

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

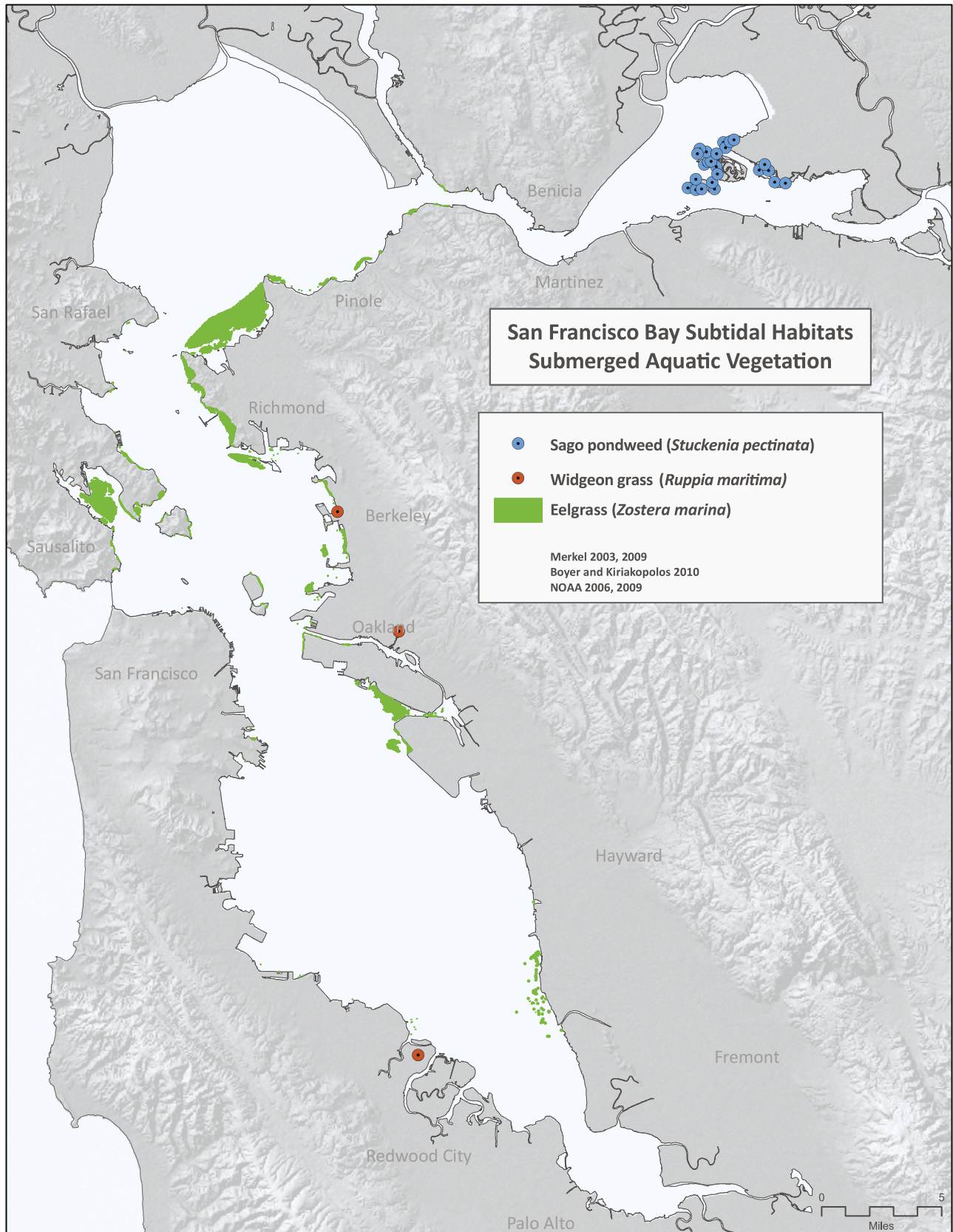


Figure 8-1: Distribution of Submerged Aquatic Vegetation Habitat in San Francisco Bay. Locations for sago pondweed and widgeon grass are approximate.

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.

