Habitat Type and Associated Biological Assemblages

SOFT BOTTOM SUBSTRATE

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General Description

Soft bottom substrate habitats include mud/silt/clay (particles 0.001 to 0.062 mm in diameter), sand (particles 0.062 to 2.0 mm in diameter), pebble/cobble (particles 2 to 256 mm in diameter), and shell mix (a mix of mud/silt/clay or sand and shell fragments). Soft bottom substrates are characterized by a lack of large stable surfaces for plant and animal attachment. Exposure to wave and current action, temperature, salinity, and light penetration determine the composition and distribution of organisms within the sediments (USGS 1998). While comprehensive bottom surveys are unavailable for San Francisco Bay, survey data (Greene and Bizzaro 2003, San Francisco Bay Regional Monitoring Program (RMP), San Francisco Bay Regional Effects Monitoring Program (REM), National Oceanic and Atmospheric Association's Regional Monitoring Program (EMAP)) and anecdotal information from scientific sampling and commercial and recreational fishing, and from commercial uses of the Bay (e.g., dredging for vessel traffic, sediment extraction) indicate unconsolidated sediments are present throughout and are the most common substrate type in the San Francisco Bay (Figures 4, 10).

Unconsolidated bottoms provide an array of functions to San Francisco Bay flora and fauna. Mud/silt/clay substrates provide a source and sink of suspended sediment; they store, transport, transform and make available trace elements and organic compounds (e.g., carbon, nitrogen, phosphorous, sulfur); they provide a substrate for invertebrate epifauna (organisms on the surface) and infauna (sessile organisms which live within sediments); and they provide a substrate for fish, birds, and marine mammals to reproduce, rear, feed, and grow. Sand habitats provide similar functions for invertebrate epifauna and infauna, fish, birds, and marine mammals, and provide for bed load transport. Shell mix and pebble-cobble habitats provide similar functions for invertebrate epifauna and infauna, fish, birds, and marine mammals, but the substrate is more three-dimensional and more stable, and so provides a higher level of refuge from predators, and a substrate for attached organisms.

Figure 10. Soft bottom and hard bottom substrates in San Francisco Bay interpreted from multibeam bathymetric images and side-scan sonar mosaics after Greene and Bizarro (2003).

Taxonomic Groups

Plants

Plants associated with soft bottom habitats include algae and submerged aquatic vegetation (SAV; Table 2). In most cases, these plants need coarse grain particles such as pebbles or shells to become established in this habitat. There are very few species that exclusively inhabit soft bottoms and when they do, they are mainly found in sheltered embayments such as Richardson Bay (Josselyn and West 1985). Such genera include the macroalgae *Ulva/Enteromorpha*, which are found in the euhaline to the mesohaline parts of the Bay.

Eelgrass (*Zostera marina*) is found in both fine and course grain sediments. Eelgrass can grow in thick, muddy sediments like those off Point Molate and Point San Pablo, or in sandy sediments like those off Crown Beach. Very little is known about relationships between grain size and distribution of eelgrass around San Francisco Bay.

Invertebrates

In this report, we aggregate the sessile invertebrate infauna into assemblages by location as a proxy for salinity (Table 3). Because of their usefulness as lifetime integrators of *in situ* water and sediment quality, benthic communities are usually monitored at fixed locations over time. This monitoring scheme has been used in San Francisco Bay, thus, our discussion reflects data from these locations. Data from monitoring stations have been grouped based on location that is representative of a given salinity category during normal hydrologic years. As discussed in the Physical Description above, we can anticipate the general salinity range within a specific area of San Francisco Bay during different seasons in normal water years. Soft bottom invertebrate taxa at the fresh and euhaline ends of San Francisco Bay traditionally have the most stable species composition. Communities between these end points show the most seasonal and inter-annual variability, reflecting changes in freshwater flow at tidal and seasonal time scales. However, all communities change with flood and drought events.

When possible, seasonal and inter-annual patterns are noted for dominant species in each assemblage within each habitat. Using existing information, we further divide these assemblages into main channel, channel edge, slough channel, and shallow subtidal topographical regions. Data is not always available for all topographic regions at all locations. These sub-assemblages allow us to consider benthic communities by feeding-type and availability to predators whose feeding capabilities are depth and habitat specific (e.g., diving ducks that feed only on surface dwellers), and to identify assemblages most likely to be affected by depth-specific anthropogenic alterations of the system. For the most part, information on invertebrate taxa on soft bottom substrate does not allow us to separate taxa found on specific sediment types (i.e., sand, silt, cobble). There is information, however, on taxa found on shell mix, which is discussed separately at the end of this section.

There is no recent summary of the soft bottom benthic community, and it is likely that all summaries, including this one, will be outdated soon after they are written due to the high rate of non-native species introductions in the system (Cohen and Carlton 1995, Cohen and Carlton 1998). The only comprehensive summary of any compartment of the soft bottom benthos was written in 1986 (Nichols and Pamamat 1988), just prior to the invasion of *Corbula* (formerly known as *Potamocorbula*) *amurensis*, a bivalve that altered the soft-bottom benthos community structure (Nichols *et al.* 1990, Peterson 2002) and changed the trophic state of northern San Francisco Bay (Alpine and Cloern 1992, Thompson 2005). Two long term studies demonstrate that the soft bottom infaunal community has been substantially changed by exotic species: (1) Only 2 of the 58 species seen in Grizzly Bay are confirmed native species with 25 of the species being confirmed as exotic and 3 as cryptogenic species (Peterson 2002); (2) Of the 37 species seen on a mudflat in South Bay, only one is a confirmed native species with 27 species confirmed as exotic and 3 as cryptogenic (Nichols and Thompson 1985 updated with new findings in Cohen and Carlton 1995). Lee *et al.* (2003) included data from throughout the bay, including the less-invaded euhaline section, and reported that 19 to 41 percent of the species during a four-year period were non-indigenous or cryptogenic.

The data used to describe infaunal benthos in this system are limited to the post-*Corbula* invasion period due to the dominance of the bivalve in the communities where it resides. The major data sources and their abbreviations include: (1) long-term monitoring data collected monthly from the freshwater Delta to the Richmond San Rafael Bridge by the California Department of Water Resources (DWR); (2) 2 to 3 year bimonthly data collected by the Regional Effects Monitoring Program in 1986 to 1989 (REM); (3) long-term near-monthly data collected by the USGS south of Dumbarton Bridge in Palo Alto (USGS-PA); (4) the summary of semi-annual data collected by various agencies as listed in Thompson *et al.* 2000 (Regional Monitoring Program [RMP], Long-term monitoring program [LMP], and Bay Protection and Toxic Clean-Up Program [BPTCP]); (5) samples taken as part of NOAA's National Benthic Investigation in August 2000 and 2001 (Environmental Monitoring Program [EMAP]); (6) a monthly study of the bivalves south of San Mateo Bridge collected by the USGS in 1990 to 1996 (Thompson 2005, Thompson 1999); and (7) unpublished rapid assessment survey data from the California Academy of Sciences (C. Brown, Smithsonian Institute, pers. comm.). The focus here is on the most common species found within samples and does not include all species found at every sampling location during each sampling event. Because only a few studies include biomass data, the discussion will be limited to abundances unless otherwise noted.

Lower Estuarine River

The Lower Estuarine River region incorporates the summer extent of X2[1] during most non-drought years and includes the estuarine river upstream of Honker Bay to Colinsville on the Sacramento River. During normal hydrologic years the benthic community in this location would be considered oligohaline. Soft bottom, sessile invertebrates found in this region are divided into channel and channel edge locations. The channel assemblage is found mostly in sand habitats and is characterized by organisms living in high velocity areas among and in sand waves. The community is dominated by two invasive filter-feeding bivalves, *Corbicula fluminea* and *Corbula amurensis*, with *C. amurensis* appearing during dry months (summer and fall) and dry years. Both bivalves filter-feed, but *C. fluminea* is also capable of pedal deposit-feeding. *C. amurensis* lives at or just below the surface and the presence of barnacles on their anterior shell is an indication that extending this part of the body into the flow is common. *C. fluminea* may be slightly less available to some surface predators as they live slightly below the surface, and their shell is considerably thicker. Small but interannually persistent populations of subsurface, deposit feeding oligochaetes (*Varichaetadrilus angustipenis* and *Limnodilus hoffmeisteri*) and tube-dwelling, surface deposit-feeding spionid polychaetes (*Marenzellaria viridis*) co-occur with the bivalves. Amphipods are seasonally and interannually ephemeral with the surface-tube dwelling *Americorophium spinicorne*, *Americorophium stimpsoni*, and free living *Gammarus daiberi* commonly seen in small numbers.

The channel edge community is also dominated by *C. fluminea* and *C. amurensis*. These two species are much more numerous in the channel edge than in the channel, with an order of magnitude increase in *C. fluminea* abundance and at least twice as many individuals of *C. amurensis* as seen in the channel. *C. fluminea* abundance tends to peak in spring, whereas *C. amurensis* can have either or both a spring and fall abundance peak. Unlike the channel, *C. amurensis* becomes the dominant bivalve in dry years on the channel edge. In the channel edge community, oligochaetes are 10 times more plentiful and include more species than in the channel; *V. angustipenis* and *L. hoffmeisteri* are still the dominant oligochaetes. Surface feeding polychaetes are at least twice, and up to 10 times, as abundant as in the channel. This niche is still dominated by *M. viridis* but also includes a sabellid polychaete, *Laonome* sp. *M. viridis* shows a seasonal cycle with peak abundances in spring that is not seen in the sabellid. Amphipods are an order of magnitude more abundant in the channel and consistently peak in spring and summer with the same *Americorophium* species dominating the channel edge community as in the

[1] X2 is defined as the distance upstream from the Golden Gate Bridge to the point where daily average salinity at 1 meter from the bottom is 2 ppt (Jassby *et al.* 1995).

channel community. The free-living *Gammarus daiberi* is inter-annually persistent with slightly smaller abundances on the channel edge versus in the channel.
Common mobile invertebrates found in oligohaline salinity zones in San Francisco Bay soft bottom habitat include the oriental shrimp (*Palaemon macrodactylus*) and the mud crab (*Rhithropanopeus harissii*), both of which are non-native introduced species.

Suisun Bay Region

The Suisun Bay reach includes two shallow bays (Honker and Grizzly Bays), a deeper bay (Suisun Bay), and a deep water channel that connects these bays and San Pablo Bay (Figure 1). During normal hydrologic years, the benthic community at these locations would be considered a mesohaline community. Invertebrate communities in soft bottom sediments have been further classified by channel, channel edge, slough channel, and shallow subtidal topography. *C. amurensis* is the dominant bivalve in the channel with *C. fluminea* arriving during wet years, and once settled, remaining as adults for 2 to 3 years beyond the low salinity years. In addition to the bivalves, the spinoid polychaete *M. viridis*, the subsurface deposit feeding polychaete *Heteromastus filiformis*, and the surface dwelling cumacean *Nippoleucon hinumensis* occur in small numbers in the channel (EMAP).

The channel edges tend to have muddier sediments with higher organic carbon content (Hymanson *et al.* 1994) and the benthic community has a higher number of species and individuals than seen in the channel areas. The channel edge community is dominated by *C. amurensis*, which tends to peak in fall at this location. The oligochaetes are much less numerous than in the up-bay Estuarine River region and are joined by *Heteromastus filiformis* in the subsurface deposit feeding niche. The tube dwelling polychaetes (mostly *M. Viridis*) are also less abundant than in up-bay regions. The most abundant crustacean is the cumacean *N. hinumensis*, with the deposit feeding isopod *Synidotea laevidorsalis* and filter feeding barnacle *Balanus improvisus* being consistent members of the community. The surface dwelling crustaceans and polychaetes show peak abundances in spring whereas the deposit feeding species and *C. amurensis* tend to peak in fall.

The benthic communities in the two shallow bays are similar, with variation reflecting their relative position to freshwater inflow. Honker Bay, the more upstream bay, has a high percentage of coarse plant material and gravel/sand (EMAP 2000). *C. amurensis* occurs throughout Honker Bay, but in higher numbers in the western than in the eastern bay (EMAP). A similar abundance gradient occurs for *M. viridis*. Grizzly Bay has been described by Hymanson *et al.* (1994) and Peterson (2002). The species richness and abundance is lower than at estuarine river and San Pablo Bay locations. The community is dominated by *C. amurensis*, which peaks in abundance in fall during the wet and normal water years, and peaks in summer and fall in dry and below normal years. Minimum abundance for this bivalve is seen in spring or early summer in most years. Abundance patterns for the tube-dwelling, surface-deposit feeding spionid polychaete *M. viridis* (peak abundance late spring-early summer, followed by a several month minimum) co-varies with *Monocorophium alienense*, an amphipod with similar habits and food but with which peaks in abundance in late fall/early winter.

Montezuma and Suisun Slough Channels occur in the Suisun Marsh and have similar sediment (clay and silty clay) and benthic communities as seen in the nearby shallow Grizzly Bay areas (EMAP). The abundances of all species, including *Corbula amurensis*, *Marenzellaria viridis*, and *Nippoleucon hinemensis* are much smaller in the Suisun Marsh sloughs than in Grizzly Bay. *Ampelisca abdita* is found in the marsh sloughs but occurs in highest numbers near the interface with the bay.

Similar to estuarine river regions, the exotic oriental shrimp (*Palaemon macrodactylus*) is common in mesohaline regions of San Francisco Bay. Also, *Crangon franciscorum* is the most common shrimp in the Bay during most years and is targeted by shrimp trawlers.

San Pablo and South Bays

The San Pablo Bay and South Bay regions are separated by the connection to the Pacific Ocean (Figure 1). Sessile invertebrate communities in both bays are considered mesohaline during normal hydrologic years, although the proximity of San Pablo Bay to freshwater flow from the Sacramento and San Joaquin Rivers can lead to seasonal and interannual patterns in the benthic community that differ from those in the South Bay.

The soft bottom invertebrate communities in these bays have been further classified by main channel, slough channel, and shallow subtidal topography. The main channel sediment is mostly muddy sand with low organic carbon content (RMP, REM, EMAP). The bivalves *C. amurensis*, *Mya arenaria*, *Venerupis japonica*, *Macoma petalum*, and *Musculista senhousia* are common inhabitants that as a group can dominate the biomass but not necessarily the abundance of individuals in this community. All of these bivalves are capable of filter-feeding although *M. petalum* can also surface deposit feed. *M. arenaria* and *M. petalum* live deep in the sediment with the rest residing in the near surface. The most accessible bivalve species to predators is the thin-shelled *M. senhousia* that lives on the surface in a mat of byssal threads. *C. amurensis* has a strong seasonal pattern with abundance peaking in summer or fall. The surface tube-dwelling amphipod, *Ampelisca abdita*, can reach extremely high numbers in the estuarine channels (>40,000/m^2); maximum abundance commonly occurs in summer and fall. Other tube-dwelling amphipods, including several species of *Corophium* and spionid worms (mostly *M. viridis* and *Streblospio benedicti*) can also reach moderate abundances. Surface and subsurface deposit feeders are present with several species such as the cumacean *Nippoleucon hinumensis*, the polychaete *Cirriformia spirabrancha*, oligochaete *Tubificoides* species, and the bivalve *Theora lubrica* being common.

San Pablo Bay and South Bay include many small slough channels, including those in the Napa and Petaluma Rivers that flow into San Pablo Bay. The sediment in these sloughs is mostly mud with some localized areas of sandy mud. Species richness and abundance is higher in downstream Napa River benthic communities with the community being quite similar to that seen at the channel edge. The lower Napa River benthic community can include large populations of *Ampelisca abdita* (EMAP).

South Bay sloughs differ from those in the Petaluma and Napa Rivers due to larger populations of the amphipods *Monocoprhium alienense* and *Grandidierella japonica*, the cumacean *Nippoleucon hinumensis*, the bivalve *Macoma petalum*, and two polychaetes (*Sabaco elongates* and *Neanthes succinea*). Large populations of the maldanid polychaete *Sabaco elongatus*, a head down deposit feeder with tubes that can be close to a meter in length can structure the rest of the community. Surprisingly, *A. abdita* and the bivalves mentioned above are capable of living among *S. elongatus* tubes which extend 1 to 2 cm above the substrate surface. Many of the species in this assemblage are patchy in space and time with some, like *M. senhousia* and *A. abdita*, having very high abundance one year and low abundance the next year (REM, USGS).

The species composition of the benthic community in the shallow, subtidal areas is similar to that seen in the main channel. The bivalves *C. amurensis*, *Mya arenaria*, *Venerupis japonica*, *Macoma petalum*, and *Musculista senhousia* are common, but show very strong seasonal patterns with declines in bivalve abundances to near zero each winter/early spring. The bivalves are therefore mostly annual species in this habitat with peaks in abundance occurring in late spring/early summer. The amphipods (*Corophium heteroceratum* and *Ampelisca abdita*) can show similar annual patterns except during dry years when *A. abdita* in particular seems to persist through the winter. As seen in the channel, the cumacean *Nippoleucon hinemensis* is common and peaks in spring of most years.

