Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay

Final Report
August 5, 2004
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Subject: Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay – Final Report

Dear Al:

LFR Levine·Fricke (LFR) is pleased to submit the enclosed final report entitled "Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay." We have enclosed an unbound paper copy as well as an electronic copy in PDF format on CD.

Thank you for requesting LFR to perform this project. We look forward to working with you in the future on related LTMS projects.

Please call me at 510-596-9588 if you have any questions.

Sincerely,

Phil Lebednik

Phillip A. Lebednik, Ph.D.
Principal Scientist
Ecosystem Services Group

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1.0 INTRODUCTION

1.1 Background

In 2002, the Environmental Windows Committee of the San Francisco Bay ("Bay") Long-Term Management Strategy (LTMS) developed a preliminary work plan to be implemented by a Science Assessment and Data Gaps Work Group ("Work Group"). The mandate and structure of the Work Group was designed to facilitate overall scientific coordination, priority setting, and review of activities and information. The Work Group began meeting in January 2003 and comprises voluntary stakeholder participants, including natural resource management and regulatory agencies ("agencies"), the dredging and ports community, interested parties such as environmental and fishing groups, and consultants. The Work Group met several times and identified a number of priority science issues and topics that were recommended for funding. The mandate of the Work Group includes fish, mammal, and bird species; however, the Work Group has agreed to focus initially on fish species.

During the initial meetings of the Work Group and in communications between the Work Group and LTMS Program Managers, it became evident that there was a need for a work plan within which the Work Group would conduct its activities. For the Work Group to develop such a plan, a comprehensive framework was needed that identified the issues of concern. Such a framework would facilitate the activities of the Work Group and assist in identifying and prioritizing ongoing and future activities. The framework would also facilitate identification of projects that, if funded, would address data gaps and/or issues of concern. These results would be provided to the agencies so as to inform and reduce uncertainties associated with environmental windows, biological consultation, and permitting associated with dredging operations in the Bay. Accordingly, the Work Group requested that the Chair, Dr. Phillip Lebednik, prepare this document as the framework for the Group's activities. Dr. Lebednik was assisted in this effort by Mr. Ryan Lafrenz. The literature review was conducted prior to February 2004.

1.2 Purpose and Scope

The purpose of this framework is to evaluate science data needs for all the sensitive fish species for which there are environmental windows in the Bay. More specifically, the framework identifies issues of concern to the agencies, as expressed in interviews with agency personnel. The framework identifies topics related to the effects of dredging on the species and lists the key scientific questions associated with each topic (in this report, unless otherwise indicated, the term "effects" may refer to demonstrated, probable, and/or potential effects). This framework also includes summaries of literature on the LTMS process in the Bay, species of concern, and dredging effects. These summaries are intended to serve as a resource for the Work Group to assist in its development of a work plan.

In general usage, the term "dredging" may refer either to the act of dredging alone or to the act of dredging and subsequent disposal of dredged materials. The latter definition is often used because the act of dredging dictates the necessity for disposal. The impacts associated with in-bay disposal of dredged materials was the subject of an Environmental Impact Statement and Report (EIS/EIR) process (USACE et al. 1998) that resulted in an overall plan for management of dredging and disposal of dredged materials in the Bay, including environmental windows. This process resulted in the LTMS Management Plan, currently being implemented, to reduce the impacts of in-bay disposal. Accordingly, this framework primarily focuses on the effects of dredging operations.

1.3 Approach

The framework was developed using several sources of information:

- interviews of agency personnel and other stakeholders concerned with dredging in the Bay
- a list of topics developed by the Work Group
- Bay LTMS documents (including technical reports, the LTMS EIS/EIR [USACE et al. 1998], and related agency documents)
- reports and publications on fish species of interest
- reports and publications on dredging and its effects on fish
- reports and publications on conditions in the Bay

The information gathering included a limited review of the most relevant literature, including available review papers on the effects of dredging. The interviews were focused on the interviewees' perspectives on potential effects of dredging on windows fish species. The information gathered is included in this report, as well as a synthesis of the results formatted as a science assessment framework.

2.0 SAN FRANCISCO BAY ENVIRONMENTAL FISH WINDOWS

2.1 San Francisco Bay Long-Term Management Strategy

Starting in 1990, the U.S. Environmental Protection Agency (USEPA), the U.S. Army Corps of Engineers (USACE), the San Francisco Bay Regional Water Quality Control Board (SFBRWQCB), the Bay Conservation and Development Commission (BCDC), and the State Water Resources Control Board (SWRCB) joined together with navigation interests, fishing groups, environmental organizations, and the public in a cooperative effort to establish a comprehensive LTMS for Bay Area dredged material. The goals are to conduct necessary dredging and dredged material disposal in an environmentally sound and economically prudent manner, to maximize the "beneficial reuse" of dredged material, and to develop a coordinated permit review process for dredging projects.

The LTMS agencies jointly published a final "Policy Environmental Impact Statement/Programmatic Environmental Impact Report" to select an overall long-range approach to implement the goals and to develop a detailed management plan (USACE et al. 1998, hereafter "EIS/EIR"). The EIS/EIR focused primarily on dredged material disposal options, although a description of generic dredging impacts and mitigation measures for special status species was included. Detailed evaluation of the impacts of dredging (as opposed to disposal) was explicitly excluded from the scope of the EIS/EIR (USACE et al. 1998, p. 1-5).

A tabulation of the species of concern, the effects of dredging and disposal on the species, and recommendations for restricting the timing and design of dredging and disposal projects was included in Section 5 and Appendix J of the EIS/EIR. Tables 5.1-1, J-3, and J-4 depicted the recommendations for dredging restrictions. These tables are the first published version of what has become known as the Environmental Work Windows (the EIS/EIR windows tables were subsequently updated in the Management Plan; see below).

The long-term strategy selected in the LTMS EIS/EIR, adopted in the federal Record of Decision (ROD), signed by the USACE and USEPA in 1999, and reflected in the SFRWQCB's Water Quality Control Plan amendments and the BCDC's San Francisco Bay Plan amendments of 2001 involves low disposal volumes at in-bay sites, medium disposal volumes in the ocean, and medium volumes for beneficial reuse.

Full implementation of the long-term dredging, disposal, and beneficial reuse strategy selected in the EIS/EIR required further changes to existing management approaches and the creation of new approaches. Consequently, the LTMS developed the "LTMS Management Plan" (USACE et al. 2001, hereafter "Management Plan").

Information included in the documents described above that address the effects of dredging is discussed in Section 6.

