spring-run. The four runs are distinguished based on the timing of adult upstream migration and spawning. These runs are differentiated based on the maturity of the fish entering freshwater, time of spawning migrations, spawning areas, incubation times, incubation temperature requirements, and the migration timing of juveniles (USFWS 1994).

Fall-run salmon migrate through the Estuary to their spawning grounds in the Sacramento and San Joaquin River Basin from July through November. Late-fall salmon migrate during October to February, winter-run migrate December to April, and spring-run migrate April to July. Juvenile fish mature in the ocean off the California coast, with fall and winter-run fish remaining in continental shelf waters and spring-run chinook moving into the high seas (Allen and Hassler 1986). Adult chinook typically return to freshwater to spawn during their third or fourth year (Allen and Hassler 1986). Juveniles feed primarily on macro-invertebrates in freshwater, and on zooplankton during their migration through the Delta (SFEP 1992a). An estimated 10 to 50 million juvenile smolts migrate through the Delta annually (SFEP 1992a). Out-migration peaks between April and June (Allen and Hassler 1986; Kjelson et al. 1982). Nursery areas for chinook salmon are in the Sacramento and San Joaquin rivers and their tributaries, as well as the Delta.

While salmon support a large ocean sport fishery off the coast of San Francisco, environmental changes caused by dam construction, water diversion, pollution, habitat degradation, and overfishing have significantly reduced salmon populations in the Estuary. Historically, chinook salmon were abundant in the Sacramento and San Joaquin rivers and their tributaries. In the mid-1800s, the commercial salmon fishery was initiated due to the large abundance of salmon. By 1919, following mean annual catches of more than 3,000 tons, commercial salmon canning was banned (Skinner 1962). Today, salmon populations have greatly declined due to dam construction, water diversion, pollution, overfishing, and habitat degradation. As a result, some runs have been almost totally extirpated.

The winter-run chinook salmon population, in particular, has declined over the past two decades. Population levels have dropped from an estimated 117,000 fish in the late 1960s to slightly less than 350 fish by 1993 (USFWS 1995). The Sacramento River supports the only remaining winter-run chinook salmon population in California and is currently listed as endangered by the federal and state government (USFWS 1995). In November and December, winter-run chinook migrate through the San Francisco Bay as adults to spawn upstream and may be present in the Estuary until April. Spawning occurs by May, followed by juveniles that pass through on their way to the ocean as early as June. Peak out-migration occurs during February and March (CDFG 1991). Shallow water habitats within the Sacramento River and the Estuary provide important cover and feeding habitats for out-migrating and/or rearing fry and smolts en route to the Pacific Ocean. Winter-run chinook salmon typically spend between 2 and 3 years in the ocean.

The primary causes of winter-run decline are thought to be habitat loss and degradation, along with fish entrainment from dams and diversions on the Sacramento River and the Delta. Specifically, the Shasta and Keswick dams blocked access to the upper Sacramento tributary streams, and the Red Bluff Diversion Dam inadequately screened water diversions. Additionally these structures created inadequate passage for adults and juveniles (USFWS 1995). Following the construction of the Red Bluff Diversion Dam in conjunction with the drought in 1976 and 1977 and again in 1987, increase in water temperature, reduced flow and lack of access, further reduced the winter-run population. Other factors that may contribute to the decline are dredging and disposal activities that result in interference with migration due to delay or temporary blockage. Degradation of water quality may directly affect the winter-run chinook salmon as well as suspended sediments affecting their foraging habitat and food resources (CDFG 1991).

The fall-run is now the largest and is primarily supported by hatcheries; the majority of chinook salmon migrating through the Estuary are fall-run fish (SFEP 1992a). Today only sportfishing is allowed in the Estuary. The 1991 sport and commercial harvest south of Point Arena totaled 316,100 fish. On February 25, 1998, the NMFS proposed listing the spring-run chinook salmon as endangered, and the fall and late-fall runs as threatened.

