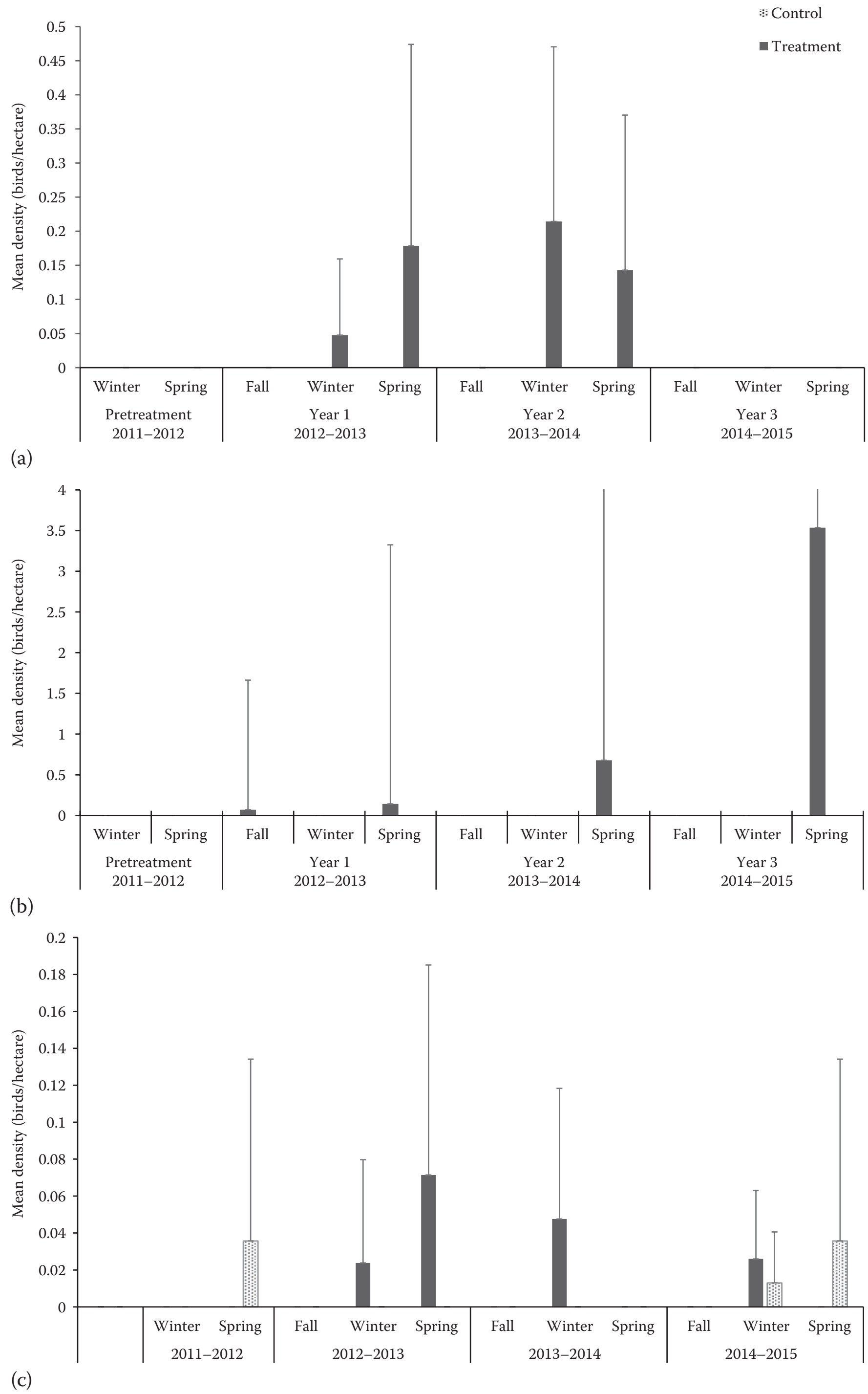
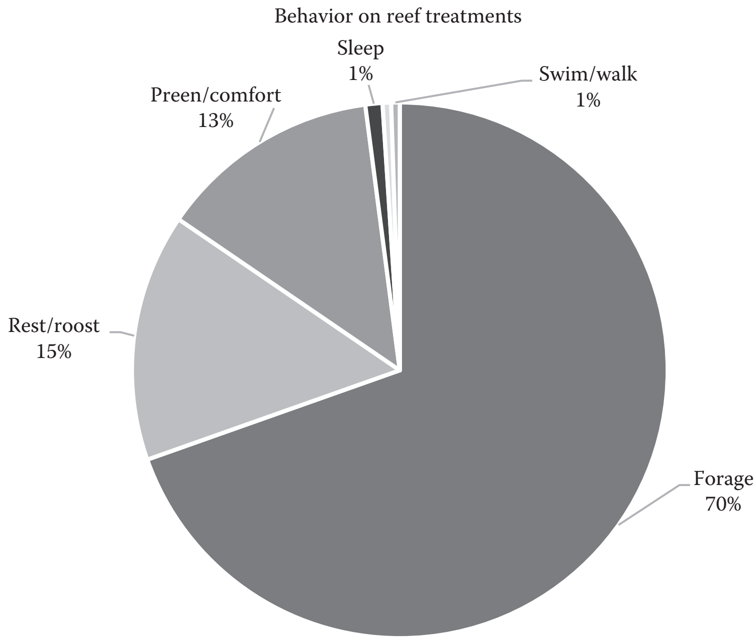
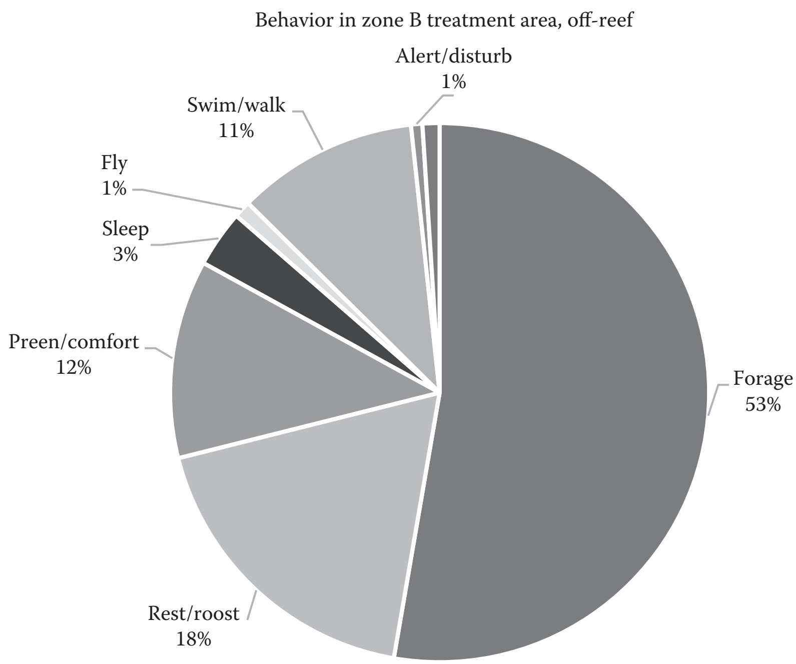


Figure 17.9 Mean seasonal density (with 95% CIs) of (a) black oystercatchers, (b) Forster's terns, and (c) wading birds during low tide at the San Rafael site among pretreatment (2011–2012) and post-treatment years (2012–2015), in the control (gray) and treatment (black) areas. No surveys were conducted during fall of the pretreatment year. Note: *y* axis differs among graphs.



(a)



(b)

Figure 17.10 Percentage of birds (all species) engaged in different behaviors based on low tide scan surveys in Zone B (oyster and eelgrass treatment plots) at San Rafael. (a) Bird behaviors in the treatment plots ("reefs") only, and (b) bird behaviors excluding individuals directly in treatment plots ("off-reef").

eelgrass-only, and eelgrass + oyster treatments (unpublished data). While amphipods were the densest invertebrate, polychaetes comprised the majority of ash free dry weight at San Rafael, and 83% of total polychaete biomass is attributed to a single species, the bamboo worm, *Sabaco elongatus*.

17.6.1.6 Physical Effects

Our measurements show localized sedimentation adjacent to the reefs, with sedimentation over the larger mudflat area less pronounced. Hydrographic surveys of the mudflat surface within 100 m of the reefs at San Rafael in May 2012 and June 2014 show a pattern of erosion bayward (east) of the plots and sedimentation (approximately 0.07 m) shoreward of the plots. Patterns of erosion and deposition are similar for the treatment and control plots. The mudflat surveys also show a north–south trend of increasing erosion to the north, which may be related to the proximity of San Rafael Creek to the north. These results are for only one repeat survey; future surveys are needed to identify longer-term trends. Localized sedimentation has occurred adjacent to both the baycrete structures and the shell mound units and, to a greater extent, inside the shell mound elements comprising the shell mound units. After an initial pulse of sedimentation adjacent to the shell mound units (average of 0.17 m in the first year), sedimentation rates slowed, and in some areas, a net loss of sediment has been observed since construction. The reefs subsided approximately 10 cm in the first 5 months, followed by largely stable conditions (Figure 17.11). The combination of shell bag settling, sediment accumulation around the reefs, and subsidence means that not all of the surface area of the individual elements is available to support oysters (Figure 17.11).

Wave heights show different patterns in the lee (shoreward) of the oyster–eelgrass plot and the control plot, with fewer waves in the lee of the oyster–eelgrass plot. Waves measured over a 2-month period in February to April 2013 ranged in height from 0.06 m (the minimum analyzed) to 0.26 m for both plots. However, there were far fewer waves above 0.06 m shoreward of the oyster–eelgrass compared to the control (21 and 45, respectively) (Figure 17.12). According to wave modeling conducted for the project, for waves immediately offshore of the plots, the oyster–eelgrass plot dissipates approximately 30% more wave energy than the control at mean tide level (MTL). This reduction adds to the wave attenuation benefits of the broad offshore mudflat, which extracts substantial energy before waves reach the plots.

17.6.2 Hayward (ELER) Site

17.6.2.1 Eelgrass

Eelgrass at this smaller-scale project site reached 75% of planted densities by July 2013 (after a May 2013 replant) and survived through the fall months; however, major declines occurred during the next winter and only two shoots remained by summer 2014 across the 10 small plots. Eelgrass was always shorter at Hayward (~80 cm) than San Rafael, perhaps owing to shallower site conditions at the former. Plants at this site had high densities of the Eastern mud snail, *Ilyanassa obsoleta* (both adults and eggs) on their leaves and also appeared to experience substantial sediment movement and burial; either or both could have contributed to the observed eelgrass mortality.

17.6.2.2 Olympia Oysters

Oyster recruitment at Hayward did not occur until spring 2013 and at a much lower rate than at San Rafael. At its peak in summer 2013, the population on the restoration substrates was estimated at ~2000 oysters on our test elements there; even this relatively modest effort increased the population of native oysters at that site by one order of magnitude. Currently, it appears that there are few oysters on the restoration substrates at this site. Oyster blocks and higher tidal elevations appeared

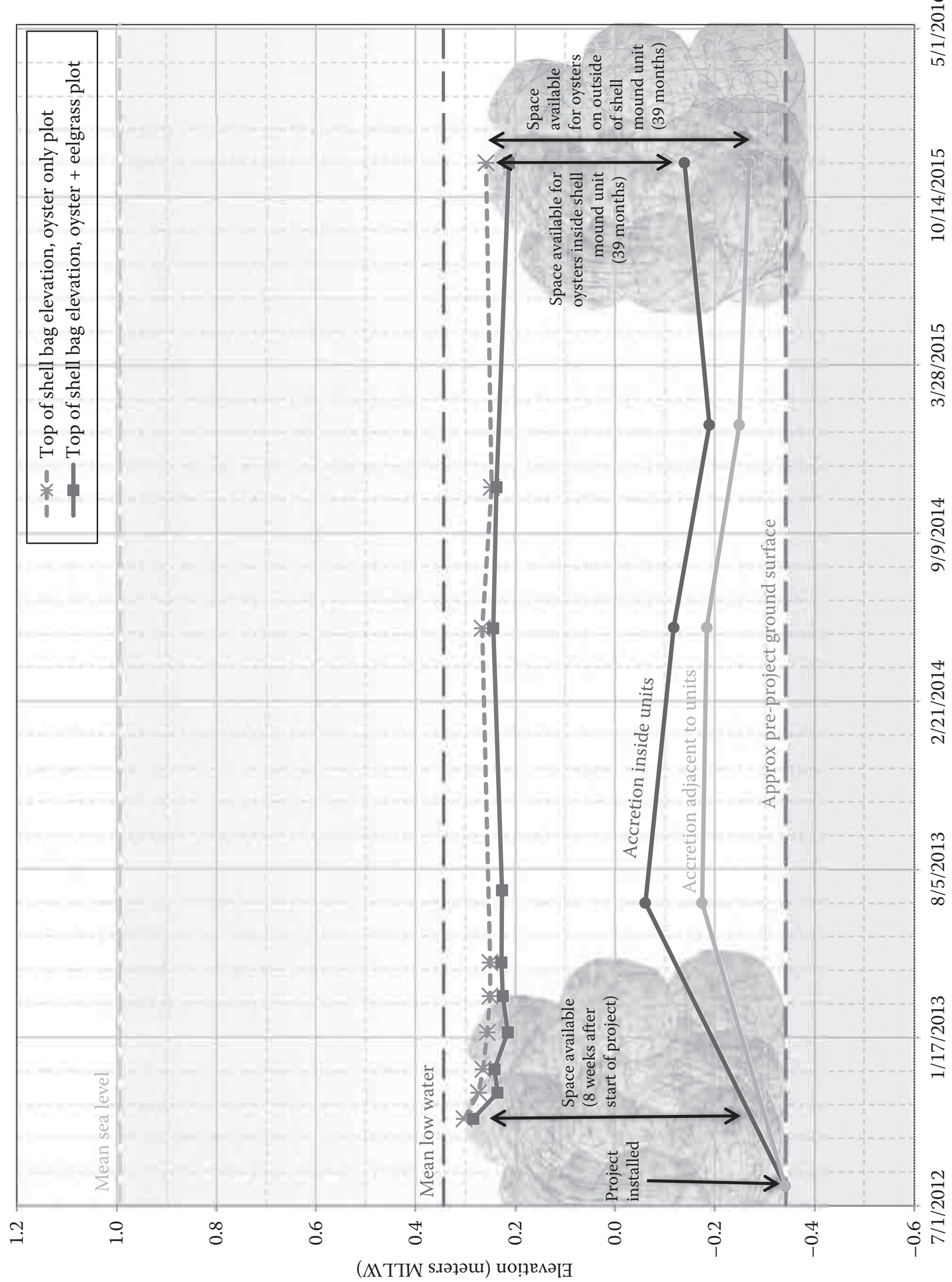


Figure 17.11 Sedimentation and oyster space for shell bags at the San Rafael site over time.

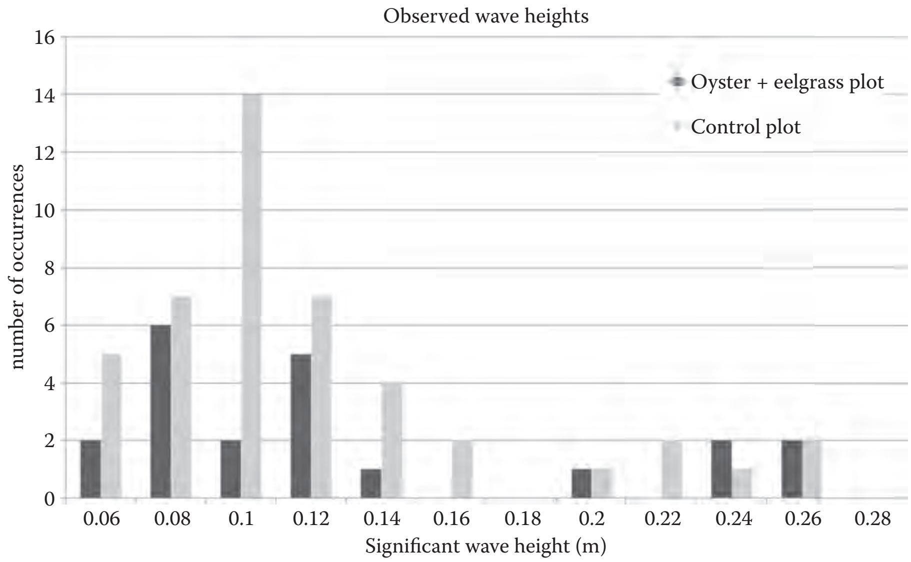


Figure 17.12 Wave heights measured on the shore side of the oyster + eelgrass and control plots at the San Rafael site, February 26, 2013, to April 15, 2013. There were a total of 45 significant waves measured in-shore of the control plot and 21 significant waves measured in-shore of the oyster + eelgrass plot for the sampling duration, indicating that the latter limits significant wave occurrences.

to be the best at supporting oysters for the longest at this site, in contrast to the oyster shell bags and lower tidal elevations performing best at San Rafael. This difference is likely attributed to predation by the Atlantic oyster drill, *Urosalpinx cinerea*, which is more abundant at lower tidal elevations, where it exerts greater predation pressure (as confirmed by field experiments at the site, in which >50% of oysters were killed on substrates placed at +7 cm MLLW within a month, but no predation occurred on substrates placed at +37 cm). The drill is not present at the San Rafael site.

17.6.2.3 Epibenthic Invertebrate Response

Trapping results at Hayward showed that shore crab (*Hemigrapsus oregonensis*) abundances increased within the treatment area relative to the control area and preproject conditions. Eastern mud snails (*I. obsoleta*) were by far the most common invertebrates in traps, with hundreds found per trap in some seasons but no difference with added structure relative to the control area. Suction sampling of epibenthic invertebrates on the oyster shell mounds and eelgrass plots indicated that the mounds developed a distinct community relative to eelgrass when the eelgrass was still present, but in general, there was much overlap in assemblage characteristics with the control area and preproject conditions, perhaps because of the small footprint of the added structure at this site (Pinnell 2016).

17.6.2.4 Fish Response

Only trapping was conducted to assess fish use of this site, in the treatment area versus control (unmanipulated) area. Besides leopard sharks (*T. semifasciata*), which were commonly caught in both control and treatment areas, only one to three individuals of other species were caught (barred surfperch [*Amphistichus argenteus*], Pacific staghorn sculpin [*Leptocottus armatus*], topsmelt [*Atherinops affinis*], jacksmelt [*Atherinopsis californiensis*], Pacific sand dab [*Citharichthys* *sordidus*], and sevengill shark [*Notorynchus cepedianus*]) over the course of the project to date, making it impossible to discern patterns relative to the addition of reef structure (and eelgrass before the end of 2013).

17.6.2.5 Bird and Infaunal Invertebrate Response

Although the footprint of the treatment area was substantially smaller at Hayward than at San Rafael, the same zone arrangement was used to assess bird and infauna responses to treatments and for consistency between the two sites. While avian diversity and richness were higher at San Rafael, both pre- and postinstallation avian densities were higher at the Hayward treatment and control sites, where small shorebirds predominated. Even with the small project footprint, wader species increased substantially (ANCOVA, $F_{1,117} = 3.52$, $p = 0.063$) postinstallation in the treatment area at Hayward. As at San Rafael, the Hayward treatment area was used primarily for foraging at low tide and nonforaging (resting, preening, etc.) behaviors at high tide. We observed a substantial increase in bivalves in the first posttreatment installation sampling period. Several years of monitoring at this site have established a baseline of avian and infaunal invertebrate characteristics that will be very useful if larger-scale restoration projects go forward in the future.

17.6.2.6 Physical Effects

Subsidence of the individual elements at Hayward was similar to San Rafael and was not found to differ by substrate type. The small-scale treatments did not allow for physical monitoring of wave attenuation and sediment accretion.