Five large, motile invertebrates are common in San Pablo Bay and South Bay. Dungeness crab reproduces in the ocean and rears in nearshore and estuarine areas. Juvenile Dungeness crabs immigrate to San Francisco Bay from May to early June, using bottom currents, and rear in the Bay for 8 to 15 months (Tasto 1983, Hieb 2006). Juveniles that rear in the Bay grow faster than and reach adult size one to two years before ocean-reared individuals (Hieb 2005). Dungeness crab abundance is typically lowest when ocean temperatures are warm (i.e., El Niño years) and highest when ocean temperatures are cool. Abundance in 2005 was low, likely due to above-average sea surface temperatures in the Gulf of the Farallones in winter 2004 to 2005 (Hieb 2006). Dungeness crab support a valuable sport and commercial fishery along the coast. The blackspotted shrimp (*Crangon nigromaculata*) is the second most common shrimp in the Bay overall and the most common shrimp in some years. *Ilyanassa obsoleta* is the most abundant intertidal snail on San Francisco Bay mudflats and in the lower reaches of marsh channels, where it is often found in large groups. It has been collected in the Bay in salinities of 10 to 32 ppt and water temperatures of 13 to 22° C (Cohen 2005). The American spider crab, *Pyromaia tuberculata*, and the nudibranch *Sakuraeolis enosimensis* are also common.

Central Bay

The Central Bay region is at the nexus of the South Bay, San Pablo Bay and Pacific Ocean, and includes the northern extreme area of South Bay (Figure 1). Sessile invertebrates in Central Bay are representative of euhaline communities during most years, with extreme freshwater flood events affecting only the shallow sections. The soft bottom invertebrate taxa in Central Bay have been further classified into deep water channel, slough channel, harbor, and shallow subtidal topography. Within these topographic areas, there are typically moving sand and sand waves in Central Bay channels, muddy-sand and sandy-mud in the lee of islands, and sand and sandy-mud areas south of the Bay Bridge (EMAP).

The invertebrate taxa in the sand substrate is characterized by the free living, predatory polychaete *Heteropodarke heteromorpha*, several low abundance species of amphipods (*A. abdita*, *Monocorophium acherusicum*) and cumaceans, and a few bivalves including the filter feeding *Mya arenaria* and the surface deposit feeder *Tellina nuculoides* (EMAP, RMP). The muddy-sand benthic community in Central Bay and northern South Bay have a diverse polychaete community represented by several subsurface deposit feeding capitellid species, a tube dwelling filter feeding species (*Euchone limnicola*), a carnivorous species (*Exogone lourei*), and the maldanid polychaete *Sabaco elongatus*. There are also several surface deposit feeding *Ameana* spp. persisting throughout the year (Thompson and Peterson 2004). The ascidean *Molgula manhattensis* is found throughout euhaline areas of northern South Bay, adhering to any solid object and developing "bloom" abundances during some years.

The slough channels in Central Bay that have been sampled are near harbors in China Basin and Corte Madera Creek. Communities in these sloughs are more similar to those in San Pablo and South Bay than the benthic community seen in the euhaline shallow subtidal zone in Central Bay. In most cases, the same species occur as in San Pablo Bay, with a few additional species such as the amphipod *Monocorophium acherusicum*, the bivalve *Mya arenaria*, the surface deposit-feeding polychaetes *Psuedopolycora diopatra* and *Tharyx* sp., and the tube dwelling filter-feeding polychaetes *Euchone limnocole* and *Polydora cornuta*. Major harbors and ship channels in the estuary are located in Central Bay and are a mix of the benthic community from surrounding areas (deep and shallow-water and slough marine communities). The only abundant obligate filter-feeders in the harbors are the tube dwelling amphipod *Ampelisca abdita* and tube dwelling polychaete *Euchone limnicola*. Probably indicative of the increased water column residence time and increased sedimentation in harbors, the majority of the species are deposit feeders, or in the case of the amphipods *Grandidierella japonica*, *Monocophium acherusicum*, and *Monocorophium alienense*, are species that both filter and deposit feed. The two surface deposit feeding polychaetes *Streblospio benedicti* and *Psuedopolydora diopatra* are tube dwellers. There is a relatively high number of subsurface deposit feeding polychaetes and oligochaetes in these areas; *Tubificidae* spp., *Mediomastus* spp., *Heteromastus filiformis*, and *Sabaco elongatus* dominate the areas studied. There is also sufficient community complexity and abundance to support relatively high abundances of three carnivorous polychaete species: *Exogone lourei*, *Harmothoe imbricata*, and *Glycinde armigera*.

Mobile invertebrates of the euhaline salinity zone are characterized by crustaceans such as blackspotted shrimp (*Crangon nigromaculata*), California bay shrimp (*Crangon franciscorum*), and the slender rock crab (*Cancer gracilis*), which may crawl on or burrow in bottom sediments. They provide an important food source for carnivorous fishes, marine mammals, and birds. In San Francisco Bay, the abundance of blackspotted bay shrimp peaks from May through August and again from December to February (Hieb 1999b). The California bay shrimp is the most common *Crangon* spp. in San Francisco Bay (CDFG 1992). It is found throughout the Bay, but the center of juvenile distribution is normally between San Pablo Bay and the western Delta (Hieb 1999b). Juveniles rear in shallow, low salinity areas and migrate to deeper, higher salinities areas as they grow (Hieb 1999b). There is a strong positive relationship between California bay shrimp annual abundance and freshwater outflow in spring (CDFG 1987, CDFG 1992). The slender rock crab is smaller than other common Cancer crabs, rarely exceeding 85 mm carapace width (Hieb 2005). Slender rock crabs are most common in Central Bay, and probably utilize San Francisco Bay as an extension of nearshore coastal habitat (Hieb 1999a). Slender rock crab abundance in San Francisco Bay decreased in both 2004 and 2005 following a decade of relatively high abundances (Hieb 2006).

Within the soft bottom substrate habitat, taxa on shell mix habitat differ from taxa on other soft bottom substrate habitat (Table 3b). Two clams, a mussel and an ascidian (*Corbula amurensis*, *Molgula manhattensis*, *Musculista senhousia*, and *Venerupis philippinarum*, respectively) are found on shell mix habitat, as well as on other soft bottom sediment types in San Francisco Bay. An anemone, a mussel, two barnacles, and an isopod (*Diadumene lineate*, *Mytilus tossulus/galloprovincialis*, *Balanus crenatus*, *Amphibalanus improvisus*, and *Gnorimosphaeroma oregonense*, respectively) are found on both shell mix habitat and hard bottom substrate. All other species are common only on shell mix substrate.

Fishes

Mesohaline/Oligohaline

In the mesohaline/oligohaline community of San Francisco Bay, common fishes over unconsolidated sediments include sturgeon (*Acipenser* spp.), Sacramento splittail (*Pogonicthys macrolepidotus*), longfin smelt (*Spirinchus thaleichthys*), and the starry flounder (*Platichthys stellatus*) (Table 4). Sturgeon are anadromous, spending most of their lives in marine or estuarine waters and moving to the Sacramento River to spawn. Sturgeon are associated with turbid water, and use their specialized tube-like mouth to prey on benthic organisms. There are two species of sturgeon in San Francisco Bay: the white sturgeon (*Acipenser transmontanus*) and the federally threatened green sturgeon (*Acipenser medirostris*). In San Francisco Bay, the white sturgeon is more abundant than green sturgeon and spawn in the Sacramento River system during the winter months (Moyle 2002). White sturgeon are an important recreational species, and good management practices (size limits) have helped bring this species from near extinction due to commercial fishing in the late 19th and early 20th century back to stable population levels (Moyle 2002). Fishing pressure has had less of an impact on green sturgeon, as their poor taste makes them less desirable to consumers. Green sturgeon spawning grounds are limited due to habitat alteration, however, making it vulnerable to decline (Moyle 2002).

The Sacramento splittail was federally listed as threatened from 1999 to 2003. Young-of-the-year and yearlings are most abundant in the summer months in shallow water areas such as Suisun Marsh (Moyle 2002). Adults move upstream during the winter and spring to forage and spawn in flooded areas (Moyle 2002). The longfin smelt is an anadromous species that spawns in the Delta and rears in the brackish areas of the San Francisco Bay and Delta. It is common in Suisun Bay and upper San Pablo Bay during winter and spring, and disperses throughout San Francisco Bay in late spring, summer and fall (Messersmith 1966, Hieb and Baxter 1993). Longfin smelt abundance in San Francisco Bay is a function of freshwater outflow (Stevens and Miller 1983), although the relationship changed to substantially lower longfin smelt abundance with outflow after the introduction of the invasive clam *Corbula amurensis* in the late 1980s. This corresponded with a decline in phytoplankton and zooplankton abundance due to grazing by *C. amurensis* (Kimmerer 2002). Adult starry flounder primarily inhabit and spawn in marine waters, while juveniles seek shallow fresh to brackish water in bays and estuaries to rear (Orcutt 1950, Haertel and Osterberg 1967, Bottom *et al.* 1984, Hieb and Baxter 1993). Juveniles enter San Francisco Bay via strong gravitational currents present during wet years (Moyle 2002) and appear to remain in the Bay through at least their second year (Baxter 1999). Juvenile abundance declined through the mid-1980s and early 1990s, increased with the high outflow years of 1995 to 1998, and has been cyclic since, with a recent increase from 2002 to 2005. Juveniles are caught from San Pablo Bay upstream to the Delta, with the younger fish further upstream. (Greiner *et al.* 2006).

Polyhaline

In the polyhaline community of San Francisco Bay, fish assemblages over unconsolidated sediments include Pacific staghorn sculpin (*Leptocottus armatus*) and English sole (*Parophyrs vetulus*). English sole adults enter San Francisco Bay to spawn, and juveniles use intertidal and subtidal sand and mudflats for refuge and feeding (Pearson and Owen 2001). Age-0 English sole are found primarily in areas where temperatures are between 12.8 and 14.5 ° C and salinities are between 12 and 24 ppt (Baxter 1999). As temperatures increase in spring and summer, fish move to deeper and cooler areas.

Euhaline

Within the euhaline community, the fish community is primarily dominated by elasmobranchs, such as the brown smoothound (*Mustelus henlei*) and leopard shark (*Triakis semifasciata*), brown rockfish (*Sebastes auriculatus*), plainfin midshipman (*Porichthys notatus*), and flatfishes such as the California halibut (*Paralichthys californicus*) and the speckled sanddab (*Citharichthys stigmaeus*). Leopard shark individuals may remain in San Francisco Bay year-round or utilize the Bay seasonally, emigrating to the ocean in fall and winter (Smith and Abramson 1990). Adults migrate to shallow water in San Francisco Bay in late winter and spring to pup and forage. Although found from South Bay to San Pablo Bay, leopard shark abundance is highest in South Bay. Reproduction occurs between April and May, with each female producing four to 29 pups. Catch in San Francisco Bay has exhibited a downward trend since 1984 (Greiner *et al.* 2006). Leopard shark is fished commercially and recreationally in the Bay, although the recreational fishery accounts for the majority of the catch (Smith and Abramson 1990). Juvenile brown rockfish emigrate to the Bay from nearshore coastal areas in spring to rear (Baxter 1999). Juveniles rear in the Bay for 3 to 4 years and have high site fidelity (Kendall and Lenarz 1986). Brown rockfish is found from South Bay to San Pablo Bay, but abundance is highest in Central Bay (Baxter 1999). It is found in rocky areas and near piers and other structured habitats. California halibut became common in San Francisco Bay during the 1980s and 1990s when abundances increased, apparently a result of a succession of warm water and El Niño years (Baxter 1999). Adult California halibut enter San Francisco Bay to forage and spawn, and juveniles use intertidal sand and mud flats for refuge and feeding (Pearson and Owen 2001). California halibut spawning and survivorship and growth of juveniles increase when temperatures are between 15 and 16.5 oC (Gadomski and Caddell 1991, Caddell *et al.* 1990). California halibut is found from South Bay upstream to the Carquinez Straight, but highest juvenile catchs are in South Bay (Greiner *et al.* 2005). The California halibut supports an important offshore commercial fishery and is targeted in the Bay by sport anglers. The plainfin midshipman is a demersal, marine fish that buries into soft sediments during the day and moves into the water column to feed at night (Fitch and Lavenberg 1971). Plainfin midshipman adults migrate from coastal areas to bays and estuaries in late spring and summer to spawn (Wang 1986). Juveniles rear in estuaries through at least December (Baxter 1999). In San Francisco Bay, plainfin midshipmen are found primarily in Central Bay, with record high catches from 2001 to 2004 (Greiner *et al.* 2006).

Birds

The diving benthivore feeding guild uses unconsolidated sediment habitat for foraging on benthic infauna (Table 5). Among this guild, canvasback (*Aythya valisineria*) within San Francisco Bay are declining (Trost 2002). Members of the genus *Aythya* including greater and lesser scaup and canvasback are diving ducks which use San Francisco Bay for over wintering, and are associated with together because they are difficult to tell apart during aerial surveys. Scaup feed on benthic infauna including mussels and clams. Canvasbacks forage in depths up to 9 m on submerged aquatic vegetation and small invertebrates (Fix and Bezener 2000). Canvasbacks are most abundant from October to January in Suisun Bay, San Pablo Bay, and South Bay (Goals Project 2000). The San Pablo National Wildlife Refuge was established, in part, for the protection of canvasbacks (Goals Project 2000). The surf scoter is associated with euhaline and polyhaline salinities, where they dive for bivalves, molluscs, crustaceans, and other marine and estuarine invertebrates. Scoters are most abundant in Central Bay and South Bay (Goals Project 2000).

Marine Mammals

Soft bottom habitats are used for feeding by several marine mammal species (Table 6). Harbor seals (*Phoca vitulina*) will feed throughout the year on fish and invertebrates such as California halibut, speckeld sanddabs, and mysid shrimp that occur in and on top of soft bottom substrates. Harbor porpoise (*Phocoena phocoena*) also often feed on species associated with soft bottom substrates such as rockfish, flatfish, and speckled sanddabs. California and lions (*Zalophus californianus*) also occasionally feed on species associated with soft bottom habitat. The Eastern Pacific Gray whale (*Eschrichtius robustus*) uses soft bottom substrates in San Francisco Bay during stopovers on bi-annual migrations between calving grounds in Baja, Mexico and feeding grounds in Alaska and Canada. Gray whales feed on small crustaceans, polychaete worms, mollusks, amphipods, and other sessile invertebrates by actively sucking up sediments, entangling food in baleen, and using the tongue to push out sediment, leaving food items behind.

Harbor seals also use intertidal soft bottom habitats to rest, molt, and breed. Most of the haul-out sites within San Francisco Bay are on soft bottom habitat in the South Bay including the primary breeding site within the Bay, Mowry Slough. Nearly 100 pups have been documented shallow, polyhaline to oligohaline salinities. Greater (*A. marila*) and lesser scaup (*A. affinis*) are often grouped at this site compared to 50 at Castro Rocks, the next largest colony site (Risebrough *et al.* 1981, Green *et al.* 2006). Haul-out sites usually have a small slope and immediate access to deep water, and are remote from human activities and close to foraging areas.

HARD BOTTOM SUBSTRATE

(by Natalie Cosentino-Manning, Janet Thompson, Katie McGourty, Susan Wainwright-De La Cruz and Sarah Allen)

General Description

Hard bottom substrate in San Francisco Bay consists of natural and artificial surfaces. Natural substrates include boulders, rock face outcrops, and low relief rock. These habitats are found primarily in Central San Francisco Bay, where soft sediment has been scoured by tidal flow (Figure 10). Boulders occur around islands including Yerba Buena, Angel, and Alcatraz Islands. Boulders are also found around peninsulas and in channels such as Marin and Tiburon Peninsulas, Racoon Strait, Belvedere Dumbarton Narrows, San Pablo Point, and the north and south sides of the Golden Gate channel. Submerged rocks are found in west Central Bay including Arch Rock, Harding Rock, Shag Rock, and Blossom Rock. The tops of these rocks were flattened by the U.S. Army Corps of Engineers to minimize navigation hazards; they are approximately 50 meters high and 11 to 12 meters deep. Rock face outcrops can be found around Yellow Bluff and in northern Golden Gate channel. Artificial hard substrate includes vessel structures, pilings, rip rap, and pipelines. Pilings, rip rap, and pipelines can be found in every San Francisco Bay region.

Hard substrate provides habitat for an assemblage of marine algae, invertebrates and fishes. All hard substrate in San Francisco Bay provides substrate for invertebrate attachment and refugia and foraging for fishes and invertebrates. Natural hard substrate provides substrate for algae and diatoms and foraging areas for birds and marine mammals. Boulders and rock face outcrops provide substrate for fish rearing, spawning, and growth.

Unfortunately, natural hard substrate within the bay has been poorly studied; whereas artificial hard structures have been examined to describe invasion of exotic species over time. The existing knowledge of benthic invertebrate communities in natural hard substrate of San Francisco Bay consists of only one 4-day ROV survey of Harding, Shag, Arch, and Blossom rocks conducted September 11 to 15, 2001 (Garcia & Associates 2001). A complete investigation of the community was not attempted. The most common species noted were "turf" organisms (hydroids, bryozoans, and anenomes) and sea stars.

Since 1993, the San Francisco Estuary Institute has been performing Rapid Assessment Surveys (RAS) during summer months to describe exotic species distribution throughout San Francisco Bay on artificial hard substrates including pilings, docks, and boat ramps. Currently, there are 896 records of 294 distinct taxa (Cohen *et al.* 2005). The majority of these records (62%) are from floating docks, followed by intertidal benthos (20%) and benthic grabs (13%). The Smithsonian Institute also completes periodic RAS; information from these surveys are cited here as C. Brown (Smithsonian Institute, pers. comm.). Table 3c represents the most commonly observed species on artificial hard substrate. The majority of species in this habitat must be filter- or suspension-feeders with a much smaller number of surface deposit feeders that live within these communities benefiting by the left-over food, pseudo-feces and feces produced by the filter and suspension feeders (J. Thompson, USGS, pers. comm.). Some scrapers also survive in this habitat by eating algae that has adhered to the substrate or by eating encrusting bryozoan colonies (J. Thompson, USGS, pers.comm.).