Delta Smelt (*Hypomesus transpacificus*). The federal and state status for the delta smelt is threatened. The delta smelt is a nongame species endemic to the upper Sacramento-San Joaquin Estuary. They are found primarily in the Delta below Isleton on the Sacramento River and below Mossdate on the San Joaquin River, as well as in Suisun Bay (USFWS

1994). From January to July they move into freshwater for spawning and, during high flows, they can be washed downstream into San Pablo Bay (Ganssle 1966 as cited in Moyle et al. 1992). They are known to occur in the Napa River and White Slough. Designated critical habitat for the Delta smelt includes the Delta west to the Carquinez Bridge.

Delta smelt inhabit open surface waters where they school. Spawning occurs primarily in sloughs and shallow edge-waters of channels in the upper Delta and in the Sacramento River. The delta smelt eggs are demersal and adhesive, sticking to hard substrates and submerged vegetation (Moyle 1976). Delta smelt feed on zooplankton, primarily copepods.

In 1993, the federal government listed the delta smelt as a threatened species. The delta smelt has declined nearly 90 percent over the last 20 years and is primarily threatened by freshwater exports from the Sacramento and San Joaquin rivers for agriculture and urban use. The decline also coincided with increased human changes to the Delta hydrology and the accompanying changes in the temporal, spatial, and relative ratios of water diversions. These changes, coupled with drought and the introduction of non-indigenous species appear to have reduced this species' capacity to recover (USFWS 1994). The USFWS has determined that the delta smelt is highly vulnerable to extinction because of its short life span, small population size, and restricted distribution. The delta smelt is also vulnerable to disposal activities that result in habitat degradation to its limited spawning grounds.

Sacramento Splittail (*Pogonichthys macrolepidotus*). The federal status for the Sacramento splittail is proposed threatened; the state status is species of special concern. The Sacramento splittail is a cyprinid endemic to California (Moyle 1976). It was once found throughout the Central Valley and is now largely confined to the Sacramento-San Joaquin Estuary (Meng and Kanim 1994 as cited in Meng and Moyle 1995). Splittails are common in the backwaters of Suisun Bay, Suisun Marsh, the inland Delta near the Sacramento and San Joaquin rivers, and the Petaluma River (Meng and Moyle 1995; Moyle 1976; Caywood 1974). The Sacramento splittail is usually found in dead-end sloughs and slow-moving portions of the river (Moyle et al. 1989). They spawn from early March through May in the Delta in submerged or flooded vegetation in seasonal wetlands, tidally influenced sloughs, and in shallow, low velocity channel edge waters (Meng and Moyle 1995; Wang 1991; Moyle 1976). Larvae remain in vegetated shallow water areas near spawning sites, but move into deeper offshore habitats as they mature (Wang 1986). Sacramento splittail are benthic foragers, although opossum shrimp (*Neomysis mercedis*) and detritus comprise a high percentage of their diet (Daniels and Moyle 1983).

In 1994, the USFWS proposed the Sacramento splittail as a threatened species. Over the last 15 years, this species has declined by over 62 percent. This is a result, in part, of large freshwater exports from the Sacramento and San Joaquin River diversions, prolonged drought, loss of shallow-water habitat, introduced aquatic species, and agricultural and industrial chemicals (Meng 1993).

Coho Salmon (*Oncorhynchus kisutch*). The federal status for the coho salmon is proposed threatened; state status is threatened south of San Francisco Bay. The coho salmon is an anadromous fish found in the Pacific northwest. Following approximately 18 months in the ocean, coho salmon begin their spawning migration. Spawning usually occurs from October to March, peaking in November to January (Moyle et al. 1989). Coho salmon use different types of spawning areas but generally prefer small coastal creeks or the tributary headwaters of larger rivers (Brown et al. 1994). Juvenile salmon prefer deep pools in the shaded areas of streams. This type of habitat is synonymous with that found in old growth forests and therefore the decline of the coho salmon in the Pacific northwest is attributed to the elimination of the old growth forest on the California coast (Brown et al. 1994). Juveniles initiate their migration to the ocean during late March and early April. This migration usually peaks in mid-May. These salmon remain in nearshore waters close to their parent stream, then gradually move northward (Brown et al. 1994).

Coho salmon have declined by at least 70 percent since the 1960s. Counts for the current presence of coho salmon in the LTMS planning area did not identify any in the Sacramento River and other tributaries of San Francisco Bay. It is believed that the coho salmon is nearly extirpated in the San Francisco Bay tributaries and very few remain in the Sacramento River drainage (Brown et al. 1994). Brown et al. (1994) estimates the current population of coho salmon in California at 31,000 fish, of which hatcheries contribute approximately 57 percent. Their decline is attributed to loss of stream habitat due to large dams and diversions as well as logging, agriculture, and urbanization.