17.7 PROGRESS IN ADDRESSING THE PROJECT'S OBJECTIVES

17.7.1 Objective 1: Use a Pilot-Scale, Experimental Approach to Establish Native Oysters and Eelgrass at Multiple Locations in San Francisco Bay

As this project is the first living shorelines design carried out in San Francisco Bay and one of few focused on native oyster and eelgrass habitats on the West Coast, it was important to start small to gain acceptance for such projects among regulators and the public. However, we recognized the need for the project to be large enough to allow assessment of physical effects along shorelines and to attract species that require a larger habitat area for food or refuge services. Thus, at the San Rafael site, we chose a size deemed large enough to meet our science goals but small enough to still be a reasonable pilot project to install and permit.

An experimental approach was important to the project team, as we wished to understand the successes and shortcomings of the restoration project in a rigorous way. However, we settled on only one replicate of each treatment type at the San Rafael site because of space limitation on the San Rafael Shoreline parcel (owned by The Nature Conservancy). Also, current regulatory policies limit the amount of fill (including oyster shell) that can be placed in the estuary; thus, our project team worked thoughtfully to limit the overall size of the installation to meet current permit requirements, while carefully experimenting with methods and techniques to construct the largest reefs in San Francisco Bay to date. The goal of this pilot project is to learn what materials, designs, and approaches work best, ideally leading to additional pilot projects at more sites and also larger-scale projects of this type in the future. From the standpoint of statistical analysis, having only one plot per treatment type means that replicate samples within a plot are not true replicates, as they are not interspersed with other treatment types across the space of the San Rafael property. The risk in interpreting data with only the four large plots spread across the site is that there could be other differences across that space that are not related to the treatments (e.g., sedimentation), thus confounding interpretation of differences by treatment. Still, with care in interpretation, we can say quite a bit about how the treatments evolved habitat and physical functioning characteristics over time and relative to each other. For the smaller-scale comparison of oyster substrates, we were able to achieve true replication at both the San Rafael and Hayward sites, making a rigorous comparison of treatments possible statistically for a number of measures.

We intended to repeat the same design in multiple locations around the bay so that we could determine how environmental context influenced our results; however, we found it difficult to identify locations that met our site selection criteria (e.g., simple bathymetry, relative ease of access, appropriate depths for eelgrass and oysters, willing landowners, etc.) and thus began with just one larger-scale project in this first phase of the work. At Hayward, many of our site selection criteria were met; however, we felt we did not have enough information about the site to be confident that we could establish both oysters and eelgrass and were unwilling to scale up to a larger project until that was achieved.

The project team is assessing seven candidates sites in SF Bay for a next-phase living shorelines project, to actively enhance four native foundation species: eelgrass and Olympia oysters as in the current project, as well as the tidal marsh plants Pacific cordgrass (*Spartina foliosa*) and marsh gumplant (*Grindelia stricta*). Our integrated approach involves restoring these habitats as a linked gradient from marsh to intertidal reefs and subtidal aquatic beds, to increase habitat connectivity and structure and promote both restoration goals and physical goals such as wave attenuation.

17.7.2 Objective 2: Compare the Effectiveness of Different Restoration Treatments in Establishing These Habitat-Forming Species

We have used five approaches to address the effectiveness of different restoration treatments in establishing native oysters and eelgrass. **First**, our project explicitly aimed to test whether restoring oysters and eelgrass together versus each organism alone would improve outcomes for either species. This test entails evaluating eelgrass growth patterns (densities, heights, etc.) when eelgrass is grown alone versus in proximity to oyster shell reef, and similarly by assessing oyster growth patterns (densities and sizes) when oyster shell reef is restored alone versus in proximity to eelgrass. **Second**, we tested five types of oyster settlement substrates to determine which would perform the best. In the ideal, a substrate would promote native oyster recruitment, growth, and survival, while discouraging the growth of nonnative species; would not be prone to sinking into soft sediment substrates; and would not cause significant scour, or accumulate large amounts of sediment. Obviously, restoration substrates also need to maintain their structural integrity over time or until biogenic species can add or maintain physical structure independently. **Third**, we tested transplants versus seeding of eelgrass at the San Rafael site. **Fourth**, we tested whether the donor (the natural bed collected from) mattered to the outcomes achieved for eelgrass establishment and development of functional attributes of the restored eelgrass. **Fifth**, we assessed whether the position on oyster elements or the placement of whole oyster settlement substrates at different elevations would influence the effectiveness of native oyster success.

For the first approach, several lines of evidence suggest that there is a benefit to restoring native oysters and eelgrass together. Although trapping has caught a limited number of individuals, a few species of fish were found among oyster reefs at San Rafael only when eelgrass was also present. In addition, suction sampling of epibenthic invertebrates showed that the eelgrass in the combined eelgrass + oyster treatment at San Rafael supported additional species found in the oyster-only plots as well as those found in the eelgrass-only plot. On the other hand, we have not found benefits of oyster reef presence to eelgrass growth characteristics (and in fact eelgrass spread is likely to be limited by the surrounding oyster reefs in our checkerboard design), nor have we seen oyster abundance or size increase in the presence of eelgrass. At Hayward, eelgrass was present for a limited time; thus, we are unable to assess this effect there. We are also collecting stable isotope samples from the common producer and consumer species at the San Rafael site, and these may prove useful in indicating how the food web may differ in either habitat with the presence of the other species and associated species in that habitat. Further, stable isotope analysis should allow us to disentangle trophic links within and among those different treatments, to assess the level of connectivity with adjacent habitats (bare mudflat, marsh) and to identify the main sources of organic matter fueling the food webs and supporting target restoration species' growth. In order to adequately test for effects of dual restoration, we need additional sites where oysters and eelgrass are restored both together and separately, although we suggest greater spacing between oyster reefs and eelgrass in future projects.

For our second approach, we found that oysters performed equally well across the various types of baycrete structures at San Rafael, with one exception—there were far fewer oysters on layer cakes. This was likely because oysters generally did better on vertical versus horizontal surfaces, and layer cake surface area is primarily horizontal. Shell bag mounds outperformed all baycrete structures in terms of number of oysters on a per-element basis. Two element types appear to have less structural integrity than the others: layer cakes and small reef ball stacks, both of which are beginning to shift or break down. Very little sediment accumulated on the surfaces of baycrete elements (generally <2 mm). While shell bag mounds did trap significant amounts of sediment on the lower portions, they still outperformed the baycrete elements. We have not formally analyzed the cover of nonnative species, but the sponges, tunicates, and large arborescent bryozoans found particularly at lower tidal elevations on the elements are not present inside the shell bags.

At Hayward, oysters recruited initially to shell bags only, but currently longer-term survival appears to be best on the oyster blocks, with the other baycrete structures doing less well (layer cakes were not included at this site because of the expectation that they would not hold up under high wave action). This may be because the oyster block elements at Hayward have more vertical surface area at higher tidal elevations than the other structures, which appears to discourage oyster drills.

For our third approach, we were only able to use buoy-deployed seeding at the San Rafael site and flowering shoots only from the Point San Pablo donor site, as flowering shoots were not available at the time of our late summer project start for the other three populations used as donors for transplant material. At San Rafael, we did not detect seedling recruitment in the spring of 2013 after buoy-deployed seeding, and we did not repeat seeding after we conducted the second transplant that April; we would not have had flowering shoots available until summer and did not want to risk damaging transplants by adding the seed buoys into the plots afterward. Thus, in comparing the two methods of eelgrass establishment, we conclude that transplanting whole shoots was the more effective technique overall, in terms of both availability of propagules and success of establishment. However, we still recommend seeding when possible because sexual reproduction can increase the genetic diversity of restored stock and may therefore increase the resiliency of eelgrass to perturbations at restoration sites over time.

In our fourth approach, the Point Molate donor bed initially showed a trend of greater transplant success at San Rafael, with higher overall densities than the Point San Pablo donor. This trend continued and became magnified over time, especially in the eelgrass-only plot. We suggest that Point Molate eelgrass may be better adapted to the sediment conditions found at San Rafael, as both sites have a higher proportion of fine sediments than at Point San Pablo (Boyer and Wyllie-Echeverria 2010). Although we found no difference in growth characteristics between the two donors used at the Hayward site in the limited time we had to assess the eelgrass, the trend of differential success among donors at San Rafael, and similar evidence from previous projects (Lewis and Boyer 2014), lends support to our hypothesis that donor choice can matter to restoration success.

In our fifth and final approach to assessing restoration techniques, we found tidal height, surface orientation, and direction to have strong effects on oyster density at the San Rafael site, although these effects decreased over time. Across all element types at San Rafael for the first several sampling periods, more oysters were present at the lower and mid-level elevations than at the high elevation. More oysters were present on the north side than on the south side and on vertical versus horizontal faces. While longer immersion times could explain greater abundance at lower tidal elevations, the north–south and surface orientation differences strongly suggest that heat or desiccation stress was a factor in determining initial oyster abundance at San Rafael. Oyster abundances at the mid- and low tidal elevations began to decline in spring 2014, while those at the highest elevation remained unchanged, and as of July 2015, densities at all tidal elevations were similar. This decrease is likely concurrent with our observed increase in fouling species, particularly bryozoans, sponges, and algae at these lower tidal elevations, which may compete with oyster spat for settlement space or overgrow adult oysters. At Hayward, while oysters recruited initially to shell bags and then to the interior surfaces of the large oyster balls, two structure types that would be expected to be the best in mitigating heat and desiccation stress, more oysters are currently found on the higher elevations of oysters blocks and large reef balls. As mentioned above, this is likely attributed to predation by the Atlantic oyster drill *U. cinerea*, which is more abundant at the lower elevations. Results from this work and elsewhere (e.g., Trimble et al. 2009) indicate that oysters generally settle in higher numbers and grow faster at lower tidal elevations. At Hayward, this nonnative predator may thus be restricting oysters to a nonoptimal tidal elevation.

17.7.3 Objective 3: Determine the Extent to Which Restoration Treatments Enhance Habitat for Invertebrates, Fish, and Birds, Relative to Areas Lacking Structure and Pretreatment Conditions

We have accumulated evidence that providing the physical structure of our project design attracted mobile invertebrates that benefit from such structure. Preliminary data suggest that several fish species of concern visited the project site at San Rafael, although additional analysis is necessary to evaluate these patterns. At both San Rafael and Hayward, wading bird presence increased after the placement of reef structures, and at San Rafael, black oystercatchers and Forster's terns are utilizing the reefs for foraging and roosting. Additional monitoring is necessary to determine how the strengths of these relationships develop over time.

17.7.4 Objective 4: Determine if the Type of Treatment (e.g., Oyster Reefs, Eelgrass Plantings, or Combinations of Oyster Reefs and Eelgrass) Influences Habitat Values Differently

Preliminarily, we can conclude from the San Rafael experiment that certain species are benefited more by one substrate than the other. Black oystercatchers and wading birds increased in the presence of the oyster reef structures. Black surfperch and bay pipefish were shown to have a greater association with eelgrass habitat than with oyster-only or control plots, and epibenthic invertebrate assemblages are beginning to become differentiated between the eelgrass and oyster reef habitats. Eelgrass presence increased the occurrence of certain fish species among oyster reef structures (bay pipefish, shiner surfperch, and saddleback gunnel), suggesting that restoring the two habitats in proximity to each other can increase the richness of species present.

17.7.5 Objective 5: Begin to Evaluate Potential for Subtidal Restoration to Enhance Functioning of Nearby Intertidal Mudflat, Creek, and Marsh Habitats (e.g., by Providing Food Resources to Species That Move among Habitats)

As we do not have marsh or creek habitat in proximity to the San Rafael site, we are not able to determine the degree to which our added structures influence functioning or provide subsidies to these habitats. We are able to say that increasing physical structure enhances functions relative to mudflats, at least for species that benefit from the refuge and food resources that are provided by our project. An increase in wading birds and in black oystercatchers through the addition of our project is a good indication that certain guilds of birds are benefiting.

17.7.6 Objective 6: Evaluate Potential for Living Subtidal Features to Reduce Water Flow Velocities, Attenuate Waves, and Increase Sedimentation, and Assess whether Different Restoration Treatments Influence Physical Processes Differently

Our measurements of physical processes have shown accumulation of sediment adjacent to the reefs, but only a small impact on accretion across the whole area of the project; additional measurements are needed over time to assess this trend. We observed less and shorter-term subsidence of the reefs in soft sediment than we expected. Our data showing only a 10-cm subsidence into the sediments, which ended after 5 months, suggest that even in the very soft sediments of the San Rafael site, sinking of reef structures is not a great concern. Sediment accumulating around the oyster shell bags means that these are unlikely to support oyster survival at the lower elevations. This led us to include only the upper portions of the reefs in our estimates of oyster abundance and also suggests that future projects should consider this issue when predicting habitat availability on the reefs. Since, with the exception of the layer cakes and small reef ball stacks, the different element types appear to have performed similarly in terms of stability, the choice for the construction of future reefs should be made based on their performance in oyster habitat terms, which may point to the use of shell bags, reef balls, or perhaps oyster blocks (based on the Hayward results). Future deployments should allow for the loss of available space for oysters owing to subsidence and sedimentation. Larger elements, if used in the future, will tend to subside more.

Our reefs achieved a reduction in wave energy (30%) more so than the broad mudflat alone at MTL; however, we are cautious in our interpretation of this result considering we measured only a limited combination of waves and water levels. Ideally, we would have similar reefs located in multiple locations with different slopes and wave regimes to permit further assessment of such structures in attenuating wave energy along San Francisco Bay shorelines.

17.7.7 Objective 7: Determine if Position in the Bay, and the Specific Environmental Context at That Location, Influences Foundational Species Establishment, Habitat Provision, and Physical Processes Conferred by Restoration Treatments

Although we currently have just two project sites to compare, and only the small substrate comparison that can be made at the Hayward site, there are a number of preliminary conclusions we can draw about the effects of environmental context. For example, eelgrass persistence and spread was far superior at San Rafael, perhaps because of much less exposure on the low tides in this deeper site or because of the Eastern mud snails at Hayward (not present at San Rafael) weighing down the plants or blocking light to the leaves with their egg masses. In addition, oyster shell bags easily outperformed other substrates in terms of oyster recruitment at San Rafael, but at Hayward, oyster blocks appeared to be the best. A shell bag element offers more surface area than any of the baycrete elements and greater protection from heat or desiccation stress attributed to more shading and water retention and perhaps the somewhat lower tidal elevation relative to the baycrete structures. However, at Hayward, where predation pressure is strong and greater at lower elevations, taller structures with more exposed surfaces have ultimately outperformed shell bags. Thus, it appears that selection of optimal substrate needs to be guided by an understanding of the key stressors for eelgrass and oysters at each site. Having additional sites at which to deploy test substrates and measure potential stressors would be useful to further refine site-specific design criteria.

17.7.8 Objective 8: Where Possible, Compare the Ability to Establish Restoration Treatments, Habitat Functions, and Physical Changes along Mudflats/Wetlands versus Armored Shores

At this point, our project does not include a comparison of a soft shoreline versus hardened shoreline environment. A future project at Hayward could accomplish this by comparing areas north (riprap) and south (marsh) of Mount Eden Creek. We are working to identify additional areas where such a comparison could be made in future phases of the work, which we also intend to include active restoration of foundational marsh plant species in an integrated design with eelgrass and oyster reefs, as described earlier.

17.8 FUTURE DESIGN CRITERIA

So far, we are able to draw the following conclusions toward future designs:

- This project and several others (Boyer, unpublished data) suggest that eelgrass should be restored early in the growing season; we did not have success in establishing eelgrass at either site in late July and early August 2012. Our second planting in April and early May 2013 was much more successful at both sites (although the Hayward site failed to support eelgrass by fall/winter 2013).
- We can eliminate two of the baycrete element designs: layer cakes and small reef ball stacks. Neither stands up well structurally over time, and layer cakes have fewer oysters compared with other configurations.
- Key stressors for oysters vary with location within San Francisco Bay and may also shift over the life of a restoration project. It is unlikely that there is a single best design that can be used across estuaries or even within the Bay. Identifying potential stressors and taking these into account in project design may increase project success. For example, shell bags potentially offer protection from heat and desiccation stress and provide a lot of complex surface area for oysters and other organisms to attach to and live in, and greater recruitment and faster growth may occur at lower tidal elevations, but surfaces and tidal elevations that are more stressful in terms of exposure may provide oysters with some measure of protection from marine predators and nonnative fouling species where these species are a concern, especially over the longer term.
- Where possible, pre–site selection surveys and experimental deployments should evaluate longer-term survival as well as recruitment of oysters over several tidal elevations. This might help us identify the “sweet spot” for oysters that provides the best balance between the biotic and abiotic stresses associated with different tidal elevations.
- Additional protection from oyster predators and cover of fouling species might be gained by encouraging larger mobile predators (such as cancrid crabs) and mesograzers to settle on restoration substrates. Future designs might include developing substrate types and configurations that attract large crabs and fish.
- We tentatively suggest that restoration projects incorporating both oyster reef and eelgrass together should be considered; although neither species appears to be benefiting from the other so far, the preliminary evidence that differences in the two habitats encourage a greater number of invertebrate and fish species suggests that their co-location will maximize habitat value. A different configuration for integrating oysters and eelgrass, including spacing them farther apart, might reduce the negative impacts on eelgrass noted in this project.
- Oyster reef designs should consider the fact that the lower portion of elements will experience sediment burial. Future designs could be elevated on materials (such as oyster blocks made of baycrete) that are less difficult to source than bags of Pacific oyster shell, which will be less available in the future.
- Wave energy reduction measured in our San Rafael project is encouraging, but we recommend additional sites be used for similar projects and measurements in order to determine optimal designs and the need for site-specific differences in reef configuration.