Taxonomic Groups

Plants

Natural hard bottom substrates within the intertidal and subtidal are more common along the shores closest to the opening of the Bay and are almost absent in Suisun, San Pablo and South San Francisco Bays. The lack of hard substratum for attachment is one of the major limiting factors for the occurrence of macroalge in San Francisco Bay. Silva (1979) found that hard substrata such as outcroppings, rocks, pebbles, seawalls and shells supported the greatest diversity of macroalgae compared to soft substrates. In a long-term study conducted by San Francisco State and University of California Berkeley, nine sites around San Francisco Bay were surveyed for macroalge from 1978 to 1983 (Josselyn and West 1985). Of the 162 species found, 129 species resembled assemblages found on the rocky, euhaline shores outside of the Bay and only 33 were determined to be polyhaline. Five of the species found were non-native. Two of these, *Codium fragile* subsp. *Tomentosoides* and *Sargassum muticum* were introduced in the 1970s and are known to be nuisance species in other estuaries (Silva 1979).

The majority of the species found during the surveys were located in the middle to upper intertidal zones and 21 species were found to occur in the subtidal zone. The Twin Sisters, a rocky outcropping in San Pablo Bay, was found to have the highest diversity of species due to the strong reversing currents which scour the lower intertidal and subtidal during each tidal cycle. The kelps, *Laminaria* and *Egregia* are found here. Other species such as *Ahnfeltiopisis* (formerly *Gymnogongrus*) and *Halymenia* that are common on the outer exposed rocky coast, were also known to be present.

The only angiosperm, of the genus *Phyllospadix*, is found at the entrance to San Francisco Bay and is not found any further east than Fort Baker and Fort Point, which flank the Golden Gate Bridge. *Phyllospadix* requires a euhaline environment with heavy wave exposure.

Invertebrates

Mesohaline

The large filter-feeding mussel *Mytilus trossulus/ gallopgrovincialis* and filter-feeding barnacle *Amphibalanus improvisus* are the most visible members of the attached invertebrate taxa in mesohaline regions (RAS). Other attached, non-mobile species include an anemone, *Diadumene* sp., a hydrozoan, *Garveia franciscana*, the sponges, *Halichondira bowerbanki*, *Haliclona* sp., and *Clanthria prolifera*, and a bryozoan, *Conopeium cf. tenuissimum*; all species that suspension feed (RAS, C. Brown, Smithsonian Institute, pers. comm.).

In mesohaline/oligohaline regions, several species of isopods and amphipods can be found crawling among sessile invertebrate species. These species include surface deposit-feeders (i.e., *Gnorimosphaeroma* sp., *Synidotea laevidorsalis*), grazers on attached algae (i.e., *Ampithoe valida*, *Sphaeroma quoianum*, *Eogammarus confervicolus*), and carnivores on the bryozoan colonies (i.e., the opistobranch, *Hopkinsia plana*) (RAS).

Polyhaline

Invertebrate taxa in polyhaline regions are much more diverse than that seen in mesohaline regions. The attached filter-feeding species include three bivalves, *M. trossulus/gallopgrovincialis*, *Musculista senhousia*, and *Ostrea conchalphila,* and seven ascidians (RAS, C. Brown, Smithsonian Institute, pers. comm.). The barnacles *Balanus glandula* and *A. amphitrite*, in addition to *A. improvisus*, are seen throughout this zone. Attached suspension feeders include at least six sponges (e.g., *Halichondria bowerbanki*, *Clathra prolifera*, *Mycale macginitiei*, *Leucilla nuttingi*, *Sycon* sp., *Haliclona* sp.), the hydrozoans *Ectopleura crocea* and *G. franciscana*, seven bryozoans, and at least two species of the anemone genus *Diadumene* (RAS, C. Brown, Smithsonian Institute, pers. comm.). Hard bottom substrate in polyhaline sloughs is poorly represented in available studies, but the small amount completed shows the barnacle *A. improvisus* and the bryozoan *Victorella pavida* as present in the community (RAS). The commercially important Dungeness crab, discussed above, is also found in polyhaline hard bottom substrate.

In polyhaline regions, surface deposit feeding isopods are similar to those seen in mesohaline/oligohaline regions, with the addition of *Paranthura japonica* (RAS). Several additional amphipods are also present including *Incisocalliope derzhavini*, *Jassa marmorata* and *Stenothoe valida* (RAS). Dungeness crabs (*Cancer magister*) occur in hard bottom polyhaline regions, as discussed above in the soft bottom substrate section.

Euhaline

The species richness of sessile invertebrates on hard bottom euhaline regions increases relative to polyhaline regions with the addition of filter-feeding bivalves *Hiatella artica* and *Modiolus rectus*, several bryozoans, the barnacle *Balanus crenatus*, the anemone *Metridium senile*, and the echinoderm *Pisaster brevispinus* (RAS, C. Brown, Smithsonian Institute, pers. comm.).

In euhaline regions, amphipods are still a major component of the community, but the isopods are less prevalent (RAS). Three species of multi-functioning caprellids (i.e., they are detritivores, carnivores, and deposit feeders) are present (RAS, C. Brown, Smithsonian Institute, pers. comm.). Omnivorous and carnivorous polychaetes, including two species of scale worms join the caprellids moving among the bases of the many attached epifauna and epiflora (RAS). Pacific rock crab (*Cancer antennarius*) and the red rock crab (*C. productus*) inhabitat rocky, intertidal and subtidal areas in the Pacific Ocean, and likely use San Francisco Bay as an extension of their coastal habitats (Hieb 1999a). Adult (age 1+) Pacific rock crabs are most commonly found in Central Bay in both the fall and spring months. Juveniles are most common in Central Bay from January to May and in South Bay from July to December (Hieb 1999a). Pacific rock crabs move seasonally from channels (January to April) to shoals (June to December)(Hieb 1999a). The Pacific and red rock crabs are targeted by sport anglers from piers and jetties (Hieb 2006). Rock crab abundance increased from the mid-1990s to 2004, but in 2005, decreased to levels typical of the 1980s (Hieb 2006).

Fishes

Oligohaline/Mesohaline

Within oligohaline/mesohaline hard bottom taxa, the prickly sculpin (*Cottus asper*) is found in every freshwater tributary of San Francisco Bay. As a demersal species, prickly sculpins camouflage themselves in areas of hard substrate, and spawn in areas with flowing water and loose rocks, where males will locate nests (Moyle 2002). In San Francisco Bay, prickly sculpins are most abundant during periods of high freshwater outflow (Baxter 1999). Larvae are commonly found January through May, with a peak occurring in March; adults are most common from May through July (Baxter 1999).

Polyhaline

Fish species occurring over hard substrate in polyhaline salinity zones have not been documented.

Euhaline

In the euhaline community, brown rockfishes (*Sebastes auriculatus*) and surfperches (family *Embiotocidae*) are the most common fishes associated with natural hard substrates. All surfperches are livebearers, with the young born fully developed after a three to six month gestation period (DeLeon 1999). Most species are transient, immigrating to bays and estuaries to give birth in spring and summer. Both species of surfperch are distributed from South to San Pablo Bays. Shiner perch move from South and San Pablo Bays to Central Bay as they mature (DeLeon 1999). There are both recreational and commercial fisheries for surfperch in San Francisco Bay for use as food and live bait. Recreational anglers, mostly fishing from piers, docks, and along the shore, catch surfperch primarily in Central Bay. All surfperch common to San Francisco Bay underwent a precipitous abundance decline in the mid-1980s (DeLeon 1999). In response to the decline, CDFG changed their sportfishing regulations to be more protective, and abundance of four surfperch species (walleye surfperch, white seaperch, shiner perch, and dwarf perch) increased between 2000 and 2004 in the Bay (Greiner *et al.* 2006). However, shiner perch abundance decreased again to 10% of the 2004 abundance in 2005 (Greiner *et al.* 2006).

During winter months, Pacific herring (*Clupea pallasii*) enter euhaline areas of San Francisco Bay to spawn during periods of low salinity. Schools of adult herring enter the Bay during fall and winter, depositing adhesive eggs onto submerged aquatic vegetation and hard bottom substrate (O'Farrell and Larson 2005). CDFG conducts herring spawning surveys November through March throughout Central San Francisco Bay, the area of highest spawning concentration (Watters *et al.* 2004).

Birds

Piscivorous birds such as cormorants (*Phalacrocorax* spp., including the double-crested cormorant, Brandt's cormorant, and the pelagic cormorant), the pigeon guillemot (*Cepphus columba*), the herring gull (*Larus argentatus*), and the mew gull (*L. canus*) forage over hard bottom substrate in San Francisco Bay. For more in depth discussion on cormorants, please refer to the Water Column Habitat discussion below. The pigeon guillemot, a member of the family *Alcidae*, which includes the common murre, murrelets, auklets, and puffins, is commonly seen in summer months. Pigeon guillemots nest and forage in nearshore rocky habitats from March to September including sea cliffs, offshore rocks, and periodically docks and bridges. Pigeon guillemots forage by diving for fishes, mollusks, crustaceans, and worms (Fix and Bezener 2000). Both the mew and herring gull are observed during winter months and occupy similar niches, feeding opportunistically on fishes, crustaceans, and other small prey items. The mew gull remains in near-shore areas, however, avoiding anthropogenic food source areas such as garbage dumps and in-shore agricultural areas where herring gull are commonly observed (Fix and Bezener 2000).

Marine Mammals

Hard bottom substrates attract fish assemblages, providing prey for harbor seals and sea lions, including sculpins, rockfish, perch and herring. Hard substrates are an important feeding habitat for harbor seals, including from the Golden Gate east to Treasure Island, northwest to Tiburon Peninsula, and southward to Yerba Buena Island (Goals Project 2000, Green *et al.* 2006). Also, many harbor seal haul-out sites are located in close proximity to subtidal hard substrate including Point Bonita, Castro Rocks, Yerba Buena Island, and Angel Island (Goals Project 2000). Sea lions also feed in deep, marine waters of San Francisco Bay; however, they feed mostly on seasonally abundant herring associated with hard structures and eel grass beds in the Central Bay, and on spawning salmonids that are migrating up the Bay across multiple habitats to freshwater tributaries. Pacific herring is a major prey item for many marine mammal species that are drawn to the Bay, including harbor porpoise and Steller sea lions.

SHELLFISH BEDS

(by Andrew Cohen, Natalie Cosentino-Manning and Korie Schaeffer)

General Description

Past studies in San Francisco Bay have used the term "shellfish bed" to refer to locations where commonly harvested mollusks or crustaceans were found in sufficient concentrations to warrant their harvest. Earlier studies (e.g., Bonnot 1932 and 1935, Skinner 1962, Barrett 1963) primarily referred to locations of commercial interest, including planted or cultured beds of exotic bivalves. The species involved included the native Olympia oyster (*Ostrea conchaphila*), the exotic Virginia oyster (*Crassostrea virginica*) and Pacific oyster (*C. gigas*), the exotic soft-shell clam (*Mya arenaria*) and Japanese littleneck or Manila clam (*Venerupis philippinarum*), and the native bay shrimp (*Crangon* spp.), all of which were commercially harvested for food. More recent studies (e.g., Wooster 1968, USEPA 1972, Dahlstrom 1977, Jones & Stokes 1977, Sutton 1978, 1981) have focused on concentrations that are or could be sport-harvested, primarily beds of the clams, *V. philippinarum* and *M. arenaria*. Sutton (1978) also delineated beds of the rough piddock (*Zirfaea pilsbryi*), a native clam that bores into soft rock or clays, as a potential species for sport harvest, and suggested that there may be significant subtidal beds of the native bentnose clam (*Macoma nasuta*), which was commonly harvested by Native Americans. Some studies refer in passing to beds of the exotic freshwater Asiatic clam (*Corbicula fluminea*; harvested for food or bait), native California mussel (*Mytilus californianus*), bay mussel (consisting of the native *M. trossulus*, the exotic *M. galloprovincialis*, and their hybrids), exotic ribbed horsemussel (*Geukensia demissa*), native ghost shrimp (*Neotrypaea californica*), and the blue mud shrimp (*Upogebia pugettensis*). Jones & Stokes (1977) and Sutton (1978) implied that the ribbed horsemussel might be a sport-harvested species in the San Francisco Bay. The ghost shrimp and blue mud shrimp are used for fish bait, though it's not clear that there are or ever were beds of blue mud shrimp in San Francisco Bay.

In this report, "shellfish bed" is defined structurally rather than in terms of human usage. As a working definition, we propose that in order to constitute a bed, living specimens of the nominal bivalve must cover at least 50 percent of the surface over at least several square meters and, in concentration, must provide a distinct, three-dimensional substrate. We discuss five types of shellfish beds that occur or may occur in San Francisco Bay: beds of California mussels and bay mussels, which occur on hard surfaces to which they attach by byssal threads; beds of the ribbed horsemussel, which typically occur either partially buried in the sediment in salt marshes, or on hard surfaces similar to California and bay mussels; beds of the green bagmussel, which in dense concentrations occur in a mat of interwoven byssal threads on the sediment surface, and beds of the Olympia oyster, which cement to hard substrates including other oysters, and which in the past built up in extensive congregations on bottom sediments in the Bay.

Little to no information is available on biotic assemblages associated with specific types of shellfish beds. Where specific information is available, it is discussed below. Some information on species use of shellfish beds in general exists based on observations within San Francisco

Bay and elsewhere. For example, three marine mammal species, the harbor seal (*Phoca vitulina*), the California sea lion (*Zalophus californianus*) and the California sea otter (*Enhydra lutris*) are thought to be commonly associated with shellfish beds based on location of prey items (S. Allen, National Park Service, pers. comm.). Harbor seals have been observed foraging at two oyster restoration sites, Bair Island and the Marin Rod and Gun Club. Sea otters, if feeding within the Bay, would be attracted to shellfish beds for food, as they do within other estuaries such as Elkhorn Slough in Monterey Bay.

California Mussel (Mytilus californianus) Beds

Mytilus californianus is a native, primarily outer coastal species that ranges from Baja California to the Aleutian Islands. It forms large beds on rocks and pilings exposed to the surf. It feeds mainly on suspended organic detritus and plankton, especially dinoflagellates (one species of which, *Gonyaulax catenella*, produces a neurotoxin that accumulates in *M. californianus* and may render the species unsafe to eat during the summer months). *M. californianu* attains a maximum length of 25 cm, but usually grows no bigger than 13 cm in intertidal populations in California (Haderlie and Abbott 1980).

In San Francisco Bay, *M. californianus* is found only in the western part of the Central Bay, with records inside the Bay as far as the east side of the Tiburon Peninsula, Angel Island, Alcatraz Island and northwestern Yerba Buena Island (A.N. Cohen unpublished data). Here it is primarily found on rocks and seawalls, and occasionally on floating docks or buoys. No studies have been made of the distribution or species composition of its beds in the Bay. There are, however, many studies of *M. californianus* beds on the outer coast, where it typically forms beds down to around MLLW and up to the surge zone in exposed sites. It is usually associated with the gooseneck barnacle (*Pollicipes polymerus*), either intermixed or in alternating beds. Other organisms typically found on or among them on the outer coast include sea cucumbers, *Cucumaria* spp., the pile worm, *Nereis vexillosa*, the isopods, *Cirolana harfordi*, *Idotea wosnesenskii* and *Idotea stenops*, the barnacles, *Semibalanus cariosus*, *Balanus glandula* and *Tetraclita rubescens*, and feeding on the mussels, the sea star, *Pisaster ochraceus* (Kozloff 1973). Some of these may be associated with *M. californianus* near the mouth of San Francisco Bay.

Bay Mussel (Mytilus trossulus/galloprovincialis) Beds

In California, the bay mussel, identified in older literature as *Mytilus edulis*, is in fact a mix of two species, the native *Mytilus trossulus* and the Mediterranean mussel (*Mytilus galloprovincialis*), which are difficult to differentiate without molecular analysis. *M. trossulus* is the dominant mussel from northern California to Alaska, and *M. galloprovincialis* is dominant in southern California, where it was introduced sometime prior to 1947 (Cohen and Carlton 1995). San Francisco Bay and nearby bays in central California are in the boundary zone between the two populations, where both of the species and their hybrids occur in substantial numbers (McDonald and Koehn 1988, Sarver and Foltz 1993, Geller *et al.* 1993, 1994). It is not known whether the location of this boundary in central California is determined by the two species' environmental requirements, and thus is relatively stable, or is an invasion front, and thus likely to shift further north as *M. galloprovincialis* continues to expand its range[2]. In the latter case, we would expect the bay mussels in San Francisco Bay to become increasingly dominated by *M. galloprovincialis*.

The larvae of bay mussels can settle on the outer coast, and adults are occasionally found there. In wave-exposed situations, however, they are out-competed by *M. californianus*, which attach more strongly and grow larger (Haderlie and Abbott 1980). In San Francisco Bay, bay mussels are found mainly from the northern South Bay to southern San Pablo Bay, with a few records ranging as far as the Dumbarton Bridge, Port Sonoma, and Martinez (Hopkins 1986, Cohen and Chapman 2005, A.N. Cohen unpublished data). Roughly the same distribution was reported by Packard (1918) in dredge samples from the 1911 to 1912 Albatross survey, suggesting that the arrival

[2] Global warming could shift an environmental boundary northward also, though probably not quickly as an invasion front.

of *M. galloprovincialis* has not markedly affected the range in the San Francisco Bay.