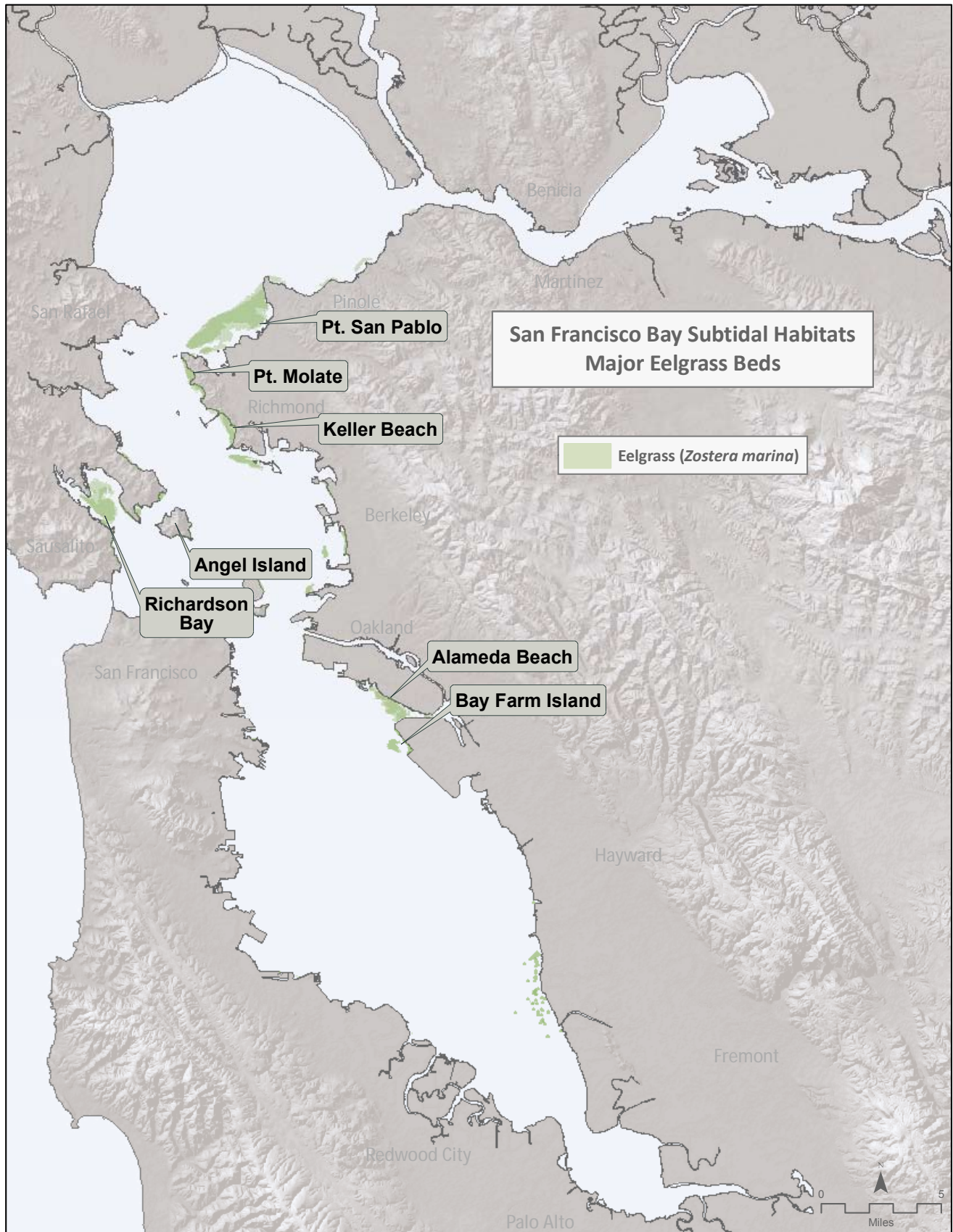


Figure 8-2: Locations of San Francisco State University's Seven Site Eelgrass Bed Survey (2005–2010).