Longfin Smelt (*Spirinchus thaleichthys*). The longfin smelt is a federal species of concern; the state status is species of special concern. Longfin smelt are planktivorous fish found within the Estuary. Adults occur seasonally from south San Francisco Bay upstream to Rio Vista on the Sacramento River, although they are primarily concentrated in salt and brackish waters in Suisun, San Pablo, and north San Francisco bays (USFWS 1994). In the fall, adults migrate upstream into freshwater habitats of the upper Estuary and lower Sacramento River. Most spawning occurs between February and April in the upper end of Suisun Bay and the lower and middle Delta, primarily in the Sacramento River and adjacent sloughs (USFWS 1994; Wang 1991). The diet of the longfin smelt consists of opossum shrimp and other large zooplankton (Moyle 1976).

The longfin smelt has declined steadily over the past few decades (USFWS 1994). The cause of decline may be attributed to the reduction in outflows, entrainment losses to water diversions, drought, pollution, predation, and introduced species (USFWS 1994). Disposal activities could result in habitat degradation of spawning grounds.

Steelhead Trout (*Oncorhynchus mykiss mykiss*). In August 1997, steelhead trout of the San Francisco Bay eastward to the Napa River (inclusive) were listed by the NMFS as threatened under the Endangered Species Act. Steelhead trout that spawn farther upstream in the Sacramento and San Joaquin rivers are still under review by the NMFS. Steelhead trout are the anadromous form of rainbow trout. They migrate to the Sacramento and San Joaquin river basins from October to April, and spawn from December to May. Their life history and environmental requirements are similar to those of chinook salmon with two major differences. First, steelhead do not always die after spawning (Barnhart 1986); many return to the ocean and spawn in subsequent years. The second major difference is that steelhead spend from 1 to 4 years rearing in freshwater before migrating to the ocean (Barnhart 1986).

Currently, steelhead make spawning runs into several rivers and small creeks flowing into the Bay, including the Napa River, Petaluma River, Sonoma Creek, and Guadalupe River. Spawning runs are also made into the Sacramento and San Joaquin river basins. Hatcheries greatly augment the natural production of steelhead. However, the overall population size of steelhead has declined substantially, with many rivers supporting only remnant fish runs. Steelhead populations are currently supported primarily by hatcheries, which support a small recreational sportfishery. The factors contributing to the decline of steelhead are similar to those affecting chinook salmon. Habitat degradation resulting from disposal of dredged material may adversely affect the steelhead.

COMMERCIAL AND RECREATIONAL FISHES. Fisheries of the Estuary include anadromous and resident species, crab, and shrimp. All portions of the Bay/Delta support commercially and/or recreationally important fisheries. This section describes the life history, status and distribution of fishes and invertebrates that are commercially and/or recreationally important.

Striped Bass (*Morone saxatilis*) were first introduced into California in the Carquinez Strait in 1879 (Skinner 1962). They are the principal sport fish in the Estuary and are highly sought after despite recent declines in their populations. Their successful introduction into the Estuary was primarily due to their anadromous nature as well as their semi-buoyant, non-adhesive eggs which are not susceptible to suffocation by silt loads from hydraulic mining (SFEP 1992a). Survival of the striped bass requires a large river for spawning with water velocities capable of suspending their eggs during incubation, abundant forage fish, and an estuary where juveniles can forage on large invertebrate populations (Moyle 1976).

Striped bass spawn in May and June in the lower Sacramento and San Joaquin rivers and their tributaries. Eggs and larvae are transported into Suisun Bay during high flow years and into the western Delta during low flow years. The larvae and young juveniles usually concentrate in the vicinity of the entrapment zone in Suisun Bay or the Delta, where they feed on zooplankton and amphipods (Turner and Chadwick 1972). Juveniles range into San Pablo Bay. Adults live up to 20 years and prey upon threadfin shad, smaller striped bass, northern anchovy, chinook salmon, and shiner perch (Stevens 1966; Moyle 1976).