2.2 Biological Opinions and Related Documents

Current fish windows restrictions on dredging are based upon Section 7 consultations with the resource agencies and a few additional documents. The biological opinions of the National Marine Fisheries Service (NMFS) and U.S. Fish and Wildlife Service (USFWS) provided Endangered Species Act "take authorization" for those projects complying with the conditions of the program. The federal biological opinions together with that of the California Department of Fish and Game (CDFG) were included in the ROD for the LTMS process (ROD 1999). Certain clarifications and minor corrections of the NMFS biological opinion (NMFS 1998) were described by Whitlock (1999). This biological opinion addressed chinook salmon (including Sacramento River winter-run, Central Valley evolutionarily significant units [ESUs] spring-run, Central Valley

ESU fall/late fall-run, and southern Oregon and California coastal ESU), coho salmon (southern Oregon/northern California coast ESU [not expected in the LTMS area] and central California ESU), steelhead trout (central California coast ESU, south/central California coast ESU, and Central Valley ESU). The USFWS biological opinion included two fish species: the delta smelt (*Hypomesus transpacificas*) and Sacramento Splittail (*Pogonichthys macrolepidotus;* Goude 1999). While this report was in preparation, the splittail was delisted by USFWS. The information on biology and ecology of splittail is included in Appendix B. Longfin smelt were assigned a window in anticipation of its being listed as a threatened or endangered species. However, it was not listed and was not included in the USFWS biological opinion. Information on biology and ecology of longfin smelt was compiled and is included in Appendix A. The CDFG biological opinion did not include any specific discussion of fish species, but adopted the NMFS biological opinion (Lollock 1998; see also clarifications regarding the biological opinion by Johnston 1999, and Sutton 1999).

Pacific herring are commercially harvested in the Bay, are not a special status species, and therefore were not included in any biological opinion issued relative to LTMS. Concerns and proposed mitigation measures regarding the effects of dredging and disposal on this species were described by Turner (1993) and a herring window was included in the EIS/EIR and Management Plan. Turner (1993) was not included in the ROD, but is generally considered to be the basis for the herring window and other dredging restrictions related to herring.

Information included in the documents described above that address the effects of dredging is discussed in Section 6.

2.3 Environmental Fish Windows

Section 3.8 of the Management Plan includes the Environmental Work Windows that were in use in the Bay in 2003 (see Appendix C) and are updated from those included in the EIS/EIR (Goeden and Goldbeck 2003). The Windows within which dredging and disposal may occur are defined on a regional basis as contiguous periods within a calendar year when operations may be conducted without formal consultation with natural resource agencies. During non-window months, formal consultation is required. Windows are identified by species, geographical regions of the Bay, and in some instances, by more specific criteria. Most fish windows are regional. The determination of appropriate work windows was based on the premise that the species is not likely to be present in the location during the window period.

3.0 SAN FRANCISCO BAY ENVIRONMENT

The focus of this framework is on the LTMS planning area as depicted by the heavy dashed line in Figure 1. The estuarine habitat within this area encompasses all of the Bay proper and extends eastward toward the Sacramento/San Jaoquin River Delta as far as Sherman Island. The San Francisco Bay watershed overlaps slightly with the legal definition of the Delta, in the area between Chipps and Sherman islands, east of Suisun Bay (see Figure 2 in Meiorin et al. 1991). Also included are the rivers and creeks that are tributary to the estuarine habitats.

To provide an appropriate base of information upon which to consider the effects of dredging on fish in the Bay, a discussion of the characteristics of the Bay's environment relevant to the species and dredging effects is provided in this section. Most of this discussion is adapted from the EIS/EIR.

The Estuary, with a surface area of 1,631 square miles, is the largest estuary on the Pacific coast of North and South America (SFEI 1994). The San Francisco Bay is located at the mouth of two major rivers, the Sacramento and the San Joaquin rivers, which carry 60 percent of the state runoff from tributary rivers and streams draining about 40 percent of California's surface area (Conomos et al. 1985; Nichols and Pamatmat 1988).

The Estuary can be divided into several segments: the Sacramento-San Joaquin Delta, Suisun Bay, Carquinez Strait, San Pablo Bay, Central Bay, and South Bay. The most upstream portion of the Estuary, the Sacramento-San Joaquin Delta (Delta), is a 1,150-square-mile, triangular-shaped region of land and water at the confluence of the Sacramento and San Joaquin rivers. The Delta is bounded by the city of Sacramento to the north, Vernalis to the south, and Chipps Island to the west. The Delta's western segment is subject to the greatest tidal effects. The central Delta, surrounded by the other segments, includes many channels where waters from all four rivers mix (Sacramento, San Joaquin, Cosumnes, and Mokelumne). The Delta's rivers, sloughs, and excavated channels comprise a surface area of about 75 square miles (SFEP 1992b). Suisun Bay is a shallow embayment between Chipps Island at the western boundary of the Delta and the Benicia-Martinez Bridge at the eastern end of Carquinez Strait. Adjacent to Suisun Bay is Suisun Marsh, the largest brackish marsh in the United States. The narrow, 12-mile-long Carquinez Strait joins Suisun Bay with San Pablo Bay. San Pablo Bay is a large, open bay that extends from Carquinez Strait to the San Pablo Strait near the Richmond-San Rafael Bridge. Adjacent to San Pablo Bay lies the northern part of San Francisco Bay, known informally as the Central Bay; it is bounded by the San Pablo Strait to the north, the Golden Gate Bridge to the west, and the Oakland-San Francisco Bay Bridge to the south. The southern part of San Francisco Bay, known informally as the South Bay, includes all Bay waters south of the Oakland-San Francisco Bay Bridge.

3.1 Hydrology

Hydrology is especially important to fish species in estuaries because it describes the water flows and determines salinity, two of the most important environmental factors for fish. The northern reach of the San Francisco Bay (comprised of Suisun Bay, Carquinez Strait, and San Pablo Bay) is geographically and hydrologically distinct from the Central and South bays. The South Bay is a tidally oscillating, lagoon-type estuary, where variations are determined by water exchange between the northern reach and the ocean. Water residence times are much longer in the South Bay than in the North Bay. The northern reach is a partially to well-mixed estuary (depending on the season) that is dominated by seasonally varying river inflow. The timing and magnitude of the highly seasonal river inflow modulates permanent estuarine circulation, which is largely maintained by salinity-controlled density differences between river and ocean waters. Freshwater inflows, tidal flows, and their interactions largely determine variations in the hydrology of the Bay/Delta. Hydrology has profound effects on all species that live in the Bay/Delta because it determines the salinity in different portions of the Estuary and controls the circulation of water through the channels and bays.

3.1.1 Freshwater Flows in the Sacramento-San Joaquin Delta

Approximately 60 percent of all the fresh water runoff in California enters San Francisco Bay via the Sacramento-San Joaquin Delta. Sacramento River flow dominates the northern Delta, while waters of the San Joaquin River dominate the southern Delta, and waters of the Cosumnes and Mokelumne rivers dominate the eastern Delta. The Delta's western segment is subject to the greatest tidal effects. The central Delta, surrounded by the other segments, includes many channels where waters from all four rivers mix. The Delta's rivers, sloughs, and excavated channels comprise a surface area of about 75 square miles (SFEP 1992a). The Estuary receives 90 percent of its fresh water inflows from streams and rivers of the Central Valley and about 10 percent from tributaries and other sources surrounding San Francisco Bay. Of the fresh water flows entering the Estuary from the Central Valley, the Sacramento River typically accounts for 80 percent, the San Joaquin River 15 percent, and smaller rivers and streams the remainder. However, the total volume of water flowing into the Delta and subsequently into the San Francisco Bay system (discussed below) is extremely variable on both a seasonal and annual basis.