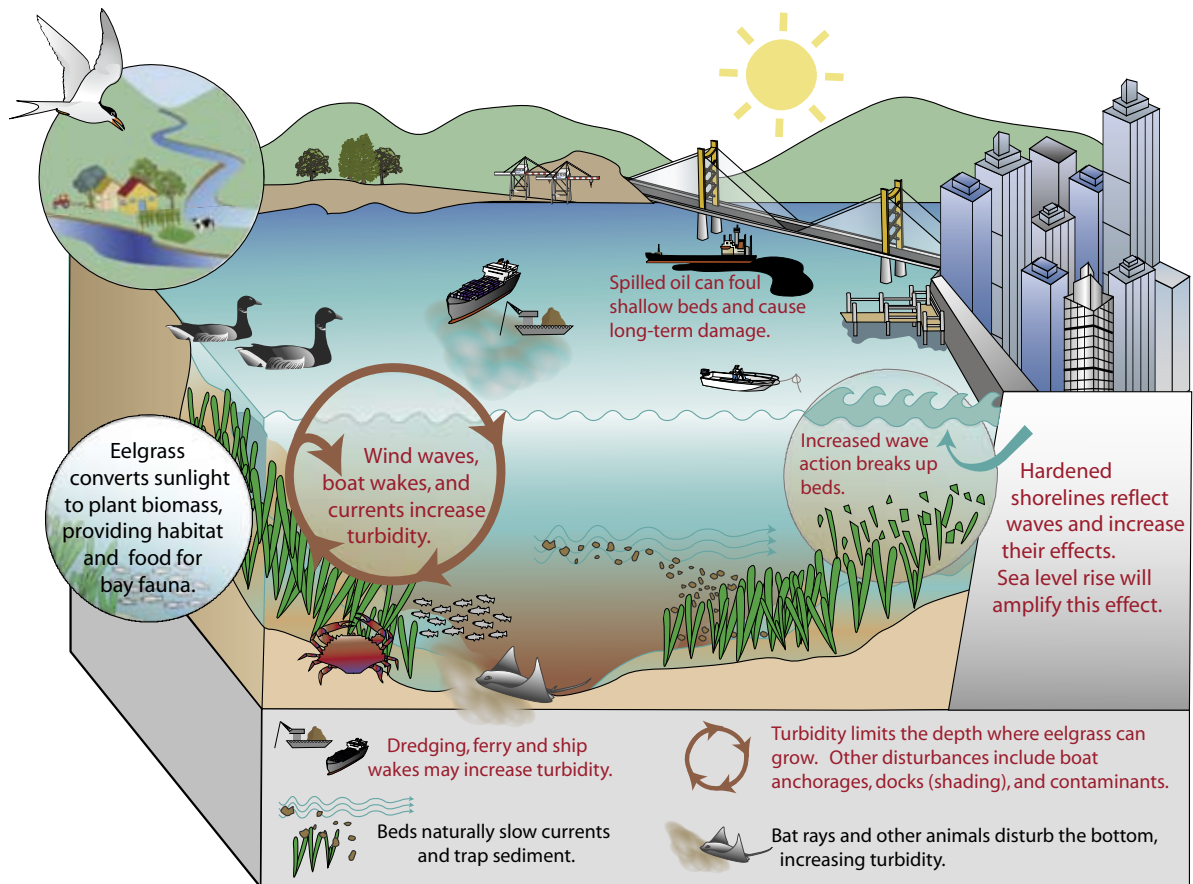


Figure 8-3: Conceptual diagram for eelgrass in San Francisco Bay. This diagram displays processes that occur in and on eelgrass beds, some of the ecosystem services these habitats provide, and threats to eelgrass beds.

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.