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APPENDIX

Taxon	Abbreviation	Site	Survey
Annelids			
Oligochaete	OLIsp	SR, KB, PM, H	su, sh
Polychaete	POLsp	SR, KB, PM, H	su, sh
Crustaceans			
Crabs			
Cancer maenas	CANMAE	SR, H	t
Cancer productus	CANPRO	SR	t
Hemigrapsus oregonensis	HEMORE	SR, H	t
Megalopae	Megal	SR, KB, PM	sh
Metacarcinus magister	METMAG	SR, H	t
Pugettia productus	PUGPRO	SR	t
Romaleon antennarium	ROMANT	SR	t
Amphipods			
Ampelisca sp.	AMPsp	SR	su, sh
Ampithoe valida	AMPVAL	SR, KB, PM, H	su, sh
Caprella californica	CAPCAL	SR	sh
Caprella sp. (incl. juveniles)	CAPsp	SR, KB, PM, H	su, sh
Corophidae (incl. *Monocorophium* sp.)	CORsp	SR, KB, PM, H	su, sh
Gammarus sp.	GAMsp	SR, PM, H	su, sh
Grandidierella japonica	GRAJAP	SR, KB, PM, H	su, sh
Jassa sp.	JASsp	SR, KB	su, sh
Paradexamine sp.	PARsp	SR, KB, PM, H	su, sh
Isopods			
Isopod	ISOsp	SR, PM, H	su, sh
Pentidotea resecata	PENRES	KB, PM	sh
Shrimp			
Cumacean	CUMsp	SR, H	su, sh
Shrimp (incl. *Crangon franciscorum* and *Palaemon macrodactylus*)	Shrimp	SR	t

Other crustaceans			
Cirripedia	CIRsp	SR, H	su, sh
Copepod	COPsp	SR, KB, PM, H	su, sh
Ostracod	OSTsp	SR, H	su, sh
Bivalves			
Gemma gemma	GEMGEM	SR, H	su
Potamocorbula amurensis	POTAMU	SR, H	su
Siliqua patula	SILPAT	H	su
Gastropods			
Ilyanassa obsoleta	ILYOBS	H	t
Patella sp.	PATsp	SR	sh
Phyllaplysia taylori	PHYTAY	SR, PM	sh
Urosalpinx cinerea	UROCIN	H	su
Snail (round)	Snail 1	SR, KB, PM, H	su, sh
Snail (cork)	Snail 2	SR, H	su, sh

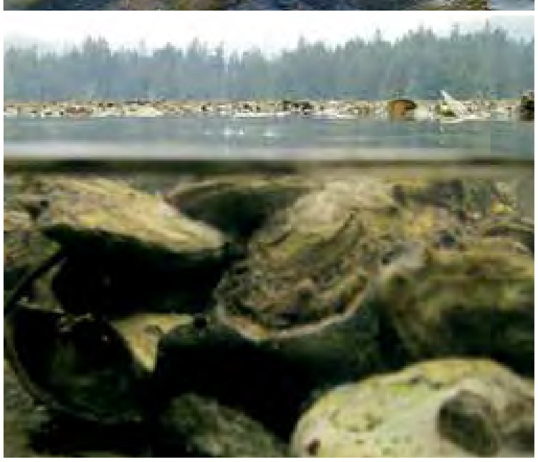
Exhibit 7

A Guide to Olympia Oyster Restoration and Conservation

ENVIRONMENTAL CONDITIONS AND SITES THAT SUPPORT SUSTAINABLE POPULATIONS

California State University Fullerton
Smithsonian Institution
Coastal Conservancy
National Estuarine Research Reserve System
Elkhorn Slough Foundation Since 1982
UC Davis
San Francisco State University
California Fish & Wildlife






A Guide to Olympia Oyster Restoration and Conservation

ENVIRONMENTAL CONDITIONS AND SITES THAT SUPPORT SUSTAINABLE POPULATIONS

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Contents

Synopsis

This guide identifies key environmental conditions that affect Olympia oysters. A qualitative evaluation of 28 embayments along much of the range of the species identifies the areas at risk due to low population sizes or unreliable recruitment, and characterizes patterns of exposure to stressors. The most frequently encountered stressors were sedimentation and predation. Competition, cold water temperatures, warm air temperatures, and freshwater inputs were also common concerns at many bays. Quantitative site evaluations incorporating oyster attributes and environmental conditions were conducted at six estuaries in California and Oregon to prioritize sites for conservation value and restoration potential. Development of an online site evaluation tool allows end-users to conduct similar evaluations in new regions, thereby guiding future restoration and management efforts.

Executive Summary

High densities of Olympia oysters at China Camp State Park, San Francisco Bay, California.

The Olympia oyster *(Ostrea lurida)* has declined at many estuaries in its native range along the Pacific coast from Baja California to British Columbia. In the past decade, efforts have begun to conserve, enhance or restore Olympia oyster populations. The purpose of this guide is to inform these initiatives, with emphasis on environmental conditions that will foster success.

Sustainable oyster populations exhibit a suite of attributes, including large adult population size, high density on hard substrates, high and reliable rate of juvenile recruitment, diversity of size classes, and high survival rate.

Numerous environmental factors affect these attributes of sustainable oyster populations. Based on results from field monitoring and laboratory experiments, combined with a thorough literature review and our own expert opinions, we determined how sensitive Olympia oysters are to a variety of potential stressors. We found that Olympia oysters are highly sensitive to sedimentation and freshwater inputs, and moderately sensitive to excessively cold water temperature, high air temperature, food limitation, predation, and hypoxia. In contrast, sensitivity to a variety of other environmental factors currently appears to be relatively low; these factors include high water temperature, contaminants, competition, acidification, sea level rise, pathogens and diseases.

In addition to examining sensitivities of Olympia oysters to a variety of environmental factors, we characterized their exposure to these stressors. This is an important distinction, because oysters may be quite sensitive to an environmental factor and yet this is not relevant for management if they are rarely

Researcher examining oysters in Nootka Sound, Vancouver Island, British Columbia.

Into the cold bay
Place oysters where they can best
Survive stressful times

exposed to this factor in a given location. We solicited assessments by local experts of exposure to stressors in 28 embayments across much of the range of the species.

Sedimentation was by far the most commonly encountered stressor, affecting populations in 71% of the embayments examined. Predation by drills and by other species was the next most common, identified as significant at 43% of embayments. Competition, cold water temperatures, warm air temperatures, and freshwater inputs also frequently pose threats to oysters (at 25–39% of embayments). Other stressors appear to be less common across this broad range; hypoxia, food limitation, contaminants, disease, warm water temperatures and acidification were identified as important at fewer than 20% of embayments, although at these places they may play a significant role.

This evaluation of 28 embayments provides an unprecedented synthesis of stressors faced by Olympia oysters across much of the range of the species. This comparison also yields insights into the status of oyster populations. The regional comparison identified that 21% of embayments experience many years with zero or near-zero recruitment of juveniles, which poses a threat to their long-term sustainability. Adult population sizes were also estimated. At 39% of embayments, there are estimated to be more than 1 million oysters present. While this is perhaps still a fraction of historical population sizes, these larger populations are likely to be fairly stable. At 43% of the embayments, populations were estimated at between 10,000 and 1 million individuals, which may raise some concern for their sustainability without management intervention. At 18% of embayments, estimates indicated that fewer than 10,000 oysters were present. These areas are excellent candidates for additional conservation and restoration efforts.

In addition to the broad comparisons among embayments, we also conducted much more detailed evaluations of sites within some of them. We incorporated quantitative field data on oyster attributes and environmental conditions into tables that served to prioritize sites for oyster conservation or restoration. We conducted such site evaluations at six estuaries in Oregon and California. We also developed an online site evaluation tool (available at www.climate-and-oysters.org) that can be applied by any user to assess other sites with new data.

This approach to quantifying the relative conservation value and restoration potential of multiple sites can be used to inform management actions. Agencies, nongovernmental organizations, community groups, or others considering the launch of a new restoration project can determine whether a particular site is likely to yield success. Funding agencies can use scores to help evaluate multiple restoration proposals and regulatory agencies can use the scores to direct policy protecting valuable existing populations.

In summary, this guide supports Olympia oyster conservation and restoration by enhancing the understanding of the attributes of sustainable oyster populations, the environmental conditions that most strongly affect them, and the embayments and specific sites that best support them.

Background

Purpose and development of this guide

The purpose of this guide is to inform restoration and conservation of Olympia oysters *(Ostrea lurida)*. It was prepared by an interdisciplinary team funded by NOAA's National Estuarine Research Reserve Science Collaborative from 2011 to 2015. We first completed a guide for Central California in close collaboration with stakeholders and with substantial new data from field monitoring and laboratory experiments (Wasson et al. 2014). The current guide is an update of the earlier one, including evaluation of embayments along much of the range of the species, and incorporating input from oyster researchers and literature from other regions to increase generality. The intended audience includes oyster restoration practitioners, restoration scientists, and organizations involved in planning, funding, or permitting restoration and conservation.

Top: dense oyster recruitment on the San Francisco Bay Living Shorelines Project. Above: spreading shell for restoration in Netarts Bay, Oregon.

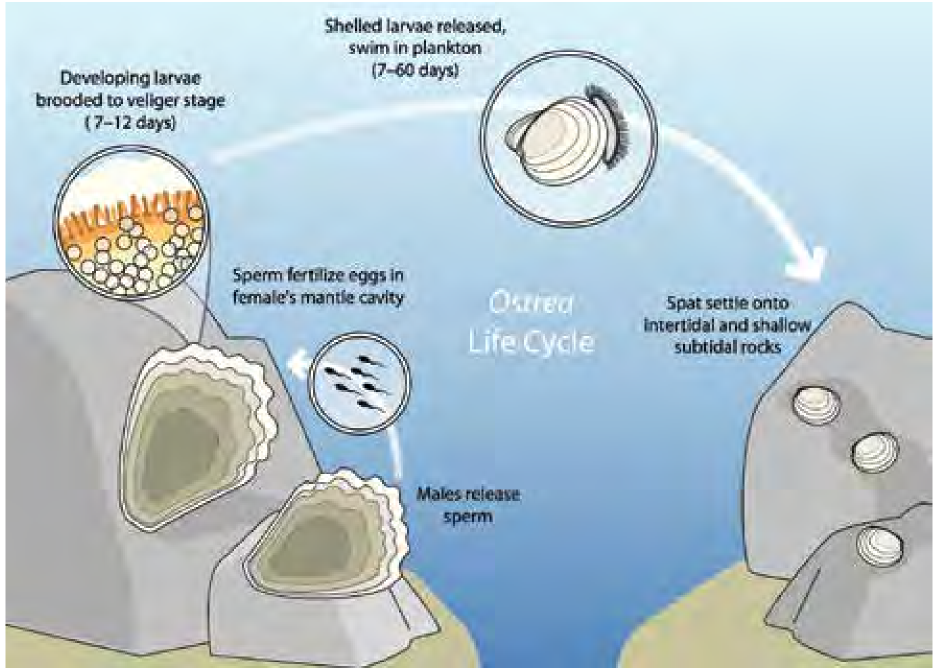
We characterized oyster populations and environmental factors that affected them at two spatial scales. Most broadly, we compared oysters and environmental stressors across much of the range of the species, to identify key opportunities and threats. At a much narrower spatial scale, but with greater depth, we also conducted site evaluations intended to aid end-users in prioritizing sites within particular embayments. We conducted site evaluations in Central California (Wasson et al. 2014), Southern California (Appendix 1) and southern Oregon (Appendix 2).

This is not a "how to" manual for field restoration methods, nor does it address the human processes that are essential for restoration and conservation (permitting, community support, public outreach, etc.). Guides that address these issues are sorely needed and would complement the current effort.

Olympia oysters: challenges and opportunities

LIFE-CYCLE AND ECOLOGY

Olympia oysters are primarily estuarine and generally not found on the open coast (Baker 1995). In Central California, they are most abundant around the 0-meter tide mark, Mean Lower Low Water (MLLW), and in Southern California at –0.3 m (authors' unpublished data), but have been reported from as high as 1 m above MLLW to depths of 10 m (Baker 1995). They require hard substrate on which to settle. They are sequential hermaphrodites—typically, but not always, starting out as males—and may switch sexes twice within the course of a year (Moore et al. in prep.). Females brood larvae in their mantles for 7–12 days (Coe 1931, Hopkins



Schematic of Olympia oyster life cycle. Adult males release sperm that is taken up by nearby females. Eggs are fertilized within the mantle cavity and developing larvae are brooded to the veliger stage, released into the plankton, and transported with tides and currents. Larvae settle irreversibly onto hard substrate as juvenile oysters and grow to sexual maturity within months to a year. (Julia C. Blum)

1936, Strathmann 1987), after which they are released to swim in the plankton for 5 days (authors' personal observations) to 4 weeks (Breese 1953).

Large adult oysters sharing space with bay mussels at the Berkeley Marina, San Francisco Bay.

TRENDS IN DISTRIBUTION AND ABUNDANCE

Olympia oysters range from Central Baja California, Mexico, to British Columbia, Canada (Polson and Zacherl 2009). Abundance varies enormously from scant, but persistent, populations consisting of a handful of individuals, to locations with nearly 100 percent cover of oysters on hard substrates at MLLW (authors' personal observations). In most locations, the size of the pre-European-contact population is unknown. However, there were sufficient populations in many locations, including San Francisco Bay prior to the Gold Rush, to support a commercial fishery (Conte and Dupuy 1982; reviewed in Zu Ermgassen et al. 2012). Based on a review of the former extent of commercial oyster grounds from the earliest available records (mid-1800s to early 1900s), Zu Ermgassen et al. (2012) estimated oyster grounds in Puget Sound, Humboldt Bay, San Francisco Bay, Elkhorn Slough and Mission Bay to be at 1% of historic levels.

CONSERVATION AND RESTORATION

The earliest efforts to restore Olympia oysters began in Puget Sound in 1999 (Peter-Contesse and Peabody 2005) and included seeding oyster shell and large-scale deployment of Pacific oyster shell for natural set. Current smaller-scale projects in Oregon and in Central and Southern California range from deploying small structures to assess recruitment patterns and best methods, to larger-scale mixed-species restoration projects with both physical and biological objectives in a "living shorelines" model.

Rocky substrate with oysters in San Francisco Bay.

Winter storm, downpour
Bay oysters shut their valves tight
Long wait to exhale

It is worth noting that the term "restoration" is used rather broadly, to describe efforts to increase regional numbers of Olympia oysters, back towards levels that were presumed to be considerably higher historically and prehistorically along the entire coast (Zu Ermgassen et al. 2012). At the level of specific sites, there is usually no information about historic oyster densities. Moreover, human activities have changed conditions such as sedimentation and freshwater inputs so that the best locations for oysters today may differ from the best historic sites. Thus, at the level of an individual site, a project may more accurately be described as oyster "enhancement" rather than "restoration".

Sedimentation rates have also increased at many estuaries, such that oysters can no longer survive on tiny bits of natural hard substrate on the bottom or the low-relief oyster reefs that Olympias may have once made. Thus, some restoration efforts provide large artificial hard substrates raised above the sediments, which result in quite different oyster habitat than was historically present.

Climate change is a challenge that must be understood and addressed as a part of restoration. Current model projections suggest rising air and water temperatures, acidification of surface waters and more frequent and severe flood events. These are likely to affect both existing oyster populations and restoration efforts. Climate change stressors may interact with and perhaps act synergistically with each other and with other anthropogenic stressors such as invasive species (for example, predatory oyster drills and potential space competitors such as the Pacific oyster *Crassostrea gigas*), high nutrient levels, and pathogens and disease. Climate change effects are not likely to be the same in all locations, nor are other anthropogenic stressors equally important everywhere. Conservation and restoration efforts require a better understanding of the importance of local environmental factors, both now and in the future.

Intertidal community with oysters.

Information sources for this guide

Stressor experiments on oysters at Bodega Marine Lab, California.

IDENTIFICATION OF KEY OYSTER ATTRIBUTES AND ENVIRONMENTAL STRESSORS

We relied heavily on our earlier guide (Wasson et al. 2014) for assessments of oyster attributes and environmental stressors. That in turn was based on extensive new field data collection and analysis at sites in central California, and laboratory experiments on stressors, both of which are described in detail in the original guide and associated appendices (Wasson et al. 2014), as well as a recent publication (Cheng et al. 2015). Both the original and current guide also involved syntheses of the existing published literature, unpublished data and observations of the authors, and personal communications from colleagues. Earlier reviews (Couch and Hassler 1989, Baker 1995, White et al. 2009) provided an excellent base for identification of key environmental factors. Many of the oyster attributes and environmental factors we included are the same as the "universal metrics" recommended for oyster restoration monitoring (Baggett et al. 2014), though we emphasize those most relevant to Olympia oysters.

EXPERT ASSESSMENTS OF WEST COAST EMBAYMENTS

We invited oyster researchers working along the entire range of the species to evaluate embayments with regard to oyster populations and environmental conditions. The assessments were not quantitative, but rather involved determining whether oyster attributes or stressors fell into "high," "medium" or "low" categories. Broad definitions of these categories (see Table 1) helped provide consistency among assessments by different experts. These expert assessments provide a basis for examining geographic patterns in status of Olympia oyster populations and in expression of stressors.

SITE EVALUATIONS

The data and approach used for site evaluations of Southern California and southern Oregon are detailed in Appendices 1 and 2, respectively. Our earlier site evaluations of Central California are detailed in Wasson et al. 2014.

Azevedo Pond in Elkhorn Slough, California.

Location of embayments where experts conducted assessments of oyster attributes and environmental stressors. Note that multiple regions within San Francisco Bay, Puget Sound, and the Strait of Georgia were assessed.

Field monitoring at the Berkeley Marina, San Francisco Bay.

Attributes of Sustainable Oyster Populations

OVERVIEW

Successful Olympia oyster populations exhibit a suite of biological attributes that we characterized and describe below. These are attributes that can be assessed at the level of individual sites, as a part of site evaluations. Two of these attributes (population size and reliability of recruitment) are also included in our comparison of entire embayments.

The attributes we have focused on include two "universal metrics" recommended for oyster restoration monitoring (Baggett et al. 204), oyster density and size frequency distribution. However, other metrics that apply to larger, reef-forming oysters such as reef height and area are not useful for Olympia oysters and were not included. Conversely, we included metrics not part of the universal recommendations, but very important to Olympia oysters such as recruitment—recruitment failure is common in this species, perhaps because of relatively low population sizes.

MODERATE-TO-HIGH ADULT DENSITIES (importance: *very high*)

The density of adult oysters at a site can serve as a cumulative indicator of its appropriateness for conservation or restoration; moderate to high adult densities result from one or more years of significant recruitment and survival. Current oyster density data are important for prioritizing conservation areas, yet some populations fluctuate from year to year and it is better to have multiple years of data for greater confidence. High oyster densities on existing substrate can be used to assess suitability for restoration at that site, provided there is existing hard substrate to begin with. In a survey of 24 locations across the species' entire range, Polson and Zacherl (2005) recorded a wide range of densities from one individual to 146.8 /m^2 , but we recorded much higher densities at several sites in San Francisco Bay in 2012–13, up to 961/ m^2 in San Francisco Bay. Densities in Newport Bay and San Diego Bay are generally much lower (up to 55/m^2 and 219/m^2, respectively). Similarly, Coos Bay sites we evaluated were generally lower (up to 76.4/m^2), although recent survey work at a mitigation site found densities as high as 1000/m^2 (S. Groth personal communication).

TOTAL ABUNDANCE AT SITE (importance: *very high)*

An order-of-magnitude estimate of the total number of oysters living at a site is a good indicator of its relative conservation value. In some cases, adult density per square meter of hard substrate may not represent density at larger scales (e.g., hectares), because there is very limited hard substrate. A site that has a million oysters within a hectare should have greater conservation value than a site that has a thousand oysters per hectare, and far greater than one that has ten oysters per hectare, even if all those sites have the same density per square meter. Therefore, it is important to establish where to draw the line around a site of interest and whether or not to include the full tidal range encompassing all colonized hard substrate. For assessments in Central California, we limited the total

Monitoring a remarkably dense population of Olympia oysters in Nootka Sound, Vancouver Island, British Columbia.

area for each site calculation to a 1-m wide band extending 300 m alongshore and centered around study transects at the tidal elevation of maximum oyster density. We were then able to use our density measurements (above) to generate order of magnitude estimates of total population. Site-level oyster population estimates in all California study bays ranged from fewer than 100 to 10,000s of individuals, with a high of estimate 100,000s of individuals at a single site in San Francisco Bay.

Broad assessments of abundance at the level of entire embayments are also useful for comparisons. Table 1 reveals that in 39% of embayments assessed, Olympia oyster populations are estimated to be above 1 million individuals. At 43%, populations are estimated at between 10,000 and 1 million oysters. However, at 18%, abundance of Olympia oysters is estimated at fewer than 10,000 individuals, which is of concern for long-term stability and persistence.

OYSTER SIZES: BROAD SIZE DISTRIBUTION (importance: *high)* AND LARGE SIZES (importance: *medium)*

The presence of oysters distributed among a broad range of size classes is a good indicator of a healthy population, indicating a combination of recent recruitment, growth, and long-term survival. Each is an important aspect of a sustainable population, but it is time-consuming and sometimes logistically challenging to measure each separately. Because recruitment can vary from year to year, the best estimates of size distribution will include several years of data. At the very least, estimates ought to be made after the recruitment season, to include newly settled juveniles. Consistent absence of particular size classes does suggest potential limitations for populations. For example, absence of small sizes might suggest recruitment limitation or absence of large size classes might indicate a lack of long-term survival. However, although a broad range of sizes is regularly seen at high quality sites in Central California, not all Olympia oyster populations show persistent evidence of previous recruitment, particularly if growth to adult size happens very quickly and subsequent growth of those same individuals is limited. We measured oysters in quadrats

Top: measuring oysters. Above: multiple age classes.

along our study transects, categorized these into 10 mm size classes, and generated a size-class diversity index using a formula typically used to compare species diversity, the Gini-Simpson index. Our sites ranged from an index of 0.25 at a location in Elkhorn Slough where all oysters were from a single recruitment event, so that size diversity was very low, to an index of 0.876, at a site in San Francisco Bay where there were many oysters in multiple size classes. Newport Bay and Southern Oregon sites were all between 0.50 and 0.77.