3.1.2 San Francisco Bay Circulation

Water flows in the Estuary follow complex daily and seasonal patterns. Circulation is affected by tides, local winds, basin bathymetry, and the local salinity field (Cloern and Nichols 1985). The Estuary has two low tides and two high tides every 24.8 hours. During each tidal cycle, an average of about 1.3 million acre-feet of water, or 24 percent of the Bay/Delta's volume, moves in and out of the Estuary. On the flood tide, ocean water moves through the Golden Gate and into the Estuary's southern and northern reaches, raising the water level at the end of South Bay by more than 8 feet, and raising the height of the Sacramento River at the upstream edge of the Estuary by about 3 feet. It takes about 2 hours for tidal influence to reach the end of South Bay and 8 hours to reach Sacramento. Under the historically recent flow regime, freshwater flowing from the Delta usually meets saltwater from the ocean in the vicinity of Suisun Bay. Because freshwater is less dense than saltwater, when they meet, freshwater tends to flow over the surface of the saltwater before the two are partially mixed by tidal currents and winds. This separation of fresh and salt water results in a vertical salinity gradient that may occur over an area extending several miles in length and which is most prominent when Delta outflow is high. When outflow is low, the waters are well-mixed, with only a small salinity gradient from the surface to the bottom. The downstream flow of the freshwater surface layer induces an upstream counter-current flow of saltier water along the bottom in a pattern known as gravitational circulation. The most landward zone of gravitational circulation, where bottom ebb and flood currents are nearly equal, is called the null zone. The location of the null zone is influenced mainly by Delta outflow. A moderate Delta outflow of about 10,000 cubic feet per second (cfs) positions the null zone at the upstream end of Suisun Bay. A flow greater than about 20,000 cfs positions it in San Pablo Bay, and a flow of less than 5,000 cfs positions it in the upstream waters of the Sacramento River. Tidal currents also influence the location of the null zone, moving it upstream and downstream 2 to 6 miles twice each day. Associated with the null zone is a region just downstream where gravitational circulation concentrates suspended materials such as nutrients, plankton, and very fine suspended sediments in what is called the entrapment zone. In this zone, suspended materials are circulated as they settle out of the upper water layer and are carried upstream by the bottom current and toward the surface by vertical currents near the null zone. In this way, the entrapment zone concentrates phytoplankton, zooplankton, and nutrients, providing a rich habitat thought to be important for the rearing of young striped bass and other fish species. Concentrations of suspended sediments and plankton are often many times higher in the entrapment zone than upstream or downstream of the entrapment zone.

Suisun and San Pablo bays receive the majority of freshwater input. There, density/salinity-driven currents show ebb dominance of the surface water and flood dominance of the bottom water. Thus, waters in these embayments are characterized by being oxygenated, of low to moderate salinity, and high in suspended solids. The residence time of water in the Estuary's northern reach, particularly in Suisun and San Pablo bays, is strongly influenced by Delta outflow. During the low flow period of the year (late summer), the residence time of freshwater moving from the Delta to the ocean can be relatively long (on the order of months) compared to when outflow is very high (winter), when freshwater can move from the Delta to the ocean in a matter of days. Water residence time affects the abundance and distribution of many estuarine organisms, the amount of production by phytoplankton, and some of the chemical and physical processes that influence the distribution and fate of pollutants. Central Bay is most strongly influenced by tidal currents due to its proximity to the Pacific Ocean. The Central Bay is characterized by Pacific waters that are cold, saline, and low in total suspended sediment. Water quality parameters fluctuate less than in other sectors of the Bay due to the predominance of ocean water. Net exchanges of ocean and Bay waters depend on net freshwater flow in the Bay, tidal amplitude, and longshore coastal currents. The South Bay receives less than 10 percent of the freshwater budget of the Bay. It also receives the majority of wastewater discharged to the Bay (>75 percent). During the summer, treated sewage discharge exceeds freshwater in-flow in this area. South Bay waters are influenced by Delta outflow during the winter months, when low-salinity water moves southward into the southern reach displacing the saline, denser water northward. In the summer months, however, South Bay currents are largely influenced by wind stress on the surface; northwest winds transport water in the direction of the wind, and the displaced water causes subsurface currents to flow in the opposite direction. Because the South Bay receives only minor amounts of freshwater in-flow from the surrounding watershed, it is essentially a tidal lagoon with a relatively constant salinity.

3.2 Bathymetry

The average depth of the Bay is about 19 feet at mean lower low water while median depth is about 6 feet (Conomos et al. 1985). The Bay's deepest sections, at the Golden Gate (360 feet) and the Carquinez Strait (88 feet) are topographic constrictions where scouring by strong tidal currents contributes to maintaining these depths. The bathymetry of the Bay is an important factor affecting sediment dynamics. San Pablo Bay, Suisun Bay, and the South Bay are characterized by broad shallows that are incised by narrow channels, which are typically 33 to 66 feet deep. These shallower areas are more prone to wind-generated currents and sediment resuspension than deeper areas such as the Central Bay.

3.3 Currents and Circulation

Currents created by tides, freshwater inflows and winds cause the erosion and transport of sediments. Tidal currents are usually the dominant form of observed currents in the Bay. There is more intense vertical mixing and reduced vertical stratification during spring tides than during neap tides (Cloern 1984). Tidal currents are stronger in the channels and weaker in the shallows, and tend to parallel the bathymetry of the Bay (Cheng and Gartner 1984). These processes enhance exchange between shallows and channels during the tidal cycle, and contribute significantly to landward mixing of ocean water and seaward mixing of river water. Also, the South Bay begins flooding while San Pablo Bay is still ebbing, making it possible for South Bay to receive some water from the northern reach (Smith 1987).

Generally, tides appear to have a significant influence on sediment resuspension during the more energetic spring tide when sediment concentrations naturally increase, and particularly during the ebbs preceding lower low water when the current speeds are highest (Cheng and McDonald 1994). The substantial increase in suspended sediment concentrations following a lower low water ebb on a spring tide may be due to the longer duration of higher currents as well as a greater absolute current velocity. Powell et al. (1989), however, observed no correlation between tidal cycle and suspended sediment loads or distribution in the South Bay, although tidal cycling may have had an impact on sediment resuspension at times of the year other than winter/spring high-water flow. Their conclusion was that winds were the most important factor in resuspending sediments in the South Bay, and that local sources of sediments were more important than the import of sediment resuspended from elsewhere (Reilly et al. 1992).

As described earlier, freshwater inflows induce gravitational circulation, where salinity/density differences result in ebb currents near the surface and flood currents near the bottom. Although gravitational currents are generally weaker than tidal currents, they contribute significantly to the sediment cycle within the Bay. Freshwater inflow carries sediment loads downstream via surface currents. Suspended sediments settle out as mixing occurs and salinity concentrations increase. The fine sediments that settle out near the bottom are carried back upstream by the counter-flowing gravitational circulation near the bottom. The sediment cycle begins again as the fine suspended sediments are entrained in the freshwater flow and carried back downstream (Cheng and McDonald 1994). The landward extent of gravitational currents are determined by the magnitude of inflows. Strong seasonal winds create circulation and mixing patterns and add to tide- and river-induced current forces. Wind-induced currents have a significant effect on sediment transport by resuspending sediments in shallow waters (Krone 1979; Cloern et at. 1989). It has been estimated that 100 to 286 mcy of sediments are resuspended annually from shallow areas of the Bay by wind-generated waves (Krone 1974; SFEP 1992b).

In summary, net circulation patterns within the Bay are influenced by Delta inflows, gravitational currents, and by tide- and wind-induced horizontal circulation. The cumulative effects of the latter three factors on net circulation within embayments tend to dominate over that of freshwater inflows except during short periods after large storm events (Smith 1987). Exchanges between embayments are influenced both by mixing patterns within embayments and by the magnitude of freshwater inflows (Smith 1987).