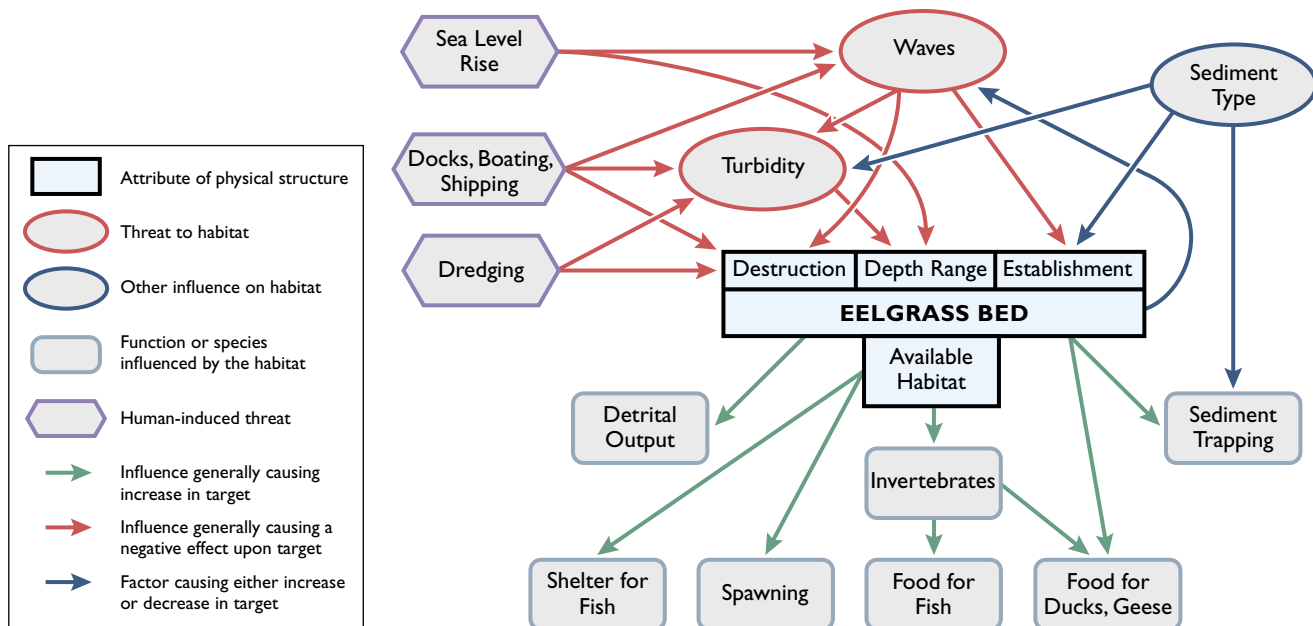


Figure 8-4: Influences on eelgrass beds and functions and services provided by eelgrass beds. The elements in this diagram are site-specific, and all do not apply at all sites. See also Fig. 3 in Thom et al. (2005).

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.

