San Francisco Bay Subtidal Habitat Goals Report

CONSERVATION PLANNING FOR THE SUBMERGED AREAS OF THE BAY

50-YEAR CONSERVATION PLAN • 2010

California State Coastal Conservancy and Ocean Protection Council
NOAA National Marine Fisheries Service and Restoration Center
San Francisco Bay Conservation and Development Commission
San Francisco Estuary Partnership

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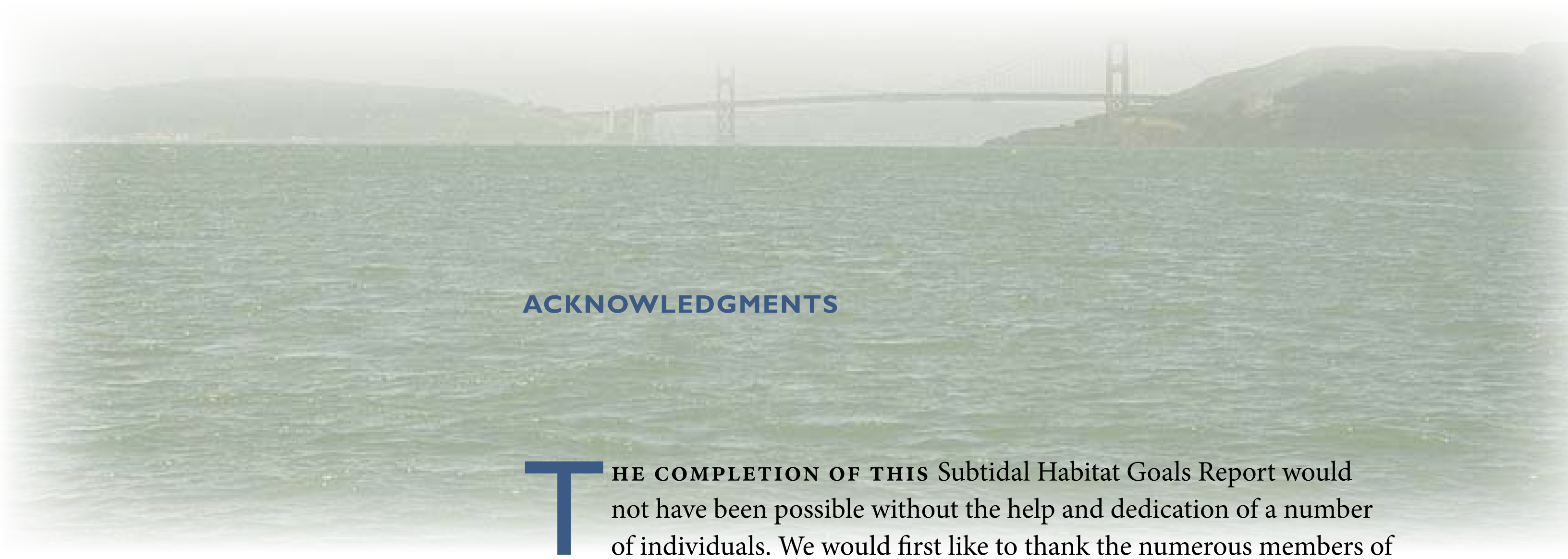

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We also sincerely appreciate the support and input received from our science, management, restoration, and executive steering committee members. Please see the list of members in Appendix 1-1. These dedicated and knowledgeable individuals include experts in biology, botany, fisheries, invertebrates, hydrology, wetlands, geology, engineering, contaminants, policy, restoration, management, and other fields related to subtidal habitats. Many of these committee members have participated since the inception of this project in 2001, and have tirelessly provided valuable input and their best scientific advice even in the face of multiple gaps in data. We truly value their time and input to the Project, and especially their review of multiple drafts over the past couple of years.

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CONTENTS

Appendices can be found on disk, inside back cover. The appendices, report, and interactive versions of the maps can be found at www.sfbaysubtidal.org.

San Francisco Bay Subtidal Habitat Goals Project

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CEQA DETERMINATION

The Subtidal Goals document is statutorily and categorically exempt from the California Environmental Quality Act (CEQA), for the reasons presented below.

The Subtidal Goals Project will result in documents that provide information, recommendations and goals for protection, restoration, appropriate use, and research to improve the subtidal habitats in San Francisco Bay. The project involves data collection, resource evaluation, and planning; all of these activities are exempt under CEQA. The documents that are prepared for the Subtidal Goals Project will not have a legally binding effect on later activities of public agencies.

The portions of the Subtidal Goals Project that consist of basic data collection and resource evaluation activities are categorically exempt from CEQA review, under 14 CCR Section 15306 ("Information Collection"). The information-collecting activities will be implemented in a manner that will not result in a serious or major disturbance to an environmental resource.

The portions of the Subtidal Goals Project that involve planning are statutorily exempt pursuant to Public Resource Code Section 21102 and 14 CCR Section 15262 ("Feasibility and Planning Studies") since they are for possible future actions that have not been approved, adopted, or funded. The planning studies will include consideration of environmental factors, to avoid impacts to sensitive environmental resources.

EFFECTS OF THE PROJECT

The Subtidal Habitat Goals Project will result in a recommendations document that is intended to provide general technical assistance and discretionary guidance for managing San Francisco Bay subtidal habitats. The document will result in no direct or indirect effects on resources of concern as outlined in the National Environmental Policy Act (NEPA) checklist. Implementation of specific recommendations or goals identified in the document will undergo individual NEPA analysis, as necessary.

NEPA DETERMINATION

After reviewing the project in relation to NAO 216-6, including the criteria on the NEPA checklist, and review by the Southwest Regional NEPA Coordinator, NOAA concluded that the proposed action would not have a significant effect, individually or cumulatively, on the human environment. Further, NOAA determined that the proposed action may appropriately be categorically excluded from the requirement to prepare either an environmental assessment or environmental impact statement, in accordance with Categorical Exclusion 6.03.c.3(i) Other Categories of Actions Not Having Significant Environmental Impacts. More specifically, this action represents guidance of an administrative, technical, or procedural nature, the environmental effects of which are too broad, speculative, or conjectural to lend themselves to meaningful analysis, and will be subject later to the NEPA process, either collectively or case-by-case.

San Francisco Bay Subtidal Habitat Goals Report

CONSERVATION PLANNING FOR THE SUBMERGED AREAS OF THE BAY

EXECUTIVE SUMMARY

SAN FRANCISCO BAY is one of the largest estuaries on the West Coast and one of the most important both for the habitat it provides for fish and wildlife and for the many benefits and opportunities it offers people. Its natural beauty gives the Bay Area the iconic identity for which it is known throughout the world, while its waters ensure an enviable climate and quality of life for over 7.5 million residents. Residents commute across the bay on ferries, or enjoy it while boating, fishing, swimming, windsurfing, and birding in and around its waters. Visitors from around the country and world are drawn to this heart of the Bay Area as well, adding millions of dollars each year to the local and state economies. The bay is a busy center of commerce: cargo ships and tankers from around the Pacific Rim depend on its ports and infrastructure, and approximately two million tons of sand are mined from beneath its surface each year for use in construction. Historical oyster shell deposits are mined for livestock and chicken feed, soil conditioner, and as a dietary supplement for human consumption.

In addition to offering these aesthetic, economic, and recreational values, the bay supports a critical food web. Herring and Dungeness crab, among many other species of fish and shellfish, rear in its waters while sturgeon, salmon, and steelhead feed and rest in the bay during their migrations to and from its

rivers and streams and the ocean. Its vast open water, sloughs, rivers, streams, and tidelands host millions of migratory birds every year as they move up and down the Pacific Flyway, as well as provide habitat for numerous resident water, shore, and song birds. The bay also provides important habitat for marine mammals, shellfish, and aquatic invertebrates—the smaller, often unseen but important inhabitants of the estuarine ecosystem.

Looking Beneath the Surface

Subtidal habitat is a critical piece of this ecosystem. Subtidal habitat, as defined in this report, includes all of the submerged area beneath the bay's water surface: mud, shell, sand, rocks, artificial structures, shellfish beds, eelgrass beds, macroalgal beds, and the water column above the bay bottom. Although this hidden underbelly of the bay is often thought of as a featureless mud bottom, its unique habitats provide diverse three-dimensional structures, including sand waves more than three meters high. Its eelgrass and shellfish beds act as ecosystem engineers and provide substrate for reproduction and food resources for species such as herring and salmon; rocky outcrops offer substrate for seaweeds and invertebrates; mixed sediments in shoals and channel banks are used by a variety of species. Many shellfish, macro- and micro-invertebrates, fish, marine mammals, diving ducks, and other wildlife feed, rest, hide, and reproduce in subtidal areas. Large populations of shorebirds feed on the estuary's subtidal and intertidal mudflats.

The bay also supports a variety of indirect ecosystem services, including nutrient cycling, climate regulation, flood protection, water quality maintenance, and sediment transport. The Subtidal Habitat Goals Report recommends preserving and restoring the bay's subtidal resources for their ecosystem functions and habitat values as well as for their ecosystem services to humans. The vision statement and goals presented in the report were developed using the best available science in the interest of supporting, maintaining, and improving upon these ecosystem functions, values, and services.

Report Audience and Use

Along with the Baylands Ecosystem Habitat Goals Project and the Uplands Habitat Goals Project, the San Francisco Bay Subtidal Habitat Goals Project (Subtidal Goals Project) represents a milestone in regional habitat planning for San Francisco Bay and its watersheds. Bay Area planners and resource managers now have a comprehensive and innovative ecosystem-based management vision for a continuum of habitat types from the bottom of the bay to tidal wetlands and grassland transition zones to upland areas.

Bay Area planners and resource managers now have a comprehensive and innovative ecosystem-based management vision for the bottom of the bay to tidal wetlands and grassland transition zones to upland areas.

The Subtidal Goals Project report is neither a policy nor a regulatory document. It is designed to give resource managers, regulatory agencies, environmental groups, researchers, industry, and anyone interested in this important bay habitat the basic information they need to plan conservation, restoration, research, and protection activities related to subtidal habitat in the San Francisco Estuary.

Implementation of the goals in the report will occur through a number of avenues: local governments may incorporate these recommendations into their planning processes and documents. Non-profits may use the report when seeking funding for restoration or management projects, and researchers may wish to refer to it for guidance in writing proposals. Regulatory agencies may use this report to evaluate, revise, or implement their policies. However, new policies or modifications to existing policies proposed on the basis of this report will require a separate process in which each agency will analyze recommended policies in the context of its existing authorities and public input process.

The Subtidal Goals Project is a collaboration among the San Francisco Bay Conservation and Development Commission (BCDC), California Ocean Protection Council (OPC)/California State Coastal Conservancy (SCC), the National Oceanic and Atmospheric Administration (NOAA), and the San Francisco Estuary Partnership (SFEP). Lead staff from those agencies worked with the broader scientific community, managers, restoration practitioners, and stakeholders over several years to develop the goals set forth in this document. More about the process used to develop the project can be found in Appendix 1-1.

NOAA, BCDC, SFEP, and SCC each have different authorities, mandates and policies regarding conservation and management of subtidal habitats. As such, each agency may choose to use this document in different ways.

- While this document does not supersede or change NOAA authorities or mandates, NOAA staff may reference information in this document when implementing consultations pursuant to the Endangered Species Act and the Essential Fish Habitat provisions of the Magnuson-Stevens Fishery Conservation and Management Act.

- NOAA may reference this document when evaluating research priorities both for NOAA Science Centers and other scientific entities.
- The NOAA Restoration Center may use this document to help prioritize restoration projects for funding and support.
- San Francisco Bay Conservation and Development Commission staff may use this document as background when considering future revisions to the San Francisco Bay Plan and may reference it when evaluating proposed projects under BCDC's existing regulatory authority over development in and around San Francisco Bay.
- The San Francisco Estuary Partnership may reference this document when implementing the Comprehensive Conservation and Management Plan for San Francisco Bay, in seeking federal dollars for San Francisco Bay conservation, and in selecting restoration and/or research projects to fund.
- The State Coastal Conservancy may use this document to identify acquisition opportunities, prioritize conservation and strategic planning, and develop restoration projects to support and fund. The Ocean Protection Council may utilize the document in making decisions and prioritizing research areas, especially as they relate to issues of land-sea interactions, ecosystem research, and climate change planning.

Planning Framework and Approach

The vision statement of the project is to achieve a net improvement of the subtidal ecosystem in San Francisco Bay through science-based protection and habitat restoration.

The Subtidal Goals Project takes a bay-wide approach to setting science-based goals for maintaining a healthy, productive, and resilient ecosystem. The vision statement of the project is to achieve a net improvement of the subtidal ecosystem in San Francisco Bay through science-based protection and habitat restoration. Where possible, these subtidal goals are designed to connect with intertidal habitats and with goals developed by other projects, including goals for baylands and uplands habitats. Unlike in the Baylands Goals effort, historical information about subtidal habitat is lacking. Thus the goals set forth in this document do not attempt to restore the bay to historical conditions but are designed to improve the condition of the subtidal ecosystem. The baseline for the project is 2010, and the planning horizon is 50 years.

Collecting and mapping baseline geospatial data of all of the subtidal habitat types was a critical piece of this project. Maps of habitat distribution, ownership, and stressors for each habitat type—as well as proposed restoration sites for native oysters and eelgrass and pilot locations for intertidal sand beaches and living shorelines—are presented throughout the report.

Early in the process, the following key planning decisions were made:

- The geographic scope of the Subtidal Goals Project is San Francisco Bay from Sherman Island west to the southern extent of the bay and seaward to the Golden Gate (Point Bonita to Point Lobos). Although the Sacramento-San Joaquin Delta is not included in the project scope, conditions in the delta and their relationship to subtidal habitat in the bay are addressed in the sections on freshwater input and climate change (see Chapter 3).
- For the purposes of this project, "*subtidal habitat*" includes all submerged areas of the bay. The project also includes certain *intertidal habitats* that were not specifically addressed in the 1999 Baylands Ecosystem Goals Report: intertidal mudflats, eelgrass, sand beaches, rocky intertidal and subtidal areas, and artificial substrate.
- The report uses a precautionary approach, erring on the side of conserving and protecting resources.
- Available information about existing conditions serves as a baseline.
- The goals build upon opportunities and information developed by existing subtidal pilot projects, including in-the-water monitoring, restoration, mitigation, and research projects in San Francisco Bay.
- This document avoids setting priorities among habitats although restoration of some may result in conversion of others: for example, some soft substrate may be lost or enhanced through restoration of eelgrass or shellfish beds.

- Because there is a great deal of uncertainty about the functions and value of subtidal habitats and the utility and likely success of restoration, this report recommends using an adaptive management approach in implementing the goals.
- As part of adaptive management, progress on achieving the goals—as measured by improved scientific understanding and practical experience in subtidal habitat restoration and protection—should be reviewed and evaluated in a report by 2020. The goals can then be modified as needed. Interim updates on particular topics can be provided within 10 years, and discussed at regional forums and conferences.

Establishing the Goals

Goals for each of the subtidal habitats are based on the vision statement and the following **foundational science goals**:

- Understand the value of the habitats
- Understand the interactions among habitats
- Understand the long-term prospects for subtidal habitats
- Develop mechanisms for adapting to climate change

Cross-Habitat Goals were also developed in response to four issues—invasive species, oil spills, marine debris, and public access/awareness—that affect all subtidal habitats:

- Minimize the impacts of aquatic invasive species on native subtidal habitats in San Francisco Bay.
- Protect San Francisco Bay from both acute and chronic oil spills.
- Prevent and capture land or marine sources of trash before they enter the bay.

- Identify, prioritize, and remove large sources of marine debris from intertidal and subtidal areas of the bay.
- Increase public awareness and foster support for subtidal habitat protection.

Taking into account the extent of scientific understanding of each habitat each goal was then vetted through a decision tree. That process led to establishing specific habitat goals and actions in one of four broad directions:

- Enhancing, creating, or restoring particular habitats
- Protecting habitats
- Observing habitats, taking no action
- Eliminating habitats

Other key conclusions reached after vetting each habitat through the decision tree include:

- Subtidal to intertidal mudflats support valued services and are under various threats from human activities and climate change. Opportunities for restoration are based on uncertain techniques, so this report emphasizes protecting habitat and applying restoration methods experimentally.
- Muddy soft-bottom habitat is essential for some species and probably supports the most known ecosystem services of any habitat. Although it is plentiful, several threats exist. However, there are few opportunities for restoration, leading to an emphasis on protection.
- Sand bottom is used for sand mining, but little is known about its role in non-extractive ecosystem services. This lack of knowledge leads to a recommendation to protect existing sand resources while pursuing research into the impacts of sand mining and the value of this habitat type to species and ecosystem services.

- Rock outcrops support ecosystem services and are under threat, but restoration would be logistically difficult and therefore unlikely; the report thus recommends protection actions only.
- Artificial structures support valued ecosystem services but also can impair others. Since they are artificial, most of them cannot be considered to be in short supply, nor are they under threat. Conversely, there is interest in removing some of them, especially derelict structures no longer in use, leading to an expansion of other more favored habitats.
- Several habitats (e.g., eelgrass, oyster beds) have clear benefits in supporting valued ecosystem services, although the degree of support is uncertain. They are likely in short supply and under various threats, and restoration has been successful at small scales. Therefore restoration goals are the principal focus for these habitats, although protection goals are also necessary.
- Algal beds support ecosystem services (although at a small scale), but they can also be nuisances under some conditions. Because it is unknown whether and which species of algal beds are under threat or in short supply, the decision tree process led to identifying research goals only.
- The water column forms the background for all of the other habitats. It supports all ecosystem services. Its existence is not threatened, but water quality could become degraded. However, as discussed in Chapter 3, water quality is the province of various agencies and is not addressed in this project.

Habitat Snapshots

Science, protection, and restoration goals were developed for the following six subtidal habitats:

Soft Substrate

1. *Soft Substrate.* More than 90% of the estuary's bottom is composed of particles small enough to be moved by tidal currents. Soft-bottom habitat includes the soft substrate, organisms living on or within the substrate, and the overlying water column. This habitat is threatened by construction activities, deposition of material from dredging and sand mining, wakes from ships and ferries, and a variety of contaminants, including some toxic "hot spots." Soft-bottom habitat may also be threatened by an overall decrease in sediment supply from upstream, and by sea-level rise. The report therefore recommends that the quality of this habitat be improved and that it be managed properly.

Rock

2. *Rock.* Relatively little hard substrate occurs naturally in the estuary. Rock habitat encompasses boulders to bedrock; i.e., rock that is not normally moved by currents. Shellfish beds and some algal beds are a subset of rock habitat. This habitat is threatened by blasting for navigational safety, colonization by invasive species, possibly by sediment deposition, and in the case of intertidal rock, from oil spills and trampling. While rock habitats support valued ecosystem services and are in short supply in the estuary, restoration seems impractical. The Subtidal Goals Project recommends protecting and managing rock habitat from being removed for vessel traffic and damaged by public access, and enhancing it by removing invasive species and debris. It also recommends improving scientific understanding of the ecosystem services this habitat provides and the species that use it.

Artificial Structures

3. *Artificial Structures.* Artificial structures are found throughout the estuary and include a wide variety of human-built objects designed to protect shorelines and shoreline structures and for transportation, recreation, and more recently, restoration (oyster shell and artificial reefs). While artificial structures support some valued ecosystem services, they are not in short supply, and they can have some detrimental effects. The Subtidal Goals Project recommends further study of the advantages and disadvantages of removing abandoned pier pilings, and if removal is decided upon, that it be done using an adaptive management approach. It also recommends using a pilot project approach, and if creosote pilings are removed, providing eelgrass as a substitute substrate for attracting spawning herring. Goals for artificial structures focus on protecting the habitat values of existing actively-used structures, removing and preventing structures that harm the subtidal system, and improving understanding of the role of these structures in the subtidal system.

Shellfish Beds

4. *Shellfish Beds.* Hard-bottom shellfish beds are locations where a shellfish species occupies more than 50% of an area of more than a few square meters. Five species of shellfish occur in San Francisco Bay: native Olympia oysters, California mussels, hybridized Bay mussels, and non-native ribbed horsemussel and green bagmussels (the latter two are not considered in this report). Small populations of the non-native Pacific oyster are found in the South Bay, where eradication efforts are underway. The Olympia oyster is the most abundant and the only species that is a native confined to estuaries. Numerous individuals have been found on hard substrates in the Central Bay and to a lesser extent in San Pablo and the South Bays. Native oysters are threatened by high rates of sedimentation and extended periods of low salinity. Human-induced threats include water pollution, boating, shipping, and dredging, which can disrupt oyster beds or cause sediment to smother the beds. The Subtidal Goals Project recommends building upon the demonstration oyster restoration work that has been performed to date, and moving toward larger-scaled pilot projects while focusing on knowledge gained in the process (adaptive management). Goals for shellfish beds include protecting existing native oyster beds, creating and enhancing additional beds, and improving scientific understanding of ecosystem services, factors influencing the beds, and restoration methods.

Submerged Aquatic Vegetation

5. *Submerged Aquatic Vegetation.* The term "submerged aquatic vegetation" (SAV) refers to all underwater flowering plants. In the San Francisco Estuary, SAV includes sago pondweed (*Stuckenia pectinata*, formerly *Potamogeton pectinatus*), eelgrass (*Zostera marina*), and other species of seagrass, including the surfgrasses (*Phyllospadix torreyi* and *P. scouleri),* and widgeongrass (*Ruppia maritima*). Several freshwater plant species, mostly introduced, are found mainly in the delta (e.g., the Brazilian waterweed *Egeria densa*, an invasive nuisance species) and are outside of the geographic scope of this project. In San Francisco Bay, eelgrass is much more extensive than other SAV, and its role and restoration potential are understood better than for other SAV (Appendix 8-1). The largest eelgrass beds in the estuary are in shallow subtidal regions of San Pablo Bay and Richardson Bay, with smaller beds scattered in shallow areas mainly between Carquinez Strait and Hayward. The largest bed in the bay is located between Point San Pablo and Point Pinole, and contains about half of the total acreage. Threats to SAV in San Francisco Bay include activities associated with shipping and boating, which can disrupt seagrass beds directly through destruction of plants by boat propellers, anchors and anchor chains, dredging, and construction of facilities (e.g., docks, harbors, breakwaters, ports). Indirect effects arise through increased suspended sediments due to dredging and boat wakes, or shading from structures such as docks. Hardening of the shoreline can reflect waves, increasing wave action and limiting or destroying beds. Most of these threats apply to eelgrass in the San Francisco Estuary but

are focused in localized areas. Impacts from dredging seem to have a limited spatial and temporal effect; damage from boat anchors, shoreline development, and ship wakes is also likely to be localized. Oil spills can inundate and smother eelgrass beds, particularly those in the intertidal or shallow subtidal zones. Eelgrass beds may respond to rising sea level by establishing closer to the present-day shoreline and dying out at greater depths. The dwindling sediment supply to the estuary may decrease turbidity, allowing eelgrass to grow at greater depths but possibly also promoting competing blooms of phytoplankton.

The restricted extent of eelgrass beds may limit their support of valued ecosystem services. Restoration has been demonstrated to be feasible although questions remain about the anticipated trajectory of restoration and associated response of ecosystem functions and services. Restoration is warranted for eelgrass beds, but should be done within an experimental framework.


Macroalgal Beds

6. *Macroalgal Beds*. Four species of macroalgae—*Ulva* spp., *Gracilaria pacifica, Fucus gardneri,* and the introduced *Sargassum muticum*—are sufficient to create beds in the estuary; however, their distribution and extent is poorly known. Macroalgae provide a suitable food source for a variety of grazers, predominantly macroinvertebrates. Water birds use it to line their nests. The beach wrack produced by macroalgae is an important food source for invertebrates living in beaches, mudflats, and marshes: they in turn provide food for shorebirds and other species along the shore. There have been few reports of nuisance blooms of macroalgae in the bay, although this could change if turbidity decreases. Intertidal algal beds are vulnerable to trampling and recreational harvesting as well as oil spills and dispersants. Because it is unclear whether additional macroalgal beds would be beneficial in the bay or that they are in short supply, and because it is difficult to distinguish algal beds that support ecosystem services from those that interfere with them, the Subtidal Goals Project recommends that additional research be performed and existing macroalgal beds protected.

The Science Goals[1]

Three key principles governed the establishment of science goals for subtidal habitats:

- Acknowledge key gaps in the knowledge needed for decisions about the value of restoration, and for effective protection and restoration. Substantial gaps are addressed by the following research questions:

  Which ecosystem services do the target habitats support, and how?

  What is the relationship between quantity of the habitat and the amount or value of those ecosystem services?

  What interactions (conflicts or synergies) are likely among those services or the ecosystem processes that produce them?

  What are the threats to various habitats or the species using them?

  What actions would enhance or diminish the amount or value of ecosystem services?

- Take a broad, long-term perspective. The goals should account for both long-term change in the estuary and spatial patterns at all scales. Research that informs managers about future conditions and applies broadly across the estuary should take the highest priority.

- Acknowledge and allow for limitations on gathering knowledge. The science goals should be achievable in a reasonable time and realistic as to the likely outcomes. Conducting research on subtidal habitats is difficult, particularly so in turbid estuaries where these habitats are largely invisible. These limitations should be acknowledged in determining research priorities and sequencing, and in setting expectations for the information needed for restoration and protection.

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1. This summary presents the broadest level goals. More detailed, specific objectives and actions can be found in the report.

SCIENCE GOALS
Soft Substrate
Understand the extent of ecosystem services provided by soft-bottom habitats.
Understand the threats to mudflats and other soft-bottom habitats.
Determine suitable methods for protecting mudflats and beaches.
Understand the magnitude of the ecological risks posed by contaminants bound to the sediments.

Rock Habitats
Understand the ecosystem services provided by rock habitat and the species dependent on them.
Understand the ecosystem services provided by restored rock habitat.

Artificial Structures
Understand how artificial structures generally affect the estuarine ecosystem.
Determine the roles of individual artificial structures proposed for removal.

Shellfish Beds
Understand the ecosystem services the shellfish beds support, and in what quantities, in their current state and after restoration.
Understand the factors controlling the development and persistence of oyster and other shellfish beds.
Develop the most effective ways of restoring and protecting oyster beds.

Submerged Aquatic Vegetation (SAV)
Understand the ecosystem services the eelgrass beds support, and in what quantities, in their current state and after restoration.
Understand the factors controlling the development and persistence of eelgrass beds.
Develop the most effective ways of restoring and protecting eelgrass beds.
Assess the status and distribution of other SAV.

Macroalgal Beds
Understand the roles of macroalgal beds of different species in providing ecosystem services or interfering with services provided by other habitats.
Understand changes in the extent or condition of macroalgae.

The Protection Goals

Protection goals for each of the habitat types focus on preserving existing habitat. When information about specific threats to each habitat was available, more detailed protection objectives and actions were included.

The resource management committee prioritized stressors that can degrade or otherwise influence subtidal habitats, and the administrative core group conducted an exercise to compare severity, scope, and irreversibility of these stressors against each subtidal habitat type (see Appendix 1-1). This exercise resulted in the following key conclusions:

- Bottom disturbance is a stressor of concern across several habitats.
- Placement of artificial structures is a potential stressor of concern for the shellfish and submerged aquatic vegetation "living" habitats.
- Eelgrass habitat has multiple stressors of concern.
- Contaminants are a stressor of concern for soft substrate, especially mud habitat.

This was the starting framework for developing protection goals. This information was then further developed by science advisor Dr. Wim Kimmerer and the science committee (see Appendix 1-1) and incorporated into conceptual models for each habitat. Those models more fully describe the functions of and threats to the habitats and form the basis for all of the goals for each habitat type in Chapters 4–9.

PROTECTION GOALS
Soft Substrate
Consider the potential ecological effects of contaminated sediments when developing, planning, designing, and constructing restoration projects or other projects that disturb sediments.
Promote no net increase in disturbance to San Francisco Bay soft bottom habitat.
Promote no net loss to San Francisco Bay subtidal and intertidal sand habitats.
Develop a coordinated, collaborative approach for regional sediment management for San Francisco Bay.
Rock Habitats
Promote no net loss of natural intertidal and subtidal rock habitats in San Francisco Bay.
Artificial Structures
Enhance and protect habitat functions and the historical value of artificial structures in San Francisco Bay.
Improve San Francisco Bay subtidal habitats by minimizing placement of artificial structures that are detrimental to subtidal habitat function.
Shellfish Beds
Protect San Francisco Bay native shellfish habitats (particularly native oyster *Ostrea lurida*) through no net loss to existing habitat.
Protect areas in San Francisco Bay with potential for future shellfish expansion, restoration, or creation.
Submerged Aquatic Vegetation (SAV)
Protect existing eelgrass habitat in San Francisco Bay through no net loss to existing beds.
Establish eelgrass reserves.
Identify and protect areas in San Francisco Bay for future eelgrass expansion, restoration, or creation.
Protect existing widgeon grass habitat in San Francisco Bay.
Protect existing sago pondweed habitat in San Francisco Bay.
Macroalgal Beds
Protect San Francisco Bay *Fucus* beds through no net loss to existing beds.
Protect San Francisco Bay *Gracilaria* beds through no net loss to existing beds.

The Restoration Goals

Restoration should be targeted to locations and situations where long-term success is most likely.

In this report, the term "restoration" includes creating, enhancing, remediating, and rehabilitating habitat. The restoration goals are not meant to return subtidal habitats in San Francisco Bay to conditions that may have existed in the past. Rather, they are meant to improve upon conditions that exist today, with restoration targets based on what is known about ecosystem services provided by habitats, limiting factors, and the potential for habitats to be created or enhanced within the bay. Restoration should also be designed for the long term, and planning must therefore account for expected long-term changes. Restoration should be targeted to locations and situations where long-term success is most likely. This report recommends developing a better understanding of the likely success of restoration in particular areas, the local processes and conditions as they may affect the habitat, and the present and future threats.

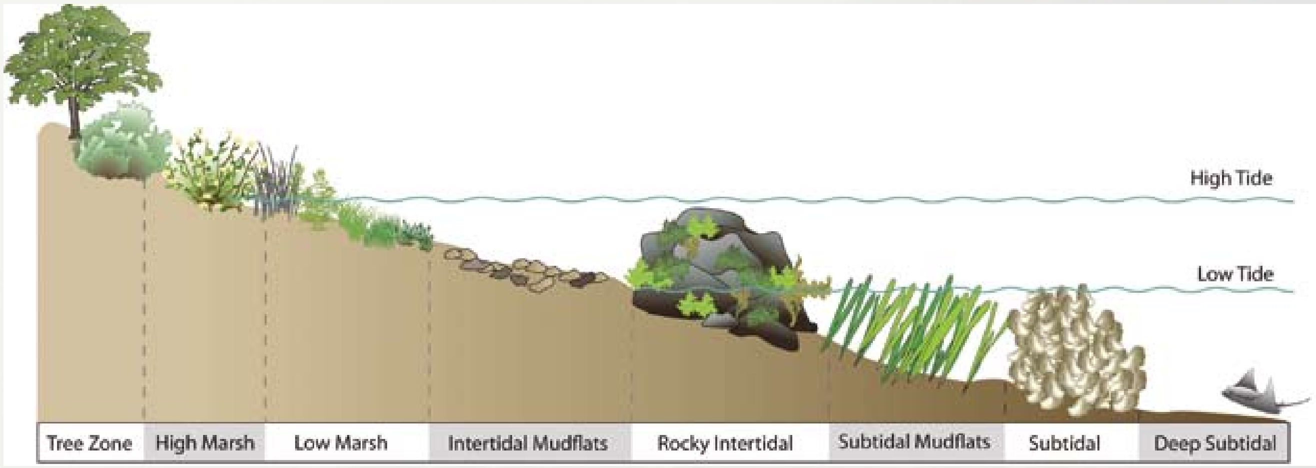
RESTORATION GOALS
Soft Substrate
Encourage the application of sustainable techniques in sand habitat replenishment or restoration projects.
Encourage removal of artificial structures that have negative impacts on soft bottom habitat function.
Rock Habitats
Restore and maintain natural intertidal and subtidal rock habitats in San Francisco Bay.
Artificial Structures
Where feasible, remove artificial structures from San Francisco Bay that have negative or minimal beneficial habitat functions.
Promote pilot projects to remove artificial structures and creosote pilings at targeted sites in combination with a living shoreline restoration design that will use natural bioengineering techniques (such as native oyster reefs, stone sills, and eelgrass plantings) to replace lost habitat structure.
Shellfish Beds
Increase native oyster populations in San Francisco Bay within 8,000 acres of potential suitable subtidal area over a 50-year time frame through a phased approach conducted within a framework of adaptive management.
Submerged Aquatic Vegetation (SAV)
Increase native eelgrass populations in San Francisco Bay within 8,000 acres of suitable subtidal/intertidal area over a 50-year time frame using a phased approach under a program of adaptive management.

Integrating Subtidal Habitat Restoration with Other Habitats

Integrating subtidal restoration with tidal wetland projects helps protect the enormous investment that has been made in restoring tidal wetlands around the bay.

Most of the habitat restoration projects implemented in and around San Francisco Bay in the last 40 years have focused on single habitat types such as marshes and riparian zones. Yet integrating restoration of subtidal and nearby marsh and upland habitats may provide greater ecological benefits and cost savings, help ameliorate habitat fragmentation, and help protect shorelines from climate change impacts, including sea level rise. Integrating subtidal restoration with tidal wetland restoration projects whenever possible thus helps protect the enormous investment that has been made over the past several decades in tidal wetlands around the bay.

One means to integrate them is through living shorelines. Living shorelines utilize a suite of bank stabilization and habitat restoration techniques to reinforce the shoreline, minimize coastal erosion, and maintain coastal processes while protecting, restoring, enhancing, and creating natural habitat for fish and aquatic plants and wildlife. This technique coined the term because it provides



"living space" for estuarine and coastal organisms, accomplished by the strategic placement of native vegetation, sand fill, organic materials, and reinforcing rock or shell for native plants and animals to settle on.

The decision tree used for vetting goals for the other habitat types (see Chapter 2) provides no guidance for integrating subtidal habitats with marshes and riparian habitats or for establishing living shorelines. The Subtidal Goals Project therefore suggests using an adaptive management approach to implementing pilot restoration projects that integrate subtidal habitat with other habitat types.

HABITAT INTEGRATION SCIENCE GOALS
Understand the ecosystem services supported by marsh-subtidal integration and living shorelines, and in what quantities.
Develop best practices for integrating subtidal restoration with adjacent wetlands.
Develop best practices for pilot projects to develop living shorelines.

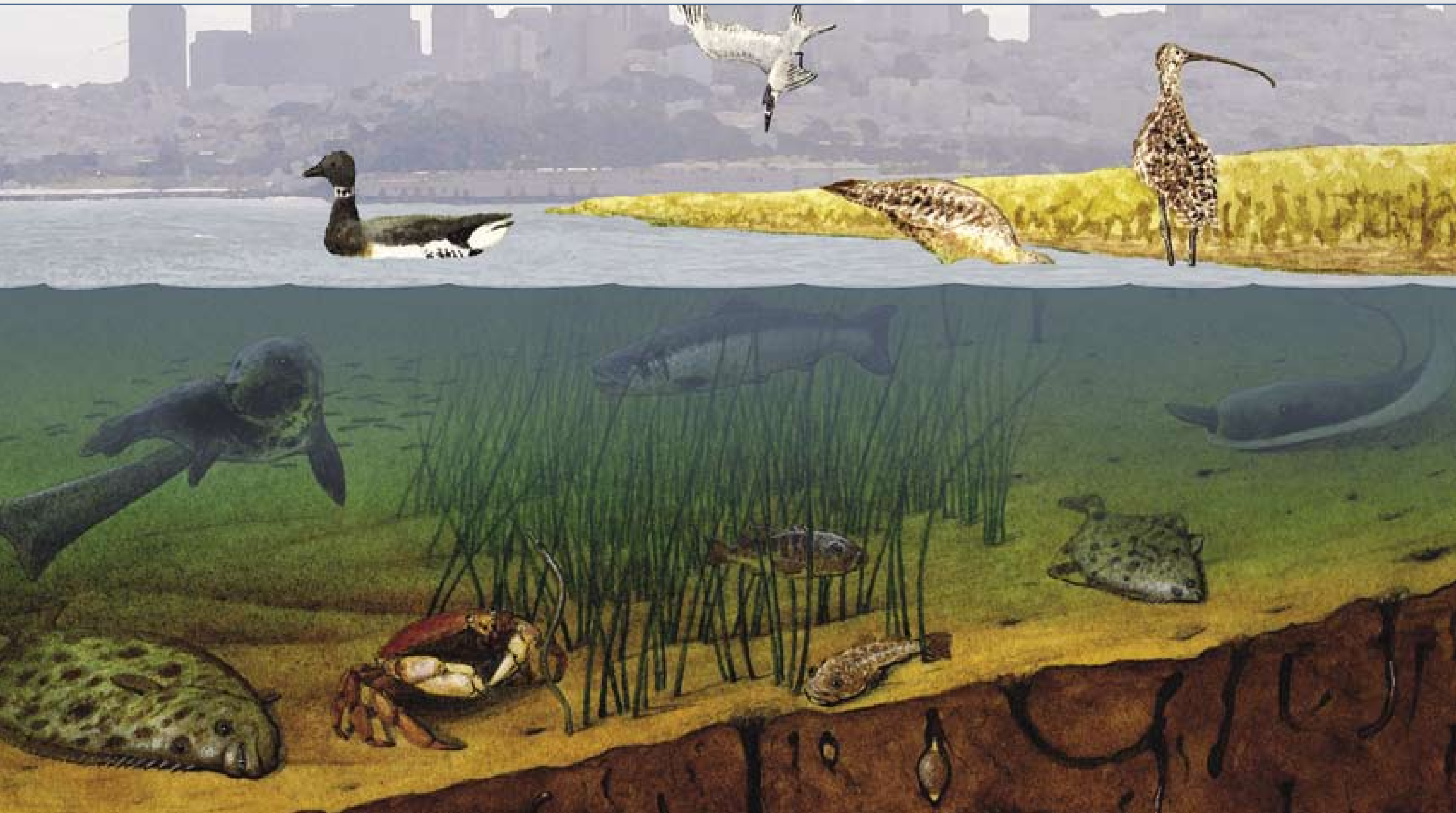
HABITAT INTEGRATION RESTORATION GOALS
Explore the integration of upland, intertidal, and subtidal habitats in San Francisco Bay.
Integrate habitat flexibility to increase resilience in the face of long-term change at habitat restoration sites around the bay.
Explore the use of living shoreline projects as a way to achieve multiple benefits in future shoreline restoration.

Potential Future Regulatory Actions for Subtidal Habitat

Several agencies regulate activities within the subtidal area of the bay. Some are focused on species protection, fisheries management, or water quality. Others have a broader habitat focus, while others must balance ecosystem and development needs. In reviewing these goals, some agencies may determine it prudent to take regulatory action through their existing authorities or to expand their current authorities through legislation or regulation changes. In either case, agencies must utilize existing public rule making processes. While regulatory measures would likely reduce impacts to the subtidal habitats, more research about these habitats is needed. As research is completed to better understand the functions and ecosystem services of subtidal habitats, information gained should directly inform management actions. In the interim, the Subtidal Goals Project recommends using a precautionary approach in managing subtidal habitats.

Implementing the Goals

To implement the goals, consistent and enduring support will be needed from a wide variety of stakeholders and yet may be difficult to secure, given political changes, staff turnover, budget fluctuations, and shifts in priorities. Successful implementation of the goals will require an entity or entities charged with raising funds and overseeing the realization of the goals in this document and the process of adaptive management necessary to realize the ecosystem benefits envisioned by this program. Implementation will require organizing stakeholders, identifying



owners of subtidal parcels, monitoring and tracking restoration projects, reviewing and reporting on knowledge gained and on progress in implementing the goals, revising the goals as needed, and educating the public about subtidal habitat in the estuary. This implementing entity might be an existing organization, a collaborative partnership among several agencies, or a new entity (such as a Joint Powers Authority or special district) created for this purpose.

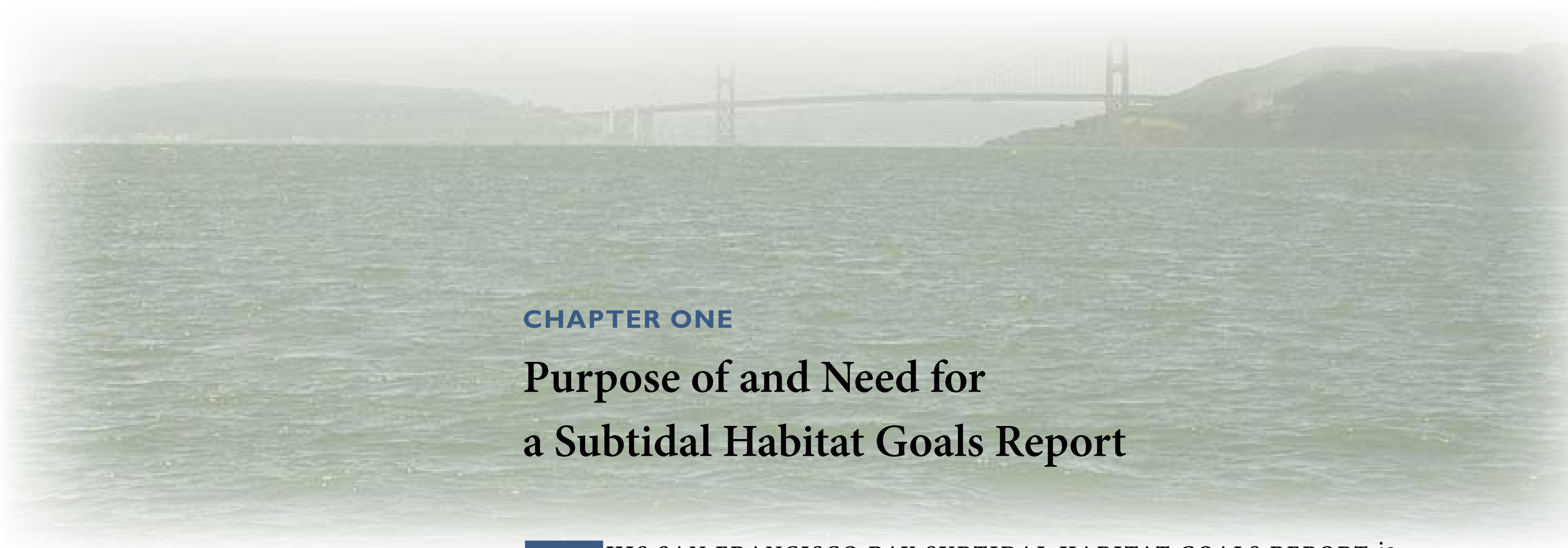
The Subtidal Goals Project recommends that the lead entity (or entities) establish a Bay Area Subtidal Habitat Forum (Forum) to engage a broad network of agencies and partners who will participate in implementing subtidal habitat research, protection, and restoration goals. This Forum, made up of local, state, and federal agencies, academic institutions, non-profits, businesses, and industry, would increase regional coordination, collaborative planning, and support for and awareness of subtidal protection and restoration. The Forum should be charged with leading adaptive management and ensuring progress is being made towards the goals in this document.

Thoughtful planning must be put into the process by which the Forum is constituted, including determining how leadership is selected, which members should be included for participation and how they will be selected, what operating practices should be adopted, which agency staff resources will be provided, and what additional funding or resources are needed and where those resources will come from. Existing successful regional partnerships such as the San Francisco Bay Joint Venture and the Southern California Wetlands Recovery Project provide models for such a Forum.

A NOTE ON THE APPENDICES

Multiple reports informed the planning process for the Subtidal Goals Project. Because they are voluminous, the appendices are available on disk inside the report's back cover, and on-line at www.sfbaysubtidal.org.

The San Francisco Bay regulatory, agency, and environmental communities have an impressive record of taking bold and innovative actions to protect estuarine habitats and encourage public involvement. Making the goals set forth in this report a reality will take similar bold, sustained, and innovative efforts. The goals offer measurable objectives and actions that when implemented, will improve San Francisco Bay subtidal habitats. We hope you will join us in embracing the principles and recommendations included in this plan and look forward to working with a diverse group of stakeholders on implementing the goals.



CHAPTER ONE

Purpose of and Need for a Subtidal Habitat Goals Report

THIS SAN FRANCISCO BAY SUBTIDAL HABITAT GOALS REPORT is designed to give resource managers, regulatory agencies, environmental groups, researchers, industry, and anyone interested in this important bay habitat the basic information they need to plan conservation, restoration, research, and management activities related to subtidal habitat in the San Francisco estuary.

As defined here, subtidal habitat includes all of the submerged area beneath the bay water's surface: mud, shell, sand, rocks, artificial structures, shellfish beds, submerged aquatic vegetation, macroalgal beds, and the water column above the bay bottom.

The Need for a Subtidal Goals Project

Pacific herring (shown here in kelp) use eelgrass beds as a spawning substrate in San Francisco Bay.

In the past several decades, with the goal of improving the San Francisco Bay ecosystem, resource agencies and environmental groups have made enormous efforts—many are completed or underway, and others still in the planning stages—to restore the wetlands at the bay's edges, the streams and riparian areas throughout its watersheds, and, more recently, the remaining open spaces of its uplands. Much of this effort has focused on restoring tidal wetlands. However, most wetland restoration projects to date have not been designed with subtidal resources in mind, despite the fact that subtidal areas are intrinsically connected to mudflats, wetlands, creeks, and uplands. Until very recently the area beneath the bay's surface was "out of sight, out of mind"—unless obstacles needed to be removed or channels dredged to ensure safe passage for ships, or when sand, shell, or mud were needed for construction and other human activities.

Government agencies with authority for managing the estuary lack sufficient information about subtidal habitats in the bay to inform management decisions. Although a tremendous amount of scientific information is available from research and monitoring in the bay, little of it is useful in making decisions about specific proposals for development or restoration as they relate to subtidal habitat. Part of the reason for this shortfall is that subtidal habitats are usually invisible in the bay's turbid waters, and most sampling methods cannot provide detailed information about the location and condition of the various habitats. Furthermore, relatively little research has been conducted that would provide key support for the Subtidal Goals Project on the extent and value of the ecosystem services provided by each habitat, and the threats those habitats face—information that is needed to protect and restore these habitats. Equally important is the need to learn more about the functions of these habitats, how they respond to environmental change, and how to protect and enhance them.

A number of ongoing planning efforts successfully address various aspects of natural resource conservation in the San Francisco Bay region (see box for a list of other such planning efforts). Many of these planning efforts address components of subtidal habitats from different planning or regulatory perspectives, depending on the entities involved in the efforts and their individual mandates and authorities. The Subtidal Goals Project is the first effort to focus on all subtidal habitats within San Francisco Bay. Implementation of the goals presented here is intended to build upon and complement existing efforts. In particular, the perspective of the Subtidal Goals Project is physical habitat rather than protection or enhancement of species, which is the purview of agencies implementing federal or state Endangered Species Acts or regulating collection and harvest.

OTHER PLANNING EFFORTS RELATED TO SUBTIDAL HABITAT

Bay Delta Conservation Plan (http://baydeltaconservationplan.com/default.aspx)

Baylands Ecosystem Habitat Goals Project (http://www.sfei.org/)

Comprehensive Conservation and Management Plan (www.sfestuary.org)

Humboldt Bay Subtidal Goals Project (http://groups.ucanr.org/HumboldtHabitatGoals/)

North Richmond Shoreline: A Community Vision (http://www.restorationdesigngroup.com/docs/NorthRichmondShorelineVision.pdf)

Regional Boards Basin Plan (http://www.waterboards.ca.gov/sanfranciscobay/basin_planning.shtml#2004basinplan)

Regional Monitoring Plan (http://www.sfei.org/rmp/)

Richardson Bay Plan (http://www.tiburonaudubon.org/conserve_planning.html)

Richardson Bay Special Area Plan (http://www.bcdc.ca.gov/laws_plans/plans/plans.shtml)

San Francisco Bay Plan (http://www.bcdc.ca.gov/laws_plans/plans/sfbay_plan.shtml)

Uplands Habitat Goals Project (http://www.uplandhabitatgoals.org/)

Long Term Management for Disposal of Dredged Material in San Francisco Bay (http://www.bcdc.ca.gov/dredging/ltms/ltms_program.shtml)

Dredged Materials Management Office (http://www.spn.usace.army.mil/conops/dmmo.htm)

Above and below the surface of the bay (near the Tiburon Peninsula).

Vision Statement

The vision of the Subtidal Goals Project is to achieve, over the next 50 years, a net improvement of the San Francisco Bay's subtidal ecosystem through science-based protection and restoration of habitats. To achieve this improvement, the Subtidal Goals Project proposes:

- Increasing the quantity of desired but currently limited habitats;
- Emphasizing support of native species;
- Increasing our understanding of the physical and biological processes that affect subtidal habitats and the use of these habitats by species.

Neither a policy nor regulatory document, this report offers guidance on opportunities for subtidal restoration and protection. Implementation will occur through a number of avenues: local governments may incorporate these recommendations into their planning processes and documents, non-profits may use them when seeking funding for restoration or management projects, and researchers may wish to refer to the report when setting priorities. Regulatory agencies may use this report to evaluate, revise, or implement their policies.

New policies or modifications to existing policies proposed on the basis of this report will require a separate process in which each agency will analyze recommended policies in the context of their existing authorities and public input process.

San Francisco State University researchers monitor the eelgrass bed at Point Orient on the Richmond shoreline.

Planning Framework and Approach

The Subtidal Goals Project is a collaboration among the San Francisco Bay Conservation and Development Commission (BCDC), California Ocean Protection Council (OPC)/California State Coastal Conservancy (SCC), National Oceanic and Atmospheric Administration (NOAA) and the San Francisco Estuary Partnership (SFEP). Lead staff from those agencies worked with the broader scientific community, managers, restoration practitioners, and stakeholders over several years to develop the goals set forth in this document. See Appendix 1-1 for details on project methods and participant roles.

The Goals Project was inspired by the 1999 Baylands Ecosystem Habitat Goals report (Figure 1-1), which set a bold vision for restoring 100,000 acres of wetlands and related habitats around the bay that have resulted in 13,000 acres of newly restored habitat, with an additional 40,000 acres acquired and in various stages of restoration planning. The Subtidal Goals Project also takes a bay-wide approach in setting science-based goals for maintaining a healthy, productive, and resilient ecosystem. Where possible, these subtidal goals are designed to connect with intertidal habitats and with goals developed by other projects, including goals for baylands and uplands habitats. Unlike in the Baylands Goals effort, however, historical information about subtidal habitat is lacking. Thus the goals set forth in this document do not attempt to restore the bay to historic conditions but are designed to improve the condition of the subtidal ecosystem. The baseline for the project is 2010, and the planning horizon is 50 years.

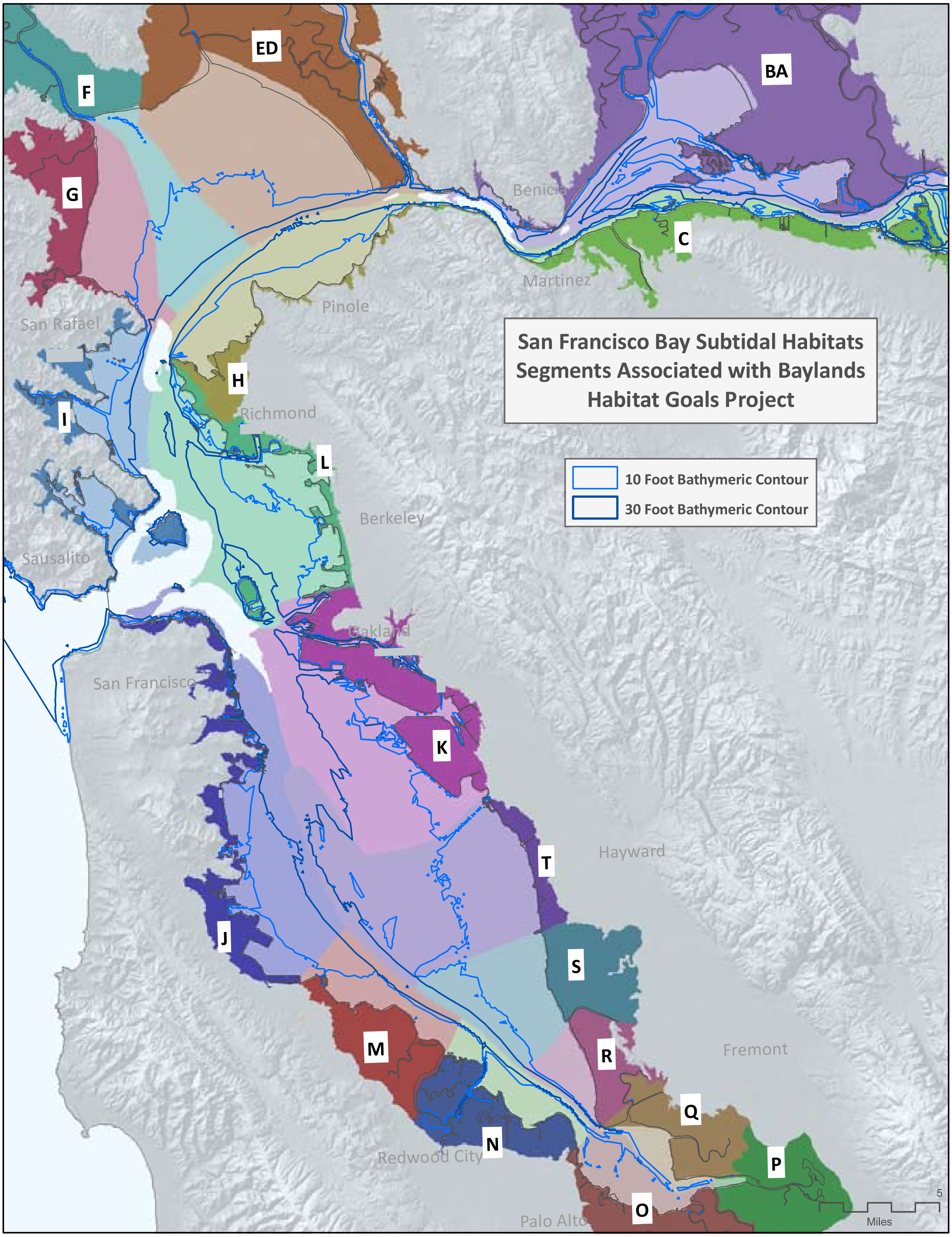


Figure 1-1: Map of Subtidal Habitat Goals aligned with Baylands Ecosytem Habitat Goals segments (represented by letters), extended to three depth categories: 10', or less, 30' or less, and 30' and greater.