3.4 Sediment Budgets

River inflow is the major source of new sediment input into the Estuary. Most new sediment (approximately 80 percent) originates in the Sacramento-San Joaquin River drainage and enters primarily as suspended load during the high winter inflows. Long-term average estimates of the sediment budget have been performed by several researchers, including Gilbert (1917), Krone (1979), and LTMS (1992e). A revised sediment budget was in preparation by D. Schoellhamer during the preparation of this document. Although Krone (1979) estimated a long-term average annual new sediment input of 10.4 mcy, the sediment budget study reported in LTMS (1992e) demonstrated that between 1955 and 1990, an average of 7.88 mcy of sediment flowed into the Bay system annually from the Central Valley and local streams. Sediment loading into the Bay system, particularly that associated with winter and spring flows, has been reduced as a result of managed impoundments and diversions. Freshwater diversions and releases may be the largest factor controlling Bay sedimentation processes. Flow regulation using releases and diversions is primarily intended to control salinity within the western Delta (LTMS 1992e). Other factors affecting the overall sediment delivery to the Bay include upstream dam trapping, delta channelization, and increasing urbanization. Estimates of the fraction of the new sediment input that is discharged to the ocean vary widely: from 4 percent by Gilbert (1917) and 6 percent by Conomos and Peterson (1977), to 30 percent of an annual 11.1 mcy by Schultz (1965), 42 percent of an annual 10 mcy by the USACE (USACE 1967), 43 percent of the 7.9 mcy by LTMS (1992e), and 50 percent of the 10.4 mcy by Krone (1979). Much of the winter sediment load from the Sacramento-San Joaquin rivers initially settles out in San Pablo Bay. During the lower flow summer months, wind-generated waves and tidal currents erode the previously deposited sediment and redistribute it over a wide area. Sediment loading aside, there are numerous other factors that significantly influence the natural sedimentation cycle of the Estuary. Changes in the rates or patterns of sediment loading as well as changes in hydrodynamics affecting sediment transport have caused a shift in the important (and little understood) equilibrium between sedimentation and erosion. For example, reclamation of floodplain and tidal wetlands in the Delta and the Bay margins have eliminated these areas as natural sediment traps. Water diversions have altered flows, reducing the volume of freshwater available to scour and flush sediments from various portions of the Estuary. The alterations in flow patterns that result from these and other human activities disturb the dynamic equilibrium that controls sediment deposition, resuspension, and the overall stability of the deposit (SFEP 1990). Disposal of significant quantities of dredged material in upland and ocean environments, compared to continuing to dispose of most material within the Estuary, could alter the overall sediment budget of the San Francisco Bay, and has the potential to significantly alter the sediment budgets within each embayment.

3.5 Water Quality

The most comprehensive data sets describing water quality in the Estuary come from the Regional Monitoring Program managed by the San Francisco Estuary Institute (SFEI 1994) and ongoing studies by the Interagency Ecological Program (IEP) focusing on parameters affected by water flow. In addition, numerous short-term studies that focus on specific sites, resources, or pollutants are conducted on a regular basis by researchers and entities discharging permitted wastes. The primary water quality parameters discussed below include the following: salinity, dissolved oxygen, pH, total suspended solids (TSS), turbidity, un-ionized ammonia, and pollutants. The potential impacts associated with dredged material disposal on these water quality parameters are also described below.

3.5.1 Salinity

The salinity of water entering the Estuary varies greatly. The Sacramento River and eastside streams flowing into the Delta are low in salts, with salinity averaging less than 0.1 parts per thousand (ppt). San Joaquin River water is more saline than these tributaries and, since the 1930s, its average salinity has increased from less than 0.2 ppt to about 0.4 ppt, primarily as a result of increased agricultural drainage. The salinity of the Estuary's northern reach varies considerably and increases along a gradient from the Delta to Central Bay. At the mouth of the Sacramento River, for example, the mean annual salinity averages slightly less than 2 ppt; in Suisun Bay it averages about 7 ppt; and at the Presidio in Central Bay it averages about 30 ppt. The entrapment zone is generally located where the surface salinity is between 1 ppt and 6 ppt and the near-bottom salinity is 2 ppt. In the southern reach, salinities remain at near-ocean concentrations (32 ppt) during much of the year. However, during the summer, high evaporation rates may cause salinity in South Bay to actually exceed that of ocean water. Seasonal changes in the salinity distribution within the Estuary are controlled mainly by the exchange of ocean and Bay water, and by river inflow. River inflow has the greater influence on salinity distribution throughout most of the Estuary because inflow varies widely, while ocean input varies relatively little. In winter, high flows of freshwater from the Delta lower the salinity throughout the Estuary's northern reach. High Delta flows also intrude into South Bay, lowering salinity there for extended periods. In contrast, during the summer, when freshwater inflow is low, saline water from the Bay intrudes into the Delta. The inland limit of salinity intrusion varies greatly from year to year. Salinity of 1 ppt has extended upstream of Rio Vista several times in this century. Channel dredging increases gravitational circulation and enhances salinity intrusion (Nichols and Pamatmat 1988). Disposal of dredged material may have local, short-term effects on salinity within disposal site areas. There is often a salinity gradient with depth at most locations throughout the Estuary. Disposal of material can cause an increase in vertical mixing, but any associated changes in salinity are expected to be very short-term and limited to the disposal site. Salinity may also be affected in situations where material is dredged from saline waters and disposed in upland or inland freshwater areas.

3.5.2 Dissolved Oxygen

Oxygen concentrations in estuarine waters are increased in several ways: by the mixing action of wind, waves, and tides; by photosynthesis of phytoplankton and other aquatic plants; and by high dissolved oxygen in freshwater inflow. Dissolved oxygen concentrations are lowered by plant and animal respiration, chemical oxidation, and bacterial decomposition of organic matter. The Estuary's waters are generally well oxygenated, except during the summer in the extreme southern end of the South Bay where concentrations are reduced by poor tidal mixing and high water temperature. Typical concentrations of dissolved oxygen range from 9 to 10 mg/l throughout the entire Estuary during periods of high riverine flow, 7 to 9 mg/1 during moderate riverine flow, and 6 to 9 mg/1 during the late summer months when flows are the lowest. Unlike the 1950s and 1960s, when inadequately treated sewage and processing plant wastes depleted oxygen in parts of the Bay and Delta, today there are few reports of places in the Estuary where low oxygen concentrations adversely affect beneficial uses. Today, the lowest concentrations in the Estuary are typically observed in the extreme South Bay but, in some instances, dissolved oxygen levels in semi-enclosed embayments such as Richardson Bay can be much lower than in the main water body (SFEI 1994). The disposal of dredged sediment has the potential to affect levels of dissolved oxygen at any disposal site, particularly in waters near the Bay floor. Short-term depressions in dissolved oxygen levels were measured in waters immediately adjacent to the Carquinez site during disposal of material from the Mare Island Strait in 1973. Levels of dissolved oxygen near the Bay floor declined from 80 to 85 percent to 20 to 30 percent saturation within several minutes after material was released from the barge, but recovered to ambient levels within 10 minutes (USACE 1976c). The extent of this kind of effect 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 temporary depression in dissolved oxygen levels at the disposal site. However, the effects of dredged material disposal on dissolved oxygen levels in Bay waters are usually short term, generally limited to the plume associated with each dump, and confined to the disposal area and immediately adjacent waters. However, disposal in areas where dissolved oxygen levels are already depressed (such as in the South Bay or in Richardson Bay) and/or disposal at high dumping frequencies could cause more extensive water quality impacts.