In addition, when we included data on the largest oysters, the table was more accurate in ranking sites that we know from previous research have had consistent recruitment and moderate to high densities of oysters over time periods longer than the current study. We used the mean of the upper quartile of oyster sizes measured in our quadrats. Across study sites, the average sizes of the largest oysters ranged from 12 mm—a site in San Francisco heavily impacted by oyster drill predation—to 66 mm at an Elkhorn Slough site. Across all bays, largest oysters were typically between 30 and 50 mm, although oysters at most Elkhorn Slough sites tended to be above 50 mm.

RECRUITMENT RATE: HIGH RECRUIT DENSITY (importance: *high)* AND RELIABLE RECRUITMENT (importance: *medium)*

Recruitment is absolutely necessary for a site to support a sustainable oyster population in the long run. Several factors influence whether or not there is high and reliable recruitment at a site, including processes affecting larval transport and retention, and the number and proximity of other colonized sites that could serve as larval sources. Estimating recruitment rate may be especially important for sites without adults where restoration actions are being considered. However, potential restoration sites that exhibit low recruitment may not need to be eliminated if seeding those sites with settled oysters is a viable option, and if this can be done at a large enough scale that a new, self-sustaining population can be formed, producing and retaining sufficient larvae. In central California, we counted recruits to standardized settlement tiles, deployed and retrieved quarterly, to arrive at a measure of recruits/unit area/day. We also calculated the coefficient of variation (CV) quarterly per site to generate a measure of reliability of recruitment; a low CV indicates a relatively consistent rate while a large one inconsistent recruitment. In Central California, quarterly average recruit density ranged from 0 at several Elkhorn Slough sites to 88 recruits/m^2/day at a San Francisco Bay site. In Southern California sites, where recruitment rate was calculated between June and October, rates ranged from 24–42 recruits/m^2/day in Newport Bay and from 136–1349 recruits/m^2/day in San Diego; measurements from southern Oregon calculated for a similar time period ranged from 3–39 recruits/m^2/day. Recruitment CV ranged from 0.5 at a Newport Bay site to ~3 at several Elkhorn sites and one in San Francisco Bay, all of which had recruitment in only one of two study years.

Table 1: Synopsis of Oyster Population Attributes and Stressors Across Range of Olympia Oyster

	Oyster Attributes		Stressors[3]														
	Population Size[1]	Recruitment[2]	Sedimentation	Predation by Drills	Predation by Other Species	Water Temp. Too Low	Competition by Pacific Oysters	Competition by Other Species	Air Temp. Too High	Low Salinity	Food Limitation	Disease/ Pathogens	Acidification	Water Temp. Too High	Contaminants	Hypoxia	Sources
CALIFORNIA																	
San Diego Bay																	S. Briley & H. Henderson, personal communication
Newport Bay																	S. Briley & D. Zacherl, personal communication
Alamitos Bay																	S. Briley & D. Zacherl, personal communication
Elkhorn Slough																	Wasson 2010, Wasson et al. 2014, Wasson, personal communication
SAN FRANCISCO BAY																	
South Bay																	Grosholz et al. 2008, Zabin et al. 2010, Wasson et al. 2014
Central Bay																	Grosholz et al. 2008, Zabin et al. 2010, Wasson et al. 2014
North Bay																	Grosholz et al. 2008, Zabin et al. 2010, Wasson et al. 2014
Tomales Bay																	Kimbro et al. 2009, E. Grosholz, personal communication
Humboldt Bay																	D. Couch & K. Ramey, personal communication
OREGON																	
South Slough																	A. Helms & B. Yednock, personal communication
Coos Bay																	A. Helms & B. Yednock, personal communication
Yaquina Bay																	D. Vander Schaaf, personal communication
Netarts Bay																	D. Vander Schaaf, personal communication
WASHINGTON																	
Willapa Bay																	Trimble et al. 2009, J. Ruesink, personal communication
PUGET SOUND																	
Henderson Inlet																	B. Allen, personal communication
Totten Inlet																	B. Allen, personal communication
Noth Bay, Case Inlet																	White et al. 2009, J. Ruesink, personal communication
Belfair, Hood Canal																	J. Ruesink and S. Valdez, personal communication
Dabob/Quilcene, Hood Canal																	J. Ruesink and S. Valdez, personal communication
Port Gamble Bay																	B. Allen, personal communication
Discovery Bay																	B. Allen, personal communication
Dyes Inlet																	B. Allen, personal communication
Liberty Bay																	B. Allen, personal communication
Fidalgo Bay																	P. Dinnel, personal communication
BRITISH COLUMBIA																	
STRAIT OF GEORGIA																	
Victoria area																	J. Carolsfeld, personal communication
Nanaimo area																	S. Dudas, personal communication
Baynes Sound area																	S. Dudas, personal communication
Quadra/Cortes Island area																	S. Dudas, personal communication

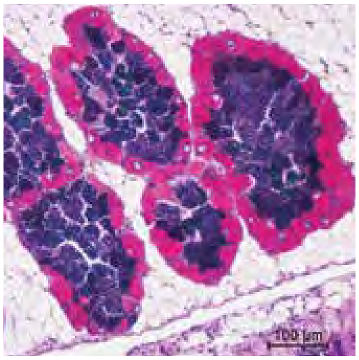
1. Population size estimate for estuary/region (intertidal and subtidal combined, even though latter is very uncertain)
   - <10,000
   - <1 million
   - >1 million

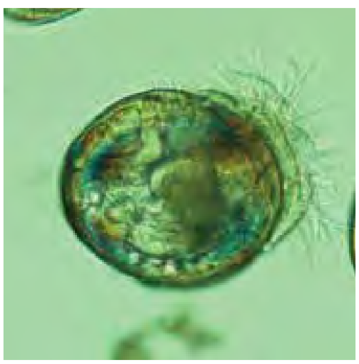
2. Recruitment assessment
   - many years with zero or near zero recruitment
   - occasional years with zero or near zero recruitment
   - no years with zero or near zero recruitment

   (for entire estuary/region)

3. Stressor assessment: negative effects include low recruitment, dieoffs of adults, or absence of oysters at otherwise favorable sites
   - stressor affects >10% of population every year or >25% every 5 years
   - significant problems, but not regularly or affecting much of the bay
   - no evidence of significant problem

Lighter colors indicate lower levels of certainty.





From top to bottom: life stages of the oyster: gonads, brooded larvae, free-swimming veligers, "spat"—settled young oysters.

Across the range of the Olympia oyster, there is reliable recruitment at some embayments (Table 1). However, at 61% of them, there are at least some years with zero or near zero recruitment. At Elkhorn Slough, Tomales Bay, South Slough, Netarts Bay, Fidalgo Bay and in the northern Strait of Georgia, there are many years with zero recruitment. Such populations may be at risk of local extinction, particularly if changing climate conditions lead to increased numbers of consecutive years with zero recruitment. The sites with unreliable recruitment were ones that did not have large (over 1 million oysters) population sizes (Table 1).

HIGH JUVENILE SURVIVAL RATE (importance: *high)*

Juvenile stages are particularly susceptible to predation and other stressors that could lead to mortality. Survival to the adult stage is critical for reproduction and the overall sustainability of a population. In many cases, high rates of juvenile survival will be reflected in a broad range of oyster sizes present at a site (with the abovementioned exceptions). Thus, while survival rates are not critical to measure *in situ,* doing so allows for a more precise understanding of why certain size classes might be missing at a site. In central California, we allowed oysters to recruit to tiles in the field and then tracked the survival and growth of these oysters. For locations that did not have natural recruitment, we deployed tiles from nearby locations that had recruitment. Across embayments measurements of survival were made on oysters of different ages and over different time scales, making direction comparisons impossible. Early survival was high in San Diego (typically 99.9%/day for 90 days) and at most Central California sites (99.9% to 99.45%/day). Survival of juveniles on tiles in Coos Bay ranged from 45 to 79% at three sites across a study period of six months (January to July) (Rimler 2014). The methods used for the site evaluation table were too different to compare among embayments.

HIGH JUVENILE GROWTH RATE (importance: *low to high)*

As noted above, juvenile oysters are generally more susceptible to predators and environmental stressors than are adult oysters, suggesting the clear benefits of growing quickly after settlement. High juvenile growth rates indicate favorable conditions (such as available food and sufficiently high salinity and dissolved oxygen) and should lead to healthy adult populations. However, sites with high food resources and warm water, which can promote growth, may also suffer from low dissolved oxygen. Additionally, low juvenile growth rate does not necessarily indicate poor field conditions. Growth may be limited by high recruitment densities rather than by a lack of food or by other unfavorable conditions. Marking and remeasuring oysters is time-consuming. Size-class distribution calculations, as mentioned above, provide indirect measurements of growth and survival. Such calculations could be substituted for direct measurement in sites with existing oyster populations. For sites without oysters or with few oysters, deploying settled oysters on tiles, as we did, to observe growth and mortality, can indicate whether conditions at a site are appropriate for restoration with seeded oysters. Across embayments growth

Top: tracking survival and growth of oysters on monitoring tiles. Middle: Olympia oyster spat on Pacific oyster shell. Above: juvenile Olympia oysters on eelgrass.

measurements were made on oysters of different ages and over different time scales, making direction comparisons impossible. For Central California, growth ranged from 0.037 mm/day at one San Francisco Bay site to 0.11 mm/day at four Elkhorn Slough and one San Francisco sites across six quarters. At San Diego Bay sites, growth of ~30 day old oysters was 0.24 to 0.39 mm/day over a two month period. In Southern Oregon growth ranged from 0.03 to 0.14 mm/day from April to July.

HIGH LARVAL CONTRIBUTION TO REGION (importance: *medium to high)*

Sites that support significant adult populations also might export larvae and be of particular conservation value to the regional population. Ideally, this information would be included in evaluating sites for conservation. Measurements of fecundity and larval connectivity can help to identify what sites might most contribute to regional larval supply, but a thorough understanding of larval sources and sinks also requires an understanding of tidal currents and other transport processes around and between sites. At present this represents a major data gap in consideration of specific sites for restoration as well as for understanding the importance of oyster populations within regions.

Using shell chemistry analysis, we were able to evaluate the relative contributions of larvae produced in regions within San Francisco Bay to other regions in the Bay in 2012. Due to low adult densities and/or low fecundity at some sites, only six sites were evaluated in this portion of our research. For the locations we evaluated, our estimates ranged from 3 million larvae exported from a South Bay site to more than 26 million exported larvae from a North Bay site (Wasson et al. 2014). Carson (2010) used shell chemistry analysis to determine the origin of newly settled spat and thus the connectivity between sites in San Diego Bay, Mission Bay, and Agua Hedionda and Batiquitos in north San Diego County. Over the course of the whole recruitment season, sites in San Diego Bay and North County supplied more than half of their own recruits, while newly settled spat in Mission Bay were almost all from the other locations. However, Carson noted that the proportions of self-recruits and the relative contributions from each bay varied between the first and second half of the summer. Source and sink dynamics also likely vary between years, so the results of these two studies should not be considered definitive.

Larvae floating free
Attach to hard surfaces
Forever settled

Environmental Stressors

OVERVIEW

The distribution and abundance of Olympia oysters are affected by numerous environmental factors. We identified those environmental factors most important to Olympia oysters. Three of these—temperature, salinity, and dissolved oxygen—are ones considered "universal metrics" to monitor for any oyster restoration project (Baggett et al. 2014).

Through our data from field monitoring and laboratory experiments, combined with a thorough review of the literature and our team's expert opinion, we determined the *sensitivity* of Olympia oysters to a variety of potential stressors. Sensitivity is the degree of responsiveness to a realistic level of the environmental factor, for instance, high mortality rates or high recruitment failure in response to a potential stressor is considered high sensitivity, while limited sublethal effects would represent low sensitivity. Below, we explain how we determined sensitivity, highlighting the data or literature used to make the assessment. However, this categorization of sensitivities should not be considered final and comprehensive; as new studies are conducted our understanding will evolve. For instance, as a result of collaboration with colleagues from a broader geographic area, our evaluations of sensitivity have already been updated from our earlier efforts for Central California (Wasson et al. 2014).

In addition to assessing sensitivity of Olympia oysters, we also evaluated their *exposure* to environmental stressors. Exposure is the actual experience that oysters have with the stressor in the field. The distinction between sensitivity and exposure is important. For instance, Olympia oysters are quite sensitive to

Table 2: Overview of Olympia Oyster Sensitivity and Exposure to Different Stressors

STRESSORS	SENSITIVITY	EXPOSURE
Sedimentation	High	High
Low salinity	High	Medium
Predation	Medium	Medium
Water temperature too low	Medium	Medium
Air temperature too high	Medium	Medium
Food limitation	Medium	Medium
Hypoxia	Medium	Low
Competition	Low	Medium
Water temperature too high	Low	Medium
Acidification	Low	Medium
Sea level rise	Low	Medium
Contaminants	Low	Medium
Disease/Pathogens	Low	Medium

KEY: LOW, MEDIUM, HIGH

HIGH: For sensitivity, this indicates teh stressor can have strong negative effects on oysters; for exposure, indicates it was considered a concern at $\geq$50% of surveyed bays

MEDIUM: For sensitivity, this indicates the stressor can have moderate negative effects on oysters; for exposure, indicates it was considered a concern at $\geq$25% of surveyed bays

LOW: For sensitivity, this indicates the stressor has few negative effects on oysters; for exposure, indicates it was considered a concern at $<$25% of surveyed bays

Sensitivity assessments were based on literature review, field data, and laboratory experiments. *Exposure* assessments were based on the evaluation of 28 bays by local experts (Table 1).

Top: large cobble provides hard substrate in Elkhorn Slough, California. Above: oysters in muddy conditions in Alamitos Bay, Southern California.

prolonged periods of low salinity. However, this is only relevant to those places that receive significant freshwater input, such as northern San Francisco Bay. The interannual variation in the amount of freshwater flow leads Olympia oyster populations to expand upstream in dry years into areas that are then inundated with fresher water in wetter years, causing mass mortality. Patterns of exposure at 28 embayments are characterized in Table 1. A summary of both sensitivity and exposure is provided in Table 2. We considered overall exposure to be high if concerns were identified (yellow or red colors) at ≥50% of embayments that were assessed; medium if ≥25% of embayments identified concerns, and low if <25% of embayments identified concerns.

Below, we review a series of environmental factors relevant to oysters. For each we first discuss sensitivity, then methods for quantifying stressor levels, and then exposure.

SEDIMENTATION (sensitivity: *high;* exposure: *high)*

Sensitivity: Olympia oysters cannot survive extended durations of burial in soft sediments. Exact tolerances to burial are not known for this species, but sedimentation has been identified as a stressor (Blake and Bradbury 2013). Other oyster species have been shown to be able to survive short-term burial (Hinchey et al. 2006), but longer-term burial can reduce recruitment and increase mortality (Lenihan 1999). Grain size is an important aspect of sedimentation (Thrush et al. 2004); while significant accumulation of fine-grained sediment could limit water circulation and challenge feeding and respiration, even complete sediment burial in coarser-grained sands may not be detrimental. Sediment types and deposition and movement rates interact with availability of larger hard substrates at a site. If the only hard substrates available to oysters at a site are limited numbers of shells of other oysters, then they cannot survive much deposition of fine sediments. However, at sites with large hard substrates, such as natural boulders or artificial rip rap, oysters can be raised above the sediment sufficiently to avoid burial. For instance, the majority of Elkhorn Slough consists of mudflats with deep fine sediments. Oysters are entirely absent from these areas, except where artificial hard substrates are available for attachment, allowing them to avoid burial (Wasson 2010). In Willapa Bay, removal of extensive accumulated shell mounds during harvesting of Olympia oysters a century or more ago may continue to hamper recovery of Olympia oyster populations, because oysters that settle on smaller, less stable substrates are more prone to burial (Trimble et al. 2009). Oysters are thus highly sensitive to sedimentation, and generally absent from areas with deep fine sediments, but this sensitivity can be mitigated with sufficiently large hard substrates. Many restoration efforts provide hard substrate for oysters through addition of bare Pacific oyster half shell, reef balls, and other techniques. One example is the Coastal Conservancy's San Francisco Bay Living Shorelines Project, which constructed reefs in 2012 with mounds of clean Pacific oyster shell, and with artificial reef methods such as structures made from cement mixed with mined oyster shell and sand. Up to 3 million native oysters have settled onto these shell bags and cement structures.

Constructed reefs with Pacific shell bags provide hard substrate in San Francisco Bay.

Assessment method: To determine potential negative effects of sedimentation on oysters at a site, both sediment depth and availability of hard substrates at the appropriate tidal elevation must be assessed. Wasson (2010) plotted the relationship between sediment depth and substrate size needed to sustain live oysters for Elkhorn Slough, but this relationship probably differs somewhat among embayments. As a general guide, the diameter of hard substrates available should be comparable to the depth of fine sediments. For example, if there are 2 cm of fine sediments at a site, then small bits of shell 2 cm in size probably can support oysters. However, if the mud is 50 cm deep, rocks 50 cm in size are needed to prevent burial and support live oysters. Other dynamic factors, such as seasonal deposition or strong currents that can turn rocks, can complicate this rule of thumb.

In stormy winters
Many oysters do perish
Empty shells linger

Exposure: Table 1 reveals that exposure to sedimentation is high, with moderate or high stressor levels reported at 71% of embayments. Thus sedimentation limits the potential distribution and abundance of oysters at many embayments. However, at some estuaries, such as San Diego Bay, there is such extensive man-made hard substrate (armored shores, cobble, rip rap) that sedimentation is not considered an important threat at many sites. In the northern part of the range, oysters are often found in less muddy habitats where they can survive on small bits of natural hard substrate.

LOW SALINITY (sensitivity: *high;* exposure: *medium)*

Sensitivity: Salinity places basic physiological constraints on all marine and estuarine organisms (Hochachka and Somero 2002), and is a fundamental determinant of where species can live in an estuary (Remane and Schlieper 1971). Although Olympia oysters tolerate a range of salinity levels, low salinity exposure is stressful, can reduce reproduction (Oates 2013), and cause death in severe cases (Gibson 1974). In a laboratory experiment, we found that juvenile Olympia oysters suffered significant mortality when exposed to salinity levels below 10 for five or more days (Cheng et al. 2015). However, our field data from Central California showed a strong negative correlation between exposure to salinity below 25 and several oyster attributes, including average size, recruitment rate, and growth (Wasson et al. 2014). Thresholds may show local adaptation and vary across regions.

Die-off of oysters at China Camp, San Francisco Bay, after prolonged heavy winter rains in 2006.

Assessment method: Salinity can be best measured with *in situ* sondes continuously collecting data, but can also be assessed with less frequent spot samples (weekly or monthly). The salinity data must then be related to thresholds relevant to oysters, which could potentially vary between locations.

Exposure: Low salinity limits the distribution or abundance of oysters at about a quarter of embayments (Table 1). For instance, in San Francisco Bay, high freshwater flow in wet years following precipitation events and snowmelt can lead to low salinity conditions and subsequent massive die-offs in oyster populations that settled during dry years (Zabin et al. 2010). In Coos Bay, oyster reproduction was lower at a site with lower salinity (Oates 2013). However other estuaries, such as Elkhorn Slough and Humboldt Bay (D. Couch, personal communication) oysters are found in strongly marine-influenced areas, with rapid flushing of freshwater and thus little exposure of oysters to prolonged salinity stress. In other embayments, spatial salinity patterns may be fairly consistent across years, such that there are brackish or freshwater areas where no oysters occur, and consistently higher salinities in the areas where oysters do occur.