FREQUENTLY USED TERMS

Ecosystem: a dynamic complex of plant, animal, and microorganism communities and the nonliving environment, interacting as a functional unit. A well-defined ecosystem has strong interactions among its components and weak interactions across its boundaries.

Habitat: As used by ecologists, "habitat" refers to a combination of physical, chemical, and biological conditions that supports a population of some species. In this document it is used to distinguish among areas of the estuary mainly on the basis of physical configuration, under the assumption that suitable physical conditions will support desirable ecological functions or species.

Intertidal zone: The area that is exposed to the air at low tide and underwater at high tide (for example, the area between tide marks). This area can include many different types of habitats, including rocky areas, sandy beaches, or wetlands (e.g., vast mudflats).

Restoration: Restoration is defined as actions taken in a converted or degraded natural habitat that result in the reestablishment of ecological processes, functions, and biotic/abiotic linkages and lead to a persistent, resilient system integrated within its ecological landscape. For the Subtidal Goals Project, the term "restoration" is also meant to include actions such as creating, enhancing, remediating, and rehabilitating.

Subtidal habitat: all of the submerged area in the estuary.

For more definitions, please see the Glossary, Appendix 1-4.

How the lead agencies will use this report

NOAA, BCDC, SFEP, SCC, and OPC each have different authorities, mandates, and policies regarding conservation and management of subtidal habitats. As such, each agency may choose to use this document in different ways.

- While this document does not supersede or change NOAA authorities or mandates, NOAA staff may reference information in this document when implementing consultations pursuant to the Endangered Species Act and the Essential Fish Habitat provisions of the Magnuson-Steven Fishery Conservation and Management Act.
- NOAA may reference this document when evaluating research priorities both for NOAA Science Centers and other scientific entities.
- The NOAA Restoration Center may use this document to help prioritize restoration projects for funding and support.
- San Francisco Bay Conservation and Development Commission staff may use this document as background material when considering future revisions to the San Francisco Bay Plan and may reference this document when evaluating proposed projects under BCDC's existing regulatory authority over development in and around San Francisco Bay.
- The San Francisco Estuary Partnership may reference information in this document when implementing the Comprehensive Conservation and Management Plan for San Francisco Bay, in seeking federal dollars for San Francisco Bay conservation, and in selecting restoration and/or research projects to fund.
- The State Coastal Conservancy may use this document to identify acquisition opportunities, prioritize conservation and strategic planning, and develop restoration projects to support and fund. The Ocean Protection Council may utilize the document in making decisions and prioritizing research areas, especially as they relate to issues of land-sea interface interactions, ecosystem research, and climate change planning.

Background

San Francisco Bay is one of the largest and most important estuaries on the West Coast, both for the habitat it provides for fish and wildlife and for the many benefits and opportunities it offers people. Its natural beauty gives the Bay Area the iconic identity for which it is known throughout the world, while its waters ensure an enviable climate and quality of life for over 7.5 million residents. The bay provides numerous benefits to humans known as "ecosystem services" (see sidebar and Table 1-1). Many residents commute across the bay on ferries, or enjoy it while boating, fishing, swimming, windsurfing, and birding in and around its waters. Visitors from around the country and world are drawn to San Francisco Bay as well: in 2009, the City of San Francisco hosted over 15 million visitors, adding some $8 billion to the Bay

Table 1-1: Subtidal Habitat Ecosystem Services
Through successful implementation of the subtidal goals and vision, the Subtidal Goals Project hopes to sustain and improve upon the ecosystem services and functions provided by subtidal habitat.

	Soft substrate	Rock	Artificial substrate	Shellfish beds	SAV beds (submerged aquatic vegetation beds)	Macro–algal beds	Water column
PROVISIONING SERVICES: products obtained from the ecosystem such as food (e.g. fishing), fiber, fuel or materials (e.g. sand)							
Commercial harvest (i.e., fishing)	•	•		•	•	•	•
Sand and shell mining	•						
Shipping and ports	•						•
Marinas	•						•
REGULATING SERVICES: benefits obtained through ecosystem processes (e.g., maintenance of air and water quality, erosion control, climate regulation, storm protection)							
Clean water	•			•	•	•	•
Shoreline protection		•	•	•	•	•	
CULTURAL SERVICES: nonmaterial benefits from spiritual enrichment, reflection, recreation, and aesthetic experiences (e.g., cultural diversity, educational values, inspiration, sense of place, recreation and ecotourism)							
Diversity of ecosystem	•	•	•	•	•	•	•
Inspiration for art, folklore, national symbols, architecture	•	•	•	•	•	•	•
Aesthetics		•	•	•	•	•	•
Sense of place		•	•	•	•	•	•
Recreation—wildlife viewing	•	•	•	•	•	•	•
Recreation—harvest	•	•		•	•	•	•
Recreation—boat use							•
Recreation—shoreline/beach use	•	•	•				•
Ecotourism	•	•	•				•
SUPPORTING SERVICES: indirect services, or those that occur over long periods of time, that are necessary for the production of all other ecosystem services (e.g., production of oxygen through photosynthesis, primary production, nutrient cycling, water cycling)							
Primary production	•				•	•	•
Nutrient cycling	•			•	•	•	•
Biodiversity	•	•	•	•	•	•	•

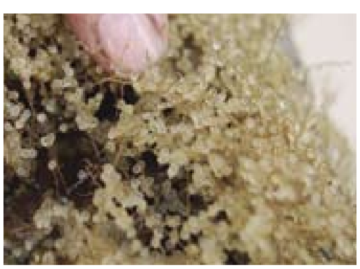
Above left: Dozens of private and public boats join the Queen Mary II as it enters San Francisco Bay. Above right: Shorebirds forage on intertidal and subtidal mudflats.

Area economy. The bay is also a busy center of commerce: cargo ships and tankers from around the Pacific Rim depend on its ports and infrastructure. Approximately two million tons of sand are mined from subtidal areas each year for use in construction. Historical oyster shell deposits are mined for livestock and chicken feed, soil conditioner, and as a dietary supplement for human consumption.

The bay also supports a variety of "indirect" ecosystem services including nutrient cycling, climate regulation, flood protection, water quality maintenance, and sediment transport. For more information on these uses and benefits of the bay, please refer to Appendix 1-2, the San Francisco Bay Subtidal Economic Evaluation Final Report.

Native Olympia oysters attach themselves to Pacific oyster shells, which are used as a substrate for restoration projects.

In addition to offering these aesthetic, economic, and recreational values, the bay supports a critical food web. Herring and Dungeness crab, among many other species of fish and shellfish, rear in its waters while sturgeon, salmon, and steelhead feed and rest in the bay during their migrations to and from its rivers and streams and the ocean. Its vast open water, sloughs, rivers, streams, and tidelands host millions of migratory birds every year as they move up and down the Pacific Flyway, as well as provide habitat for numerous resident water, shore, and song birds. The bay also provides important habitat for marine mammals, shellfish, and aquatic invertebrates—the smaller, often unseen but important inhabitants of the estuarine ecosystem.



Herring roe spawn on restored native oyster reefs in San Rafael.

Subtidal habitat is a critical piece of this ecosystem. Although this hidden underbelly of the bay is often thought of as a featureless mud bottom, it includes a suite of unique habitats: sand waves more than three meters high; eelgrass and shellfish beds that act as ecosystem engineers and provide substrate for organisms to attach their eggs to and food resources for species such as herring and salmon; rocky outcrops covered in seaweeds and invertebrates; and mixed sediments in shoals and channel banks that are used by a variety of species. Many shellfish, macro- and micro-invertebrates, fish, marine mammals, diving ducks, and other wildlife feed, rest, hide, and reproduce in these areas. Large populations of shorebirds feed on the estuary's subtidal and intertidal mudflats.

The focus of this report is on preserving and restoring the bay's subtidal resources for their ecosystem functions and habitat values and for their ecosystem services to humans (see Table 1-1). As such, while all of the ecosystem services provided by San Francisco Bay subtidal habitats are important, this report identifies a subset of ecosystem services that are not directly extractive or destructive of those habitats. The vision statement and goals presented herein were developed to support, maintain, and improve upon this subset of ecosystem services for continued future benefit to Bay Area residents.

Physical setting

The distribution of habitats within the estuary results from a combination of geology, tidal and freshwater flows, currents, wind, biological activity, and human activity. The geologic setting of the estuary includes two features that are key to its shape and characteristics. First, this tectonically shaped estuary bisects the Coast Range, resulting in areas where river flows during lower stands of sea level carved out narrow, deep channels (Golden Gate, Raccoon and Carquinez Straits) interspersed with broad regions (e.g., South Bay, San Pablo Bay) where the estuary spreads into extensive shallow shoals. Second, the estuary's watershed includes 40% of the area of California and some of the state's highest terrain in the Sierra Nevada, providing the fresh water to establish a salinity gradient, and sediment that allows shoals to form (and keeps the bay turbid). The sediment pulse resulting from hydraulic mining in the late 19th century caused over a meter of shoaling in some areas of the estuary, and has yet to fully dissipate; when it does, the ensuing sediment shortage due to trapping behind dams in the Sierra foothills may cause erosion of valued habitats.

The estuary is comprised of the Sacramento-San Joaquin Delta, Suisun Marsh, and four basins linked through passes or over shoals (Figure 1-2). All of the basins have shallow areas with mud to sand bottom, and deeper channels with mainly sand bottom. All have mean depths of 5m or less, except the Central Bay, which has an average depth of 12m. Shorelines vary from armored revetments to beaches to marsh, and all basins adjoin mainly urban and industrial areas. Tidal currents are strong in many parts of the estuary, particularly the narrower sections where the estuary penetrates the Coast Range at the Golden Gate and Carquinez Strait. Wind is also strong, especially during summer and east of gaps in the Coast Range. Wind-driven waves re-suspend sediments and increase turbidity locally. Salinity varies from oceanic values near the Golden Gate to freshwater values in the northern estuary, typically in Suisun Bay or the western delta depending on freshwater flow from the delta.

Suisun Bay is the easternmost of the estuary's large basins. In the north are Grizzly and Honker Bays, which link to Suisun Marsh, a network of channels and sloughs adjacent to islands that are mostly managed as freshwater marshes for waterfowl, with a small area of remnant natural brackish marshes. A deep

Figure 1-2: Map of sub-basins.

New eelgrass shoots from a transplant restoration project along the San Rafael shoreline.

channel near the southern shore of Suisun Bay links the delta, to the east, to Carquinez Strait to the west. A shallower channel to the north connects to the main channel near Benicia and Pittsburg. Salinity is typically fresh in wet winters and brackish in dry summers and is usually vertically unstratified.

San Pablo Bay is linked to Suisun Bay by Carquinez Strait, a narrow, sinuous channel with maximum depth of about 40m. San Pablo Bay has a single deep water channel and a broad shoal extending to the northwest. This is the only basin with substantial agriculture along the shore. Several salt ponds have been restored or are in planning for restoration to tidal wetlands or enhanced managed ponds along the northern shore. Brackish tidal marshes adjoin San Pablo Bay, including the San Pablo Bay National Wildlife Refuge and the National Estuarine Research Reserve site at China Camp. Salinity can be fresh during extreme floods but is typically near seawater salinity values in dry summers, and is often stratified, especially during high-flow periods. This is an important area for migratory shorebirds and ducks.

The Central Bay is the deepest basin, has the largest extent of rocky substrate, including areas around islands and seamounts, and is the most influenced by the coastal ocean. Much of the bottom is either rocky or sandy, with large sand waves illustrating the strength of tidal currents in this region. The deepest point is over 100m deep near the Golden Gate Bridge. The water here is the saltiest in the bay (on average), with strong stratification present during high-flow periods, and is the clearest of all the basins. This region is a crossroads for shipping to and from the numerous bay ports, and the most popular for water-based recreation such as sailing, because of the dependable winds, varied conditions, and spectacular views. Central Bay has the most marine species and probably the highest species diversity in the estuary.

Above: Sand dredger in San Francisco Bay. Right: Maintenance dredging at the Port of Richmond.

The South Bay is an isolated arm of the estuary. Its shoreline is mostly urban and industrial, but in the far south numerous salt ponds adjoin the bay, some of them slated for conversion to tidal wetlands or enhanced managed ponds. The South Bay Salt Ponds Project is the largest tidal restoration project west of the Mississippi. During high-flow periods, salinity in the South Bay is reduced by brackish water from the Central Bay and fresh water from streams. During the dry season, salinity in the South Bay becomes somewhat elevated because of evaporation, and its only freshwater supply comes from wastewater treatment plants. The South Bay is also an important area for shorebirds and water birds.

A changed estuary

In addition to historical impacts from gold-mining, humans have altered the shape and size of the bay, converted shorelines from marsh to seawall, diverted water from upstream rivers, preventing it from flowing into the estuary, added innumerable structures to its edges and bottom, removed submerged rocks, and plied the bay with ships, boats, trawls, and dredges.

Activities associated with fishing, marinas, shipping and ports, dredging, sand and shell mining, transportation, recreation, and industry have all had impacts on the bay's subtidal habitat. Subtidal habitat is also threatened by invasions of non-native species (as a result of human actions, most non-intentional), legacy pollutants (such as mercury from gold mining and a variety of chemicals formerly used in industry), and modern-day pollution from "point sources," such as industry and sewage treatment plants, as well as "non-point sources," such as the runoff from our streets and watersheds.

Since the Gold Rush, the bay has lost more than 90% of its historic tidal wetlands. Filling of the shoreline and in the bay has shrunk the bay by almost a third. This has caused a substantial (but unknown) loss of subtidal habitat. This loss and degradation has decreased the value and extent of habitat for many species. The biomass of wetland and subtidal vegetation and shellfish has been reduced; these resources likely provided copious food resources to humans and animals alike in the past. The intricate matrix of wetland channels, with their three-dimensional surfaces, has been filled in to build salt ponds, urban landfills, airports, ports, and marinas. The resulting loss of habitat complexity probably reduced the abundance of many types of estuarine and marine organisms and the productivity of pelagic and benthic food webs. Yet despite these changes and challenges,[1] estuarine life persists.

Report Scope, Content, and Organization

The geographic scope of the Subtidal Goals Project is San Francisco Bay from Sherman Island west to the southern extent of the bay and seaward to the Golden Gate (Point Bonita to Point Lobos). Although the delta is not included in the project scope, conditions in the delta and their relationship to subtidal habitat in the bay are addressed in the sections on freshwater input and climate change (Chapter 3). For the purposes of this project, "subtidal habitat" includes all submerged areas of the bay.

This report describes six subtidal habitat types with maps showing their known current distributions, and analyzes present-day threats to those habitats. It presents recommendations for addressing those stressors, for advancing scientific research and understanding, and for protecting and restoring subtidal habitat within the constraints and challenges of an urbanized estuary and incomplete knowledge. It also describes some of the pioneering efforts that have taken place to restore subtidal habitat in the bay. Where appropriate, the report includes discussion of certain intertidal habitats that are not addressed by the Baylands Ecosystem Habitat Goals Project: intertidal mudflats, rocky shorelines, sand beaches, and eelgrass and oyster beds.

Chapter 2 describes the considerations used in the planning decisions that were made in setting the goals for subtidal habitat. Chapter 3 describes both the foundational science goals and other goals that apply to all of the habitat types. Descriptions of specific subtidal habitats and the science, protection, and restoration goals for each of them are set forth in Chapters 4 through 9. Chapter 10 focuses on integrating subtidal planning with wetland and shoreline planning, while Chapter 11 presents recommendations for implementation of the goals. A companion document, NOAA's August 2007 *Report on the Subtidal Habitats and Associated Biological Taxa in San Francisco Bay* (http://www.swr.noaa.gov/hcd/HCD_webContent/nocal/SHABTinSFBay.htm), summarizes existing information regarding subtidal habitats and species use in San Francisco Bay.

1. For a more comprehensive description of human impacts on subtidal habitat since the time of European settlement around the bay, see Appendix 1-3.

CHAPTER TWO

Planning Decisions and Considerations

The Subtidal Goals Project focuses on habitats rather than individual species (except for those habitats that are created by a single species, e.g., eelgrass or oyster beds), an approach that avoids prioritizing some species over others. The key decisions and planning considerations described here were developed by the administrative core group representing the lead agencies, with extensive input from all of the active committees and consultants (see Appendix 1-1 for more information about committee roles and processes). The following key decisions were made in identifying goals for subtidal habitat:

The administrative core group held multiple meetings with committee members and stakeholders to discuss Subtidal Goals development.

- The geographic scope of the Subtidal Goals Project is San Francisco Bay from Sherman Island west to the southern extent of the bay and seaward to the Golden Gate (Point Bonita to Point Lobos). Although the delta is not included in the project scope, conditions in the delta and their relationship to subtidal habitat in the bay are addressed in the sections on freshwater input and climate change (see Chapter 3).
- For the purposes of this project, *"subtidal habitat"* includes all submerged areas of the bay. The project also includes certain *intertidal habitats* that were not specifically addressed in the 1999 Baylands Ecosystem Goals Report: intertidal mudflats, eelgrass, sand beaches, rocky intertidal and subtidal areas, and artificial substrate.
- The report uses a precautionary approach, erring on the side of conserving and protecting resources.
- Available information about existing conditions serves as a baseline.
- The goals build upon opportunities and information developed by existing subtidal pilot projects, including in-the-water monitoring, restoration, mitigation, and research projects in San Francisco Bay.
- This document avoids setting priorities among habitats; however, restoration of some may result in conversion of others. For example, some soft substrate may be lost or enhanced through restoration of eelgrass or shellfish beds.
- Because there is a great deal of uncertainty about the functions and value of subtidal habitats and the utility and likely success of restoration,

Eelgrass thrives in Raccoon Strait between Angel Island and the Tiburon Peninsula.

this report recommends using an adaptive management approach in implementing the goals. See discussion of adaptive management later in this chapter.

- As part of adaptive management, progress on achieving the goals—as measured by improved scientific understanding and practical experience in subtidal habitat restoration and protection—should be reviewed and evaluated in a report by 2020. The goals can then be modified as needed. Interim updates on particular topics can potentially be provided within 10 years, and discussed at regional forums and conferences.

Rationale for Setting Goals

Goals for each of the subtidal habitats are based on the Vision Statement described in Chapter 1 and the Foundational Science Goals described in Chapter 3, taking into account the extent of scientific understanding of each habitat. These specific habitat goals lead to actions in one of four broad directions:

- Enhancing, creating, or restoring particular habitats
- Protecting habitats
- Observing habitats, taking no action
- Eliminating artificial habitats

This section describes the process that was used in choosing a course of action for investigating, protecting, and restoring each habitat. The process began with a determination that a given habitat is likely to provide some valued ecosystem services, and then proceeded through a decision tree to determine the most suitable course of action (Figure 2-1).

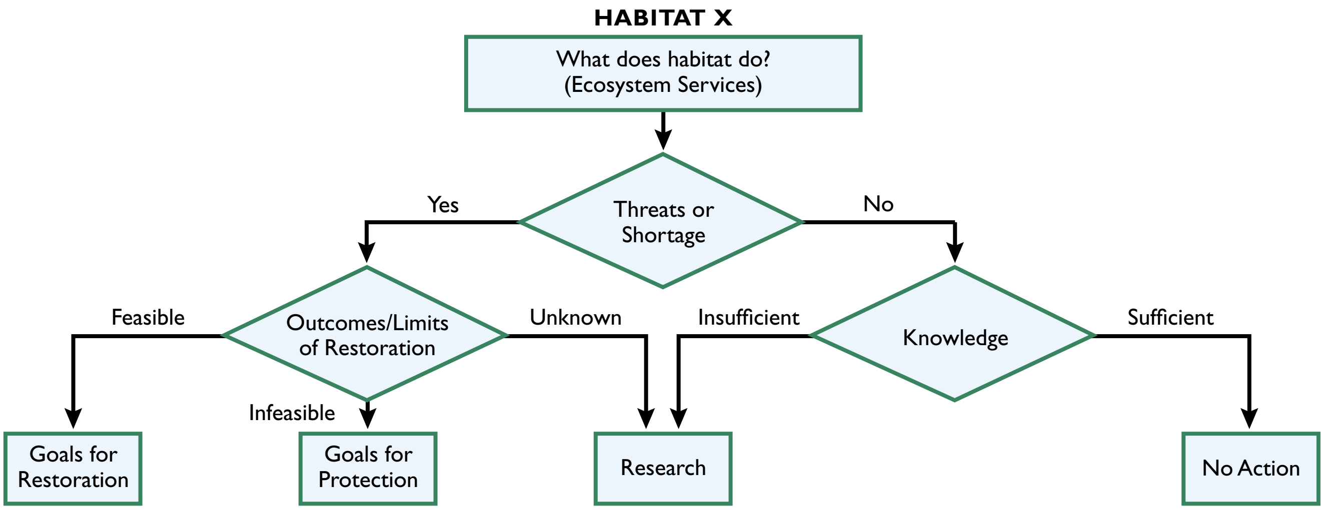


Figure 2-1: Decision tree for the Subtidal Habitat Goals Project, illustrating the pathway considered in the goal development process.

The decision tree helped decide which of these ecosystem services to emphasize, and how far to go in taking protection or restoration actions for a particular habitat. This process is not meant to be static. Improved knowledge, including experience gained through progress toward achieving the goals, and changes in the system will require revisiting these decisions periodically. This can be done through a formal program of adaptive (i.e., experimental) management, discussed later in this chapter.

West Coast Native Oyster meetings bring together researchers and restoration practitioners working on native oyster projects in California, Oregon, and Washington.

Vetting each habitat through Figure 2-1 led to the following conclusions (more specific details are presented in Chapters 4–9):

- Subtidal shoals to intertidal mudflats support valued services and are under various threats from human activities and climate change. Opportunities for restoration are based on uncertain techniques, so this report emphasizes protecting habitat and applying restoration methods experimentally.
- Muddy soft-bottom habitat is essential for some species and probably supports the most ecosystem services of any habitat. Although soft-bottom habitat is plentiful in the bay, it is threatened by various activities. Few opportunities exist to restore it, so protection goals are emphasized instead.
- Sand bottom is mined for sand, but little is known about its role in non-extractive ecosystem services. This lack of knowledge leads to a recommendation to protect existing sand resources while learning more about the impacts of sand mining and the value of this habitat type to species and the ecosystem services it provides.
- Rock outcrops support ecosystem services and are under threat, but restoration would be logistically difficult and therefore unlikely, calling for protection actions and research-based pilot restoration only.

- Artificial structures support valued ecosystem services but also can impair others. Since they are artificial, most of them cannot be considered to be in short supply, nor are they under threat. Conversely, there is interest in removing some of them, leading to an expansion of other more favorable habitats.

- Several habitats (e.g., eelgrass, oyster beds) have clear benefits in supporting valued ecosystem services, although the degree of support is uncertain. They are likely in short supply and under various threats, and restoration has been successful at small scales. Therefore restoration goals are the principal focus for these habitats, although protection goals are also necessary.

- Macroalgal beds support ecosystem services (although at a small scale), but they can also be nuisances under some conditions. Because it is unknown whether and which species of macroalgal beds are under threat or in short supply, the decision tree process led to identifying research goals only.

- The water column forms the background for all of the other habitats. It supports all ecosystem services. Its existence is not threatened, but water quality could become degraded. However, as discussed in Chapter 3, water quality is the province of various agencies and is not addressed in this project.

Graduate students monitor eelgrass beds.

Considerations for Research

Three key principles govern the establishment of science goals for subtidal habitats:

1. Acknowledge key gaps in the knowledge needed for effective protection and restoration;
2. Take a broad, long-term perspective;
3. Acknowledge and allow for limitations on gathering knowledge.

Key knowledge gaps: These gaps include such fundamental information as the spatial extent of some of the habitats and their functions in the ecosystem. Filling these gaps will take time, but that should not delay actions to protect habitats. Rather, restoration and protection should be designed and practiced to allow for these gaps and to reduce either their size or their effect on desired outcomes. In addition, research plans should address the most time-critical knowledge gaps first, specifically in terms of how they will affect meeting project goals through protection and restoration activities. These key knowledge gaps are set forth below as questions.

Which ecosystem services do the target habitats support, and how?

This is a relatively straightforward question that can be answered by considering the conceptual models of the habitats within the context of the overall model. The answer may be "we don't know," although we have listed ecosystem services likely to be provided by one or more habitats (Chapter 1). For example, intertidal mudflats are well known to support various species of birds that are either species of concern, have intrinsic value, or provide recreational opportunities for birdwatchers. This may be reason enough to protect such habitat. By contrast, sandy bottom provides a resource for sand mining, but its support of other ecosystem services is poorly understood. This points to a key role for research.

What is the relationship between quantity of the habitat and the amount or value of those ecosystem services?

This is a much harder question to answer than the previous one, but it should form the basis for all decisions about restoration and protection of habitats. If the potential area suitable for restoration of a habitat can be estimated, what would be the ecosystem-scale response if all of that habitat were to be restored? How would that change if only 10% or 50% were restored?

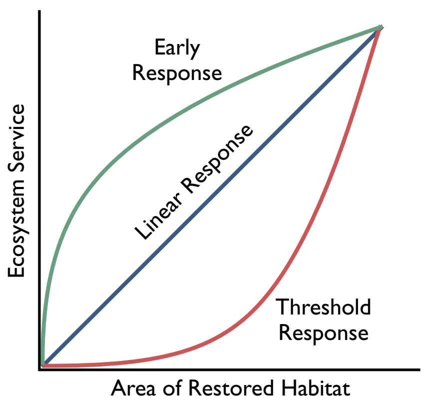


Figure 2-2: Schematic diagram of potential alternative responses of the extent or amount of an ecosystem service to restoration or loss of habitat area. The benefit of small-scale restoration depends heavily on the actual form of this curve.

The default assumption is that habitat value increases linearly with habitat area, but other responses are possible (Kondolf et al. 2008). For example, the number of birds that feed on mudflats in winter could be limited initially by feeding conditions in the local habitat and then by conditions in their remote summering habitat. In that case, restoration may have little effect on birds once the quantity of local habitat exceeded some threshold (upper curve, Figure 2-2). Conversely, there may be a threshold of habitat area above which some part of the ecosystem shifts into a different, preferable state, in which case the cumulative restoration must exceed the threshold before this benefit is achieved (lower curve, Figure 2-2).

What interactions (conflicts or synergies) are likely among those services or the ecosystem processes that produce them?

This is one of the more difficult topics, and answers may be limited to speculation. In particular, restoration of one habitat implies reduction in quantity of another.

What are the threats to various habitats or the species using them?

Threats are those stressors (Appendix 2-1) that are likely to reduce the quantity or impair the quality of a habitat. These include such influences as physical damage (e.g., from dredging, sand mining, shipping, trawling, boat wakes), contaminants, climate change and sea level rise, and over-harvest. Identifying direct threats is fairly straightforward, but indirect threats are harder to establish. For example, how would overfishing affect eelgrass beds?

What actions would enhance or diminish the amount or value of ecosystem services?

This question is intended to encompass deliberate actions taken either to restore a habitat, or to accomplish some other goal (e.g., building a ferry terminal) that might affect a habitat.

Broad perspective: The goals should account for both long-term change in the estuary and spatial patterns at all scales. Research that informs managers about future conditions and applies broadly across the estuary should take the highest priority.

The estuarine ecosystem has changed substantially and will continue to change (see Table 3-1 and Appendix 2-2). The local influences of climate change that have been forecast and observed include rising sea level and a shift to an earlier snowmelt peak in the Sierra, resulting in a larger seasonal cycle in freshwater flow and salinity. Increasing temperature is likely to have a predominantly indirect effect through the northward shift in distributions of organisms, with the likely result of species extirpations and species introductions to the estuary. Other effects, such as increased wind speed and increased frequency or severity of storms, are forecast with less certainty or without consensus among climate models. Human responses to climate change, such as building hard structures to protect against rising sea level, could have profound effects on subtidal habitats.

Significant impacts from climate change will occur over time scales of decades to a century and longer. Over that time frame, many other changes will likely occur in the estuary, including population growth, which will result in increased demand for water supply, waste discharge, infrastructure, recreation, and development near the bay. Changes in transportation such as a substantial increase in ferry traffic would have significant impacts on subtidal habits throughout the estuary. Changes in management and plumbing of the delta will influence annual and interannual patterns of salinity in the bay.

Random or unpredictable events, notably earthquakes but also levee failures in the delta, are reasonably sure to happen sometime during the next century. Multiple levee failures in the delta will have a tremendous effect on the entire estuary because salinity will penetrate farther into the estuary and (in some scenarios) the tidal prism will increase. As with sea level rise, human responses to these events will affect long-term outcomes; for example, whether flooded islands will be diked and drained, and how water managers will respond.

Limits to knowledge: The research goals should be achievable in a reasonable time and be realistic as to the likely outcomes. Conducting research in natural ecosystems is difficult, particularly so in estuaries. These systems are extraordinarily variable in space and time and have myriad interacting components, only a handful of which can be observed in a research program. Monitoring is essential but generally limited to counts of organisms (e.g., fish), collected during the day in deep water. Most ecosystem processes are unmonitored. Human impacts are frequent and sometimes subtle, such as impacts from contaminants, including oil, and alteration of the sediment budget. Finally, the estuary's water is turbid, and even intertidal habitats can be seen only when exposed at low tide. All this is not to say that gaining knowledge is impossible, but that these limitations should be acknowledged in determining research priorities and sequencing, and in setting expectations for the information needed for restoration and protection.

The waters of San Francisco Bay inside the Golden Gate.

Adaptive Management

Adaptive management (Holling 1978, Walters 1986) is specifically designed as a way of managing in the face of uncertainty. This approach treats protection actions as experiments, acknowledging the value of learning as well as that of taking action. This approach is entirely consistent with the current state of knowledge regarding subtidal habitats; in most cases, not enough is known to support well-informed decisions even about whether to restore or protect habitats. In such a preliminary state of knowledge, taking action without an experimental, analytical component would be unwise.

Adaptive management (AM) has had a mixed record, mainly because of institutional resistance to implementation and because many people use the term without fully understanding the meaning. One of the key impediments to AM arises in attempts to apply it to large, complex, unreplicated systems. When the system can be subdivided to allow for replication and controls, the experimental aspects of AM become much more powerful and informative. The Subtidal Goals Project is therefore ideally suited to an adaptive approach at the project level, because habitats can be subdivided for different treatments.

Numerous documents outline the approaches to be used in AM (for example, Thom 2005). Most center on a diagram of the AM process emphasizing that the process is cyclic and has multiple decision points. Figure 2-3 presents such a diagram customized for the Subtidal Goals Project. It expands on the decision tree in Figure 2-1 to include the key elements of adaptive management. The key points to take from this diagram are that AM requires both (1) an explicit statement of expectations in the form of models and metrics to evaluate progress; and (2) explicit loops from the synthesis of data and re-examination of outcomes back to all of the decision points. This process forces managers to think about how to measure and display performance and how to determine

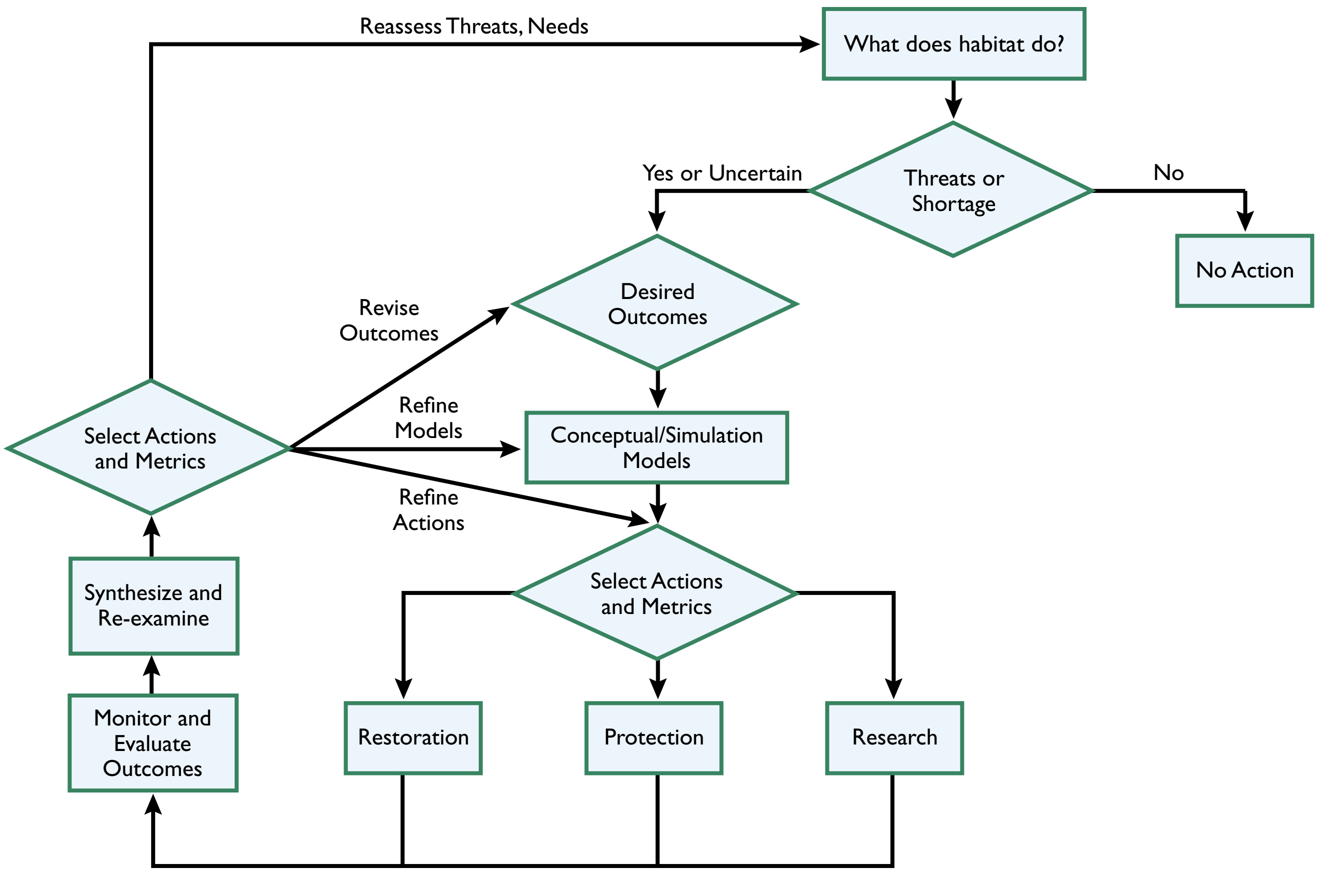


Figure 2-3: Flow diagram of the sequence of activities in adaptive management in the Subtidal Habitat Goals Project. Starting from the top, the ecosystem services provided by the habitat are identified; then threats to the habitat or shortage of the quantity of that habitat are evaluated. This may lead to a decision to take no action (see Figure 2-1); otherwise, a series of steps are taken including making decisions about desired outcomes, development of models, and choice of scale of the action. The action may emphasize restoration, maintenance of the habitat (e.g., through regulatory protection), or research. Every one of these actions, however, requires a set of metrics to evaluate progress, and a process of monitoring and evaluation that leads to periodic synthesis and re-examination of the action. This results in a feedback loop in which any of the decision points or preparatory activities can be revised and the whole process refined. The feedback loops would likely come at progressively longer time scales going up the diagram, since they would require progressively more complex decisions.

Below: Biologists study invertebrate use of restored oyster reefs in San Rafael.

whether an action is working as expected. Thus, the key elements of AM that distinguish it from most other kinds of management include:

- Explicit statements of problems and goals.
- Clear conceptual models of processes to be affected.
- Predictions of outcomes of the action and potential alternatives, and performance measures; predictions may be based on simulation modeling.
- Designed monitoring programs with embedded analysis for evaluating progress toward goals and consistency with the vision.
- A team charged with evaluating results and making recommendations for revising goals, desired outcomes, models, or actions.
- An entity with the authority and will to maintain the process and make changes recommended by the evaluation team.

Please see Chapter 11 for additional ideas on how adaptive management can be applied to achieve the subtidal goals.

Considerations for Protection

This report is a planning document and not meant to be policy or regulation (see discussion in Chapter 1). Agencies and organizations may use this report as a guidance document when implementing their authorities and mandates, or developing or updating policies. Protection goals included in the following chapters were developed with the intent of protecting subtidal habitats in San Francisco Bay, and were not weighed against other agency mandates or socioeconomic concerns, such as public access or economic development. Any policy modification or policy development will entail a separate process in which an individual agency will need to analyze the recommendations within the context of its existing authorities and mandates.

This report takes a precautionary approach. When the decision process (described above) directed focus on research goals for a particular habitat, protection goals were also included in order to maintain existing habitat while research is conducted and evaluated for future protection or restoration needs.

Below: Biologists access subtidal habitats in deep bay muds. Right: A plankton tow in San Francisco Bay.

Creosote pilings provide roosting areas for birds.

For all habitat types, protection goals focus on preservation. When information existed about specific threats, more detailed protection objectives and actions were included.

The resource management committee identified policy-level stressors that can degrade or otherwise influence subtidal habitats:

1. Freshwater inflow
2. Invasive species
3. Climate change

From this list, freshwater inflow and climate change were looked at in a broad sense (see Chapter 3), and specific goals were developed for invasive species (see Chapter 3). Funding allowed five additional stressors to be evaluated, so the resource management committee prioritized five stressors that can degrade or otherwise influence subtidal habitats:

1. Contaminants
2. Bottom Disturbance
3. Suspended Sediments
4. Placement of Artificial Structures
5. Nutrients

Consultant Dr. Andrew Cohen developed narrative descriptions for each stressor (see Appendix 2-1). Working with the resource management committee, the administrative core group conducted an exercise to compare severity, scope, and irreversibility of these stressors against each subtidal habitat type (see Appendix 1-1). This exercise resulted in the following key conclusions:

1. Bottom disturbance is a stressor of concern across several habitats.
2. Placement of artificial structures is a potential stressor of concern for the shellfish and submerged aquatic vegetation "living" habitats.

A derelict creosote piling structure slowly falls into the bay.

3. Eelgrass habitat has multiple stressors of concern.
4. Contaminants are a stressor of concern for soft substrate, especially mud habitat.

This was the starting framework for developing protection goals. This information was then further developed by science advisor Dr. Wim Kimmerer and incorporated into conceptual models for each habitat, which more fully describe the functions of and threats to the habitats and form the resulting basis for all of the goals (see Chapters 4–9).

Considerations for Restoration

In this report, the term restoration includes creating, enhancing, remediating, and rehabilitating habitat (see definition in Chapter 1). The restoration goals are not meant to return subtidal habitats in San Francisco Bay to conditions that existed in the past. Rather, they are meant to improve upon conditions that exist today, with restoration targets based on what is known about limiting factors and the potential for habitats to be created or enhanced within the bay.

Restoring a habitat should be undertaken with a clear view of the long-term prospects for success whenever possible, using an adaptive management approach. This will require answers to the research questions in the following sections. Although there are gaps in knowledge, restoration should still be pursued at an experimental level based on potential habitat distributions. An assessment could begin by determining the maximum possible extent of valued habitats for which restoration or protection is an identified priority, such as eelgrass and oyster beds and mudflats. How much of that habitat is actually likely to exist over the next 50 years, at what level of effort and cost, and what will be the result in terms of ecosystem services? (See Foundational Science Goal 1 for each habitat type in Chapter 3.) Answers to these questions, however approximate, will help to scale expectations and plans for restoration, and these answers will be refined as knowledge improves.

Restoration should also be designed for the long term, and planning must therefore account for expected long-term changes (see Foundational Science

Goal 2 for each habitat type in Chapter 3). Restoration should be targeted to locations and situations where long-term success is most likely. This requires a better understanding of the likely success of restoration in particular areas, the local processes and conditions as they may affect the habitat, and the present and future threats.

Mapping of Subtidal Habitat

An important first step in developing the subtidal goals was collecting and mapping baseline subtidal habitat geospatial data for the entirety of San Francisco Bay. The Subtidal Goals Project has assembled existing subtidal habitat data layers and created the first set of comprehensive GIS maps[1] illustrating the locations and extent of the bay's core subtidal habitats.[2] See also Figure 2-4. Habitat data, from side-scan sonar and multibeam data and sediment samples, were compiled from a 2003 report (Greene et al 2003), as well as anecdotally from experts involved in the Subtidal Goals Project. The 2003 report distinguished 91 different bottom types in the Central and South Bays at the time of data collection although these likely change as strong tidal currents transport sediments around. For the purposes of this project, these 91 habitat types were consolidated, on the basis of their predominant sediment, into 6: soft substrates (including mud, sand, gravel, cobble, and shell mix); rock; artificial structures; shellfish beds; submerged aquatic vegetation beds; and macroalgal beds. This approach, while necessary for the purposes of the project, undoubtedly simplifies habitat types throughout the bay, when in reality most subtidal areas are a vast combination of varying and ever-changing substrates.

In addition, existing data layers of activities (and artificial structures) that can impact the bay's subtidal habitats were collected and mapped to spatially illustrate the relationship between habitats and stressors. Finally, for some habitat types in the bay, proposed restoration sites are shown, based upon areas that had successful existing pilot projects or were identified as suitable habitat (see Chapters 7 and 8). Three types of maps were created and included in this report:

1. Habitat distribution maps
2. Stressor maps. There are four main stressor categories, and each has multiple activities that have been mapped:

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1. The information for the GIS maps for the San Francisco Bay Subtidal Habitat Goals Project came from a variety of sources, including NOAA's 2003 Electronic Navigation Charts and 2006 Environmental Sensitivity Index; 2002 CDFG Bathymetry maps; Gary Greene et al. October 2003 Report: Benthic Habitat Maps of San Francisco Bay Interpreted from Multibeam Bathymetric Images and Side-Scan Sonar Mosaics; Merkel & Associates, Inc. 2010. San Francisco Bay Eelgrass Inventory October–November 2009. Submitted to: California Department of Transportation and National Marine Fisheries Service.; Native oyster survey data Grosholz et al. 2007; the Water and Emergency Transit Agency (WETA); the San Francisco Harbor Commission; the U.S. Coast Guard; and others. Subtidal Habitat Goals Project committee members also provided anecdotal information based upon their knowledge of habitat distributions, which was incorporated into the maps.

2. For a description of additional mapping and surveying needs, see Chapter 11.

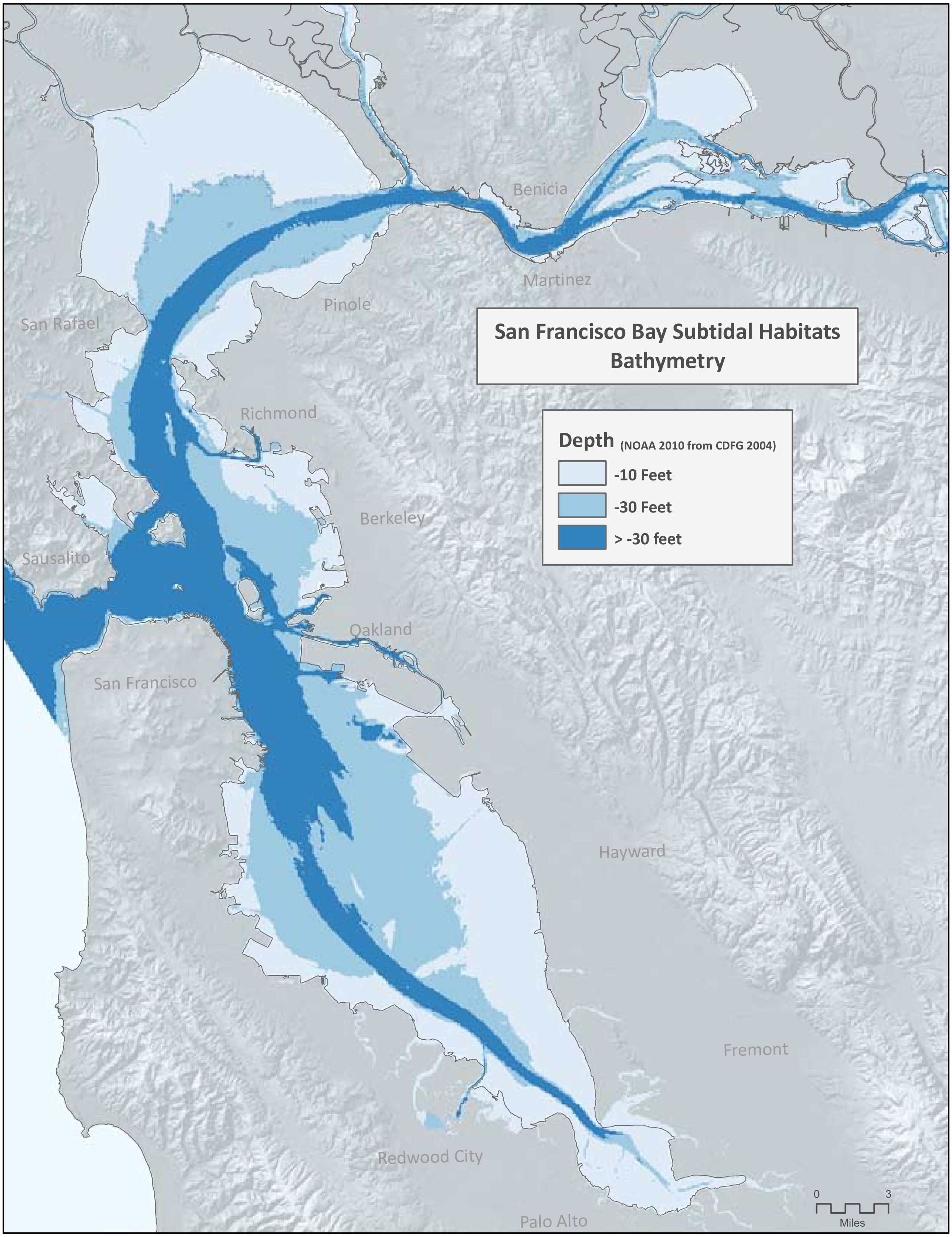


Figure 2-4: San Francisco Bay Bathymetry Map (NOAA 2010 from CDFG 2004), broken down into three depth categories: less than 10', less than 30', and greater than 30'.

Surf scoters on open water.

- Activities that increase or redistribute contaminants: wastewater discharge, coastal industry (power generation, oil refining, and chemical processing), dredging and disposal, sand mining, shell mining, commercial fishing, research and education, natural resource management and restoration, and urban development.
- Activities that increase bottom disturbance: shipping, construction of marinas, ports and wharfs, dredging and disposal, sand mining, shell mining, commercial fishing, research and education, natural resource management and restoration.
- Activities that increase suspended sediments: commercial fishing, dredging and disposal, sand mining, shell mining, research and education, natural resource management and restoration, and urban development.
- Placement of artificial structures: ports and wharfs, pilings, buoys, berthing areas, beacons, duck blinds, among others; and activities associated with coastal industry, bridges, wastewater discharge, commercial shipping and recreational boating, and urban development.

3. Proposed restoration site locations: native oysters, native eelgrass, and suggested pilot locations for intertidal sand beaches and living shorelines.
4. Ownership of the subtidal lands: public and private parcel ownership data. (See Figure 2-5.)

Although there are some data gaps that need to be filled and more maps that need to be made (see next section), the maps in this report should allow individuals, agencies, non-profits, governments, and others to see the submerged areas of the bay in an entirely new light. With these maps,

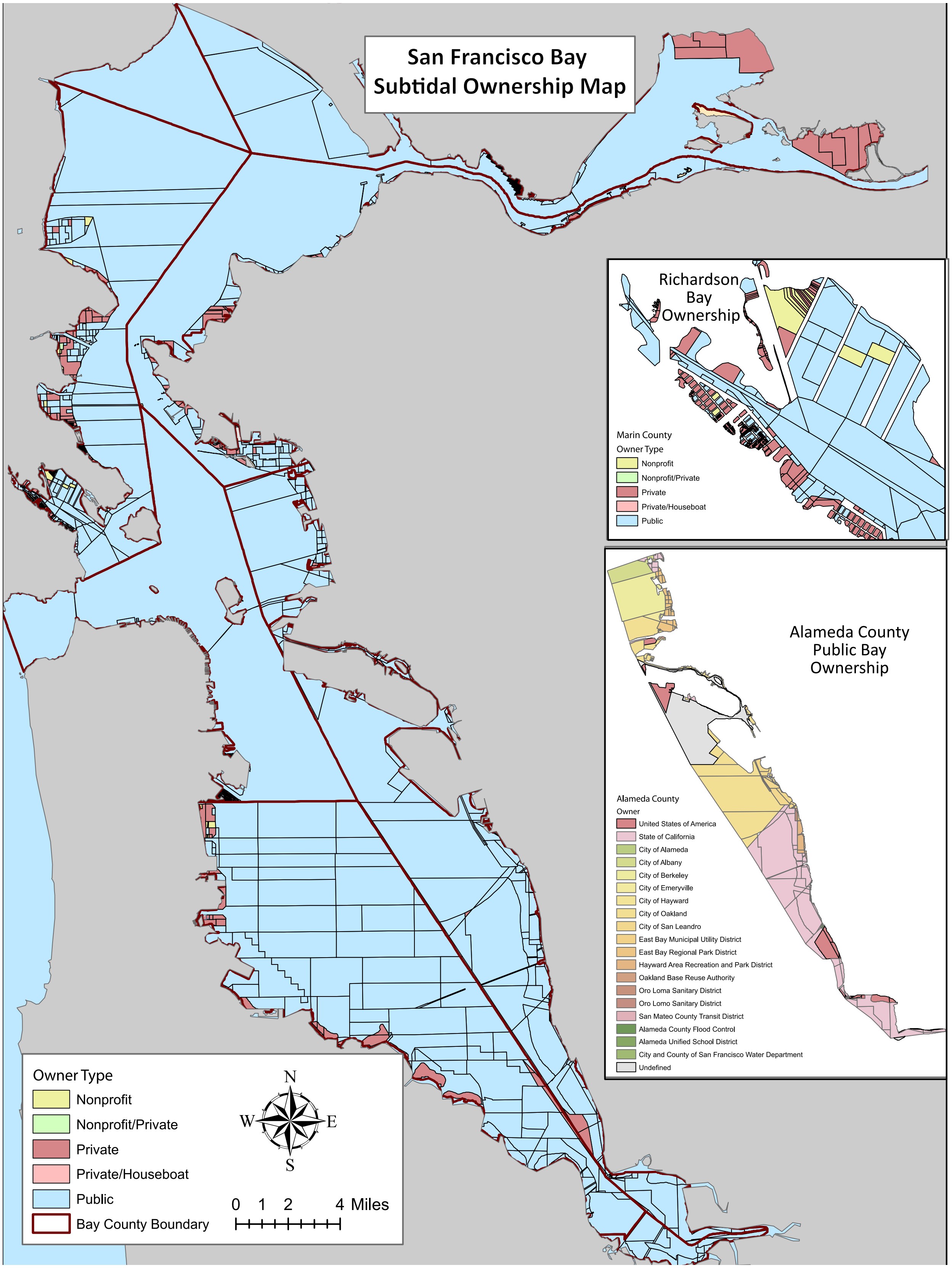
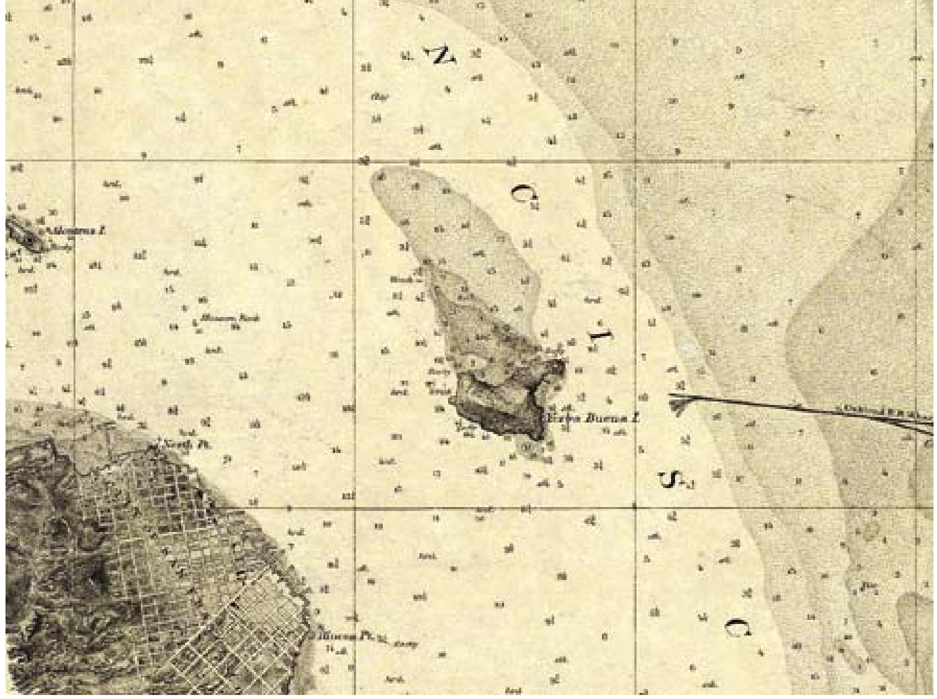


Figure 2-5: San Francisco Bay Subtidal Lands Parcel Ownership. Parcel ownership data compiled by Dan Robinson, NOAA fellow at BCDC, 2008.



Central Bay segment of historic hydrographic sheets developed by the former US Coast Survey.

interested parties will be able to access a wealth of data and new information for use in their own projects. These maps will

- improve existing resource management
- provide better data for use in research projects
- allow a finer assessment of stressor impacts on particular habitats at given site locations
- highlight appropriate restoration project sites
- facilitate improved cumulative impact assessments
- illustrate and help resolve overlapping human use conflicts
- allow consideration of lands for acquisition and restoration

The information in the maps can also be used in potential future Marine Protected Area or Marine Spatial Planning projects in San Francisco Bay.

Additional Mapping and Data Needed to Implement the Goals

1. Nearshore bathymetry: Updated bathymetry data for the entirety of the bay, and specifically for the bay's shallow areas from the shoreline to 3m below mean sea level. Existing bathymetric data sets do not show this area accurately enough to properly manage impacts and implement protection strategies.
2. Physical setting: Stratigraphy needs to be determined bay-wide to better understand the structure of habitats. More than 90% of the bay's bottom is made up of soft, unconsolidated sediments. Research goals in Chapters 4–9 provide the basis for the need to better define areas of mud, sand, and shell hash, so managers can better assess potential impacts and protection strategies. Because they have been mapped as navigation hazards, large

rocky outcrops are probably the best mapped habitats, but small rock and cobble could be better delineated in the bay.

3. Living bottom types: Excellent mapping data are available for native oysters in intertidal and shoreline areas. But there is only anecdotal information supporting the existence of subtidal populations of native oysters, and these areas have never been mapped. Eelgrass beds were mapped in 2003 and again in October 2009 by Merkel & Associates, Inc., but ongoing monitoring is needed to understand interannual variability in distribution and density of all subtidal habitats, particularly for macroalgal beds and submerged aquatic vegetation other than eelgrass since no spatial data exists for these habitats.