In the Bay, bay mussels are commonly observed to form beds on seawalls, dock sides and pilings, and possibly also on bedrock or riprap, though there are no studies of the distribution of these beds. Similarly, although there are published studies of the bay mussel bed community in other Pacific Coast bays, there are none in San Francisco Bay, and studies from these other bays may not apply to the distinct, invasion dominated biota of San Francisco Bay. In general, however, we expect a wide variety of organisms in bay mussel beds in the Bay, on and among the shells and among their byssal threads, (e.g., sponges, hydroids, snails (limpets and *Urosalpinx cinerea*), barnacles, tanaids, sphaeromatid and cirolanid isopods, gammarid and caprellid amphipods, bryozoans and tunicates) with the communities varying with salinity, tidal exposure, and other variables. One mussel bed observed over the past decade, on pilings and rocks near the Fruitvale Bridge in Oakland, has consistently yielded numerous large specimens of the yellow sponge, *Halichondria bowerbanki*, large colonies of the hydroid, *Obelia cf. longissima*, large numbers of the barnacles, *Balanus glandula* and *Amphibalanus improvisus* along with a few *Amphibalanus amphitrite*, the tanaid, *Sinelobus* sp., the isopod, *Cirolana cf. harfordi*, the amphipod, *Ampithoe valida* and the tunicates, *Molgula manhattensis* and *Styela clava* (Cohen *et al.* 2005, A.N. Cohen unpublished data).

Ribbed Horsemussel (Geukensia demissa) Beds

The ribbed horsemussel (*Geukensia demissa*) in a non-indigenous, invasive species that was first collected in South San Francisco Bay in 1894 (Stearns 1899). It is now one of the most abundant bivalves in San Francisco Bay (Cohen and Carlton 1995). It commonly forms beds in salt marshes and along the edge of steep salt marsh channels from the South Bay to San Pablo Bay, where it frequently lies embedded with its posterior margin protruding above the mud (Cohen and Carlton 1995, A. Cohen, San Francisco Estuary Institute, pers. comm.). The ribbed horsemussel is also found on rocks and along seawalls in Lake Merritt, a shallow, brackish lagoon on San Francisco Bay. It may also occur in beds on soft bottom and natural and artificial hard bottom subtidal areas from the South Bay to San Pablo Bay, but no surveys have been completed to identify or document such beds. There is no documented information on taxonomic groups associated with ribbed horsemussel beds, but native barnacles, *Balanus glandula*, have been observed attached to individual mussels within the beds (A. Cohen, San Francisco Estuary Institute, pers. comm.).

Green Bagmussel (Musculista senhousia) Beds

The green bagmussel (*Musculista senhousia*) is native to Japan and China and was introduced to central California with Japanese oysters (*Crassostrea gigas*) for harvest (Kincaid 1949). It was first collected in San Francisco Bay in 1946 (Carlton 1979). Green bagmussels tend to occur in very high densities along the eastern shore of Central San Francisco Bay (A. Cohen, San Francisco Estuary Institute, pers. comm.). It occurs in the bottom of Lake Merritt in dense byssal mats that can be pulled from the bottom in sheets and in the Oakland estuary mixed with bay mussels and *Diadumene* sp. anemones (A. Cohen, San Francisco Estuary Institute, pers. comm.). It is frequently the most common benthic organism from South Bay to San Pablo Bay, where it has been collected at densities of up to 1,000 to 2,000 clams/m^2 and is occasionally collected in Suisun Bay but not necessarily at densities high enough to form beds (Nichols and Thompson 1985, Hopkins 1986, Markmann 1986).

Olympia Oyster (Ostrea conchaphila) Beds

Shellfish bed habitat includes areas of living Olympia oysters (*Ostrea conchaphila*, formerly *O. lurida*), and remnant beds composed of dead shell material. Olympia oysters can survive in a broad range of habitats but are most abundant in estuaries, small rivers, and streams. Along the Pacific coast, Olympia oyster beds are formed in the subtidal zone and are bordered by mud flats at high tidal elevations and by eelgrass beds at low tidal elevations. They are found at depths of 0 to 71 meters (Hertlein 1959). Oysters may attach to the underside of rocks higher in the intertidal zone, where the bottom is gravel or rock (Kozloff 1973).

Native oyster bed habitat is undoubtedly the most poorly understood of any San Francisco Bay subtidal habitat types. While anecdotal information indicates that historically Olympia oysters were a large component of the Bay ecosystem, to date no live subtidal Olympia oyster beds have been documented in San Francisco Bay. Intertidal populations, however, have been found throughout the Bay (Figure 11) and are currently receiving much attention by researchers and restoration practitoners. Elsewhere along the Pacific coast, Olympia oyster shell serves as a substrate for epifauna such as mussels, *Mytilus galloprovincialis* and *M. trossulus*, barnacles, and boring sponges (Baker 1995). Information on invertebrate taxa associated with oyster beds in the Bay is limited to on-going monitoring at three restoration sites (Richardson Bay, Bair Island, and Marin Rod and Gun Club), which use Pacific oyster shell as substrate for Olympia oyster recruitment (MACTEC 2006; Table 7).

The Richardson Bay oyster restoration site included a fish-monitoring component. Long-line and minnow trap techniques were used on a monthly basis for a period of 8 months. The most abundant species included the bat ray (*Myliobatis californica*), leopard shark (*Triakis semifasciata*), shiner surf perch (*Cymatogaster aggregata*), diamond turbot (*Hypsopsetta guttulata*), thornback (*Pltyrhinoidis trisderiata*), and bay pipefish (*Syngnathus leptorhynchus*) (McGowan 2005).

Diving benthivore birds such as the eared grebe (*Podiceps nigricollis*), the ruddy duck (*Oxyura jamaicensis*), and the common goldeneye (*Bucephala clangula*) have been observed foraging in shellfish beds (Table 5). Eared grebes may be observed throughout the year in San Francisco Bay (Goals Project 2000). Eared grebes make shallow dives for prey items such as small crustaceans, fishes, and mollusks (Fix and Bezener 2000). An estimated 85 percent of the Northern American ruddy duck population primarily uses the San Francisco Bay as over-wintering habitat (Goals Project 2000). The greatest ruddy duck abundance has been observed in the South Bay (Goals Project 2000), which is a historic area for native oysters (Figure 11). Ruddy ducks feed on submerged aquatic vegetation and small crustaceans (Fix and Bezener 2000). Similar to other diving benthivores, the common goldeneye is most abundant during the winter months, with San Francisco Bay representing a major over-wintering area. Goldeneyes feed on a variety of prey including crustaceans, mollusks, small fishes, and plant material (Fix and Bezener 2000).

Table 7. Sessile invertebrates associated with native oyster restoration sites at Marin Rod and Gun Club and Redwood City sites in San Francisco Bay from MACTEC (2006).

		Native Oyster Restoration		
	Species	RC Pallets	MRGC Necklace	MRGC Pallets
Sponges	*Halichondria bowerbanki*	X	X	X
	Haliclona sp.	X		
	Clathria prolifera	X		
Hydroids	*Tubelaria* sp.	X	X	X
	Obelia sp.	X	X	X
Anenomes	*Diadumene* sp.	X	X	X
	Haliplanella lineata	X	X	
Flatworms	*Platyhelminthes* sp.	X	X	
Scale Worms	*Halosydna brevisetosa*		X	
	Harmothoe "imbricata"	X		
	Lepidontus squamatus			
Family Syllidae	*Typosyllis nipponica*	X		X
Family Neridae	*Neanthes succinea*	X	X	X
	Nereis vexillosa		X	
	Nereis latescens		X	
Family Eunicidae	*Marphysa* sp.	X		
Family Terebellidae		X		
Barnacle	*Balanus* sp.	X	X	
Isopods	*Synidotea laevidorsalis*	X	X	X
	Paranthura elegans	X		
	Sphaeromatid type	X	X	X
Amphipods	Unknown gammaridian sp.	X	X	X
	Ampelesca sp.	?	X	
	Corophium sp.	X	X	X
Caprellid shrimp	*Metacaprella kennerlyi*		X	
	Caprella sp.			
Caridea shrimp	*Palamon macrodactylus*	X		X
	Hemigrapsus nudus	X		
	Hemigrapsus oregonensis	X	X	X
	Rhithropanopeus harrisii	X		
Pycnogonida		X		
Gastropods	*Urosalpinx cinera*	X		
	Crepidula plana	X		
	Crepidula convexa	X		
	Philine sp.	X		
Opisthobranchs	*Sakuraeolis enosimensis*	X	X	
	Dirona picta		X	
	Elysia hedgpethi		X	
	Haminoea sp.	X		

RC Pallets — Oyster shell pallets at Redwood City site.
MRGC Necklace — Oyster shell necklace at Marin Rod and Gun Club
MRGC Pallets — Oyster shell pallets at Marin Rod and Gun Club site.

Table 7. Sessile invertebrates associated with native oyster restoration sites at Marin Rod and Gun Club and Redwood City sites in San Francisco Bay from MACTEC (2006).

		Native Oyster Restoration		
	Species	RC Pallets	MRGC Necklace	MRGC Pallets
Bivalves	*Venerupis philipparum*	X		X
	Musculista senhousia	X	X	X
	Ostrea conchaphila	X	X	X
	Mytilus edulis (mussel)		X	
Bryozoans	*Schizoporella sp.*	X	X	X
	Bugula sp.	X	X	X
	Watersipora subtorquata	X		
	Conopeum sp.			X
	Other unknown species	X	X	X
Tunicates	*Molgula manhattensis*	X	X	X
	Styela clava	X	X	X
	Ciona sp.	X		
	Botrylloides sp.	X		

RC Pallets — Oyster shell pallets at Redwood City site.
MRGC Necklace — Oyster shell necklace at Marin Rod and Gun Club
MRGC Pallets — Oyster shell pallets at Marin Rod and Gun Club site.

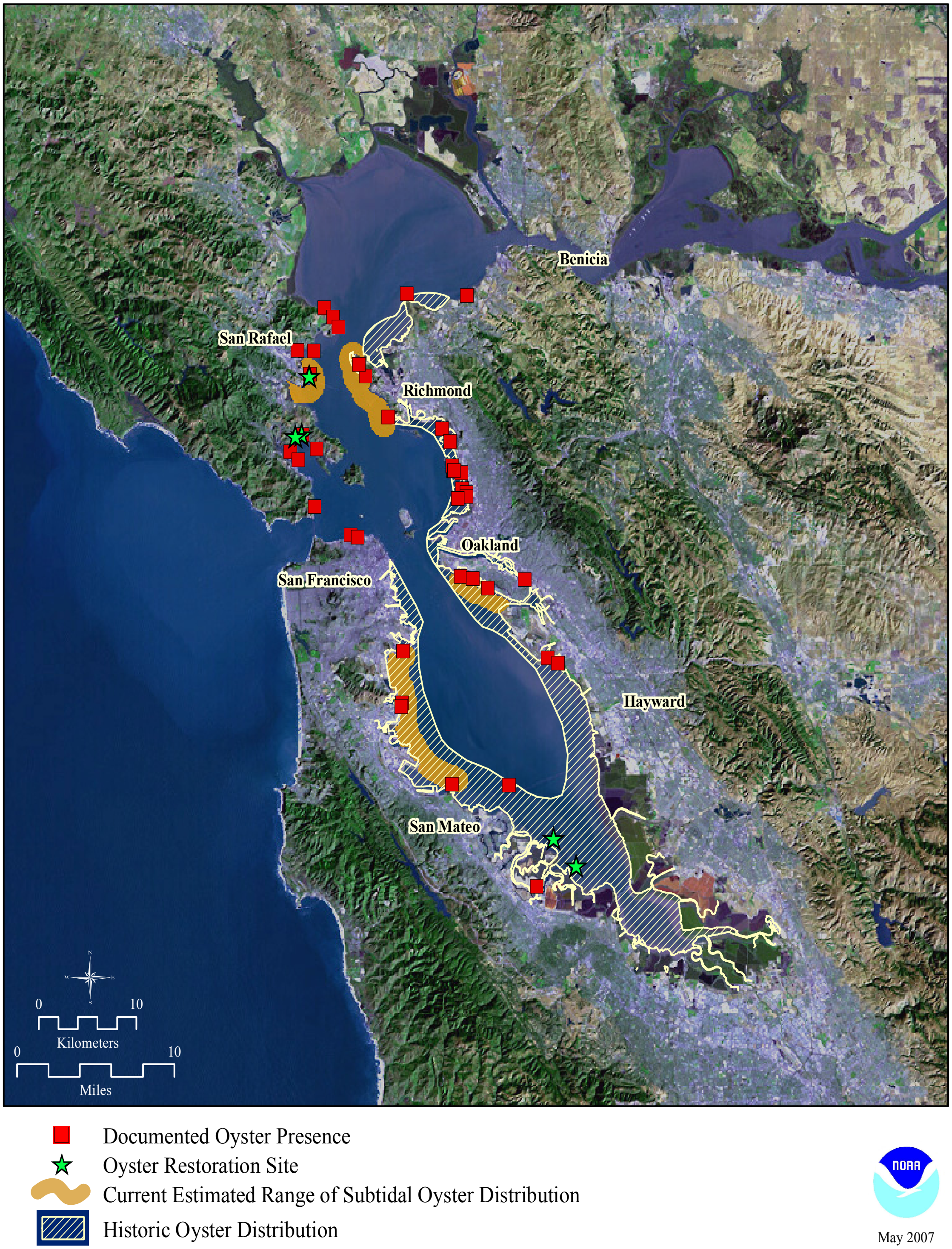

Figure 11. Historic native oyster distribution from Barrett (1963), sites of known oyster occurrence at present from Harris (2004), and native oyster restoration sites in San Francisco Bay. Historic oyster distribution is for the period prior to 1915 and is an approximation.

PLANT BEDS

(by Natalie Cosentino-Manning, Katie McGourty and Susan Wainwright-De La Cruz)

General Description

Subtidal plant beds in San Francisco Bay include two major groups: algal beds (both macro and micro) and angiosperm beds, more commonly referred to as submerged aquatic vegetation (SAV). Although there is very little historical data (pre-gold rush) for the two groups, surveys in the past 20 years described the Bay as having the same taxonomic diversity as other estuaries on the west coast (Josselyn and West 1985).

Macroalgae Beds

Macroalgae occur in San Francisco Bay both as floating drift and as attached plants. Most of the macroalgae seen as drift in the Bay has been ripped off the outer coast by strong currents or storms and carried into the Bay with the tides (N. Cosentino-Manning, NMFS, pers. comm.). This generally occurs during winter storms or during the upwelling months (April to June), when offshore winds are strong. The macroalgae (benthic and drift) belong to the taxonomic groups Chlorophyta (green), Rhodophyta (red), and Phaeophyta (brown) and are mostly found within Central Bay, where salinity levels are mainly euhaline. However, the green algal distribution extends further into the polyhaline and mesohaline parts of the Bay, although exact distribution limits for a particular species are difficult to determine (Wilkinson 1980).

Evidence from other estuaries within the United States show that estuarine macroalgae contribute significantly to a number of estuarine processes. Productivity of macroalgae can at times match or exceed that of phytoplankton (Dillion 1971) and can act as a nutrient sink. Algae also deteriorate faster than terrestrial plants and therefore can contribute significantly to the particulate organic matter in estuaries (Josselyn and Mathieson 1980).

In this report we focus on four species of bed forming macroalgae, *Ulva*, *Gracilaria*, *Fucus*, and *Sargassum*.

Ulva Beds

Probably the most conspicuous alga along the shores of San Francisco Bay, especially at low tide, is *Ulva*. *Ulva* species live primarily in euhaline to polyhaline environments. It lives attached to rocks or on mudflats in the middle to low intertidal zone, and as deep as 10 meters in calm, protected harbors. *Ulva* plants are usually seen in dense groups. Commonly known as the sea lettuce, the genus includes species that look like bright, green sheets. Shapes of *Ulva* species are quite varied from circular to oval to long and narrow and tubular, ranging in size from microscopic to 65 cm.

Ulva species have high nitrogen requirements, a reduced ability to take up nitrogen in low nitrogen conditions, and a limited ability to store nitrogen. These features can limit the distribution of *Ulva* to nitrogen-rich environments. When nitrogen is available in particularly high concentrations, however, *Ulva* species are able to take up nitrogen quickly and use it to grow rapidly. Thus, nuisance growth of *Ulva* species can occur in areas with nitrogen-rich sewage pollution, especially if they are within enclosed or semi-enclosed sub-embayments and experience little mixing (Valiela *et al.* 1997). In these areas, *Ulva* species comprise a large proportion of drift plants, and can smother the benthic communities below. Species associated with *Ulva* include the isopods *Idotea* sp. and *Sphaeroma* sp. and the amphipod *Gammarus* sp. Small littorine snails are also associated with *Ulva*. (N. Cosentino-Manning, NMFS, pers. comm.).

Gracilaria Beds

Gracilaria pacifica (formerly *verrucossa*), also known as the red spaghetti alga or agar, is a resident species to San Francisco Bay and can be found within quiet embayments such as Richardson Bay or on the leeside of islands such as Treasure Island and Angel Island. *Gracilaria* requires a euhaline to polyhaline environment and can be found attached or floating (free-living). Many times it is found in areas where eelgrass (*Zostera marina*) is growing. It is unknown if there is a link between the two species or if similar habitats types are preferred.