3.5.3 pH

The pH of waters in San Francisco Bay is relatively constant and typically ranges from 7.8 to 8.2. The disposal of dredged material may change the pH of waters at disposal sites as the material is typically more acidic than Bay waters. Such an effect, however, is expected to be of extremely short duration and limited to the disposal site area. Dredged material disposal thus is not expected to significantly affect this water quality parameter.

3.5.4 Total Suspended Solids and Turbidity

Turbidity and total suspended solids (TSS) are used interchangeably in some of the literature. The distinction lies mainly in the method of measurement, i.e., turbidity measurements are optical, while TSS measurements are gravimetric. In general, higher TSS results in more turbid water. The level of turbidity and TSS in Estuary waters is a function of the dynamic sediment processes described above. Regions of maximum suspended solids occur in the North Bay in the null zone (generally 50 to 200 mg/l, but as high as 600 mg/1 TSS). The null zone also accumulates high concentrations of phytoplankton (Smith 1987). The specific location of the null zone changes depending upon freshwater discharge from the Delta. TSS levels in the Estuary vary greatly depending on the season, ranging from 200 mg/1 in the winter to 50 mg/1 in the summer (Nichols and Pamatmat 1988; Buchanan and Schoellhamer 1995). Shallow areas and channels adjacent to shallow areas have the highest suspended sediment concentrations. TSS levels vary throughout the Estuary depending upon season, tidal stage, and depth (Buchanan and Schoellhamer 1995). The Central Bay generally has the lowest TSS concentrations; however, wind-driven wave action, tidal currents, as well as dredged material disposal and sand mining operations cause elevations in suspended solids concentrations throughout the water column. Schoellhamer (1996) concluded that variations in suspended sediment concentrations in South San Francisco Bay were most influenced by winds (including afternoon sea breezes) and the tidal cycle (neap-spring tide differences).

Suspended sediment plumes associated with dredging are different from those caused by disposal; nevertheless, there are some similarities in the characteristics of the two types of sediment plumes and the following discussion on disposal plumes is included for that reason. The disposal of dredged material causes a temporary increase in the level of suspended material (turbidity) in site waters. Most of the material in the descending cloud reaches the substrate, but a small percentage (approximately 10 percent of sediments dredged from a clamshell dredge) of finer material remains in the water column (SAIC 1987b). In addition to this material, a more dense cloud of material forms near the bottom after dynamic collapse of released material. This near-bottom plume of highly concentrated suspended solids spreads horizontally until its momentum has dissipated. The turbidity plume resulting from disposal typically disperses, and water column TSS levels return to near-background within 15 to 20 minutes of release (Reilly et al. 1992). Observed plumes migrate in the direction of the current at time of discharge (SAIC 1987b). For example, vertical profiles of turbidity plumes at the Alcatraz site monitored in 1976 showed that the maximum increases in suspended solids on site occur at near-bottom depths. At a depth of 1 meter, suspended solid concentrations rose from roughly 25 mg/1 TSS (background) to approximately 275 mg/l TSS 50 meters from the release point, then declined again to near-background levels 400 meters from the release point. Suspended sediment concentrations at 5 and 9 meters above the Bay floor were much lower, ranging from 25 to 75 mg/l TSS (USACE 1976c). At any unconfined aquatic disposal site, disposal of dredged material is thus expected to cause short-term changes in water column turbidity with each material dump. These changes are primarily limited to near-bottom waters within and immediately adjacent to the disposal site. At disposal frequencies that exceed or approach the time it takes for the near-bottom plumes to disperse or settle, the effect on this water quality parameter would be greatly increased. In addition, the nature and significance of the impact depends on the characteristics of the embayment; areas and seasons of low turbidity would be affected more than areas or seasons with naturally higher levels of turbidity. The disposal of large quantities of dredged material also has the potential to alter the sediment budget, which in turn can affect levels of suspended sediment within each embayment. Analysis of turbidity data collected by Johnson Offshore Services demonstrated that substantial changes in turbidity (as measured over a 17-day period with nephelometers at a depth of 4.6 m) in the vicinity of the Alcatraz disposal site were related to tidal action. The source of turbidity, however, was speculated to be either tidally transported from other locations, or a result of resuspension of material in and around the region of Alcatraz. The latter explanation was determined to be the more likely (O'Connor 1991).

3.5.5 Un-ionized Ammonia

Ammonia is produced as a result of the microbial breakdown of nitrogenous organic matter that is derived from natural sources (e.g., plant and animal matter) or from anthropogenic sources (e.g., sewage). The toxicity of aqueous ammonia to aquatic organisms is primarily attributable to the un-ionized form. Because the speciation of ammonia varies as a function of pH, temperature, and salinity, these parameters must be considered when attempting to determine the bioavailable fraction of ammonia in a sample. Generally, concentrations of un-ionized ammonia are low in Estuary waters, with the highest levels typically found near the mouths of rivers and creeks during periods of high flow. Concentrations in the extreme South Bay and the mouth of the Napa River ranged from 0.18 to 0.30 mg/1 during a period of high riverine flow in 1993, compared to levels ranging from 0.10 to 0.16 mg/l at most of the other monitoring stations (SFEI 1994). During periods of moderate and low riverine flow, ammonia levels were much lower, ranging from 0.001 to 0.01 mg/1 throughout the Bay. The magnitude and extent of changes in ammonia levels as a result of dredged material disposal has not been extensively monitored in San Francisco Bay. Short-term changes in this water quality parameter are expected to occur, particularly in conjunction with the near-bottom turbidity plume described above under Total Suspended Solids and Turbidity. However, oxidative removal of ammonia from the water column generally occurs quite rapidly in well-oxygenated waters such as those of the Estuary (and particularly in the Central, San Pablo, and Suisun bays).

3.5.6 Hydrogen Sulfide

Hydrogen sulfide was not discussed extensively in the EIR/EIS; however, concern regarding this compound has been expressed by NOAA Fisheries. According to Dillon and Moore (1990), hydrogen sulfide is often associated with low dissolved oxygen concentrations and may occur in ionized and un-ionized forms. It is a metabolic poison that is lethal to most fish at less than 1 mg/l. Determining the effects of this compound is difficult because of its association with hypoxic conditions that are also lethal to fish. Dillon and Moore reported sediment sulfide concentrations in Bay area sediments ranging from 0 to 730 mg/kg wet weight; however, interstitial concentrations of hydrogen sulfide were below detection (less than 0.05 mg/l). They attributed this result to the rapid formation of insoluble complexes with iron in the presence of dissolved oxygen. They indicated that elevated levels of hydrogen sulfide are often associated with low levels of dissolved oxygen. Consequently, aside from highly ephemeral increases during dredging operations, risks to fish from hydrogen sulfide may be of greatest concern when dredging operations result in depressed dissolved oxygen concentrations near the bottom.