4. Tracking soft-bottom habitat types: High-resolution sub-bottom seismic reflection profiling systems can be used to determine the thickness of sedimentary units, which, along with repeated bathymetric surveys, can then be used to track the dynamic and ever-shifting nature of the bay's subtidal habitats. Using this data, a mapping effort could be undertaken to distinguish persistent and temporal habitats and address the dynamic influences that re-work the bay-floor.

5. Hardened shorelines: There is a need to better understand fill type, especially in regard to assessing the impact of wave velocities and rising sea levels in order to better predict their impacts on foreshore slopes. Understanding various fill types and the nature of hardened shorelines better informs the planning of subtidal restoration sites and techniques, as well as helps plan for sea level rise and other climate change impacts throughout San Francisco Bay.

Researchers at the San Rafael oyster and eelgrass restoration site.

6. Submerged creosote pilings: The San Francisco Estuary Institute (SFEI) and NOAA conducted a detailed survey and mapped most of the creosote piling complexes that could be seen at low tide above the surface via boat (see Appendix 6-1). This survey documented over 33,000 derelict pilings in the bay, and estimated at least that many more pilings (and stubs of pilings) occur below the surface of the water at low tide. Beyond locating and mapping these submerged pilings to improve navigational safety, this mapping effort provides information for any potential future removal projects.

7. ESI data: NOAA's Environmental Sensitivity Index maps were released in 2006. Since then, innumerable changes have occurred to the bay shoreline. The Environmental Sensitivity Index (ESI) Maps for California are being updated, pending funding. An update to the San Francisco Bay ESI maps is needed to include the most recent information on the location and extent of subtidal habitats along the shoreline, any changes to management boundary areas, and subtidal restoration projects.

Raccoon Strait is one of the naturally deepest areas of the bay.

8. NOAA's hydrographic sheets: Based on data collected in the bay since the 1850s by the former Coast Survey, NOAA's "H" sheets are similar to the Terrestrial "T" sheets, which have been valuable in developing maps to illustrate the comparison between past and present wetland habitats in the bay (see SFEI's Ecoatlas). "H" sheets include depths based on boat soundings and information about bottom types based on bottom grab samples. Nearly all of the depths on the H sheets have been digitized (Dr. Bruce Jaffe, USGS, 2010, pers.comm.), but additional work needs to be done to analyze the bottom type against current conditions.

9. Human uses: Although the Subtidal Goals Project has gathered extensive data on human activities that may impact subtidal habitats, additional mapping of the bay's current and predicted future human uses is needed to assess stressors and restoration site considerations.

10. Oil spill response: The Office of Oil Spill Prevention and Response GIS maps should be regularly updated to include high priority subtidal protection areas and locations of available equipment, and used during future oil spills in San Francisco Bay.

11. Database and mapping tool for active subtidal restoration and monitoring projects: Such a database could be accessed and used by multiple partners (academic, non-profit, consultant, and agency). The subtidal database could be linked to existing databases such as the San Francisco Bay Joint Venture restoration database and the Wetland Tracker.

CHAPTER THREE

Science and Cross-Habitat Goals for All Subtidal Habitat Types

THIS CHAPTER DISCUSSES informational needs and issues that cross multiple habitat types, including the water column as a unifying habitat type. It includes a conceptual description of all subtidal habitats and the water column. It lays out foundational science and research goals for all subtidal habitat types, and discusses issues that warrant management and restoration goals for all habitats—for example, invasive species, oil spills, marine debris, and public access and awareness.

Conceptual Model for All Habitats

The habitat types discussed in this report (Figure 3-1) include habitats defined by physical structure (soft-bottom, rock, artificial substrate), habitats created partly by organisms (eelgrass beds, shellfish beds, and macroalgal beds), and the water column (see next section). All of the habitats except the water column are fixed in place, so the water column must be considered as part of these habitats as well as a separate habitat itself.

Shallow subtidal habitat at the Marin Islands National Wildlife Refuge.

The various subtidal habitats support valued ecosystem services (see Chapter 1), although the degree of support, and the relationship of quantity of habitat to level of support, are unknown. Conceptual models, including text and diagrams, were developed to describe the broader subtidal system, and for each of the habitat types. The habitat-specific models in subsequent chapters provide information on what each habitat does, both in terms of its function and the ecosystem services it supports. They also describe short- and long-term threats—human and other activities that may impair or reduce the amount of each habitat.

The Water Column

In setting goals for subtidal habitat, the Subtidal Goals Project used the water column—the water covering submerged substrate, including all volume between the substrate and the water surface—as an aspect of the conceptual models for all of the other habitats.

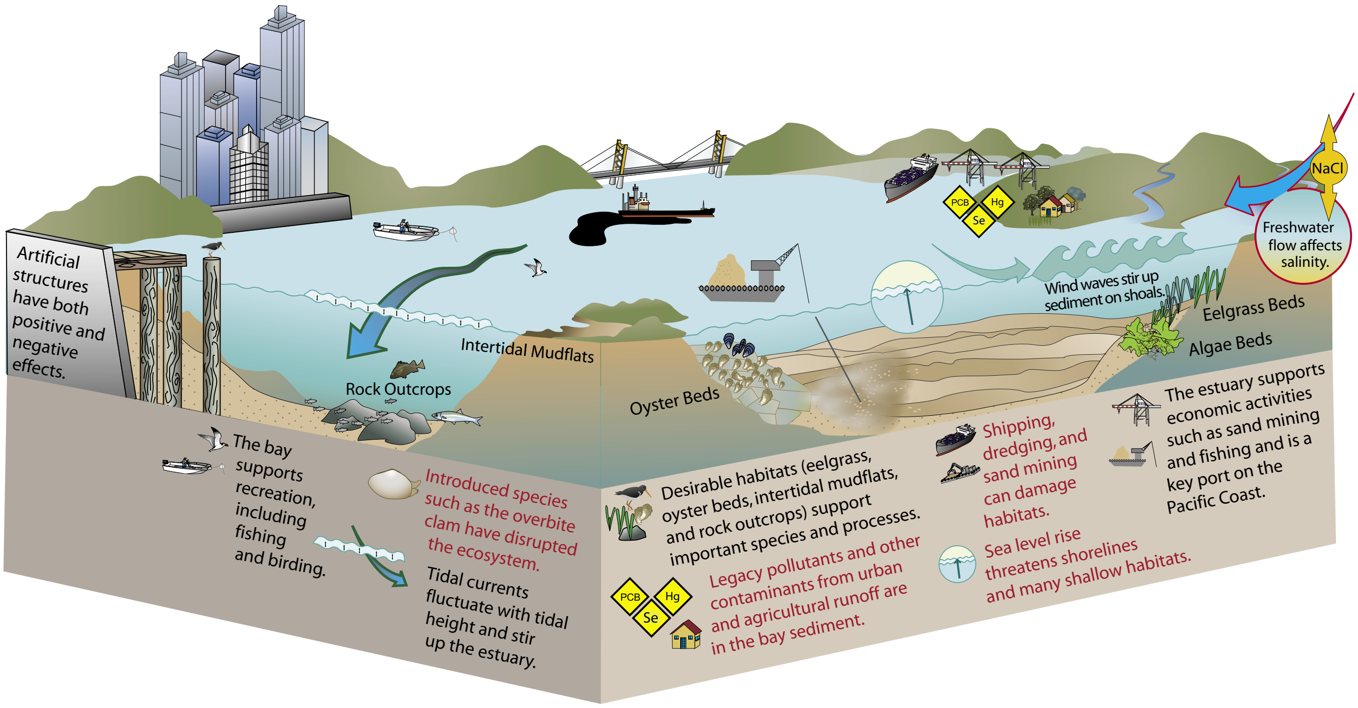


Figure 3-1: Conceptual diagram for subtidal habitats in the San Francisco Estuary. This diagram displays some of the key concepts involved in subtidal habitats, particularly the processes linking habitats with each other and the surrounding land, and some of the threats to the habitats. Similar diagrams in Chapters 4–9 depict details of each of the individual habitat types, including ecosystem services they provide and threats to them.

The estuary's water column is both the medium for each of the other subtidal habitats and a separate habitat in its own right. The water column transports material and organisms to and from the other habitats, and many estuarine organisms live their lives entirely within the water column. Since water-column processes influence other habitats, understanding these processes is essential for managing the other habitats.

More scientific research and monitoring have been done on the water column than on any other habitat, and the literature is far too extensive to provide a review of it here. Some of this material has been synthesized before (Kimmerer 2004). The physical forces that affect the water column, how the water responds, and how this interaction affects the organisms living in the water are described below.

Physical dynamics

The principal drivers of water motion in the estuary are, in decreasing order of importance, tides, freshwater flow, and wind. Tidal oscillations in the coastal ocean move water into the estuary at a dominant period of 12.4 hours. Tidally-driven currents and longer-period level changes in the ocean, such as those from storm surges, are responsible for most of the mixing and transport of materials in the estuary. Freshwater flow in the rivers entering the estuary mainly in the delta induces a net seaward flow throughout the estuary that also moves materials and some organisms seaward. The relative importance of this net flow compared to tidal flow increases going landward into the estuary. Typical net flows of freshwater are a few percent of tidal flows at the eastern end of Suisun Bay, and much less than that in central San Francisco Bay.

A prominent outcome of the interplay between freshwater flow and tidal currents is the estuarine salinity gradient. This gradient penetrates into the estuary to the western delta during dry periods, and to western Suisun Bay in most winters. Doubling freshwater outflow from the delta moves the salinity gradient about 8 km seaward with about a two-week lag time. Salinity at any point within that gradient decreases correspondingly with increasing flow. The salinity gradient is also a density gradient, which tends to oppose the net river-derived flow out of the estuary. The situation is different in the South Bay where freshwater input comes from wastewater treatment plants most of the time, except during high-flow events in the delta when lower-salinity water enters the South Bay from the north.

The interaction between net river flow, opposing density gradient, and tidal currents also determines the vertical density stratification, by which currents in the deeper channels tend to flow toward land (if averaged over the tidal cycle) and surface currents tend to flow to sea. The resulting complex pattern of water motion has a profound influence on retention of sediments and organisms within the estuary. Wind can modify the tidal currents, especially in shallow water (< 1m) through breaking wind waves, and very strong wind can limit stratification even in deep water.

Sediment movement is even more complex than water movement because sediment particles can settle to the bottom and be resuspended, and the tendency to settle depends on grain size. Wind waves in shallow waters are important in resuspending sediments, which are then moved mainly by tidal currents. Coarser sediments such as sand are most apparent in high-energy environments where finer sediments can't settle, including beaches (because of the action of wind waves), and deep channels (because of tidal currents). The finest sediments, generally clay particles (~1 μm in diameter) remain in suspension and are largely responsible for the high turbidity of the water throughout the estuary. This suspended sediment load may be decreasing as the pulse of sediment from hydraulic mining dissipates, and because dams have cut off the supply of fine sediment to the bay (Schoellhamer 2009).

Water temperature in the San Francisco Estuary has a rather narrow range partly because of the modulating effect of the coastal ocean. Seasonal fluctuations are highest in the delta (10–21°C at Antioch) and lowest at the Golden Gate (10–16°C).

Harbor seals haul out on rocks near the Richmond-San Rafael Bridge.

The pelagic food web

Nearly all estuarine organisms are limited to a certain range of salinity through a combination of physiological and ecological effects. Pelagic organisms (those in the water column) move with the water and therefore are not subject to salinity stress the way benthic organisms (those on the bottom) are.

The food webs of the San Francisco Estuary are supported mainly by phytoplankton production, which is usually low because the high suspended sediment concentration limits light penetration, and in some areas grazing by clams limits the buildup of phytoplankton biomass. High ammonium concentrations mostly from wastewater treatment plants in the delta may further suppress phytoplankton growth and production (Dugdale et al. 2007).

This low productivity is reflected throughout the food web. For example, zooplankton throughout the estuary feed mainly on microzooplankton, presumably because phytoplankton biomass is low, and zooplankton are food limited much of the time. The low productivity is the principal reason why there is no major commercial fishery in the estuary. Another consequence of high turbidity and low phytoplankton productivity is that nutrient concentrations remain high most of the time, and eutrophication has not occurred since sewage treatment plants were upgraded in the 1970s. If the trend toward increasing water clarity (Schoellhamer 2009) continues, eutrophication might become possible sometime in the future.

Volunteers move bags of Pacific oyster shell by kayak for placement at the San Rafael restoration site.

Interactions

The water-column habitat interacts with all of the other habitats in the bay, and with the delta and coastal ocean. Water supplies nutrients, food, and oxygen to benthic habitats, removes waste, and redistributes plankton and larvae. Its interaction with the soft bottom is particularly important, because of the soft bottom's great extent and because many benthic organisms feed on particles in the water column, and in turn are fed upon by fish, crabs, and shrimp.

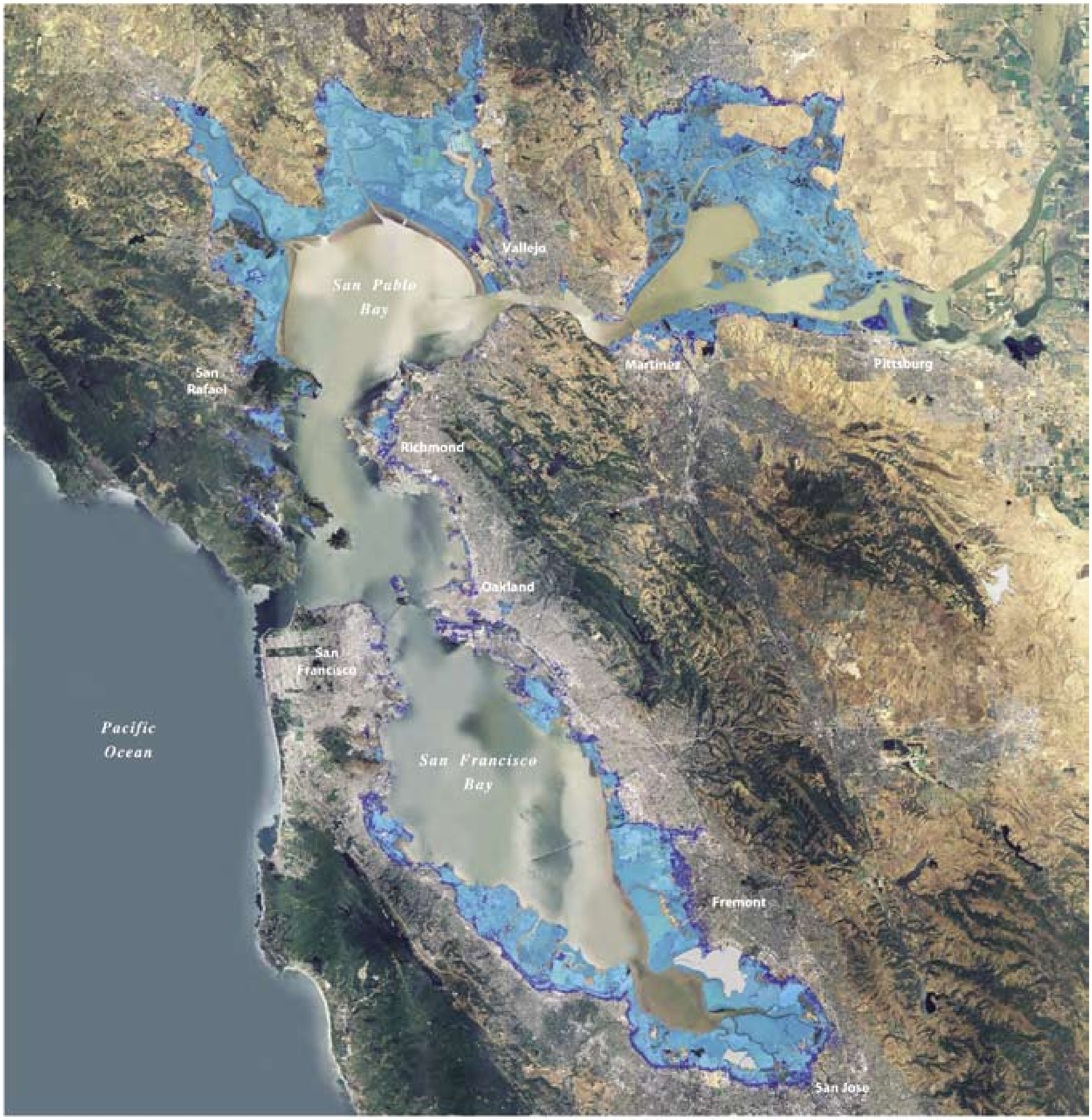
Exchange with the coastal ocean removes sediment, organisms, and wastes from the bay, and brings in coastal organisms. Perhaps more important is exchange that occurs through movement of fish and other organisms: there is no barrier between the bay and the coastal ocean. Ocean conditions (for example, El Niño, Pacific Decadal Oscillation) can influence the bay directly (through temperature or water level) and indirectly through changes in the species composition and abundance of fish that then enter the bay.

Another important exchange is with the rivers entering the delta, which supply sediments, nutrients, and organic matter to the water column, but also many contaminants such as pesticides, herbicides, mercury, and selenium. Additional sources of contaminants are the urban and industrial areas surrounding the estuary, ships within the estuary, and contaminants stored in sediments.

The water column is also subject to a variety of human influences that can then affect other habitats. These include the various influences of climate and other long-term changes (Table 3-1, Figure 3-2, and Appendix 2-2).

Table 3-1: Long-term changes projected or likely to occur in the estuary, and some potential consequences for the more seaward reaches of the estuary. Causes in bold are those with a high probability of occurrence, or that are already observed. Other causes are either weakly or inconsistently supported by models.

Cause	Consequence
Sea level rise	Habitats will be in deeper water, less suitable because of turbidity; landward shift limited by shoreline conditions.
	Higher tide and tidal range may increase erosion and alter shorelines, mudflats, and marsh boundaries.
	Increase in tidal range may increase intertidal area; depends on sediment characteristics and sediment supply rate.
	Increased salt penetration due to enhanced estuarine circulation.
	Increase in tidal range will increase the strength of tidal currents, possible erosion.
Temperature rise	Change in phenology, biogeography of estuarine and marine species.
	Species introductions and local extinctions.
	Reduce survival, reproduction, and growth of eelgrass and native oysters.
	Higher winter, lower spring/summer flow (salinity opposite).
Total precipitation	More total flow and lower salinity with increase.
Wind speed	Increased resuspension of sediment from intertidal and shallow subtidal areas with increased wind speed.
Storm frequency	Increased shoreline erosion with increased storm frequency.
Acidification	Impaired calcification of shellfish. Note that scientific support for ocean acidification is very high, but the estuary may respond more to local conditions.
Interactions	Higher sea level with stronger currents and wind, accelerate erosion.
Levee failures in delta	In short term, rapid rise in salinity (if during wet season); in long term, chronically higher salinity.
Changed delta configuration	Depending on operating criteria, potential increase in salinity.
Population growth	Increased demand for all ecosystem services; increased urbanization, impacts from transportation and infrastructure.
Continued reduction in sediments	Continued shortage of sediments to build marshes, mudflats, erosion of shorelines.
Introduced species	Impossible to predict; depends on which species and where.
Industrial development	Desalination plants may be constructed, with attendant impacts on water column and other habitats. Tidal or wave-driven power sources would alter flows and increase artificial structures, and possibly have impacts on fish and marine mammals.



SOURCE: Inundation data from Knowles, 2008. Additional salt pond elevation data by Siegel and Bachand, 2002. Aerial imagery is NAIP 2005 data.

DISCLAIMER: Inundation data does not account for existing shoreline protection or wave activity. These maps are for informational purposes only. Users, by their use, agree to hold harmless and blameless the State of California and its representatives and its agents for any liability associated with its use in any form. The maps and data shall not be used to assess actual coastal hazards, insurance requirements, or property values or be used in lieu of Flood Insurance Rate Maps issued by the Federal Emergency Management Agency (FEMA).

San Francisco Bay Conservation and Development Commission

Area vulnerable to an approximate 16-inch sea level rise

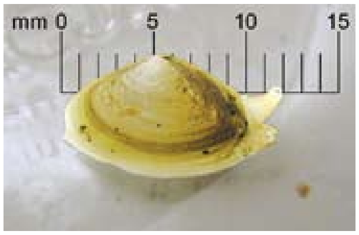
Area vulnerable to an approximate 55-inch sea level rise

No Data

0 2 4 8 MILES

NORTH

Figure 3-2. Shoreline areas vulnerable to sea level rise, San Francisco Bay Area.



Corbula clam

The taller invasive cordgrass on the right has invaded marshes throughout the bay.

A particular human influence on the water column occurs over long distances: alien organisms are introduced through vectors such as shipping, deliberate introductions for fisheries (including oysters and their associated fauna), sales of live bait, and careless or deliberate introduction of unwanted aquarium or food organisms. Although most of the introduced species in South Bay to San Pablo Bay have been benthic, the zooplankton species of the brackish regions of the estuary are largely introduced, as are the fishes of the freshwater regions. The most notable introduction of the last several decades in terms of system-wide impact was that of the overbite clam, *Corbula amurensis,* whose filter-feeding reduced phytoplankton production of the northern estuary to about 20% of its previous value.

Protection of the Water Column

This document does not recommend specific goals for water-column habitat. The benthic habitats (e.g., eelgrass) are assumed to include the overlying water column for the purposes of setting and achieving goals for those habitats. For example, the movement of propagules (eelgrass seeds, oyster larvae) among beds is mediated by water motion, and therefore this motion must be considered in efforts to restore or enhance the beds. The greatest concerns for protecting the water column are reducing contaminants and improving water quality for fish. The effects of emerging contaminants[1] (hormones, antibiotics, and other pharmaceuticals) on bay resources have been identified as an area of concern and initial protection recommendations are identified (see Chapter 4). Many of these pollutants are entering the bay through wastewater treatment plants that currently lack the technology to remove them. These issues are under the purview of existing agencies operating under various laws and authorities, such as the federal Clean Water Act and the Porter-Cologne Water Quality Control Act. Recommendations on these topics in this document would likely be redundant with existing laws and policies, and were not considered a high priority for this report.

1. For more information on current science and considerations for the management of Emerging Contaminants, see http://www.calost.org/CA%20CEC%20Workshop%20Final%20Report%20Sept%202009.pdf.

Foundational Science Goals

Scientific uncertainty about subtidal habitats precludes immediate decisions about undertaking restoration activities or implementing protective measures. The functions of the habitats, the ecosystem services they support, the threats to them, and the prospects for restoration or protection are all poorly understood. The goals and questions below form the basis of the science that is needed for all of the habitats.

FOUNDATIONAL SCIENCE GOAL 1

Understand the value of the habitats.

Question A. What ecosystem services do the habitats support?

Question B. What is the relationship between the extent of desired habitats (especially oyster beds, eelgrass beds, and intertidal mudflats) and the extent of ecosystem services provided?

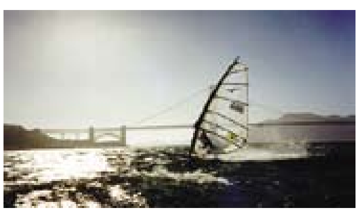
FOUNDATIONAL SCIENCE GOAL 2

Understand the interactions among habitats.

Question A. How do the various habitats interact, and is there synergy or antagonism between them?

If one habitat provides some benefit (e.g., chemical or biological output, or refuge) to another nearby habitat, the result may be a greater level of ecosystem services than would be expected from the individual habitats.

An obvious interaction occurs in that each habitat can grow only at the expense of other habitats. For some habitats this probably doesn't matter. For example, establishing eelgrass beds in all of the feasible locations would make only a small dent in the availability of mud-bottom habitat. Because eelgrass will grow only in the margins of the bay in suitable substrate, depth, and salinity, it is unlikely that the scale of eelgrass restoration would significantly decrease the ecosystem services of the soft subtidal substrate. In addition, multiple habitat types can coexist in the same area, such as eelgrass blades growing over a soft mud bottom.



Windsurfers on the bay.

Question B. How will these interactions change as the estuary changes?

Long-term changes, particularly sea level rise and decreased sediment supply, will alter the way the various habitats function and interact (Appendix 2-2). These changes may either amplify or negate the benefits of various actions taken in the near term. One possible outcome is a landward movement of the shoreline, such that the landforms are similar, and functions continue, but at locations farther inland. This can happen only where hardened structures such as roads do not impede this landward movement. Therefore understanding this future trajectory will be essential in planning actions for all habitats.

FOUNDATIONAL SCIENCE GOAL 3

Understand the long-term prospects for subtidal habitats.

Biologists survey a new native oyster restoration site at Cesar Chavez Park near the Berkeley Marina.

The future trajectory of the estuary is likely to impinge on some habitats, some favorably and others not. In addition, long-term changes such as sea level rise may increase motivation for restoring certain habitats as part of a strategy for adapting to a rising sea. Of all the trends projected, those of sea level rise, decreased sediment supply, increasing temperature, increasing salinity, and further species introductions seem to be the greatest threats to subtidal and intertidal habitats. Potential effects of ocean acidification may affect the central bay but are likely to be controlled within most of the estuary by local processes.

Question A. What is the current extent of each of the habitat types, and how is it changing?

Because subtidal habitats sometimes shift with changing conditions, asking and answering this question periodically should be part of any plan for managing these habitats. Knowledge of habitat extent is essential to determine and document how the habitats are changing over time and whether restoration goals are being achieved.

Question B. How will individual habitats respond to forecasted changes in the estuary?

This question may never be answered, but consideration of these issues should provide the underpinning for all decisions about restoration and protection of habitat. Although many people are now aware of some of the consequences of climate change, relatively few have imagined the state of the estuary 50 years hence. The impacts of climate change are numerous, but the impacts of some more immediate anthropogenic influences are just as important (Table 3-1); although many of these impacts (for example, due to water shortages or levee failures) will be most severe in the delta, most will be felt throughout the estuary.

Question C. How is the balance between sediment deposition and erosion likely to change, and how will these changes affect subtidal habitats?

The sediment budget of the estuary may now be negative, i.e., there may be more erosion than can be supported by the supply of sediment from rivers (Chapter 4). This has strong implications for all subtidal habitats, but particularly for soft-bottom and eelgrass habitats.

Question D. What are the likely effects of projected changes in temperature and salinity on key estuarine species?

Salinity will likely be closer to oceanic values for more of the year than is currently the case. Pacific herring may require depressed salinity for some part of the life cycle. Subtle changes in the food web may alter foraging opportunities for fish, birds, and marine mammals.

Researchers study eelgrass beds in Richardson Bay.

Question E. What are likely effects of the potential loss of important transient species such as Chinook salmon?

Higher temperature will have a substantial effect on salmon through its effect on survival of spawning adults, embryos, and juveniles in the rivers. Loss of a substantial fraction of the salmon could remove a fairly significant proportion of the fish present in some seasons.

Question F. What potentially damaging invaders to the estuary might arrive either through range expansions due to temperature and salinity changes, or through ongoing introductions in ballast water and other vectors?

Question G. How will changing sea level and shoreline erosion affect seal rookeries and haulout sites and habitat for shorebirds and waterfowl within the bay?

The potential loss of shallow subtidal and intertidal areas could drastically alter the availability of what is essentially temporary terrestrial habitat for aquatic vertebrates and shorebirds. This should be examined together with the availability of alternative habitat.

FOUNDATIONAL SCIENCE GOAL 4

Develop mechanisms to adapt to climate change.

Adaptation to some of the trends identified in Appendix 2-2 may be possible.

Question A. How can restoration and protection measures be established so as to accommodate forecasted changes?

Some habitats may be too vulnerable to survive the anticipated changes in all locations. Planning for restoration or construction of habitats such as eelgrass beds should consider the likely future configurations of various parts of the estuary.

A researcher shows the length of San Francisco Bay eelgrass, which can grow to 2 meters or more.

Question B. What technologies are available, and how effective are they in adapting to the effects of elevated sea level and loss of sediment supply while protecting habitats?

There may be opportunities to adapt to sea level rise and long-term reductions in sediment supply through construction practices that provide some habitat, through the use of living materials such as eelgrass or oyster beds to buffer and protect vulnerable areas from erosion and inundation ("living shorelines"), and by linking subtidal restoration with marshes (see Chapter 10). These practices are largely untested and should be attempted only in an experimental framework.

Cross-Habitat Goals

The goals presented in the following sections relate to issues that affect all subtidal habitat types, specifically invasive species, oil spills, marine debris, and public access and awareness.

Invasive Species

Invasive cordgrass eradication.

An "invasive species" is defined as a species 1) that is non-native and 2) whose introduction causes or is likely to cause economic or environmental harm or harm to human health. Over 230 non-native species now live in San Francisco Bay, many of which have altered benthic habitats and water column function by modifying the community structure or the physical or chemical environment.

Invasive species have been introduced in a variety of ways, some intentional and some unintentional. Eradication of invasive species is feasible only in unusual circumstances, notably during early stages of invasion with an intertidal species that is easy to see and identify. Critical factors to assess before committing resources to control or eradication include considering the likely harm if the introduced species is left unchecked; whether ecosystem services from specific habitats will be reduced; the potential for eradication or reduction to acceptable levels within a reasonable time frame (for example, no longer than 10 years); whether the proposed methods for treatment are known to work; and whether there is reasonable assurance that no identifiable vector will re-introduce the species proposed for control or eradication.

The non-native cordgrasses *Spartina alterniflora, densiflora, anglica, and patens* were planted in San Francisco Bay for restoration purposes. The plants have since become invasive, and *S. alterniflora* and its hybrids threaten to replace pickleweed and native *S. foliosa* in existing and restored intertidal habitats and to overgrow mudflats. The result would be a monoculture of invasive *Spartina,* and a major loss of functions and values of these habitats. Since 1999, the California Coastal Conservancy has managed a regionally coordinated effort to solve this problem through its Invasive Spartina Project. Over $14 million has been spent on *Spartina* eradication to date.

Invasive cordgrass is eradicated by a helicopter spraying herbicide near Old Alameda Creek at Eden Landing Ecological Reserve.

In 2006, the NOAA Restoration Center and other partners coordinated a successful early eradication effort to control the introduction of the brown alga *Ascophyllum nodosum* at sites in San Leandro Bay. In 2009, the Smithsonian Environmental Research Center and other partners began coordinating an early eradication effort for known small populations of the introduced alga *Undaria pinnatifida* at two marinas in San Francisco Bay.

Many invasives move as unknown stowaways and "hitchhikers" when people and their products are transported. A wide variety of invasive species have found their way into San Francisco Bay in ballast water, holding tanks, and bait and seafood packing material, and via fouled vessels. The overbite clam *Corbula amurensis* is one of the most notable subtidal invasives brought to the bay most likely in ship ballast. Unfortunately, the widespread distribution of the species throughout soft-bottom habitats, especially in the northern parts of the bay, makes eradication infeasible.

While ballast water moves a much greater number of species, aquaculture is probably a far more effective mechanism for introducing exotic parasites, diseases, and other pests of fish and shellfish. For example, Pacific Coast oyster growers began importing and culturing Virginia oysters *(Crassostrea virginica)* from the Atlantic Coast in 1869, and Pacific oysters *(Crassostrea gigas)* from Japan in 1902, which resulted in many Atlantic and Japanese species (including several oyster pests such as the oyster drill) becoming established in the bay. More recent types of marine aquaculture (such as salmon and abalone farming) have also released exotic species into Pacific waters (Cohen 2005).

Invasive species control goals focus on removing four invasive species for which removal efforts are already underway and eradication is reasonably attainable, and on preventing additional invasions. The goals presented below represent regional implementation of the California Aquatic Invasive Species Management Plan (http://www.dfg.ca.gov/invasives/plan/) as related to subtidal habitats within San Francisco Bay.

CROSS-HABITAT INVASIVE SPECIES CONTROL GOAL 1

Minimize the impacts of aquatic invasive species on native subtidal habitats in San Francisco Bay.

- Cross-Habitat Invasive Species Control Objective 1-1: Eradicate four species of existing aquatic invasive species in San Francisco Bay that affect intertidal and subtidal habitats.

  Cross-Habitat Invasive Species Control Action 1-1-1: Continue to fund and implement the California Coastal Conservancy's Invasive *Spartina* Project and eradicate *Spartina alterniflora* (cordgrass) and its hybrids by 2012.

  Cross-Habitat Invasive Species Control Action 1-1-2: Identify and secure funding for efforts to remove 100% of all *Undaria pinnatifida* (wakame) from San Francisco Bay by 2012.

  Cross-Habitat Invasive Species Control Action 1-1-3: Identify and secure funding for removal of 100% of all *Ascophyllum nodosum* (knotted wrack weed) material from San Francisco Bay by 2012.

  Cross-Habitat Invasive Species Control Action 1-1-4: Continue to support funding for exotic oyster and oyster drill removal projects and eradicate all known populations of *Crassostrea gigas/virginica* by 2011.

- Cross-Habitat Invasive Species Control Objective 1-2: Prevent the introduction or establishment of aquatic invasive species in San Francisco Bay.

Invasive *Undaria pinnatifida* beneath a dock at the San Francisco Marina.

Cross-Habitat Invasive Species Control Action 1-2-1: Establish an expert panel to review new non-native species invasions and their potential ecological effects when they occur, and make decisions regarding feasibility of eradication and reasonable levels of resources.

Cross-Habitat Invasive Species Control Action 1-2-2: Develop and implement an early detection monitoring program for high priority aquatic invasive species (including but not limited to *Zostera japonica, Caulerpa taxifolia* or other *Caulerpa* spp., *Undaria pinnatifida, Ascophyllum nodosum, Crassostrea gigas* and *C. virginica)* specific to the bay. Components would include risk assessments to identify avenues for vector introduction, and prioritization of ecologically sensitive sites and high concentration areas.

Invasive *Undaria pinnatifida.*

Cross-Habitat Invasive Species Control Action 1-2-3: Develop and implement a coordinated system for rapid response, such as the Bay Area Early Detection Network, to contain newly detected aquatic invasive species. Identify lead agencies that can provide financial and logistical support for rapid response, and identify key scientific organizations and agency personnel to lead eradication efforts.

Cross-Habitat Invasive Species Control Action 1-2-4: Support improvements in ballast water and sea chest inspections through additional training and staffing.

Cross-Habitat Invasive Species Control Action 1-2-5: Create an education program focusing on proper disposal of non-native algal packing material and encourage fishermen to dispose of non-native algal packing material in trash receptacles.

Cross-Habitat Invasive Species Control Action 1-2-6: Fund and implement clean boating and recreational education programs. Work with the bait fish, restaurant, and aquarium communities to develop best management practices. Provide outreach materials and signage at marinas, recreational shops, and boating facilities to inform users of the risks of accidental release of invasive species.

Cross-Habitat Invasive Species Control Action 1-2-7: Use only native species in restoration, inspecting all live restoration and construction materials for aquatic invasive species and cleaning all equipment prior to and post restoration/construction.

Oil Spills

In the past 15 years, San Francisco Bay and surrounding coastal waters have been impacted by several oil spills. Two of the largest spills, the *Cape Mohican* (40,000 gallons in 1996) and the *Cosco Busan* (54,000 gallons in 2007) impacted miles of bay and coastal habitat. Rocky intertidal, sand beaches, mudflats, fringing marshes, and eelgrass beds as well as the animals that use them were harmed by these spills. Although large oil spills are relatively infrequent, the risk of one happening is always present. Non-point source pollution, including petroleum in runoff from roadways, contributes significantly to effects on intertidal and subtidal biota on a more consistent basis.

Types of oil spilled in the bay include crude oil, refined petroleum products (such as gasoline or diesel fuel) and by-products, bunker fuel, oily refuse, or oil mixed in waste. Spills can take months and even years to clean up. In many cases oil washes onto both subtidal and intertidal habitats. Intertidal and subtidal shorelines, more than any other part of the marine environment, are exposed to the effects of oil, as this is where it naturally tends to accumulate. Oil floating on top of water limits the photosynthesis of marine plants and phytoplankton, and oil attached to leaves of aquatic vegetation can smother the plants. Epiphytes and epibenthic macroinvertebrates can also be smothered in the process or can absorb the chemicals.

In some circumstances, subtle changes to rocky shore communities can be triggered by a spill, which can be detected for 10 or more years afterwards. Soft sediment shores are extremely vulnerable to impacts from oil spills. If oil penetrates into fine sediments it can persist for many years, increasing the likelihood of longer-term effects. The upper fringe of "soft" shores is often dominated by salt marshes, which are generally only temporarily harmed by a single oiling. However, damage lasting many years can be inflicted by repeated oil spills or by aggressive cleanup activity, such as trampling or removal of oiled substrate.

Immediate oil spill response and cleanup are crucial in minimizing impacts to intertidal and subtidal habitats. The Incident Command framework used for oil spill response in California is mandated at the state and federal levels. The United States Coast Guard, the California Department of Fish and Game (through the Office of Oil Spill Prevention and Response), the National Oceanic and Atmospheric Administration, and other trustee agencies are charged with working with the Responsible Party (ship owners) to implement response and cleanup. The Marine Safety Branch of the Office of Oil Spill Prevention and Response is charged with oil spill prevention, and has programs in place to monitor on-water fuel transfers, track tug escorts, and work with local Harbor Safety Committees to prevent vessel collisions that result in oil spills. Because San Francisco Bay has several busy ports and refineries and tanker traffic, future oil spills are possible, so continuing to learn from past spills and developing spill readiness plans is important. The following goals focus on preventing oil spills from occurring and improving response in order to minimize their impacts when they do occur[2].

They include specific recommendations for improving specific subtidal habitat protection and response via existing programs and regional coordination and response to oil spills. Sewage and wastewater treatments spills also occur in

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2. For more information on the lessons learned from the 2007 *Cosco Busan* spill, and new legislation in place, see http://www.uscg.mil/foia/CoscoBuscan/CoscoBusanISPRFinalx.pdf.

San Francisco Bay, but recommendations in these areas are not included in this report (see discussion on water column at the beginning of this chapter).[3]

CROSS-HABITAT OIL SPILLS PREVENTION GOAL 1

Protect San Francisco Bay from both acute and chronic oil spills.

- **Cross-Habitat Oil Spills Prevention Objective 1-1:** Enhance oil spill preparedness and response capabilities to reduce impacts to subtidal habitats.

  Cross-Habitat Oil Spills Prevention Action 1-1-1: Increase coordination with Regional Response Teams and develop well-trained teams (including Incident Command agencies, local agencies and municipalities, non-profit groups, volunteers or others) to assist in rapid response, wildlife recovery, and injury documentation.

  Cross-Habitat Oil Spills Prevention Action 1-1-2: Integrate best available intertidal and subtidal habitat information into the San Francisco Bay and Delta Area Contingency Plan and provide it to all levels of government to enhance rapid response booming and subsurface capabilities to protect sensitive pelagic and benthic areas.

  Cross-Habitat Oil Spills Prevention Action 1-1-3: On an annual basis, update the Office of Oil Spill Prevention and Response's Environmental Sensitivity Index maps and GIS maps to include the most current information on locations of sensitive or valued existing or restored subtidal habitats.

  Cross-Habitat Oil Spills Prevention Action 1-1-4: Support the development of new technologies (e.g. boom type and size sufficient for San Francisco Bay waves and currents and technologies to protect subsurface habitats) for oil spill prevention and response specific to the protection of subtidal habitats.

A US Fish and Wildlife Service biologist monitors a section of shoreline after the *Cosco Busan* oil spill.

- **Cross-Habitat Oil Spills Prevention Objective 1-2:** Prevent oil spills from a variety of sources, including vessels, pipelines, facilities, vehicles, and railroads.

  Cross-Habitat Oil Spills Prevention Action 1-2-1: Update and improve spill prevention technology/programs on pipelines (fueling platforms, wharfs, and transfer facilities) and refineries that are located near water.

  Cross-Habitat Oil Spills Prevention Action 1-2-2: Educate boaters and fishermen on oil and fuel spill prevention and clean boating practices (e.g., oil absorbing bilge pads, used oil recycling).

  Cross-Habitat Oil Spills Prevention Action 1-2-3: Support education programs that promote automobile oil recycling and vehicle maintenance programs.

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3. For more information on regional efforts to reduce sewage and wastewater treatment spills, including recent legislation, see http://baykeeper.org/our-work/sick-sewage-campaign.

Right: The container ship *Cosco Busan* leaked oil into the bay from a hole in its hull.

Oil from the *Cosco Busan* was evident in intertidal and subtidal areas.

- **Cross-Habitat Oil Spills Prevention Objective 1-3:** Use Natural Resource Damage Assessments (NRDA) to ensure the public is adequately compensated for the loss of ecological services to the subtidal ecosystem.

  Cross-Habitat Oil Spills Prevention Action 1-3-1: Develop a centralized NRDA database and mapping application, to help responders determine spill trajectories and initial priorities after a spill. Use most current Environmental Sensitivity Maps and available subtidal data to better integrate information on seasonal distributions and habitat use by species listed under the Endangered Species Act, other aquatic native species, as well as sea and shore birds.

  Cross-Habitat Oil Spills Prevention Action 1-3-2: Coordinate all shoreline response and cleanup activities with local resource biologists to prevent damage to subtidal habitats. Ensure the Office of Oil Spill Prevention and Response's best practices are implemented by local agencies and private landowners (avoid washing rocky intertidal habitats with high-pressure hot water, removing un-oiled shoreline wrack, and using dispersants).

  Cross-Habitat Oil Spills Prevention Action 1-3-3: Perform baseline monitoring and laboratory analysis on the effects of polycyclic aromatic hydrocarbons on subtidal habitats and organisms and develop recovery curves (timelines for recovery of species and habitats) for use in restoration planning.

  Cross-Habitat Oil Spills Prevention Action 1-3-4: Create and maintain a subtidal restoration project list and cost estimates for settlement of damages to the restored habitats.

  Cross-Habitat Oil Spills Prevention Action 1-3-5: Implement pilot restoration techniques for subtidal algal habitats impacted by oil spills or trampling that occurred during cleanup activities.

Marine Debris

State and local governments spend millions of dollars every year attempting to clean up marine debris. Despite decades-long efforts to reduce marine debris through cleanup and outreach and education efforts, the proliferation of plastic debris continues, in large part due to increased use of single-use plastic products. Plastic litter, which comprises up to 60–80% of all marine debris and 90% of floating debris, the majority of which comes from land based sources, can last for hundreds of years in the environment without ever completely biodegrading. It can harm hundreds of marine species, from birds and fish that ingest small pieces of debris, to marine mammals that get entangled in fishing gear. The vast majority (80%) of litter reaching the ocean arrives primarily via runoff from land-based sources; the remaining 20% comes from ocean-based activities, such as fishing and shipping. Some communities throughout California have enacted measures to prevent, reduce, and clean up litter before it reaches the ocean, providing successful examples for a statewide effort.

Abandoned and deteriorating vessels are another form of marine debris and can have significant and diverse impacts on the bay's aquatic environment. Abandoned vessels may be releasing oil and other pollutants, thereby impairing water quality, impacting wildlife, and posing a human health risk. They also decrease public use of intertidal and subtidal habitats and can crush the substrate. Abandoned vessels can have an aesthetic impact that may also result in an impact to the economy of a local area (i.e., a marina with several abandoned vessels). Finally, abandoned vessels pose a significant navigational hazard, particularly in inclement weather. The long-term outcomes from removing marine debris will be to reduce navigational hazards, restore tidal hydrology and habitat connectivity, improve water quality, increase the amount of bay volume and surface area, and restore subtidal habitat (eelgrass beds and benthic habitat) for use by a variety of aquatic organisms.

Protection goals for subtidal habitat related to marine debris focus on expanding resources to prevent debris from reaching the bay, establishing cleanup programs, removing derelict vessels, increasing pollution prevention infrastructure, and identifying marine debris impacts to subtidal habitats. Restoration

BCDC has documented more than 400 abandoned vessels that need to be removed from Richardson Bay and other areas.

goals include surveying sites for marine debris, increasing removal activities, conducting pilot projects for creosote pile removal, removing derelict vessels, and installing pollution prevention infrastructure.

MARINE DEBRIS CONTROL GOAL 1

Prevent and capture land or marine sources of trash before they enter the bay.

- Marine Debris Control Objective 1-1: Install catchment devices that trap litter in storm drains and waterways before it enters the bay (e.g., catch basins, aquatic debris separators, and trash curtains).
- Marine Debris Control Objective 1-2: Place trash and recycling receptacles, such as fishing line recycling stations, and educational information at boating facilities. *(See also Rock Habitats Action 1-1-6).*
- Marine Debris Control Objective 1-3: Develop subtidal restoration and monitoring techniques that minimize the deployment of non-biodegradable materials.

MARINE DEBRIS CONTROL GOAL 2

Identify, prioritize, and remove large sources of marine debris from intertidal and subtidal areas of the bay.

- Marine Debris Control Objective 2-1: Survey and map undocumented submerged debris, including abandoned boats, fishing gear, and other debris for removal.
- Marine Debris Control Objective 2-2: Collect data on types of debris entering San Francisco Bay.

Kayaks are used to clean up trash in the bay.

The Watershed Project uses student volunteers to monitor habitat.

Marine Debris Control Action 2-2-1: Track debris in a centralized database to identify potential impacts to the water column and subtidal habitats, and pinpoint principal debris sources.

- **Marine Debris Control Objective 2-3:** Remove existing marine debris from the bay.

  Marine Debris Control Action 2-3-1: Promote and expand efforts, such as the California Coastal Commission's Coastal Cleanup Program and NOAA's derelict fishing gear removal program to remove intertidal debris (e.g., tires, shopping carts, electronic appliances, pieces of creosote pilings) from shoreline and wetland areas.

  Marine Debris Control Action 2-3-2: Promote and support the US Army Corps of Engineers San Francisco District's debris collection-and-control mission.

  Marine Debris Control Action 2-3-3: Promote and support the California Department of Boating and Waterway's Abandoned Watercraft Abatement (AWAF) Fund and its vessel surrender program.

  Marine Debris Control Action 2-3-4: Remove existing identified abandoned derelict vessels (approximately 40) from Richardson Bay within 5 years.

Elementary school students enjoy an outing on the bay.

Public Access and Awareness

Providing opportunities for people to access subtidal habitats allows the public to discover, experience, and appreciate subtidal habitats in the bay and can foster public support for subtidal habitat restoration and protection. However, studies indicate that public access may have immediate direct and indirect effects on habitats and wildlife. Potential adverse effects on habitat may be avoided or minimized by siting, designing, and managing public access to reduce or prevent adverse impacts. In addition, providing diverse and satisfying public access experiences can reduce adverse impacts that may result from unmanaged, informal access. (See Chapter 11 for more ideas on public involvement and education.)

PUBLIC ACCESS AND AWARENESS GOAL 1

Increase public awareness and foster support for subtidal habitat protection.

- **Public Access and Awareness Objective 1-1:** Provide diverse and satisfying access and recreational opportunities for the public to experience various subtidal habitats while avoiding or minimizing adverse impacts to subtidal habitats.

- **Public Access and Awareness Objective 1-2:** Provide access to natural rocky habitats in the bay that encourages appreciation of the habitat and its inhabitants while protecting the habitat from trampling.

Volunteers collect data at a native oyster restoration site.

California Conservation Corps members and volunteers bag clean Pacific oyster shell donated from Drakes Bay Oyster Farm.

Public Access and Awareness Action 1-2-1: Conduct docent-led tours, and place signs at high use rocky intertidal sites to raise awareness about the importance of rocky intertidal shoreline areas and ways to avoid impacts while visiting these locations.

Public Access and Awareness Action 1-2-2: Provide sufficient staffing at existing protected rocky intertidal areas to inform and educate individuals about harmful activities (such as collection of organisms or release of non-native species).

Public Access and Awareness Action 1-2-3: Use durable materials on trails and guide rails to reduce erosion of adjacent habitats and to minimize the creation of alternate access routes.

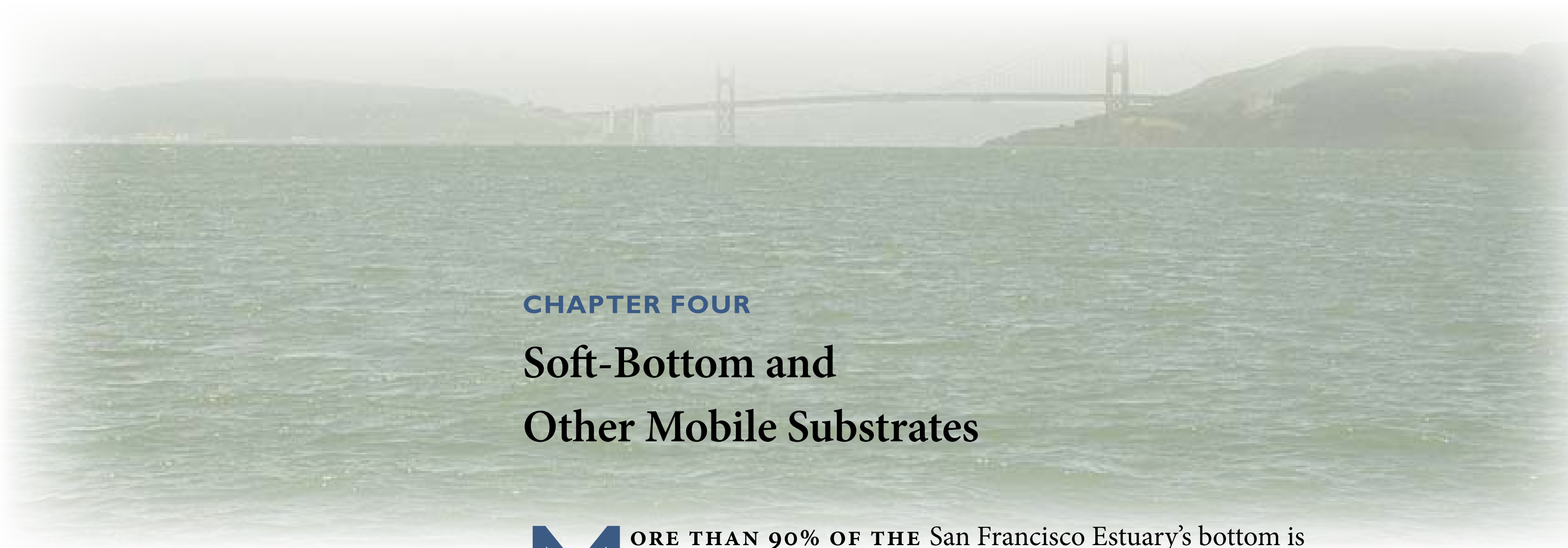
Public Access and Awareness Action 1-2-4: Provide diverse and interesting access opportunities to reduce the creation of informal access routes.

Public Access and Awareness Action 1-2-5: Develop and place educational materials and signs at boating facilities to educate boaters and other recreational users about the importance of rock and eelgrass habitats and best boating practices in these areas to prevent damage from anchors and anchor chains.

- Public Access and Awareness Objective 1-3: Support environmental education programs, local museums and nature centers, and schools to better integrate current science and subtidal habitat information into curriculum and field trip programs.

- Public Access and Awareness Objective 1-4: Support hands-on involvement and community-based restoration programs that focus on San Francisco Bay intertidal and subtidal habitats. Increase coordination between academic organizations and non-profit restoration groups to create better partnerships in research and restoration projects that involve community and student volunteers.

Save the Bay and other non-profit groups educate youth on the bay.



CHAPTER FOUR

Soft-Bottom and Other Mobile Substrates

More than 90% of the San Francisco Estuary's bottom is composed of particles that are small enough to be moved by tidal currents. Soft-bottom habitats include the substrate, organisms living on or within the substrate, and the overlying water column. See Figure 4-1.

Pebbles and cobbles on the bottom of San Francisco Bay near Angel Island.

Soft-bottom habitat includes sediments that range in size from clay (0.001–0.0039 mm) to silt (0.0039–0.0625 mm), and sand (0.0625–2 mm). "Mud" refers to clay and silt together. All of these particles can readily be moved by tidal currents. Larger particles such as gravel (2–64 mm) and cobble (64–256 mm), are somewhat mobile and are also included in this category. Deposits of bivalve shells can be mobile and are also considered in this section.

Most of the soft sediment in the estuary is fine material (Keller 2009), particularly on shoals. Sand deposits are found throughout deeper parts of the Central Bay, the main channel through San Pablo Bay into Carquinez Strait, and parts of the Suisun Bay channel (Figure 4-3 in Hanson et al. 2004). Most of this material, out to the sill seaward of the Golden Gate, originated within the bay and its watershed (P. Barnard, USGS, 2010, pers. comm.). Parts of the Central Bay that have been mapped in detail reveal large areas of sand waves (Greene et al. 2007), and some deposits of gravel and cobble occur east of the Golden Gate (Keller 2009). Apparently all but the larger boulders are moved by very strong

An endangered California clapper rail takes refuge in cordgrass on intertidal mudflats.