Commercial fishing of striped bass began in 1888, only 9 years after their initial introduction into the Bay. Following a decline of the population, commercial fishing for striped bass ended in 1935

(SFEP 1992a). Annual catches from 1936 to 1953 were between 1 million and 2.3 million fish annually (Chadwick 1964). The striped bass is now managed as a sportfishery. Despite the ban on commercial fishing of the striped bass, its population continues to decline. Annual recreational catches today are currently less than 100,000 and the estimated population in 1991 was only 625,702 fish (CDFG 1992). While the subsidiary industries supported by the striped bass fishery are estimated to bring $45 million to local economies, declines since the 1970s have reduced this estimate by more than $28 million (SFEP 1992a).

Northern Anchovy (*Engraulis mordax*) reside primarily along coastal waters of California and migrate into the Estuary in late spring for feeding. They out-migrate in the fall. The majority of anchovies spawn outside the Estuary, although eggs and larvae are found in abundance in the Estuary. The young anchovies are transported by currents into the Bay, where they feed on phytoplankton and zooplankton in the midwater zone (SFEP 1992a). Eggs are widely distributed within the Bay, while larvae are found in areas of high zooplankton abundance. The diet of the northern anchovy consists of zooplankton and phytoplankton (SFEP 1992a).

Northern anchovy are the most abundant fish in San Francisco Bay (SFEP 1992a). In most years they are abundant in Central Bay and generally more abundant in San Pablo Bay as compared to the South Bay (SFEP 1992a). Due to overfishing of sardines, the northern anchovy population increased (Baxter 1967). While anchovies have not replaced the Pacific sardine industry, they support a commercial bait fishery. Due to the large population of anchovy offshore, there is little concern over the impact of the bait fishery on the population (Smith and Kato 1979).

Pacific Herring (*Clupea harengeus*) spawn and rear in the Bay. Adult Pacific herring enter San Francisco Bay in late November, initiating spawning primarily from December into March. Spawning locations within the Estuary have shifted in the past 20 years from Richardson Bay to the San Francisco and Oakland waterfronts (CDFG 1993a). This may be in response to habitat loss (SFEP 1992a). Spawning most often occurs in intertidal and shallow habitats on aquatic vegetation or marina pilings. Herring do not spawn over mud substrates found on the east side of the Bay. As juveniles, they are distributed in shallower habitats in South, Central and San Pablo bays. As they grow they move to deeper waters and emigrate from the Bay between April and August (SFEP 1992a).

The Pacific herring support a large fishery in the Estuary as bait and human food, but more importantly as the roe and roe-on-kelp fishery for export to Japan. The roe fishery is closely regulated by the California Department of Fish and Game (CDFG 1993a).

Dredging activities within Central San Francisco and Richardson bays could result in interference with spawning activity, reduced hatching success and larval survival.

American Shad (*Alosa sapidissima*) is an anadromous fish of the herring family introduced to the Estuary in 1871. American shad are oceanic as adults yet move into the Estuary to spawn in freshwater. Spawning occurs in the north Delta and the Sacramento River and its tributaries, beginning in March and ending by June (Stevens 1966). Young shad migrate to open water shortly after hatching. Their diet consists of zooplankton and small fish. While most adults die after spawning, some return to the ocean and spawn again a few years later (SFEP 1992a).

Soon after introduction of the shad, it supported a large commercial fishery. Commercial fishing was later banned in 1957 due to declining populations. Today a sport fishery exists in the Estuary.

White and Green Sturgeon (*Acipenser* spp.) are anadromous and native to the Estuary (Moyle 1976). Sturgeon can by found in saltwater from Mexico to the Gulf of Alaska (Miller and Lea 1972). The white sturgeon is much more abundant than the green sturgeon in the Bay and Delta and is an important fishery resource. The green sturgeon is a former federal candidate threatened species, now a federal species of concern.

White sturgeon generally complete their life cycle within the Estuary and its major tributaries, although a few fish enter the ocean and make extensive coastal migrations (Moyle 1976). During most of the year, adults are concentrated in San Pablo and Suisun bays feeding primarily on bottom-dwelling invertebrates. Adult sturgeon mature slowly and do not begin to spawn until they are about 10 years old. Individuals spawn in the Sacramento River and its tributaries roughly every 5 years (Moyle 1976).