3.5.7 Pollutants

Pollutant loading to San Francisco Bay has long been recognized as one of the many factors that have historically stressed the environmental resources of the aquatic system. Pollutants enter the aquatic system through atmospheric deposition, runoff from agricultural and urbanized land, and the direct discharge of waste to sewers and from industrial activity. The Bay's sediment can be both a source of and a sink for pollutants in the overlying water column. The overall influx of pollutants from the surrounding land and waste discharges can cause increases in sediment pollutant levels. Natural resuspension processes, biological processes, other mechanical disturbances, dredging, and sediment disposal can remobilize particulate-bound pollutants. The potential impacts of dredged material disposal on water column levels of pollutants is described in more detail below.

3.5.7.1 Concentrations of Metals in the Water Column

Ten trace metals are monitored in the aquatic system and in waste discharged to the Bay on a regular basis. Total and dissolved fractions are sampled three times a year at Regional Monitoring Program (RMP) stations throughout the Estuary and typical trace metal concentration ranges taken from 1993 RMP data are reported in SFEI (1994). Dredging and disposal of dredged material has the potential to remobilize metals associated with sediment particles into the water column. The primary factors controlling the degree of mobilization are the oxidation-reduction potential of the sediment, the pH of the sediment pore water and overlying water, and the salinity of water on site. Higher oxygen levels in site water than in the sediment would promote some initial oxidation of substances in dredged material, which would, in turn, influence the adsorption and desorption of chemical contaminants to/from complexes (e.g., with sulfides). The typically higher pH of Central Bay waters compared to dredged material would also promote desorption of contaminants. Conversely, higher on-site salinity, which is a less important factor than pH or redox potential, would serve to increase adsorption of contaminants onto sediments (U.S. Navy 1990). Studies conducted in the early 1970s found dissolved concentrations of lead, cadmium, and copper in disposal plumes were 9, 6, and 4 times greater, respectively, than concentrations observed in surrounding Central Bay waters. However, these elevated concentrations lasted less than 1.5 hours (USACE 1976d). Other studies during the same period indicate that cadmium, copper, lead, and zinc can be released into oxygen-rich conditions, increasing water column concentrations by as much as two times (USACE 1977). The overall impacts of short-term increases of pollutant levels in the water column depend on background concentrations present in the water column, whether water quality objectives are exceeded, and the extent of the mixing zone within which concentrations are elevated above ambient levels. The highest risk of environmental impact from this phenomenon occurs when dredging or disposal could cause increases in water column concentrations above EPA criteria or state water quality objectives. This is particularly true in cases where water quality within an embayment is already impaired. Within the Estuary, ambient concentrations of some metals are already at or above criteria or objectives. Of particular concern is chromium in Suisun Bay, Carquinez Strait, and San Pablo Bay; copper, mercury and nickel in South, San Pablo, and Suisun bays, and Carquinez Strait; and lead in San Pablo Bay and Carquinez Strait. At certain times of the year, depending on riverine flows, ambient concentrations of these metals in these embayments have exceeded EPA criteria (SFEI 1994). As mentioned above, sediments are often the sink for water column pollutants (especially in estuarine conditions), and dredged material disposal can be a further source of water column pollutants.

3.5.7.2 Concentrations of Organic Pollutants in the Water Column

Three general types of trace organic contaminants are measured in San Francisco Bay water on a regular basis: polynuclear aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), and pesticides. Water column concentrations of PAHs were below EPA criteria (31 ppt) at all monitoring stations throughout the Estuary in 1993 (SFEI 1994). Total levels of PAHs measured in Bay water ranged from 4 to 28 parts per trillion (pptr) with the highest concentrations seen at the Dumbarton Bridge and the lowest in the San Joaquin River. The pattern of dissolved PAHs was different, ranging from 1 to 7 pptr, with the highest concentrations measured at Yerba Buena (SFEI 1994).

PCB concentrations measured throughout the Estuary in 1993 were above water quality criteria (45 parts per quadrillion [ppq]) with total concentrations of PCBs monitored in water ranging from 239 to 847 ppq (SFEI 1994). Within the Estuary, the highest total concentrations were found at the Dumbarton Bridge, Yerba Buena Island, and the Napa River. Dissolved concentrations ranged from 26 to 492 ppq with the highest concentrations observed at the same locations.

Measured water concentrations of pesticides were highest in the rivers and the extreme South Bay; lowest levels were observed in the Central and San Pablo bays. Total levels ranged from 1,629 to 9,011 ppq and dissolved levels ranged from 1,477 to 7,512 ppq during a period of high riverine flow in March 1993 (SFEI 1994). Concentrations of chlordane and dieldrin were above water quality criteria (590 ppq and 140 ppq, respectively) in most samples taken throughout the Estuary; dichlorodiphenyltrichloroethane (DDT) levels exceeded the water quality criteria (590 to 840 ppq) in Suisun Bay and the Sacramento River. Disposal plume studies performed by the USACE have shown that levels of chlorinated hydrocarbons increase immediately after disposal, then return to background levels within 30 minutes (USACE 1976d). As with metals, the potential impact of short-term increases in organic pollutant concentrations in the water column depends on background concentrations.

3.6 Sediment Quality

Sediment quality in the Estuary varies greatly according to the physical characteristics of the sediment, proximity to historical waste discharges, the physical/chemical condition of the sediment, and sediment dynamics that vary with location and season. Sediments in the Bay generally contain elevated levels of pollutants compared to coastal reference sites. Generally, the level of sediment contamination at a given location will vary depending on the rate of sediment deposition, which varies with seasons and tides (Luoma et al. 1990). Chemical contaminant dynamics in an estuary are closely associated with the dynamics of suspended and deposited sediments. Overall, a sediment's physical characteristics, chemical characteristics, and the bioavailability and toxicity of sediment-associated chemicals to aquatic organisms are particularly important in determining their potential impact on environmental quality. While pollutant loading to the Estuary from point and non-point sources has declined dramatically over the past two decades, and surface sediment contamination may be declining from historical highs, Bay sediments are still an important source and sink of pollutants. Much of the data documenting concentrations of trace metals and organics in Bay sediments are found in the historical summary of Long and Markel (1992) and in the more recent monitoring efforts by the state's Bay Protection and Toxic Cleanup Program (BPTCP; SFBRWQCB 1994) and Regional Monitoring Program (SFEI 1994 and 1995). Sediment data from these studies are summarized below for 10 of the most commonly measured metals and three classes of organic compounds. These data represent both sediments from polluted/industrialized areas as well as those removed from contaminant sources. Values derived from a subset of data obtained from areas removed from known sources of contamination have been termed "ambient" concentrations (in contradistinction to "background" levels, which are considered to reflect pre-industrial concentrations; Gandesbery and Hetzel 1998).

3.6.1 Concentrations of Metals in San Francisco Bay Sediments

The mean concentrations of metals in sediments vary according to grain size, organic carbon content, and seasonal changes associated with riverine flow, flushing, sediment dynamics, and anthropogenic inputs. Anthropogenic inputs appear to have the greatest effect on sediment levels of copper, silver, cadmium, and zinc, but may also have elevated concentrations of chromium, nickel, and cobalt above background (SFBRWQCB 1994).