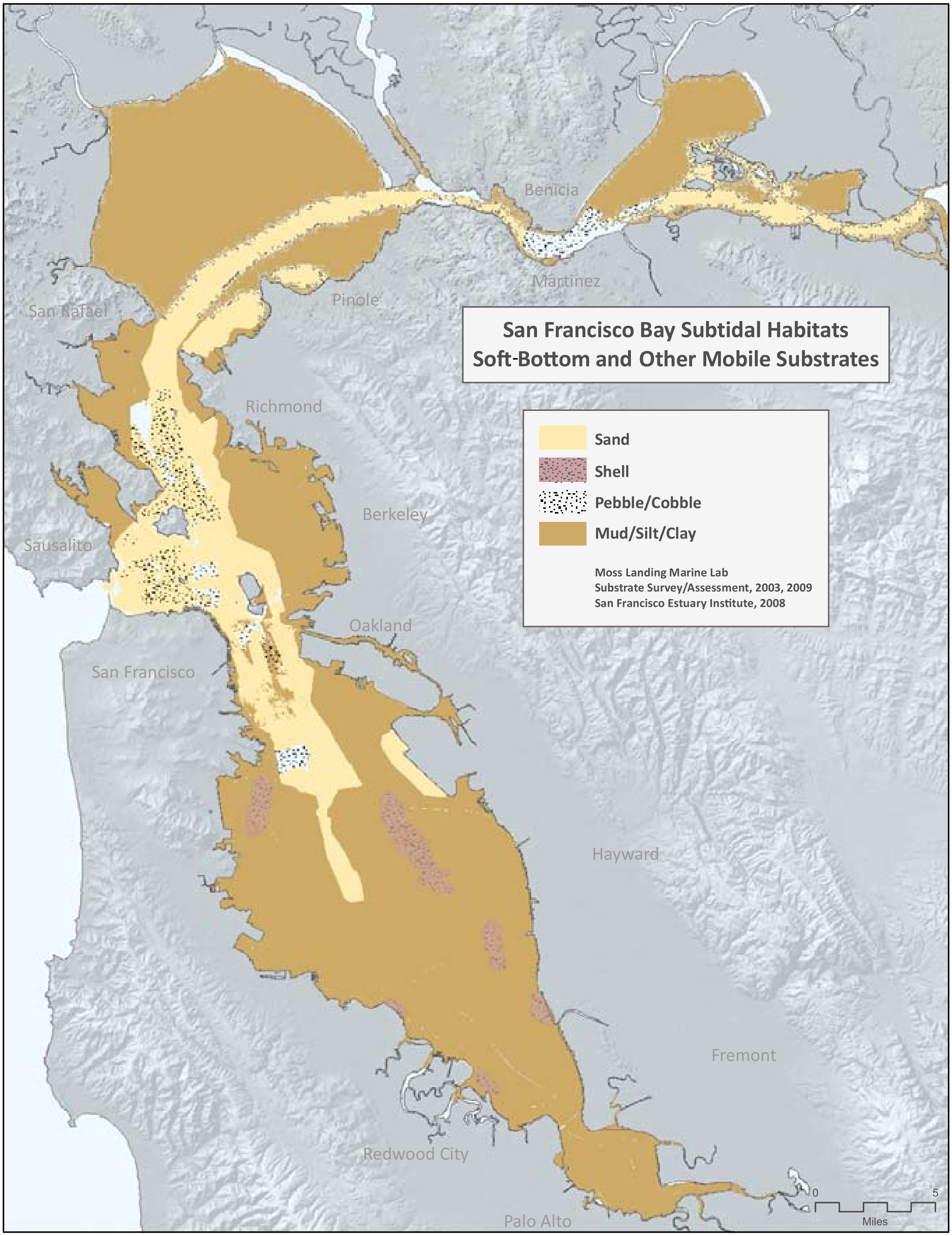


Figure 4-1: Distribution of Soft-Bottom Habitats in San Francisco Bay.

tidal currents in that region, and flood dominance of bottom currents in parts of the cross-section results in sorting of sediments with grain size decreasing eastward from the Golden Gate (Keller 2009).

Sandy beaches occur mainly in the Central Bay, but there are far fewer than were present historically, and all of the remaining beaches are constrained by shoreline development. Benthic surveys in the northern estuary have shown sand deposits in the channels, silt to clay elsewhere, and a few shell deposits near shore (Hymanson 1991). However, these surveys lack the spatial resolution of the Central Bay mapping. Shell hash from native oysters is found in extensive but localized deposits in the South Bay, where it is presumably trapped by current patterns. Gravel and cobble are uncommon except in certain areas of the Central Bay.

Conceptual Model for Soft Substrates

Sediment grain size is the key to movement and sorting of sediments and to the biological and chemical conditions in the sediments (Figure 4-2 and Figure 4-3). Grain size is largely a function of proximity to sediment sources such as rivers and the ocean, and of water movement, which includes waves, tides, and tidally-averaged currents. Fine-grained, soft substrate is the most common substrate in most estuaries. Paradoxically, fine-grained sediments are

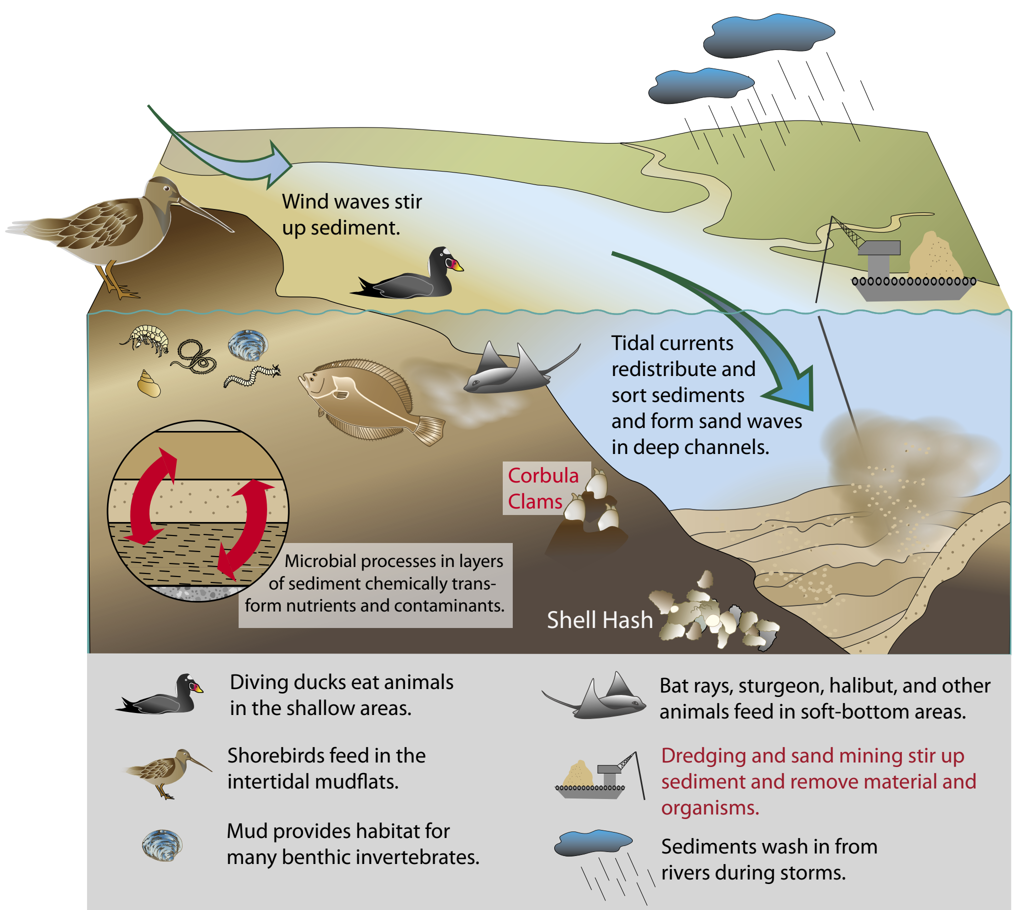


Figure 4-2: Conceptual diagram for soft-bottom substrates in the San Francisco Estuary. This diagram displays key processes that occur in and on soft substrates, some of the ecosystem services these substrates provide, and threats to soft substrates.

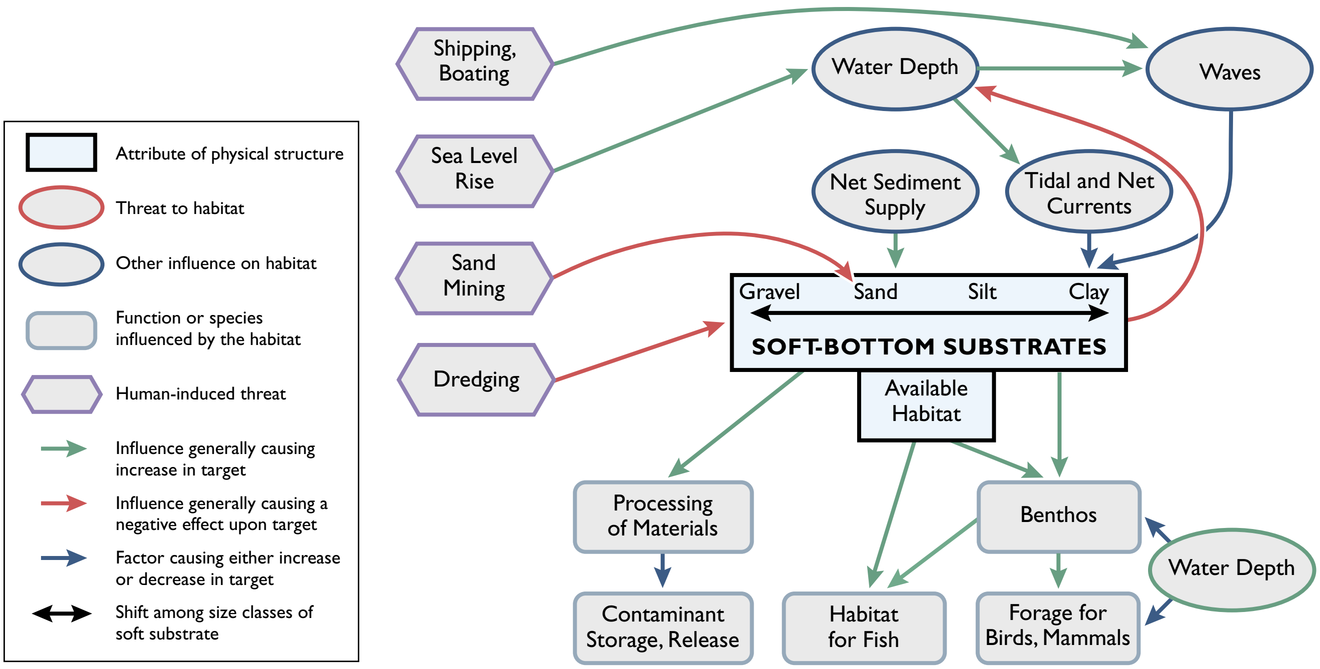


Figure 4-3: Influences on soft substrate, and functions and services provided by soft substrate. "Available habitat" refers to soft substrate that provides habitat for one or more species.

readily kept in suspension by tidal currents and wind-driven waves, but once deposited they can become consolidated, sometimes with the aid of organisms such as mats of microalgae and biofilm, making them more resistant to erosion than sand. This combination results in the establishment and maintenance of shoals and mudflats composed of fine sediments, and the bimodal depth distribution of much of the estuary, with its extensive shoals cut by narrow, deep channels. The shoals act as a sediment reservoir, storing fine sediments from winter floods, which are then resuspended by strong tidal currents and wind waves and gradually winnowed out through the dry, windy summer and fall (Schoellhamer et al. 2007). The strong current regime makes the San Francisco Bay floor a dynamic environment with major bedforms such as sand waves that shift in position and shape. Over time, significant alteration of the bay floor takes place, and substrate types may move or disappear entirely (Greene et al. 2007).

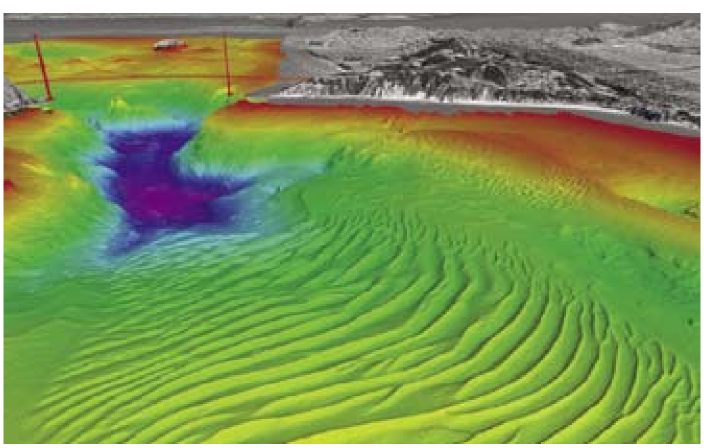
Coarser sediments are confined to high-energy environments where waves (beaches and sand bars), river flows (sand deltas), or tidal currents (bay-mouth bars, sand waves, channel bottoms) inhibit deposition of finer sediment. Sand deposits may also be found where past storms and floods have increased currents temporarily. Sand moves primarily as bedload but can also be transported in suspension by strong tidal currents or river flood flows.

Grain size is critical for the establishment of flora and fauna. Larger sediment particles such as cobble, gravel, or shell, if they remain in place long enough, may provide substrate for settlement of organisms otherwise found on hard substrates, such as oysters and barnacles, and clams may occupy spaces between cobbles. Fine-grained sediment is generally stable and compact enough to allow many kinds of organisms to reside in or on the sediment. Because of its mobility, sand is not a favorable substrate for many benthic organisms, and only those well adapted to a transitory environment are found there. Mixed sand and mud deposits can be stable enough to support diverse benthos (J. Thompson, USGS, 2009, pers. comm.). Some species of fish, notably California halibut, occur over sandy bottom, but the exact nature of that relationship is unknown. Juvenile Dungeness crab may use sand waves and formations as transit routes to migrate out to the ocean.

For some species, the paucity of benthic food resources limits the value of sandy habitat. Fine-grained sediment is a key component in estuaries for chemical transformations mediated by microbes, such as nitrogen fixation, denitrification, and oxidation and reduction of metals. Substances in sediments diffuse much more slowly than in the turbulent water column. Microbes oxidize organic matter within sediments, and the limited diffusion of oxygen and other substances sets up a sharp vertical gradient in oxidation state of the sediments. This allows for a variety of microbially mediated oxidation-reduction reactions to occur in thin but distinct layers. For example, a vertical profile of activities in the sediment proceeds from photosynthesis at the surface to aerobic respiration in the upper, well-oxygenated layer, and then to various kinds of anaerobic respiration resulting in denitrification, metal reduction, sulfide and methane production, and other processes that create black, sulfurous sediments below the sediment surface.

Despite extensive studies, particularly in the last decade, very little is known about these microbial activities in the sediments of the San Francisco Estuary. In particular, production by benthic microalgae has been estimated only for limited areas of mudflat (Guarini et al. 2002). Benthic chemical processes and exchange with the overlying water column have been measured in only a few studies, most of them limited to South San Francisco Bay (e.g., Grenz et al. 2000).

A multibeam sonar image of sand wave formations on the bottom of the bay.



Microbial activity and deposition of organic matter in and on the surface of fine-grained sediments support a rich food web of infauna (organisms living in the sediment), epifauna (those living on the surface of the sediment), and demersal species (motile fish or macroinvertebrates associated with the sediment surface). The near-surface sediments, their microbial flora, and settled organic matter from the overlying water column support deposit feeders such as polychaete worms and some clams. Filter feeders use the sediment more for support than for food, obtaining particles or even dissolved organic matter from the overlying water column. Many of the macro-organisms produce burrows that irrigate deeper sediments,

Bat ray on sand.

altering the positions of the oxidation-reduction zones. Most benthic organisms have planktonic larval stages that drift in the water for days to weeks before settling to the bottom. Benthic production supports a variety of predators in the overlying water column. Predation can disrupt sediments and re-oxygenate near-surface sediments; in shallow waters, bat rays and some sharks and other fish disturb the bottom searching for food, leaving depressions in the sediment.

Invertebrates living in intertidal to subtidal mudflats support large numbers of shorebirds and diving ducks that feed during low tide. The shoals of San Francisco Bay are designated by the National Audubon Society as an Important Bird Area, a site that provides essential habitat for one or more species of birds; these shoals are particularly important to diving ducks.

To summarize, interactions between the water column and the sediment are strong. They occur through physical (settlement and resuspension), chemical (transport and transformation of byproducts of microbial activity), and biological processes (feeding and burrowing by benthic and water-column or demersal organisms, production and settlement of larvae).

Species Composition

As in most estuaries, the soft bottom harbors most of the San Francisco Estuary's benthic organisms (Schaeffer et al. 2007) but probably not most of its species.

Green sturgeon.

Benthic species composition is highly variable and depends on water depth, sediment grain size, and position along the estuarine salinity gradient. Most of the species of the soft-bottom benthos are introduced, and species composition is highly variable in time and space (Nichols and Thompson 1985). Species composition at any one location is largely determined by the overlapping distributions of the species in salinity space (Schaeffer et al. 2007, Figure 35 in Kimmerer 2004). Distributions of benthic organisms shift as the salt field moves in response to changing freshwater flow. For example, when the salt field moves landward during a dry period, a region that was once fresh becomes brackish. Freshwater organisms die or fail to settle in this region, and more salt-tolerant species, previously excluded by low salinity, begin to settle there. The reverse happens with an increase in freshwater flow. In both cases it can take months after the die-off of the initial group of organisms for the new group to settle and grow. During these periods, regions of the estuary are left depauperate (Nichols 1985).

The introduced overbite clam *Corbula amurensis* seems to be an exception to the above pattern, as it is found in all salinities from oceanic almost to freshwater, where its distribution overlaps with that of the introduced freshwater clam *Corbicula fluminea*. Filtration by these clams has an overwhelming influence on the plankton of the overlying water (Alpine and Cloern 1992, Thompson 2005, Lopez et al. 2006).

Harbor seal.

Benthic organisms support many demersal fish, including recreationally important species (e.g., California halibut, striped bass) and threatened species such as green sturgeon. Some demersal fish such as bat rays forage on mudflats at high tide. Numerous bird species forage in shallow soft substrate, including diving ducks (canvasback, greater and lesser scaup, surf scoter). The San Francisco Estuary is a key stop on the Pacific Flyway for ducks and shorebirds, which forage in salt ponds and intertidal mudflats (Warnock et al. 2002). Marine mammals forage on the bottom (gray whales) or consume demersal and pelagic fish (seals, sea lions).

Sediment Budgets

Gray whale.

Several attempts have been made to estimate sediment budgets for the estuary, summarized by Cohen (Appendix 2-1) and McKee et al. (2006). About 57% of the sediment load to San Francisco Bay comes from the Central Valley (McKee et al. 2006), the rest entering the bay from local watersheds and the ocean. Most of the sediment budgets have not distinguished among particle sizes, so determining budgets for subsets of the sediment pool (e.g., sand, or individual basins) will be difficult. In particular, sediment supply from the rivers is probably important to the sand budget only during high-flow years, and then only if bedload transport is included in the estimate. Schoellhamer et al. (2005) constructed a sediment budget and estimated the import of sand from the coastal ocean at about 5.5 million cubic meters per year, but more recent work shows that the sand sill outside the Golden Gate is probably of estuarine and watershed origin (P. Barnard, USGS, 2010, pers. comm.). Sediment deposits in the bay are replenished largely by the major rivers, with some sediment coming

A subtidal slough meanders through a mudflat.

A sand barge near the Port of San Francisco.

from the coastal ocean as well as local tributaries and erosion. The entire sedimentary system of the estuary and its watershed underwent a substantial alteration due to a large increase in sediment from hydraulic mining in the watershed in the late 1800s. The sediment budget for the estuary may still be out of equilibrium because of this historical modification (Jaffe et al. 2007, Hanes and Barnard 2007). The influx of sediment during hydraulic mining caused shoaling in much of the estuary, but much of the excess material has since eroded away.

The present sediment budget is uncertain, but erosion of mudflats and shoals is likely to continue because of reduced sediment supply due to water control structures, damming of rivers (Appendix 2-1, Wright and Schoellhamer 2004, McKee et al. 2006), and the loss of the large pool of sediment from hydraulic mining (Jaffe et al. 2007, Schoellhamer 2009). One result of decreased sediment supply is likely to be loss of mudflats, possibly accelerated by the capture of intertidal areas by the invasive hybrid cordgrass (Neira et al. 2006). In addition, the supply of sand from the rivers has been greatly reduced, and aggregate mining likely exceeds the supply rate, resulting in an ongoing loss of sand from the estuary.

Threats to Soft Substrates

Threats to the soft-bottom communities are numerous; although many are localized, their overall impacts may be large (see Figure 4-4). Dredging and dredge material disposal associated with shipping and boating disturb the bottom periodically in relatively small areas of the estuary. Wakes from ships and ferries can accelerate erosion of shoals. Construction in or adjacent to the estuary, for example, for bridges, piers, and harbors, causes short-term disruption. Permanently installed structures displace the benthic habitat and cause long-term alteration of patterns of sediment movement and deposition. All of these activities can disrupt the functions of the soft bottom by killing or removing organisms, mixing the sediments, and disrupting the layers of different oxidation conditions. More broadly, activities that alter sediment transport and deposition, current patterns, or salinity distributions can disrupt soft-bottom communities. Globally, the most pervasive harm to these communities arises from hypoxia due largely to eutrophication, which has not been an issue in this estuary for several decades (see Chapter 3, Water Column).

The Port of Oakland's Inner Harbor 50' deepening project.

Contaminants

Contamination by chemical substances is widespread in sediments in the estuary (e.g., Oros et al. 2007) with some areas identified as contaminant "hot spots." Contaminants are a particular issue for soft substrates for several reasons. First, many organic compounds and metals bind to fine-grained sediments and are available for transfer up the benthic food web. Second, contaminants (e.g., mercury, silver, DDT) can be stored in sediments long after their

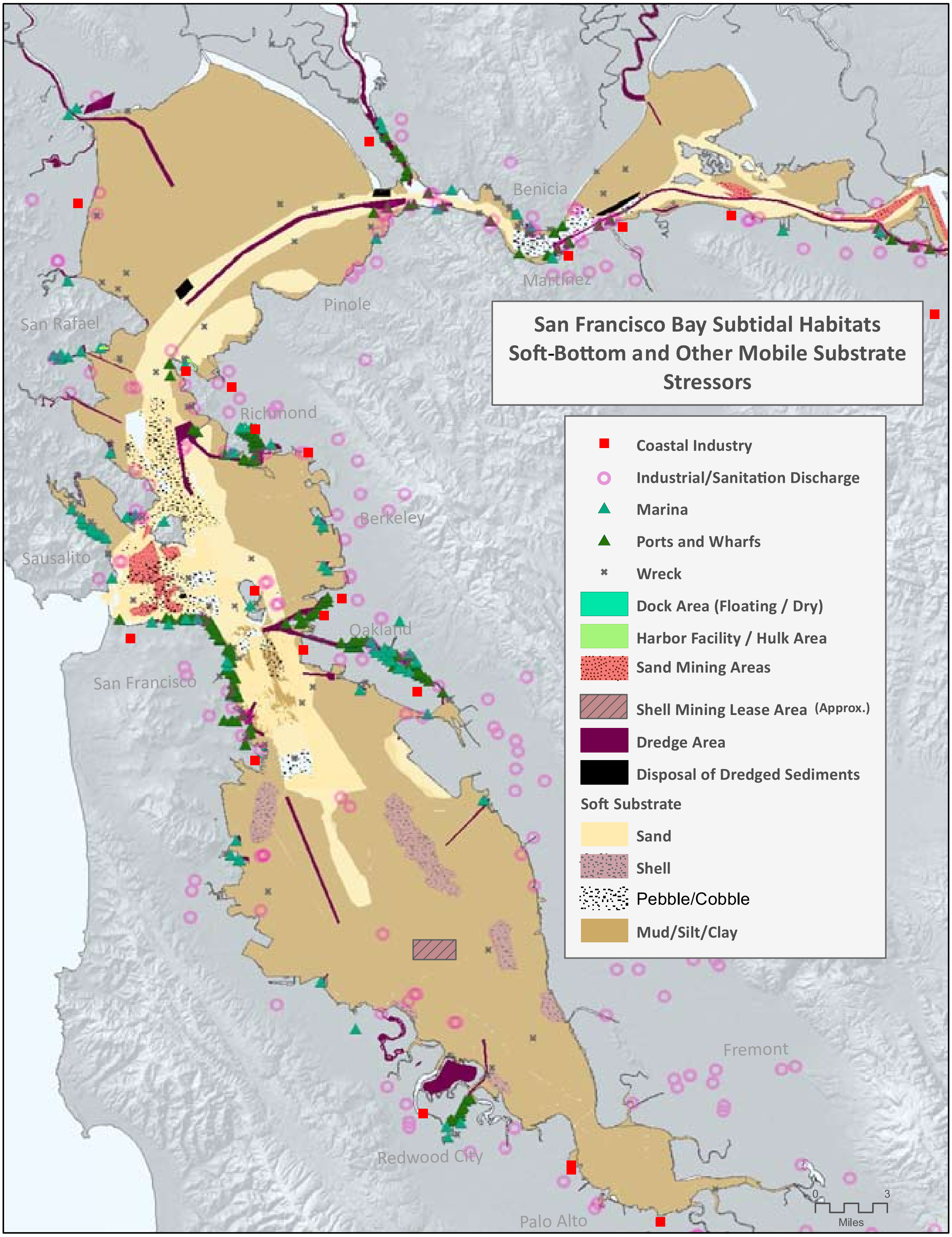


Figure 4-4: Locations of Soft-Bottom Habitat Stressors in San Francisco Bay.

inputs to the estuary have been stopped. Third, metals in the sediments can be reduced to soluble forms by microbial activity, increasing their bioavailability. Finally, the erosion in some areas due to sediment imbalance may be resuspending deeper sediments with their contaminant loads into the water column, making the contaminants available to the food web. Chemical contamination can significantly disrupt survival, fitness, or reproductive success of various organisms including fish (Ostrach et al. 2008) and birds (Takekawa et al. 2002, Ackerman et al. 2008). In addition, sediment-bound contaminants such as mercury, PCBs, and organic compounds can be concentrated in the food web, resulting in concentrations in fish that prompt warnings to limit consumption by humans. Contamination identified in testing can limit the utility of dredged material for wetland restoration and other purposes. Emerging contaminants such as endocrine disruptors may have ecological effects although the importance of sediments as reservoirs for these contaminants is less clear than for the other substances mentioned above.

Benthic Disruption/Removal

Mining for sand occurs under several leases in the Central Bay, and Suisun Bay (Hanson et al. 2004). During March 2002–February 2003 about 1.3 million cubic meters was mined, mostly from the Central Bay (Hanson et al. 2004). The relationship of this volume of sand to either the extant quantity of sand or the sand supply rate is being investigated (P. Barnard, USGS, 2009, pers. comm.). There is evidence of net loss of 14 million cubic yards of sand between 1997 and 2008 in lease areas in Central Bay (P. Barnard, USGS, 2009, pers. comm.). Potential environmental effects of sand mining were reviewed by Hanson et al. (2004). These include entrainment of water column and benthic organisms in the dredge suction, impacts associated with the sediment plumes, and removal of benthic habitat. Entrainment of water column organisms probably has a

Maintenance dredging at the Port of Richmond.

Intertidal and subtidal mudflats support many resident and migrant shorebirds.

Invasive cordgrass threatens mudflats.

minor impact because of its small scale. The volume of water ingested by the sand dredges is around three to four times the volume of the sand mined (Hanson et al. 2004), which amounts to about 0.1% annually of the volumes of the estuarine basins where sand mining occurs. Sediment plumes are unlikely to have lasting effects given the high background turbidity; dredging plumes were found to have only a localized effect (Schoellhamer 2002). The scale of the loss of benthic organisms is unknown mainly because their abundance in sandy areas is unknown. Since the lease areas are well-delineated, a comparative study between lease and non-lease areas could be conducted to help resolve whether substantial resources are being lost through sand mining.

Areas of shell hash, particularly in the South Bay, have also been mined for industrial uses of the shell, leaving large depressions that are clearly visible on sonar records. The impact of current and historical mining on the amount of shell deposits and on benthic biota is unknown; however, historic mining has resulted in changes to bathymetry (Jan Thompson, USGS, 2009, pers. comm.).

Rationale for Establishing Goals for Soft Substrates

The approach outlined in Chapter 2 leads to the conclusion that soft-bottom habitats are perhaps threatened by decreasing sediment supply, locally by the effects of dredging and sand mining, and by various contaminants. However, since there is no real opportunity for increasing the quantity of these habitats, the best we can do is to improve their quality and manage them properly.

The soft-bottom habitats that are of principal concern, in terms of persistence and maintenance, are intertidal and subtidal mudflats, which are threatened by erosion and encroachment of cordgrass. The term “mudflat” is used below to include both subtidal and intertidal areas. Loss of mudflats will likely be accelerated by sea level rise if the rate of rise exceeds the rate of sediment accumulation or wave action increases because of hardened shorelines. Increases in ferry travel on the bay would increase erosion along soft shorelines due to wakes. There is no obvious mechanism for protecting mudflats, so some consideration might be given either to establishing buffer zones or other methods to minimize the impact of wakes in important mudflats, or to manipulating sediments to encourage growth and maintenance of mudflats.

The ecological benefits of mudflats in the estuary have not been quantified, although large numbers of birds are observed to forage there. The relationship between quantity of mudflat and the numbers or distribution of various bird species, and use of the mudflats by other groups of organisms, would need to be determined to support informed choices about protection of these areas. A better understanding of both the function of sand habitats and the effect of sand mining on subtidal or intertidal habitats is needed to better manage sand habitat in the bay.

Goals for soft sediment habitats focus on protection, including reducing effects of contaminants and bottom disturbance, preventing loss of mudflats and beaches, and improving our understanding of ecosystem services and threats to this habitat as well as our ability to protect it. Other goals and objectives are intended to reduce impacts from existing known contaminants, so that they are not contributing to bioaccumulation in fish, birds, or mammals. Intertidal mudflats and sand beaches are of particular concern because of their habitat value for various fish and birds, and because of long-term threats to their existence. Protection goals should not limit creation of other desirable habitats (e.g., eelgrass beds, native oyster beds) within existing soft sediment habitats. As soft bottom sediments are by far the most abundant subtidal habitat type in San Francisco Bay, conversion to eelgrass or shellfish beds at appropriate sites is encouraged.

Science Goals for Soft Substrates

SOFT SUBSTRATE SCIENCE GOAL 1

Understand the extent of ecosystem services provided by soft-bottom habitats.

Question A. How important are mudflats in the life cycles of birds and other organisms that use them?

What would be the impact on the bird or fish populations of a substantial loss of mudflats? At present, bird populations may be limited by conditions in remote locations, but if the local habitat shrinks and alternatives are not available, mudflat area could become the chief limiting factor to bird populations. Alternatively, birds and fish may simply forage elsewhere.

Question B. What is the distribution of various sediments by size and depth throughout the estuary?

A better set of sediment maps for the parts of the estuary not already thoroughly surveyed would help to assess conditions and define actions. These maps would have to be updated periodically to account for erosion and deposition.

Question C. What is the overall sediment budget for the estuary and its major basins, and the relationship of sand removal to sand supplies?

A better grasp of the estuarine sediment budget would be useful both for projecting long-term changes in sediment distributions and for placing sand mining in context. An understanding of the sand budget for mining lease areas is essential for effectively managing the mining activities.

Question D. What is the spatial extent of shell deposits and what services do they provide?

There is no information on the importance of shell deposits as habitat, and little information on their spatial extent.

Shorebirds feed on intertidal and subtidal mudflats.

Question E. What is the ecological value of intertidal and subtidal sand deposits?

These deposits are important in beach formation, but their ecological value is poorly known.

Question F. What are the species composition of the benthos, key functions occurring in the soft sediment, and ecosystem services supported by soft sediment?

This applies to all depths and grain sizes. Although much of the emphasis for management is on sand mining areas and mudflats, the deep soft-bottom habitat comprises much of the estuary's area and is therefore likely to be far more important in supporting ecosystem services than other habitat types that occupy small areas.

SOFT SUBSTRATE SCIENCE GOAL 2

Understand the threats to mudflats and other soft-bottom habitats.

Question A. How are individual mudflats changing over time, and what is causing them to change?

To predict the fate of individual mudflats requires knowledge of sediment budgets at basin and sub-basin scales, and also the short-term, local processes of deposition and wind- and current-driven resuspension. Encroachment of cordgrass and restoration of salt ponds are both localized and quantifiable, and determining their influence on mudflats should therefore be tractable. Furthermore, local vertical movement due to seismic activity may alter sea level relative to the elevation of mudflats. A long-term monitoring program of rates of change in area and elevation of mudflats would be valuable.

Question B. How and why do mudflats differ regionally in their support of species such as shorebirds and bottom-feeding fish?

A decline in extent of mudflats in one region may result in a behavioral shift of these species to other regions, but only if other conditions are suitable.

Therefore, knowing the use of different regions and the underlying motivations behind those specific uses would help in understanding the likely responses to changes in mudflat extent.

Question C. Is it feasible to construct simulation models of the formation and erosion of mudflats?

Improved hydrodynamic models of the estuary provide useful predictions of conditions under alternative scenarios of inflow, bathymetry, and sea level. However, modeling sediments is considerably more difficult than modeling the movement of water. Modeling scenarios may be feasible, but predictive modeling seems beyond our current reach because of the difficulties in estimating coefficients for deposition and erosion.

Question D. What are the broad-scale impacts of sand and shell mining and dredging on sediments and on estuarine biota?

Management of these habitats requires knowledge of local and estuary-wide impacts to gauge the cumulative impacts of sand and shell mining, including the effects of persistent borrow pits left after removal of material, and the contributions of individual mining leases to these impacts.

Question E. What is the recovery time of the benthos from disturbance?

This information is essential for answering the previous question. Most impact assessments focus only on the immediate impact, but disturbances could persist.

Sand beaches and offshore sand shoals provide roosting habitat for birds.

SOFT SUBSTRATE SCIENCE GOAL 3

Determine suitable methods for protecting mudflats and beaches.

Question A. What methods are available for protecting mudflats and beaches, and how effective are they?

An initial review of the available information on engineering long-term solutions to mudflat and sand beach loss should be the first step in answering this question. Depending on the results of such a review, experimental manipulations might be considered to test alternative approaches using adaptive management over the long term.

Question B. How do mudflats in different parts of the estuary differ in their sensitivity to change, and in their support of the ecosystem services that are at risk?

If ways to protect mudflats are available, it is essential to determine which mudflats provide the most support for desired ecosystem services, which are at high risk of loss or degradation because of changing sea level, erosion, or other threats, and which can be protected most effectively.

SOFT SUBSTRATE SCIENCE GOAL 4

Understand the magnitude of the ecological risks posed by contaminants bound to the sediments.

Question A. What are the distributions and concentration of various contaminants in estuarine sediments?

Contaminant concentrations are an important consideration for management of sediments in the estuary. Decisions about dredging, dredge disposal, and removal of artificial habitat, which may disturb sediment-bound contaminants, must be made with knowledge about the contaminants likely to be released. However, developing maps of the distributions of contaminants may not be cost-effective beyond what is already being done by the Regional Monitoring Program. Individual contaminant measurements are expensive, and distributions can be very heterogeneous spatially, and temporally variable as sediments move around. Therefore, site-specific investigations may be more cost-effective than attempting to develop general maps of contaminant distributions.

Question B. What ecological risks (distinct from risks to human health) do these contaminants pose?

Mercury and selenium from the environment have been shown to impair the health of organisms in higher trophic levels such as birds and some fish. However, knowledge of the risks of some other contaminants, and particularly multiple contaminants, is not well developed. As with questions about distribution, answers to this question may be more specific to certain locations and contaminants, rather than broad and general.

Protection Goals for Soft Substrates

SOFT SUBSTRATE PROTECTION GOAL 1

Consider the potential ecological effects of contaminated sediments when developing, planning, designing, and constructing restoration projects or other projects that disturb sediments.

- Soft Substrate Protection Objective 1-1: Identify and prioritize ecological risks associated with contaminated sediments in the estuary.

  Soft Substrate Protection Action 1-1-1: Work with the appropriate agencies to identify and prioritize ecological risks associated with contaminated sediments and locations where priority risks occur within the estuary.

  Soft Substrate Protection Action 1-1-2: Work with the appropriate agencies to develop a sampling protocol to assist interested parties in delineating the extent of contaminated sediments that may pose an ecological risk at non-dredging sites.

- Soft Substrate Protection Objective 1-2: Develop an effective solution to address contaminated sediments that are determined to pose an ecological risk.

  Soft Substrate Protection Action 1-2-1: Collaborate with the appropriate agencies to develop a simplified regulatory process for voluntary cleanups.

  Soft Substrate Protection Action 1-2-2: Develop funding sources to support delineation of contamination, planning, and contaminant removal.

  Soft Substrate Protection Action 1-2-3: Provide funding for and development of regional multi-user rehandling and disposal facilities for contaminated bay sediments.

- Soft Substrate Protection Objective 1-3: Work collaboratively on monitoring and prioritizing emerging contaminants of concern and relevant protocols and policies that may impact bay sediments, and restoration or other projects.

  Soft Substrate Protection Action 1-3-1: Promote discussion of emergent contaminants affecting soft substrates and research needs at existing annual or semiannual forums including the State of the Estuary conference, Dredge Material Management Office's annual meeting, and Regional Monitoring Program annual meeting.

  Soft Substrate Protection Action 1-3-2: Develop stable funding sources to continue the joint NOAA/State Water Resources Control Board mussel watch data collection and early detection of emerging pollutants pilot project.

SOFT SUBSTRATE PROTECTION GOAL 2

Promote no net increase in disturbance to San Francisco Bay soft bottom habitat.

- Soft Substrate Protection Objective 2-1: Minimize bottom disturbance in the bay.

  Soft Substrate Protection Action 2-1-1: For new construction projects, encourage placement in appropriate areas, such as areas of low sedimentation.

  Soft Substrate Protection Action 2-1-2: For projects involving reconfigurations of existing structures, encourage placement of project components in a way that avoids or minimizes the need for dredging.

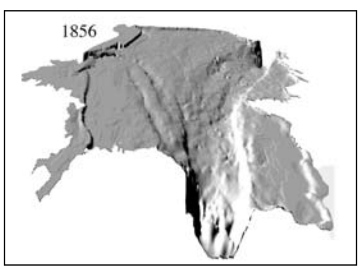
- Soft Substrate Protection Objective 2-2: Minimize placement of structures in subtidal and intertidal soft bottom habitats of the bay. (See Artificial Structures, Chapter 6, and discussion of how to minimize impacts from restoration and living shoreline projects in Chapters 3, 7, and 8).

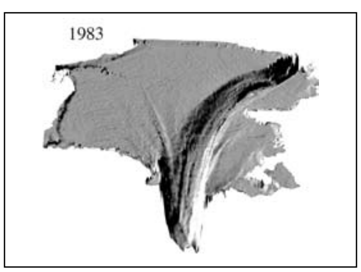
SOFT SUBSTRATE PROTECTION GOAL 3

Promote no net loss of San Francisco Bay subtidal and intertidal sand habitats.

- Soft Substrate Protection Objective 3-1: Continue the efforts of the interagency sand mining working group to encourage harvests of sand at levels replenished through natural processes.

SOFT SUBSTRATE PROTECTION GOAL 4





Three-dimensional images show long-term changes in the soft bottom of San Pablo Bay.

Develop a coordinated, collaborative approach for regional sediment management for San Francisco Bay.

- Soft Substrate Protection Objective 4-1: Promote riparian restoration techniques that provide for sediment storage capacity in stream and wetland systems while allowing for excess sediment to be transported to the bay through natural hydrogeomorphic processes.

- Soft Substrate Protection Objective 4-2: Develop and promote flood control methods, including floodplain restoration, that nourish marshes from the watershed.

- Soft Substrate Protection Objective 4-3: Promote beneficial reuse of suitable dredged sediment in habitat restoration/beach nourishment projects.

  Soft Substrate Protection Action 4-3-1: Determine storage and stockpile locations for dredged sand for later beneficial reuse. Develop restoration projects that are in close proximity to dredging projects.

Soft Substrate Protection Action 4-3-2: Identify funding sources and facilitate transport of mud and sandy material from maintenance dredging projects to areas needing sediment, including in areas using the Reef Ball© technique associated with native oyster and living shoreline restoration (see Chapters 7, 10).

Restoration Goals for Soft Substrates

In developing restoration goals for sand beaches, existing efforts to increase sand beach protection and restoration, including those described in "Prospects for San Francisco Bay Beach Expansion" (Baye 2007, unpublished) were considered.

SOFT SUBSTRATE RESTORATION GOAL 1

Encourage the application of sustainable techniques in sand habitat replenishment or restoration projects.

- Soft Substrate Restoration Objective 1-1: Promote sand beach creation, restoration, and replenishment projects that use clean, maintenance-dredged sand where possible and in areas where sand is deposited, such as at the river delta interface. See Figure 4-5.
- Soft Substrate Restoration Objective 1-2: Consider incorporating living shoreline techniques to retain sand, either from natural deposition or from sand replenishment.

Sand Replenishment Project Examples	Project Contact
Crown Beach in Alameda	**East Bay Regional Park District**
Vincent Park in Richmond	**Bob Battalio, PWA**
Pier 94 Sand Nourishment Project	**Roger Leventhal, FarWest Restoration Engineering**

POTENTIAL SAND BEACH CREATION, RESTORATION, AND REPLENISHMENT SITES

- Eastshore State Park, including Albany Beach
- Pt. Isabelle Regional Shoreline, Albany and Richmond
- Pt. Pinole Regional Shoreline, Pinole
- San Rafael shoreline
- San Leandro Regional Shoreline
- Hayward Regional Shoreline
- San Francisco southeastern shoreline
- Coyote Point

SOFT SUBSTRATE RESTORATION GOAL 2

Encourage removal of artificial structures that have negative impacts on soft bottom habitat function. (See Artificial Structures, Chapter 6).

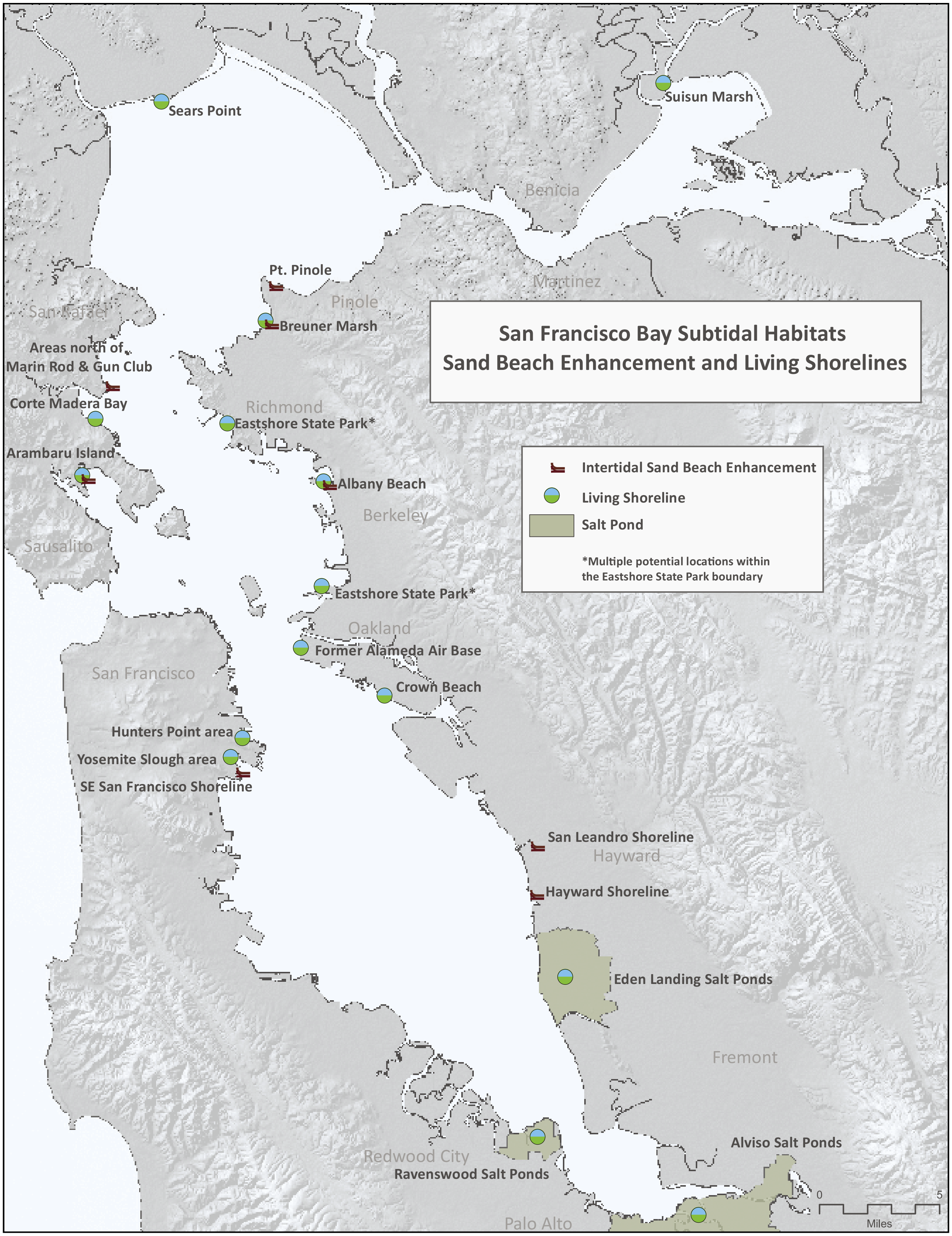


Figure 4-5: Suggested locations for pilot intertidal sand beach enhancement and living shorelines.

CHAPTER FIVE

Rock Habitats

RELATIVELY LITTLE HARD SUBSTRATE occurs naturally in the estuary, owing mainly to the vast quantities of fine sediment that have been deposited by the rivers. Rock habitat is one class of hard substrate, the other being artificial structures (Chapter 6). Rock habitat in this chapter encompasses boulders to bedrock; that is, rock that is not normally moved by currents.

Rock habitat occurs mainly as scoured low-relief bedrock in the deep, narrow channels where the estuary passes through the Coast Range and as bedrock outcrops and boulders in the areas of the Central Bay where currents are strong. Many rock outcrops, especially those near the entrance to San Francisco Bay, have been lowered by blasting to reduce the hazards they present to ships, and they may be lowered further as ships with greater draft are built (Sea Surveyor 2000). See Figure 5-1. Some rock outcrops are flat-topped and are surrounded by boulder fields, presumably a result of previous blasting (Garcia and Associates 2001, Chin et al. 2004).

A kayaker navigates over rocky subtidal habitat.

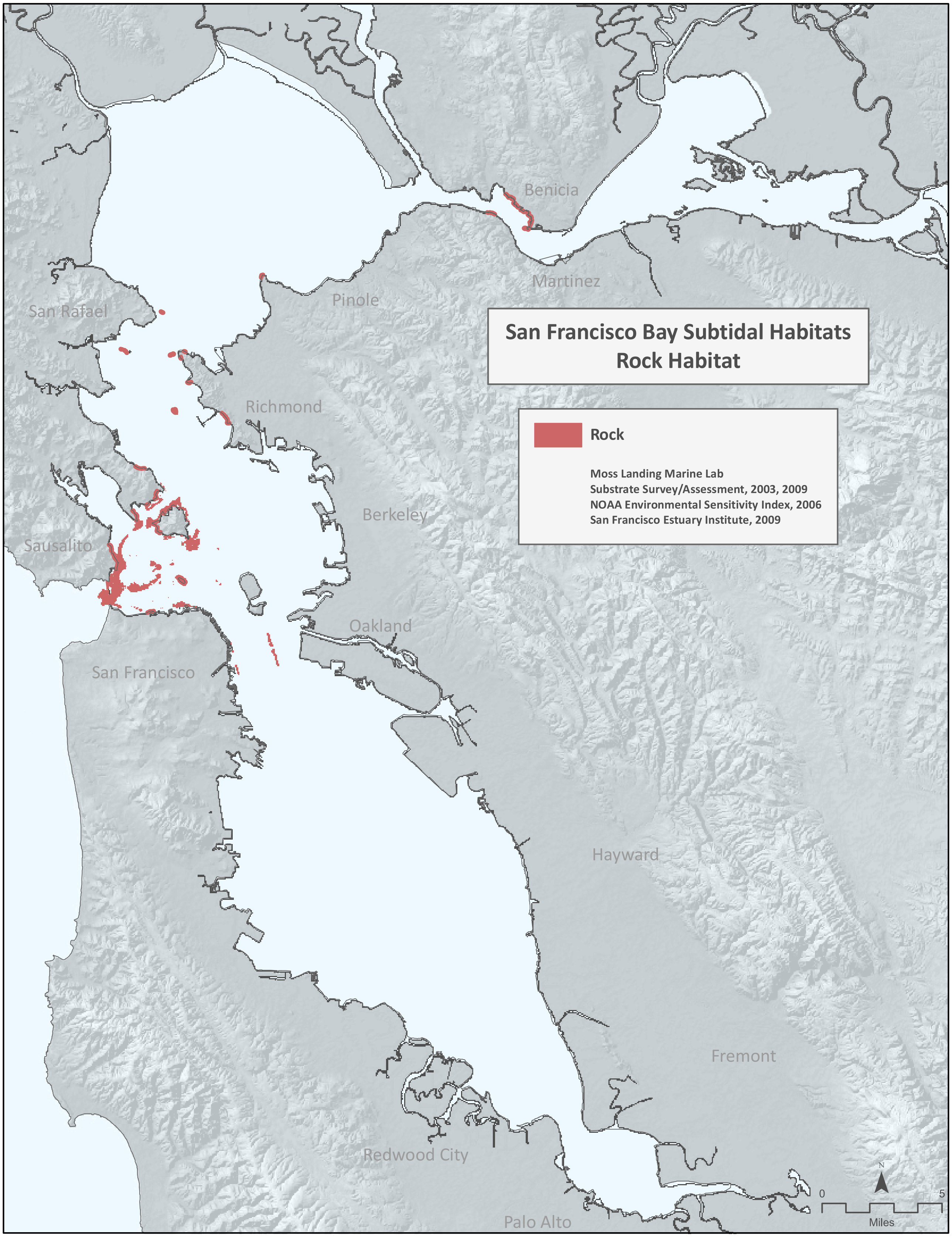


Figure 5-1: Distribution of Rock Habitats in San Francisco Bay.

West Marin Island in the Marin Islands National Wildlife Refuge provides critical nesting area for egrets and herons.

Conceptual Model for Rock Habitats

Rock substrates alter flow fields, distorting patterns of sedimentation and altering surrounding soft-bottom habitat (Appendix 2-2; Figures 5-1 and 5-2). Once a bacterial film has been established, submerged rock can be colonized by a variety of organisms. These organisms include attached algae and animals such as sponges, bryozoans, tunicates, hydrozoans, anemones, barnacles, mussels, and oysters. Numerous other invertebrate animals (for example, amphipods, isopods, crabs) and fishes (for example, prickly sculpin, rockfish) reside on, under, or near areas of hard substrate, using rocky habitats for protection or food supply.

Some fish species such as rockfish use alterations in the tidal flow field caused by irregularities of bottom topography, including rocky substrate, to their advantage in feeding. Some fish (for example, sculpin) reside among hard substrate features, and their association with these features may be obligatory or opportunistic. Some species, notably Pacific herring but also some invertebrates, use rock and other hard substrate as well as attached vegetation for spawning. Other fish and invertebrates found around hard substrates, for

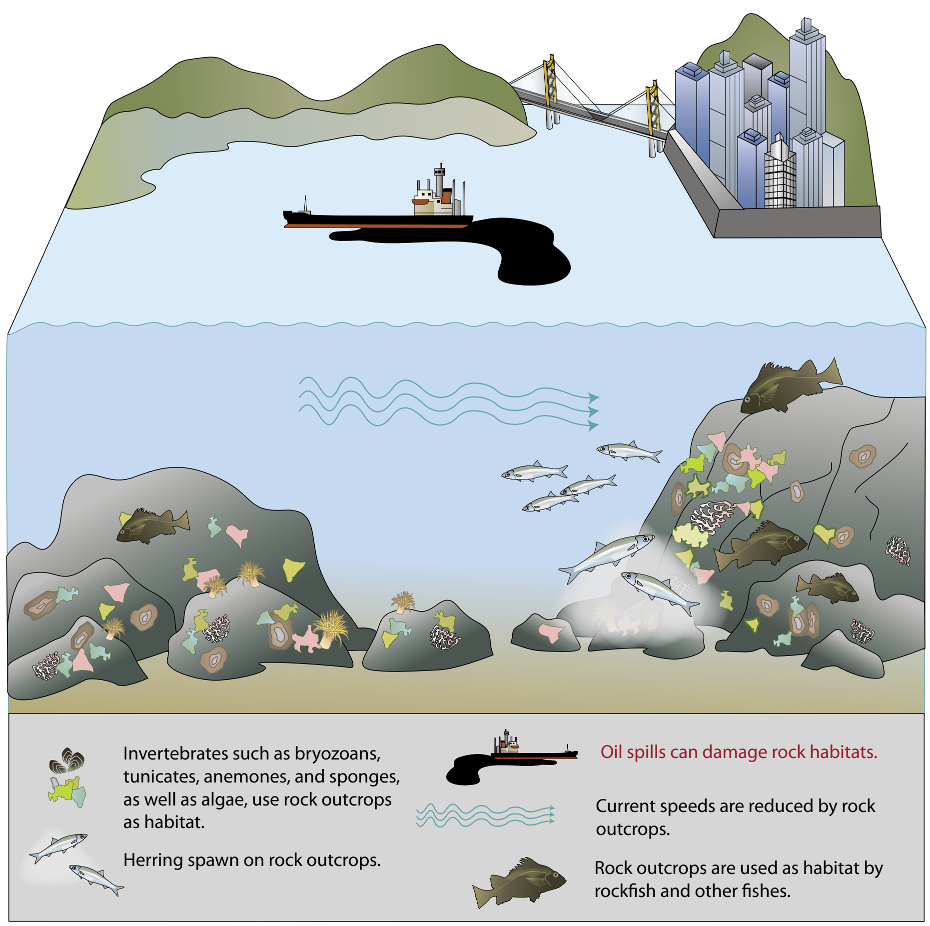


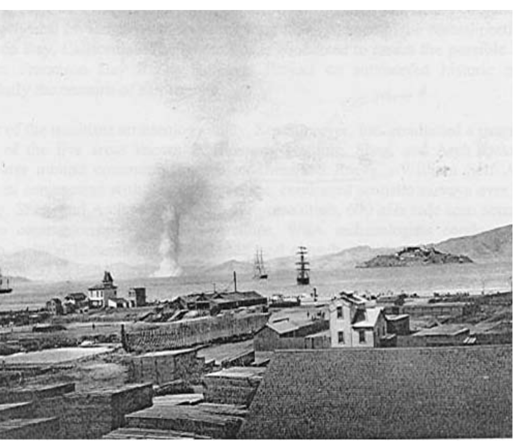
Figure 5-2: Conceptual diagram for rock habitat in the San Francisco Estuary. This diagram displays key processes that occur in and on rock, and some of the ecosystem services these substrates may provide.

Seals rest on rocks at the Brothers Islands near Point Molate in Richmond.

example, pelagic fishes such as anchovy, are equally abundant elsewhere. Birds use exposed sections of hard substrate for resting and nesting, and seals and sea lions also rest on them at low tide.

Because most rock outcrops occur in saline water within a tidal excursion of the Golden Gate, species composition of the flora and fauna should be similar to those on other extensive rocky subtidal habitats along the Central California coast. Detailed species composition of animals has not been determined for bay rock outcrops although video and photographs taken from a remotely operated vehicle (ROV) identified several species also found commonly outside the bay (Garcia and Associates 2001). The bay outcrops were covered with a "turf" of sessile organisms including bryozoans, tunicates, anemones, and sponges. Rocky shores are confined to a few areas near the Golden Gate, and may also harbor organisms found in similar sites on the outer coast.

A total of 162 species of attached algae have been reported from surveys within the estuary, most attached to hard substrate; of these, most were species also found on the open coast. Thirty-three species classified as estuarine were found mostly on artificial substrate (Josselyn and West 1985).