Suisun Bay and the Delta are the principle nursery areas for sturgeon during their first year. The young sturgeon feed primarily on small crustaceans, while older sturgeon feed on clams, crabs, polychaete worms, fish, and fish eggs. Adult white sturgeon utilize muddy bottom habitats of the Delta, Suisun, San Pablo and San Francisco bays throughout the year (Miller and Lea 1972).

White sturgeon are particularly vulnerable to the effects of over-harvesting because they mature slowly. Commercial fishing of sturgeon dates back to the mid-1800s, but declined by the early 1900s. In 1954, the Fish and Game Commission abolished the commercial fishery and established a sport fishery that continues today. Populations have continued to decline in recent years. The major factor affecting sturgeon populations is believed to be decreased outflow into the Bay (CDFG 1992).

Flatfishes. Two species of flatfish present in the Estuary that are commercially and/or recreationally important are the English sole (*Parophrys vetulus*) and the starry flounder (*Platichthys stellatus*). These flatfish are found throughout the Estuary and in coastal waters. The English sole occur in the Bay as young adults. They spawn in the shallow areas along the coast from November to May, primarily in Central Bay as well as South and San Pablo bays (Wang 1986 as cited in SFEP 1992a). Starry flounder occur in high numbers in San Francisco Bay. Adult starry flounder appear to be most abundant near Alcatraz and San Pablo Bay. Young flounder are found in Suisun Bay. Both the English sole and the starry flounder immigrate into the Bay using both density and tidal currents. The young of both species rear in the Bay and in coastal waters. Larvae are bilaterally symmetrical and feed on zooplankton. Juveniles become laterally asymmetrical and feed primarily on crabs, polychaete worms, and molluscs (Wang 1986).

The adult English sole and starry flounder support a small commercial ocean fishery. While English sole shows no signs of decline, the starry flounder has declined specifically in San Pablo and Suisun bays. The starry flounder appears to be more sensitive to hydrologic and environmental changes (SFEP 1992a).

Dungeness crab (*Cancer magister*) has provided a valuable commercial fishery for San Francisco for over a century. Dungeness crab reproduction occurs entirely in nearshore ocean waters. Spawning occurs primarily in October and November. Dungeness crabs enter San Francisco Bay as juveniles during May or June and leave the Bay by August or September of the following year. The Bay serves as a nursery ground with an abundance of juveniles located in navigational channels and shallow berthing areas from Richardson Bay through Suisun Bay. San Pablo Bay has consistently served as a nursery for high numbers of juveniles (CDFG 1983).

The commercial fishery of the Dungeness crab began around 1848. Following a concern over a declining population, the crab fishery began to be regulated in 1903 by the State Board of Fish Commissioners (CDFG 1983). While there is currently an active offshore commercial and sportfishery, sport fishing of Dungeness crab inside the Bay was banned by the CDFG in 1978 due to concern over excess sport take (CDFG 1983).

Shrimp. The four most common shrimp in the Estuary are the blacktail bay shrimp (*Crangon nigricauda*), blackspotted bay shrimp (*Crangon nigromaculata*), California bay shrimp (*Crangon franciscorum*,) and an introduced shrimp from Korea (*Palaemon macrodactylus*) (SFEP 1992a). These shrimp, commonly referred to as grass shrimp, are important prey for Estuary fishes.

Each species has unique salinity preferences and therefore occurs in different areas of the Estuary. Factors limiting their abundance include hydrological modification, competition, and predation (SFEP 1992a).

The shrimp fishery for human consumption diminished by the 1950s following the discovery of offshore populations of shrimp and prawns. Currently, there is an active commercial bait fishery in the Estuary taking over 68 tons of shrimp each year from the Bay for striped bass and sturgeon fishermen (Siegfried 1989).

4.3.1.6 Marine Mammals

There are several species of marine mammals found in the Estuary. Most notably, a group of sea lions reside at Pier 39 along the northern edge of the San Francisco waterfront, and small colonies of harbor seals range throughout South, Central, and San Pablo bays. Harbor seal haulout grounds are found at several sites in the South Bay, Castro Rocks near the Richmond-San Rafael Bridge, Corte Madera Marsh, and on lower Tubbs Island in San Pablo Bay. Occasionally, individual juvenile whales also enter the Bay during their migrations up and down the coast of California.