Gracilaria appearance ranges from dark brown to bright red in coloration. *Gracilaria* is considered a "bloom" species because it has the ability to grow and dominate a community under increased nitrogen loads. In some estuaries, *Gracilaria* has even replaced *Zostera* beds (Valiela *et al.* 1997). It is unknown whether the current abundance levels for *Gracilaria* in the San Francisco Bay are at normal or bloom levels.

Species associated with *Gracilaria* include the isopods, *Idotea* sp. and *Sphaeroma* sp., and the amphipod, *Gammarus* sp. (N. Cosentino-Manning, NMFS, pers. comm.). The red algal parasite, *Gracilariophila oryzoides*, was found on specimens collected from 1970 to 1980 (Silva 1979). The Pacific herring is the only documented fish associated with *Gracilaria*. The CDFG has documented herring spawning on *Gracilaria* (Tom Moore, CDFG, pers. comm.). Herring may benefit from high abundance of *Gracilaria* because of its increased surface area for spawning.

Fucus Beds

Another conspicuous alga on the intertidal shores of San Francisco Bay is the brown fucoid algae *Fucus gardneri*, also known as rockweed. *Fucus* is flat and dichotomously branched and ranges in color from golden brown to almost black if dessicated. When reproductive, the tips of the plant become inflated and a mucus discharge is evident. *Fucus* is found throughout the euhaline Central Bay in sheltered and exposed intertidal habitats. It is most apparent on hard bottom substrate such as rip-rap, boulders, and concrete harbor pilings.

Fucus provides habitat for many sessile and motile invertebrates. Small acorn barnacles such as *Balanus glandula* and *Chthamalus* sp. reside under the wet blades of *Fucus* and are protected from desiccation during the low tide cycle. Gammaridian amphipods are also found in large congregations between and under the blades. (N. Cosentino-Manning, NMFS, pers. comm.).

Sargassum Beds

Sargassum muticum is a brown algae (Phaeophyta) originating from Japan and introduced to the West coast of the United States in 1945 (Abbott and Hollenberg 1976). The alga is yellowish- or olive-brown and can be distinguished from most other Pacific coast seaweeds by its small, spherical air bladders (pneumatocysts) that allow the alga to rest on the water at high tide. In San Francisco Bay, *Sargassum* can be found throughout the euhaline and polyhaline portions of the Bay and is mostly restricted to calm enbayments or within harbors and marinas. It grows attached to rocks, shells or other hard objects, in the lower intertidal zone to the shallow subtidal (3 m to 5 m). It can grow up to 4 m in length.

There are many reports of *Sargassum muticum* competing with and displacing native species of seaweed and eelgrass, at least in part by shading and reduction of light levels. At Santa Catalina Island in southern California, it appears to have taken over large shallow beds of the seaweed *Scytosiphon* (Nicholson *et al.* 1981). It may also exclude native species by occupying areas when they become temporarily vacant, as was reported following a die-back of the kelp *Macrocystis pyrifera* at Santa Catalina Island, and for eelgrass die-backs in Atlantic France (Den Hartog 1997). Silva (1979) reported that "there is no evidence that *Sargassum muticum* is displacing the native biota of San Francisco Bay." There is no data on the distribution or abundance of *Sargassum* in San Francisco Bay and how it affects other species in the Bay.

Sargassum muticum beds do provide habitat to several invertebrate species such as caprellidae amphipods, isopods, littorine snails and juveniles of both the red rock crab and the Dungeness crab.

Submerged Aquatic Vegetation

Submerged aquatic vegetation (SAV) are rooted, vascular, flowering plants that, except for some of the flowering structures, live and grow below the water surface. SAV can be found in euhaline to oligiohaline environments within the Bay. Although SAV sometimes occurs intertidally or extends to the water's surface, these plants are generally submerged and cannot survive if removed from the water for any length of time (Hurley 1990). The leaves and stems of SAV have specialized thin-walled cells with large intracellular air spaces to provide buoyancy and support. Leaves and stems are generally thin and lack the waxy cuticle found in terrestrial plants. The lack of a waxy cuticle increases the exchange of water, nutrients, and gases between the plant and the water (Hurley 1990). The extensive root and rhizome system anchors the plants, and also absorbs nutrients (Thayer *et al.* 1984). Reproduction occurs both sexually and asexually.

SAV in San Francisco Bay has been poorly studied and very little is known about its distribution and abundance. Four types of SAV communities are known to occur within San Francisco Bay; surfgrass (*Phyllospadix scouleri*), eelgrass (*Zostera marina*), widgeon grass (*Ruppia maritima*) and sago pondweed (*Potamogeton pectinatus*). Each species of SAV has varying salinity requirements and is found in distinct parts of the Bay. Based on limited surveys of the Bay, the most widely distributed SAV habitat is eelgrass (Merkel & Associates, Inc. 2003), followed by widgeon grass, sago pondweed and surf grass (Figure 12). All four SAV species provide primary productivity and decrease erosion by dampening wave action, preventing sediment resuspension, increasing sedimentation, providing attachment for sessile organisms, and providing a resource area for invertebrates, fishes, birds, and marine mammals.

Sago Pondweed *(Potamogeton pectinatus)* Beds

Sago pondweed (*Potomogeton pectinatus*) is found in fresh non-tidal to moderately oligohaline waters; sago pondweed can die back when water salinity exceeds 15 ppt (Kantrud 1990). It can tolerate high alkalinity and grows on silty-muddy sediments. It tolerates strong currents and wave action better than most bay grasses because of its long rhizomes and runners. The precise abundance and distribution of sago pondweed in San Francisco Bay have not been well documented, but anecdotal evidence suggests that beds are mainly located in the shallow areas of Suisun Bay surrounding Simmons, Ryer, and Roe Islands (N. Cosentino-Manning, NMFS, pers. comm.) and in Little Honker Bay (S. Siegel, Wetlands and Water Resources, Inc., unpub. data). Feminella and Resh (1989) conducted a 3-year study on sago pondweed density in Coyote Hills Marsh, a man-made marsh in Alameda County. The study cover area contained 71 percent sago pondweed in 1984. By 1986, sago pondweed had been eliminated by the invasive crawfish *Procambarus clarkii*.

Sago pondweed is considered one of the most valuable food sources for waterfowl in North America. Its highly nutrient seeds and tubers, as well as leaves, stems, and roots, are consumed by numerous species of ducks, geese, and marsh and shorebirds. Martin *et al.* (1951) found wigeongrass composed 10 to 25 percent of the diet of redheads (*Aythya americana*) and scaup (*Aythya* spp.); 5 to 10 percent of the diet of pintails (*Anas acuta*) and ruddy ducks (*Oxyura jamaicensis*); and 2 to 5 percent of the diet of mallards (*Anas platyrhynchos*), canvasback (*Aythya valisineria*), and green-winged teal (*Anas crecca*). Sago pondweed has been found to compose 50 percent or more of the diet of canvasbacks; 25 to 50 percent of the diet of mallards and redheads; and 10 to 25 percent of the diet of pintails, green-winged teal, and scaup (Martin *et al.* 1951). The importance of sago pondweed as a waterfowl food resource in San Francisco Bay is unknown.

Widgeon Grass (*Ruppia maritima*) Beds

Like eelgrass, widgeongrass (*Ruppia maritima*) is found in polyhaline to euhaline regions, however, widgeon grass can tolerate and grow in both fresh water and high-salinity environments. Widgeon grass has been documented within Suisun Bay, Lake Merritt (MSI 2005), and within one South Bay salt pond (Anderson 1970). Widgeon grass has become a management issue for Lake Merritt and is routinely harvested for removal.

Figure 12. Distribution of eelgrass (*Zostera marina*), the marine alga, *Gracilaria*, and widgeon grass (*Ruppia maritima*) in San Francisco Bay after Merkel & Associates (2003) and N. Cosentino-Manning (NMFS, pers. comm.).

Eelgrass (*Zostera marina*) Beds

Eelgrass, *Zostera marina*, is a subtidal marine flowering vascular plant, with all stages of the life cycle occurring underwater, including flowering, pollination, and seed germination. Eelgrass is widespread through the Atlantic and Pacific and has a restricted distribution in the Mediterranean. It is the only SAV species that extends into the Arctic Circle.

Intermittent eelgrass surveys suggest eelgrass abundance has varied greatly in San Francisco Bay in the last several decades. In the late 1920s, eelgrass was reported as an abundant species along the shores of San Francisco Bay (Setchell 1929). In 1987, 60 years later, a survey of the Bay revealed only 128 hectares (only 0.1 percent total Bay bottom coverage) of eelgrass throughout the San Francisco Bay, with much of the existing habitat exhibiting conditions of environmental stress (Wyllie-Echeverria and Rutten 1989, Wyllie-Echeverria 1990). A decade later, surveys of the San Pablo Peninsula documented over 162 hectares of eelgrass (SAIC and Merkel & Associates, Inc. 1999a, 1999b). However, in a series of acoustic surveys between June 4 and October 12, 2003, 1165.7 hectares of eelgrass were documented (Merkel & Associates, Inc. 2004, Figure 13).

Currently, eelgrass beds within San Franicsco Bay are found in euhaline to polyhaline salinities and are found mainly along the eastern shores of San Pablo and Central Bays. Existing eelgrass beds cover approximately 1 percent of San Francisco Bay, which is at least an order of magnitude less than seen in other large estuarine systems (Merkel & Associates, Inc. 2003) (Figure 12). Due to the large size of the San Francisco Bay, however, even a minor proportional representation amounts to substantial eelgrass resource on a state wide basis.

The majority of the eelgrass in San Francisco Bay is located on the east shoreline between Point Pinole and Bayfarm Island (Figure 13). A few solitary plants are recorded north of Point Pinole near Wilson Point and several individual plants and two small patches are observed south of the San Mateo Bridge along the Alameda shoreline. The range of eelgrass distribution during the Merkel 2003 survey and the Wyllie-Echeverria and Rutten 1989 survey were similar.

The largest eelgrass bed in the Bay is the Point San Pablo bed, which is located between Point Pinole and Point San Pablo north of the Richmond-San Rafael Bridge (Figure 13). This bed was approximately 608.9 hectares (1,504.5 acres) during 2003, and comprised 52.2 percent of the total eelgrass coverage of the Bay (Merkel & Associates, Inc. 2003). The bed lies on a shallow depositional shoal approximately -1.5 to -0.5 m MLLW.

The second largest eelgrass bed is found in Richardson Bay near Sausalito in Marin County (Figure 13). This bed is approximately 176.7 hectares (436.7 acres) during the 2003 survey, the densest part of which was located among the boat moorings and near the marinas on the western side of the Bay. Eelgrass in Richardson Bay occurred between -3.0 and -0.5 m MLLW.

Eelgrass beds are important habitats in euhaline and polyhaline waters because they are home to many small organisms that are food for larger species and they provide protective cover for migrating salmon, provide spawning substrate for Pacific herring, and act as a nursery for many other smaller fish such as gobies. Eelgrass stabilizes and binds substrates and absorbs nutrients from sediments. They reduce water currents by frictional forces, dampen wave energy, and slow erosional processes. They are primary producers removing inorganic nutrients from the sediments and the water column and through photosynthesis convert them into organic material.

Plants

Epiphytic plants, such as diatoms and microscopic green algae, can be found on eelgrass blades. *Gracilaria* sp. often co-occurs with SAV for reasons not understood. Other macroalgal genera found in eelgrass include salt/brackish (*Ulva*, *Codium*, *Gracilaria*) species and the macroalgae, *Ectocarpus*, *Cladomorpha*, and *Chaetomorpha* (Mallin *et al.* 2000, Thayer *et al.* 1984).

Location	Abundance in 1987 (Acres)	Abundance In 2003 (Acres)
San Pablo Bay	124	1,504.5
Point Orient	3	2.3
Naval Supply Depot	12	77
Point Molate Beach	26	32
Toll Plaza West	0.5	0
Toll Plaza East	0.5	2.5
Point Richmond, North	7	24
Point Richmond, South	4	65.6
Richmond Breakwater, North	18	19
Richmond Breakwater, South	7	86.3
Brickyard Cove		17.7
Emeryville (breakwater)	13	28.7
Emeryville Flats		21.6
Yerba Buena Island		1.7
Treasure Island		5.1
Alameda	55	269.9
Bayfarm, North	2	4.4
Bayfarm, South	4	127.9
Coyote Point	1	0.6
Richardson Bay	13	436.7
Angel Island West	3	1.6
Angel Island South		0.7
Angel Island East		2.8
Belvedere Cove	5	21.8
Point Tiburon	1	0.2
Keil Cove	10	20.4
Paradise Cove, North	4	13
Paradise Cove, South	30	0.2
Pt. San Quentin		0.5
Pt. San Pedro		1.6
Minor Beds and Patches		90.2
TOTAL	**316**	**2,880.5**

Sources: (WyllieEcheverria et al. 1989); (Merkel 2003a, b)

Figure 13. Eelgrass (*Zostera marina*) density in San Francisco Bay in 2003 after Merkel & Associates (2004) and Wyllie Echeverria *et al.* (1989).

Invertebrates

Epiphytic invertebrates such as bryozoans and hydroids are commonly observed on eelgrass blades (Kozloff 1973). Herbivorous snails such as *Littorina* sp. and *Tegula* sp. graze on epiphytic diatoms and algae on eelgrass blades, while carnivorous whelks such as *Nassarius* sp. and hermit crabs are commonly observed (Ricketts *et al.* 1985). Along the Pacific Coast, several species of nudibranchs (sea slugs) can be found among eelgrass blades, including *Mebile leonina*, which feeds on small crustaceans, *Aeolidia papillosa*, feeding on anemones, and *Phyllaplysia taylori*, a photosynthetic nudibranch endemic to eelgrass beds (Kozloff 1973). Crustaceans inhabiting Pacific Coast eelgrass beds include skeleton shrimp (*Caprella californica*), the Dungeness crab, the red crab, the graceful crab (*Cancer gracilis*), and amphipods (small crustaceans). Similar species may inhabit eelgrass beds in San Francisco Bay. Merkel & Associates, Inc. (2003) conducted six benthic infaunal samples from the San Francisco Bay from August 5 to 8 and September 22 to 25. Arthropods (composed primarily of amphipods), mollusks, and annelid worms were the most abundant phyla found (Merkel & Associates, Inc. 2005).

Fishes

Eelgrass beds throughout California serve as a nursery area for several fish species including rockfish (*Sebastes* sp.) and surfperch (*Embiotocidae*), and a refuge and foraging area for year round resident fish species such as the bat ray (*Myliobatis californica*) and the bay pipefish (*Syngnathus leptorhynchus*) (Table 4). Two studies have been undertaken in San Francisco Bay to determine fish species utilization of eelgrass beds. ENTRIX, Inc. (1998) conducted a survey of fish communities in eelgrass in relation to the Port of Oakland's Harbor Navigation Improvement Project in the spring, summer, and fall of 1997. Twenty-two fish species were observed; the most abundant were Pacific herring (*Clupea pallasi*), shiner surfperch (*Cymatogaster aggregata*), speckled sanddab (*Citharichthys stigmaeus*), bat ray, the bay pipefish, and black perch (*Embiotoca jacksoni*). Merkel & Associates, Inc. (2005) and NOAA Fisheries conducted fish surveys from June 14 to 17 in 2004 using four different gear types (purse seine, large seine, otter trawl, and minnow traps). Thirty-six fish species were observed, with topsmelt (*Atherinops affinis*), shiner surfperch, dwarf surfperch (*Micrometrus minimus*), and northern anchovy (*Engraulis mordax*) most abundant.

Eelgrass beds provide refuge for a diverse assemblage of fishes uncommon in other areas of San Francisco Bay. Black perch (*Embiotoca jacksoni*) are relatively rare in San Francisco Bay; CDFG found only 77 individuals over 15 years of monthly monitoring (DeLeon 1999). Black perch mate from April to June, and after a six-month gestation period give birth to an average brood of 14 offspring from September to November (DeLeon 1999, Baltz 1984). The bay pipefish is closely related to the Pacific seahorse. Members of this family are unique because males brood and care for young in a specialized brooding pouch.

Birds

Similar to the unconsolidated sediment and shellfish bed habitats, diving benthivores commonly forage in SAV (Table 5). In addition to diving benthivores, piscivorous terns including the Caspian tern (*Sterna caspia*), the Forester's tern (*S. forsteri*), and the elegant tern (*S. elegans*) forage in eelgrass beds. Forester's tern can be observed year-round in San Francisco Bay. During spring and fall, Forester's terns migrate from breeding grounds to feeding grounds and become more abundant within San Francisco Bay. During the winter months, a comparatively smaller number of Forester's terns (28 breeding colonies) breed in South Bay (Goals Project 2000). Caspian terns, the largest of tern species found in San Francisco Bay, migrate great distances between breeding and foraging grounds and can be found on every continent except Antarctica. Caspian terns arrive to San Francisco Bay in late spring to breed and are present until August (Goals Project 2000). Caspian tern breeding sites are concentrated in Central and San Pablo Bays (Goals Project 2000). Elegant terns use San Francisco Bay as a stop-over point during their migration from late spring through early fall. Annual abundance varies in accordance with oceanographic conditions (Fix and Bezener 2000). All three tern species feed by hovering over the water and making quick dives for small, schooling fishes.