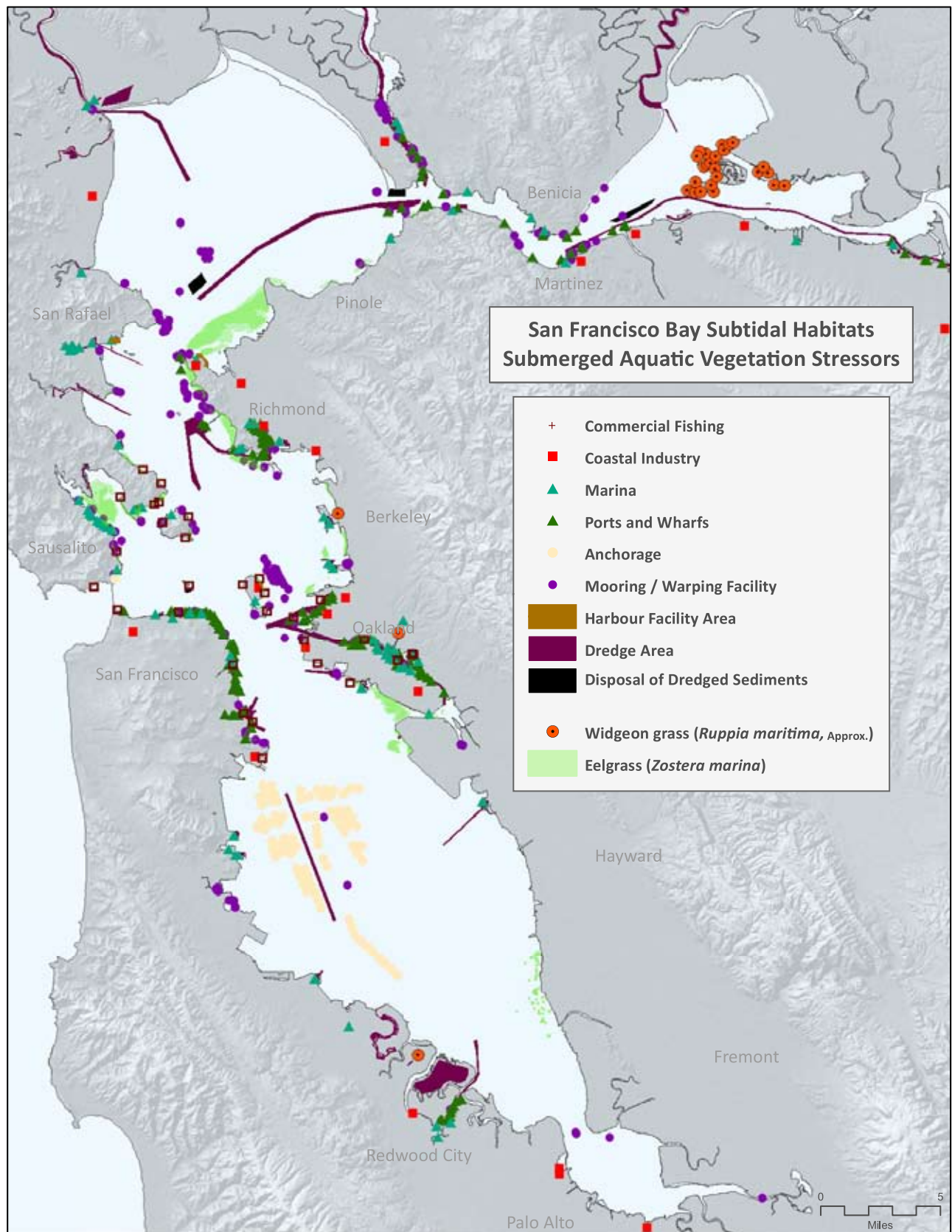


Figure 8-5: Locations of Submerged Aquatic Vegetation Stressors in San Francisco Bay.

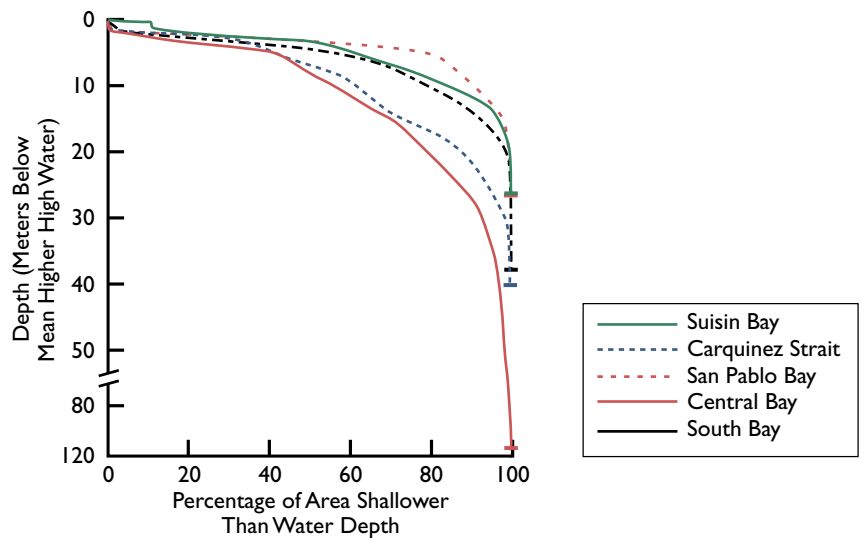


Figure 8-6: Hypsographic curve for the major basins of the San Francisco Estuary (Kimmerer 2010). Each line gives the percent of the geographic area of the basin (x axis) that is shallower than the depth (y axis) below Mean Higher High Water. Symbols indicate deepest depths in each basin. All basins 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 I-1 and I-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 I

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?

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?



San Francisco State University researchers get ready to monitor eelgrass.

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.