PREDATION (sensitivity: *medium;* exposure: *medium)*

Sensitivity: Olympia oysters may be quite sensitive to some types of predation. In particular, studies from West Coast estuaries have shown that introduced species such as Atlantic oyster drills *(Urosalpinx cinerea)* and Japanese oyster drills *(Ocenebra inornata)* can have substantial local impacts on oyster populations (Willapa Bay, Buhle and Ruesink 2009, Tomales Bay, Kimbro et al. 2009, Humboldt Bay, Koeppel 2011, Puget Sound, Blake and Bradbury 2013). However, the importance of drill predation within a bay appears to be highly variable, due at least in part to variability of drill abundance (Buhle and Ruesink 2009, Kimbro et al. 2009, Koeppel 2011). For example, *U. cinerea* is well established in some parts of San Francisco Bay, and appears to impact populations where it is especially abundant, but it is present in low abundance or absent from many other locations. Additionally, recent work at one site in San Francisco Bay found that drill predation varied with tidal elevation: drills killed ~60% of adult oysters at +7 cm MLLW within two months, while oysters at +37 cm were not preyed upon (Kiriakopolos et al. 2014).

Crabs, particularly larger cancrid crabs, may also prey on native oysters, and pose a significant source of mortality in some locations. Koeppel (2011) reported evidence of crab predation (chipped/crushed shells) from two study sites in Humboldt Bay; in follow-up feeding trials in the laboratory *Cancer productus* readily consumed oysters attached to tiles while *Romaleon antennarium* did not. In contrast, positive effects of crabs on oysters have been found elsewhere as crabs prey on oyster drills, reducing predation pressure on oysters (Buhle and Ruesink 2009, Kimbro et al. 2009). Seastars can also exert high predation pressure in fairly marine sites (Ruesink, personal communication) Other predators, such as rays, birds and small mammals may also prey on native oysters, but to our knowledge such predation has not been quantified. Human collection of Olympia oysters is likely not a major factor in most locations, but this might

Monitoring at Elkhorn Slough, California.

change if native oyster populations become more abundant in easily accessible locations and may occur occasionally (anecdotal information reported to Zabin at Elkhorn Slough 2012).

Assessment method: Oyster drill abundance can be quantified in field transects of oyster beds. Drill densities may not correlate exactly with per capita effects on oysters, because these are also affected by availability of other prey types and potential predators of drills, as noted above. Predation by crabs, rays, birds and small mammals is harder to quantify. Manipulative experiments—such as comparing mortality in caged vs. uncaged oysters—are needed to shed light on strength of predation effects at a site.

Exposure: Significant effects of drills on oysters have been noted in 43% of embayments assessed, but drills are entirely absent from others, such as many Southern California bays, Elkhorn Slough, South Slough and Coos Bay in Oregon, and at British Columbia sites (Table 1). Predation by other species is also considered significant at 43% of embayments, with a variety of predators involved, although in many cases these impacts have not been experimentally tested or quantified. Ray and duck predation have been frequently observed at Humboldt Bay (D. Couch, personal communication); predation by crabs has been observed in Netarts Bay (D. Vander Schaaf, personal communication) and extremely high predation pressure from seastars has been observed at one site in Puget Sound, Dabob/Quilcene in Hood Canal (J. Ruesink, personal communication). Elsewhere in Puget Sound, predation by the crabs *Cancer productus* and *Cancer gracilis* and the sea stars *Pisaster brevispinus* and *Evasterias troschellii* has been observed (B. Allen, personal communication). In Totten Inlet, Henderson Inlet, and Port Gamble Bay and other historic Pacific oyster culture sites in Puget Sound a predatory

Non-native oyster drills prey on native oysters.

Non-native green crab with Olympia oysters in Nootka Sound, British Columbia.

flatworm introduced with Pacific oysters *(Koinostylochus ostreophagus)* has been noted (Blake and Bradbury 2013, B. Allen, personal communication).

WATER TEMPERATURE TOO LOW (sensitivity: *medium;* exposure: *medium)*
WATER TEMPERATURE TOO HIGH (sensitivity: *low;* exposure: *low)*

Sensitivity: Temperature is a major driver of virtually all physiological processes, such as respiration, metabolism, filtration, and excretion (Hochachka and Somero 2002). Excessively cold water can hamper oyster reproduction and growth. Numerous studies have correlated onset of reproduction or larval settlement with particular temperatures; for instance recently Oates (2013) found gametogenesis to occur at temperatures greater than 14.5°C in Coos Bay, Oregon, while other recent studies documented reproduction at a range from 12–21°C, but higher temperatures led to much faster production of larvae following reproductive onset (Santos et al. 1993). However, temperature thresholds for reproduction not only vary across different embayments but also may not show clear patterns within a system (Seale and Zacherl 2009). Our laboratory experiments showed significantly increased growth of juvenile oysters at 24 vs. 20°C (Cheng et al. 2015). Our field data from central California showed positive correlations between percentage of days with temperatures >12°C measured at a site and several oyster attributes, including growth rate, average size, recruitment rates, and adult density (Wasson et al. 2014). On the other hand, excessively warm water can have negative effects on oysters. However, such thresholds appear to occur at quite high temperatures; experiments in central California have shown that Olympia oysters have an LT50 (50% mortality) between 38 and 39°C (Brown et al. 2004, Cheng, unpublished data). Thresholds may vary across the range of the species.

Assessment method: Water temperature can best be assessed by continuous measurements taken by *in situ* instruments. To evaluate temperature conditions for oysters, these measurements can be related to thresholds. Such thresholds would probably differ across a latitudinal gradient.

For instance, for our evaluations of sites in Central California, we quantified the percentage of measurements taken that were above 12°C, because this threshold provided most significant statistical relationships with oyster attributes (Wasson et al. 2014). In Coos Bay, 15°C was used based on locally observed thresholds for reproduction (Pritchard 2014). In Newport Bay, temperature was recorded from three study sites only and critical thresholds were not known. We used the average warm-season temperature and ranked lower a site with an average of <17°C compared with others where the average was ~19°C.

Liberty Bay, Puget Sound, Washington, following enhancement project.

Exposure: Exposure to lower than optimal water temperatures is common across the range of the oyster, since fastest reproduction and growth occurs above 20°C, yet few sites have average temperatures this high. Low water temperatures were listed as a concern for 39% of embayments. One might suspect that these were mostly northern sites, but in fact there is no particular latitudinal pattern. In some more southern embayments such as Tomales Bay, sites near the mouth of the bay can have very cold summer temperatures due to strong oceanic influence and low residence time, while some more northern embayments such as in the Strait of Georgia have less direct marine influence and shallow depths that allow for substantial warming in the breeding season.

Historical data and near-term models suggest that increased sea surface temperatures have occurred and will continue to occur in estuaries worldwide (Cloern et al. 2011). Near-term warming of estuarine waters will probably be beneficial for oyster growth and reproduction, based on existing experimental work. Exposure to greater than optimal water temperatures appears to be rare in most embayments (Table 1).

AIR TEMPERATURE TOO HIGH (sensitivity: *medium;* exposure: *medium)*

Sensitivity: Air temperatures during low tide can reach and exceed oysters' thermal maximum, while water temperatures rarely reach these high levels. Our lab experiments showed that Olympia oysters can withstand high air temperatures during low tide exposure, with some mortality beginning to occur at 40°C (Wasson et al. 2014). When paired with another stressor, such as low salinity, high air temperature can have more pronounced lethal effects (Wasson et al. 2014). Oysters may also be sensitive to low air temperatures and the northern limit of the species may be set by freezing (Baker 1995), but we lack data on sensitivity and have not included this stressor here. In various bays in Oregon and Washington, significant negative effects of low air temperature have been observed, (B. Allen, personal communication).

Olympia oysters on hard substrate in Elkhorn Slough, California.

Blazing heat and air
Meet a patch of oysters bare
How will they now fare?

Assessment method: To precisely quantify low tide air temperatures, *in situ* temperature loggers deployed near the oysters are ideal. Percentage of days above a threshold, such as 40°C, can be calculated. Thresholds may show local adaptation and vary across regions.

Exposure: In our site evaluations in Central California and Oregon, we found air temperatures rarely to exceed 30°C during low tide exposure. In these areas, the lowest tides (with longest air exposure) mostly occur near dawn or dusk, resulting in low measured air temperatures at low tide. However in Washington estuaries, summer low tides often occur close to midday. In Willapa Bay, exposure to high air temperatures results in significant mortality of juvenile oysters at higher tidal elevations (Trimble et al. 2009). High air temperatures were also identified as a concern at the most southern embayments. Thus in the regional comparison (Table 1), exposure to high air temperature does not follow a clear latitudinal gradient, but rather shows some expression in both southern and northern sites, but not at intermediate ones. Such exposure is projected to increase with climate change.

Oysters in a high flow habitat in Newport Bay, California, which may enhance feeding and oxygenation.

FOOD LIMITATION (sensitivity: *medium;* exposure: *medium)*

Sensitivity: Phytoplankton (single-celled planktonic algae) serves as food for filter-feeding oysters. Both food concentration and feeding time can be limiting, for example in intertidal areas with periods of aerial exposure compared with constantly submerged subtidal areas (Kimbro et al. 2009, Deck 2011). Limited food supply can result in reduced growth, shifts in size frequency, and reduced or delayed reproductive ability in other oyster species (e.g. Hofmann et al. 1994, Powell et al. 1995). Food limitation also may lead to reduced growth and weight, and delayed time to settlement in Olympia oyster larvae (Hettinger et al. 2013). Chlorophyll concentrations also correlate with reproduction in the field in Oregon (Oates 2013). Our field data from Central California indicate that levels of chlorophyll *a* are positively correlated with oyster performance (Wasson et al. 2014).

Assessment method: To estimate phytoplankton abundance at sites, one can measure the abundance of chlorophyll *a*, a plant pigment that is commonly used as a proxy for phytoplankton biomass. Exact thresholds are not known, but concentrations below 5 µg/L during summer-fall are probably too low, and concentrations >10 µg/L are desirable.

Exposure: Little is known about whether food is limiting for Olympia oysters at many sites across their range. In Central California, some sites had levels (<5 µg/L) that may be too low to sustain successful oyster populations (Wasson et al. 2014). Food limitation was identified as a potential stressor at seven embayments in California and Oregon. Exposure to food limitation was not listed as a concern at the other 75% of embayments that were evaluated (Table 1), presumably because productivity is high in these places.

LOW OXYGEN (sensitivity: *medium;* exposure: *low)*

Sensitivity: Hypoxia is the depletion of oxygen from water, typically defined as a dissolved oxygen threshold below 2–5 mg/L (by different standards). Estuaries and near-shore systems often exhibit hypoxia as a result of eutrophication. Eutrophication stimulates the primary production of plants, which then die and are decomposed via microbial consumption, which depletes the water column of oxygen. Overproduction of plants (e.g., algae) can also reduce dissolved oxygen at night when plants respire. Worldwide, hypoxia appears to be expanding in frequency and areal extent (Diaz and Rosenberg 2008). Our experimental results suggest that diel-cycling hypoxia (modeled after the conditions at Elkhorn Slough) is not lethal, but has substantial sublethal effects on growth (Cheng et al. 2015). Periodic die-offs have been observed at Elkhorn Slough at sites with restricted tidal exchange following unusually long anoxic periods (Wasson, unpublished data).

Assessment method: Ideally, dissolved oxygen concentrations should be measured with *in situ* sondes collecting data continuously. One can then quantify hypoxia through measures such as the percentage of measurements where dissolved oxygen was lower than 5 mg/L. However, many monitoring programs only collect grab samples during the daytime. We have found that variance from 100% saturated oxygen conditions (both increases or decreases) in day-time measurements correlate quite well with duration of nighttime hypoxia. So measures of average variance from fully saturated oxygen conditions (such as 9 mg/L) can be used as a proxy for hypoxia.

Exposure: Across embayments, hypoxia was only identified as a high threat for oysters at Elkhorn Slough (Table 1), an estuary very heavily affected by agricultural nutrient loading. Oxygen levels are expected to decrease as climate warms (Levin and Breitburg 2015), so this stressor may increase in frequency and may occur in new locations.

Oysters raised in the lab, subjected to low dissolved oxygen (top) and normal levels (bottom).

COMPETITION (sensitivity: *low;* exposure: *medium)*

Sensitivity: Other species co-occurring with Olympia oysters on hard substrates may compete with them for space on which to settle or grow, or for food. Our field data from Central California showed no negative correlation between space covered by other sessile species and oyster density, recruitment, or growth at/near MLLW (Wasson et al. 2014). The main groups of species present at MLLW were the green algae *Ulva* spp., red filamentous algae, and barnacles. Many sites were high in bare hard substrate availability. Previous work indicates that the effects of competition are variable, and more likely to have an impact on early life stages of Olympia oysters. The presence of competitors reduced total recruitment in San Francisco Bay and reduced recruit size in Tomales Bay, though effects varied by site (Deck 2011). Competitive effects increased at some sites at lower tidal heights, but this was not consistent across sites or bays. Only minimal effects were observed on other aspects of oyster life stages. Wasson (2010) found no correlation between recruit size or survival and distance to the nearest competitor near MLLW in Elkhorn Slough. However, greater low intertidal and subtidal coverage by fouling species was observed, which could indicate potential effects at lower height. In the Pacific Northwest, Trimble et al. (2009) found that high cover of sessile invertebrate species, mainly barnacles and ascidians, reduced juvenile survival and growth, and tidal height did not affect this. In Puget Sound, barnacles, jingle shells and bryozoans compete for space, potentially limiting oyster recruitment (B. Allen, personal communication).

Competition with the introduced Pacific oyster *Crassostrea gigas* has been demonstrated in Willapa Bay to negatively impact Olympia oyster growth and increase mortality (Buhle and Ruesink 2009, Trimble et al. 2009). Although the potential impacts of *C. gigas* on *O. lurida* are not known for San Diego Bay, concerns about potential competition as well as a desire to not enhance *C. gigas* populations have been a factor in the design of restoration projects there. Indeed, many restoration practitioners are worried about inadvertently increasing populations of nonnative species through the provision of new hard substrates intended for native oysters.

Tube worms co-occur with oysters in Elkhorn Slough, California.

Assessment method: Percent coverage of potential competing species can be assessed in field transects along with oysters. Another simple proxy for effect of competition is percent coverage by bare space on hard substrates—if this is high, competition is presumably not a major factor. To truly determine the effects of potential competitors on oysters, manipulative experiments are required.

Exposure: Multiple factors, including the identity and abundance of potential competing species, environmental stressors, predation, and the timing of recruitment and growth of potential competitors, will determine the degree to which competition is a factor in any given location. Competition with *C. gigas* was identified as being of moderate importance in a number of bays in California, Oregon and Washington, but unimportant elsewhere (See Table 1). Competition with other species was indicated as being potentially of high importance at Netarts and Yaquina, and of moderate importance at various bays in Oregon, Washington, and British Columbia.

ACIDIFICATION: LOW pH/ALKALINITY (sensitivity: *low;* exposure: *low)*

Sensitivity: One of the better-studied consequences of global change is the increasing acidity of ocean water due to the greater concentration of carbon dioxide (CO_2) in the atmosphere. Aragonite is the form of calcium carbonate used by most larval bivalves to build their shells; one aspect of more acidic water is that aragonite is less available to larvae, resulting in small, thinner or malformed shells and/or death (Ekstrom et al. 2015). Experimental studies of Olympia oysters have demonstrated some negative effects of acidification (Hettinger et al. 2012, 2013), though these were mostly sublethal and not as strong as effects demonstrated on other oyster species. Many estuaries, such as San Francisco Bay and Tomales Bay, have relatively large seasonal and diurnal fluctuations in pH and carbonate saturation as the result of inputs from both watershed (river inflow) and nearshore oceans (via upwelling), and the influence of plant metabolism (daily cycles of photosynthesis and respiration)

Monitoring Olympia oysters among Pacific oysters and mussels in Newport Bay, Southern California.

(Smith and Hollibaugh 1997). Consequently, organisms in these locations, including oysters, often already experience a very wide range of pH and carbonate saturation conditions, and we are not aware of any evidence to suggest that oysters currently are negatively impacted by these fluctuating conditions in much of the range. At some estuaries, such as Netarts Bay, acidification is a new stressor for *Crassostrea gigas,* leading to lower larval production and growth (Barton et al. 2012), and may also affect *Ostrea lurida* (D. Vander Schaaf, personal communication), although the brooding habits of this species may offer greater protection to larvae.

Assessment method: Measurements of pH by water quality instruments provide a reasonable estimate of acidification, but the precision of typical sensors is too low to detect subtle trend changes. Calculations can be made of frequency or duration of low pH events. More precise pH sensors, and at least occasional assessment of alkalinity and dissolved inorganic carbon is ideal, although the required instruments are expensive.

Exposure: Across embayments, acidification was currently ranked as a low threat to oysters, with the exception of Netarts Bay where it was ranked high, and Tomales, Yaquina and Victoria, where it was ranked of moderate importance (Table 1). Acidification has been shown to negatively impact growth and potentially increase mortality in larval Pacific oysters in hatcheries in Oregon (see Barton et al. 2012). Although we are unaware of documented impacts to Olympia oysters under current conditions, acidification may impact native oysters more strongly in the future. Potentially, exposure to acidification will increase as increasing atmospheric CO_2 results in increasing water-column pCO_2, along with future changes in river inflows and upwelling inputs (Cayan et al. 2008, Checkley and Barth 2009), although the complexity of carbonate chemistry in the coastal zone makes predicting impacts difficult (Waldbusser and Salisbury 2014).

Monitoring restoration at Netarts Bay, Oregon, a site where Pacific oysters have been threatened by acidification.

Live oyster surrounded by oil at Angel Island, San Francisco Bay, following 2009 Cosco Busan oil spill.

CONTAMINANTS (sensitivity: *low;* exposure: *low)*

Sensitivity: Polluted water, notably the discharge of high amounts of sulfite wastes from paper mills in the Pacific Northwest, once had major impacts on native oysters (Blake and Bradbury 2013), and the dumping of untreated sewage may have harmed oysters in San Francisco Bay as well as shut down oyster farming operations due to public health concerns (multiple reports, reviewed by Baker 1995).

Despite the persistent presence of contaminants at many sites, oysters do not appear to be very sensitive to them, generally. In California, Olympia oyster populations exist in habitats formerly considered "polluted," such as near a wastewater treatment outfall in Humboldt Bay, CA, in marina basins in San Francisco Bay, and in an area formerly contaminated with heavy metals and polychlorinated biphenyls near Stege Marsh, Richmond, CA (Couch and Hassler 1989, Hwang et al. 2013). In many locations, heavy metals and other long-lasting pollutants that are the legacy of now-closed industry may be taken up by oysters. For example, a sample of 20 apparently healthy oysters taken in 2006 from an oyster restoration site in San Rafael (San Francisco Bay) indicated very high levels of copper, suggesting the presence of a substantial source of this pollutant nearby (Gerhart, personal communication). However, oysters continue to thrive at this site and at other restoration sites nearby.

Assessment method: Contaminant sampling methods for sediments and oyster tissue differ by the contaminant in question. Many estuaries are contaminated by a range of PAHs, heavy metals and legacy pesticides as well as emerging contaminants. Quantifying the bioavailability and toxicity of these compounds, let alone their interactive effects, is very expensive and technically challenging.

Exposure: Current environmental laws have reduced the use and release of contaminants, such as organic biocides (Axiak et al. 1995), polycyclic aromatic hydrocarbons, and heavy metals (Connor 1972), which were previously found to affect oyster populations. Contaminants were considered a low threat across embayments, with the exception of Yaquina Bay and Discovery Bay, where this stressor was ranked a moderate threat (See Table 1).