Historic photo of rock blasting to remove navigational hazards inside the Golden Gate.

Threats to Rock Habitats

Blasting to remove or deepen outcrops for safety of navigation is a significant threat to rocky habitats. Potential threats also exist from sediment deposition and, for intertidal rock, oil spills and trampling by humans. Colonization by invasive species is also a threat to these habitats. See Figure 5-3, and Chapter 3.

Rationale for Establishing Goals for Rock Habitats

Applying the approach outlined in Chapter 2 (Figure 2-1), it is clear that rock habitats support valued ecosystem services and are in short supply in the estuary (Figure 5-3). However, restoration of rock habitat in the sense of providing more of it seems impracticable. This directs our attention to protection and maintenance rather than restoration. There are restoration methods directed at the biota associated with rock habitat but those are primarily discussed in the shellfish, macroalgal, and living shoreline sections.

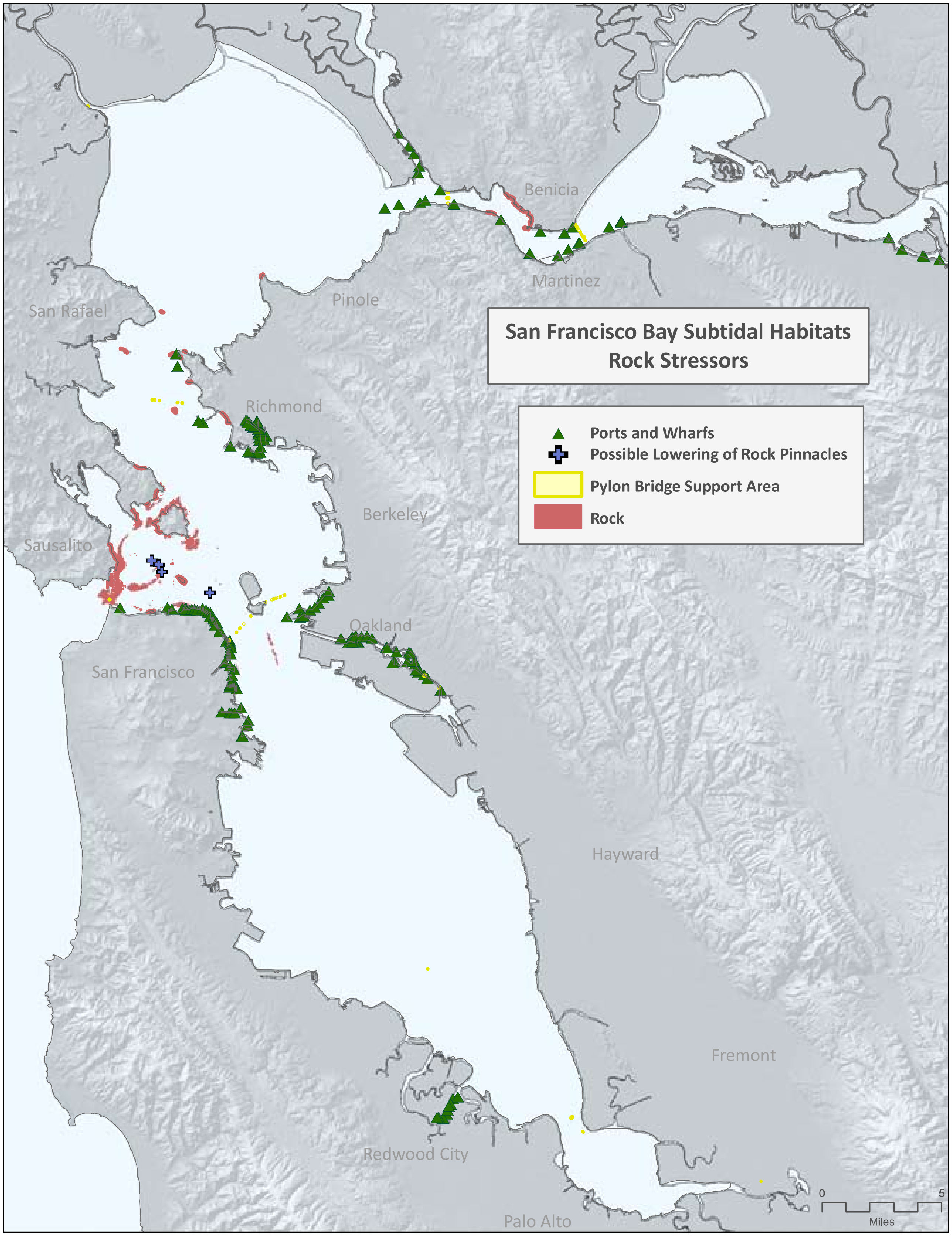


Figure 5-3: Locations of Rock Habitat Stressors in San Francisco Bay.

The increase in size and draft of vessels using San Francisco Bay could require further deepening of the channels and blasting of the rock outcrops (Carlson et al. 2000) to provide safe navigation. It would be useful to know which species are using these habitats to assess the environmental impacts of any proposed blasting. In the interim while waiting for the data based on the research questions, our recommendation is to protect these rock outcrops as much as possible.

Goals for rock habitat focus on protecting existing intertidal and subtidal rock from being removed for vessel traffic and damaged by public access; on enhancing this habitat by removing invasive species and debris; and on improving our understanding of the ecosystem services this habitat provides and the species that utilize rock habitats.

Science Goals for Rock Habitats

ROCK HABITATS SCIENCE GOAL 1

Understand the ecosystem services provided by rock habitats and the species dependent on them.

Question A. What lives on the rock outcrops, and in what abundance?

Without knowing what is there, it is difficult to say what would be lost by further deepening of the outcrops. By knowing which species are present and how abundant they are it should be possible to estimate the relative value of these habitats. In particular, the presence of or potential for re-establishing endangered, special-status, or important fishery or forage species known to associate with rock outcrops should be determined.

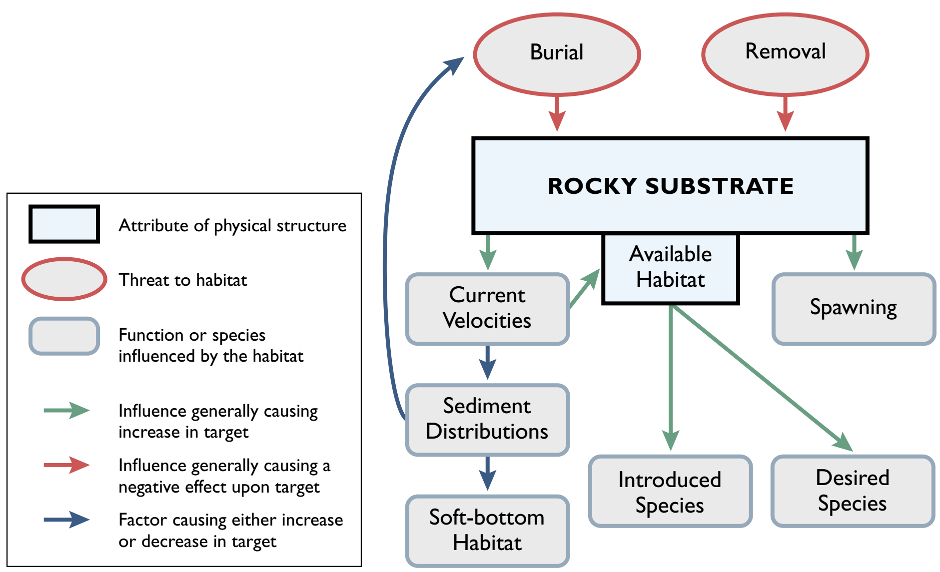


Figure 5-4: Influences on rocky habitat, and functions and services provided by submerged rock. "Available habitat" refers to rocky substrate that provides habitat for one or more species.

Above: Rocky intertidal shoreline extends to rocky subtidal habitat. Rocky intertidal shoreline provides habitat space for seaweeds, oysters, and other invertebrates.

Question B. What lives on rocky shores, and in what abundance?

Although these sites are much more visible (and visited) than rock outcrops, little information on species composition has been published. Such information would help us understand what can be gained by protecting these habitats.

ROCK HABITATS SCIENCE GOAL 2

Understand the ecosystem services provided by restored rock habitats.

Question A. What are the ecological consequences or benefits of using quarried rock in restoration?

Quarried rock may be used for restoration and shoreline protection as sea level rises. It is important to understand how rock habitat placed through restoration actions functions relative to existing, natural rock habitats.

Protection Goals for Rock Habitats

ROCK HABITATS PROTECTION GOAL 1

Promote no net loss of natural intertidal and subtidal rock habitats in San Francisco Bay.

- Rock Habitats Protection Objective 1-1: Promote preservation of natural rock habitats in the bay by minimizing removal or lowering of rock pinnacles and outcrops.
- Rock Habitats Protection Objective 1-2: Provide access to natural rock habitats in the bay that encourages appreciation of the habitat and its inhabitants while protecting it from human trampling. See additional actions under Chapter 3, Public Access and Awareness section.

Restoration Goals for Rock Habitats

ROCK HABITATS RESTORATION GOAL 1

Restore and maintain natural intertidal and subtidal rock habitats in San Francisco Bay.

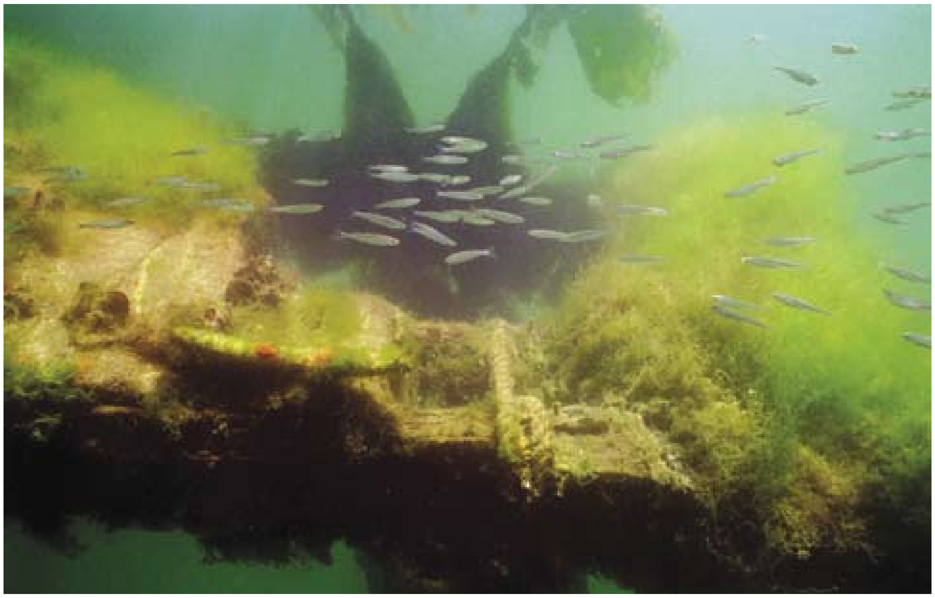
- Rock Habitats Restoration Objective 1-1: Remove invasive species from San Francisco Bay that may impact rocky intertidal habitats (see Chapter 3, Invasive Species section, *Undaria* and *Ascophyllum)*.
- Rock Habitats Restoration Objective 1-2: Provide funding and programs to clean up and prevent debris and derelict equipment at boating facilities (such as installing fishing line recycling stations) and upland sites adjacent to or within rock habitat. (See Chapter 3, Marine Debris*)*.
- Rock Habitats Restoration Objective 1-3: Incorporate living shoreline techniques to enhance the function of existing natural rock (see Chapter 10, Living Shoreline section).

Ochre star in the rocky intertidal zone.

CHAPTER SIX

Artificial Structures

ARTIFICIAL STRUCTURES ARE FOUND throughout the estuary and therefore are exposed to the full range of estuarine conditions, in particular to all salinities. Artificial structures include a wide variety of human-built objects, mainly associated with development, and discarded objects (Figure 6-1). Artificial structures were built to protect shorelines and shoreline structures (seawalls, jetties, revetments), for transportation (bridge and pier pilings, wharfs, moorings, wrecks, derelict vessels, the reserve or "mothball" fleet in Suisun Bay) and recreation (fishing piers, boat ramps, marinas, duck blinds), to support industry (shore-side buildings, water intakes or outfalls, transmission towers, pipelines, cables), and more recently for restoration (oyster shell and artificial reef structures). Artificial structures (Figure 6-2) are similar to rocky habitats in that they alter local wave and current patterns and provide physical habitat for a variety of species. However, artificial structures differ from rocky habitats in their spatial distribution in the estuary, and contain structural features that do not occur on rock outcrops. Thus, the fish and invertebrate assemblages on natural rocks may differ from those on artificial substrates.



Sunken marine debris encrusted with algae and invertebrates provides artificial habitat for fish.

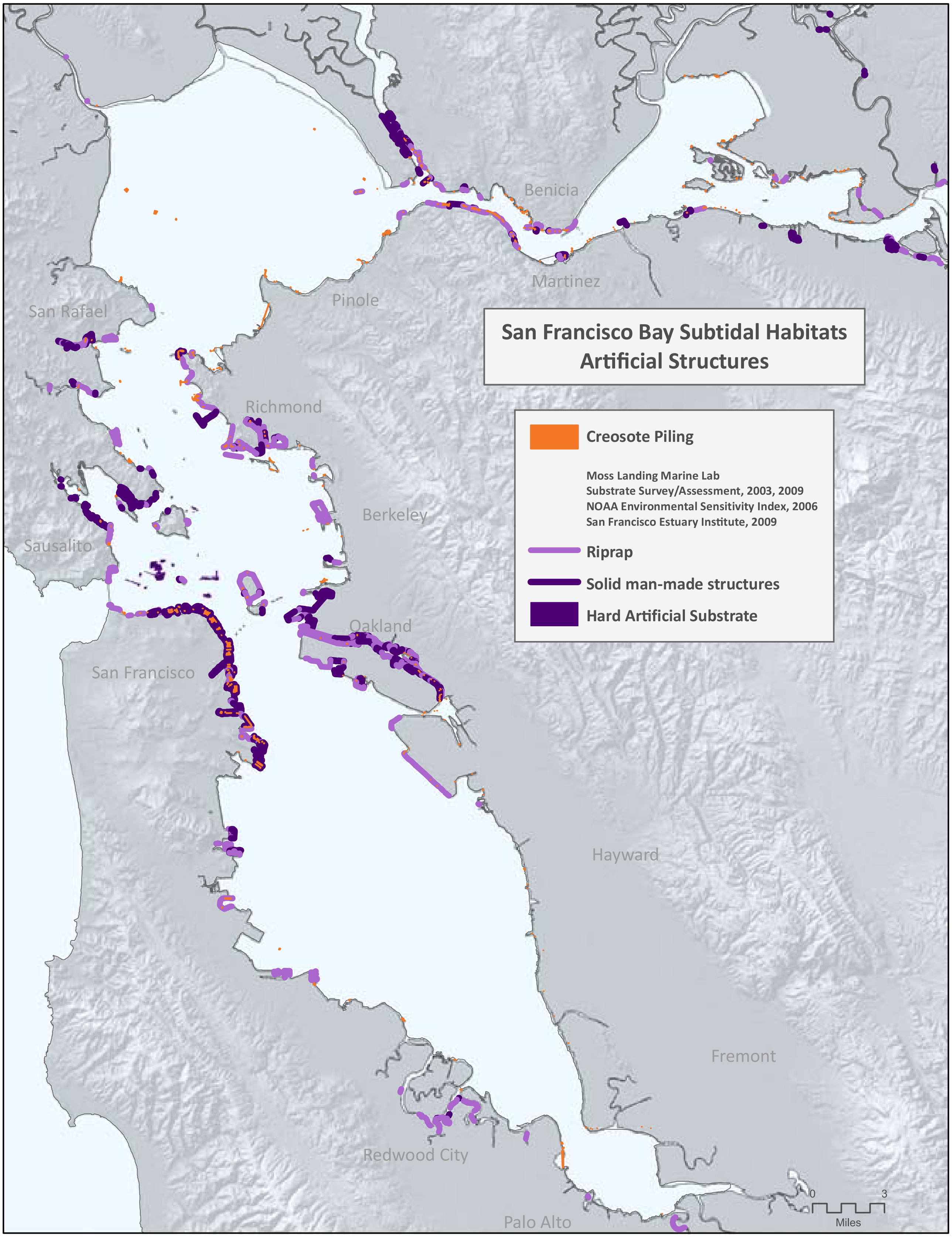


Figure 6-1: Distribution of Artificial Structures in San Francisco Bay.

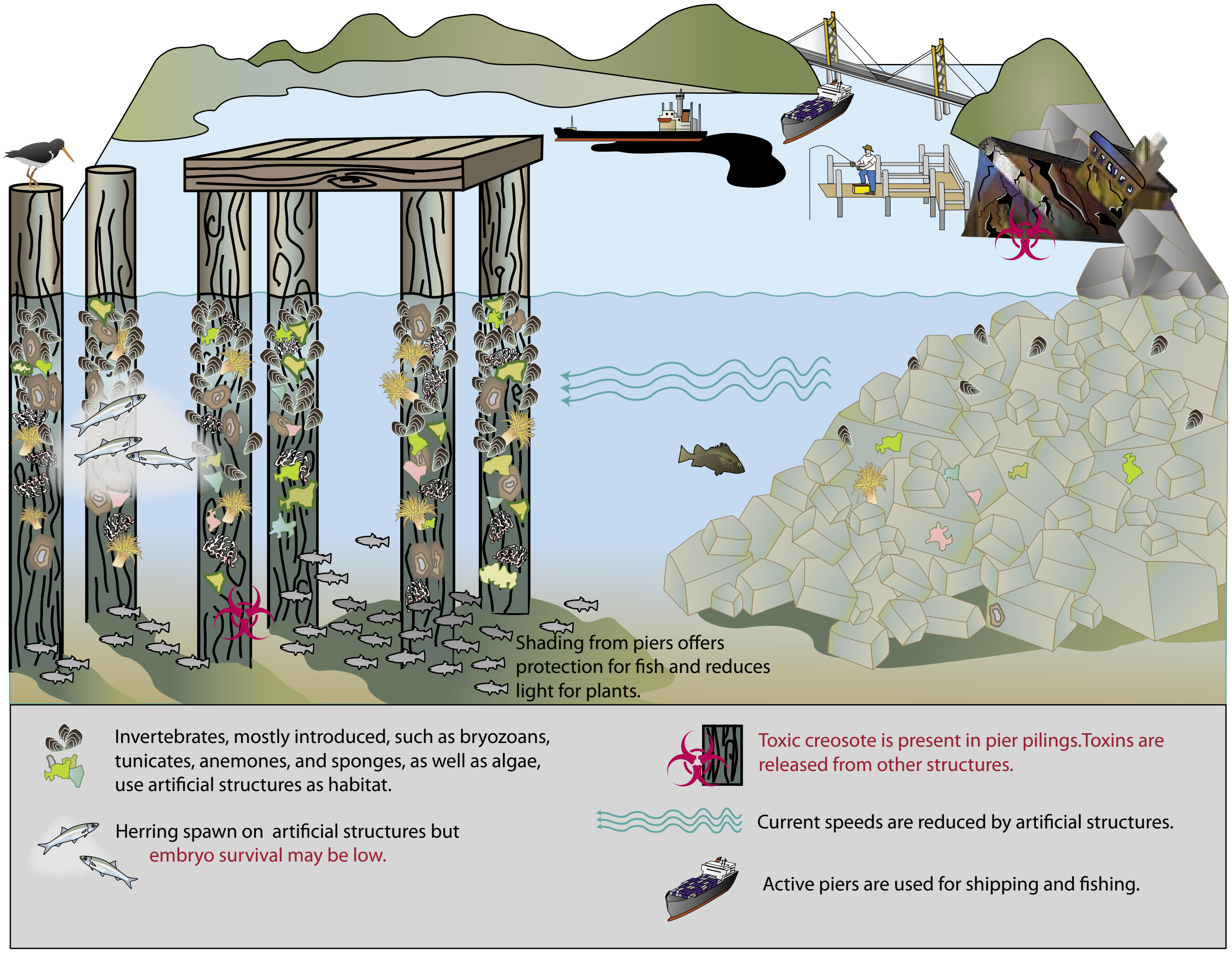


Figure 6-2: Conceptual diagram for artificial structures in the San Francisco Estuary. This diagram displays processes that occur in and on artificial substrates.

The potential removal of abandoned structures for aesthetic or practical reasons is of particular interest. Although artificial substrates function as habitat for many organisms such as herring, some substrates are potentially toxic. The removal of structures offers an opportunity for adaptive management, serving to answer questions about how structures in general affect the habitat and how this effect varies with structural material, size, shape, and location. On the other hand, the value of artificial structures as habitat may exceed the advantages of removing them, as discussed below.

Conceptual Model for Artificial Structures

Like rocky substrates, artificial structures alter wave patterns and flow fields, induce local scouring and deposition of sediment, and provide physical habitat (Appendix 2-2; Figures 6-2 and 6-3). Sessile organisms such as mussels and oysters use both habitats for attachment, and artificial structures provide refuge and foraging areas for various organisms including fish, resting and nesting sites for birds, and haulouts for seals and sea lions.

However, these two habitat types differ in their distribution within the estuary. For example, some artificial structures such as rock jetties and revetments (riprap) may provide habitat resembling natural rock but were installed in locations that would not naturally have much rock. Since hard substrate is naturally in short supply in fresh to brackish regions of the estuary, it is likely that few native species in these regions are obligate users of hard substrate. Rather, most of the organisms found on artificial structures are not native to the estuary (Appendix 2-2). In addition, the placement of artificial substrates can differ from that of rock outcrops. Artificial structures may be isolated from the shore or the bottom or continuously exposed to surface conditions, and can shade the bottom (Appendix 2-2). These differences imply a different habitat value from that of natural rock outcroppings and boulders.

Structures can affect local wave and current patterns mainly by introducing additional friction. This reduces current speeds and breaks up waves, causing deposition of sediments in some areas and scour in others. When structures change the movement of sediment, coastal erosion may result in some places while other areas may need to be dredged. Walls and revetments in particular, designed to protect shorelines, can shift the focus of erosion to other nearby locations. Generally the effects of these structures on waves and currents are localized, so removing the structures may increase current speeds and wave energy in the immediate vicinity, potentially resulting in erosion. Larger-scale effects, for example from removal of large or numerous structures in narrow parts of the estuary, seem unlikely but should be investigated before any such removal is undertaken.

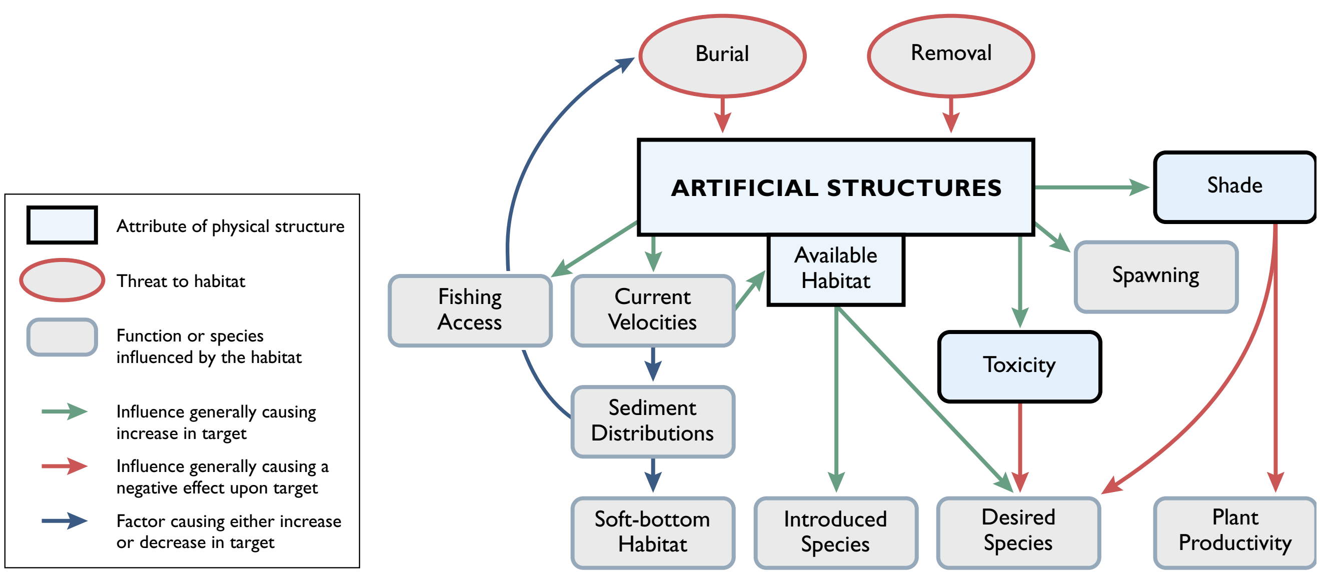


Figure 6-3: Influences on artificial structures, and functions and services provided by artificial structures. "Available habitat" refers to artificial structures that provide habitat for one or more species.

The "mothball fleet" of ships from World War II has released heavy metals into Carquinez Strait.

Many of the artificial structures in the bay have wooden pilings that were injected with creosote to minimize fouling (see Appendix 6-1). Creosote contains polycyclic aromatic hydrocarbons (PAHs) that are persistent in the environment and toxic to some organisms. Although the reproductive success of herring that spawn on creosote is unknown, experiments showed toxic effects on herring embryos from pieces of 40-year-old creosote-impregnated pilings (Vines et al. 2000). Strong circulation around pilings probably minimizes direct effects of creosote on motile organisms, but organisms that feed mainly on prey species inhabiting the pilings may be exposed to creosote through their food.

Piers and breakwaters, also often treated with creosote for its preservative qualities, are popular sites for recreational fishing because they provide easy access to the deeper waters of the bay and shoreline and because such structures attract fish.

Some other artificial structures may be local sources of toxic materials. For example, the reserve "mothball fleet" in Suisun Bay has released metals and paint debris into the estuary in the past; however, these ships are being removed, so such releases should not be a problem in the future.

This abandoned structure with creosote pilings presents both a human safety and environmental hazard.

Rock revetments (riprap) are one of the most abundant artificial substrates. Revetments lack the potential toxicity of pier pilings and may provide some of the same functions as natural rock substrate. However, before large-scale modification of the estuary, the areas now protected by rock would have consisted of mudflats and marshes, presumably more valuable habitat for supporting ecosystem services. Furthermore, the location and overall habitat value of constructed rock or concrete structures is unlikely to match that of natural rock, which often has a greater density and diversity of potential habitat for various organisms.

Rationale for Establishing Goals for Artificial Structures

Applying the approach outlined in Chapter 2 (Figure 2-1), it is clear that while artificial structures support some valued ecosystem services, they are not in short supply, and they can have some detrimental effects. If abandoned pier pilings interfere with the function of surrounding habitat, the decision tree would direct us to restore the surrounding habitat by removing the pier pilings. The advantages and disadvantages of doing this are being investigated and, if this activity is to be pursued, it should be done within an adaptive management framework (see Chapter 2) and based on recommended methods (see Appendix 6-1). Removing selected artificial substrates would be done in pilot projects to investigate and analyze the expected effects of eliminating this habitat and reversing its effects on local wave, current, and sedimentation patterns. One large-scale, long-term strategy for the Central Bay and the Richmond shoreline might be to restore eelgrass near sites where creosote pilings are being removed, to provide eelgrass as a natural substrate to attract spawning herring.

Advantages of removal may include:

- Reduced substrate for introduced species
- Reduced shading of the bottom and water column
- Reduced toxic effects of creosote and other contaminants
- Reduced restrictions to flow and sediment movement
- Restoration, re-creation, or realignment of intertidal mudflats, sand flats, rock, and shellfish, eelgrass, and macroalgal beds

Disadvantages may include:

- Disruption during removal (physical damage, turbidity, and toxicity)
- Reduced habitat for fish and invertebrates including native oysters
- Reduced resting or nesting sites for birds

Additional considerations for removal include:

- Reduced navigational hazards
- Aesthetics

- Reduced recreational fishing opportunities
- Loss of historical value and cultural connections

Goals for artificial structures focus on protecting the habitat value of existing and active structures, removing and preventing structures that are detrimental to the subtidal system, and improving our understanding of the role of artificial structures in the estuarine system.

The recommendations that follow focus on the potential for removing derelict creosote pilings at pilot locations, and enhancing the subtidal functions that artificial structures offer (see Chapter 10 for more detail).

Derelict creosote piling structures on the North Richmond shoreline.

TYPES OF ARTIFICIAL STRUCTURES IN SAN FRANCISCO BAY

Ships and Vessels
- Recreational boats
- Commercial vessels
- Abandoned vessels
- Exposed shipwrecks (Point Molate)
- Sunken shipwrecks
- National Defense Reserve Fleet (Suisun Bay)
- Houseboats (Richardson Bay)

Pilings
- Marina areas
- Ports
- Vehicle bridges
- Foot bridges
- Fishing piers

Wharves

Floating Docks
- Private docks
- Public docks

Abandoned, Derelict Piers
- Berkeley Pier
- Point Molate Pier

Jetties

Breakwaters
- Riprap breakwaters
- Concrete breakwaters

Other Riprap
- Hardened shoreline functioning as levee
- Concrete blocks and other debris

Seawalls and Bulkheads
- Wooden seawalls
- Concrete seawalls

Buoys

Pipeline

Cables

Transmission Towers/Power Lines

Power Plants
- Cooling-water Intakes

Outfall Structures
- Power plants
- Water treatment plants
- Other pipelines

Duck Blinds

Moorings

Anchors

Pacific Oyster Shell (Restoration Projects)

Large Debris
- Shopping carts
- Tires
- Abandoned equipment

The recommendations incorporate information from the San Francisco Estuary Institute's San Francisco Bay Creosote Piling and Artificial Structures Assessment (Appendix 6-1).

Science Goals for Artificial Structures

ARTIFICIAL STRUCTURES SCIENCE GOAL 1

Understand how artificial structures generally affect the estuarine ecosystem.

Question A. How do pier pilings and other unused artificial structures affect wave and current patterns?

This question is general, concerned with the overall evaluation of the ecosystem services provided by these structures and the potential harm of either leaving them in place or removing them.

Question B. What species use these structures for habitat, and is any of this use obligate?

Question C. How does habitat use change as areas of soft bottom and shoreline are converted to hard bottom, for example by construction of riprap?

Question D. How are rock-like artificial structures such as revetments and seawalls used by native oysters and other attached species, and how does that vary regionally?

These concrete "slagpools" provide limited habitat in comparison to a natural wetland or rocky intertidal edge, but can often show greater diversity of species and niche space than classic riprap. The pools host several species of seaweeds, mussels, oysters, barnacles, and a variety of other bay invertebrates.

Much of the bay shoreline has been riprapped.

The existing hard shoreline at Virginia Street on the Berkeley shoreline includes riprap, old concrete fill foundations from wharf and industrial facilities, and areas where concrete was simply poured onto the shoreline to act as a tidal barrier.

ARTIFICIAL STRUCTURES SCIENCE GOAL 2

Determine the roles of individual artificial structures proposed for removal.

Question A. What is the effect of removing a particular structure on local hydrodynamics and sediment transport?

This is related to Science Goal 1, Question A above, but concerns individual structures. The details of the structure, the physical configuration of the area, and the local current and wave environment all contribute to the alterations that a particular structure introduces. Removal may result in rapid erosion and resuspension of sediments when current speeds increase. Most of these structures fall below the spatial scale that today's hydrodynamic models can resolve, so investigation may require developing small-scale models together with field studies.

Question B. Which species use this particular structure for habitat, and how?

Removal should be contingent upon an investigation into the habitat value of the particular structure in the environment where it is found.

Question C. How important is this structure for recreational use?

This question is related to the previous one but also to issues of access and current use. Some piers are heavily used for fishing, and other structures may be used for fishing or birdwatching because they attract fish or birds.

Children fish at the Marin Rod and Gun Club historic pier.

Protection Goals for Artificial Structures

ARTIFICIAL STRUCTURES PROTECTION GOAL 1

Enhance and protect habitat functions and the historical value of artificial structures in San Francisco Bay.

- Artificial Structures Protection Objective 1-1: Improve water quality and hard substrate for habitat by encapsulating existing creosote pilings and piers, or by replacing them with inert materials, especially within current and historical herring spawning areas.

- Artificial Structures Protection Objective 1-2: When artificial structures (for example, shoreline stabilization structures) are installed, replaced, or maintained, use materials or methods that mimic natural habitat features, incorporate natural habitat (for example, emergent marsh, submerged aquatic vegetation, riparian vegetation, and oyster shell) into structure design, and use native seeding or other techniques to minimize establishment of invasive species. (See Chapter 10).

ARTIFICIAL STRUCTURES PROTECTION GOAL 2

Improve San Francisco Bay subtidal habitats by minimizing placement of artificial structures that are detrimental to subtidal habitat function.

Please see Appendix 2-2 for more information on the impacts of artificial structures.

Restoration Goals for Artificial Structures

ARTIFICIAL STRUCTURES RESTORATION GOAL 1

Where feasible, remove artificial structures from San Francisco Bay that have negative or minimal beneficial habitat functions.

- Artificial Structures Restoration Objective 1-1: Where appropriate, remove creosote pilings from intertidal and subtidal habitats of the bay, with a focus on those areas that have high concentrations of individual pilings or piling complexes and are within current and historic spawning grounds for herring.

  Artificial Structures Restoration Action 1-1-1: Initiate programmatic evaluation of pilings pursuant to the National Historic Register and associated guidelines.

CREOSOTE PILINGS IN SAN FRANCISCO BAY

Wooden pilings have been used in marine construction projects for thousands of years. Beginning with the Gold Rush, wooden wharves and piers proliferated on the San Francisco waterfront. Several creosote plants operated in Alameda and other areas. The remnants of old creosote-treated piers and dilapidated maritime facilities are common sights along the intertidal and subtidal shorelines of San Francisco Bay. Creosote was used from the mid-1800s into the 1950s as a method for preserving marine structures from decay. It is a complex mixture of chemicals, many of which are toxic to fish and other marine organisms. Because of concerns over toxicity, creosote was banned in 1993 by the California Department of Fish Game.

Removal of these structures has been proposed as a possible restoration focus for San Francisco Bay. Creosote-treated wood and debris removal operations are underway in other regions of the United States. There is particular concern that chemicals leaching from creosote-treated structures could harm Pacific herring, one of the last fisheries in the region, because herring spawn on hard surfaces, including old pier pilings. There is also concern that dilapidated creosote-treated pilings are hazards to navigation and that they will pose even greater hazards as sea level rises. Removal and encapsulation projects conducted at the Port of Oakland and the Port of San Francisco are discussed in Appendix 6-1.

There are more than 33,000 derelict creosote pilings in San Francisco Bay.

Artificial Structures Restoration Action 1-1-2: Remove 6,500 tons of creosote pilings from areas of high piling concentration (i.e., San Francisco Waterfront, Richmond Point, Napa River Mouth, and Carquinez Strait) within 5 years (see the following goal).

- Artificial Structures Restoration Objective 1-2: Where appropriate, remove shoreline stabilization structures and riprap from the bay that are no longer providing protection or may be contributing to coastal erosion.

ARTIFICIAL STRUCTURES RESTORATION GOAL 2

Promote pilot projects to remove artificial structures and creosote pilings at targeted sites in combination with a living shoreline restoration design that will use natural bioengineering techniques (such as native oyster reefs, stone sills, and eelgrass plantings) to replace lost habitat structure.

- Artificial Structures Restoration Objective 2-1: Fund three pilot restoration projects to test new material types and configurations for three types of artificial structures: riprap shoreline, breakwater, and dock. (See Chapter 10, Restoration Goals for Living Shorelines.)

CHAPTER SEVEN

Shellfish Beds

THIS CHAPTER ADDRESSES SHELLFISH BEDS on hard substrate such as rock or shell aggregates, or mud/shell mix, together with the associated water column. (Shell hash areas in soft substrate are addressed in Chapter 4.) Shellfish beds are defined as locations where a shellfish species occupies more than 50% of an area of more than a few square meters (Schaeffer et al. 2007). Five species of shellfish occur in San Francisco Bay: native Olympia oysters (*Ostrea lurida*), California mussels (*Mytilus californianus*), hybridized Bay mussels (*Mytilus trossulus/galloprovincialis*), and non-native ribbed horsemussel (*Geukensia demissa*) and green bagmussel (*Musculista senhousia*). The latter two species are common in the estuary but do not occupy hard-bottom habitats and are not discussed further in this report. There are also small populations of the non-native Pacific oyster (*Crassostrea gigas*) in the South Bay, where eradication efforts are underway. Much of this discussion is based on Schaeffer et al. (2007), Grosholz et al. (2007), and Appendix 7-1.

Multiple age classes of native oysters can be found in rocky intertidal areas.

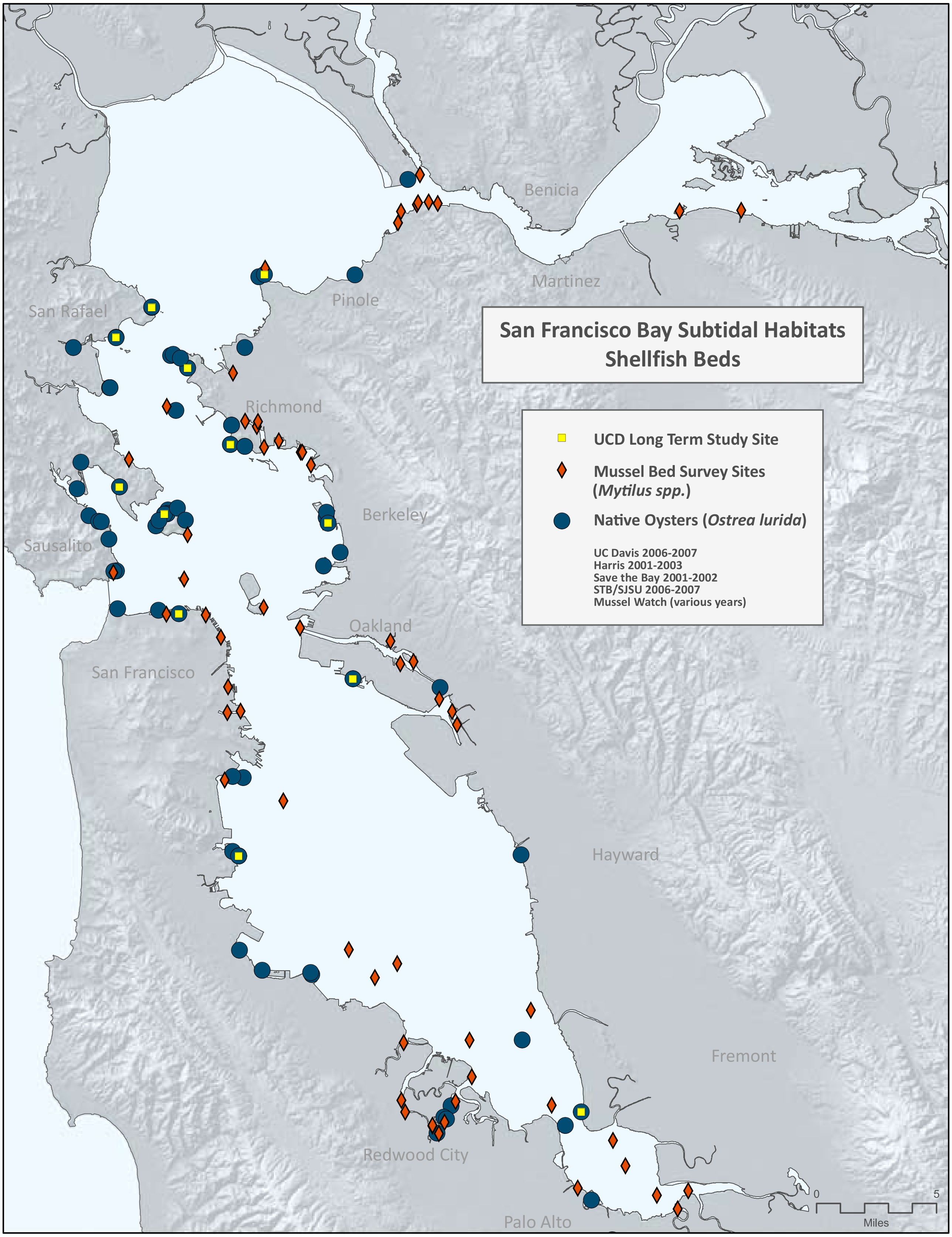


Figure 7-1: Distribution of Shellfish Habitat in San Francisco Bay.

Of these species, the Olympia oyster is by far the most abundant and is the only species that is a native confined to estuaries. Recent surveys for oysters in the intertidal zone have found numerous individuals on hard substrates in the Central Bay and to a lesser extent in the San Pablo and South Bays (Figure 7-1; Zabin, et al. 2009). The abundance of oysters in the subtidal zone is unknown because methods for surveying them are inadequate. Oysters settle on natural soft substrate such as mud/shell mix (Chapter 4), hard substrate such as rock outcrops (Chapter 5), and some artificial structures (Chapter 6).

Declines in extent of these rock habitats due to lowering for vessel traffic safety have been offset by the installation of artificial substrates (Chapter 6) such as riprap and seawalls.

The intertidal rocky shoreline is covered in sea lettuce and native oysters.

Shells of native oysters occur in the vast shell middens at various sites around the bay along with those of mussels and clams, attesting to the pre-European settlement presence of the native oyster. However, the actual historical abundance of oysters is poorly known, in part because of confusion between native oysters and *Ostrea lurida* brought from Washington or Oregon and planted in the bay. Townsend (1893) referred to native oysters as very abundant and overgrowing the shells of eastern oysters which had been introduced for aquaculture. Commercial harvest was important "since the days of the Spaniards" (Bonnot 1935), and native oyster reportedly made up about 15% of the total oyster harvest from San Francisco Bay in the late 1800s to early 1900s, producing up to 150 tons of meat per year during 1888-1904 (Barrett 1963).

The vast majority of available information on native shellfish species is on native oysters, and most of the following discussion addresses native oyster beds. Many of these issues would also apply to other hard-bottom shellfish beds, although there may be less interest in restoring them at this time than there is for oyster beds.

Various species of mussel can be abundant enough to form beds; most are confined to the more saline regions in and near the Central Bay where rocky substrates are common (Schaeffer et al. 2007). San Francisco Bay is marginal habitat for the native *Mytilus californianus*. The two native mussels (*M. californianus* and *M. trossulus*), and *M. galloprovincialis*, introduced in 1947, are common along the outer coast and presumably the bay populations are linked to the outer coast populations through larval exchange. The introduced Pacific oyster *Crassostrea gigas* may be completing its life cycle in the bay (C. Zabin, 2009, pers. comm.).

ONGOING OYSTER RESTORATION PROJECTS

Interest in restoring and maintaining oyster beds is demonstrated by the numerous restoration and research projects underway in San Francisco Bay, Elkhorn Slough, and the Pacific Northwest.

- http://www.bioone.org/toc/shre/28/1
- http://www.elkhornslough.org/research/conserv_oysters.htm
- http://www.habitat.noaa.gov/media/publications.html

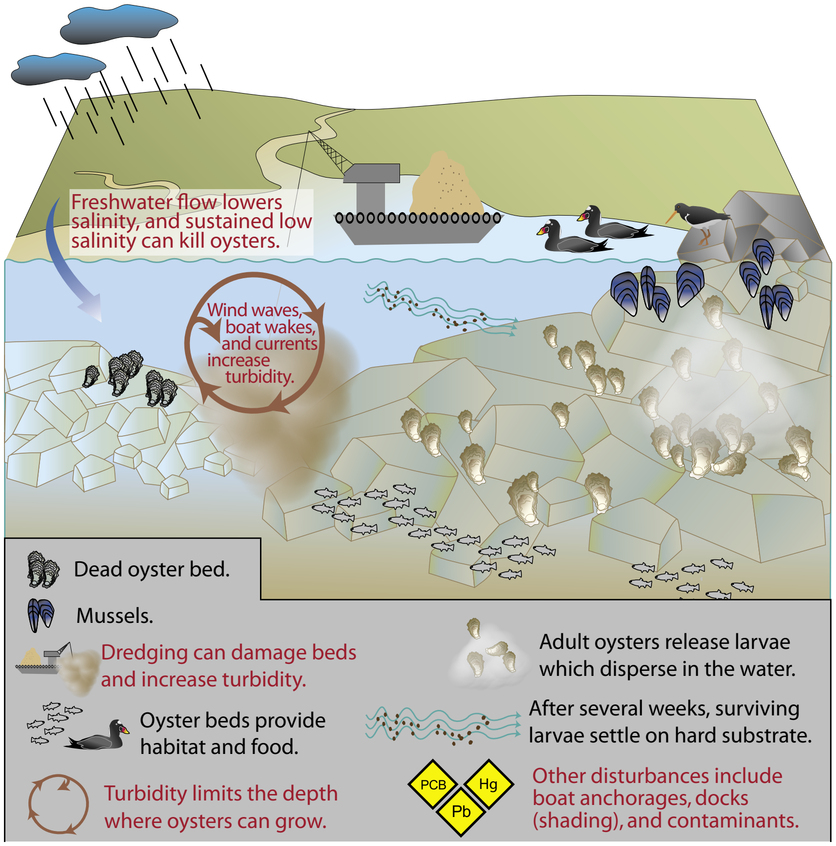


Figure 7-2: Conceptual diagram for shellfish beds in the San Francisco Estuary. This diagram displays processes that occur in and on shellfish beds, some of the ecosystem services these habitats provide, and threats to shellfish beds.

A native oyster on cobble at the Emeryville Crescent.

Conceptual Model for Shellfish Beds

Shellfish beds (Figures 7-1 and 7-2) provide several ecosystem functions and support several ecosystem services. The native oysters do not commonly form tall, three-dimensional reefs, as do Virginia oysters, although they can add structure to hard substrates and may be able to colonize and overgrow soft substrates. In this sense they can be considered a "foundation species" or ecosystem engineer, altering their environment by increasing bottom roughness, reducing current speeds, and as a result, trapping sediments. Oysters also increase physical heterogeneity, which can increase diversity of other marine invertebrates and also result in higher fish diversity and abundances than in neighboring, less complex habitats. Increased abundance of native oysters can locally increase the number of other benthic invertebrates (Kimbro and Grosholz 2006 for Tomales Bay). With their associated invertebrates, oysters provide food for fish, birds, and crabs.

Not all the functions attributed to oyster beds are applicable in the San Francisco Estuary. One key function of bivalves in many estuaries and lakes is increasing water clarity. In locations such as the Chesapeake Bay, turbidity results mainly from high phytoplankton biomass, which can be severely

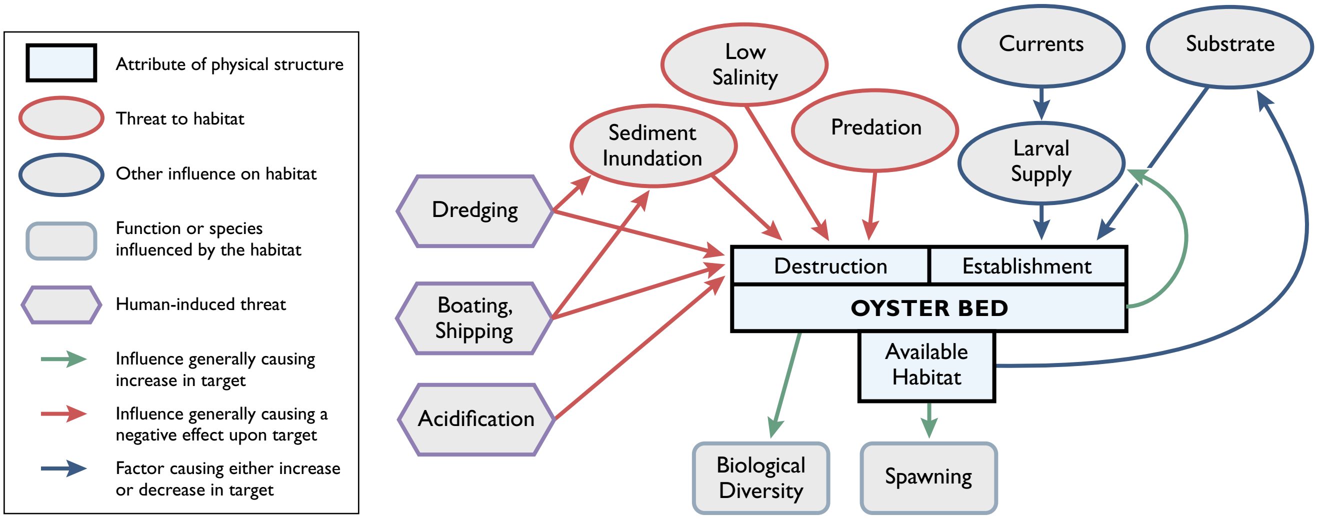


Figure 7-3: Influences on oyster beds and their functions and services.

reduced by bivalve grazing. In the San Francisco Estuary most of the turbidity is due to inorganic particles (Kimmerer 2004). No effect on turbidity was noted after the invasion of the "overbite" clam, *Corbula amurensis,* in 1987, despite its enormous abundance in soft sediments of the brackish northern estuary (Alpine and Cloern 1992). Since the greatest conceivable extent of restored and natural oyster beds is minuscule compared to the area suitable for clams, it is unlikely that oyster beds could exert a measurable control on turbidity except possibly in water immediately over or near dense oyster beds.

Native oysters colonize a mix of hard and soft substrate at China Camp State Park.

So far very few oysters have been found on soft substrates, although that could be partly due to inadequate sampling, owing to the lack of suitable technologies to carry out broad-scale surveys in the shallow subtidal zone. Oysters in Puget Sound are able to colonize on soft substrates (Betsy Peabody, 2007 West Coast Native Oyster Meeting), but in San Francisco Bay oysters probably cannot establish beds on soft substrate without larger particles for attachment due to the high resuspension rates of soft sediments (due to shallow water and wind waves). Since oysters are known to settle on existing shell, oyster beds could become established on shell deposits if the deposits are not too mobile.

The time scale for dispersal of oyster larvae (~2 weeks) is shorter than estimates of residence time in the estuary, which are up to 60 days for the northern estuary in summer and much longer for the south bay (Walters et al. 1985). This implies that a large proportion of the larvae would settle within the estuary. However, within-bay currents are large enough to disperse particles among the major basins in a few days, implying that the propagules generally should disperse broadly within the estuary before settling. Apart from larval supply, several factors may limit the development and maintenance of oyster beds. Juvenile oysters are particularly vulnerable to poor environmental conditions and predation, so variation in mortality of juveniles presumably has a big effect on subsequent abundance. Food limitation is very likely given the low chlorophyll concentrations in the northern estuary (and formerly in the south;

Cloern et al. 2007). Food limitation generally results in low growth rate, which extends the time to maturity, decreasing survival of oysters to maturity. In locations with low larval supply from other beds, local larval settlement may be limited by the density of adult oysters in the bed.

Threats to Native Oysters

The principal threats to native oysters seem to be high rates of sedimentation and extended periods of low salinity. Competition for space may be more important in the South Bay where hard substrate is limited and in the subtidal zone where fouling organisms such as sponges, tunicates, and hydroids are abundant. Intertidal substrate examined during surveys was around 40% clear of oysters, indicating that lack of attachment space may not limit abundance of intertidal oysters (Appendix 7-1). Other limiting factors include potential contaminant effects, especially for intertidal beds that are vulnerable to oil spills, and predation by fish, birds (for example, diving ducks), and possibly crabs. Oyster drills and small predatory snails present a low to moderate source of mortality to young oysters particularly in the South Bay. Diseases and parasites do not present a major threat, although this could change if population density increases and changes in water temperatures occur due to climate change. Heat stress in warm intertidal areas and overgrowth by algae may reduce oyster survival in local areas.

Below: Native oyster.
Bottom left: Native oysters settled on rock.
Bottom right: Native oyster larvae ready to disperse into the water column.

A recent bay-wide survey in 2006–07 (Appendix 7-1) found large areas of empty oyster shells in good condition, suggesting recent death. The high flows of 2006 may have reduced salinity for a long enough time in San Pablo Bay and possibly the South Bay to kill the oysters there. Daily mean salinity at the Romberg Tiburon Center monitoring site went as low as 5 ppm in spring of 2006, and X2 (distance up the estuary to where tidally-averaged bottom salinity is 2 ppm, Jassby et al. 1995) went below 45 km for several days, and was below 55 km for 3 months. This was the second longest duration of low salinity in the record since 1955 (Figure 7-4). Salinity in intertidal areas is subject to the large-scale salinity distribution in the estuary but can also be affected by local

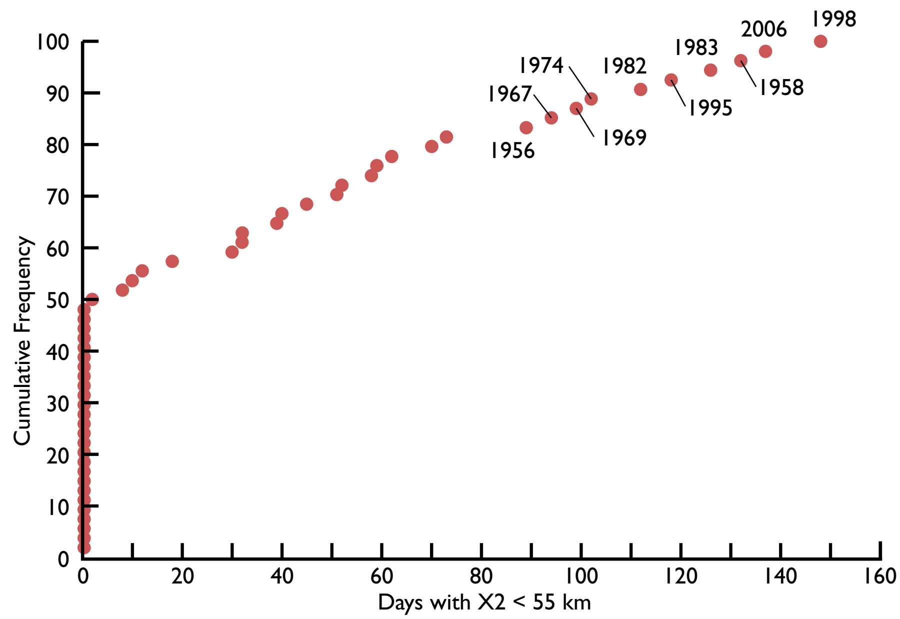


Figure 7-4: Low-salinity events in San Francisco Bay. The graph shows the frequency distribution of days with salinity less than 2 (near the landward limit of salinity penetration) < 55 km, approximately at the Benicia Bridge. The mean return time for a low-salinity event is the inverse of the frequency of events of at least that duration. For example, about 10% of the years have had low-salinity events at least as long as that in 1982 (112 days), so such an event can be expected roughly once in 10 years. Prediction of the frequencies of oyster die-offs would be more precise given estimates of the salinity-time envelope for survival of oysters. Data from Jassby et al. 1995 updated using the Interagency Ecological Program's Dayflow data (http://www.iep.ca.gov/dayflow/index.html).

runoff and discharge from wastewater treatment plants. This influence would be difficult to predict, and local runoff can be poorly correlated with flows through the delta. A San Rafael oyster restoration site lost around 99% of settled oysters after spring 2006, but the population recovered quickly (R. Abbott, Environ, 2009, pers. comm.).