3.6.1.1 Cadmium

Sediment cadmium levels measured in state monitoring programs ranged from 0.04 to 0.4 parts per million (ppm) with the highest concentration observed at Pinole Point in 1994. In contrast, Long and Markel (1992) report average concentrations of 0.7 ppm in San Pablo and Central bays and 1.44 ppm in the South Bay. Cadmium in samples from the northern reaches of the Estuary was generally higher than that in sediments elsewhere in the Bay. Concentrations of cadmium in sediments taken from harbors and other enclosed areas around the Bay margins exhibit higher concentrations than those found in the main embayments. Reported concentrations at peripheral sites range from 0.65 to 2.47 ppm (Long and Markel 1992). These concentrations are higher than the median ambient concentration of cadmium reported for each of the embayments (0.2 ppm).

3.6.1.2 Chromium

Chromium levels in South, Central and San Pablo bays generally range from 50 to 102 ppm (SFBRWQCB 1994) but have been observed as high as 280 ppm at locations in San Pablo Bay (Long et al. 1988). Concentrations of chromium in known impacted areas along the periphery of the Bay can be much higher; levels in Islais Creek were found to average 140 ppm (Long and Marke11992) and sediments from the Oakland Inner Harbor ranged from 289 to 368 ppm (USACE and Port of Oakland 1994). In contrast, median ambient concentrations range from 76 to 93 ppm.

3.6.1.3 Cobalt

Cobalt concentrations in Bay sediments ranged from 11.1 to 19.7 ppm with the highest levels observed at the mouths of the Petaluma and Napa rivers and Suisun Bay (16.5 to 19.7 ppm). The lowest concentrations were found in Central and South bays and the San Joaquin River mouth (11.1 to 16.4 ppm; SFBRWQCB 1994). Median ambient concentrations for cobalt are not available for comparison.

3.6.1.4 Copper

Copper concentrations in Bay sediments are generally much lower in the central area of each embayment compared to levels found in samples taken from harbors and enclosed areas along the periphery. Long and Markel (1992) report average concentrations in South and Central bays of 33 ppm, slightly lower than values reported in the state's monitoring studies that show these sites ranging from 28 to 54 ppm. Levels in San Pablo Bay sediment appear to be roughly the same as those from the South and Central areas (20 to 50 ppm), while concentrations in Suisun Bay are the highest for any main embayment (40 to 70 ppm). Concentrations in periphery samples taken at Oakland Harbor, Islais Creek harbor, and Redwood Creek range from 87 to 102 ppm (Long and Markel 1992). Sediment copper concentrations in the central areas of the South, Central, and San Pablo embayments are similar to the median range of ambient copper concentrations (33 to 46 ppm).

3.6.1.5 Lead

Sediment concentrations of lead range widely from 6 to 110 ppm in San Francisco Bay and from 8 to 27 ppm at the mouths of the Sacramento and San Joaquin rivers. Long and Markel (1992) report average concentrations in the main embayments of 30 to 34 ppm, with much higher levels in sediments that are in the vicinity of historical industrial activity (39 to 102 ppm). State monitoring program data suggest that concentrations at the mouths of sma1l rivers are also generally higher than in the main embayments; in 1991 and 1992, Napa and Petaluma River station samples ranged from 37 to 65 ppm (SFBRWQCB 1994). Concentrations from harbors and other stations along the periphery of the Bay indicate a much higher degree of contamination, ranging from 87 to 102 ppm (Long and Markel 1992). These lead concentrations are higher than the median for ambient conditions (approximately 22 ppm).

3.6.1.6 Mercury

Mercury concentrations in sediment measured in the state's monitoring programs ranged from 0.15 to 0.540 ppm. The lowest levels were observed in Central Bay near the Golden Gate. The highest levels were found at Pinole Point during high flow, and in the extreme South Bay. The lower end of this concentration range is similar to the median range observed at ambient stations (0.2 to 0.3 ppm).

3.6.1.7 Nickel

Nickel levels in Bay sediment ranged from 46 to 110 ppm. The highest concentrations were measured in the Suisun Bay in 1994, when concentrations ranged from 90 to 124 ppm (SFEI 1994). However, even these nickel concentrations are not dramatically elevated over median ambient concentrations, which range from 73 to 76 ppm.

3.6.1.8 Selenium

Selenium levels in surficial sediments throughout the Bay vary according to season. During a period of high riverine flows, concentrations ranged from 0.07 to 0.43 ppm, and 0.17 to 3.30 ppm during low flow in 1993 (SFEI 1994). Levels in the South Bay range from 0.23 to 1.3 ppm; in Central Bay, 0.14 to 0.86 ppm; in San Pablo Bay, 0.14 to 1.51 ppm; and in Suisun Bay, 0.16 to 3.30 ppm. Median ambient concentrations are generally lower, approximately 0.3 ppm.

3.6.1.9 Silver

In state monitoring, silver concentrations in estuarine sediments are generally lowest at the confluence of the Sacramento and San Joaquin rivers (0.05 to 0.3 ppm). Long and Markel (1992) report average concentrations in San Pablo Bay sediment as 0.45 ppm, Central Bay as 0.72 ppm, and South Bay as 0.57 ppm. Peripheral areas such as Islais Creek harbor and Cordornices Creek had levels that were significantly higher (4.7 ppm and 1.8 ppm, respectively). These peripheral concentrations are significantly elevated in comparison to median ambient levels which range from 0.2 to 0.4 ppm.

3.6.1.10 Zinc

Sediment concentrations of zinc measured in state monitoring programs ranged from 50 to 151 ppm and were generally lowest in Central Bay (50 to 120 ppm - excluding a boat yard in Richardson Bay). Zinc levels in river sediments ranged from 72 to 110 ppm during low riverine flows. These levels are similar to median ambient concentrations, which range from 88 to 120 ppm. The highest zinc levels were observed in 1991-1992 at peripheral areas of the Bay such as Cordornices Creek (320 ppm) and Emeryville Marsh (278 ppm).

3.6.2 Concentrations of Organic Pollutants in San Francisco Bay Sediments

Numerous organic contaminants have been measured in Bay sediments. These include three major classes of compounds: PAHs, PCBs, and pesticides.

3.6.2.1 PAH

Great differences are observed in sediment concentrations between basins and peripheral areas, with the latter often having PAH concentrations 3 to 10 times greater than the former. For example, Long and Markel (1992) reported mean basin concentrations in the Bay to range from 2,600 to 3,900 parts per billion (ppb), whereas mean concentrations at peripheral stations such as Oakland Inner Harbor and Islais Creek Harbor were 7,200 and 62,700 ppb, respectively. Likewise, state monitoring programs have identified several areas with elevated PAH concentrations in sediments, such as Castro Cove and Cordornices Creek, where mean PAH concentrations were as high as 28,000 ppb and 9,900 ppb, respectively (SFBRWQCB 1994). PAH levels measured in basin samples of the state monitoring programs ranged widely from 160 to 7,600 ppb in the South Bay, 170 to 6,200 ppb in the Central Bay, and 380 to 7,500 ppb in San Pablo Bay. PAH levels were generally lowest in the North Bay with a range of 180 to 4,300 ppb. In contrast, median concentrations of PAHs in ambient sediments

(550 to 2,400 ppb) are lower than those observed near industrial activity, although maximum ambient concentrations as high as 6,800 ppb are occasionally observed.