PATHOGENS AND DISEASES (sensitivity: *variable;* exposure: *low)*

Sensitivity: Overall, oyster diseases and pathogens currently do not appear to be a major factor influencing native oyster populations in Central California. While individual oysters may suffer from infections, rates are low overall and no observed population diebacks have been linked to disease.

However, it would be unwise to entirely dismiss disease as a potential stressor for Olympia oysters. Eastern oysters in the Chesapeake and Delaware bays were apparently disease-free for decades until the introduction of oysters from the Gulf of Mexico led to emergence of two new diseases in the 1950s. Oyster disease agents are certainly present, having been reported from both commercially grown Pacific oysters and native oysters in multiple bays along the coast, including Elkhorn Slough, and Tomales and Humboldt bays in California, and Netarts, Yaquina, and Alsea bays in Oregon (Mix and Sprague 1974, Friedman et al. 2005, Burge et al. 2007, Moore et al. 2011). Olympia oysters may become more susceptible to disease as restoration moves forward and population density increases. Additionally, disease prevalence and impact may increase as a result of other stressors associated with climate change, such as increasing water temperatures, which have been linked to herpes outbreaks in commercial oyster species in Tomales Bay (Burge et al. 2007).

Assessment method: An overview of assessment methods for oyster diseases and pathogens is provided by Baggett et al. (2014). Microscopic examination of stained histological sections and/or genetic analyses are appropriate for detecting various pathogens or diseases. If oyster density is considered too low to sacrifice animals for pre-restoration health surveys at the restoration location, information from the nearest population(s) that can be sampled is useful. Additionally, seed oysters from nearby populations with known health history may be deployed at the proposed site. To understand population-level effects, one must quantify percentage of individuals infected, intensity of individual infections and outcomes for those individuals.

Exposure: Overall, exposure to disease appears to be low according to the expert assessments (Table 1). We review highlights of potential disease concerns from south to north.

Monitoring at Nootka Sound, Vancouver Island, British Columbia.

Reef balls deployed in Elkhorn Slough (top) and San Francisco Bay (bottom).

From Southern California to Tomales Bay, disease was not considered a significant factor affecting Olympia oysters in any embayment (Table 1). The most recent published surveys of disease in Olympia oysters in the San Francisco Bay Area (Friedman et al. 2005; Moore et al. 2011) reported that potentially pathogenic bacteria, viruses, and protists are present only in a minority of oysters, and typically at levels lower than those associated with disease. These studies showed little evidence for presence of disease except for disseminated neoplasia in Drakes Estero, and Candlestick Point, Oyster Point, and Coyote Point in San Francisco Bay (Friedman et al. 2005, et al. 2008, Moore et al. 2011). The levels measured at these four sites are unlikely to seriously affect oyster populations or negatively affect restoration efforts (Grosholz et al. 2008).

In Humboldt Bay, there is evidence of the occurrence of Denman Island disease, and oyster experts coded this as a moderate concern because of potential mortality in older oysters following cold temperatures (D. Couch and K. Ramey, personal communication). However, there is no evidence from any site that Denman Island disease causes significant population level effects on Olympia oysters (J. Moore, personal communication).

In Coos Bay, disease was considered a moderate stressor because 17% of Olympia oysters tested for diseases showed tissue irregularities, focal hemocytosis, and nuclear degeneration (Rumrill 2010). In Netarts and Yaquina bays concerns about *Vibrio tubyashi* led to scores of moderate and high stressor levels for diseases (D. Vander Schaaf, personal communication).

Disease was not considered an important stressor at any embayment in Washington or British Columbia. While several disease agents were recently identified in surveys of Olympia oysters in British Columbia, these were generally detected at low prevalence and intensity and were not believed to have significant health impacts (Meyer et al. 2010).

San Francisco Bay Living Shorelines Project constructed reefs at the San Rafael Shoreline.

Sunset low tide monitoring at Point Orient, San Francisco Bay.

SEA LEVEL RISE (sensitivity: *low;* exposure: *low)*

Sensitivity: Olympia oysters are not very sensitive to projected sea level rise. One potential impact of sea level rise could be increased local resuspension of sediment due to greater wave action and tidal currents associated with deeper waters. This could result in stressors associated with increased sediment burial in shallower areas. However, more hard substrate may be available for oysters as sea levels rise, both because existing hard substrates protecting human infrastructure may become submerged, and due to further shoreline hardening to protect human land uses from sea level rise. Given the drawbacks of traditional shoreline hardening, measures such as living shorelines—creating habitat for multiple species—are increasingly being incorporated into thoughtfully planned nature-based solutions.

Assessment method: One can assess hard substrate availability at different elevations to determine potential effects of projected sea level rise on habitat availability for oysters.

Exposure: Rates of sea level rise on the northeast Pacific coast have been relatively slow compared to other regions, but are anticipated to accelerate soon (Bromirski et al. 2011). Exposure to sea level rise also depends on change in land surface elevation, which can be affected at a regional scale by factors such as geologic uplift, or at a local scale by factors such as groundwater overdraft leading to subsidence.

INTERACTIONS BETWEEN STRESSORS

Environmental stressors often occur in combination. It is therefore important to understand not only the impacts of individual stressors but also the effects of combinations of multiple stressors on Olympia oysters. Multiple stressors can produce additive effects (i.e., equal to the sum of the stressor impacts), or interactive ones (i.e., either more detrimental or less detrimental than would be expected by simply adding the effects of the stressors).

We used field studies in Central California, combined with previous work, to measure baseline patterns of potential environmental stressors in relation to oyster demographics. We used several multivariate analyses of a broad suite of environmental variables (including air and water temperature, salinity, and dissolved oxygen) and oyster demographic parameters (density, growth rate, size, recruitment rate) to identify which stressor or combinations of stressors explained the most variation in oyster demography.

We used laboratory experiments to more closely investigate causal relationships between multiple stressors and Olympia oyster survival and performance. In the first experiment, we examined interactions between warm water temperatures and low oxygen levels applied as simultaneous stressors. Following a recovery period, we applied low salinity stress, so that interactions between all three stressors could be examined. Here, we found no evidence for interactive effects, but rather, these stressors were additive (Cheng et al. 2015). In the second experiment, we assessed the effects of low salinity and high air

Tank experiments examining multiple stressors at the Bodega Marine Lab in California.

temperature simultaneously, and with different amounts of time between applying the two stressors. When applied simultaneously, we saw synergistic effects (detrimental effects beyond what would be predicted by simply adding the effects of low salinity and air temperature). When oysters were given recovery time between stressors, this synergistic response disappeared (Wasson et al. 2014). Previous studies have found interactive effects to be generally more common than additive effects (Crain et al. 2008, Darling and Cote 2008), but we found that results are dependent on the specific stressors and their timing. Although some stressors like low salinity and high air temperature may co-occur (for example, during springtime in some parts of San Francisco Bay) and produce synergistic effects, realistic recovery time between stressors may lead to effects that are more additive in nature.

Many of the environmental factors discussed above also interact with tidal elevation. For instance, feeding time is longer at lower elevations, so phytoplankton concentrations need not be as high to support subtidal populations as high intertidal ones. Exposure to warm air increases with increasing tidal elevation, while coverage of most sessile invertebrates decreases with increasing tidal elevation. For rigorous comparisons among sites, it is thus important to examine biological and environmental conditions across similar tidal elevations; in our assessments of Central California sites, we focused on Mean Lower Low Water because this is where oyster densities are typically highest. For practitioners elsewhere using our site evaluation tool to rank sites for their restoration potential, it is important to consider the role of tidal elevation. For instance, a site that receives a low score because of frequent high air temperatures may be a fine place to do a subtidal restoration project. Considerations of interactions between environmental factors and tidal elevations is thus essential.

Rocky intertidal habitat at Strawberry (Brickyard Cove), San Francisco Bay.

Site Evaluations

Background and Goals

Resource managers and restoration practitioners indicated a need for tools to help rank sites in terms of their suitability for native oyster restoration and conservation (Wasson et al. 2013). Site evaluations have been conducted by other researchers in some regions, including Puget Sound (Blake and Bradbury 2013) and British Columbia (Stanton et al. 2011). However, there was no quantitative methodology for comparing sites in terms of their restoration potential or conservation value. We thus developed quantitative metrics and report-card style summary tables to evaluate sites. With extensive grant funding, we were able to conduct thorough field monitoring data and evaluate 21 sites in Central California (Wasson et al. 2014). Subsequently, we were able to conduct scaled-back evaluations of sites in Southern California (Appendix 1) and southern Oregon (Appendix 2) using existing data for those regions. Furthermore, we developed an online version of the site evaluation tables as a tool for scientists and practitioners working in other estuaries (available at www.climate-and-oysters.org).

Our Approach to Site Evaluation

The site evaluation tables score sites based on oyster performance and on measurements of key environmental parameters. To create the tables, we used the same oyster attributes described above, and all the environmental stressors with high and medium oyster sensitivities discussed above (with the exception of sedimentation, not relevant to most of our sites, which had ample large hard substrates preventing sediment burial, or would have them as a result of restoration projects).

For each parameter for which data were available, we converted raw data to a score. This conversion was based on thresholds we set using expert judgment. For instance, one parameter was oyster drill density. If there were zero oyster drills per square meter, this was assigned a 100, the best score. If there were more than five oyster drills per square meter, this was assigned a 0, the worst score. Intermediate densities received intermediate scores (25 for 3–5 drills, 50 for 1–2 drills, and 75 for between 0–1 drills per square meter). Thresholds were different for Oregon, Central California, and Southern California, and depended on the range of the raw data and/or knowledge of key thresholds at each location, with the goal being to rank sites relative to one another within each region. We shaded cells in the tables, with light colors for low scores and dark colors for high scores, to make patterns easily distinguishable at a glance (Appendix 1, 2, and Wasson et al. 2014).

We assigned weightings to each parameter in the tables. In particular key oyster attributes such as density and recruitment were weighted highly relative to other parameters, since they are the most reliable indicators of oyster success. Relationships between environmental factors such as temperature and oysters are weaker (and were not quantified for Southern California, Coos Bay or South Slough) and thus were weighted lower. The weightings are clearly shown in the tables so the process of obtaining a total score is transparent. In the on-line tool, users can adjust the weightings themselves.

We calculated overall scores using all the weighted parameters. The tables include three different overall scores at the bottom: 1) a score indicating suitability of the site for restoration through addition of hard substrates; 2) a score indicating suitability of the site for restoration through addition of hard substrates seeded with juvenile oysters, sufficient to establish a self-sustaining population supplying larvae to this area, and 3) a score indicating value of this area for conservation of existing oyster populations. Details on all the parameters included their weighting, and calculation of the overall scores are included in the notes associated with the tables (Appendix 1, 2 and Wasson et al. 2014 [including their appendices 2,4]).

Site Evaluation Case Studies

CENTRAL CALIFORNIA

We evaluated twelve sites in San Francisco Bay and nine sites in Elkhorn Slough (Wasson et al. 2014). On the whole, sites in San Francisco Bay scored higher than those at Elkhorn Slough, generally due to higher scores for oyster parameters. Top scoring sites were Berkeley Marina, Strawberry (Brickyard Cove), Point Pinole, and San Rafael Shoreline in San Francisco Bay and South Marsh and Kirby Park at Elkhorn Slough. Major stressors differed between the two bays, with more sites in San Francisco Bay experiencing periodic low salinity, higher air temperatures, and relatively low chlorophyll *a*; while low dissolved oxygen was the major stressor at Elkhorn Slough, with low chlorophyll *a* and low water temperatures mainly at a few marine-influenced sites near the mouth of the estuary. At both estuaries, mid-estuary sites generally scored higher than other sites, which is consistent with our working knowledge of the sites. Although North Bay sites in San Francisco Bay also scored high during this relatively short study period, these sites are more vulnerable to low salinity events. Over the nearly 10 years we have been working in San Francisco Bay, we have seen populations at these sites decline steeply during years of heavy rain. Sites in the South Bay, which have oyster drill populations and warmer air temperatures, such as Eden Landing and Coyote Point, scored lower. At Elkhorn Slough, several sites with little to no recruitment and/or adult oysters, such as Vierra and Moss

Urbanized conditions in San Francisco Bay (near right) compared to rural conditions at Elkhorn Slough, California (far right).

Landing, also received low overall scores, as did some upper estuary and tidally muted sites with low recruitment and poor water quality.

SOUTHERN CALIFORNIA

Fourteen sites, seven each in Newport Bay and San Diego Bay, were evaluated using data collected between 2010 and 2014 as part of several research projects. Not all data were collected at all sites, but measurements of some critical oyster parameters were similar enough to allow comparisons.

Overall, greater variability between sites existed within San Diego Bay, whereas the sites in Newport Bay were more similar in all oyster attributes studied. San Diego sites as a rule had much higher recruitment rates (one to two orders of magnitude) than Newport Bay sites, and thus had higher restoration scores overall. San Diego sites also had high juvenile growth rates compared with Central California, although these were somewhat skewed by the short time period (70 days) over which these new settlers were tracked; there was also high survivorship of juveniles over this same time period. These parameters were not available for Newport Bay. Adult densities were low at four sites in San Diego; two sites had no adults and two sites had fewer than 10 individuals/m^2. This was due to a paucity of hard substrate at these locations. All sites in San Diego received high to medium high scores for restoration success due to high recruitment rates, rapid juvenile growth and good juvenile survival, although data on potential critical environmental parameters were missing. Three sites—Chula Vista Wildlife Refuge, J Street Marina, and Coronado Cays—received the highest restoration scores, with Chula Vista scoring the highest of the three due to high densities of adult oysters (291/m^2). Chula Vista also received the highest conservation score due its large oyster population (estimated in 10,000s).

Monitoring site in Newport Bay, Southern California.

Olympia oyster restoration in South Slough, Oregon.

None of the Newport Bay sites received a high score for restoration success, but neither did any site rank poorly—rather, all sites scored medium high. All sites had moderate to moderately high scores for adult densities, sizes and size-class distributions, and the three sites for which recruitment was tracked also had moderate scores. Two sites received high scores for conservation, 15th Street, and Newport Aquatic Center, but the latter was evaluated on the basis of its population estimate only (15,000 individuals) as other data were unavailable. Water temperature was the only environmental parameter measured for Newport Bay and only for three sites, so potential environmental stressors for this bay could not be quantified.

SOUTHERN OREGON

We evaluated three locations in the northeastern portion of the Coos estuary (referred to as Coos Bay), and two sites in South Slough, which comprises the major southern arm of the Coos estuary (Appendix 2). In Coos Bay, large deposits of recent fossil Olympia oyster shells have been found in dredge spoils and American Indian shell middens, but oyster populations became locally extinct prior to European settlement. Only after accidental introductions in the 1980s through aquaculture activities did they become reestablished in the estuary (Baker et al. 2000). The sites in Coos Bay consist of fairly established oyster populations stemming from this re-introduction. In South Slough, Olympia oysters were absent until they were reintroduced through a project that began in 2008. As a result, in general, Coos Bay sites had higher adult densities than the South Slough sites.

The highest scoring site for restoration in Coos Bay was Downtown, although Haynes Inlet received only a slightly lower score. Downtown had the highest adult and recruit densities and larval abundance. For habitat attributes, Downtown also had the highest availability of hard substrate, which was a potential limiting factor for other sites. All Coos Bay sites had substantial freshwater inputs, with daily salinity averages below 25 for up to 76 percent of the year, but this seemed compatible with substantial oyster populations, perhaps due to local adaptation to lower salinity. Coalbank Slough had the highest risk of low pH events, but pH at this site was highly variable. Average chlorophyll *a* concentrations measured at Haynes Inlet and Coalbank Slough were moderate and may contribute to higher oyster performance at these sites whereas average chlorophyll *a* concentrations in South Slough were lower. At nearby weather stations, high air temperature events were rare. Sedimentation in South Slough appears to be high and may impact future restoration seeding operations.

Top: monitoring tiles at Kirby Park in Elkhorn Slough, California. Bottom: students with The Watershed Project.

Challenges and Limitations to Site Evaluations

It is important to keep in mind that the site evaluation tables are based strictly on biological/ecological measurements and do not take into account other important considerations in site selection, such as community support, access, funding, and permit procedures.

Even from a strictly scientific perspective, there is still much to learn about native oyster population biology and ecology in our region, and of course there are many unknowns as we project into the future, given a changing climate. In many cases, data are available only for short time spans that likely do not represent the full range of conditions at a site over longer periods, or, particularly for many of the physical parameters, detailed data are only available at larger spatial scales, yet conditions may vary with microclimates at the site level. Many of the physical parameters likely to be important to oysters are difficult and/or costly to measure. Also unknown is the degree to which oysters may display adaptation to local conditions, such that the relative importance of any given physical parameter might vary between embayments. Additionally, we don't yet know the degree to which populations are connected, which could mean that the critical factor of recruitment rate may be partially decoupled from site-level conditions. While oyster attributes, such as size or density, are easily measured, our understanding of the relative importance even of these parameters to the sustainability of oyster populations in a given region is also limited. Thus, in the creation of these tables, we relied on our expert opinion to weigh the relative importance of oyster performance data and the likelihood of extreme climate events at our study sites, particularly in converting raw data into weighted ranks. As such, the tables represent a combination of empirically derived data and judgment calls.

Thus, site scores should be considered advisory only and are intended to provide guidance for restoration by comparing sites within regions, rather than as an absolute ranking across all locations. For some sites, it is also possible that modifications to the restoration approach could help ameliorate stressors. For example, substrates could be deployed in the shallow subtidal rather than in the intertidal zone to reduce heat stress at a site with frequent very-high air temperatures.

Online Site Evaluation Tool

We have created an online site evaluation tool in Excel that allows users to populate a table with their own data (available at www.climate-and-oysters.org). There are separate sheets for assessing conservation value of sites for existing oyster populations vs. restoration potential (with and without seeding). Users can adjust the weight of different parameters as they see fit. The table allows for assessments to be conducted with considerably fewer parameters than we included in our original evaluations (Wasson et al. 2014), which in most locations is likely to be the case.

Installing monitoring tiles in San Francisco Bay.

At an absolute minimum, we recommend collecting data on adult oyster densities and diversity of size classes for restoration sites being considered (these are also two of the four "universal metrics" recommended for oyster restoration monitoring by Baggett et al. 2014). To determine a site's conservation value the extent of shoreline with hard substrate at the appropriate tidal height should be assessed. This, together with density, can provide an estimate of abundance of oysters at the site. Data on recruitment rates, derived by deploying clean substrate at the start of recruitment season, should be collected if at all possible; ideally these data should be collected over several years, as recruitment can be highly variable at some locations. Recruitment to deployed substrate and subsequent measurements of growth and survival should be evaluated for sites that do not have hard substrate but are being considered for restoration involving substrate addition. If possible, data on environmental variables should also be incorporated. Across embayments, the most critical factors to assess appear to be: 1) the longer-term risk of low salinity exposure; 2) exposure to high air temperatures, 3) risk of predation by oyster drills and other species, and 4) competition with *Crassostrea gigas* and other sessile organisms. Data from a nearby monitoring station can often be used to determine whether there is a risk of extended freshwater events during wet years, and to calculate maximum daily summer air temperatures (although exposure to air temperatures will be mitigated by tides and influenced by micro-climates at the site level.) Chlorophyll and water temperature data are also regularly available from water monitoring programs and yield important information. Assessing whether oyster drills and other potential predators and competitors are abundant at the site can also be done fairly easily.

Placing shell bags for restoration at Netarts Bay, Oregon.

Management Applications of Site Evaluation Tools

The site evaluation tools developed here can be applied to two main types of management questions:

Student volunteers with The Watershed Project monitor conditions at Point Pinole, California.

1. **Conservation: Which sites currently support healthy and abundant existing oyster populations that are most likely to be sustainable in the long-term?**

   Example of management decisions: strategic planners and resource agency staff involved in permitting determine which sites/populations need special protection from development or nearby disturbance; regulatory agency considers oyster needs when designating a new marine protected area.