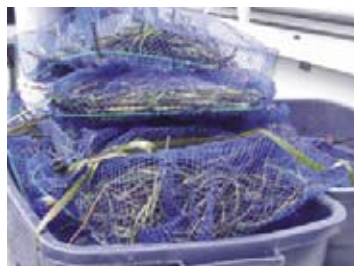
- **Submerged Aquatic Vegetation Protection Objective 3-1:** Maintain and improve physical conditions (for example to bathymetry, light availability, currents) needed to support eelgrass survival and growth in areas identified in this report for future eelgrass restoration.
- **Submerged Aquatic Vegetation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

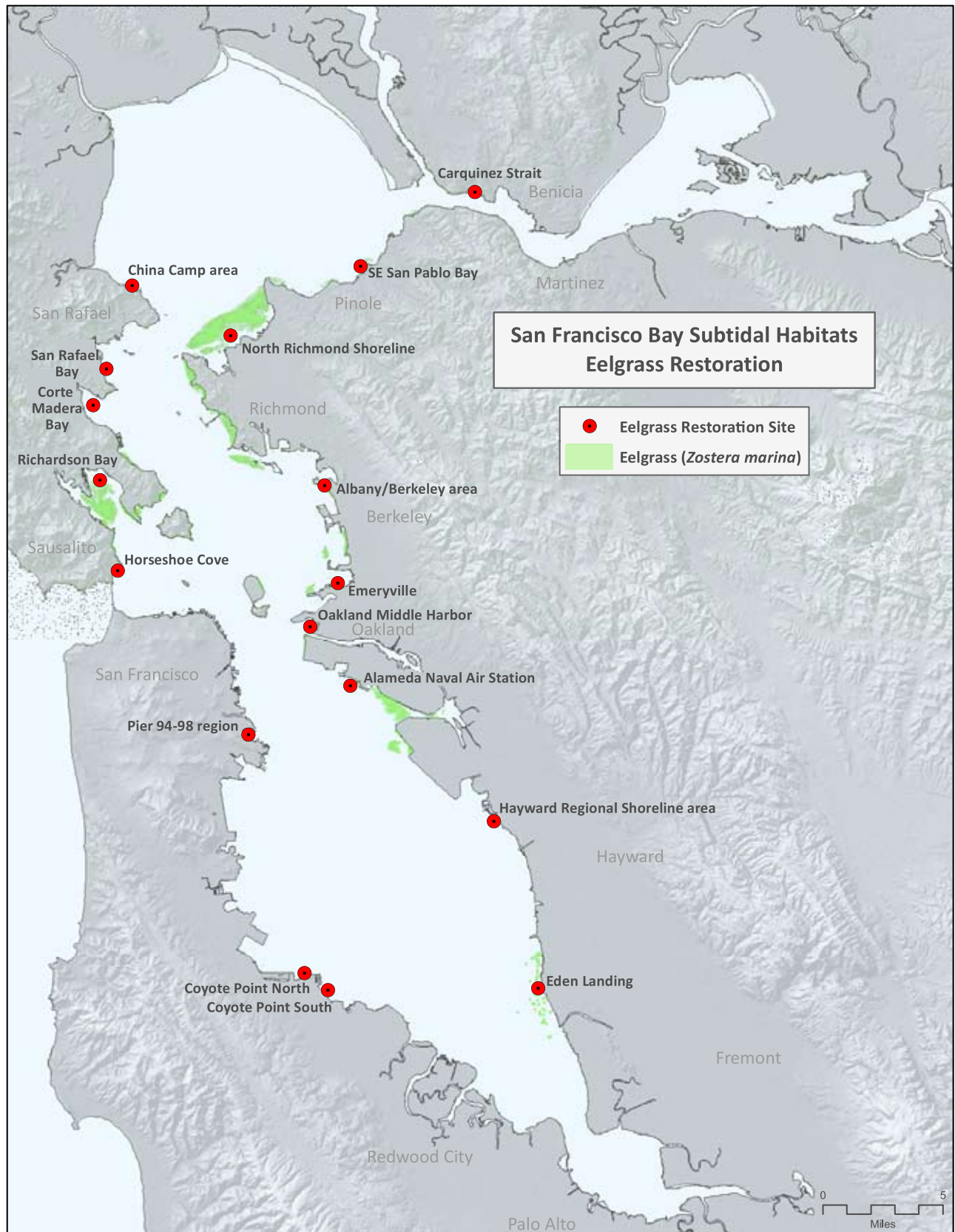


Figure 8-7: Recommended sites for phased native eelgrass restoration in San Francisco Bay.

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.