Marine Mammals

Marine mammals often feed in submerged aquatic vegetation where high abundances of fish and invertebrates occur. Eelgrass, in particular, provides an important foraging habitat for all seven species of marine mammals found within San Francisco Bay (Table 6) due to high concentrations of prey items such as schooling fishes. Eelgrass is the most productive foraging area for California sea lions and harbor seals during winter months when Pacific herring are in high abundance (S. Allen, National Park Service, pers. comm.). Harbor seals in this habitat will also forage on perch, top smelt, anchovies, California halibut, and speckled sanddabs. Gray whales periodically feed on epiphytic growth on eelgrass, with the ability to feed in depths as shallow as 1.5 to 2.5 m (S. Allen, National Park Service, pers. comm.). *Gracillaria* beds are similarly important foraging habitat for marine mammals because herring and other fish congregate there. Harbor seals will also rest in eelgrass beds, laying on the bottom and surfacing to breathe.

Surfgrass (*Phyllospadix scouleri* and *torreyi*) Beds

The surfgrasses, *Phyllospadix scouleri* and *torreyi* are similar to eelgrass in that they are angiosperms with true leaves, stems, rootstocks, and flowers. Surfgrass can be found from Alaska to Baja California, Mexico. Surfgrass grows attached to rocks, many of which are exposed at low tide. Surfgrass occurs below the mean lower low water level (Ricketts *et al.* 1985) and requires euhaline salinity with exposure to wave action. Surfgrass is found only at the entrance to San Francisco Bay and is not found any further east than the two forts (Fort Baker and Fort Point) that flank the Golden Gate Bridge (N. Cosentino-Manning, NMFS, pers. comm.).

The ecology and importance of *Phyllospadix* is not known nearly as well as that of eelgrass. *Phyllospadix* vegetation can protect rocky substrate from erosion and transform it into sandy beaches or sublittoral sand flats by accumulating sand in and between the tussock (Phillips 1979). Surfgrass provides habitat for many species of algae (Stewart and Myers 1980) and provides shelter for many invertebrates. The red algae, *Smithora naiadum* and *Melobesia mediocris*, and the green algae, *Kornmannia zostericola*, (Kozloff 1973) are exclusively epiphytic on sea grasses, such as surfgrass (Abbott and Hollenberg 1976). Small herbivorous snails including the chink snail (*Lacuna* sp.) and limpets such as *Notoacmea paleacea* graze on epiphytic algae found on surfgrass (Kozloff 1973).

Colonial tunicates, sponges, various species of amphipods, the limpet, *Notoacmea insessa*, the sea anemone, *Anthopleura xanthagrammica*, and crabs such as the kelp crab (*Pugettia producta*), and Cancer crabs (*Cancer antennarius* and *productus*) inhabit surfgrass beds. Isopods (*Isopodea* sp.), a type of crustacean, cling to blades and feed on surfgrass leaves (Kozloff 1973). Several species of nudibranchs can also be found in protected areas of surfgrass, including *Hermissenda crassicornis*, the Spanish shawl (*Flabellinopsis iodinea*), and the sea lemon (*Anisodris nobilis*). Surfgrass also provides nursery habitat for fishes such as gobies, gunnels, and the monkey-faced eel (*Cebidichthys violaceus*) (Engle 1979). Marine mammals such as the harbor seal (*Phoca vitulina*) can be seen resting at low tide on *Phyllospadix* covered rocks. (N. Cosentino-Manning, NMFS, pers. comm.).

Phyllospadix is susceptible to desiccation and heat stress during low midday tides (Raimondi *et al.* 1999). It is also sensitive to sewage (Littler and Murray 1975) and oiling (Foster *et al.* 1998). If the rhizome systems remain viable, then recovery following disturbance can be fairly rapid; however, recovery is long if the entire bed is lost because recruitment is irregular (Turner 1983, 1985), and restoration projects have been unsuccessful.

WATER COLUMN

(by Korie Schaeffer, Kathryn Hieb, Katie McGourty, Susan Wainwright-De La Cruz, and Sarah Allen)

General Description

The water column consists of the area between the benthos and the water surface. Temperature, salinity, dissolved oxygen, and turbidity vary within the water column depending on depth, location, and season. Species assemblages occur in the lower, middle, and upper portion of the water column depending on available cover, light, and predator-prey interactions. The water column may be classified as a channel (deeper area with "u" or "v" shape geomorphology with stronger currents) or shoals (shallow, flat areas with weaker currents).

Water column habitat allows for horizontal and vertical water transport and mixing, tidal propagation, and suspension or deposition of sediments, and provides a medium for primary and secondary production, foraging areas for invertebrates, fishes, birds, and marine mammals, and nursery and spawning areas for fishes and invertebrates. Shoals function as recipients and dispersers of non-local sources of detritus. Channels provide a connection from marine to freshwater ecosystems.

Taxonomic Groups

Plants (phytoplankton)

Phytoplankton of San Francisco Bay includes those species produced within the water column, those that are exchanged between the water column and the sediments, those transported into the Bay with freshwater flow, and those transported into the Bay with tidal exchange from the Pacific Ocean. Cloern and Dufford (2005) characterized the phytoplankton community based on seasonal samples taken along the salinity gradient from the Sacramento River to Central Bay to South San Francisco Bay between 1992 and 2001. The phytoplankton assemblage was dominated by a small number of species; diatoms were the dominant phytoplankton type, followed by dinoflagellates and cryptophtes. Each of these three groups of phytoplankton contributed 81, 11, and 5 percent, respectively, to cumulative biomass. A species list from this study is provided in Table 8. Within this list, the top 17 ranked species include 12 diatoms, 2 dinoflagellates, 2 cryptophytes, and *Mesodinium rubrum*. During the period of sampling, some phytoplankton taxa apparently disappeared after 1996 while others first appeared and have occurred yearly since 1997 to 1998. The general timing of these changes mirror large-scale changes in ocean temperatures, regional wind patterns, and biological communities across the Pacific basin (Chavez *et al.* 2003). (Cloern and Dufford 2005)

Many phytoplankton species occur across broad salinity and temperature ranges, and are not easily classified into specific salinity categories. For example, pico-cyanobacteria and some small eukaryotes (e.g., *Nannochloropsis* sp., *Teleaulax amphioxeia*, *Plagioselmis prolonga*) are persistent and ubiquitous across large habitat gradients in San Francisco Bay. Exceptions to this general rule include more commonly marine species (e.g., *Thalassiosira frauenfeldii*, *Ceratium furca*, *Pyramimonas parkeae*, *Ceratium* spp., *Alexandrium catenella*, *Prorocentrum micans*, *P. gracile*, *Dinophysis acuminate*, *Heterosigma akashiwo*), which are confined to areas of higher salinity; and freshwater taxa, such as *Skeletonema potamos*, which are transported to San Francisco Bay with river flow. (Cloern and Dufford 2005)

Historically, median phytoplankton primary production in San Francisco Bay has been relatively low (120 $gCm^{-2}yr^{-1}$) compared to other estuaries world wide (average 200 $gCm^{-2}yr^{-1}$) (Jassby *et al.* 2002). Eutrophication and hypoxia, which are of concern in many estuaries, including Chesapeake Bay, are not high-priority concerns for San Francisco Bay. Despite the relatively low production levels, phytoplankton photosynthesis is the primary energy supply to food webs of San Francisco Bay (Jassby *et al.* 1993, Sobczak *et al.* 2002, 2005).

Table 8. Common phytoplankton taxa in San Francisco Bay from Cloern and Dufford (2005).

Only those species that occurred in >10 (of 599) samples and contributed >0.1% of cumulative biomass as biovolume contained in all samples; n=number of occurrences.

Species	Division	Biomass (%)	n
Thalassiosira rotula	Bacillariophyta	20.97	140
Chaetoceros socialis	Bacillariophyta	11.98	48
Skeletonema costatum	Bacillariophyta	9.51	277
Ditylum brightwellii	Bacillariophyta	7.44	103
Gymnodinium sanguineum	Pyrrophyta	7.40	41
Coscinodiscus oculus-iridis	Bacillariophyta	6.30	66
Thalassiosira hendeyi	Bacillariophyta	4.85	203
Thalassiosira punctigera	Bacillariophyta	3.31	27
Plagioselmis prolonga var. nordica	Cryptophyta	2.65	495
Coscinodiscus curvatulus	Bacillariophyta	2.15	49
Mesodinium rubrum	Holotrich ciliate	2.03	190
Teleaulax amphioxeia	Cryptophyta	2.02	375
Chaetoceros debilis	Bacillariophyta	1.84	31
Eucampia zodiacus	Bacillariophyta	1.80	29
Coscinodiscus radiatus	Bacillariophyta	1.77	66
Thalassiosira eccentrica	Bacillariophyta	1.48	136
Protoperidinium sp.	Pyrrophyta	1.45	21
Thalassiosira decipiens	Bacillariophyta	0.90	136
Coscinodiscus centralis var. pacifica	Bacillariophyta	0.72	23
Rhizosolenia setigera	Bacillariophyta	0.49	102
Noctiluca scintillans	Pyrrophyta	0.46	36
Nitzschia bilobata	Bacillariophyta	0.44	33
Cyclotella atomus	Bacillariophyta	0.43	304
Coscinodiscus jonesianus	Bacillariophyta	0.33	17
Pyramimonas orientalis	Chlorophyta	0.31	175
Rhodomonas marina	Cryptophyta	0.26	116
Protoperidinium depressum	Pyrrophyta	0.23	41
Heterocapsa triquetra	Pyrrophyta	0.23	138
Protoperidinium claudicans	Pyrrophyta	0.22	52
Cyclotella choctawhatcheeana	Bacillariophyta	0.22	74
Alexandrium tamarense	Pyrrophyta	0.21	109
Nannochloropsis sp.	Chrysophyta	0.20	424
Thalassiosira nodulolineata	Bacillariophyta	0.18	40
Chlorella salina	Chlorophyta	0.17	97
Chaetoceros wighamii	Bacillariophyta	0.17	43
Eutreptia lanowii	Euglenophyta	0.16	167
Prorocentrum minimum	Pyrrophyta	0.16	116
Aulacoseira lirata	Bacillariophyta	0.17	43
Rhizosolenia styliformis	Bacillariophyta	0.13	22
Entomoneis paludosa	Bacillariophyta	0.12	30
Odontella mobiliensis	Bacillariophyta	0.11	17
Gyrosigma balticum	Bacillariophyta	0.11	36

Phytoplankton biomass and growth in San Francisco Bay is controlled by a number of factors, including light availability (Alpine and Cloern 1988, Cloern 1999), residence time driven by horizontal transport by freshwater inflow, and predation by benthic suspension feeders (Jassby *et al.* 2002). Nutrient limitation is not usually a controlling factor for phytoplankton in San Francisco Bay. (Jassby *et al.* 2002)

Jassby *et al.* (2002) reconstructed annual primary productivity from historical water quality data for 1975 to 1995 for the Delta, including Suisun Bay. These reconstructed values do not apply to all of San Francisco Bay, but provide an idea of levels in northern San Francisco Bay. Annual primary production averaged 70 gCm^{-2} but varied by over a factor of five among years, likely due to: invasion of the clam, *Corbula amurensis*; long-term decline in total suspended solids and associated increase in water transparency; fluctuation in residence time with river inflow; and unexplained winter biomass declines (Jassby *et al.* 2002).

The most notable of these factors is the invasion of *Corbula amurensis*, which became widely established in 1987. Following invasion, chlorophyll biomass became persistently low and primary production was reduced 5-fold in the northern part of San Francisco Bay (Alpine and Cloern 1992). The concurrent decrease in total suspended sediments represented a 25 percent increase in the photic zone depth. This should have translated to a higher growth rate and higher primary productivity for light-limited phytoplankton in the Bay. It appears, however, the increased predation by *Corbula* more than compensated for this potential increase in production due to increased light availability (Jassby *et al.* 2002).

Since the late 1990s, the "baseline" or annual minimum chlorophyll in San Francisco Bay downstream of Suisun Bay has increased 5 to 10 percent per year, blooms are observed in winter-fall and not just in the spring and spring blooms are larger between San Pablo Bay and San Mateo Bridge. As a result average primary productivity has increased from 120 $gCm^{-2}yr^{-1}$ in 1993 to 1996 to 215 $gCm^{-2}yr^{-1}$in 2001 to 2004 (Jassby *et al.* 2002), bringing productivity levels in these regions of San Francisco Bay within the range often measured in temperate latitude estuaries. The specific reasons for these changes are unknown, but Cloern *et al.* (2006) proposed relaxed light limitation, reduced metal loading from progress in wastewater treatment, increased ocean sources of phytoplankton, and increased predation of bivalves by an opistobranch, fishes, or birds and of zooplankton by an invasive predatory copepod. In contrast to southern San Francisco Bay, productivity in Suisun Bay where *Corbula* persists remains low. (Cloern *et al.* 2006)

In addition to inter-annual trends in production, phytoplankton blooms can occur in both the northern and southern parts of San Francisco Bay causing high seasonal variability. The timing, location, and magnitude of blooms change from year to year, depending on tides, river flow, wind dynamics, and nutrients.

South San Francisco Bay has been described as a lagoon-type estuary, with a longer residence time, lower turbidity levels, and higher phytoplankton population growth than northern San Francisco Bay (i.e., San Pablo Bay and Suisun Bay) (Cloern *et al.* 1996). Historically, there was slow phytoplankton growth in South San Francisco Bay through the winter, with increasing growth during spring that culminated in a spring bloom. *Mesodinium* blooms occur during years when the water column stratifies and dissolved inorganic nitrogen and silicon in the water column are depleted (Cloern 1996, Cloern *et al.* 1994). As noted above, smaller blooms have recently been observed during fall and winter, with the bloom intensity increasing towards the southern extreme end of the San Francisco Bay. Spring blooms are the source of much of the total annual primary production in South San Francisco Bay (Cole *et al.* 1986).

Annual blooms in South San Francisco Bay occur when physical processes, such as freshwater inflow and weak tidal mixing, result in reduced vertical mixing. The resulting decrease in turbidity releases phytoplankton populations from strong light limitation (Cloern 1996, Lucas *et al.* 1999a, 1999b, May *et al.* 2003). During years with high freshwater inflow, salinity stratification can isolate some of the phytoplankton cells in the euphotic zone resulting in large magnitude, persistent blooms.

Stratification aids phytoplankton growth by increasing light availability for the surface-dwelling phytoplankton and by reducing the loss of phytoplankton to the bottom-dwelling, benthic grazers (Cloern *et al.* 1985, Lucas *et al.* 1998). Smaller, localized blooms can also occur during periods with weak tides and low wind mixing.

The general absence of blooms in summer and early fall in South San Francisco Bay is caused by high vertical mixing rates due to the strong diurnal winds during this period, as well as from an increase in predation by benthic predators, whose biomass and grazing rates are highest in the summer (Cloern 1996).

The northern San Francisco Bay is more river-influenced than South San Francisco Bay. As such, phytoplankton residence time is lower and turbidity is higher. Historically, there was a prolonged summer bloom of netplanktonic diatoms in Suisun Bay, coinciding with the accumulation of suspended particulates at the convergence of freshwater outflow and tidal inflow (i.e., convergence zone). This convergence only occurred when river discharge fell within a narrow flow range (100 to 400 m3/s; Cloern *et al.* 1985). This freshwater flow range results in higher water column residence times and places the convergence zone adjacent to shallow embayments in the northern Bay. Thus, shallow water-generated phytoplankton was retained in the convergence zone, resulting in a bloom. At higher discharge, the convergence zone moves to the west and phytoplankton residence times are short relative to phytoplankton population growth rates, preventing populations from increasing to bloom densities. At lower discharge, the convergence zone moves east to the Delta. During more recent years, blooms have disappeared, likely due to the high rate of benthic grazing (Alpine and Cloern 1992, Cloern 1996) and the high ambient ammonia concentrations, which inhibit nitrate uptake by phytoplankton for growth (Wilkerson *et al.* 2006).

At smaller geographic scales, mechanisms of spatial variability in phytoplankton production throughout San Francisco Bay include seasonal blooms, exchanges between sediment and water column, and horizontal dispersion from regions of high productivity in the shallows and landward areas to areas of low productivity in the deep channels and seaward areas (May *et al.* 2003, Cloern *et al.* 1985). May *et al.* (2003) modeled effects of turbidity and horizontal and vertical transport of shoal and channel areas of San Francisco Bay and determined that, given constant benthic grazing losses, different rates of vertical and horizontal clearing determine if blooms will be channel or shoal supported and whether they will be local or systemwide. Also, while nutrients are not generally are limiting in the Bay, localized concentrations of nutrients can be depleted by phytoplankton blooms, causing a bloom to die off within a given area.

Invertebrates (zooplankton)

Zooplankton includes small organisms which spend their entire life cycles within the water column such as copepods, as well as life history stages of organisms with a pelagic life history phase, such as fishes and large invertebrates. The primary taxa in San Francisco Bay are comprised of small forms (microzooplankton) including tintinnids, rotifers, and copepod nauplii, larger zooplankton including copepods, meroplankton (larvae of benthic animals and fish), and cladocerans (Table 9).

Zooplankton are often divided into freshwater, brackish, and marine species. Because zooplankton are incapable of swimming against tidal or freshwater currents, they move with a water body, and thus, are more likely to be oriented by salinity than geography. In this section, zooplankton are often discussed as northern Bay (Suisun and sometimes San Pablo Bay) and southern bay (South Bay, Central Bay and sometimes San Pablo Bay). The demarcation between northern and southern Bay for zooplankton is driven primarily by salinity.