2. **Restoration/Enhancement**

   a. Which sites are best for success and long-term sustainability of oyster restoration or enhancement projects?

   Examples of management decisions: funding agency decides between competing projects in different locations; strategic planner for estuarine restoration picks target areas; restoration group decides where to propose next project.

   b. Is an oyster restoration or enhancement project done at site X likely to be successful?

   (This question is very similar to 2a, but in this case applied to a single site as a "yes/no" question about doing restoration, rather than involving prioritization between multiple sites.)

   Example of management decision: restoration group decides whether to propose project at a particular site; funder decides whether to fund; conservation land trust or resource management organization decides whether to invest in oyster restoration at a particular property they own.

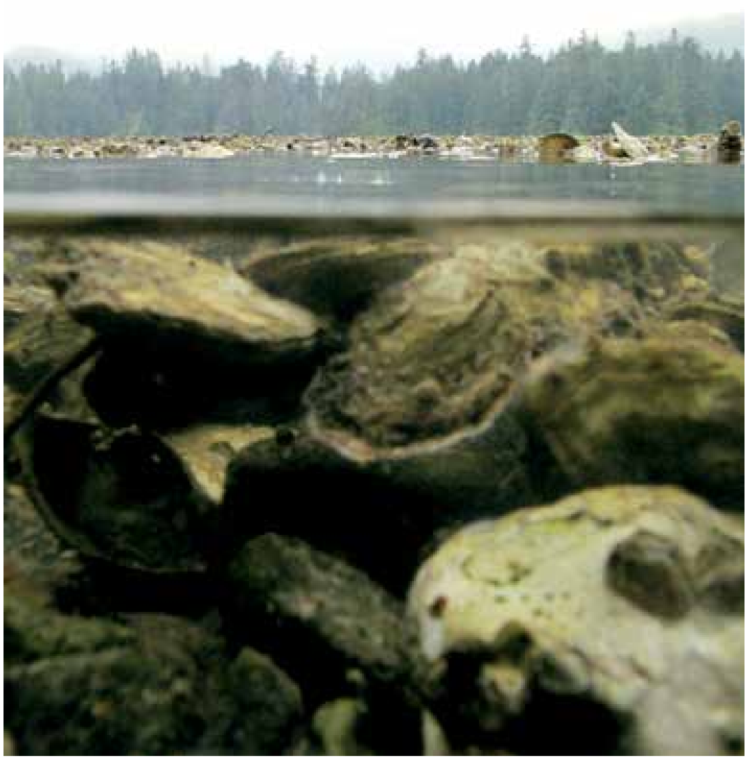
Elegant oysters,
unique history and lore.
Habitats prevail!

Conclusions

This guide has synthesized data from recent laboratory experiments and field monitoring, and the published literature. We have used this information to characterize the attributes of sustainable Olympia oyster populations, and to identify the stressful environmental factors that affect them most strongly across the range of the species.

Overall, the most frequently encountered stressors across 28 embayments were sedimentation and predation. Competition, cold water temperatures, warm air temperatures, and freshwater inputs were also common concerns at many bays. These types of stressors are natural components of marine ecosystems. However, they have been exacerbated by human activities; for instance, a major predator in some embayments is a non-native snail introduced with aquaculture, and some land uses in estuarine watersheds (hydraulic mining, agriculture) have increased sedimentation rates in some estuaries. Global climate change may also increase exposure to these stressors, for instance increasing storm intensity and freshwater inputs or increasing frequency of exposure to high air temperatures or acidified waters.

We examined interactions between different stressors under laboratory conditions and found that the types of responses observed depended on the stressor and the timing of application. We documented some linear, additive relationships between stressors, and some that were non-linear and synergistic. It is clear that decreasing stressor levels through ecosystem management (such as reducing hypoxia resulting from nutrient loading) will support oysters, but it is hard to predict whether such stressor reduction will increase resilience to other stressors, such as those related to climate change.



Top: Isthmus Slough, Oregon. Bottom: Olympia oysters in Nootka Sound, Vancouver Island, British Columbia.

We have developed a site evaluation tool and used it to assess restoration and conservation potential of Olympia oysters in two Oregon and four California estuaries. As more investigations are conducted and restoration projects are implemented, understanding of oyster sustainability will evolve, and these guidelines will need updating. We hope that in the coming years, the recommendations provided here will support improved oyster conservation and restoration.

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From waters unknown
New lives spring into being
Next generation

Image Credits

Abbreviations: T *(top),* M *(middle),* B *(bottom),* L *(left),* C *(center),* R *(right)*

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Haikus: These originated as a joking response to a request to reduce our research into short, succinct paragraphs. It turned out they were fun to do.

Appendices

Appendix 1
Southern California Site Evaluations: Newport and San Diego Bays

Appendix 2
Southern Oregon Site Evaluations: Coos Bay and South Slough

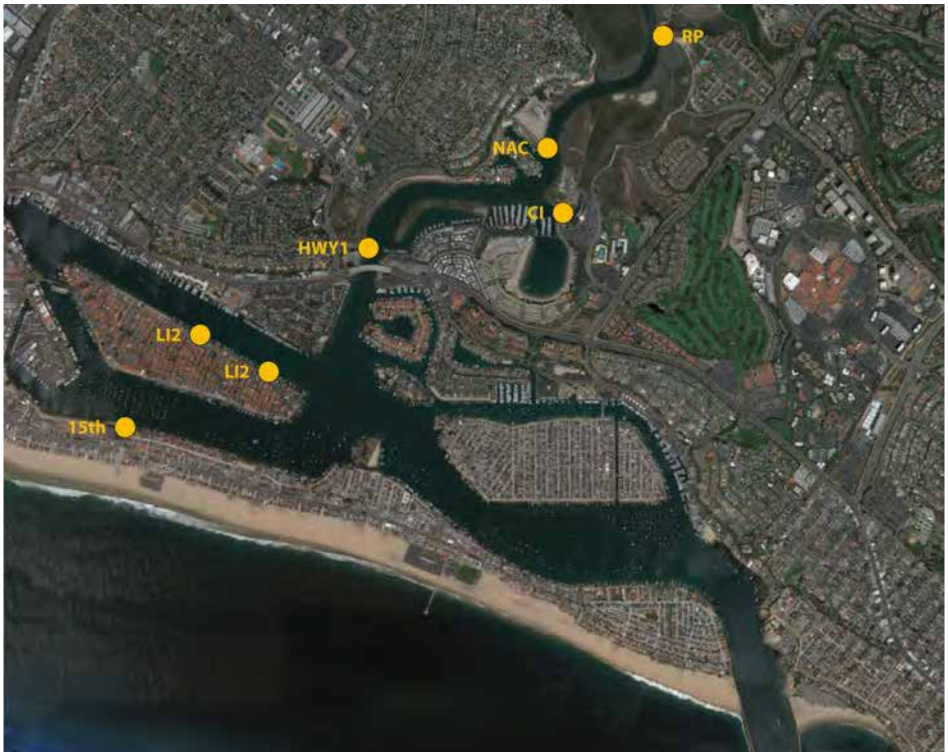
Appendix 1. Southern California Site Evaluations: Newport and San Diego Bays

Overview

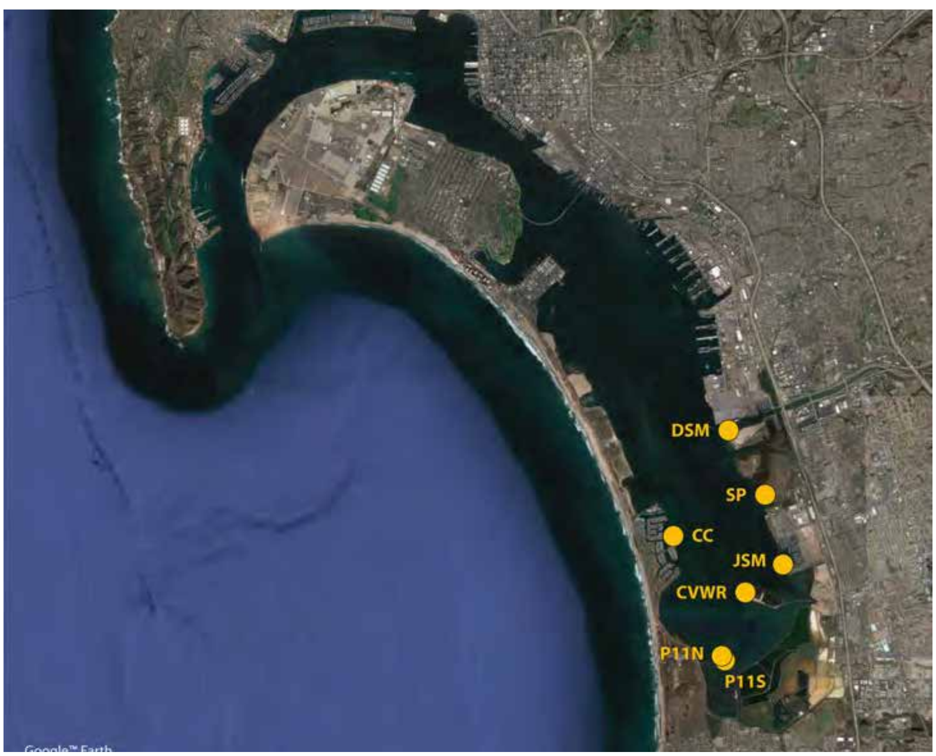
Seven sites in Newport Bay and in San Diego Bay were evaluated using the Site Evaluation Tables. The method of Wasson et al. 2014 was modified for these sites, because few environmental data were available and differences in data collection and the range of key oyster parameters required some revisions to scoring. The site locations and data collection and processing methods are described below, followed by a summary of the site evaluation results.

Table 1. List of field sites, site codes, and location by bay.

Bay	*Site Name*	*Site Code*	*GPS Coordinates*
Newport	Highway 1	HWY1	33.6178 -117.9049
Newport	Coney Island	CI	33.6196 -117.8922
Newport	15th Street	15th	33.6083, -117.9204
Newport	Rocky Point	RP	33.6295 -117.8859
Newport	Lido Island Site 1	LI 1	33.6131 -117.9157
Newport	Lido Island Site 2	LI 2	33.6113 -117.9119
Newport	Newport Aquatic Center	NAC	33.6232 -117.8933
San Diego	Chula Vista Wildlife Reserve	CVWR	32.6143 -117.1138
San Diego	D Street Marsh	DSM	32.6471 -117.1162
San Diego	Signature Park	SP	32.6333 -117.1076
San Diego	J Street Marina	JSM	32.6203 -117.1042
San Diego	Coronado Cays	CC	32.6264 -117.1294
San Diego	Pond 11 North	P11N	32.6027 -117.1180
San Diego	Pond 11 South	P11S	32.6025 -117.1179



Map 1. Newport Bay field sites.



Map 2. San Diego Bay field sites.

Field Parameters

Table 2. List of parameters measured as part of this guide. Please refer to Table 1 for site codes. Timescales: Q = Quarterly, M = Monthly, B = Biweekly, C = Continuous, P = Periodically

Oyster Attributes	*Sites and Timescale*
Adult density	Newport sites (P, Oct - Apr); San Diego sites (P, May - Dec)
Size	Only Newport sites, except NAC (P, Oct - Feb)
Growth rate	Only San Diego Bay sites (~M, May-Sept), except PIIS
Survival rate	Only San Diego Bay sites (~M, May-Sept), except PIIS
Recruitment rate	All sites (B) except HWY1, LI 1, LI 2, NAC

Table 3. List of environmental factors, sites where data were collected, and the timescale for data collection.

Environmental Factors	
Available substrate	All sites (P)
Water Temperature	15th, CI, RP (C)

Field Methods

Oyster Attributes

Adult oyster density

We monitored oyster density at Newport Bay sites between October and April from 2010 to 2013 and at San Diego Bay sites between May and December of 2013. At each site, we laid out a 50 X 2 m transect centered near 0 to +0.5 m mean lower low water (MLLW) and then counted the total number of oysters within 30 randomly placed 0.25 m^2 quadrats along the transect. Density data were also used in calculations for population estimates on hard substrate over a 2 x 150 m area at each site.

Adult oyster size

At all Newport Bay sites except Newport Aquatic Center, adult oyster sizes were surveyed October - November 2010 and January-February 2011. At haphazard points along the transect (see Adult Oyster Density, above), the longest dimension of all native oysters encountered was measured (n = 17 to 57 individuals). These data were used to generate the mean upper quartile. Size distribution data were sorted into 10 mm bins and used to calculate a size-class diversity index:

Gini-Simpson Index = 1 – Simson's index (D_s)

$D_s = \sum p_i^2$

P_i = proportion of individuals in each group

Recruitment

We monitored recruitment by deploying four 15 x 15 cm red unglazed ceramic tiles near 0 m MLLW in all San Diego sites from June to October 2013 and at 15th Street, Coney Island and Rocky Point (Newport Bay) year-round from 2006 to 2014. From June to October tiles were collected in each bay approximately every two weeks, and we used these data to calculate recruitment rate. The total number of oysters was counted on each tile using a dissecting microscope to calculate a recruitment rate for each two-week period. The average recruitment rate was determined by averaging the rate from each collection period. The reliability of recruitment over the years was calculated for Newport Bay sites as the coefficient of variation of recruitment rate.

Juvenile growth and survival

At San Diego sites two additional recruitment tiles were deployed (see Recruitment, above), on May 30, 2013 and were collected and returned to the field ~monthly through September 2013 to measure growth and survival rates. Ten oysters per tile were identified after tile collection in June 2013 and their starting lengths were measured. In July and early September 2013, tiles were collected and oysters remaining from the original 10 were measured for growth and survival. Growth and survival rates were averaged between the two collection periods for each site.

Environmental Factors

Available substrate

In each bay, we used a 50 cm x 50 cm gridded quadrat along a transect (see Adult Oyster Density, above), to determine habitat percent cover. For each quadrat, we recorded habitat cover at 49 data points (e.g., mud, sand, dead shell, *Mytilus* spp., *O. lurida,* etc.) and from this calculated habitat percent cover. We combined habitat types into hard and soft substrate, and used average percent cover of hard substrate multiplied by oyster density to generate population size estimates.

Water temperature

In Newport Bay, Onset TidbiT temperature loggers were attached to recruitment tees near MLLW at 15th Street, Coney Island and Rocky Point. Loggers collected continuous data every 15 minutes from December 2009 through May 2012. As a rough estimate of water temperature, values above 29°C were excluded to eliminate air temperatures. The average daily warm period temperature was determined as the average of daily temperature means during April – September over each year.

Modifications to the Site Evaluation Table

We made several modifications to the online version of Site Evaluation Table (Wasson et al. 2014). Because recruitment was recorded only for June-October for San Diego, we used average recruitment rate for that period only for both Newport Bay and San Diego. This resulted in significantly higher recruitment rates than the year-round rate reported for Central California. To reflect this we recalibrated the scoring bins, generally using order of magnitude differences in the raw data. Growth rates were calculated only for new settlers and only over a very short time period (~70 days), during which growth would be expected to be quite high. In contrast, the Central California data included older, larger oysters tracked over longer time periods. We adjusted scores for this parameter, reflecting the spread of the data. We also dropped scores for two sites, Coronado Cays and Signature Park, where fewer than 10 of the individuals being measured survived. We also decided to report water temperatures as the warm period daily average (April – September). We had data on water temperature for only three sites. Based on the assumption that warmer sites are generally better than cooler sites (Wasson et al. 2014), we scored the two warmer sites 100 and the cooler site at 75. It should be noted, however, that there is no indication from the data collected that the cooler site is impacting oyster performance.

Site Evaluations

Fourteen sites were evaluated in the two Southern California bays. Overall, greater variability between sites existed within San Diego Bay, whereas the seven sites in Newport Bay were more consistent in all oyster attributes studied. Chula Vista Wildlife Reserve scored among the highest in conservation value, largely due to the highest adult density of all the southern California sites surveyed. Other top scoring conservation sites included Pond 11 South and J Street Marina in San Diego Bay and Newport Aquatic Center and 15th Street in Newport Bay, although all Newport Bay sites displayed relatively high conservation scores. However, it should be noted that the high score generated for Newport Aquatic Center is based on two parameters (population estimate and drill predation) and Pond 11 South on three parameters (population estimate, recruitment rate, and drill predation). San Diego sites demonstrate exceptionally high larval recruitment, much higher than Newport Bay sites. High recruitment, along with high juvenile survival and growth rates, resulted in all San Diego sites receiving high or medium high scores as potential restoration sites. All of these can be considered a high priority for restoration through the addition of hard substrate. The top restoration sites in Newport Bay were Newport Aquatic Center, 15th Street, Rocky Point, Highway 1 and Coney Island, with the two Lido sites showing slightly lower restoration scores; generally Newport sites scored lower than San Diego sites for restoration. Newport Aquatic Center already has a large oyster population; on this basis, the other high ranking sites might be preferentially selected for restoration. All sites received a boost in overall scores in the Seeding Score tab, but given the relatively high rates of recruitment in both bays, seeding is clearly not indicated as a restoration method.

However, there are several additional factors present at these sites not incorporated into the site evaluation metrics. First is the amount of available area for potential restoration. Most of the Newport Bay shoreline in particular is heavily armored by man-made substrates including rip rap, sea walls and pilings. Though oysters may perform well at certain sites, there may be little space available for hard substrate addition, particularly Newport Aquatic Center. Another factor of growing concern is the prevalence of the non-native oyster, *Crassostrea gigas*. Densities of *C. gigas* are higher in San Diego Bay than in Newport Bay and in San Diego Bay in particular, densities of *C. gigas* at some sites (Coronado Cays and J Street Marsh) are quite high. It is unclear if high *C. gigas* densities are having a negative impact on native oysters, however, in an effort to reduce potential competition between the two oyster species, restoration practitioners have deployed oyster restoration efforts at tidal elevations lower than the height where *C. gigas* are found in greater abundance (+ 0.75 to 1 m MLLW). Therefore, it is still unclear if high *C. gigas* populations would negatively impact native oyster restoration success or whether restoration plans may be altered to limit any potential negative impacts.

Newport Bay Site Evaluation Table (detailed version available from www.oysters-and-climate.org)

	Rocky Point	Newport Aquatic Center	Coney Island	HWY 1	Lido Island Site 1	Lido Island Site 2	15th Street
ADULT OYSTER DENSITY	50	50	50	50	50	50	50
OYSTER POPULATION SIZE	75	100	75	75	75	75	100
ADULT OYSTER SIZE	50		50	50	50	50	50
DIVERSITY OF SIZE CLASSES	50		75	75	50	50	75
RECRUIT DENSITY	50		50				50
RELIABLE RECRUITMENT	100		50				100
WATER TEMPERATURE	100		100				75
DRILL PREDATION	100	100	100	100	100	100	100
OVERALL SCORES							
Restoration (natural recruitment)	69	71	68	68	62	62	70
Restoration (with seeding)	71	80	70	71	64	64	72
Conservation	71	100	74	75	73	73	89

San Diego Bay Site Evaluation Table (detailed version available from www.oysters-and-climate.org)

	D Street Marsh	Signature Park	Coronado Cays	J Street Marina	CVWR	Pond 11 North	Pond 11 South
ADULT OYSTER DENSITY	0	0	25	50	75	25	50
OYSTER POPULATION SIZE	0	0	50	75	100	25	75
RECRUIT DENSITY	75	75	100	75	75	100	100
SURVIVAL RATE	100	100	100	100	100	100	
GROWTH RATE	75			75	50	100	
DRILL PREDATION	100	100	100	100	100	100	100
OVERALL SCORES							
Restoration (natural recruitment)	66	64	79	78	81	81	82
Restoration (with seeding)	77	77	87	83	80	90	87
Conservation	0	0	72	79	91	61	85

Appendix 2.
Southern Oregon Site Evaluations: Coos Bay and South Slough

Overview

We (A. Helms, B. Yednock) evaluated three sites in the northeastern portion of the Coos estuary (referred to as Coos Bay), and one site in South Slough, which comprises the major southern arm of the Coos estuary. The majority of the data used to evaluate the three sites in Coos Bay came from previously published manuscripts (Groth and Rumrill 2009) and student theses (Pritchard 2014, Rimler 2014, Oates 2013). A small amount of unpublished data that were collected in 2014 by staff and interns of South Slough National Estuarine Research Reserve at one of the Coos Bay sites (Coalbank Slough) and at two Olympia oyster reintroduction sites in South Slough were also included in the site evaluation tables. With the exception of South Slough, where oysters were absent until they were reintroduced through a project that began in 2008, the sites in Coos Bay consist of fairly established oyster populations stemming from the reappearance of Olympia oysters to the Coos estuary in the late 1980s. As a result, in general, Coos Bay sites have higher adult densities than the South Slough sites. The site locations and data collection and processing methods are described below, followed by a summary of the site evaluation results.