Anthropogenic threats may include water pollution, boating, shipping, and dredging (Figure 7-5). If these activities occur near oyster beds they can directly disrupt beds or resuspend sediments that inundate beds. Ocean acidification is considered a growing threat to calcareous organisms in the ocean, and may become important particularly in the Central Bay with its strong oceanic influence. However, pH in much of the estuary may be controlled more by local processes (e.g., carbon dioxide input from sewage treatment plants and productivity cycles, Fuller 2010) than by any large-scale oceanic influence.

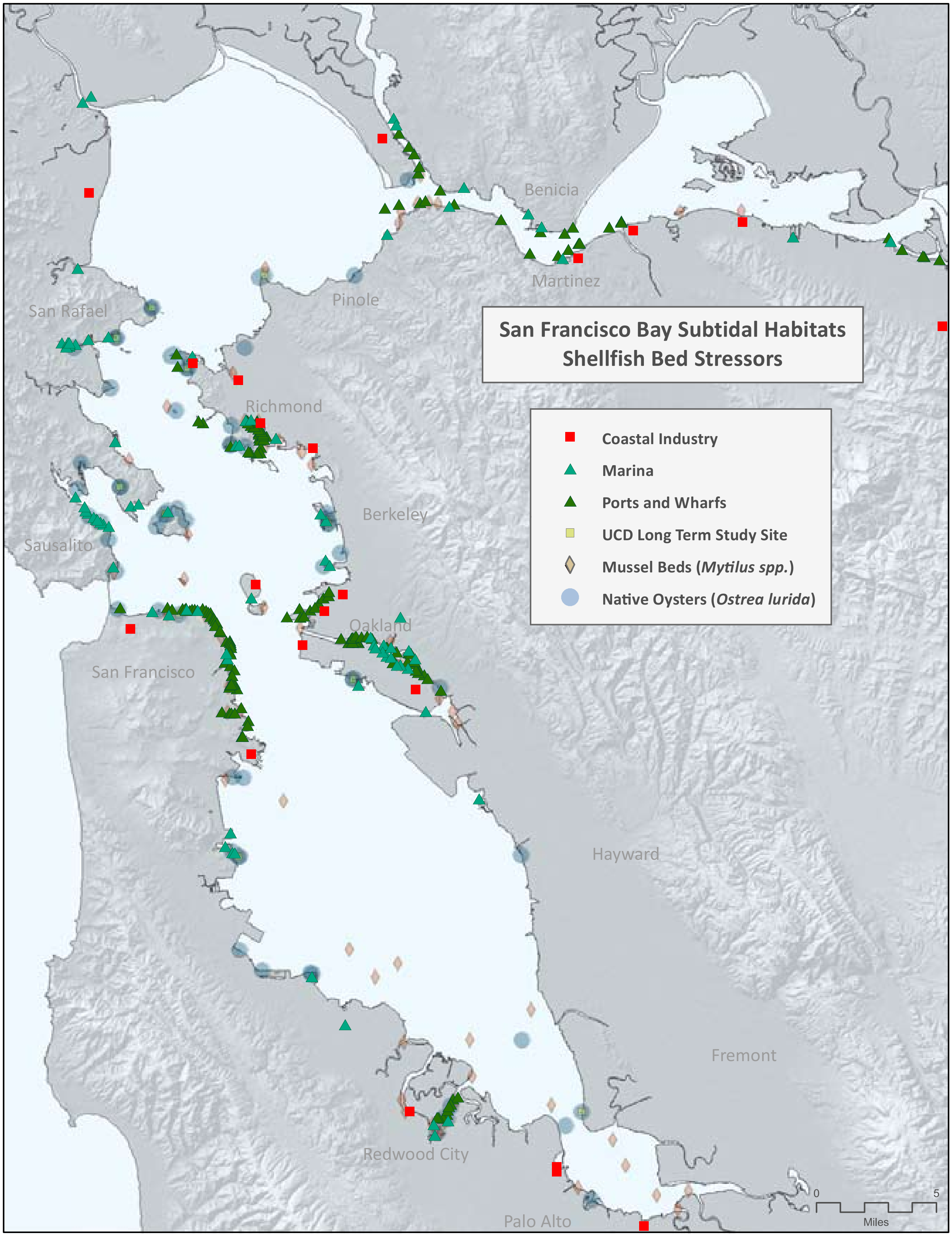


Figure 7-5: Locations of Shellfish Habitat Stressors in San Francisco Bay.

At right: Mobile oyster larvae swimming in the water column. Far right: Native oysters settled on Pacific oyster shell.

Rationale for Establishing Goals for Shellfish Beds

Shellfish beds are an intertidal to subtidal habitat created by the interaction of living organisms with particular physical conditions in the estuary. Several functions of shellfish and specifically oyster beds discussed above could be considered helpful in moving the estuary toward a more natural, less uniform state with local heterogeneity benefiting some species. In regards to restoration, it remains to be seen whether it is possible to establish persistent oyster beds over a large enough area to have substantial ecological impacts. However, small-scale restoration projects have reported increases in species use such as herring depositing roe on the structures and birds feeding on them (R. Abbott, 2009, pers comm.). It may be prudent to continue to research methods to establish oyster beds, while also further investigating their ecosystem functions. It is also not clear to what extent the functions of restored oyster beds are due to the oysters or to the structures put in place to allow oysters to settle.

Below: Size difference between small native oysters and large Pacific oyster shell, used as a substrate for oyster restoration. Bottom: Monitoring plate with newly settled oysters, tunicates, and barnacles.

Applying the approach outlined in Chapter 2, it is clear that the restricted extent of oyster beds may be limiting their support of valued ecosystem services. Furthermore, restoration has been demonstrated and is therefore feasible (Appendix 7-1), although questions remain about the anticipated trajectory of restoration and associated response of ecosystem functions and services. Therefore, restoration is warranted for oyster beds, but should be done within an experimental framework (see Adaptive, Phased Approach below and discussion of adaptive management in Chapter 2).

Ongoing restoration work near San Rafael has succeeded in obtaining population growth and good recruitment in at least some years. The oysters grow well, reach reproductive capacity early, are free of disease and parasites, and have low losses to predation (R. Abbott and C. Zabin, 2009, pers. comm.). Providing a substrate with highly complex surface areas (bagged clean Pacific oyster shells) results in high rates of settlement and abundant oysters, compared to less complex substrates such as riprap. Required maintenance appears to be minimal (R. Abbott, 2009, pers. comm.).

If restoration (including enhancement or creation) of oyster habitat should proceed, many aspects of the process will require investigation and refinement. Restoration projects should move towards larger-scaled pilot projects, but the focus should be on the value of knowledge gained as well as the value of the restoration projects themselves. Experimental restoration will help to answer broader-scale questions about the likely outcomes of restoration. Regardless of the extent of future restoration, oyster beds remain potentially valuable resources. The success of restoration, protection, and management depends on adequate understanding of how these beds develop, how they are maintained, and what threats they face.

The beds formed by mussels do not appear to be a priority for restoration in San Francisco Bay, because the beds are small, little is known of their ecological importance, and the mussels are abundant on the open coast and in other estuaries. There may be interest in researching the interaction and hybridization of *Mytilus galloprovincialis* with the native *M. trossulus*, but managing them would be difficult since these species and their hybrids are not easily distinguished.

Goals for shellfish bed habitat focus on protecting existing native oyster beds, creating and enhancing additional beds, and improving our understanding of ecosystem services, factors influencing the beds, and restoration methods, in order to improve our ability to protect and restore this habitat. The principal restoration goal, pending a satisfactory determination of its benefit, is to restore large areas of habitat suitable for native oysters. The 50-year maximum restoration targets are based on the acreage of shoreline areas out to a depth of 2m where native oysters have been documented, and correlate with recent monitoring data regarding distribution. Native oysters would not be restored throughout these target areas, but at a subset of locations within these larger

Biologists install bagged Pacific oyster shell reefs at the Marin Rod and Gun Club restoration site in San Rafael.

Mounds of Pacific oyster shells and eelgrass "seed buoys" (see stakes in the background) were used to restore oysters and eelgrass at the Marin Rod and Gun Club.

areas. The long-term acreage targets were developed with the assumption that without restoration efforts native oyster abundance will remain relatively stable. Should native oyster acreage increase considerably independent of restoration efforts, that increase should count towards the overall acreage target.

An Adaptive, Phased Approach to Oyster Restoration

An adaptive approach to restoration, conducted in phases from small scale to large (Appendix 7-1), would have two key advantages. First, the effort can begin at small enough scales to be tractable and to allow for the learning necessary to expand the scale of restoration projects in subsequent phases. Second, within a program of adaptive management, pursuing restoration in phases can ensure that information is gathered to answer the fundamental questions about the roles of oyster beds (i.e., questions under Science Goal 1, below) and the responses of oyster beds to environment (Science Goal 2), as well as questions related to restoration itself (Science Goal 3). That is, at each phase, investigations into the roles and responses of oyster beds and the relationship of these to the scale of the restoration will be embedded in any significant restoration project.

The phased approach begins with selecting sites for experimental restoration projects, mainly to refine site selection and restoration methods. Results from this phase will be used to design the pilot phase, which will scale methods to larger areas and also begin to gather evidence on the likely outcomes of restoration. Depending on results from the pilot phase, restoration could then be attempted at larger sites, with each step contingent on the development of evidence in previous phases indicating a high value for restored oyster beds.

The knowledge developed during each phase will be critical for answering the key research questions enumerated below. These include determining the effectiveness of oyster restoration in providing valued ecosystem services, the environmental controls on oyster beds, and the methods that will maximize the success of the restoration. Of these questions, the most critical is the provision of ecosystem services, since this is the justification for attempting restoration beyond the experimental scale. Thus, understanding of the extent of ecosystem services provided by restored oyster beds should be improved substantially at each phase beginning with the pilot phase, before the process moves into the next phase. To continue restoration without this knowledge could risk wasting public money if the restoration proves ineffective, and could jeopardize support for these and other restoration activities.

Before restoration is undertaken, principles for site selection should be established. These could include local conditions (for example, depth profile, sediment type, waves and currents, salinity patterns, turbidity) and the environmental context (for example, proximity to hardened shorelines, ports or piers, proximity to source beds for larvae, convenience for access and monitoring), taking into account likely changes in these attributes with long-term trends such as sea level rise and increasing water clarity. Initial work has been completed (Appendix 2-2 and 7-1).

Restoration phases may overlap to some extent; for example, evaluation could begin as soon as a year or more of data were available from each project. To maximize knowledge gained from each project, basic monitoring (for example, abundance of oysters) should continue annually after the end of the project; thus each project should be funded for a long enough period to encompass the design, construction, operation and monitoring, reporting, and post-project monitoring. The decision to terminate this monitoring should be based on the knowledge foregone by termination as well as by the additional cost of ongoing monitoring. Monitoring of the large-scale restoration projects should continue indefinitely to allow for answers to be developed about the long-term trajectories and responses to environmental conditions.

NATIVE OYSTER MONITORING AND RESTORATION PILOT PROJECTS

- Holly Harris, San Francisco State University: 1999 monitoring study, 2004 Masters Thesis
- Save The Bay/ San Francisco State University: 2001–02 recruitment study
- Richardson Bay Audubon Center: 2004–2010 monitoring and recruitment studies
- Marin Rod and Gun Club, Robert Abbott, Rena Obernolte, et al: 2004–2010 restoration project
- Berkeley Marina, Robert Abbott, Rena Obernolte, et al: 2010 restoration project
- Outer Bair Island, Robert Abbott, Rena Obernolte, et al: 2004–2006 recruitment study
- Pt Pinole Pier area, Obernolte et al, The Watershed Project: 2006–2010 recruitment study
- Save The Bay/San Jose State University: 2006–2007 recruitment study
- UC Davis, Zabin, Grosholz et al: 2007–2010 monitoring and recruitment studies

Above left: Marin Conservation Corps members and community volunteers bag Pacific oyster shell for restoration. Above right: A Marin Rod and Gun Club member shows a Pacific oyster shell string, another method of monitoring oyster recruitment.

PHASES IN AN OYSTER RESTORATION EFFORT

PHASE I. EXPERIMENTAL RESTORATION

This phase will develop the experimental design for the restoration to answer key questions about sites and methods (science goals). The phases within this group should be followed in sequence but can be accomplished for different sites at different times.

Phase I-1: No prior knowledge of site

Conduct a basic site survey.

Phase I-2: Limited site knowledge

Condition: Mapping or surveys have been conducted.

- Assess suitability of the site for restoration.

Phase I-3: Experimental restoration

Condition: Phase 1-1 and 1-2 actions completed; area is unlikely to recruit naturally and is suitable.

- Determine experimental design to fit the site.
- Establish replicated small-scale test plots at various elevations, and other treatments.
- Evaluate outcomes: persistence, recruitment, abiotic conditions, use by other organisms.
- Report evaluates restoration potential and lessons learned.

Following this phase an evaluation takes place in which decisions are made about whether and to what extent to proceed into pilot restoration. This decision should be made largely on the basis of feasibility and conditions at individual sites.

PHASE II: PILOT RESTORATION

This phase will expand on the previous experimental phase to determine the suitability of alternative methods of restoration at a larger scale than the experimental scale. It will also begin to evaluate the larger implications of restoration for its value in increasing the provision of ecosystem services (science goals 1 and 2 below).

Condition: Phase I has been completed for candidate site, and site remains suitable.

- Design small pilot restoration project (0.5 acre or less) to test hypotheses developed or provisionally tested in Phase I.
- Design includes explicit measures to determine quantitatively the use of the restored site by organisms and other evidence about the likely benefits of restoration.
- Establish replicated moderate-scale test plots.
- In the second year of the program, begin to assess aspects of ecosystem function (e.g., spawning substrate and nursery and foraging habitat).
- Evaluate outcomes including those in Phase I, and aspects of ecosystem function.
- Report findings including evaluation of restoration potential, value, and lessons learned.

Following this phase an evaluation takes place in which decisions are made about whether and to what extent to proceed into larger-scale restoration. The decision about whether to expand the scale of restoration should be based on an assessment that the restored oyster beds likely provide ecosystem services commensurate with the cost and effort involved in the restoration. This decision could be made provisionally on the basis of a few pilot projects, and re-evaluated as more pilot projects are completed. The decisions about where and how to restore should be based on lessons learned from individual sites about feasibility and conditions.

PHASE III. LARGER-SCALE RESTORATION PROJECT

This phase will expand on the pilot phase with the principal purpose being to evaluate the larger implications of restoration for its value in increasing the provision of ecosystem services (science goals 1 and 2 below). This phase will also determine how alternative methods of restoration scale up beyond the pilot scale.

Condition: Phase II has been completed for candidate site, and site remains suitable.

- Design intermediate-scale restoration project (~1 acre) to answer questions under science goals 1 and 2, and to further develop the art and science of oyster restoration.
- Design includes explicit measures to determine quantitatively the use of the restored site by organisms and other evidence about the likely benefits of restoration.
- Establish replicated larger-scale test plots.
- In the second year of the program, begin to assess aspects of ecosystem function (e.g., spawning substrate and nursery and foraging habitat).
- Evaluate the response of ecosystem functions and likely ecosystem services.
- Report findings including evaluation of restoration potential, value, and lessons learned.

If the value of the restoration as estimated in this phase continues to suggest further expansion, this phase may be repeated at different sites as pilot programs are completed, and the acreage target expanded at each site and the above process repeated. The decision about whether to expand the scale of restoration should be based on an assessment that the restored oyster beds likely provide ecosystem services commensurate with the cost and effort involved in the restoration. This decision would remain provisional with additional information coming in as pilot and then larger-scale projects are completed. The decisions about where and how to restore should be based on lessons learned from individual sites about feasibility and conditions.

At this scale a critical issue is the long-term viability of the restored oyster beds and their provision of ecosystem services.

Science Goals for Shellfish Beds

SHELLFISH BEDS SCIENCE GOAL 1

Understand the ecosystem services the shellfish beds support, and in what quantities, in their current state and after restoration.

Question A. What specific functions do shellfish beds support?

This question could be addressed in part by an examination of extant beds in different parts of the bay, supplemented by lessons learned during early restoration. These lessons may be transferable among sites if the influence of local conditions can be understood and quantified.

Question B. How much is attributable to the structure vs. the shellfish?

The basis for this question is discussed above.

Question C. How do the ecosystem services provided by restored oyster beds scale with the total area restored and its spatial configuration?

If oyster beds are being restored to support ecosystem services, enough beds must be restored to provide a substantial increase in these services. These services may scale linearly with the increase in bed area, or some other way (see discussion of restoration and ecosystem services in Chapter 3). The shape of this relationship presumably depends on feedbacks between the existing bed structure and both settlement success and mortality. This would be difficult to determine, particularly before restoration began. Assuming a linear response, though, it should be possible to calculate the extent or value of an ecosystem service of constructed oyster reefs, perhaps in terms of food, structural habitat for fishes and birds of concern, and shoreline protection per unit area or shoreline distance. This information could be used to project the value of the restored habitat, and this projection could be periodically updated with newly gathered data.

Native oysters are established on rock and soft substrates near Rat Rock in China Camp State Park.

A corollary of this question is how the degree of fragmentation of the habitat influences its function, i.e., whether a series of fragments performs the same function as a contiguous habitat of the same area.

Question D. What is the current extent of subtidal populations of oysters?

Intertidal oyster beds have been partially inventoried, but subtidal oyster beds are hard to see and most remote-sensing techniques are unsuited for use in shallow water. Knowing the extent of these beds is essential for answering the other questions about oyster beds, including their ecosystem-level effect and the large-scale impacts of restoration.

SHELLFISH BEDS SCIENCE GOAL 2

Understand the factors controlling the development and persistence of oyster and other shellfish beds.

Question A. How do individual beds respond to their local biotic and abiotic environment?

Dense beds of native oysters provide multiple habitat benefits, including establishing on available space and outcompeting non-native invasive species.

Salinity, temperature, wind and wave patterns, currents, sediment delivery, and predation or consumption may all play a role in the growth or shrinkage of oyster beds. However, these influences are understood only at the most basic level. The relationship between initial settlement of oyster larvae and hydrodynamic conditions, and between survival and both hydrodynamics and sediment supply, may determine population growth. However, predators can play an important role. Since oysters on a reef can be inventoried and examined, it should be possible to determine their population dynamics and mortality factors.

Question B. What limits the establishment of new beds, either under natural conditions or as restoration projects?

Oysters in the intertidal zone occupy less than half of the available space in regions where they occur. The extent of settlement may be related to larval supply, provided the available space is actually suitable for settlement. However, other unknown factors may be limiting the establishment of new beds.

Question C. How does estuarine circulation influence the movement of larvae and subsequent recruitment?

Once beds have been established, the potential exists for them to send larvae to other areas of the estuary and to establish remote daughter beds. This potential depends on duration of the larval stage and the very specific details of circulation both at the scale of the beds themselves and at a broader scale. Large restoration sites may contribute to settlement and even establishment of beds in remote locations provided the substrate is available and the local and regional currents are favorable. At the scale of individual beds, the rate of settlement is likely affected by local conditions and the behavior of late larval stages as well as the rate of supply of larvae.

Question D. What is the degree of connectivity among beds?

The previous question can be turned around: how do population and genetic structure vary among beds, and what can that tell us about the connectivity among beds? This is a particularly important component for understanding the larger-scale issues raised under Science Goal 1. Note that genetic structure and ecologically relevant population structure are likely to be different and operate at different scales, and require different tools for investigation. Research to date indicates some genetic structure among oyster beds (Jim Moore, 2008, CDFG, pers. comm.).

Question E. What influences survival of newly settled oysters?

Juvenile oysters are more vulnerable than adults to predation and other causes of mortality, and therefore variation in juvenile mortality can have a big effect on subsequent abundance.

Question F. What is the extent of mortality in oyster beds due to exogenous factors and how fast do the beds recover?

Low salinity caused die-backs on restored oyster beds in 2006, although the oyster populations on these beds rebounded quickly. Other potential hazards to oyster beds include oil spills, contaminant inputs, and physical disturbance.

SHELLFISH BEDS SCIENCE GOAL 3

Develop the most effective ways of restoring and protecting oyster beds.

Question A. How do physical structures, materials, spacing, and orientation of restored beds interact with the local environment to influence settlement and survival?

Local conditions including salinity, currents, and the supply rate of food, sediment, and larvae are likely to influence settlement and survival. Design and construction of oyster beds may influence settlement and survival differently depending on these local conditions. Therefore lessons from one site may not be entirely transferable to another.

Question B. What is the influence of predation, parasitism, disease, and algal overgrowth on the success of restoration?

Parasitism and disease have not yet been identified as significant factors in the dynamics of oyster populations in the estuary. This could change with increasing population density, and effects are likely to be sporadic and therefore difficult to detect and assess. Consumption by predators is both a source

Below left: Volunteers make Reef Balls™, artificial reef structures composed of native bay sediments (mud and sand), historic dredged oyster shell, and a small amount of Portland cement.
Below right: Volunteers retrieve shell bags from constructed reefs to monitor them onshore.


Volunteers monitor individual Pacific oyster shells covered in newly settled native oysters.

of mortality and a means by which the beds support ecosystem processes, so some amount of consumption is consistent with "success." Algal overgrowth has been identified in some beds.

Question C. How can beds be designed and built so as to make them self-sustaining and minimize the need for ongoing intervention?

Oysters must be dense enough on the beds to allow for reproduction. The minimum density probably depends on the physical layout and local currents. Ongoing restoration efforts indicate that oyster beds need to be cleaned of sediment periodically but require no other maintenance. Minimizing human intervention would reduce the cost of restoration and increase the likelihood of long-term persistence of the beds. This of course does not eliminate the need for periodic monitoring.

Question D. How do oyster beds and eelgrass beds interact, and how do they interact with other habitats?

Since some of the functions of eelgrass and oyster beds are similar, there may be advantages to establishing them in close proximity. Also, restoration should take into account potential negative effects on other habitats or services.

Question E. What are the best methods and timing for oyster restoration that minimize settlement of invasive species?

Question F. How do wind waves, wakes, water intakes, and turbidity affect oyster beds?

Wave action can affect beds directly or indirectly through increases in turbidity and suspended sediment. The degree and spatial extent of disruption to oyster beds by vessel wakes and turbidity and suspended sediment from wakes or dredging should be investigated to determine if protective actions are needed. Industrial intakes of water might entrain an excessive proportion of larvae if the intakes are located close to large oyster beds or restoration sites.

Question G. How do constructed oyster beds influence local water motion and sediment deposition?

Potential positive and negative effects of the beds as structure must be considered in designing and building oyster beds. These may affect the long-term success of the beds as well as conditions in the surrounding areas.

Protection Goals for Shellfish Beds

SHELLFISH BEDS PROTECTION GOAL 1

Protect San Francisco Bay native shellfish habitats (particularly native oyster *Ostrea lurida*) through no net loss of existing habitat.

Native oysters colonized on rocky substrate or possibly on artificial substrate such as a discarded tire.

- Shellfish Beds Protection Objective 1-1: Provide public access and recreational opportunities that minimize impacts to existing intertidal native shellfish habitat in the bay.

  Shellfish Beds Protection Action 1-1-1: Develop community stewardship of native shellfish beds through placement of educational materials and signs that educate the public about the importance of shellfish bed habitat. Place educational signs at high-density intertidal sites and at restaurants serving oysters, and work with agencies to include shellfish information in Water Trail, Bay Trail, and Department of Boating and Waterway educational materials.

- Shellfish Beds Protection Objective 1-2: Support preservation of existing intertidal and subtidal native shellfish habitat by locating new or reconstructed structures and shoreline infrastructure, or new dredging projects, away from high density native shellfish beds.

  Shellfish Beds Protection Action 1-2-1: When new construction or operation of shoreline infrastructure occurs close to shellfish habitat, conduct pre-construction surveys of native shellfish to determine if significant populations (high densities, large adults, multiple age classes) are present.

Native oysters and seaweeds attach themselves to monitoring stakes as part of a project by San Francisco State University researchers on the North Richmond Shoreline.

Shellfish Beds Protection Action 1-2-2: Promote partnerships with cities and counties to ensure that all proposed water intakes (for example, from once-through cooling and desalination facilities) minimize impacts to native shellfish beds by locating structures away from existing native shellfish beds and promoting use of technologies that avoid high levels of larval entrainment (for example, subsurface intakes near large shellfish beds).

SHELLFISH BEDS PROTECTION GOAL 2

Protect areas in San Francisco Bay with potential for future shellfish expansion, restoration, or creation.

- Shellfish Beds Protection Objective 2-1: Purchase subtidal property from willing sellers or create conservation easements for shellfish protection or restoration (including enhancement or creation). (Potential sources of funding may include the National Fish and Wildlife Foundation, The Nature Conservancy, State Coastal Conservancy, Audubon, NOAA Coastal Estuarine Land Conservation Program, land trusts, etc.).

- Shellfish Beds Protection Objective 2-2: If new projects are located in intertidal or subtidal areas, scale and orient them in ways that maintain or improve physical conditions (bathymetry, currents, etc.) needed to support shellfish survival and growth in areas identified in this report for future native shellfish habitat enhancement or creation projects.

Restoration Goals for Shellfish Beds

SHELLFISH BEDS RESTORATION GOAL 1

Increase native oyster populations in San Francisco Bay within 8,000 acres of potential suitable subtidal area over a 50-year time frame through a phased approach conducted within a framework of adaptive management.

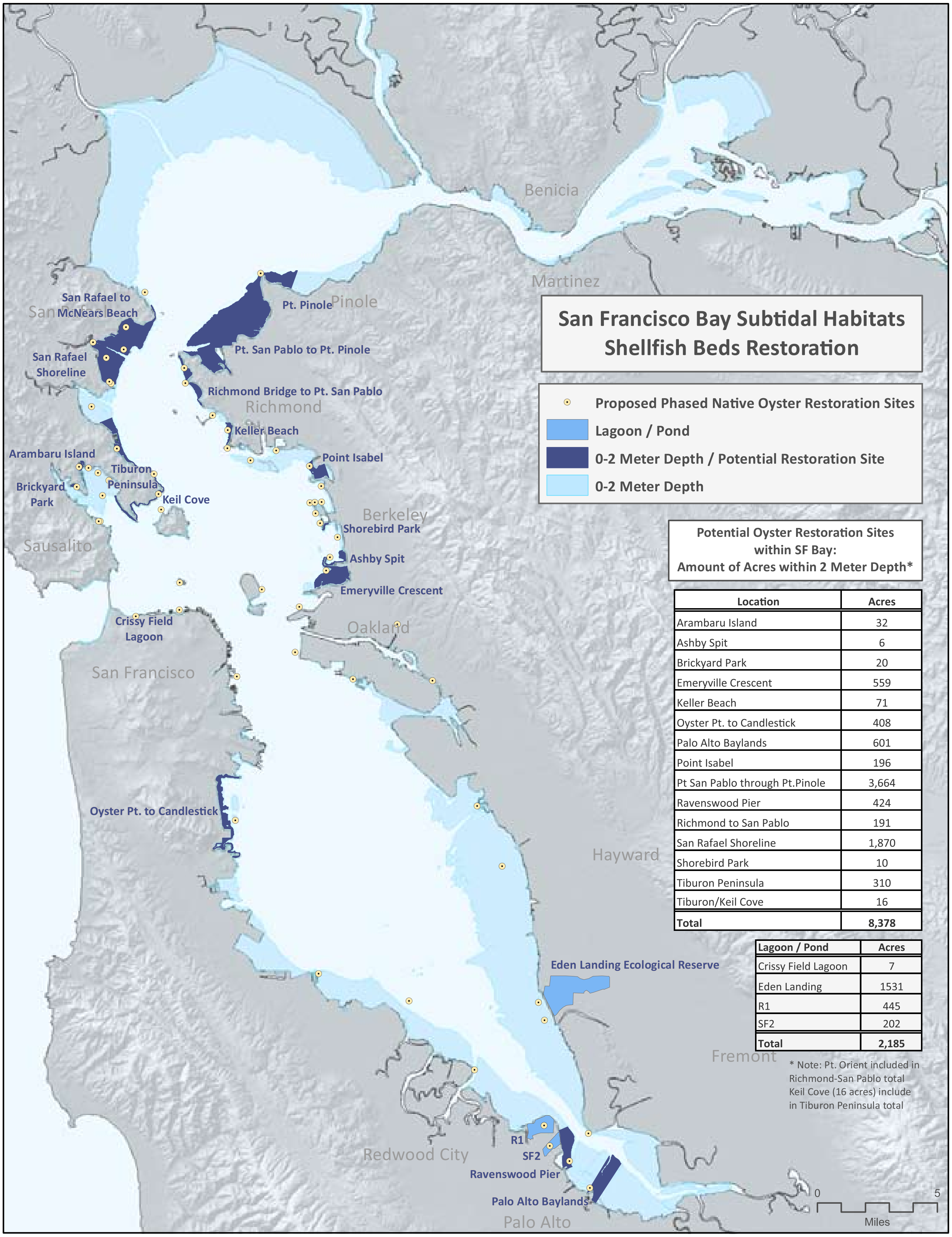
- Shellfish Beds Restoration Objective 1-1: Implement a program of adaptive management with phased restoration. Periodic reviews will determine whether the knowledge is adequate to support proceeding to the next phase. Provisionally the targets would be to increase native oyster populations within 10 acres of subtidal area within 5 years, within 400 acres of subtidal area within 10 years, and within 8,000 acres of subtidal area within a 50-year time frame (Figure 7-6).
- See list of priority native oyster restoration sites below, and more detail in the Native Oyster Restoration Table in Appendix 7-1 for site-specific phased actions.

RECOMMENDATIONS FOR RESTORING OYSTER BEDS

In areas with potential for restoration, UC Davis researchers estimate total potential acreage at preferred sites as 8,000 acres, the area defined by the shoreline segment out to 2m depth, which is about 9% of the total intertidal and subtidal habitat from the shoreline to a 2m depth. The site recommendations below are based largely on the recommendations from previous monitoring and restoration projects, two West Coast Native Oyster workshops, and the San Francisco Bay Native Oyster Working Group, and from participants in a workshop on shellfish restoration held in Tiburon, California in December 2008.

Priority native oyster restoration sites:

Earl F. Dunphy Park, Sausalito
Brickyard Park, Strawberry
Angel Island
Richardson Bay
Arambaru Island, Richardson Bay
San Rafael Shoreline from Marin Rod & Gun Club to south of McNears Beach area
Marin Islands National Wildlife Refuge
Richmond Bridge north to Point Pinole
Point Isabel Regional Shoreline
Albany Beach
Berkeley Shorebird Park
Ashby Spit to Emeryville Crescent
North Cesar Chavez Park, Berkeley
Lake Merritt, Oakland
Oakland Middle Harbor
Area adjacent to San Leandro Marina and nearby shoreline
Eden Landing Ecological Reserve, Hayward
Ravenswood Pier
South Bay Salt Ponds and adjacent offshore subtidal areas
Palo Alto Baylands Nature Preserve
West Point Harbor, Redwood City
Bair Island National Wildlife Refuge, Redwood City
Coyote Point, San Mateo
Oyster Point to area adjacent to Sierra Point Marina, South San Francisco



Location	Acres
Arambaru Island	32
Ashby Spit	6
Brickyard Park	20
Emeryville Crescent	559
Keller Beach	71
Oyster Pt. to Candlestick	408
Palo Alto Baylands	601
Point Isabel	196
Pt San Pablo through Pt.Pinole	3,664
Ravenswood Pier	424
Richmond to San Pablo	191
San Rafael Shoreline	1,870
Shorebird Park	10
Tiburon Peninsula	310
Tiburon/Keil Cove	16
Total	**8,378**

Lagoon / Pond	Acres
Crissy Field Lagoon	7
Eden Landing	1531
R1	445
SF2	202
Total	**2,185**

Figure 7-6: Locations of recommended sites for phased native oyster restoration in San Francisco Bay.

Shellfish Beds Restoration Action 1-1-1: Establish a standing objective review panel to evaluate results and make recommendations on stepping through phases of restoration.

Shellfish Beds Restoration Action 1-1-2: Develop an integrated program of research, pilot projects, and eventually full-scale projects following the adaptive management framework (Chapter 2, Figure 2-3, see Phased Approach above), with the intent of simultaneously increasing the area of shellfish beds and learning about their contributions to ecosystem services. Specific attention should be paid to assessing the quantitative ecosystem response to restoration, and the resulting increases in ecosystem services to be expected.

Shellfish Beds Restoration Action 1-1-3: Develop a programmatic environmental review and permitting process to facilitate subtidal restoration projects, including native oyster restoration projects, to achieve multiple habitat and shoreline protection objectives.

- Shellfish Beds Restoration Objective 1-2: Incorporate native oyster restoration into other regional restoration and shoreline protection projects and initiatives.

Shellfish Beds Restoration Action 1-2-1: Initiate pilot subtidal integration projects, including living shorelines and living breakwaters, to demonstrate effectiveness and collaboration. When appropriate, construct living shorelines, including reef balls™ and other techniques, from native, biodegradable materials, maintenance dredging material that can be beneficially reused, or native rock.

Shellfish Beds Restoration Action 1-2-2: Support public–private partnerships to restore native oysters. Work with regional organizations and agencies to identify partners and projects that could incorporate native oyster restoration and monitoring into existing or planned projects. Groups include the San Francisco Bay Joint Venture, California Department of Fish and Game, Jerico Products, Inc., the Wildlife Conservation Board, and others.

Shellfish Beds Restoration Action 1-2-3: Incorporate San Francisco Bay oyster restoration goals into national strategies such as The Nature Conservancy Shellfish at Risk Program and the National Fish and Wildlife Foundation's Keystone Species Initiatives.

CHAPTER EIGHT

Submerged Aquatic Vegetation

THE TERM "SUBMERGED AQUATIC VEGETATION" (SAV) refers to all underwater flowering plants. In the San Francisco Estuary, SAV includes sago pondweed (*Stuckenia pectinata*, formerly *Potamogeton pectinatus*), eelgrass (*Zostera marina*), and other species of seagrass, including the surfgrasses (*Phyllospadix torreyi* and *P. scouleri),* and widgeongrass (*Ruppia maritima*) (Schaeffer et al. 2007). Several freshwater plant species, mostly introduced, are found mainly in the delta (for example the Brazilian waterweed *Egeria densa*, an invasive nuisance species) and are outside of the geographic scope of this project.

This chapter focuses almost exclusively on eelgrass. In San Francisco Bay, eelgrass is much more extensive than other SAV, and its role and restoration potential are understood better than for other SAV (Appendix 8-1). No quantitative information is available on the extent of eelgrass in the estuary before the 1980s. Because the estuary's water is so turbid, eelgrass was long believed

An eelgrass bed at Keil Cove on the Tiburon Peninsula.

to be uncommon. However, a survey in 1987 reported 128 hectares (316 acres) of eelgrass, determined by inspection and depth-sounding from small boats (Wyllie-Echeverria and Rutten 1989). Surveys using side-scan sonar in 2003 and 2009 found 1,166 and 1,500 hectares of eelgrass beds, respectively (or 2,900 and 3,700 acres respectively), in the subtidal regions of the estuary (Merkel 2004, 2010; see Figure 8-1). However, Merkel (2004) reported that most beds identified from the 1987 survey were larger in the 2004 survey. The more recently determined areas of eelgrass comprise about 1% of the total estuarine area of around 120,000 hectares (or 300,000 acres at mean sea level), not including the delta.

Several factors could have contributed to an increase in eelgrass extent between 1987 and 2003–2009. These include a decrease in suspended sediment in the estuary that occurred around the end of 1998 (Schoellhamer 2009), the long-term improvement in water quality in the bay since the passage of the Clean Water Act, and effects of the 1983 flood and resulting months-long depression of salinity throughout the bay. The increase in reported coverage since 1987 is at least partly due to the much more efficient techniques used in the later surveys.

The reported increase in total acreage from 2003 to 2009 should not be taken as firm evidence of a trend until more surveys have been completed, as all biological populations undergo interannual variation. Furthermore, detailed surveys of individual beds have shown interannual variability in the extent and density of these beds as well as in their reproductive mode, and genetic studies have shown variability among beds, indicating some reproductive isolation (Appendix 8-1). Thus, not only is there interannual variation, but different beds of distinct genetic makeup could vary in different ways.

The largest eelgrass beds in the estuary are in the shallow subtidal regions of San Pablo Bay and Richardson Bay, with smaller beds scattered in shallow areas mainly between Carquinez Strait and the Eden Landing Ecological Reserve in Hayward (see Figure 8-1). The largest bed in the bay is located between Point San Pablo and Point Pinole on the East Bay shoreline, and comprises about half of the total acreage.

The maximum potential coverage of eelgrass is predicted to be 9,490 hectares (23,440 acres) (Merkel 2005), or about 9% of the bay, as determined by a habitat suitability model based on bathymetry (probably accurate only in water accessible by boat), current speed, exposure to wind waves, residence time, and the locations of extant eelgrass beds. Habitat characterized by the model as suitable for the establishment of eelgrass beds occurs at depths less than about 2 m in broad swaths along the shores of San Pablo, Central, and South Bays. About half of this acreage was classified as moderately suitable (modeled habitat suitability index of 34–66%) to highly suitable (67–100%). To date, restoration attempts within areas of high predicted suitability have been successful (Appendix 8-1). An area of Richardson Bay predicted by the model to have

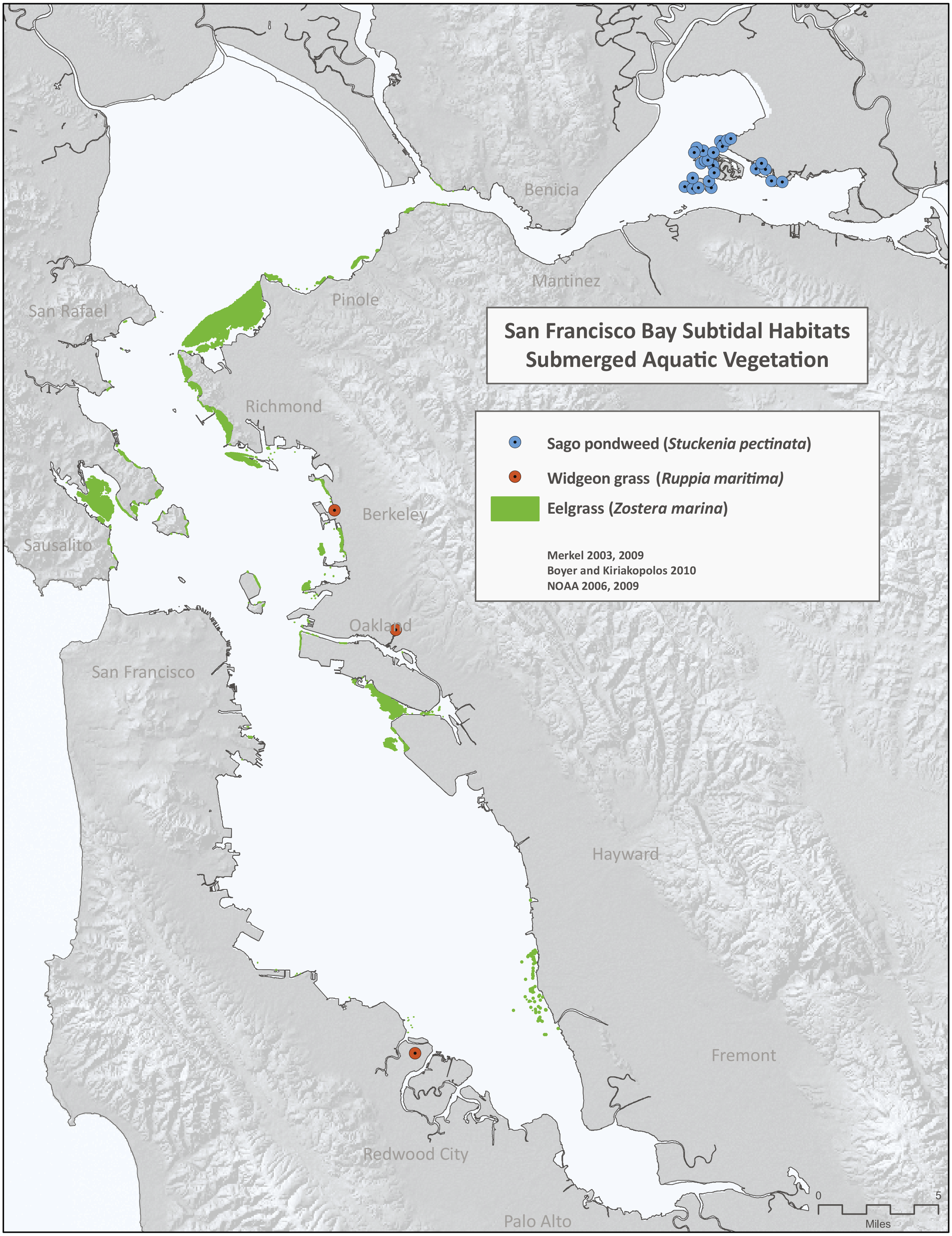


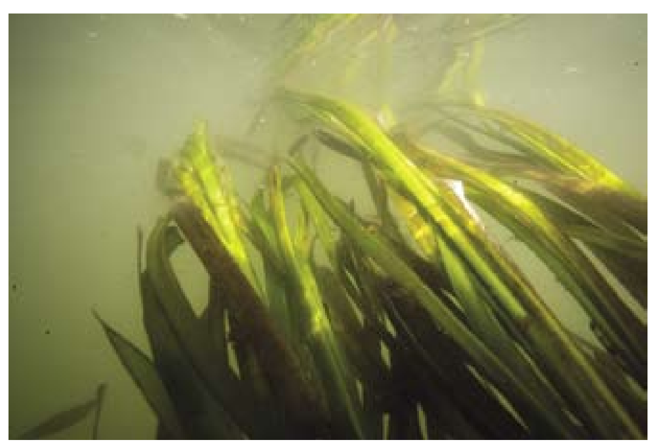
Figure 8-1: Distribution of Submerged Aquatic Vegetation Habitat in San Francisco Bay. Locations for sago pondweed and widgeon grass are approximate.

low suitability (0–33% range) did not support development of an eelgrass bed during a seeding experiment (Boyer et al. 2008).

Bay-wide surveys of eelgrass distribution were conducted in 1987, 2003, and 2009. A more detailed study was conducted in 2006–2009 of seven eelgrass beds chosen to represent a range of conditions and the geographic extent of eelgrass beds in the Bay (see Figure 8-2). Researchers visited the seven beds in spring and summer of each year. Results to date show considerable variability in shoot density among beds, and changes in bed characteristics seasonally and interannually (Appendix 8-1).

Conceptual Model for SAV

Seagrasses perform a wide variety of functions (Figures 8-3 and 8-4; Phillips 1984, Orth et al. 2006, Waycott et al. 2009). They alter local hydrodynamics, reducing the speed of currents. In doing so, they trap and stabilize fine sediment, reducing the average grain size in the bottom sediments and altering the local sediment chemistry. Globally they are much more productive per unit area than phytoplankton (Duarte and Chiscano 1999). Eelgrass transforms unstructured shallow-water areas into physically structured habitat that can support a wide variety of organisms. The complexity of this habitat can support residents that have a variety of life histories and feeding modes (Robertson 1980). Eelgrass beds have higher abundance, biomass, and productivity of consumer organisms than do unstructured habitats (e.g., Connolly 1997). Seagrass beds also provide a food source, either directly to grazers on the seagrass (amphipods, snails, ducks, geese) or indirectly, either to grazers on epiphytes, i.e., plants such as diatoms growing on grass blades, or predators consuming invertebrate grazers, or through detritus formed of dead plant material that supports the estuarine food web. Few fish species consume seagrasses directly, so the food supply from the seagrass beds to fish is indirect. Finally, seagrass beds can serve as ecological sentinels, providing advance warning of deteriorating conditions such as increasing turbidity, wave action, temperature, or contaminants (Orth et al. 2006).



Eelgrass beds thrive in Richardson Bay and Raccoon Strait.

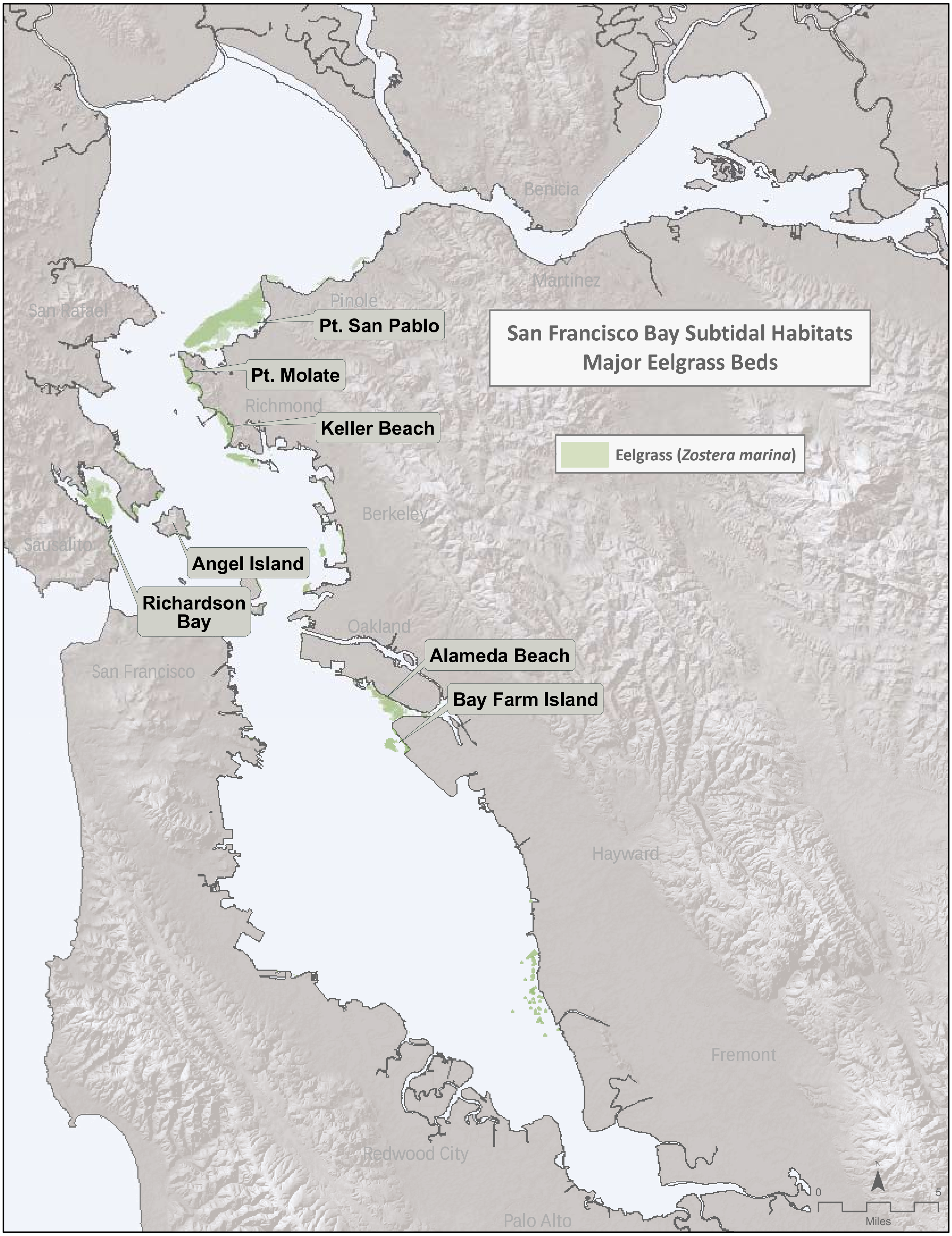


Figure 8-2: Locations of San Francisco State University's Seven Site Eelgrass Bed Survey (2005–2010).

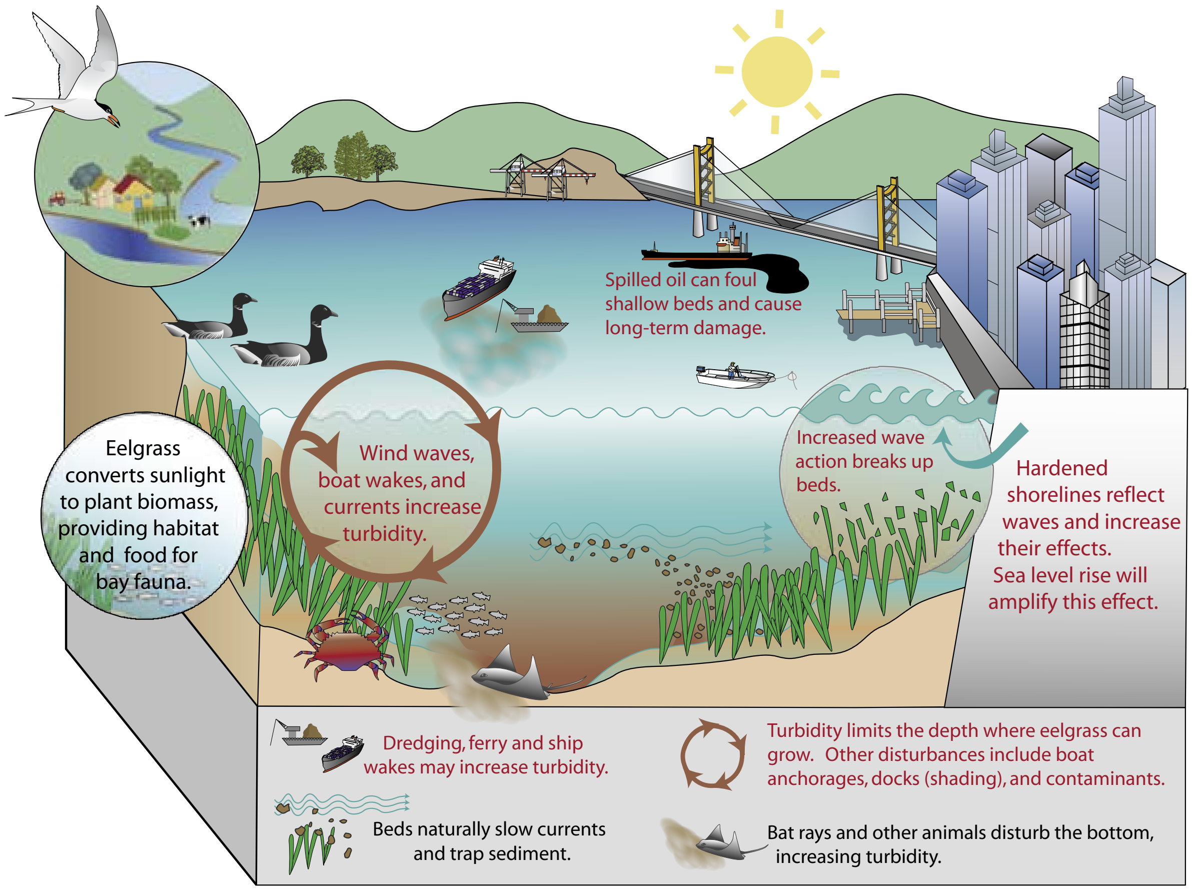


Figure 8-3: Conceptual diagram for eelgrass in San Francisco Bay. This diagram displays processes that occur in and on eelgrass beds, some of the ecosystem services these habitats provide, and threats to eelgrass beds.

Seagrass beds generally are subject to several key limiting factors. First, the beds can be established only where the substrate is suitable, meaning a bottom composed of sand to mud, where current speeds and wave energy are not excessive, and where light penetration is sufficient (i.e., the water is not too deep or too turbid). The more turbid the water, the shallower the maximum depth at which seagrass beds can grow. The supply of seeds or seed-bearing, flowering shoots is important in establishing and maintaining beds (Duarte 1991, Zimmerman et al. 1995). Seeds are denser than water and therefore transport of seeds across areas of deep water is limited (Orth et al. 1994). However, shoots break off and raft over considerable distances before rooting or dropping seeds (Harwell and Orth 2002). Once established, seagrass beds alter the substrate and reinforce their hold on the bottom by extending a network of rhizomes horizontally under the sediment, and produce new shoots vegetatively or by dropping seeds. The tendency of eelgrass to stabilize sediment, grow through shoots, and alter hydrodynamics provides for positive feedback, allowing an established bed to persist.

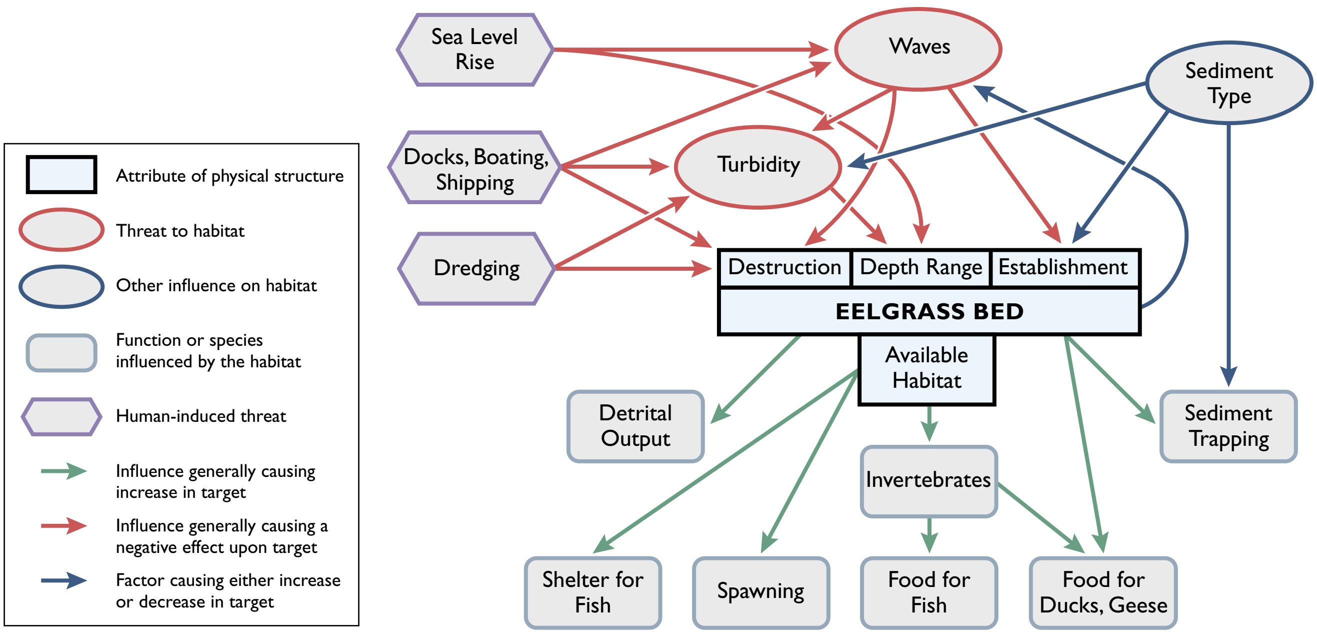


Figure 8-4: Influences on eelgrass beds and functions and services provided by eelgrass beds. The elements in this diagram are site-specific, and all do not apply at all sites. See also Fig. 3 in Thom et al. (2005).

