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.

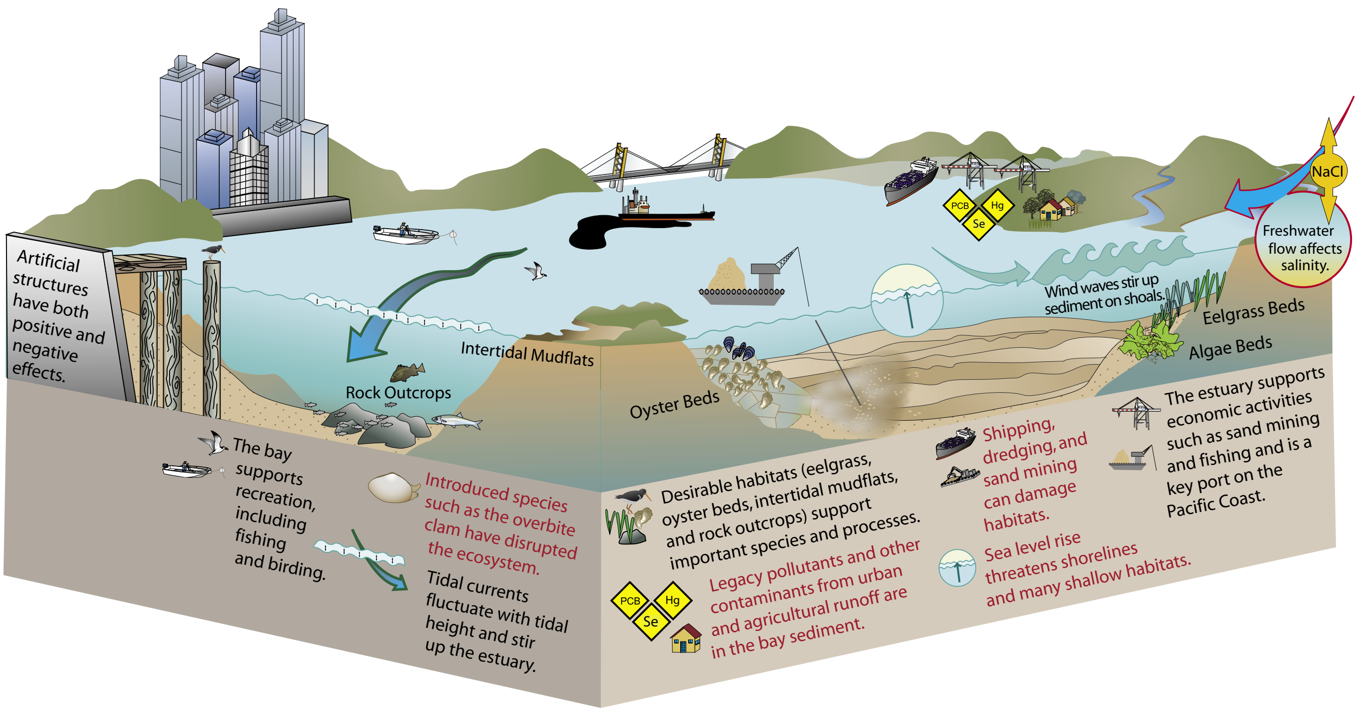


Figure 3-1: Conceptual diagram for subtidal habitats in the San Francisco Estuary. This diagram displays some of the key concepts involved in subtidal habitats, particularly the processes linking habitats with each other and the surrounding land, and some of the threats to the habitats. Similar diagrams 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.