Site selection and use of field data in site evaluations

We selected three sites (Downtown Coos Bay, Haynes Inlet, and Coalbank Slough) for restoration evaluations because these sites had data available for both adult oysters and recruits, including growth and survival rates, in addition to larval abundance. Each of these three sites also paired with water quality sonde stations in Coos Bay that were between 1.2 to 3 km away. There were three additional sites from the Groth and Rumrill 2009 study in Coos Bay (Millington, Eastside, Pony Point) where adult density measures were available but no recruitment, growth, or survival measurements were made. From Pritchard (2013) and Rimler (2013), there were three additional Coos Bay sites (Empire, Catching Slough, and Airport) with recruitment and larval abundance data, but adult oyster measurements were not made as part of their work. Therefore, these latter 6 sites were not included in this evaluation.

We selected two reintroduction sites (South Slough-Valino Island and South Slough-Long Island) in the South Slough estuary for evaluating their appropriateness for restoration, based on seeding. The Seeding Score is calculated with a formula that makes recruitment rate less important, to determine if it is appropriate for restoration with seeding by aquaculture spat. Environmental conditions for both sites were characterized by data from the same nearby continuous water quality monitoring station. These two sites do not have naturally established adult oyster populations like the Coos Bay sites that were evaluated for restoration. The adults at these two sites were generated from a reintroduction project that began in 2008 with Olympia oyster cultch from a hatchery along with settled juveniles from the hatchery (2009); both were transplanted to Younker Point in Coos Bay for growth and survival studies. Burial by sediments was responsible for the relocation of the oysters from the reintroduction project site at Younker Point to the two seeding sites, Valino Island and Long Island, located further up the estuary and across from each other separated by the main channel. Oysters were transplanted to the current two locations in 2012 and monitoring began in 2014.

We selected one site, Downtown, to evaluate for its current conservation value based on it having the highest density of adults and recruits and the highest larval abundance of the three sites evaluated for restoration. It also has comparatively more available hard substrate than the other sites, which is an important factor. This evaluation required a new parameter *adult oyster population size*, which had not been quantified for any Coos Bay sites. Based on adult oyster densities from Groth and Rumrill (2009) at this site along with a quick field assessment we conducted in May of 2015, we roughly estimated that there are likely more than 1000 oysters along 300 m of intertidal shoreline. Despite oysters being very patchy along the shoreline, there are areas of higher density including the field site where Rimler 2014 conducted her research.

Field Sites

Table 1. List of oyster field sites, site codes, and locations by sub-basin

Embayment	*Site Name*	*Site Code*	*GPS Coordinates*
Coos Bay	Downtown Coos Bay	DN	43.37853 N, 124.21559 W
Coos Bay	Haynes Inlet	HI	43.44070 N, 124.22086 W
Coos Bay	Coalbank Slough Coalbank-Railroad Bridge Coalbank-Edgewater Hotel	CB CB-RB CB-EH	43.35590 N, 124.2091 W 43.36021 N, 124.20616 W 43.36006 N, 124.20689 W
South Slough	South Slough-Valino Island South Slough-Long Island	SS-VA SS-LI	43.30775 N, 124.31962 W 43.30716 N, 124.3186 W

Table 2. List of continuous water quality and meteorological stations, station institution, and location by bay.

Embayment	*Station Name*	*Station Code*	*Station Institution*	*GPS Coordinates*	*Distance from oyster field site*
Coos Bay	Kokwel Wharf	KW	Coquille Indian Tribe	43.4034055 N, 124.219477 W	2.9 km (DN)
Coos Bay	North Point	NP	NERR, Partnership for Coastal Watersheds	43.42575 N, 124.222703 W	1.6 km (HI)
Coos Bay	Isthmus Slough	IS	NERR, Partnership for Coastal Watersheds	43.327808 N, 124.200409 W	3 km (CB)
South Slough	Valino Island	VA	NERR SWMP	43.3172374 N, 124.3216473 W	1.2 km (SS)
Coos Bay	North Bend Airport	KOTH	Southwest Oregon Regional Airport	43.4171° N, 124.2460° W	3.3 km (HI) 5.1 km (DN) 7.6 km (CB)
South Slough	Charleston Met	CM	NERR SWMP	43.3450 N, 124.3287 W	4.4 km (SS)

Field Parameters

Table 3. List of oyster attributes, sites where data were collected, and the timescale for data collection.

Oyster Attributes	*Sites*	*Timescale*
Adult density	DN, HI CB-RB, CB-EH, SS-VA, SS-LI	2006 2014
Size	DN CB-RB, CB-EH, SS-VA, SS-LI	2006 2014
Size Frequency	DN CB-RB, CB-EH, SS-VA, SS-LI	2006 2014
Growth rate	DN, HI, CB SS-VA, SS-LI	Jan - July 2013 Jan – May 2009
Survival rate	DN, HI, CB	Jan - July 2013
Recruitment rate	DN, HI, CB	July-Nov 2012, May-Aug2013
Larval abundance	DN, HI, CB	July-Nov 2012, May-Aug 2013

Environmental Parameters

Table 4. List of environmental factors, sites where data were collected, and the timescale for data collection.

Environmental Factors	*Sites*	*Timescale*
Water temperature	KW NP, IS VA	Sept 2013-March 2015 Oct 2013-March 2015 Jan 2010-Dec 2014
Dissolved oxygen	KW NP, IS VA	Sept 2013-March 2015 Oct 2013-March 2015 Jan 2010-Dec 2014
Salinity	KW NP, IS VA	Sept 2013-March 2015 Oct 2013-March 2015 Jan 2010-Dec 2014
pH	KW NP, IS VA	Sept 2013-March 2015 Oct 2013-March 2015 Jan 2010-Dec 2014
Air temperature	KOTH, CM	Jan 2013-Dec 2014
Substrate availability	DN, HI, CB	2012-2013
Chlorophyll a	VA HI, CB	2010-2013 2013

Field Methods

Oyster Attributes

Adult oyster density and size

Means for adult density per m^2 for Downtown and Haynes Inlet were used from Groth and Rumrill (2009). Mean adult size for Downtown was also used from Groth and Rumrill (2009) and only included measurements for oysters >20 mm; size data were unavailable for Haynes Inlet. Data for mean adult density per m^2 and adult size measurements were collected at Coalbank Slough and South Slough in 2014 as part of an oyster restoration monitoring project. For these surveys, data were collected at 2 m intervals along three 10 m transects at each of the two sites in South Slough and two sites in Coalbank Slough. A maximum of 10 oysters within a ½ m^2 quadrat were measured. Five density observations were also made for each transect at 2 m intervals. Data from the two sites in Coalbank Slough (CB-RB and CB-EH) were combined to represent the size and density of adult oysters in Coalbank Slough. The site (CB) where recruitment data were collected by Rimler (2014) is approximately 500 meters from CB-RB and CB-EH.

Diversity of size classes

Data from Groth and Rumrill (2009) were used to evaluate size-class diversity for Downtown. Because only oysters >20 mm in length were measured in the study, this sample represents the largest oysters, so this measurement needs to be interpreted carefully. Size data from the 2014 monitoring surveys at the Coalbank Slough and South Slough sites were used to assess size class diversity for those locations (no size limit was used for those oyster measurements). Oyster sizes were placed into 10 mm bins and used to generate a size-class diversity index (Gini-Simpson).

Gini-Simpson Index = 1 – Simpson index (D_s)
$D_s = \sum p_i^2$
P_i = proportion of individuals in each group

Growth and survival

Data for these attributes came from Rimler (2014). For this study 7 to 8 oysters (17.5 – 27.5 mm in height) were epoxied to each of four 10 cm x 10 cm unglazed ceramic tiles that were deployed at each site from 1/10/2013 until 7/10/2013. Tiles were retrieved and oysters were measured and assessed for survival four times during the deployment period. Mean growth rate per day from January to July is reported in the site evaluation tables. A survival rate (% survival from January-July) was calculated from the same data and reported in the site evaluation tables. The growth rate for the South Slough sites shown in the seeding score site evaluation table was calculated from data presented in Rumrill (2010) and based on measurements of oysters growing on shell bags that were sampled four times from January to May in 2009.

Recruitment

Recruitment data also came from Rimler (2014) in which eight replicate 10 cm x 10 cm unglazed tile plates were deployed at each site from 8/3/2012 to 11/14/2012 and 6/10/2013 to 11/18/2013. Plates were retrieved and replaced approximately every two weeks during the deployment period. The number of recruits was counted in a randomly selected subsection of each plate and used to calculate the mean number of recruits per 100 cm^2. For the site evaluation tables, we converted the means reported in Rimler (2014) to mean number per m^2 per day.

Larval abundance
Mean larval abundance data came from Pritchard (2014). For this study, larval traps were deployed at the same time and adjacent to the settlement plates used by Rimler (2014). Traps consisted of a funnel (7 cm x 5 cm), a PVC tube (61 cm x 5 cm), and a PVC stake fully inserted into the sediment. D-stage, umbo-stage, and settler abundances were counted from each of five replicate traps approximately every two weeks. Peak mean abundance of umbo-stage larvae (reported in the site evaluation tables) was calculated from collections in 2012 and 2013 and averaged across years.

Environmental Factors

Water temperature, salinity, dissolved oxygen, pH
YSI EXO2 or 6600V2 water quality sondes were deployed at permanent monitoring locations in Coos Bay and South Slough. Water quality sondes collect water temperature, specific conductivity, salinity, dissolved oxygen, pH, turbidity, and water depth data continuously every 15 minutes. Data collection and management follow standardized National Estuarine Research Reserve System-wide Monitoring Program (NERR SWMP) protocols (http://cdmo.baruch.sc.edu).

Chlorophyll *a*
For Haynes Inlet and Coalbank Slough, Oates (2013) collected chlorophyll *a* data by monthly grab samples with three replicates averaged for monthly values, however only the highest and lowest monthly values were reported in the thesis. Therefore, we present in the site evaluation table the highest monthly average for chlorophyll *a* at those sites. For the South Slough sites, chlorophyll *a* values were used from the NERR SWMP monthly nutrient program (2010-2014) which collects monthly triplicate grab samples. For comparability with the restoration sites, we also only present the highest monthly average and we only used summer months.

Air temperature
Air temperature data for the Restoration Site Evaluation Table were recorded by the North Bend, OR airport meteorological station (KOTH) and reported as daily maximum mean values. Air temperature data for the seeding sites in South Slough were recorded by the NERR SWMP meteorological station (CM) and were calculated as daily maximum mean values from 15 min averages; the data logger records measurements every 5 seconds and these are averaged over a 15 min interval.

Available substrate
The type and amount of available substrate was qualitatively described in Rimler (2014) for the three sites included in the Restoration Site Evaluation Table: Downtown, Haynes Inlet, Coalbank Slough. Because sites were described relative to each other, qualitative information was used to create categories and related scores for each category.

Modifications to the Site Evaluation Table
In general, we followed the methods of Wasson et al. (2014) for site evaluations, in terms of parameters included and thresholds used to assign scores. However, we omitted *Reliable Recruitment* and *Larvae Exported* as parameters because data for these parameters were not available for any of our sites. We included *Adult Oyster Size*, *Diversity of Size Classes*, and *Chlorophyll* a as parameters for sites when sufficient data were available. We added parameters for *Larval Abundance*, *Risk of Low pH Events*, and *Hard Substrate Availability* because these are important factors for assessing oyster success and data were available for these parameters for all of our sites. Generally, bins were

selected based on the distribution and variability in available datasets to maximize our ability to rank sites relative to one another. For *Survival Rate* and *Low Dissolved Oxygen*, we changed the scoring bin thresholds, because our units of measurement for these parameters differed from those of Wasson et al. (2014). For *Growth Rate*, we reduced all bin thresholds by 50% because data were only available for two quarters (i.e. six months) for our sites, whereas Wasson et al. (2014) averaged growth across all quarters of a year. For the *Low Dissolved Oxygen* parameter, we also used a different assessment metric since we had continuous sonde measurements; percent of data observations where DO fell below 5 mg/L were calculated. Bins for dissolved oxygen were selected to capture large site differences between the number of observations below 5 mg/L. For example, sites had a range including 0, 6, 1,035, and 3,333 instances where DO fell below 5 mg/L; these raw observations were adjusted by total number of observations in the dataset, which varied by site. For *Salinity Range,* we changed the threshold to percent days per year where average salinity was less than 15 ppt (from 25 ppt used in Wasson et al. (2014)). Evidence supports this lower threshold for Coos Bay and South Slough. Gibson (1974) found that salinities of 15 ppt and lower demonstrated deleterious effects on oyster populations in Oregon and Oates (2013) found low salinity effects on various reproductive condition indices at salinities lower than 15 ppt. However, our sites experience a wide range of salinity from 2.7 to 33.3 ppt, primarily from seasonal freshwater inputs, and oyster presence in these low salinity areas indicates oysters may be adapted to local conditions. We also changed the threshold for *Water Temperature* from 12°C to 15°C based on site-specific data on oyster temperature requirements; 15°C is thought to be a critical reproductive temperature; below this temperature spawning may not occur (Pritchard 2013). For the *Chlorophyll a* parameter, we used the highest monthly average concentration from each site because this was a common measure available for all sites.

Results of site evaluations

Restoration potential

Three sites (Downtown, Haynes Inlet, Coalbank Slough) were evaluated for restoration potential. The highest scoring site for restoration in Coos Bay was Downtown, although Haynes Inlet resulted in only a slightly lower score. Downtown had as much as 16 times higher densities of adults and 3 times the larval abundance as Haynes Inlet and Coalbank Slough. In addition, Downtown had the highest availability of hard substrate (e.g. rip-rap, rock, rubble, pilings), which is a potential limiting factor for other sites. It appears salinity may not be a major stressor for oysters at Coos Bay sites where daily averages were below 15 ppt for up to 39 percent of the year. All of the Coos Bay sites that we evaluated are located in the mid to upper estuary where they can experience long periods of high freshwater riverine input during the rainy season (November– April). In particular, Coalbank Slough had the highest percentage of years with consecutive low salinity events (6 events lasting up to 11 days) followed by Downtown with 1 event (lasting 4 days) over the 1.5 year period; Haynes Inlet had no prolonged low salinity events. Olympia oysters are generally absent from the lower reaches of the estuary where salinities are highest, with the exception of the Charleston Marina and (after reintroduction) South Slough.

Coalbank Slough and Haynes Inlet experienced lower dissolved oxygen (DO) concentrations than Downtown but overall low DO events were uncommon at all sites with < 2.5 % of values falling below 5 mg/L. Water temperatures were higher at Downtown and Coalbank Slough than at Haynes Inlet, most likely due to the location of Haynes Inlet which is lower in the estuary, although all sites had similar scoring for water temperature. Low pH events may be a stressor for oysters in upper estuary/riverine sites, although this stressor needs to be evaluated for local effects in estuaries. Coalbank Slough had the highest risk of low pH events and is located the furthest up the estuary, but pH at this site is highly variable.

Average chlorophyll concentrations measured at Haynes Inlet and Coalbank were moderate and may contribute to higher oyster performance at these sites. At all sites, high air temperature events (> 30°C) were rare (<1% days/yr), therefore this stressor doesn't currently seem to be a concern.

Additional data from three sites in Coos Bay (Airport, Empire, and Catching Slough) are available from the Pritchard and Rimler theses but the data are not presented here as these have more data gaps than the sites we included in our restoration potential evaluation tables. Density data for another location in Coos Bay (Isthmus Slough mitigation site) are also available from the work of Scott Groth (Oregon Department of Fish and Wildlife) where densities of up to $1000/m^2$ were observed. Including additional sites and filling in data gaps will be an important step for future revisions of the Coos Bay appendix of the Guide.

Restoration potential with seeding

We evaluated two reintroduction sites in South Slough to determine the restoration potential of these sites with seeding. Both sites scored similarly overall (56 & 58%). Although Valino Island (SS-VI) had slightly higher adult oyster density and size than Long Island (SS-LI), it had a lower diversity index which resulted in a slightly lower overall score. Since the sites were located very close together and relocated oysters were placed at both new sites randomly, we also considered the averaged metrics from the two sites for a combined score. The environmental factors that may contribute to potential stress for oysters were low chlorophyll levels, some low DO events (2% of observations fell below 5 mg/L), as well as prolonged low salinity events (20% of the year). However, as with the Coos Bay sites, salinity may not be a stressor for native oysters in South Slough since salinity is seasonally variable and can range from 11.3-33.3 ppt. The salinity range metric at Valino Island scored high with only 1 % of days per year averaging less than 15 ppt. Also, there are commercial oyster (*Crassostrea gigas*) operations near Long Island as well as at locations further up the estuary. On the other hand, sedimentation may be a stressor for oysters in South Slough, although it hasn't formally been assessed. The fact that high sedimentation rates required the relocation of outplanted oysters to a new site in South Slough suggests sedimentation may impact future seeding operations.

Conservation value

Downtown Coos Bay was evaluated for its value as a conservation site because it has the highest recruitment rates and larval abundances of all the sites that were evaluated. It also has suitable substrate, which would favor recruitment and reduce pressure from sedimentation. The overall oyster conservation score for Downtown (71%) is reasonably high, suggesting it may be an important site to focus conservation efforts. However, it should be noted that the adult oyster population size was a rough estimate from a brief survey to count oyster densities and that more data should be collected at this site. Overall, this site scored fairly high for the environmental parameters, with the exception of prolonged low salinity events. However, as mentioned earlier, the presence of oysters in Coos Bay at locations with low and/or variable salinities suggests native oysters may be locally adapted to these conditions. Similarly, recruits and larval abundances are all high at the Downtown site so they do not appear to be affected by low salinity.

	COOS BAY			SOUTH SLOUGH		
	Downtown Coos Bay	Haynes Inlet	Coalbank Slough	South Slough combined	Valino Island	Long Island
ADULT OYSTER DENSITY	50	25	50	50	50	50
OYSTER POPULATION SIZE	75					
ADULT OYSTER SIZE	50		25	50	50	50
DIVERSITY OF SIZE CLASSES	50		75	75	50	75
RECRUIT DENSITY	75	75	50			
LARVAL ABUNDANCE	75	25	50			
SURVIVAL RATE	75	50	75			
GROWTH RATE	25	75	25	25	25	25
WATER TEMPERATURE	75	50	75	50	50	50
AIR TEMPERATURE	100	100	100	100	100	100
CHLOROPHYLL		25	25	25	25	25
LOW DISSOLVED OXYGEN	100	75	50	50	50	50
SALINITY RANGE	75	75	25	75	75	75
RISK OF LOW SALINITY EVENTS	0	100	0	50	50	50
RISK OF LOW PH EVENTS	75	100	25	75	75	75
HARD SUBSTRATE AVAILABILITY	75	50	50			
DRILL PREDATION	100	100	100	100	100	100
OVERALL SCORES						
Restoration (natural recruitment)	67	66	50			
Restoration (with seeding)				58	56	58
Conservation	71					

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