Eelgrass Beds in the San Francisco Estuary

Appendix 8-1 provides a thorough analysis of the current state of knowledge of eelgrass beds in the estuary, including potential for restoration. Eelgrass beds provide shelter and food to small fishes of a variety of species, such as pipefish, staghorn sculpin, and three-spined stickleback (Grant 2009 for Elkhorn Slough). These include species that occupy eelgrass beds for their full life cycle (for example pipefish) and those that use eelgrass beds only as nurseries. The importance of this nursery habitat to the life histories of fish in San Francisco Bay is unknown, although the limited extent of the eelgrass suggests that the more abundant species do not depend on eelgrass beds for any part of their life cycles. Also, the extent to which eelgrass supports species of concern (for example Pacific herring, salmon) is not well known. A substantial increase in extent of eelgrass might provide resources for a wide variety of species.

Eelgrass is used as a substrate for spawning by Pacific herring, which lay sticky eggs on the plant's blades as well as on macroalgae and pier pilings and other hard surfaces. Earlier surveys revealed that most spawning in the Central and South Bays took place on human-built structures, including pier pilings (Watters et al. 2004). However, recent surveys indicate that about half takes place on eelgrass and half on artificial structures (Isaac, CDFG, 2010, pers. comm.). Only in the Northwest Central Bay (e.g., Richardson Bay, Keil Cove) was there substantial spawning on submerged vegetation, indicating that spawning on eelgrass may be limited by the small current extent of beds in the spawning area. Since the creosote in pier pilings may inhibit development of herring embryos (Vines et al. 2000), the importance of eelgrass and possibly other SAV as subsequent recruitment to the herring population may be greater than indicated by the spawning surveys.

The significance of eelgrass beds as a food resource in the San Francisco Estuary is unknown. Primary productivity of Pacific Northwest eelgrass beds is on the order of 200-500 grams carbon per square meter per year (Phillips 1984), which is higher than phytoplankton productivity in the San Francisco Estuary, which is around 100 grams carbon per square meter per year (Cole and Cloern 1984). Productivity of eelgrass in the San Francisco Estuary is currently being estimated (K. Boyer, SFSU, 2009, pers. comm.). However, the limited extent of eelgrass beds means that this extra productivity on an areal basis amounts to very little bay-wide. For example, if the productivity of eelgrass beds is four times that of phytoplankton, at the current areal coverage this amounts to only around 4% of phytoplankton productivity, well below the resolution of any method to measure it. Therefore, the only measurable impact of this productivity is likely to occur within and near the beds themselves, where the combination of complex physical habitat and high productivity should lead to high secondary productivity. This could change, were eelgrass beds to occupy a much larger fraction of their potential range.

Local food production may be important to ducks and geese that feed directly on eelgrass. In particular, brant geese feed almost exclusively on eelgrass in Humboldt Bay (Moore and Black 2006) and Morro Bay (Anonymous 2003). Although not common in San Francisco Bay, brant are seen mainly in eelgrass beds (J. Takekawa, USGS, 2009, pers. comm.). It has been reported that historically, brant congregated in large numbers in San Francisco and San Pablo Bays, but that the population decreased in San Francisco presumably because resources became limited (Grinnell and Miller 1944). Canada geese also feed on eelgrass and their grazing may have an impact on shoot survival and life history patterns (Appendix 8-1). Other birds that feed in eelgrass beds may depend on the eelgrass or on organisms within the beds (Baldwin and Lovvorn 1994).

The invertebrate fauna of eelgrass may be important resources to consumer organisms, including birds and both resident and transient fish. Amphipods

Brant feeds on eelgrass at Drake's Estero.

A moon jelly in an eelgrass bed.

were the most abundant invertebrates on eelgrass at several sites in San Francisco Bay in 2007 (Carr 2008, Carr et al. in press). Experiments in tanks showed a substantial effect of grazing by fish on amphipods, and substantial consumption of both epiphytes and eelgrass blades by amphipods when fish were excluded (Carr 2008). Thus, predation on invertebrates may be an important factor regulating the growth of eelgrass plants and the development of beds. The importance of this consumption to fish is unknown.

When eelgrass reproduces through seeds, generally in summer-fall, dispersal of seeds is facilitated by the movement of flowering shoots, which can float for up to two weeks and drop seeds for up to three weeks (Harwell and Orth 2002). The time scales for dispersal of eelgrass are shorter than estimates of water residence time in the estuary, which are up to 60 days for the northern estuary in summer and much longer for the South Bay (Walters et al. 1985). This implies that a large proportion of the seed-bearing shoots would be retained within the estuary. However, these shoots are highly subject to wind and wind-driven surface currents, which in late spring to fall implies movement generally from west to east.

Although eelgrass can establish in a range of sediment sizes where turbidity is low, once established, eelgrass beds trap mostly fine sediment and thereby further reduce turbidity. The importance of the sediment-trapping function of eelgrass in the San Francisco Estuary is unknown and likely to be localized given current levels of eelgrass coverage. As with productivity, this could change with a greater extent of eelgrass beds, and if the beds were more contiguous. Sediment trapping may be an important function of eelgrass beds that are planted as a part of living shorelines (see Chapter 10). Temperature and salinity can limit eelgrass distribution and growth. In other regions, high water temperatures can contribute to eelgrass mortality (Moore and Jarvis 2008), and wasting disease has been related to high temperature (Orth et al. 2006). Tidal currents and wind waves in many parts of San Francisco Bay are probably strong enough to prevent excessive warming; however, high temperatures have been measured on single dates in limited surveys within eelgrass beds to date (S. Kiriakopolos, unpublished data; Appendix 8-1). Salinity is a limiting factor for eelgrass beds, resulting in their absence farther up the estuary than Carquinez

Strait. However, individual plants are tolerant of low salinity (Phillips 1984), and extended periods of low salinity (as in spring 2006) do not appear to have had a negative influence on extant beds.

Eelgrass beds in the San Francisco Estuary are strongly limited in maximum depth by the high turbidity of the water. In contrast to many locations where eelgrass occurs, this turbidity is due not to phytoplankton but to inorganic mineral particles (Cloern 1987). Therefore competition for light between phytoplankton and eelgrass, a result of eutrophication in many estuaries, is not an issue in the San Francisco Estuary. Rather, growth of both phytoplankton and eelgrass are controlled by turbidity that depends on sediment supply from the rivers, wind waves, and circulation patterns. This may also limit overgrowth by macroalgae, which can otherwise occur in high-nutrient waters (Huntington and Boyer 2008), but has been seen only occasionally within eelgrass beds in San Francisco Bay (see Appendix 8-1, G. Santos, unpublished data.).

Threats to Seagrasses

Seagrasses in general are subject to many threats over short and long time scales (Figures 8-3 and 8-4), most due to human activities (Phillips 1984, Orth et al. 2006), and globally are in a state of decline (Waycott et al. 2009). The principal threat worldwide is probably eutrophication leading to excessive algal biomass and light limitation of seagrass growth (Orth et al. 2006). High temperatures associated with global climate change may increase incidence of wasting disease (Orth et al. 2006). Activities associated with shipping and boating can disrupt seagrass beds directly through destruction of plants by boat propellers, anchors and anchor chains, dredging, and construction of facilities (for example, docks, harbors, breakwaters, ports). Indirect effects arise through increased suspended sediments due to dredging and boat wakes, or shading from overwater structures such as docks. Hardening of the shoreline can reflect waves, increasing wave action and limiting or destroying beds.

Changing bathymetry or sediment composition and increasing water depth due to sea level rise, especially near hardened shorelines, can impede establishment of seagrass beds, cause restoration projects to fail, or damage or destroy existing beds. Development on adjacent shores can increase runoff of fresh water or contaminants or increase turbidity, all with negative impacts on seagrass beds. Invasive eelgrass (*Zostera japonica*) has caused habitat alterations in estuaries of the Pacific Northwest (Larned 2003) and is present in Humboldt Bay.

Most of these threats apply to eelgrass in the San Francisco Estuary but are focused in localized areas. For example, impacts from dredging seem to have a limited spatial and temporal extent (Schoellhamer 2002). Damage from boat anchors, shoreline development, and ship wakes is also likely to be localized (Figures 8-3 and 8-5). Oil spills can inundate and smother eelgrass beds, particularly those in the intertidal or shallow subtidal zones.

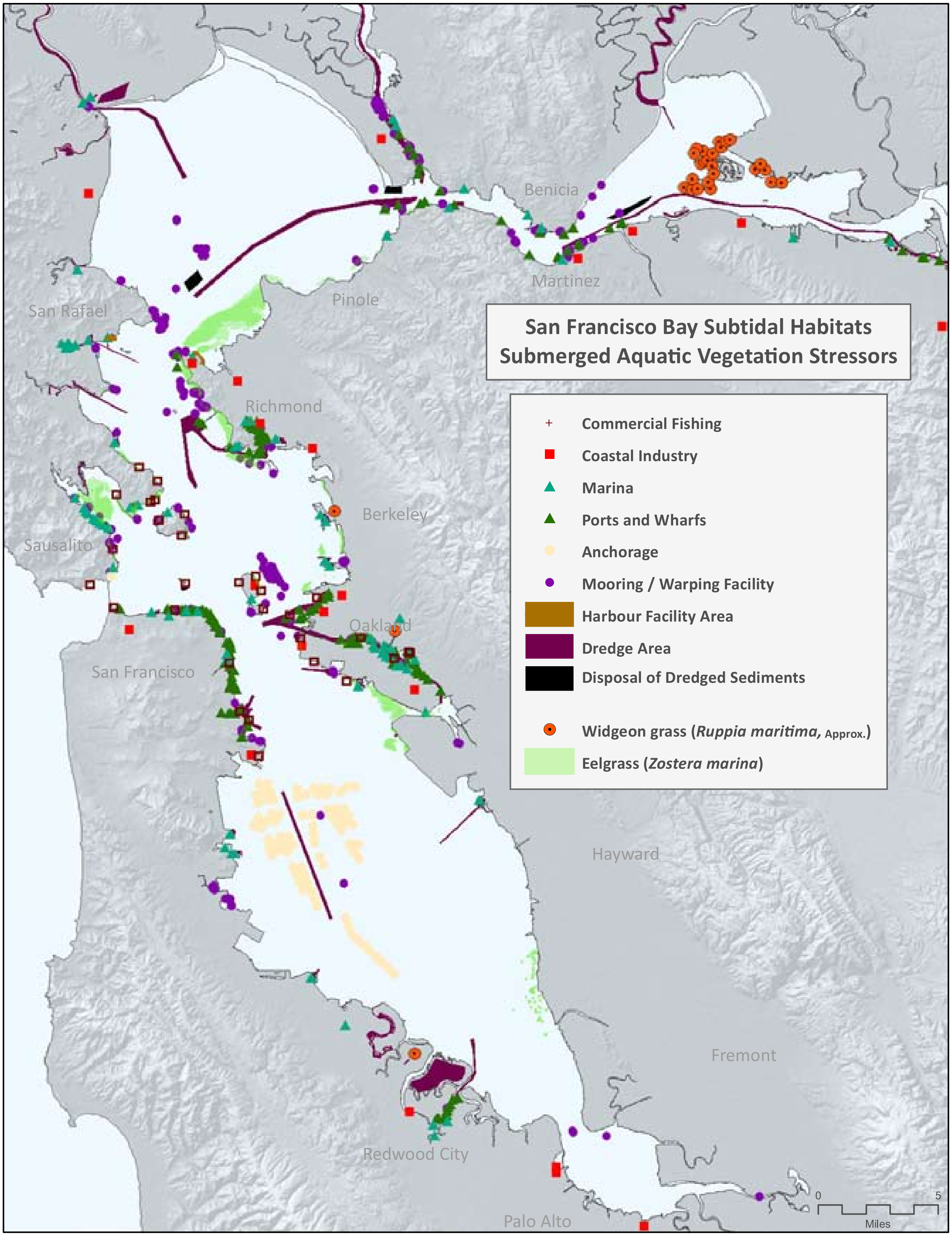


Figure 8-5: Locations of Submerged Aquatic Vegetation Stressors in San Francisco Bay.

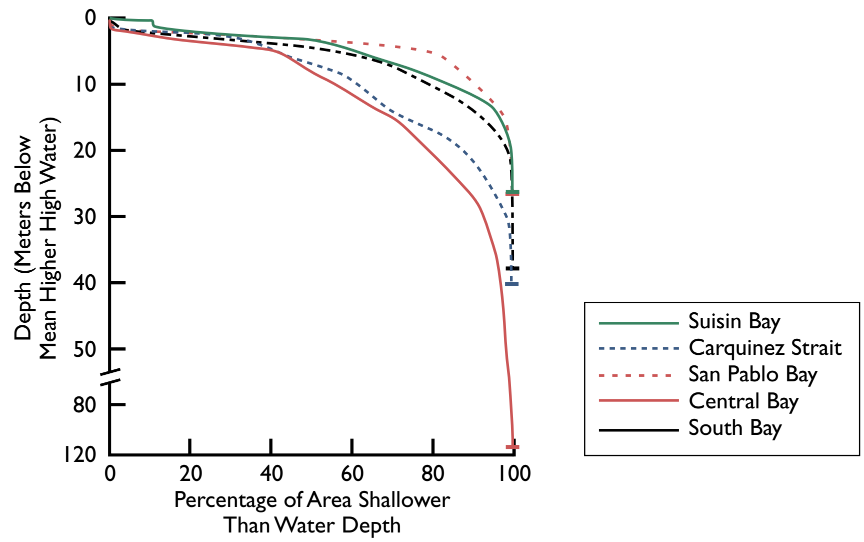


Figure 8-6: Hypsographic curve for the major basins of the San Francisco Estuary (Kimmerer 2010). Each line gives the percent of the geographic area of the basin (x axis) that is shallower than the depth (y axis) below Mean Higher High Water. Symbols indicate deepest depths in each basin. All basins have extensive regions of shallow water (e.g., 79% of the area of San Pablo Bay is 5m or less). The boundary between Central and South San Francisco Bay was set at the Bay Bridge. Data from USGS bathymetric Web site: http://sfbay.wr.usgs.gov/sediment/sfbay/downloads.html.

Rising sea level will affect eelgrass beds in several ways. Where the beds are located on a bottom that slopes gradually to the surface (Figure 8-6), rising sea level may enhance growth at the shallow end of the bed and reduce it at the deep end, resulting in an upward migration of the bed. However, much of the bay is bordered by seawalls or rock revetments, which would limit the landward extent of the beds. In these areas, rising sea level would cause a loss of eelgrass beds in the deeper sections without a concomitant gain in the shallows, possibly exacerbated by increased wave action due to reflection of waves off the seawalls.

Water clarity may be increasing as a result of the long-term decrease in suspended sediment concentration in the estuary (Schoellhamer 2009). This decrease is due mainly to the winnowing out of sediments deposited during hydraulic mining in the late 19th century (Jaffe et al. 2007, Schoellhamer 2009). The likely effects of a continuing increase in water clarity include an increase in phytoplankton productivity and a greater depth range over which eelgrass can survive, although quantitative projections of future outcomes for eelgrass are not yet possible.

Rationale for Establishing Goals for SAV

Applying the approach outlined in Chapter 2, it is clear that the restricted extent of eelgrass beds may be limiting their support of valued ecosystem services. Furthermore, restoration has been demonstrated and is therefore feasible (Appendix 8-1), although questions remain about the anticipated trajectory of restoration and associated response of ecosystem functions and services.

Eelgrass beds can be found at Keller Beach in Miller Knox Regional Shoreline in Point Richmond.

Therefore, restoration is warranted for eelgrass beds, but should be done within an experimental framework (see Adaptive, Phased Approach below, and discussion of adaptive management in Chapter 2).

Goals for eelgrass beds focus on protecting and enhancing existing eelgrass beds, creating additional eelgrass beds, and improving our understanding of ecosystem services, factors influencing the beds, and methods for restoration. Protection goals for eelgrass include protective buffers around eelgrass beds and proposed eelgrass reserves. The recommended protective buffer around eelgrass beds has been determined provisionally based on expert opinion (K. Boyer, SFSU, 2009, pers. comm. and K. Merkel, Merkel and Associates, 2009, pers. comm.), although some habitat function and ecosystem services provided by eelgrass beds can extend beyond this protective buffer. For example, waterfowl congregate within several hundred meters of eelgrass. The Subtidal Goals Project recommends protecting existing, established eelgrass beds by establishing eelgrass reserves. While establishment of eelgrass reserves at selected locations is included as a goal, specific details about how such reserves are established and ultimately function are purposefully not included here and should be developed as part of the process that implements the reserves. Eelgrass is the only habitat type the Subtidal Goals Project recommends protecting through habitat reserves.

The principal restoration goal, pending a satisfactory determination of its benefit, is to restore large areas of eelgrass based on habitat suitability determined by modeling studies (Merkel and Associates 2005). The 50-year maximum restoration targets below are based on the acreage of nearshore areas with moderate to high suitability according to indices of the model. Native eelgrass would be restored not throughout these target areas, but at a subset of locations within these larger areas. The target acreage would increase eelgrass distribution within 50% of identified potential habitat. The long-term acreage targets were developed with the assumption that without restoration efforts eelgrass acreage will remain relatively stable. Should eelgrass acreage increase considerably independent of restoration efforts, such increase should count towards the overall acreage target.

In keeping with the Subtidal Goals Project's precautionary approach, protection goals for other species of SAV, including widgeon grass and sago pondweed, are included while research is conducted to better inform our need for restoration or protection of these non-eelgrass SAV habitats.

Adaptive, Phased Approach to Eelgrass Restoration

An adaptive approach to restoration, conducted in phases from small scale to large (Appendix 8-1), would have two key advantages. First, the effort can begin at small enough scales to be experimentally and logistically tractable and to allow for the learning necessary to expand the scale of restoration projects in subsequent phases. Second, within a program of adaptive management, pursuing restoration in phases can ensure that information is gathered to answer the fundamental questions about the roles of eelgrass (i.e., questions under Science Goal 1, below) and the responses of eelgrass beds to environment (Science Goal 2), as well as questions related to restoration itself (Science Goal 3). That is, at each phase, investigations into the roles and responses of eelgrass beds and the relationship of these to the scale of the restoration will be embedded in any significant restoration project.

The phased approach begins by selecting sites for experimental restoration projects, to refine site selection and restoration methods. Results from this phase will be used to design the pilot phase, which will scale methods to larger areas and also begin to gather evidence about the likely outcomes of restoration. Depending on results from the pilot phase, restoration could be attempted at larger sites, with each step being contingent on the development of evidence in previous phases indicating a high value for restored eelgrass beds (for example a high level of use by herring or other fishes of concern).

The knowledge developed during each phase will be critical for answering the key research questions enumerated below. These include determining the effectiveness of eelgrass restoration in providing valued ecosystem services, the environmental controls on eelgrass beds, and the methods that will maximize the success of the restoration. Of these questions, the most critical is the provision of ecosystem services, since this is the justification for attempting restoration beyond the experimental scale. Thus, our understanding of the extent of ecosystem services provided by restored eelgrass beds must be improved substantially at each phase beyond the experimental phase, before the process moves into the next phase. To continue restoration without this knowledge would risk not only wasting public money if the restoration proves ineffective, but could also jeopardize support for these and other restoration activities.

Criteria for site selection include local conditions (for example depth profile, sediment type, waves and currents, salinity patterns, turbidity) and the environmental context (for example proximity to hardened shorelines, ports or piers, proximity to source beds for seeds, convenience for planting and monitoring), taking into account likely changes in these attributes with long-term trends such as sea level rise and increasing water clarity. Initial work on this has been completed (Appendix 8-1). The phases listed here are based on those enumerated in Appendix 8-1, with the added consideration of bay-wide science goals (see below) and the need to address fundamental questions about the value of restored eelgrass beds as restoration progresses. Thus, the phases have

NATIVE EELGRASS MONITORING AND RESTORATION PILOT PROJECTS TO DATE

- UC Berkeley, William Setchell surveys: 1923–1929
- University of WA, Sandy Wyllie-Echeverria surveys, common garden: 1986, 1987
- Wyllie-Echeverria and Rutten 1989
- Wyllie-Echeverria and Kitting 1990
- Fonseca et al. 1998
- Hanson 1998
- Merkel 2003, 2009
- Boyer et al. 2005–2010

PHASES IN AN SAV RESTORATION EFFORT

PHASE I. EXPERIMENTAL RESTORATION

This phase will develop the experimental design for the restoration to answer key questions about sites and methods (science goals). The phases within this group should be followed in sequence but can be accomplished for different sites at different times.

Phase I-1: No prior knowledge of site

Conduct a basic site survey.

Phase I-2: Limited site knowledge

Condition: Mapping or surveys have been conducted.

- Assess suitability of the site for restoration.

Phase I-3: Experimental restoration

Condition: Phase 1-1 and 1-2 actions completed; area is unlikely to recruit naturally and is suitable.

- Determine experimental design to fit the site.
- Establish replicated small-scale test plots at various elevations, donors, and other treatments.
- Evaluate outcomes: plant persistence, spread, abiotic conditions, use by other organisms.
- Include evaluation of restoration potential and lessons learned in a report.

  Following this phase an evaluation takes place in which decisions are made about whether and to what extent to proceed into pilot restoration. This decision should be made largely on the basis of feasibility and conditions at individual sites.

PHASE II: PILOT RESTORATION

This phase will expand on the previous experimental phase to determine the suitability of alternative methods of restoration at a larger scale than the experimental scale. It will also begin to evaluate the larger implications of restoration for its value in increasing the provision of ecosystem services (science goals 1 and 2 below).

Condition: Phase I has been completed for candidate site, and site remains suitable.

- Design small pilot restoration project (0.5 acre or less) to test hypotheses developed or provisionally tested in Phase I.
- Include explicit measures to determine quantitatively the use of the restored site by organisms and other evidence about the likely benefits of restoration in the design.
- Establish replicated moderate-scale test plots.
- In the second year of the program, begin to assess aspects of ecosystem function (e.g., spawning substrate and nursery and foraging habitat).
- Evaluate outcomes including those in Phase I, and aspects of ecosystem function.
- Include evaluation of restoration potential, value, and lessons learned in a report.

  Following this phase an evaluation takes place in which decisions are made about whether and to what extent to proceed into larger-scale restoration. The decision about whether to expand the scale of restoration should be based on an assessment that the restored eelgrass beds likely provide ecosystem services commensurate with the cost and effort involved in the restoration. This decision could be made provisionally on the basis of a few pilot projects, and re-evaluated as more pilot projects are completed. The decisions about where and how to restore should be based on lessons learned from individual sites about feasibility and conditions.

PHASE III. LARGER-SCALE RESTORATION PROJECT

This phase will expand on the pilot phase with the principal purpose being to evaluate the larger implications of restoration for its value in increasing the provision of ecosystem services (Science Goals 1 and 2 below). This phase will also determine how alternative methods of restoration scale up beyond the pilot scale.

Condition: Phase II has been completed for candidate site, and site remains suitable.

- Design intermediate-scale restoration project (~1 acre) to answer questions under Science Goals 1 and 2, and to further develop the art and science of eelgrass restoration.
- Include explicit measures to determine quantitatively the use of the restored site by organisms and other evidence about the likely benefits of restoration in the design.
- Establish replicable larger-scale test plots.
- In the second year of the program, begin to assess aspects of ecosystem function (e.g., spawning substrate and nursery and foraging habitat).
- Evaluate the response of ecosystem functions and likely ecosystem services.
- Include evaluation of restoration potential, value, and lessons learned in a report.

  If the value of the restoration as estimated in this phase continues to suggest further expansion, this phase may be repeated at different sites as pilot programs are completed, and the acreage target expanded at each site and the above process repeated. The decision about whether to expand the scale of restoration should be based on an assessment that the restored eelgrass beds likely provide ecosystem services commensurate with the cost and effort involved in the restoration. This decision would remain provisional with additional information coming in as pilot and then larger-scale projects are completed. The decisions about where and how to restore should be based on lessons learned from individual sites about feasibility and conditions.

  At this scale a critical issue is the long-term viability of the restored eelgrass beds and their provision of ecosystem services.

been expanded to encompass steps in an adaptive management program. See Appendix 8-1 for methods that may be applied in each phase.

Science Goals for SAV

Most of the science questions for SAV parallel those for shellfish, so much of the information below is duplicated in both sections. Goal 1 also applies to other SAV beds not covered explicitly here, although these may be assigned a lower priority given the greater extent of, and research interest in, eelgrass beds.

SUBMERGED AQUATIC VEGETATION SCIENCE GOAL 1

Understand the ecosystem services the eelgrass beds support, and in what quantities, in their current state and after restoration.

Question A. What specific functions do eelgrass beds support?

San Francisco State University researchers get ready to monitor eelgrass.

This question could be addressed in part by an examination of extant beds in different parts of the bay, supplemented by lessons learned during early restoration.

Question B. How much is attributable to the structure vs. the plants?

The basis for this question is discussed above.

Question C. How do the functions of restored eelgrass beds scale with the total area restored?

If eelgrass beds are being restored to support ecosystem services, enough beds must be restored to provide a substantial increase in these services. These services may scale linearly with the increase in bed area, or some other way (see Figure 2-2 in Chapter 2). For example, there may be a threshold of bed area above which some part of the ecosystem shifts into a different, preferable state, in which case the cumulative restoration must exceed the threshold before this benefit is achieved.

These subtle interactions would be difficult to determine, particularly before restoration began. Assuming a linear response, though, it should be possible to calculate the extent or value of an ecosystem service of existing natural or previously restored eelgrass beds, perhaps in terms of food, structural habitat for fishes and birds of concern, and shoreline protection per unit area or shoreline distance. This information could be used to project the value of the restored habitat, and to update this projection with newly gathered data. This projection should be done assuming that the functions of eelgrass beds may vary geographically.

A corollary of this question is how does the degree of fragmentation of the habitat influence its function, i.e., does a series of fragments perform the same function as a contiguous habitat of the same area?

Understand the factors controlling the development and persistence of eelgrass beds.

Question A. How do individual beds respond to their local biotic and abiotic environment?

Salinity, temperature, wind and wave patterns, currents, sediment delivery, and consumption may all play a role in the growth or shrinkage of eelgrass beds. However, these influences are understood only at the most basic level.

Question B. What limits the establishment of new beds, either under natural conditions or as restoration projects?

Eelgrass can establish most readily in shallow water sediments. Sandy sediments are usually associated with strong currents or wind waves that winnow out the finer particles, whereas muddy sediments are associated with high turbidity. Therefore, eelgrass may establish only under rare conditions, such as a period of neap tide with light winds (necessary for the plants to stay put) following a spring tide with storms that sort the sediment. Once a bed is established, it traps sediments, and the grain size becomes progressively finer without impairing the bed. Therefore it may be possible to establish beds in areas of fine-grained sediments, provided the other limiting factors are minimized.

The native sea slug *Phyllaplysia sp.* lives in eelgrass beds in San Francisco Bay.

Question C. How do estuarine currents including wind-driven circulation influence the movement of seed-bearing shoots and subsequent recruitment?

Once beds have been established, the potential exists for them to send seeds to other areas of the estuary and to establish remote daughter beds. This potential depends on duration of the dispersive stage and the very specific details of circulation both at the scale of the beds themselves and at a broader scale.

At the scale of estuarine basins or even the whole estuary, regions of high abundance of mature eelgrass plants are likely seeding those of low abundance, and the supply of seeds at any one location may have little to do with the abundance of mature plants at that location. Large restoration sites may therefore contribute to settlement and even establishment of beds in remote locations provided the substrate is available and the local and regional currents are favorable. At the scale of individual beds, the rate of settlement is likely affected by local conditions.

Question D. What is the degree of connectivity among beds?

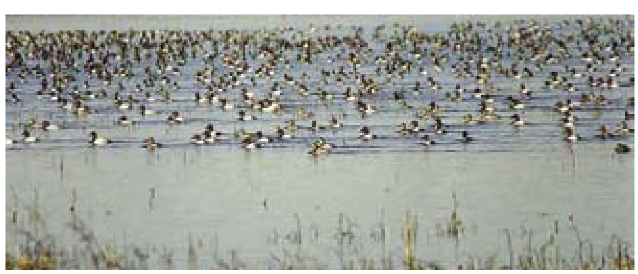
The previous question can be turned around: how do population and genetic structure vary among beds, and what can that tell us about the connectivity among beds? This is a particularly important component for understanding the larger-scale issues raised under Goal 1, Question C. Note that genetic structure and ecologically relevant population structure are likely to be different and operate at different scales, and require different tools for investigation. Research to date indicates considerable genetic structure among eelgrass beds, implying low connectivity and possibly selection based on local conditions. This must be considered in collecting donor material for restoration.

Question E. How do size of and density in a bed, and fragmentation of beds, influence persistence and expansion?

Beds vary in space and time in their spatial extent, shoot density, and degree of fragmentation. The factors that produce these changes and the effect of these changes on persistence of beds are unknown. For example, is a decrease in shoot density a harbinger of bed collapse and under what conditions?

Question F. What is the extent of mortality in eelgrass beds due to exogenous factors and what controls die-back and recovery?

Eelgrass beds do not seem very susceptible to low salinity, but the size and extent of beds can vary substantially from year to year, through some combination of die-back, seeding, and vegetative growth.



Canvasbacks congregate in large numbers in eelgrass beds in the bay.

Kayaks are an efficient, shallow draft boat used to access shallow subtidal areas in the bay. Richardson Bay Audubon conducted GPS surveys of eelgrass beds in Richardson Bay in 2006; this model could be expanded to include volunteers who want to monitor additional eelgrass beds in the bay.

SUBMERGED AQUATIC VEGETATION SCIENCE GOAL 3

Develop the most effective ways of restoring and protecting eelgrass beds.

Question A. How do physical structures, spacing, and orientation of restored beds interact with the local environment to influence the rate of seed and vegetative shoot settlement and survival?

Local conditions including salinity, currents, and the supply rate of sediment and seeds are likely to influence settlement and survival. Design of eelgrass beds may influence settlement and survival differently depending on these local conditions. Therefore lessons from one site may not be entirely transferable to another.

Question B. What is the influence of grazing disease, and algal overgrowth on the success of restoration?

Disease has not yet been identified as a significant factor in the dynamics of eelgrass populations in the estuary. This could change with increasing population density, and effects are likely to be sporadic and therefore difficult to detect and assess. Consumption by grazers is both a source of mortality and a means by which the beds support ecosystem processes, so some amount of consumption is consistent with "success."

Question C. How can beds be designed and built so as to minimize the need for ongoing intervention?

Minimizing human intervention would reduce the cost of restoration and increase the likelihood of long-term persistence of the beds. This does not eliminate the need for periodic monitoring.

Question D. How do oyster beds and eelgrass beds interact, and how do they interact with other habitats?

Since some of the functions of eelgrass and oyster beds are similar, there may be advantages to establishing them in close proximity. Also, restoration should take into account potential negative effects on other habitats or values, or on eelgrass beds because of other habitats.

Question E. How do wind waves, wakes, and turbidity affect eelgrass beds?

Wave action can affect beds directly or through increases in turbidity. Better information on the extent to which vessel wakes and turbidity disrupt eelgrass beds can inform the potential use and size of buffer zones to limit this damage.

Question F. Where and when do introduced species or macroalgal blooms damage or degrade eelgrass beds?

Disruption by potential introduced species such as the eelgrass *Z. japonica* could be considerable, and early detection is necessary to allow eradication to be attempted. Macroalgal blooms also have the potential to damage eelgrass. In other locations where algal blooms threaten seagrasses, the principal cause of the blooms is excessive nutrient loading. That is not the case in San Francisco Bay, where turbidity severely limits plant growth and nutrient concentrations are usually high. However, algal blooms might be stimulated by an increase in water clarity either due to the action of the eelgrasses themselves, or to broader-scale changes in sediment loads or distribution.

Question G. What are the best methods and timing for eelgrass restoration that minimize settlement of invasive species?

SUBMERGED AQUATIC VEGETATION SCIENCE GOAL 4

Assess the status and distribution of other SAV.

Question A. What is the distribution and abundance of each of the native SAV species other than eelgrass?

Protection Goals for SAV

SUBMERGED AQUATIC VEGETATION PROTECTION GOAL 1

Protect existing eelgrass habitat in San Francisco Bay through no net loss to existing beds. (Baseline is considered to be 3,700 acres in October 2009.)

- Eelgrass Beds Protection Objective 1-1: Promote protection of eelgrass beds through collaboration with the boating community.

  Submerged Aquatic Vegetation Protection Action 1-1-1: Develop and use best boating practices to reduce impacts from propellers, anchors, and anchor chains.

  Promote stewardship of eelgrass by placing educational materials and signs at marinas. Collaborate with the boating community to develop no-wake zones and avoidance areas to preserve eelgrass habitats. Place markers or buoys around eelgrass beds to demarcate the slower speed zone and the presence of eelgrass.

Recreational boaters can protect eelgrass beds by not anchoring directly in the beds, and taking care to prevent accidental groundings.

Submerged Aquatic Vegetation Protection Action 1-1-2: When developing new ferry routes and terminals locate them away from existing eelgrass beds.

Submerged Aquatic Vegetation Protection Action 1-1-3: Replace existing permitted moorings within or adjacent to (150 feet) existing eelgrass beds with non-dragging mooring chains. Remove unpermitted moorings within and adjacent to (150 feet) of eelgrass beds.

Submerged Aquatic Vegetation Protection Action 1-1-4: Locate new mooring areas at least 150 feet away from existing eelgrass beds.

Submerged Aquatic Vegetation Protection Action 1-1-5: Anchor barges or vessels outside of existing eelgrass habitat.

- Submerged Aquatic Vegetation Protection Objective 1-2: Support preservation of existing eelgrass beds by locating new or reconstructed structures (for example docks, piers) or new dredging projects away from eelgrass beds.

Submerged Aquatic Vegetation Protection Action 1-2-1: For new or expanded docks or structures, encourage placement at a minimum of 150 feet from existing eelgrass beds.

Submerged Aquatic Vegetation Protection Action 1-2-2: Promote use of light transmitting materials and techniques (for example grating, spacing between deck boards) in dock and pier reconstruction projects.

Submerged Aquatic Vegetation Protection Action 1-2-3: For new dredging projects, encourage placement outside existing eelgrass beds and not closer than 150 feet.

SUBMERGED AQUATIC VEGETATION PROTECTION GOAL 2

Fruiting sago pondweed.

Establish eelgrass reserves.

- **Submerged Aquatic Vegetation Protection Objective 2-1:** Establish eelgrass reserves for existing eelgrass beds with unique qualities (for example oldest beds, extensive history of research, donor populations, value to fisheries). Potential reserve sites include the following eelgrass beds:
    - Keil Cove
    - Point San Pablo
    - Point Molate
    - Richardson Bay
    - Crown Beach
    - Bay Farm Island
    - Eden Landing Ecological Reserve
    - Coyote Point

  Submerged Aquatic Vegetation Protection Action 2-1-1: Develop a committee to identify, implement, and evaluate a mechanism for establishing and managing the eelgrass reserves, and any potential areas for future eelgrass reserve designation.

SUBMERGED AQUATIC VEGETATION PROTECTION GOAL 3

Widgeon grass bud/emerging flower.

Identify and protect areas in San Francisco Bay for future eelgrass expansion, restoration, or creation.

- **Submerged Aquatic Vegetation Protection Objective 3-1:** Maintain and improve physical conditions (for example to bathymetry, light availability, currents) needed to support eelgrass survival and growth in areas identified in this report for future eelgrass restoration.

- **Submerged Aquatic Vegetation Protection Objective 3-2:** Purchase subtidal property from willing sellers or create conservation easements for eelgrass beds that are privately owned. (Potential sources of funding may include but are not limited to The Nature Conservancy, State Coastal Conservancy, Audubon, Coastal Estuarine Land Conservation Program, land trusts, etc.).

SUBMERGED AQUATIC VEGETATION PROTECTION GOAL 4

Protect existing widgeon grass habitat in San Francisco Bay.

Left: "Seed bags"—mesh bags with eelgrass seeds from donor beds—are used to create new eelgrass beds.

Right: Seed bags are hung from buoys at restoration sites, where the seeds drop and propagate eelgrass.

SUBMERGED AQUATIC VEGETATION PROTECTION GOAL 5

Protect existing sago pondweed habitat in San Francisco Bay.

Restoration Goals for SAV

SUBMERGED AQUATIC VEGETATION RESTORATION GOAL 1

Increase native eelgrass populations in San Francisco Bay within 8,000 acres of suitable subtidal/intertidal area over a 50-year time frame using a phased approach under a program of adaptive management.

- Submerged Aquatic Vegetation Restoration Objective 1-1: Implement a program of adaptive management with phased restoration. Periodic reviews will determine whether the knowledge is adequate to support proceeding to the next phase. Provisionally the targets would be to increase native eelgrass habitat by 25 acres within 5 years, 100 acres within 10 years, and up to 8,000 acres within 50 years, at 35 locations. (See site list below, and more detail in Native Eelgrass Restoration Table in Appendix 8-1 for site-specific phased actions.)

  Submerged Aquatic Vegetation Restoration Action 1-1-1: Establish an objective review panel to evaluate evidence and make recommendations on stepping through phases of restoration.

  Submerged Aquatic Vegetation Restoration Action 1-1-2: Develop a programmatic environmental review and permitting process to facilitate subtidal restoration projects, including native eelgrass restoration projects, to achieve multiple habitat and shoreline protection objectives.

The following site recommendations are based largely on the recommendations from previous monitoring and restoration projects, one San Francisco Bay native eelgrass workshop in 2006, and from participants in an eelgrass restoration workshop held in Tiburon, California in December 2008.

Algae grows on eelgrass blades.

Priority native eelgrass survey and restoration sites:

- Corte Madera Bay near the Corte Madera and Muzzi Marshes
- San Rafael shoreline to quarry near Point San Pedro
- Horseshoe Cove, Sausalito
- Richardson Bay
- West of Point San Pedro along the shoreline of China Camp State Park
- North Richmond Bed from Richmond Bridge to Carquinez Bridge
- Albany and Berkeley shorelines
- Emeryville Crescent
- Middle Harbor, Oakland
- Alameda Naval Air Station
- Hayward Shoreline
- Eden Landing Ecological Reserve
- Coyote Point area, San Mateo
- Near Piers 94 and 98, San Francisco

See Figure 8-7 for a map of existing and proposed sites for eelgrass restoration.

- **Submerged Aquatic Vegetation Restoration Objective 1-2:** Incorporate native eelgrass restoration into other regional restoration and shoreline protection projects and initiatives.

  Submerged Aquatic Vegetation Restoration Action 1-2-1: Initiate pilot subtidal integration projects that incorporate native eelgrass.

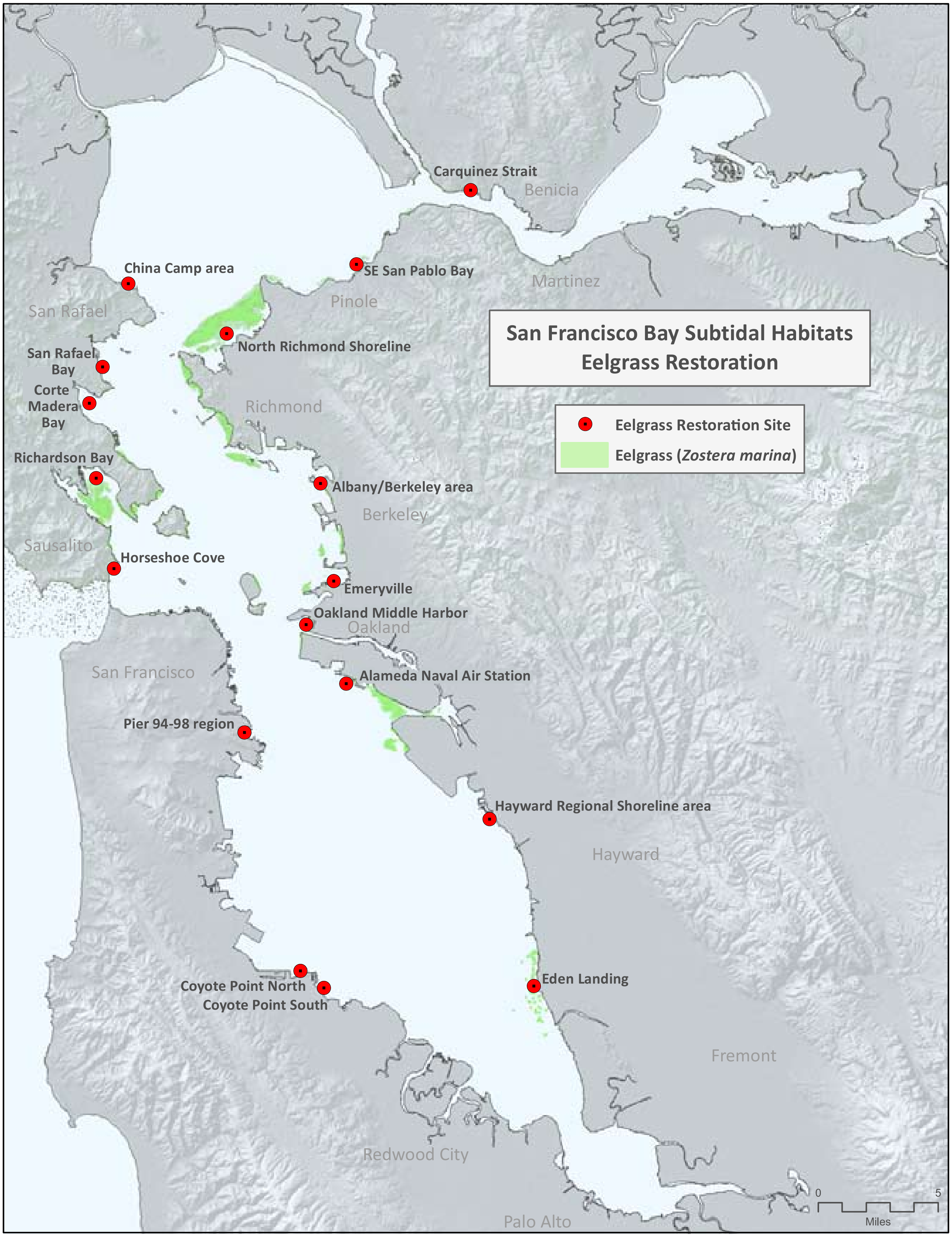
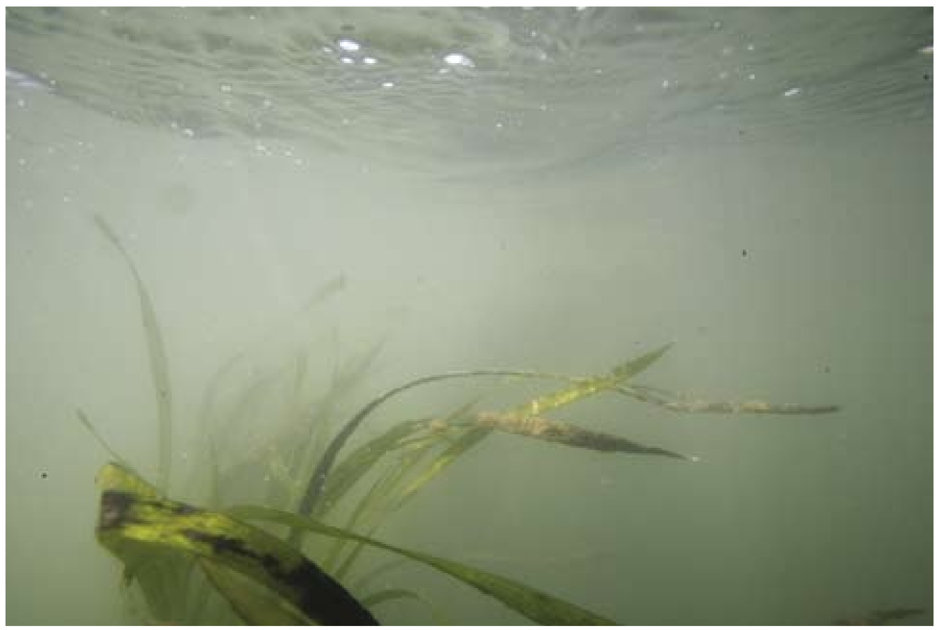


Figure 8-7: Recommended sites for phased native eelgrass restoration in San Francisco Bay.

Submerged Aquatic Vegetation Restoration Action 1-2-3: Support public–private partnerships to restore native SAV. Work with regional organizations and agencies to identify partners who could incorporate native eelgrass restoration and monitoring into existing or planned projects. Possible partners include the San Francisco Bay Joint Venture, California Department of Fish and Game, the Wildlife Conservation Board, industry, and others.

Submerged Aquatic Vegetation Restoration Action 1-2-4: Incorporate San Francisco Bay eelgrass restoration goals into national restoration strategies, such as SeaGrass.net monitoring and NOAA Restoration Center programs.

Submerged Aquatic Vegetation Restoration Action 1-2-5: Incorporate existing eelgrass beds into fish tracking studies conducted through the Long Term Management Strategy Science Work Group.



Eelgrass in Richardson Bay.

CHAPTER NINE

Macroalgal Beds

Beds of macroalgae constitute the third biogenic habitat along with submerged aquatic vegetation and shellfish beds in San Francisco Bay and are by far the smallest in total extent. Four species of macroalgae were listed by NOAA (Schaeffer et al. 2007) as sufficiently abundant to form beds: *Ulva* spp., *Gracilaria pacifica*, *Fucus gardneri*, and the introduced *Sargassum muticum*. The extent and characteristics of algal beds in San Francisco Estuary are poorly known. Together, Silva (1979) and Josselyn and West (1985) reported 162 species of macroalgae in San Francisco Bay of which 33 were estuarine and the remainder characteristic of the California coast. Five species have been reported as introduced in the bay. No quantitative analysis of the extent of subtidal beds has been conducted, although a subtidal *Laminaria* (kelp) bed has been identified off Raccoon Strait. Efforts have been made to eradicate the North Atlantic brown alga *Ascophyllum nodosum* from the bay (Miller et al. 2004). A seasonal survey of macroalgal abundance and species composition within eelgrass beds is underway (see Appendix 8-1).

Brown "feather boa" kelp, *Egregia menziesii,* occurs in the more marine regions of the Central Bay.

Like eelgrass beds, macroalgal beds provide both physical habitat and food for numerous organisms (Figures 9-1, 9-2). Also like eelgrass beds, subtidal macroalgal beds can alter flow fields, providing small organisms with shelter from currents and predators, and can trap sediments, alter sediment chemistry, and provide a substrate for spawning. The red algae, *Gracilaria/Gracilariopsis* spp., are important substrate for herring roe in the bay (Ryan Watanabe, CDFG, pers. comm.). Intertidal macroalgae can retain water, providing a refuge for intertidal organisms like juvenile Dungeness crabs during low tides.

Although algal beds constitute biogenic habitats, it is not clear whether they are always a desirable habitat. Beds of some macroalgae, including *Ulva* spp. and *Gracilaria pacifica,* can form nuisance blooms in response to high nutrient concentrations, and may overgrow eelgrass and interfere with their photosynthesis. However, to date there is little evidence of the formation of nuisance blooms in the bay, although Nichols (1979) did report decaying mats of algae in the South Bay in the summer of 1975.

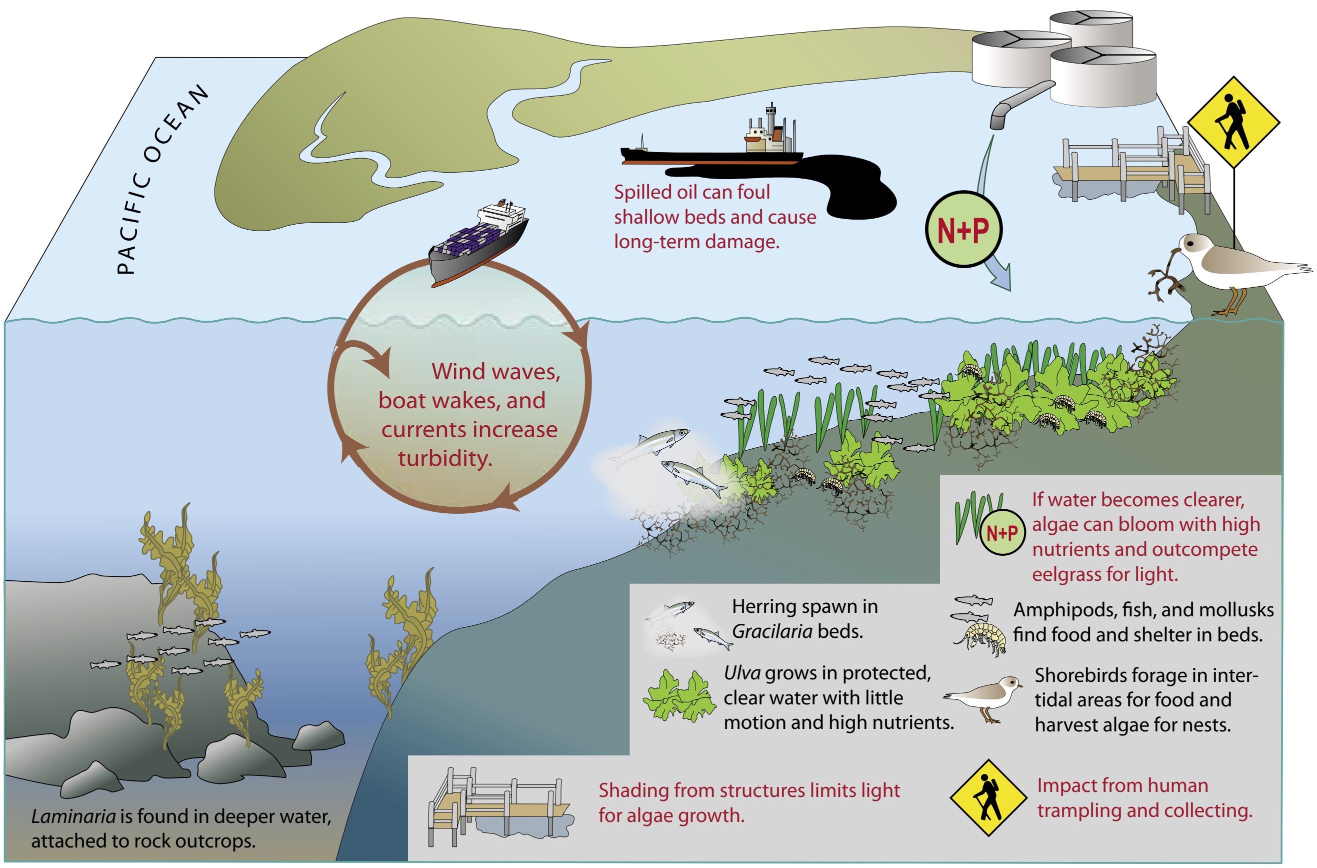


Figure 9-1: Conceptual diagram for algal beds in the San Francisco Estuary. This diagram displays processes that occur in and on algal beds, some of the ecosystem services these habitats provide, and threats to algal beds.

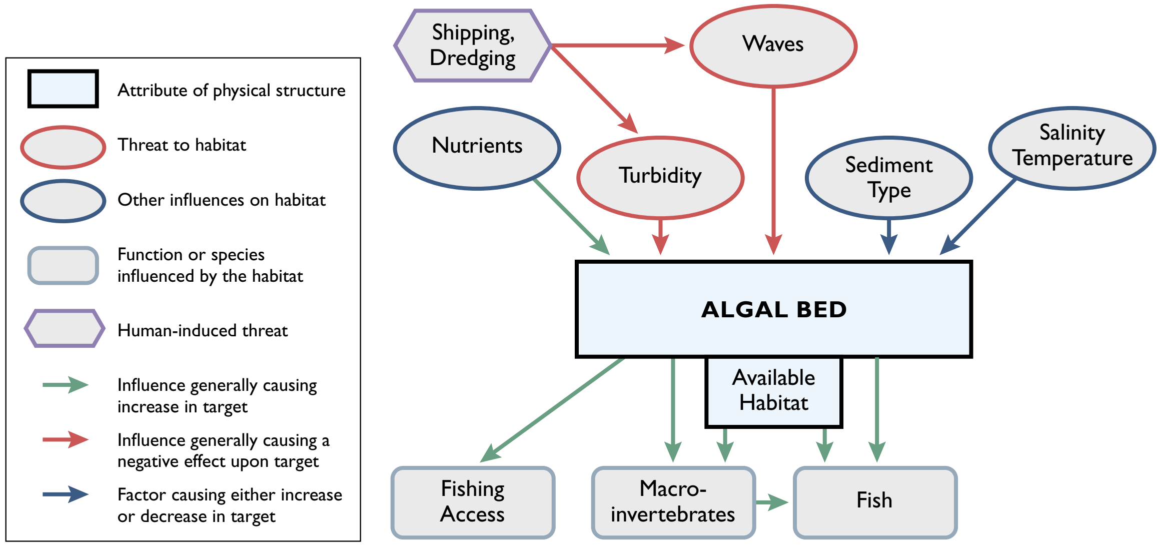


Figure 9-2: Influences on macroalgal beds and functions and services provided by algal beds. The elements in this diagram are site- and species-specific, and all do not apply at all sites.

Conceptual Model for Macroalgal Beds

Many common seaweeds can be found in San Francisco Bay, including sea lettuce (*Ulva* spp.), rockweed *(Fucus gardneri)*, and Turkish towel *(Gigartina papillata)*.

In contrast to eelgrass, many macroalgae provide a suitable food source to a variety of grazers, predominantly macroinvertebrates. At least one amphipod species, *Amphithoe valida*, readily consumes *Gracilaria* sp. (K. Boyer, SFSU, 2009 and 2010, pers. comm.). Gulls and cormorants will pick macroalgae from the intertidal beach wrack to line their nests. The wrack produced by macroalgae is an important food source for invertebrates living interstitially on beaches, mudflats, and marshes. These invertebrates in turn provide a food source for shorebirds and many other species along the shore. In contrast to tropical regions where many herbivorous fish species feed on macroalgae, a relatively small number of fish species in temperate regions use macroalgae as a substantial part of the diet. The topsmelt, *Atherinops affinis*, common in San Francisco Bay, can feed on macroalgae (Logothetis et al. 2001). There is no published information on the importance of algal beds in support of populations of consumer organisms in the bay.