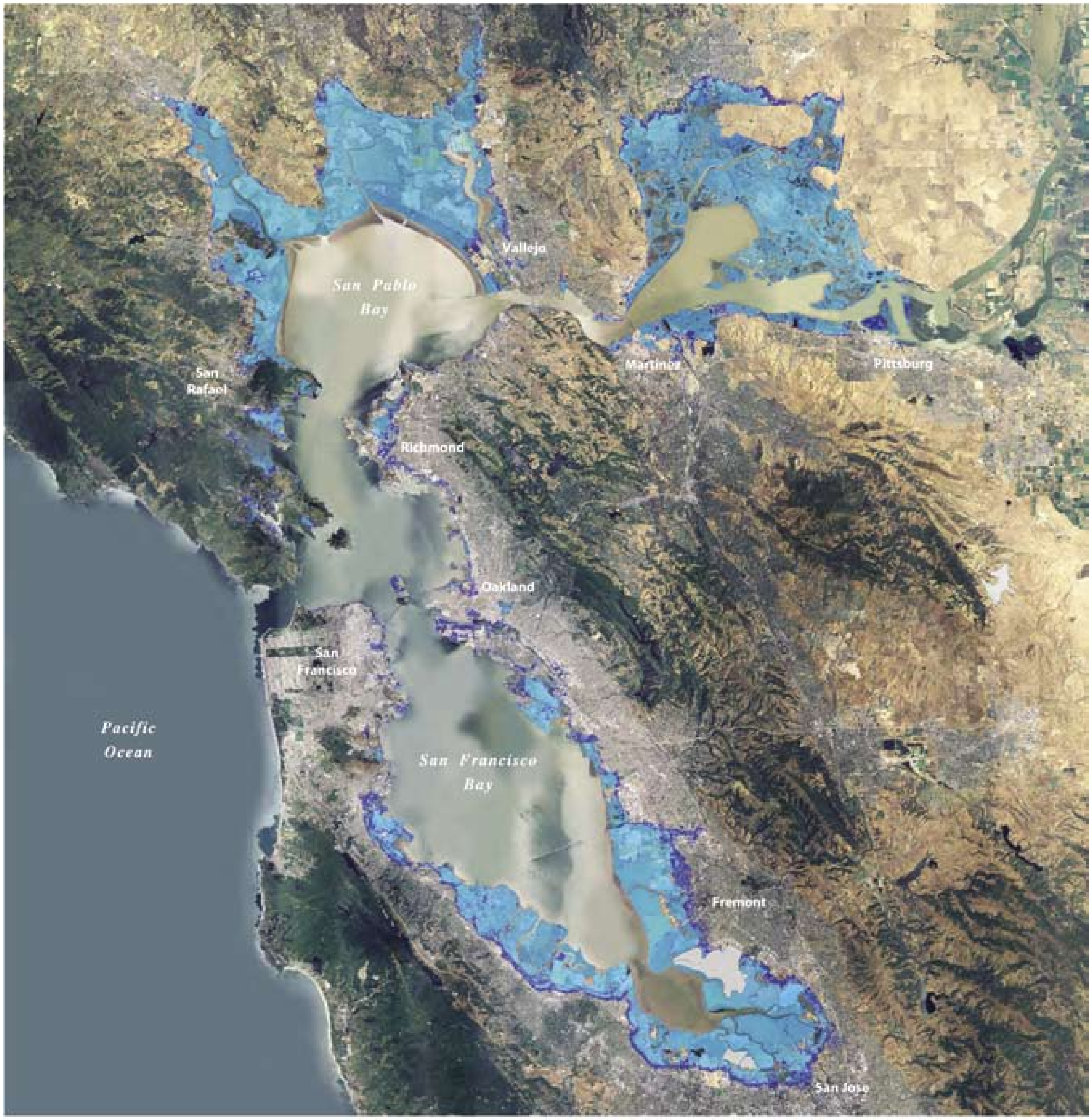
Exchange with the coastal ocean removes sediment, organisms, and wastes from the bay, and brings in coastal organisms. Perhaps more important is exchange that occurs through movement of fish and other organisms: there is no barrier between the bay and the coastal ocean. Ocean conditions (for example, 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

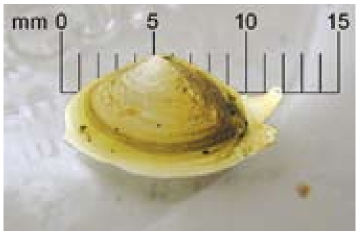
Area vulnerable to an approximate 55-inch sea level rise

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?

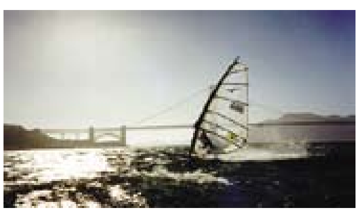
FOUNDATIONAL SCIENCE GOAL 2

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.

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.

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

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.

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.