Some zooplankton are present in San Francisco Bay throughout the year, while others have distinct seasonal patterns. Abundance patterns for microplankton have not been well studied in the Bay, so the focus here is on copepods, mysid shrimp, juveniles of fish and other invertebrates, and hydromedusae.

Table 9. Zooplankton taxa from San Francisco Bay after Kimmerer *et al.* 1999.

Taxonomic Group		Species	Status
Copepods	Calanoid	*Acartia californiensis*	native
		Acartia tonsa	native
		Acartia (Acartiura)	native
		Acartia danae	native
		Acartiella sinensis	introduced
		Epilabidocera longipedata	neritic
		Labidocera trispinosa	
		Eurytemora affinis	cryptogenic
		Pseudodiaptomus forbesi	introduced
		Pseudodiaptomus marinus	introduced
		Diaptomus sp.	
		Paracalanus quasimodo	native
		Sinocalanus doerrii	introduced
		Tortanus dextrilobatus	
		Calanus pacificus	introduced
	Cyclopoids	*Oithona davisae*	introduced
		Oithona similis	neritic
		Limnoithona tetraspina	introduced
		Acanthocyclops vernalis	
	Siphonostomes	*Corycaeus anglicus*	neritic
	Harpacticoids	*Euterpina acutifrons*	cryptogenic
		Coullana canadensis	
	Nauplius		
Other Crustaceans	Cladocera	*Podon intermedius*	
		Evadne sp.	
		Bosmina longirostris	
		Daphnia sp.	
		Ceriodaphnia sp.	
		Diaphonosoma sp.	
	Mysida	*Neomysis mercedis*	
		Acanthomysis bowmani	introduced
	Crangon sp.		
	Isopoda		
	Amphipoda	*Nippoleucon hinumensis*	
		Ampelisca abdita	
		Eogammarus confervicolus	
	Ostracod		
Meroplankton	Barnacle nauplius		
	Barnacle cyprid		
	Crab zoea		
	Shrimp larvae		
	Snail veliger		
	Bivalve larvae		
	Ctenophore		
	Polychaete larvae		
	Trochophore larvae		
	Echinopluteus larvae		
	Asteroid larvae		
	Medusa		
	Fish eggs		
	Fish larvae		
Other taxa	Rotifer		
	Chaetognath	*Sagitta* sp.	
	Larvacean	*Oikopleura dioica*	
	Ascidian larva		

Other taxa found in the zooplankton include the larvacean, *Oikopleura dioica*, barnacle nauplii, polychaete worm larvae (Kimmerer 1999), ghost shrimp (*Callianassa californensis*) larvae, and krill (i.e., *Nematoscelis dificilis*, *Thysanoessa gregaria*, and *Nyctiphanes simplex*) (CDFG 1987).

Ambler *et al.* (1985) describes zooplankton collections in San Francisco Bay from 1978 to 1981. During these years, the most frequently collected zooplankton in the South, Central and San Pablo Bays included the copepods, *Acartia clausi*, *Acartia californiensis*, *Oithona davisae*, harpacticoid copepods, tintinnids, and larvae of gastropods, bivalves, banarcles, and polychaetes. Most frequently collected zooplankton in Suisun Bay were *Eurytemora affinis*, *Sinocalanus doerrii*, cyclopoid copepods, *Bosmina* sp., the cladoceran, *Daphnia pulex*, *Brachionus* sp., and bivalve veligers. Microplankton was also present in all embayments, including the rotifers, *Synchaeta*, and tintinnids *Tintinnopsis* spp. Tintinnids were the most numerous taxa, while copepods and meroplankton dominated by biomass. Mean zooplankton biomass ranged from 10 to 50 mg Cm^{-3}, and was highest in southern San Francisco Bay during winter and spring (due to an increase in *A. clausi* and meroplankton). In the northern Bay, biomass peaked during summer and fall, due to an increase of *A. californiensis*, *E. affinis*, *S. doerrii*, and meroplantkon. In general, zooplankton biomass was highest where primary productivity was highest, suggesting a strong influence of food availability on zooplankton dynamics. (Ambler *et al.* 1985).

The zooplankton assemblage in San Pablo, Central, and South Bays was described again by Kimmerer (1999), who noted a number of changes from the early 1980s. Overall, there was a decrease in zooplankton abundance in San Pablo and South Bay, particularly during summer months. While the assemblage was still dominated by copepods and meroplankton, dominant species changed drastically, with four new species introduced after the earlier study. The most dominant species in the Kimmerer (1999) study was *Oithona davisae*, which was only moderately abundant in earlier sampling. *Pseudodiaptomus marinus* was introduced into the Bay in the late 1980s (Orsi and Walter 1991), and was the third most abundant copepod in the lower estuary. *Paracalanus quasimodo* and *Euterpina acutifrons* were quite abundant in higher salinity regions throughout the year, in contrast to earlier sampling. *Tortanus dextrilobatus*, which likely was introduced since the earlier sampling, was most abundant in mid- salinity (15 ppt) areas. Central Bay showed little change between the two collection periods.

Gewant and Bollens (2005) describe the meroplankton (including macrozooplankton and micronekton) of San Francisco Bay based on samples collected from 1997 through 2000. Eighty-two taxa were collected, but 11 taxa accounted for 98 percent of the total abundance. Dominant taxa included four species of fish and seven species of invertebrates: northern anchovy (*E. mordax*), longfin smelt (*Spirinchus thaleichthys*), Pacific herring (*Clupea pallasi*), plainfin midshipman (*Porichthys notatus*), the ctenophore, *Pleurobrachia bachei*, the isopod, *Syndotea laticauda*, the shrimps, *Palaemon macrodactylus*, *Crangon franciscorum*, and *C. nigricauda*, the mysid, *Neomysis kadiakensis*, and the medusa, *Polyorchis* spp. Variation in abundances was driven mostly by distance from the Golden Gate Bridge, seasonality, and life history. Highest abundances occurred in summer and lowest abundances occurred in spring. The authors characterized the meroplankton into four assemblages: taxa spawned from neritic adults that used mostly northern San Francisco Bay (e.g., herring, longfin smelt and plainfin midshipman), estuary-dependent taxa with broad distribution throughout San Francisco Bay year-round (e.g., *C. franciscorum*, *C. nigricauda*, and northern anchovy), resident species that remain in the estuary but occur mostly in the South Bay during the wet season (e.g., *P. macrodactlyus*, *S. laticauda*, and *N. kadiakensis)*, and gelatinous taxa that occur throughout San Francisco Bay with a single peak in North Bay and South Bay in December and January. Gewant and Bollens (2005).

Further details of abundance and changes since the 1980s are described below by individual taxa.

Copepods

Copepods are small crustaceans evolutionarily derived from oceanic animals. Copepoda is the most well-studied zooplankton taxon of San Francisco Bay. Despite this, it is difficult to summarize the assemblage because of the number of factors that affect population dynamics (location, season, freshwater inflow, coastal hydrography, and primary productivity) (Ambler *et al.* 1985) and the numerous introductions of non-indigenous copepods since the 1980s (Cohen and Carlton 1995). In fact, *E. affinis*, one of the more abundant copepods in the Bay, is a non-native species from the Atlantic (Lee 2000).

In northern San Francisco Bay (Suisun Bay and northern San Pablo Bay) from 1978 to 1981, copepod dominance followed a pattern with decreasing salinity from east to west: *S. doerrii* was most dominant at the easternmost boundary; *E. affinis* was dominant in the oligohaline mixing zone; *Acartia* spp. were dominant in polyhaline waters; and *Paracalanus parvus* was dominant at the seaward boundary. *S. doerrii*, *E. affinis*, and *A. clausi* were present year-round, while *A. californiensis* was present from August to October. This pattern is absent in southern San Francisco Bay where *Acartia* spp. had increased biomass and showed a distinct seasonal switch from higher biomass of *A. clausi* during the cold, wet season to higher biomass of *A. californiensis* in the warm, dry season. (Ambler *et al.* 1985)

Major changes have occurred in the zooplankton assemblage of San Francisco Bay since 1981. *Sinocalanus doerrii* was first recorded in 1979. Within five years of its introduction, abundance began to decline and has continued to do so through 2005 (Baxter 2006). In 1987-88, the native copepods, *Arcatia* spp. and *E. affinis* declined 53 to 91 percent coincidental with the establishment of the exotic clam, *Corbula amurensis* (Kimmerer *et al.* 1994). *E. affinis* abundance has remained at low levels through 2005 (Baxter 2006). In 1989, two calanoid copepods, *Pseudodiaptomus forbesi* and *P. marinus* became established (Kimmerer 2004). Abundance of *P. forbesi* has declined since its introduction, but remains relatively abundant in summer and fall months (Baxter 2006). In 1993, three more exotic copepods, *Limnoithona tetraspina*, *Tortanus dextrilobatus* and *Acartiella sinensis*, became established (Orsi and Ohtsuka 1999, Kimmerer 2004, Bouley and Kimmerer 2006). *Limnoithona sinensis* is reported to have disappeared about the time *L. tetraspina* became abundant (Orsi and Ohtsuka 1999). In fact, this species has not disappeared, but is caught at low numbers and is not separated from other *Limnoithona* species in collections (A. Hennessy, CDFG, pers. comm.).

Rotifers

Rotifers are microscopic multicellular invertebrates most common in freshwater. Most species are sessile, but about 100 species are planktonic. *Synchaeta*, *Keratella*, and *Brachionus* are the most abundant rotifer genera in San Francisco Bay (Herbold 1992). *Synchaeta* is common at salinities greater than 5 ppt, and is most abundant in the South Bay (Ambler *et al.* 1985). In the Central Bay and upstream, rotifer populations undergo seasonal cycles possibly due to changes in salinity. *Keratella* is usually only found in Suisun Bay and then only in spring when salinities are minimal (Turner and Chadwick 1972). Rotifer abundance in Suisun Bay decreased from 1972 to 1979, apparently associated with declining chlorophyll concentrations (Herbold 1992). Synchaeta was the only taxa that did not exhibit this trend, but abundance fell to a record low in 1988 coincident with establishment of Corbula amurensis (Herbold 1992). No exotic rotifers have been found in San Francisco Bay (Orsi 1999b).

Cladocera

Cladocera, or water fleas, are very abundant in freshwater systems worldwide, seldom occurring in salinities higher than 1 ppt. They are much more abundant in the Delta than they are in San Francisco Bay, but a few species, including *Bosmina longirostris*, *Daphnia pulex*, and *Diaphonosoma leuchtenbergianumi* are found in Suisun Bay and Carquinez Strait during periods of high Delta outflow (Herbold 1992). No exotic cladocera have been found in San Francisco Bay (Orsi 1999b).

Mysid Shrimp

Nine species of mysid shrimp have been reported in San Francisco Bay and the Delta, including six native species and three non-native species. The native species are *Neomysis mercedis, N. Kadiakensis, N. costata* (now *Holmsimysis costata*), *N. macropsis* (*now Alienacanthomysis* *macropsis*), *Deltamysis holmquistae,* and *N. rayi. N. rayi* is a coastal species that may only occasionally enter San Francisco Bay. *D. homquistae* is extremely rare; only a few specimens are collected from the Delta each year. The non-native mysids are *Acanthomysis bowmani* and *A. aspera*, two Chinese species introduced in 1992, and *A. hwanhaiensis*, a Korean species found in 1998. Recent information indicates *Neomysis kadiakensis* collected in and upstream from San Pablo Bay may actually be the introduced *N. japonica,* which would add a tenth mysid species and a fourth introduced species. (Mecum 2006).

Mysid shrimp are most abundant in low salinity (0 to 7.2 ppt) regions, and therefore within the San Francisco Bay are most abundant in Suisun Bay (Heubach 1969, Herbold 1992). Orsi and Knutson (1979) collected six species of mysid shrimp throughout the Delta and Suisun Bay, but only *Neomysis mercedis*, the opossum shrimp, was abundant. *Acanthomysis bowmani* was introduced in 1993 and quickly increased to higher abundances than *Neomysis* (Orsi 1999b). Mysid shrimp have not shown the consistent declines shown by other zooplankton; while there are increasing frequencies of low population levels, the population occasionally rebounds (Herbold 1992).

Large seasonal fluctuations in mysid shrimp abundance from mean winter densities of less than 10 m^{-3} to mean spring densities of almost 1,000 m^{-3} have been attributed to temperature (Heubach 1969, Orsi and Knutson 1979, Siegfried *et al.* 1979), low DO (Turner and Heubach 1966, Orsi and Knutson 1979), predation (Heubach 1969), reproduction (Orsi and Knutson 1979), tidal currents and estuarine circulation (Orsi and Knutson 1979), and seasonal declines in phytoplankton (Orsi and Knutson 1979). Mysid shrimp distribution is also limited to areas with water velocity <0.12 ms^{-1} and light intensity <10-5 lux (Heubach 1969). (Herbold 1992).

Scyphozoan and Hydrozoan Jellyfish

No hydrozoan jellyfish are known to be native to San Francisco Bay. Three introduced species of hydroid jellyfish, thought to be native to the Black Sea, have been reported since the 1950s. CDFG field notes and USFWS collections indicate *M. marginata* has been present in San Francisco Bay since at least 1959 (Mills and Rees 2000). *Blackfordia virginica* was collected in the Napa and Petaluma Rivers in 1970 and 1974, respectively. These two species were collected in the Petaluma River and Napa River in 1992, 1993, and 1995 (Mills and Sommer 1995). *Moerisia* sp. was collected in the Petaluma River in 1993 (Mills and Rees 2000). In 1997 and 1998, *M. marginata* and *Moerisia* sp. were collected in Suisun Bay.

All three species are thought to be present in the plankton from at least May through November, with peak abundances from August through October (Rees 1999). Salinity ranges at collection sites ranged from 0 to 20 ppt (Mills and Sommer 1995, Mills and Rees 2000, Rees 1999). Temperature at collection sites ranged from 16.5 to 25 C (Rees 1999, Mills and Rees 2000). Most observations have been made in accessible rivers and sloughs of northern San Francisco Bay. It is unknown if these species are also present over shoals and channels elsewhere in the estuary. Rees and Gershwin (2000) theorize that both species have the ability to invade all low-salinity areas of San Francisco Bay through attachment to the underside of boats.

One scyphozoan jellyfish, *Aurelia* sp., has been observed in San Francisco Bay near Foster City since 1988. Morphology and genetic examinations suggest that the specimens seen in San Francisco Bay are not the native species frequently seen in Monterey Bay and Vancouver Island, but a second, introduced species from Tokyo Bay. (Greenberg *et al.* 1996).

Fishes

Two species of *Salmonidae* occur in fresh-brackish salinity gradients: steelhead (*Oncorhynchus mykiss*), which is listed as threatened pursuant to the Federal Endangered Species Act (ESA), and Chinook salmon (*O. tshawytscha*), of which the winter-run is listed as endangered and the spring-run is listed as threatened pursuant to the ESA. Salmonids are anadromous; adults emigrate from the ocean to spawn in freshwater rivers and streams. Offspring hatch and rear in freshwater and then immigrate to the ocean to forage until maturity.

Abundance of both species has declined in part because of human-induced degradation of their spawning and rearing habitats and loss of smolts in water diversions (Leidy *et al.* 2005). Highly productive estuaries are important feeding and acclimation areas for juvenile salmonids preparing to enter marine waters.

Oligohaline/mesohaline

Common fishes in oligohaline/mesohaline water column areas include the federally threatened delta smelt (*Hypomesus transpacificus*) (58 FR 12854 12864) and striped bass (*Monore saxitilis*). Delta smelt, which are endemic, planktonic feeders in San Francisco Bay and the Delta, prefer habitat within shallow, open water areas in close proximity to transition zones between fresh and oligohaline areas (Moyle 2002). Larvae are most abundant during years of high riverine outflow from April to July, peaking in May (Baxter 1999). Juvenile and adult delta smelt distribution concentrate in Suisun Marsh (Baxter 1999). Striped bass were introduced to San Francisco Bay in 1879 from New Jersey (Moyle 2002). A commercial fishery for striped bass existed in San Francisco Bay from 1889 to 1935 (Goals Project 2000). A recreational fishery still exists today. Striped bass concentrate in San Pablo and Suisun Bay in fall months and migrate to freshwater areas to spawn in winter through early spring (Moyle 2002, Goals Project 2000).

Polyhaline

Pacific herring and larval Pacific staghorn sculpin (*Leptocottus armatus*) are common to polyhaline water column environments (Table 4). The Pacific staghorn sculpin is a common marine and estuarine fish (Miller and Lea 1972). Spawning occurs from October to April. Eggs are demersal and deposited in clusters on a variety of substrates (Wang 1986). Larvae are planktonic and then develop into juveniles at about 10 to 15 mm in length, at which point they settle out and become demersal for the remainder of their life history (Wang 1986).

Euhaline

The Pacific sardine (*Sardinops sagax*), northern anchovy (*Engraulis mordax*), and topsmelt (*Atherinops* affinis) are among the most abundant species present in euhaline, water column habitat (Table 4). The Pacific sardine is primarily an offshore pelagic species but enters San Francisco Bay in the summer months to feed. A commercial sardine fishery in San Francisco Bay existed from the early 1900s to the 1950s (Skinner 1962) until the fishery collapsed due to over-fishing and changes in off-shore ocean conditions (sardines prefer warmer ocean conditions). Since 1993, there have been seasonal populations of Pacific sardines in South Bay (MSI 2005), and Pacific sardines have been observed year round in Central Bay (Fleming 1999). The northern anchovy is the most common fish in San Francisco Bay and is an important prey species for many other animals (Greiner *et al.* 2005). Northern anchovy abundance in San Francisco Bay was below average from 1999 to 2005 (Greiner *et al.* 2006). San Francisco Bay falls between the northern and central subpopulations of northern anchovy in the Pacific Ocean. The decreased abundance in San Francisco Bay may have been due to a southward migration of the central population in response to a cool ocean regime. Abundance also varies seasonally, with highest abundance in from April to October (Fleming 1999). A small live bait fishery is supported by the northern anchovy. The topsmelt uses San Francisco Bay as a nursery area and spawning ground. Topsmelt spawn in shallow water in April-September and migrate to deeper water areas during the winter (Flemming 1999). Highest abundance of topsmelt occurs in South Bay (Flemming 1999).