Estuarine species of macroalgae differ greatly in morphology, biochemistry, and habitat requirements. Some species of macroalgae are abundant in rocky high-energy sites with strong currents and breaking waves. Others are more abundant in protected waters, where they can form beds on soft substrate (Josselyn and West 1985). Some macroalgae can have very high nutrient uptake rates that do not saturate (Kamer et al. 2004) and can therefore take advantage of the usually high nutrient concentrations in San Francisco Bay (Cloern 1999, but see Dugdale et al. 2007). The high turbidity of the bay may inhibit algal bloom formation as it does for phytoplankton and eelgrass, except in intertidal areas. In addition, low-salinity pulses likely reduce the viability of algal beds within the estuary, particularly outside of the Central Bay, but stress on macroalgae from high and low temperatures is unlikely except in sunny intertidal

Feather boa kelp on the shores of Angel Island.

locations. The distributions and local abundances of macroalgae likely vary as these influences vary.

The greatest concern over algal beds seems to be their propensity to respond to eutrophication by overgrowth and expansion, i.e., forming nuisance blooms (Valiela et al. 1997). Large blooms of macroalgae have a negative impact on eelgrass in Tomales Bay (Huntington and Boyer 2008). However, surveys of macroalgae on eelgrass beds in San Francisco Bay revealed only occasional instances where the macroalgae were likely to impede growth of the eelgrass (see Appendix 8-1). There have been few reports of nuisance blooms in the bay. This could change if turbidity of the water decreases further (Schoellhamer 2009). In addition to eutrophication, intertidal algal beds are vulnerable to other human disturbances such as trampling and recreational harvesting, as well as oil spills and the use of dispersants during cleanup (Foster et al. 1998).

Rationale for Establishing Goals for Macroalgal Beds

Applying the decision tree in Chapter 2 (Figure 2-1) to macroalgae, it is not clear that additional macroalgal beds would be beneficial, nor is it clear that macroalgal beds are in short supply. It is difficult to distinguish algal beds that support ecosystem services from those that interfere with these services. Since we do not know enough to make a definitive statement, the decision tree leads us to the need for more research as the most suitable outcome. Applying the precautionary approach adopted for this project, existing beds should be protected while research to improve our knowledge is conducted.

Goals for macroalgal bed habitat focus on conducting research, protecting existing non-nuisance beds, enhancing the beds by removing invasive species and debris, and improving our understanding of ecosystem services, bed dynamics, and nuisance versus non-nuisance beds.

Science Goals for Macroalgal Beds

MACROALGAL BEDS SCIENCE GOAL 1

Understand the roles of macroalgal beds of different species in providing ecosystem services or interfering with services provided by other habitats.

Question A. What is the current extent of macroalgal beds by species?

A survey to determine the extent of the macroalgal beds is needed to allow for an understanding of their roles, species composition, including introductions of new species, impacts on the estuarine ecosystem, and vulnerabilities, for example, to oil spills.

Question B. What ecosystem services do macroalgal beds support, and in what quantities?

If the extent of algal beds is very small, the magnitude of any services is also likely to be small. However, initial estimates of the area of beds (Question A) combined with rough estimates of the magnitude of functions, such as spawning habitat for herring, would provide a context for assessing the overall role of algal beds.

Question C. To what extent, and in what densities of which species, do algal beds or growths interfere with other habitats or form nuisance blooms?

Algae may overgrow eelgrass or oyster beds and potentially other habitats. This may result in reduced growth and possibly the survival of eelgrass and oysters.

MACROALGAL BEDS SCIENCE GOAL 2

Understand changes in the extent or condition of macroalgae.

Question A. How do the beds change with changing conditions?

It would be useful to understand any trends toward a larger or smaller extent of algal beds, and particularly the reasons for these trends.

Sea lettuce on the subtidal shores of East Marin Island.

Protection Goals for Macroalgal Beds

MACROALGAL BEDS PROTECTION GOAL 1

Protect San Francisco Bay *Fucus* beds through no net loss to existing beds.

(See Rock Habitats Protection Objectives 1-1 and 1-2.)

MACROALGAL BEDS PROTECTION GOAL 2

Protect San Francisco Bay *Gracilaria* beds through no net loss to existing beds.

(See Rock Habitats Protection Objectives 1-1 and 1-2.)

Restoration Goals for Macroalgal Beds

We do not have enough information about existing macroalgal bed distributions and threats to make specific restoration goals for this habitat type. (See experimental techniques described in Chapter 3: Cross-Habitat Invasive Species Control Objective 1-1; Cross-Habitat Oil Spills Prevention Action 1-3-5; and Chapter 10: Subtidal-Wetland Design Integration Restoration Action 3-1-2.)

CHAPTER TEN

Integrated Restoration

TOGETHER WITH THE BAYLANDS ECOSYSTEM Habitat Goals Project and the Uplands Habitat Goals Project (see box below), the Subtidal Goals Project represents a milestone in regional habitat planning for San Francisco Bay and its watersheds. We now have a comprehensive and innovative ecosystem-based management vision for a continuum of habitat types from the bottom of the bay to tidal wetlands and grassland transition zones to upland areas. Each goals report outlines recommendations for the preservation, restoration, and protection of habitat. These reports provide important tools to educate agencies, non-profits, private foundations, and others about the value of these habitats, and offer background information that can be used to seek funding for implementation. Although at present these three goals projects are proceeding independently of each other, there may be

RELATED REGIONAL PLANNING EFFORTS

Baylands Habitat Goals Project

The Baylands Ecosystem Habitat Goals Project, completed in 1999, used available scientific knowledge to identify the types, amounts, and distribution of wetlands and related habitats needed to sustain diverse, healthy communities of fish and wildlife resources in the San Francisco Bay Area. It provided a biological basis for a regional wetlands planning process to assist public and private interests seeking to preserve and restore the ecological integrity of wetland communities. Remarkably successful at articulating a vision for protecting and restoring 100,000 acres of wetland habitat, its report informed stakeholders about the importance of wetland habitat and the need for future funding.

By November 2010, more than 40,000 acres of tidal wetlands had been acquired for restoration by private, local, state, and federal partners. Many agencies and non-profit organizations have participated in implementing report recommendations. For example, the San Francisco Bay Joint Venture (SFBJV) is helping coordinate implementation of some recommendations with local, state, and federal partners, and has developed an Implementation Strategy based on the recommendations. With its partner database, the SFBJV has been tracking progress towards tidal wetland acquisition, planning, and restoration. The State Coastal Conservancy is currently planning an update to the Baylands Goals Report, to incorporate climate change considerations.

Uplands Habitat Goals Project

The San Francisco Bay Area Upland Habitat Goals Project has completed several reports over the past decade, with more underway, using a science-based process based on existing and new data supplemented by expert opinion to recommend the types, amounts, and distribution of upland habitats, linkages, compatible uses, and the ecological processes needed to sustain diverse and healthy communities of plant, fish, and wildlife resources in the Bay Area.

The project's objectives are to:

1) increase the acreage of protected lands by increasing public and private funding for habitat acquisition and restoration; and

2) develop an increased awareness of key habitats among land management agencies and local jurisdictions charged with land use planning. The GIS database and reference documents developed by this project are intended to be decision-support tools to inform voluntary, non-regulatory investments, protection strategies, and management policies of public resource agencies, nonprofit conservation organizations, local government, legislators and private foundations seeking to preserve, enhance, and restore the biological diversity of upland habitats before development eliminates remaining opportunities.

The San Francisco Bay shoreline has multiple habitat types: sand, cobble, and open water.

benefits to linking restoration projects in subtidal habitats to those in adjacent marshes and uplands. These benefits arise from landscape-scale ecological processes, i.e., processes that extend over more than one habitat type. For example, restoration at a nearshore subtidal site may enhance sediment retention that would favor persistence of an adjacent marsh.

Carrying this further, it may also be possible to design restoration of subtidal habitats not only to protect and interact with marshes and uplands, but also as a substitute for or a complement to seawalls and breakwaters used to protect vulnerable shorelines. With rising sea level (Appendix 2-2) and ongoing loss of sediment (Chapter 4), the value of shoreline protection and the consequences of erosion at unprotected shorelines become more apparent.

An Integrated Habitat Approach to Restoration

Most of the habitat restoration projects implemented in and around San Francisco Bay in the last 40 years have focused on single habitat types such as marshes and riparian zones. A few large regional restoration projects have incorporated planning for multiple habitats across landscapes, including the South Bay Salt Pond Restoration Project and the Dutch Slough Restoration Project. Integrating restoration between subtidal and nearby marsh and upland habitats may provide ecological benefits, as discussed below, and the resulting interactions may result in cost savings compared to equivalent isolated restoration projects.

Many ecosystem processes occur at a larger scale than individual habitats. These processes include:

- Sediment transport and retention (Appendix 2-1, sediment narrative) at nested scales: sediment supply and loss occur at the scale of the estuary; the major estuarine basins have water circulation cells that cause them to gain or lose sediment somewhat independently of each other; within these basins are regions where sediments accumulate or are eroded over seasonal or longer periods; and at smaller scales, marshes exchange sediment with nearby shallow subtidal regions.

- Biogeochemical processing of materials: marshes are sites of transformation of substances between alternative chemical forms. These substances may enter a marsh from the adjacent waters in one form, become transformed, and leave the marsh in a different form. This can affect nutrient availability, oxygen supply, and the availability of organic carbon to microbes both within the marsh and in nearby waters.
- Net organic production: marshes produce vast amounts of organic carbon. The importance of this carbon to the food webs of adjacent waters has been debated for decades. The magnitude and direction of movement of organic carbon between marshes and adjacent waters, and the forms (living and non-living) and degree of bioavailability of this carbon, likely vary with the physical configuration of the site, biological components, season, and freshwater flow patterns (Dame et al. 1986). The key point, though, is that there are strong links between marshes and adjacent waters.
- Movement of organisms: mobile estuarine organisms including birds, fish, and shrimp move into marsh channels and onto marsh plains, feeding there and moving living biomass from the marsh to the open water. This process may be an important mechanism for exporting high marsh productivity to the open water in a form that is usable to higher organisms (Kneib 1997). Taken more broadly, movement of organisms links marshes and adjacent subtidal habitats with the major rivers feeding the bay (anadromous fish), a large swath of the Pacific Ocean (anadromous salmon), and the Canadian and Alaskan Arctic (migratory birds).

Subtidal eelgrass bed offshore from an intertidal rocky shoreline.

Restoration can be expensive, uncertain, and difficult; therefore it seems logical to design restoration projects to capitalize on links between nearby habitats. Subtidal habitats that increase bottom friction, mainly oyster reefs and eelgrass beds, could be placed so as to attenuate wind waves and thereby buffer tidal wetlands and creek mouths from erosion. The combination of marsh restoration and nearshore subtidal habitat restoration could create local zones of sediment retention, minimizing the need for ongoing intervention. Local concentrations of oysters on constructed reefs may increase water clarity, thereby increasing the amount of light available to nearby eelgrass beds.

An additional advantage of integrated restoration is to reduce the effects of habitat fragmentation. Extant marshes are small and geographically dispersed. Even after completion of the Baylands Goals Project, these habitats will not approach the extent and contiguity of pre-settlement marshes. Yet, connectivity among habitat elements is a key feature of ecological landscapes, where subsidies of nutrients, other substances, or organisms can cross habitat boundaries and enhance overall productivity (Polis et al. 1997). Although the magnitude of this enhancement would be difficult to measure at an integrated restoration site, the existence of these known links and the conceptual importance of subsidies and flows between habitats supports the integration of subtidal and marsh or riparian restoration. Integration may also help foster upslope migration of the marsh as sea level rises at some locations. Since this movement will require additional sediment, having an adjacent subtidal source or retention area for sediment may help the marsh grow at its upland edge.

Although integrated restoration seems promising, present knowledge is inadequate to design projects that will achieve the goals of this chapter. As with restoration of individual habitats, this suggests using an adaptive, phased approach in which learning at each phase provides input to decisions about the scale, scope, and design at the next phase.

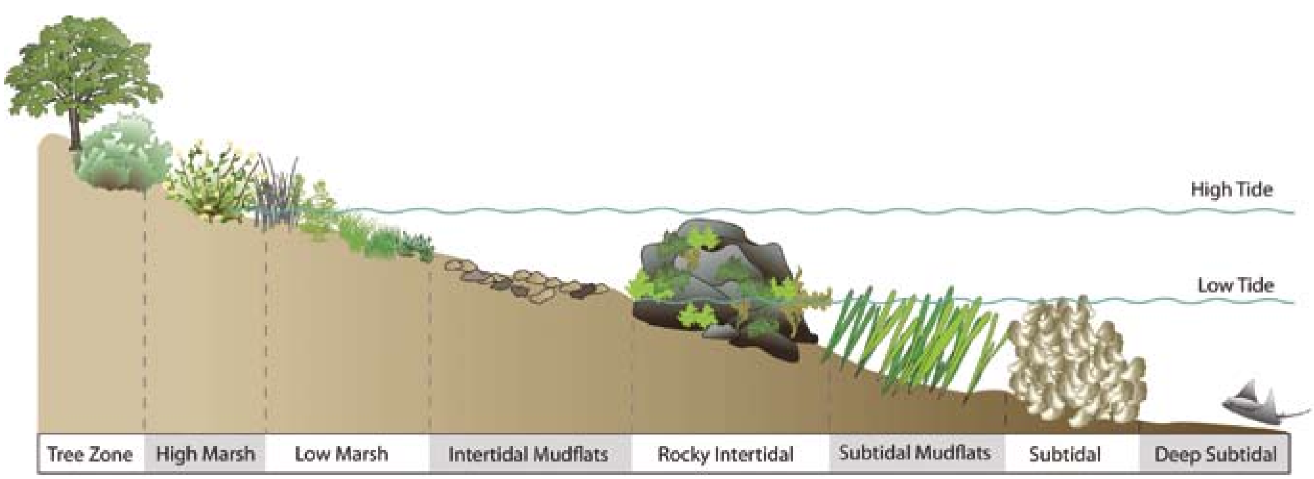


Figure 10-1: Conceptual cross-section of a living shoreline design.

NATURE'S LIVING SHORELINES

Nature provides many examples of shorelines protected by living habitats. The most obvious example is coral reefs. Reefs grow in all tropical oceans, and typically consist of a massive, rocky bed of limestone from previous reef development, and a crown comprising corals and coralline algae in a strong, wave-resistant matrix. Two elements of a coral reef are essential for its function in shoreline protection. First, the coral/algae matrix grows to approximately mean sea level, maintaining a barrier to waves. Second, the surface of the reef is rough at all spatial scales, maximizing friction and extracting most of the energy from waves.

The protective value of coral reefs can be seen most clearly on atolls, where human populations can survive on land that is at most a few meters above sea level. Even during hurricanes, overtopping of atolls by wind waves is surprisingly uncommon (although this may change with sea-level rise). Low-lying areas of high islands and mainlands can also be protected by fringing or barrier reefs.

Other examples of natural shorelines that inhibit erosion (or even trap sediments) include mangrove swamps, extensive tidal marshes, and river deltas.

Living Shorelines: Softening and Protecting Edges

People are likely to adapt to sea level rise and a decrease in sediment supply by increasing the height and extent of levees and seawalls to protect their property. These actions have consequences beyond the property boundaries. For example, seawalls reflect incoming wave energy, whereas a natural, gradually sloping shore absorbs and dissipates the energy (see also Chapter 6). The reflected wave energy is thereby available to erode unprotected shorelines elsewhere. As the degree of armoring increases, erosion of remaining unprotected shores is likely to increase. Furthermore, enhanced erosion immediately offshore from the armored shoreline realigns the distribution of sediments, which can result in unintended deposition in remote areas. These widespread consequences, such as transfer of deposition or erosion to other areas, represent an externality to the cost of the shoreline protection—a cost not borne by the property owner.

Although these effects have been known for a long time, alternative methods for protection of vulnerable shorelines have been slow in coming. A recent National Research Council publication on shoreline protection (NRC 2007) examines current practices for minimizing erosion and concludes with a call for alternative approaches at project to regional scales. They acknowledge that specific effects of hard structures on unprotected areas can be difficult to quantify:

> *In most areas, the scope and accessibility of information regarding the causes of erosion at specific sites and the overall patterns of erosion, accretion, and inundation in the broader region (estuary, lagoon, littoral cell) [are] insufficient to support the development of an integrated plan for managing shore erosion. (NRC 2007, Executive Summary)*

The NRC report nevertheless recommends alternative approaches including the use of soft structures and incorporation of living materials into shoreline protection schemes. These schemes can be characterized as "living shorelines" (Erdle et al. 2008; see also http://www.habitat.noaa.gov/restoration/techniques/livingshorelines.html) that can 1) protect adjacent vulnerable shorelines; 2) minimize externalities such as the transfer of erosion; and 3) increase the extent of potentially valuable subtidal habitat (see Chapters 7 and 8 for a discussion of the potential value of these habitats).

The idea that living materials can help protect shorelines is not new, as there are many examples of shoreline protection by naturally-occurring barriers (see sidebar). However, the use of natural materials in restoration, construction, or enhancement of shorelines for protection of vulnerable areas is not yet widespread (see, for example, Williams and Thom 2001). Reasons for this include tradition, perceptions (or reality) of high cost, and lack of knowledge necessary to design such structures (NRC 2007). In the meantime, however, integrated living shoreline projects have been successfully tested by NOAA's Community-based Restoration Program, US Fish and Wildlife Service's Coastal Program, Chesapeake Bay Foundation, North Carolina Coastal Federation, North

This degraded shoreline edge could be improved using integrated habitat restoration techniques.

A healthy shoreline edge with oysters and seaweed.

Coral reefs are one type of living shoreline.

Carolina Division of Coastal Resources, Florida Department of Environmental Protection, and other funding and restoration partners for more than two decades on the East Coast and areas of the Gulf Coast (Erdle et al. 2008).

The interest in restoration of oyster and eelgrass beds and the need for increasing shoreline protection in San Francisco Bay present an opportunity for beginning experimental work at the pilot project scale to design living shorelines. However, both the quantitative effects of hard structures (and therefore the magnitude of externalities in relation to the cost of the structures) and the best design practices for minimizing these effects are poorly known. As with restoration of oyster and eelgrass beds and integrated shorelines, this implies a need for a careful, phased approach using an adaptive management framework (Chapter 2) to ensure that fundamental questions about benefits and design can be answered early, and knowledge gained in early phases can improve practices and outcomes in later phases.

Examples of Living Shoreline Pilot Projects that Could be Attempted in San Francisco Bay

Living shorelines represent a new approach to shoreline stabilization. Yet knowledge of their benefits and best practices is scanty and is specific to locations other than San Francisco Bay. This suggests that we develop and test small pilot projects at sites vulnerable to erosion. These projects would test the use of biological treatments in place of hard structures, and test new or modified structures made of materials and in locations that may provide expanded habitat benefits. Many permitting and regulatory issues must be addressed as these pilot projects move forward, including issues of site suitability, material suitability, risk assessment, effectiveness of scale, habitat conversion and mitigation, and potential conflicts in protecting newly created habitat and structures that require ongoing, long-term maintenance.

Top: Volunteers plant a living shoreline.

Center: The Seattle Seawall tests various substrate types and orientations to identify which provide the best habitat for subtidal species.

Bottom: A living dock in Florida uses Virginia oysters to filter the water.

Classes of projects that could be attempted at the pilot scale include the following:

Living breakwaters are structures placed parallel to the shore in medium- to high-energy open-water environments to dissipate wave energy while providing habitat and erosion control benefits to an ecosystem. These breakwaters are constructed of native rock or artificial reef structures seeded with oyster spat. Quiescent areas between the breakwaters and the shoreline could be planted with SAV and marsh grasses to create intertidal and marsh habitat for aquatic organisms.

Living seawalls incorporate subtidal habitat into structures built for the primary purpose of protecting shorelines. For example, a recent experiment in Seattle installed panels along a seawall with various shapes and textures to determine rates of colonization by marine flora and fauna. Troughs were also installed extending out from the face of the seawall to mimic shallow water habitats that have largely been lost along the Seattle shoreline. The potential benefits could include greater nearshore productivity and trapping of sediment and organic matter. (http://www.cityofseattle.net/Transportation/seawall.htm)

Living docks are exemplified by a project in West Palm Beach, Florida. The dock is designed to support natural systems such as mangroves, grasses, and oysters that create habitat and provide water-filtration services. The living dock system is multi-layered and includes geotextiles enclosing a special soil mix for floating mangroves and marsh plants. Embedded within the geotextile layers are oyster shells from restaurants, which were placed to help spur natural oyster growth.

Oyster balls made of concrete and shell can be used at living shoreline sites to decrease wave energy while enhancing fish and oyster habitat. These structures can dissipate wave energy, decreasing coastal erosion and providing a reduced-energy area behind them in which newly planted vegetation can grow. As discussed in Chapter 7, key research questions need to be answered as to the benefits of the reef structures themselves versus the benefits from the settled oysters.

Biologists and volunteers deploy a Reef Ball™ that will attract native oysters.

Tidal wetlands include subtidal sloughs and channels that connect to offshore subtidal habitats.

A sand beach restoration project at San Francisco, south end of Pier 94, three months post-nourishment (2006).

Submerged aquatic vegetation such as eelgrass dampens wave energy, stabilizes nearshore sediments, improves water quality via nutrient uptake, and provides food and shelter for other marine organisms (Chapter 8). When these are used in conjunction with other living shoreline components such as marsh grasses, a natural shoreline buffer may be created that reduces coastal erosion and stabilizes sediments via root growth.

Intertidal sand beach or subtidal sand habitat is included in this discussion as an alternative to hard shorelines, although the principal function arises through geophysical rather than biological processes. Beaches and marsh berms bordering tidal marshes provide the first line of dynamic defense against wind-wave erosion during extreme high tides and storms. Nourishment of erosion-prone marsh scarps or berms with sand, gravel, or shell is likely to provide or lead to erosion buffering, shorebird refuge, and vegetation cover, and to approximate long-lost connections between beach and marsh (Baye 2007). A few pilot projects to replenish sand beaches have been conducted in San Francisco Bay, including at Coyote Beach in San Mateo and Pier 98 in San Francisco. Future projects could be designed with more specific focus on sand transport pathways and the benefits and impacts to the adjacent offshore subtidal areas.

Enhanced intertidal or subtidal rocky habitat. The extent of natural rock is limited to a few areas mainly in central San Francisco Bay (Chapter 5). Some rock has been placed into artificial configurations at sites such as Albany Beach. Opportunities exist to reuse and reconfigure existing native rock at sites where shoreline restoration is being planned and at tidal elevations that maximize colonization by native flora and fauna.

Rationale for Establishing Goals for Subtidal-Wetland Integration

In contrast to the habitats discussed in Chapters 4-9, the decision tree (Chapter 2) provides no guidance for integrating subtidal habitats with marshes and riparian habitats or for establishing living shorelines. However, the high degree of uncertainty, even about appropriate methods to conduct pilot projects under these topics, requires the application of adaptive management principles for these pilot projects to be most effective.

Goals for integration generally focus on pilot-scale projects to test concepts and practices at a large enough scale to be meaningful. This contrasts with the shellfish and SAV chapters (7 and 8), which call for a phased approach that moves beyond pilot projects once the requisite knowledge has been developed. Here the degree of uncertainty about the success of integrated restoration is sufficient to preclude planning for larger-scale projects until and unless the success of early pilot projects can be convincingly demonstrated.

The knowledge-gathering element of the pilot projects should focus in particular on the synergistic aspects of integrated restoration. That is, restoration of a particular habitat type (for example eelgrass) is assumed to proceed under an adaptive framework in which an explicitly designed process gathers knowledge about the ecosystem benefits of and best practices for restoring that habitat. In integrated restoration additional information must be gathered on the extent to which this restoration project achieves goals that cross habitat boundaries, such as enhancing connectivity with marshes or protecting vulnerable shorelines.

As with habitat-specific restoration, the degree of uncertainty about integrated restoration suggests that pilot projects lacking the full adaptive management framework will fail to provide the knowledge needed to proceed beyond the pilot stage. The only possible justification for conducting pilot projects, which are intended eventually to lead to larger-scale projects, is to develop the knowledge to determine whether a shift to a larger scale is warranted. This gives strong justification to a recommendation not to undertake such projects without the requisite pre-project analyses, monitoring and investigations during and after construction, and post-project analysis.

A healthy tidal marsh includes many subtidal channel edges.

Goals in this chapter could be refined by the introduction of expertise from places where these approaches have been tried.

Marshes are eroding around the bay's edges.

Therefore a valuable initial step is to host a workshop on these approaches. Invited participants from other locations in the U.S. and overseas would be asked to present a summary of their findings, and local participants would provide some context on current conditions and challenges. The final step in such a workshop would be to develop a set of recommendations specific to San Francisco Bay.

The specific restoration actions and sites listed below include considerations such as: (1) presence of and knowledge of existing subtidal resources; (2) presence of current pilot subtidal restoration projects that could be expanded; (3) proximity of subtidal resources to wetland restoration sites recommended by the Baylands Habitat Goals Project; and (4) for living shorelines, proximity to areas of current or anticipated shoreline erosion. Research goals focus first on the overall benefits of integration, and secondarily on further developing site criteria and best techniques for living shoreline designs and monitoring.

Science Goals for Subtidal-Wetland Integration

SUBTIDAL-WETLAND DESIGN INTEGRATION SCIENCE GOAL 1

Understand the ecosystem services supported by marsh-subtidal integration and living shorelines, and in what quantities.

Question A. What quantitative synergies in ecosystem services arise when subtidal habitats are linked to marshes and riparian areas?

The basic question of which ecosystem services are provided by the individual habitats is addressed in each of the habitat chapters. Is it possible to measure the additional benefits of locating habitat restoration sites adjacent to wetlands? Are there disadvantages, and do the benefits of such location outweigh other criteria for site selection?

Question B. Which ecosystem services are provided by living shorelines, and in what amounts?

This question should be addressed repeatedly throughout the adaptive management process for living shorelines.

SUBTIDAL-WETLAND DESIGN INTEGRATION SCIENCE GOAL 2

Develop best practices for integrating subtidal restoration with adjacent wetlands.

Question A. What characteristics of shorelines lend themselves to cross-shore integration?

Question B. Which wetland sites are likely to be most vulnerable to long-term changes in sea level and sediment supply?

Investments in tidal wetland restoration projects need to be protected in the face of climate change and other future changes to the bay.

Question C. Which approaches result in the most effective and persistent wetland-subtidal restoration projects?

SUBTIDAL-WETLAND DESIGN INTEGRATION SCIENCE GOAL 3

Develop best practices for pilot projects to create living shorelines.

Question A. What criteria should be used to choose locations for living shorelines?

Question B. How does the physical configuration of a living shoreline influence its ability to protect inshore areas, and what are its ancillary effects on other habitats?

Many habitat types can occur at the same location: eelgrass, native oysters, and macroalgal beds.

Relatively little is available in the scientific literature on the design and construction of living shorelines, although outreach programs on these topics are available at several universities, and NOAA has funded several projects. Most of these efforts are on the East and Gulf coasts. While some lessons from these projects will be applicable in the bay, several important differences (for example in tidal range, sediment characteristics, plant types) may affect the performance of different designs.

Question C. How self-sustaining are the alternative designs?

The ideal design would result in living shorelines that are self-sustaining or require minimal human intervention. Some periodic maintenance may be needed, such as cleaning shell reefs or placing clean dredged sediment to provide a source of sediment to maintain habitats.

Restoration Goals for Subtidal-Wetland Integration

SUBTIDAL-WETLAND DESIGN INTEGRATION
RESTORATION GOAL 1

Explore the integration of upland, intertidal, and subtidal habitats in San Francisco Bay.

- Subtidal-Wetland Design Integration Restoration Objective 1-1: Select sites that have the greatest opportunities for integrating subtidal habitat with other restored or important habitats for pilot subtidal restoration projects near locations identified by the San Francisco Baylands Ecosystem Habitat Goals Project.

  Possible locations include:

  - San Pablo Bay: study potential resources and restoration activities in areas offshore from Sears Point, San Pablo Bay National Wildlife Refuge and Tubbs Island, and other restoration sites.
  - Corte Madera area: Muzzi Marsh, Corte Madera Ecological Reserve, Heard Marsh: existing wetlands and restored eelgrass, link to living shoreline project
  - Richardson Bay: wetland restoration linked to existing oyster/eelgrass populations
  - Breuner Marsh and Point Molate: link to Point San Pablo eelgrass bed
  - Eastshore State Park: wetland restoration linked with oyster and eelgrass restoration, creek daylighting
  - Central and North Bay Islands: link rocky habitat with eelgrass and oyster beds
  - South Bay Salt Pond sites; Eden Landing and other sites: link to southernmost eelgrass population, native oyster restoration

- Subtidal-Wetland Design Integration Restoration Objective 1-2: Support and promote integration of subtidal habitat design and subtidal enhancement, restoration, and monitoring into tidal wetland restoration projects around the bay.

  Subtidal-Wetland Design Integration Restoration Action 1-2-1: At appropriate sites, incorporate project elevations that include gradual slopes across a range of depths, linking the shoreline edge to shallow and deep waters, and allowing for a variety of topography and micro-habitats to benefit multiple species. Some sites, such as rocky headlands with naturally steep slopes, would not be appropriate for this treatment.

  Subtidal-Wetland Design Integration Restoration Action 1-2-2: Incorporate a variety of subtidal channel configurations into tidal wetland restoration.

A typical salt pond levee with compacted soil covered in invasive crystalline iceplant. There are many opportunities to test new multi-habitat restoration approaches within the South Bay Salt Pond Project.

Subtidal-Wetland Design Integration Restoration Action 1-2-3: Reduce or modify hard artificial structures within restoration sites to protect and improve subtidal channel habitat functions. See Artificial Structures Protection Goals, Chapter 6.

Subtidal-Wetland Design Integration Restoration Action 1-2-4: Design tidal wetland restoration projects to better enhance and improve transition (edge) zones between tidal and subtidal habitat, and include multiple arrays of small habitat types (such as eelgrass beds, native oyster beds, kelp and algal fringes, rocky intertidal, and intertidal sandy beaches).

Subtidal-Wetland Design Integration Restoration Objective 1-3: Increase regional coordination and collaborative planning to advance subtidal-wetland integration.

SUBTIDAL-WETLAND DESIGN INTEGRATION RESTORATION GOAL 2

Integrate habitat flexibility to increase resilience in the face of long-term change at habitat restoration sites around the bay.

- Subtidal-Wetland Design Integration Restoration Objective 2-1: Design habitat restoration projects to account for long-term changes including sea level rise and loss of sediment, by increasing resiliency of existing habitat types and facilitating upslope habitat migration.

Subtidal-Wetland Design Integration Restoration Action 2-1-1: Design projects to include subtidal habitats and natural bioengineering techniques that buffer wave action and increase sediment deposition to minimize shoreline and wetland erosion.

Subtidal-Wetland Design Integration Restoration Action 2-1-2: Integrate natural sedimentation processes into restoration designs to capture sediments and minimize erosion. For example:

- Avoid siting restoration projects or breach locations in highly erosional areas.

- Develop designs that maximize depositional areas and integrate local creek mouths.
- Promote use of clean locally-dredged sediment to supplement sediment where appropriate.
- Design gradual slopes that slow wave action and reduce erosion.
- Use bioengineering techniques such as eelgrass plantings and rock or oyster shell to stabilize sediment.

Subtidal-Wetland Design Integration Restoration Action 2-1-3: Monitor and evaluate existing subtidal resources and habitat types to track impacts of sea level rise to subtidal habitats that occur within and adjacent to selected tidal wetland restoration projects.

SUBTIDAL-WETLAND DESIGN INTEGRATION RESTORATION GOAL 3

Explore the use of living shoreline projects as a way to achieve multiple benefits in future shoreline restoration.

- Subtidal-Wetland Design Integration Restoration Objective 3-1: Evaluate living shoreline and associated techniques outlined above by implementing five small-scale pilot projects in San Francisco Bay by 2015.

Potential living shorelines sites:

- Corte Madera Bay, Corte Madera
- Eastshore State Park, multiple sites
- South Bay Salt Pond Project (Eden Landing Ecological Reserve, Alviso Pond Complex, Ravenswood Pond Complex)
- Albany Beach, Albany
- Breuner Marsh, Richmond
- Crown Beach, Alameda
- Former Naval Air Base lands, Alameda
- Hunters Point and Yosemite Slough areas, San Francisco
- Arambaru Island, Tiburon
- Sears Point, San Pablo Bay National Wildlife Refuge
- Suisun Marsh

(*See Figure 4-5, Chapter 4: Map of suggested locations for pilot intertidal sand beach enhancement and living shorelines*).

Subtidal-Wetland Design Integration Restoration Action 3-1-1: Incorporate multiple habitat types into pilot living shoreline designs; test effectiveness at buffering wave action, stabilizing sediments, and providing habitat; and evaluate success of restoration techniques and materials, including:

- soft substrates (mudflat, shell hash, sand)
- native rock and cobbles, stone, stone sills
- artificial structures (reef balls, reef blocks, etc.)
- native oyster and mussel treatments
- native eelgrass treatments
- native macroalgal treatments

Subtidal-Wetland Design Integration Restoration Action 3-1-2: Incorporate living shoreline techniques to retain mud and sand from natural deposition or from sand replenishment activities.

- **Subtidal-Wetland Design Integration Restoration Objective 3-2:** If small pilot projects prove successful at achieving the three purposes discussed above, expand small-scale projects or implement 10 mid-scale living shoreline and living breakwater projects in San Francisco Bay by 2020.
- **Subtidal-Wetland Design Integration Restoration Objective 3-3:** Pending the results of evaluations of pilot-scale studies, incorporate living shoreline components and naturalized habitat into the design of new and replacement shoreline protection structures.

Eelgrass restoration can be integrated into rocky intertidal shorelines or tidal wetlands.

CHAPTER ELEVEN

Implementation

THIS REPORT MAKES RECOMMENDATIONS for protecting and improving subtidal habitat in the estuary. As stated previously, the recommendations are not proposed regulatory changes. However, actions could be taken by appropriate agencies in the future to further improve subtidal habitat through their own regulatory processes. The background information and associated goals in this report are designed to help resource agencies and other organizations implement subtidal habitat development, restoration, or enhancement projects. This information can be used in designing research, taking management actions, implementing protection strategies or restoration projects, or updating existing laws and policies. Agencies and other organizations can also use the document and associated goals to raise funds for scientific research and restoration projects.

To implement the subtidal goals at a broader level, agencies and other organizations may use this document to develop or modify their policies based on the goals presented herein. Any policy modification or policy development will entail a separate process in which an individual agency will need to analyze the recommendations in the context of their existing authorities and mandates.

Creosote pilings provide space for organisms to attach to but may also release toxins into bay waters.

Regulatory Agencies' Roles

Several agencies regulate activities within the subtidal area of the bay. Some are focused on species protection, fisheries management, or water quality. Others have a broader habitat focus, while others must balance ecosystem and development needs. In reviewing these goals, some agencies may decide to take regulatory action through their existing authorities or to expand their current authorities through legislation or regulation changes. In either case, agencies must utilize existing public rule making processes. The following discussion describes and lists potential actions that agencies with regulatory authority may consider implementing to protect subtidal habitats.

While these regulatory measures would likely reduce impacts to the subtidal habitats, as set forth in previous chapters, more research about these habitats is needed. As research is completed to better understand the functions and ecosystem services of subtidal habitats, information gained should directly inform management actions such as those listed below. In the interim, the Subtidal Goals Project recommends using a precautionary approach in managing subtidal habitats.

Examples of Potential New Regulatory Guidance

Benthic disturbance:

Benthic disturbance can occur in many forms. Blasting, dredging, and sand mining literally remove the substrate on or in which organisms live. Placing new structures, be they pier pilings, floating docks, outfalls, or pipelines, also eliminates the surface, and in some cases, subsurface in which organisms live. Similarly, mechanical destruction from anchors and mooring devices can impact aquatic vegetation. Because dredging, sand mining, and placing structures are the most widespread human activities that disturb the subtidal bottom to the degree of actually removing habitat, limiting these activities would protect subtidal habitats.

- Avoid new dredging, sand mining activities or removal of native rock from the bay, especially in areas with aquatic vegetation or high density shellfish beds.
- Avoid locating projects that include or may require dredging in areas of high sedimentation.
- Avoid placing structures in subtidal or intertidal areas of the bay, especially in areas with or adjacent to eelgrass, aquatic vegetation, or shellfish beds.

Benthic disturbance: damage to habitat

Subtidal habitat can also be impacted from loss of light penetration and extended periods of turbidity and high suspended sediment loads. Potential regulatory considerations for activities that create these types of impacts (i.e., dredging, vessel propeller wash, and placing structures) could be improved by the following regulatory considerations.

- Remove illegal structures, including mooring facilities, from areas with submerged aquatic vegetation.
- Locate proposed structures, including ferry terminals, away from areas with submerged aquatic vegetation, particularly eelgrass.
- Avoid anchoring barges in areas of submerged aquatic vegetation.
- Create no wake zones for vessels within 150 feet of submerged aquatic vegetation.
- Locate ferry routes a minimum of 150 feet from submerged aquatic vegetation.
- Avoid new dredging projects within 150 feet of submerged aquatic vegetation.

Implementation Approach: Adaptive Management

As discussed in Chapter 2, the Subtidal Goals Project advocates an adaptive management approach to implementation both at project-specific and overall program levels. Although it is not perfect, adaptive management is probably the best way to increase knowledge of the functions and values of the habitats the Subtidal Goals Project purports to protect and to evaluate the success of the Subtidal Goals Project itself.

Applying adaptive management would represent a serious commitment on the part of the Subtidal Goals Project. Implementing adaptive management at the project scale would require that the adaptive process (Figure 2-3) be designed into, and required as part of, any project to restore or enhance subtidal habitats. The value of knowledge must be seen as equivalent to the value of the actions themselves, given the level of uncertainty about the value of the actions. Requirements for project implementation would include conceptual and simulation modeling, predictions of outcomes, performance measures, a specific research and monitoring plan to evaluate progress and ecosystem response before and for some time after project completion, and a mechanism for reporting and, more importantly, responding to results as they become available.

In contrast to the project level, adaptive management can be implemented at the program level only if an institutional framework can be established that has the resources to do it. This will require a large-scale, long-term view and substantial budget both for the actions (including project-level adaptive management) and at the program level for the process of evaluation and revision.

Establishing a San Francisco Bay Subtidal Habitat Forum

Consistent and enduring support for implementing the Subtidal Goals Project from individual agencies may be difficult to secure given political changes, staff turnover, budget fluctuations, and shifts in priorities. Successful implementation of the goals will require an entity or entities charged with raising funds and overseeing the realization of the goals in this document and the process of adaptive management necessary to realize the ecosystem benefits envisioned by this program. Implementation will require organizing stakeholders, identifying private owners of subtidal parcels, monitoring and tracking restoration projects, reviewing and reporting on knowledge gained and on progress in implementing the goals, revising the goals as needed, and educating the public about subtidal habitat in the estuary. This implementing entity might be an existing organization, a collaborative partnership among several agencies, or a new entity (such as a Joint Powers Authority or special district) created for this purpose.

The Subtidal Goals Project recommends that the lead entity (or entities) establish a Bay Area Subtidal Habitat Forum (Forum) to engage a broad network of agencies and partners who will participate in implementing subtidal habitat research, protection, and restoration goals. This Forum, made up of local, state, and federal agencies, academic institutions, non-profits, businesses, and industry, would increase regional coordination, collaborative planning and support for and awareness of subtidal protection and restoration. The Forum should be charged with leading adaptive management and making sure progress is being made towards the goals included in this document.

Thoughtful planning must be put into the process by which the Forum is constituted, including how leadership is selected, which members should be included for participation and how they will be selected, which operating practices should be adopted, which agency staff resources will be provided, and what additional funding or resources are needed and where those resources will come from.

PUBLIC/PRIVATE PARTNERSHIPS RESTORING SUBTIDAL HABITAT

A truck loaded with donated Pacific oyster shell.

Native Oyster Restoration Projects: at the Marin Rod and Gun Club and the Berkeley Marina. Several innovative partnerships have been led by Robert Abbott and Rena Obernolte (Environ Corporation) and multiple public and private partners, including Drakes Bay Oyster Company (donated clean Pacific oyster shell); Marin Rod and Gun Club (provided permission and access to use 30 acres of subtidal land); Jerico Products (donated barge to help with reef ball and shell pallet installation; donated native mined shell for reef ball mixture); and others.

Bair Island Sediment Task Force: The Bair Island Task Force is a partnership between the Port of Redwood City, the US Army Corps of Engineers, US Fish and Wildlife Service, NOAA Fisheries, Bay Planning Coalition, Save The Bay, San Mateo County Board of Supervisors, the San Francisco Bay Conservation and Development Commission and others that has worked to accomplish navigational dredging at the Port of Redwood City and the beneficial re-use of the dredged sediment for habitat restoration at Inner Bair Island. As a result, approximately 200,000 cubic yards of sediment were pumped to Bair Island instead of being dumped in the bay or ocean. This contributed to the more-than 1 million cubic yards of soil needed to raise the elevation of Bair Island in preparation for its eventual return to a tidal wetland. At the same time, the dredging of the channel at the Port of Redwood City is crucial to ensure the ongoing economic health of the Port and surrounding businesses, and to maintain the Port's important contributions to the local and regional economies.

A boat is donated for restoring oyster beds.

Beneficial re-use of dredge material from the Port Of Oakland 50-Foot Deepening Project: Oakland Harbor is the second largest port on the West Coast and the fifth largest container port in the nation. The federal channels of the Oakland Harbor and Port-maintained berths were deepened from −42 feet to depths of −50 feet. Approximately 12.8 million cubic yards of sediment were dredged for this project and used to create eelgrass beds and to enhance shallow water and wetland habitats at the Middle Harbor Enhancement Area, the Hamilton Army Airfield Wetlands Restoration project, and the Montezuma Wetlands Restoration project. Multiple partners contributed to the planning of this effort, including Port of Oakland, San Francisco Bay Conservation and Development Commission, Army Corps of Engineers, Bay Planning Coalition, East Bay Regional Park District, the California Coastal Conservancy, and others.

A crane lifts Reef Balls™ for placement into offshore intertidal and subtidal areas.

Existing successful regional partnerships can provide a model framework for developing the Forum. Several groups of agencies have enlisted the aid of experts and stakeholders to form advisory boards to establish long-term regional goals. It is important to look to these examples and build on lessons learned and draw on their experiences. Some successful examples of regional partnerships towards advancing vetted habitat goals include:

- **San Francisco Bay Joint Venture:** The Joint Venture brings together public and private agencies, conservation groups, development interests, and others to protect, restore, increase and enhance all types of wetlands,

San Francisco Bay Joint Venture

riparian habitat, and associated uplands throughout the San Francisco Bay region to benefit birds, fish, and other wildlife. The diverse partners of the Joint Venture have been successful in advancing regional restoration projects, coordinating information about science and technical issues, and building collaborative partnerships for the benefit of multiple species and habitat types.

- **Southern California Wetlands Recovery Project:** The Wetlands Recovery Project (WRP) brings interested parties together to develop a coordinated, systematic, regional, and ecosystem-based approach to wetland protection. In 1997, with the execution of a Working Agreement, 19 federal and state agencies developed an organizational framework and committed to designing and implementing a Regional Strategy for acquisition and restoration in order to increase the quantity and quality of the region's wetlands. The long-term vision of the WRP is to reestablish a mosaic of functioning wetland and riparian systems that supports a diversity of fish and wildlife species. Projects completed since the WRP's inception in 1997 have resulted in the acquisition of 6,603 acres, restoration or enhancement of 2,161 acres, and planning for 3,204 acres of wetlands. More than $500 million have been dedicated to WRP projects, including $330 million in state funds, $30 million in federal funds, and $147 million in local and private funds.

Ideas for Implementation

Lead entities for the Subtidal Goals Project or a Forum, if formed, should consider the following specific ideas for implementation:

- Pursue funding for agencies to provide staff support for and participation in the Forum and smaller topic-specific subcommittees. These smaller groups would also develop and share information that would inform adaptive management for future projects.
- Identify opportunities to coordinate with ongoing federal, state, and local projects and programs.
- Identify and develop funding mechanisms or initiatives that further study or promote subtidal habitat ecosystem services. Potential sources of funds include the NOAA Restoration Center or the State Coastal Conservancy; or mitigation funds associated with subtidal leases and project activities through the State Lands Commission or the San Francisco Bay Conservation and Development Commission.
- Apply adaptive management both at the program level, through funding opportunities, requirements and other mechanisms, and at the programmatic level, as an organizing principle for undertaking, assessing and modifying implementation, and for revising the goals (and this document) periodically, possibly integrating them with other goals projects.

Surf scoters over open water subtidal habitats.

- Develop specific indicators of successful implementation. The indicators should be both quantitative—such as acreage restored and number of goals implemented—as well as qualitative/contextual—such as changes in policies. Develop monitoring and data analysis programs to track indicators and evaluate success at both a project and regional scale and to measure changes at the institutional and ecosystem levels.
- Create or take advantage of an existing regional database and entity that would house, maintain, analyze, and provide access to monitoring data provided by the monitoring program described above.
- Increase communication and coordination with public and private subtidal landowners and provide information regarding the benefits of healthy subtidal habitat.
- Develop a method to report on the program's success in publications, on a web site, and at the State of the Estuary conference and other conferences. Facilitate information exchange among managers and restoration practitioners across habitat types to increase opportunities for multi-habitat collaborative restoration projects and to minimize potential conflicts.
- Every 10 years, conduct a wholesale review and update of the goals and their implementation.

Volunteers work to restore eelgrass.

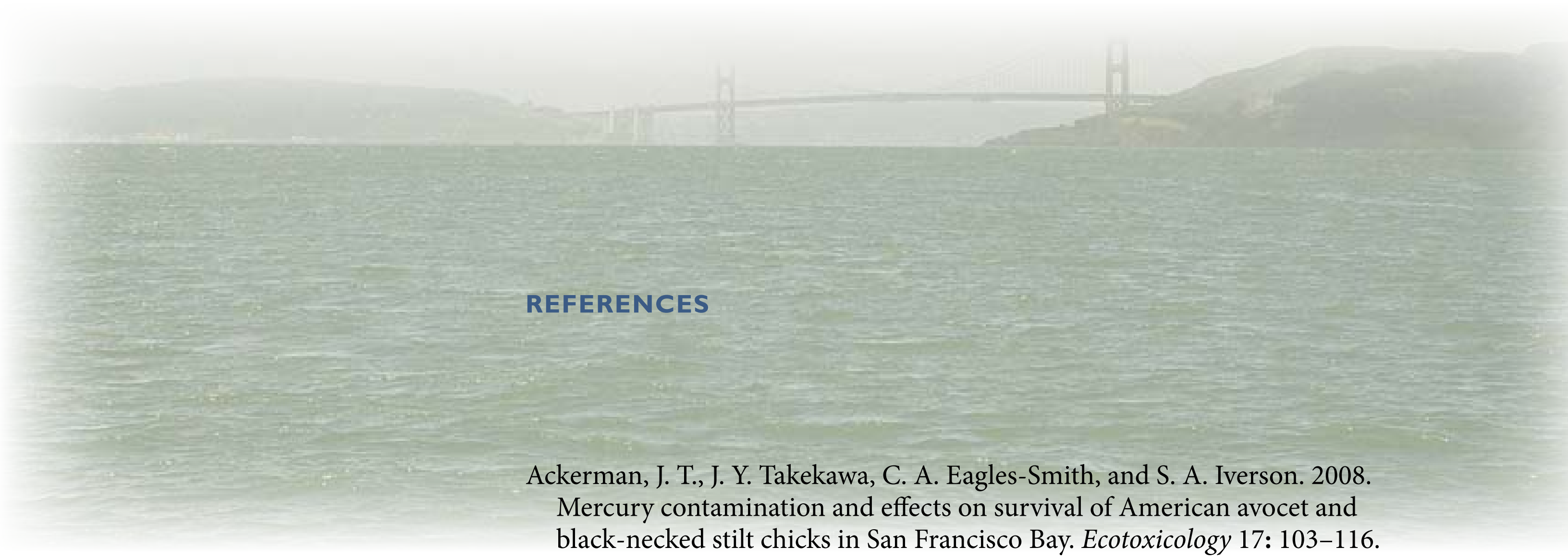
The Forum or other entities could also work to increase public awareness of and involvement in subtidal restoration. Ideas for outreach efforts include:

- Develop a web site to keep people informed of subtidal restoration projects and volunteer opportunities.
- Provide teaching materials that can be used in local schools or with local community-based volunteer groups; involve these groups in subtidal restoration and research projects.
- Use volunteers to help implement projects and raise awareness about the values of subtidal habitat. Partner with corporations, non-profits, social groups, and agencies to implement restoration and enhancement projects.
- Encourage or assist museums, aquariums, nature centers, and agencies undertaking restoration to include subtidal habitat interpretive information in outdoor signs and indoor exhibits.

- Encourage collaborations among local artists, seafood restaurants, non-profits, and other venues to raise awareness about native oyster restoration projects.
- Create a shell-recycling program, based on standard protocols that have been developed to avoid disease and non-native species introductions, with local seafood restaurants to create a source of shell for restoration projects. (See Appendix 7-1).

Moving Forward

The Baylands Ecosystem Habitat Goals Project, the Uplands Habitat Goals Project, and the Subtidal Habitat Goals Project present an inspiring vision for what can be done to improve the condition of multiple habitat types around the bay, and the species that depend on them. Each project presents specific objectives and actions that can be tracked to help resource managers and others better understand the cumulative success of the implemented actions. Together, the three plans provide more information than has ever been available to resource managers and others engaged in ecosystem-based management and in-the-water/on-the-ground projects. The concerns regarding climate change and other long-term trends make these planning efforts even more timely and necessary for predicting, monitoring, and implementing adaptation measures to long-term changes in the San Francisco Bay watershed. If implemented, the three plans will conserve, protect, and restore important habitat for fish and wildlife, as well as the ecosystem services valued and relied on by humans.



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Personal Communications

CHAPTER 2

Bruce Jaffe (USGS), 2010, to Marilyn Latta

CHAPTER 4

Janet Thompson (USGS), 2009, to Wim Kimmerer

Patrick Barnard (USGS), 2009 and 2010, to Wim Kimmerer

CHAPTER 7

Robert Abbott (Environ), 2009, to Wim Kimmerer

J. Fuller, SFSU, 2010, to Wim Kimmerer

Chela Zabin (UC Davis), 2009, to Wim Kimmerer

Robert Abbott (Environ), 2009, to Wim Kimmerer

Robert Abbott (Environ), Chela Zabin (UC Davis), 2009, to Wim Kimmerer

Betsy Peabody (Puget Sound Restoration Fund), 2007, to Marilyn Latta

Jim Moore (CDFG), 2008, to Marilyn Latta

CHAPTER 8

George Isaac (CDFG), 2010, to Marilyn Latta

Katharyn Boyer (SFSU), 2009, to Wim Kimmerer

John Takekawa (USGS), 2009, to Wim Kimmerer

Keith Merkel (Merkel and Associates), 2009, to Marilyn Latta

George Isaac (CDFG), 2010, to Korie Schaeffer

CHAPTER 9

Ryan Watanabe (CDFG), 2008, to Natalie Cosentino-Manning

Katharyn Boyer (SFSU), 2009 and 2010, to Wim Kimmerer

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Matt Manuel: 58

Marin Rod and Gun Club and Berkeley Marina native oyster restoration projects/Robert Abbott, Jerry McEwen, Rena Obernolte: 8 (center left, bottom left), 22 (both), 36 (bottom), 41, 52 (top left, center left), 89, 101 (center left, bottom left), 102 (both), 104 (both), 108 (both), 109 (both), 110 (bottom), 153 (bottom), 155, 167 (all)

Marine Mammal Center: 59 (middle)

National Oceanic and Atmospheric Administration(NOAA): 59 (top)

National Park Service: 48 (all)

NOAA Fisheries, Habitat Conservation Division, Southwest Region/Charleen Gavette: 5, 10, 27, 54, 61, 71, 74, 77, 82, 94, 100, 113, 117, 119, 125, 139

NOAA Fisheries, Habitat Conservation Division, Southwest Region/Adrienne Harrison: 15

NOAA Restoration Center/Kevin Adams: 17

Richardson Bay Audubon Center/ Suzanne Olyarnik: 42 (top), 133, 156, 157 (top)

San Francisco Bay Joint Venture: 168

San Francisco Boardsailing Association, www.SFBA.org: 40 (both)

San Francisco Estuary Invasive Spartina Project, State Coastal Conservancy: 39 (right), 43 (both), 63 (bottom)

San Francisco State University, Romberg-Tiburon Center for Environmental Studies/Wim Kimmerer: 17, 19, 22, 56, 78, 84, 97 (bottom left), 99, 121, 126, 143 (bottom left)

San Francisco State University, Romberg-Tiburon Center for Environmental Studies/Joanna York: 23 (bottom right)

San Francisco State University, Romberg-Tiburon Center for Environmental Studies/Katharyn Boyer's lab: 4, 11, 18, 23 (left), 31, 97 (bottom), 98 (bottom left), 110, 111, 114, 127, 130, 131, 157 (left)

Seattle Department of Transportation: 153 (left center)

Michael Singer Studio (design), Tom Hurst (photo): 153 (bottom left)

Smithsonian Environmental Research Center and UC-Davis Romberg Tiburon Center/Chela Zabin: 44, 45, 143 (bottom)

Steve Spiker, www.stealingbeautyphotography.com: 50

Jude Stalker: 42 (bottom), 51 (bottom), 52 (bottom), 169 (bottom)

State Coastal Conservancy/Abe Doherty: 24, 25

State Coastal Conservancy/Marilyn Latta: 88 (both), 95 (bottom), 101 (top right), 137 (top), 148

UC Davis/Brian Cheng: S-10 (top left): 106, 107

USGS/Patrick Barnard, Bruce Jaffe, Susan de la Cruz: S-12, 28, 57, 69, 76, 85 (top), 132, 169 (top)

USGS/Cindy Brown: 39 (left)

Cleo Vilett, www.cleovilett.com: S-17 (bottom), 34, 55, 75 (bottom), 83, 95 (top), 120, 142, 150

The Watershed Project/Chris Lee: 51 (top)

David Wimpfheimer, www.calnaturalist.com: 122