Dredged material disposal is not considered likely to directly impact marine mammals except in cases where equipment operating near a haulout ground causes flushing.

4.3.2 Embayments

Section 4.3.1 above generally described the environmental resources of the overall San Francisco Bay Estuary. Disposal of dredged material has the potential to affect environmental resources at specific disposal sites in very similar ways, regardless of site location. Overall, however, the environmental effects are not always confined to the disposal sites, and different collections of resources within each embayment can be affected in different ways. To fully assess the potential impacts of in-Bay disposal, a more detailed analysis of the potential for impact with each of the embayments is necessary. This section presents a more detailed discussion of the environmental resources that could be affected by dredged material disposal in each of the seven embayments: Central Bay, San Pablo Bay, Carquinez Strait, Suisun Bay, South Bay, and the Sacramento-San Joaquin Delta. Existing monitoring programs of dredging and dredged material disposal are also discussed in the following section.

4.3.2.1 Central Bay

Central San Francisco Bay is the area bounded to the north by the Richmond-San Rafael Bridge, the west by the Golden Gate Bridge, and the south by the Bay Bridge. The western portion of Central Bay is characterized by relatively deep water, high tidal water exchange through the Golden Gate, and strong currents. This area is dominated by marine habitat conditions, and is bordered by rocky shoreline. The eastern portion of Central Bay is dominated by shallow mudflats. Small embayments off the main water body also contain mudflats. Overall, habitat diversity is relatively high because Central Bay has both marine and estuarine characteristics and has the greatest depth range of any region in the Estuary. The Alcatraz disposal site is located within this embayment.

This section first describes the environmental conditions at the Alcatraz disposal site. This is followed by a discussion of environmental parameters within the broader Central Bay embayment that may be affected by dredged material disposal at the Alcatraz site.

Environmental Characteristics of the Alcatraz Disposal Site

The Alcatraz disposal site (known as "SF-11") is a 2,000-foot-diameter circle located 0.3 mile south of Alcatraz Island (centered at 37°49'17"N, 122°25'23"W) (see Figure 2.2-1 and Figure 4.3-5). Dredged material has been disposed at this site since 1894 (LTMS 1994j) and it was formally designated as a disposal site in 1972. Dredged material has been disposed at Alcatraz using both clamshell and hopper dredges; the areas where each of these types of dredges have disposed of material at the Alcatraz site are shown in Figure 4.3-6. It continues to be the most heavily used dredged material disposal site in the Bay. COE records for 1975 through 1994 indicate disposal volumes ranged from a low of approximately 1 mcy in 1980 to a high of over 9 mcy in 1985 (Figure 4.3-7). Recently the COE has been compiling monthly records of disposal volumes at Alcatraz. This information is provided in Figure 4.3-8. In the mid-1980s, as a result of frequent disposal at this site, a mound developed at its eastern portion, posing a hazard to navigation (see Chapter 2 for further discussion of the mounding problem at Alcatraz). Active management of disposal methods, frequencies, and volumes by the COE is required to maintain navigable depths at the site. Currently, there is a yearly disposal volume limitation of 4 mcy for this site.

A portion of the Alcatraz disposal site also overlaps with a portion of the Golden Gate National Recreation Area (GGNRA), as shown in Figure 4.3-9.

WATER COLUMN SALINITY. The Alcatraz site is typically dominated by marine waters, so salinity levels are generally high. Salinity measured at a nearby RMP monitoring station ranged from 24 to 33 ppt (SFEI 1994). There is often a slight salinity gradient from shallow to deep waters at the site.

DISSOLVED OXYGEN. Dissolved oxygen (DO) levels near the Alcatraz site are generally very high, ranging from 7.1 to 9.6 at a nearby RMP station at the mouth of Richardson Bay (SFEI 1994). As described in section 4.3.1.2, the disposal of dredged sediment has the potential to affect levels of DO at each disposal site, particularly in waters near the Bay floor. The extent of this depression depends on the amount of oxygen-demanding substances present in the material. Anoxic sediments containing reduced substances such as hydrogen sulfide would cause the greatest

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