Birds

Birds from all San Francisco Bay feeding guilds use the water column habitat for foraging and resting (Table 5). Some of the more abundant species include the western grebe (*Aechmophorus occidentalis* grouped with Clark's grebe, *A. clarkia*, during annual bird counts), the double-crested cormorant (*Phalacrocorax auritus*), the Brandt's cormorant (*Phalacrocorax penicillatus*), and the western gull (*Larus occidentalis*). Species of concern include the osprey (*Pandion haliaetus*), the least tern (*Sterna antillarum*), and the brown pelican (*Pelecanus occidentalis*). Grebes use San Francisco Bay primarily for foraging, peaking in abundance from October to April

(DeSante and Ainley 1980, Briggs *et al.* 1987, Shuford *et al.* 1989). Grebes prefer sheltered coves, rarely found in the open bay except along tidal currents in Racoon Straits and around Angel Island (Goals Project 2000). Grebes feed on small planktivorous fishes such as sardines and anchovies and small crustaceans (Fix and Bezener 2000).

Double-crested cormorants can be found throughout San Francisco Bay year-round, and use the estuary for both breeding and foraging (Goals Project 2000). As colonial breeders, breeding birds concentrate in San Pablo Bay, Central Bay, and South Bay (Goals Project 2000). Cormorants dive up to depths of 9 m for planktivorous fish prey (Fix and Bezener 2000). The three different species of cormorants that utilize the Bay consume prey with different characteristics. The less common pelagic cormorant (*Phalacrocorax pelagicus*) consumes solitary, cryptic prey on rocky or flat habitats; double-crested cormorants eat mostly schooling fishes that occur above the benthos; and Brandt's cormorants take fish from both the benthic habitat and the water column (Ainley *et al.* 1981). Rocky substrates appeared important for pelagic cormorant prey, while rock, sand, and mud substrates were important habitats for Brandt's cormorant prey (Ainley *et al.* 1981). Brandt's cormorants nesting on Alcatraz Island in San Francisco Bay have been shown to consume northern anchovies as well as benthic fishes such as flatfishes, sculpins, and gobies (Yakich 2005).

The western gull achieves high numbers around San Francisco Bay due to its success at acclimating to urban areas. Western gull feeding preference has shifted from oceanic and intertidal feeding grounds to industrial waterfronts, parks, and garbage dumps where food scraps are readily available (Fix and Bezener 2000). Western gull are year-round residents of San Francisco Bay.

The endangered brown pelican is a seasonal migrant to San Francisco Bay, arriving during the summer months and persisting through late fall (Goals Project 2000). However, during El Niño years, brown pelicans persist year round in San Francisco Bay (Goals Project 2000). Pelicans feed on planktivorous fishes, plunging into the water bill-first. No bay-wide survey exists to count brown pelican abundance, though numbers are estimated to be several hundred each summer and fall (Goals Project 2000). Osprey, a California state species of special concern, can be viewed year-round in San Francisco Bay, using the area for both rearing and foraging. Osprey are piscivorous, and fish averaging two pounds in weight make up 98 percent of their diet (Fix and Bezener 2000). The endangered least tern (*Sterna antillarum*) migrates to San Francisco Bay during the summer months, using San Francisco Bay as a critical breeding location (Goals Report 2000). Least terns hover over shallow to deep water areas, feeding on planktivorous fishes such as northern anchovy and silversides (*Atherinopsidae*).

Marine Mammals

Marine mammals use water column habitat in San Francisco Bay for migrating, foraging, and resting. Seasonally migrating cetaceans, such as the gray whale (*Eschrichtius robustus*) and humpback whale (*Megaptera novaengliae*), enter Central Bay during their migrations to feed. The harbor porpoise (*Phocoena phocoena*), which preys on pelagic fishes, is commonly sighted in areas of Central Bay and near the Golden Gate Bridge. The harbor seal (*Phoca vitulina*) and California sea lion (*Zalophus californianus*) feed primarily on fishes within San Francisco Bay, including schooling northern anchovy and Pacific herring, but also will feed on migratory Pacific eels, lamprey, salmonids and mysid shrimp and other invertebrates within the water column (Sarah Allen, National Park Service, pers. comm.). Weaned harbor seal pups, in particular, have been documented feeding on mysid shrimp. Both sea lions and harbor seals will sleep on the surface of the water column between foraging bouts. Additionally, harbor seals mate in the water column adjacent to colony haul out sites (Hayes *et al.* 2006, Boness *et al.* 2006).

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Index

Acanthomysis, 77, 81
Acartia, 77, 79, 80
Acipenser, 41, 45
Aeolidia, 68
Ahnfeltiopisis, 49
Alcidae, 51
Alexandrium, 71, 73
Algae, 39, 60
Ameana, 27, 44
Americorophium, 19, 20, 22, 40, 41
Ampelisca, 21, 23, 24, 25, 26, 27, 28, 29, 42, 43, 44, 77
Amphibalanus, 31, 33, 34, 35, 36, 45, 49, 54
amphipods, 42, 43, 44, 47, 49, 50, 54, 61, 62, 68, 69
Ampithoe, 33, 37, 49, 54
amurensis, 19, 20, 21, 22, 23, 24, 25, 31, 39, 40, 41, 42, 45, 46, 74, 80, 81
Anas, 45, 63
anchovy, 39, 68, 79, 83, 84
anemone, 31, 32, 33, 34, 36, 45, 49, 50, 70
anemones, 55, 68
Anisodris, 70
Anthopleura, 70
ascidean, 44
ascidians, 49
Atherinops, 39, 68, 83
Atherinopsidae, 84
Aurelia, 82
Aythya, 43, 45, 47, 63

Balanus, 31, 34, 36, 41, 45, 50, 53, 54, 55, 57, 61
barnacle, 31, 33, 34, 35, 36, 41, 49, 50, 53, 79
bass, 41, 82
bat ray, 39, 55, 68
bivalve, 19, 20, 21, 22, 23, 24, 25, 26, 27, 29, 31, 34, 36, 37, 39, 40, 41, 42, 43, 44, 52, 79
Bosmina, 77, 79, 81
Brachionus, 79, 81
Bryopsis, 16, 18
bryozoan, 31, 48, 49, 50
bryozoans, 33, 48, 50, 54, 68
Bucephala, 45, 56

C. amurensis, 40, 41, 42, 43, 46
C. fluminea, 40, 41
Callianassa, 79
Cancer, 39, 40, 45, 50, 68, 70
canvasback, 43, 45, 47, 63
Caprella, 34, 36, 37, 57, 68
Cebidichthys, 70
Cepphus, 43, 46, 51
Ceratium, 71
Chondracanthus, 16, 18
Chthamalus, 61
Cirolana, 53, 54
Cirriformia, 23, 43
Citharichthys, 40, 46, 68
cladocerans, 75
Cladophora, 16, 18
clams, 16, 45, 47, 52, 55
Clanthria, 49
Clathra, 50
Clupea, 40, 51, 68, 79
Codium, 18, 49, 66
Conopeium, 49
copepod, 74, 75, 79, 80
copepods, 75, 76, 79, 80
Corbula, 19, 20, 21, 22, 23, 24, 25, 31, 39, 40, 42, 45, 46, 74, 80, 81
Corophium, 23, 25, 29, 37, 42, 43, 57
Cottus, 42, 51
crab, 31, 39, 40, 42, 41, 43, 45, 50, 62, 68, 70
Crangon, 39, 40, 41, 42, 43, 45, 52, 77, 80
Crassostrea, 4, 52, 55
Cryptopleura, 16, 18
ctenophore, 79
Cucumaria, 53
cumacean, 20, 21, 22, 23, 25, 26, 28, 41, 42, 43
Cymatogaster, 40, 56, 68

Daphnia, 77, 79, 81
Diadumene, 31, 32, 33, 34, 45, 49, 50, 55, 57
Diaphonosoma, 77, 81
Dinophysis, 71
duck, 43, 45, 56

E. affinis, 79, 80
Ectopleura, 34, 36, 50
eelgrass, 18, 49, 39, 55, 61, 62, 63, 65, 68, 69
Egregia, 18, 49
elasmobranchs, 46
Embiotocidae, 51, 68
Engraulis, 39, 68, 83
Enteromorpha, 16, 18, 39
Eogammarus, 33, 49, 77
Eschrichtius, 49, 51, 47, 84
Euchone, 26, 27, 28, 29, 44
Eurytemora, 77, 79
Exogone, 24, 27, 28, 30, 44

Flabellinopsis, 70
flounder, 41, 45, 46
Fucus, 16, 18, 60, 61

Gammarus, 19, 20, 22, 40, 41, 60, 61
Garveia, 33, 34, 49
Gelidium, 16, 18
Geukensia, 52, 54
Glycinde, 28, 30, 44
Gnorimosphaeroma, 31, 33, 45, 49
goldeneye, 45, 56
Gonyaulax, 53
Gracilaria, 16, 18, 60, 61, 65
Gracilariophila, 61
Grandidierella, 21, 24, 27, 28, 43, 44
gray whale, 49, 50, 84
grebe, 45, 46, 56, 83
gull, 43, 47, 48, 51, 83, 84

halibut, 40, 46, 47, 69
Halichondria, 33, 35, 37, 50, 54, 57
Haliclona, 33, 35, 49, 50, 57
Halkymenia, 16, 18
Harmothoe, 29, 37, 44, 57
Hermissenda, 70
herring, 40, 47, 49, 50, 51, 52, 61, 65, 68, 69, 79, 83, 84
Heteromastus, 20, 21, 22, 24, 25, 26, 29, 41, 44
Heteropodarke, 27, 44
Heterosigma, 71
Hiatella, 36, 50
Hopkinsia, 49
hydroid, 54, 82
hydromedusae, 76
hydrozoan, 31, 49, 82
Hypomesus, 41, 82
Hypsopsetta, 56

Idotea, 53, 60, 61
Ilyanassa, 26, 43
Incisocalliope, 34, 36, 50
isopod, 21, 31, 33, 34, 35, 41, 45, 54, 79

Jassa, 34, 36, 50
jellyfish, 82

kelp, 62, 70
Keratella, 81
Kornmannia, 69
krill, 79

L. hoffmeisteri, 41
Lacuna, 69
Laminaria, 18, 49
Larus, 43, 47, 48, 51, 83
larvacean, 79
Leucilla, 35, 50
Limnodilus, 40
Limnoithona, 77, 80
limpet, 69

M. viridis, 41, 42
Macoma, 23, 24, 25, 27, 42, 43, 52
Macroalgae, 60
Macrocystis, 62
macrodactylus, 20, 41, 42, 57, 80
mallards, 63
Marenzellaria, 19, 20, 21, 22, 24, 40, 42
Mebile, 68
Mediomastus, 27, 28, 29, 30, 44
medusa, 80

Megaptera, 51, 84
Melanitta, 43, 46
Melobesia, 69
meroplankton, 75, 79
Mesodinium, 71, 73, 74
Metridium, 36, 50
midshipman, 39, 49, 46, 79
Modiolus, 36, 50
Moerisia, 82
Molgula, 23, 26, 31, 34, 44, 45, 54, 58
monkey-faced eel, 70
Monocophium, 44
Monocorophium, 21, 22, 24, 25, 26, 27, 28, 33, 34, 36, 42, 44
Morone, 41
Musculista, 23, 25, 29, 31, 34, 36, 37, 42, 43, 45, 49, 55, 58
mussel, 32, 33, 35, 37, 45, 49, 52, 53, 54, 58
Mustelus, 39, 46
Mya, 23, 24, 25, 27, 42, 43, 44, 52
Mycale, 35, 50
Myliobatis, 39, 55, 68
mysid, 49, 47, 76, 80, 81, 84
Mytilus, 32, 33, 35, 37, 45, 49, 52, 53, 55, 58

Nannochloropsis, 71, 73
Nassarius, 68
Neanthes, 24, 25, 35, 43, 57
Nematoscelis, 79
Neomysis, 77, 80, 81
Neotrypaea, 52
Nereis, 37, 53, 57
Nippoleucon, 20, 21, 22, 23, 25, 26, 28, 41, 42, 43, 77
Notoacmea, 69, 70
nudibranch, 43, 68
Nyctiphanes, 79

Obelia, 31, 54, 57
Oikopleura, 78, 79
Oithona, 77, 79
oligochaete, 19, 22, 23, 25, 27, 28, 29, 43
Oncorhynchus, 42, 82
opistobranch, 32, 33, 49, 74
osprey, 47, 83
Ostrea, 4, 16, 35, 49, 52, 55, 58

Oxyura, 45, 56, 63

Palaemon, 20, 41, 42, 80
Paracalanus, 77, 79, 80
Paralichthys, 40, 46
Paranthura, 34, 50, 57
Parophyrs, 46
Pelecanus, 43, 46, 83
pelican, 43, 46, 83, 84
perch, 40, 49, 51, 52, 56, 68, 69
Phalacrocorax, 43, 46, 51, 83
Phocoena, 49, 51, 47, 84
Phyllaplysia, 68
Phyllospadix, 18, 49, 62, 69, 70
phytoplankton, 9, 46, 60, 71, 73, 74, 75, 81
pigeon guillemot, 43, 46, 51
pintail, 45
pipefish, 39, 56, 68
Pisaster, 50, 53
Plagioselmis, 71, 73
Platichthys, 41, 45
Pleurobrachia, 79
Pltyrhinoidis, 56
Podiceps, 45, 46, 56
Pogonicthys, 45
Pollicipes, 53
polychaetes, 40, 41, 43, 44, 50, 79
Polydora, 24, 28, 44
Polyorchis, 80
Polysiphonia, 16, 18
Porichthys, 39, 46, 79
porpoise, 49, 50, 51, 47, 52, 84
Potamogeton, 18, 62, 63
Prorocentrum, 71, 73
Pseudodiaptomus, 77, 79, 80
Psuedopolycora, 44
Psuedopolydora, 28, 29, 44
Pugettia, 70
Pyramimonas, 71, 73

Rhithropanopeus, 20, 41, 57
rockfish, 40, 49, 46, 47, 52, 68
rotifer, 81
Ruppia, 18, 62, 63

S. doerrii, 79, 80
Sabaco, 24, 25, 26, 27, 29, 43, 44
sago pondweed, 62, 63
Sakuraeolis, 26, 43, 58
salmon, 42, 49, 65, 82
sanddab, 40, 46, 68
sardine, 39, 83
Sardinops, 39, 83
Sargassum, 18, 49, 60, 61, 62
SAV, 16, 39, 60, 62, 65, 66, 68
scaup, 43, 45, 47, 63
sculpin, 40, 42, 49, 46, 51, 83
Scytosiphon, 62
sea cucumbers, 53
sea lion, 49, 50, 51, 52, 53, 69, 84
sea star, 48, 53
seal, 49, 51, 52, 53, 70, 84
seals, 49, 50, 47, 52, 53, 69, 84
Sebastes, 40, 46, 51, 68
Semibalanus, 53
shark, 39, 46, 55
shrimp, 39, 40, 41, 49, 41, 42, 43, 44, 47, 52, 57, 68, 76, 79, 81, 84
silversides, 84
Sinelobus, 54
Sinocalanus, 77, 79, 80
Skeletonema, 71, 73
smelt, 41, 49, 45, 46, 69, 79, 82
Smithora, 69
smoothound, 46
snail, 32, 43, 69
sole, 40, 46
Sphaeroma, 31, 33, 49, 60, 61
Spirinchus, 41, 45, 79
splittail, 41, 45
sponges, 49, 50, 54, 55, 69
steelhead, 42, 82
Streblospio, 24, 25, 28, 29, 42, 44
sturgeon, 41, 45
Styela, 35, 54, 58
surf scoter, 43, 46, 47
surfgrass, 62, 69, 70
surfperch,, 51, 68
Sycon, 35, 50
Synchaeta, 79, 81
Syndotea, 79
Syngnathus, 39, 56, 68
Synidotea, 21, 33, 35, 41, 49, 57

tanaids, 54
Teleaulax, 71, 73
tern, 43, 47, 68, 83, 84
Tetraclita, 53
Thalassiosira, 71, 73
Tharyx, 27, 44
Theora, 23, 43
Thysanoessa, 79
Tomentosoides, 49
topsmelt, 39, 68, 83
Tortanus, 77, 79, 80
Triakis, 39, 46, 55
Tubificidae, 22, 25, 27, 28, 29, 44
Tubificoides, 23, 43
turbot, 56

Ulva, 16, 18, 39, 60, 66
Upogebia, 52

Varichaetadrilus, 19, 40
Venerupis, 23, 26, 31, 42, 43, 45, 52, 58
Victorella, 36, 50

whale, 49, 50, 51, 47, 69, 84

Zalophus, 49, 51, 47, 53, 84
zooplankton, 9, 46, 74, 75, 76, 79, 80, 81
Zostera, 18, 39, 61, 62, 65