3.6.2.2 PCBs

Like PAHs, sediment levels of PCBs vary widely throughout the Bay. Long and Markel (1992) reported concentration ranges of 27 to 71 ppb in basin locations. Likewise, PCB concentrations from basin testing performed in 1991 and 1992 for the BPTCP (SFBRWQCB 1994) ranged from 3 to 38 ppb (with the exception of a single sample from Davis Point in which levels 117 ppb were observed). PCB levels measured in sediment samples from harbor and peripheral locations can be up to an order of magnitude higher than those in basins. For example, sediment samples taken from the creek mouths and marshes along the Emeryville to Richmond shoreline in 1991 and 1992 had elevated PCBs ranging from 100 to 300 ppb (SFBRWQCB 1994). Levels of PCBs in ambient samples are generally much lower (median concentrations range from 9 to 11 ppb) than those observed in either peripheral or basin samples, although maximum values as high as 117 ppb have been observed in North Bay locations.

3.6.2.3 Pesticides

State monitoring programs typically test for a variety of chlorinated pesticides and pesticide derivatives. However, only a handful of these compounds are detected on a regular basis. Those that were most frequently detected from 1991 to 1994 include six isomers of DDT and its breakdown products dichlorodiphenyldichloroethane (DDD) and dichlorodiphenyltrichloroethylene (DDE), dieldrin, and chlordanes. Generally, pesticide concentrations in sediment were directly related to sediment type and are significantly correlated to the percent fines and total organic carbon content of a sample. Typically, total DDT concentrations at basin monitoring stations in the Bay range from 0.05 to 33 ppb. In contrast, DDT levels as high as 633,000 ppb have been observed in the Lauritzen Canal, an EPA Superfund Site located in Richmond Harbor (Lincoff et al. 1994). Total DDT measured in Richmond Harbor channel sediments outside the Lauritien channel is generally less than 500 ppb and much of the Harbor is less than 300 ppb. Elevated levels of total DDT have also been measured in sediments from other peripheral areas of the Bay, such as Codornices Creek Mouth (70 ppb) and Oakland Inner Harbor (120 ppb; SFBRWQCB 1994; Long and Markel 1992). In contrast, concentrations of total DDT in ambient sediments are generally less than 5 ppb. Sediment concentrations of dieldrin and chlordane measured in monitoring programs are generally low for both basin and peripheral sediments, with dieldrin ranging from 0.2 to 0.9 ppb and chlordanes ranging from 0.2 to 6 ppb.

3.7 Aquatic Habitats of the San Francisco Estuary

This section describes the aquatic habitats within the Estuary, including nearshore and offshore habitats. Habitats are categorized by their physical/chemical properties which are important to the formation and maintenance of biotic populations. The biotic communities themselves are described in Section 3.8.

3.7.1 Nearshore Habitats

Nearshore habitats of the Bay and tributaries include intertidal mudflats, rocky shores, salt marsh, brackish marsh, freshwater marsh wetlands and floodplains.

3.7.1.1 Intertidal Mudflats

Centuries of siltation have created approximately 64,000 acres of mudflat habitat between the open water and the vegetated or rocky shoreline of San Francisco Bay. Mudflats vary in composition from clay/silt to sand and include organic debris and shell fragments. Generally, these areas are exposed twice daily during two low tides. Where tidal marshes adjoin mudflats, receding tides bring organic materials from the marshes to the mudflats, providing a food source for millions of detritus-feeding invertebrates. The mudflats are a living system of diatoms, micro-algae, protozoans and a multitude of arthropod, annelid and molluscan invertebrates. Emergent plants are uncommon in these habitat types, however, micro- and macro-algae form the basis for the food web in this habitat. Micro-algae growing both in the shallow water column and on the sediment surface are transported across the intertidal or shallow subtidal mudflats by wind- and tide-induced currents making them available to suspension or surface deposit feeding invertebrates. The benthic invertebrates are, in turn, eaten by such large consumers as shorebirds, demersal fishes, elasmobranchs, and juvenile Dungeness crabs in the northern reaches of the Bay.

The distribution of fishes associated with these habitats varies in accordance with freshwater outflow and salinity. Both intertidal mudflat and rocky shore habitats serve as important forage habitats for a number of sportfish and special status species. These areas provide important nursery habitats for native forage fish such as Pacific herring and northern anchovy (SFEP 1991b). Important sportfish that forage and/or rear young in these areas include native species such as chinook salmon, white sturgeon, diamond turbot, and a variety of sharks in addition to the introduced striped bass. Special status species that utilize intertidal mudflat and rocky shore habitats include winter-run chinook salmon, Delta smelt, longfin smelt, and Sacramento splittail. Since pre-settlement conditions, mudflat habitat has declined throughout the Estuary, with losses since 1958 in the South Bay alone estimated at approximately 500 acres (SFEP 1991b). Within the Planning Area, general factors affecting mudflat habitats include the following: invading plants (smooth cordgrass and Chilean cordgrass), sea level rise, disturbance by boaters and fishermen, and point and non-point sources of pollution (SFEP 1992c).

3.7.1.2 Rocky Shore Habitat

The rocky shore habitat in the Estuary occurs around the margins of Central and San Pablo bays and is primarily found around Yerba Buena, Angel, and Alcatraz islands, and the shoreline of the Tiburon peninsula. Vegetation along rocky shores is predominantly algae. Fish may forage in this habitat and herring may spawn on rocks in certain locations.

3.7.1.3 Tidal Marshes

Tidal marshes are extremely productive and diverse ecological communities that provide important habitat and resources both to organisms that live solely within the marsh and to species more commonly found in upland and aquatic areas. Tidal marshes occur at scattered locations along the margins of the South Bay, along the waterways of the Delta, at the margins of San Pablo Bay, and within Suisun Marsh. These marshes can be segregated into salt, brackish, and freshwater types based on water and soil salinity. These marsh types can be further subdivided into 12 eco-geomorphic classes (LTMS 1994g).

Tidal marshes provide critical cover, forage, and nursery areas for adults and juveniles of a number of sportfish and special status fishes (SFEP 1991b). The distribution of fish communities in tidal marsh habitats is influenced by salinity, the frequency and duration of tidal inundation, and the type and density of emergent vegetation. Common fishes include native species such as arrow goby, topsmelt, Pacific staghorn sculpin, and tule perch and introduced species such as yellowfin goby, catfish, and mosquito fish. Commercially important species that rear and forage in these habitats include native chinook salmon and the introduced striped bass. Special status species that utilize tidal marshes include winter-run chinook salmon, Delta smelt, longfin smelt, Sacramento splittail, green sturgeon, and tidewater goby.

3.7.1.3.1 Tidal Salt Marshes

Tidal salt marshes are found along much of the Bay shoreline except in urbanized areas and on rocky shorelines such as the Tiburon Peninsula.

3.7.1.3.2 Tidal Brackish Marshes

Within the Planning Area, extensive stands of brackish marsh occur along the Napa and Petaluma rivers, and smaller marshes occur at scattered locations within Suisun Marsh (SFEP 1991b).

3.7.1.3.3 Tidal Freshwater Marshes

Within the Bay Area, tidal freshwater marsh habitat is limited to streams, creeks, and rivers entering the Bay, as well as being present in the Delta.

3.7.1.4 Floodplains

Several studies have shown that floodplains serve a critical function in the life history of certain Bay/Delta species, particularly Sacramento splittail (Caywood 1974, Sommer et al. 1997, Sommer 2000, CDWR and USBR 1994). Floodplains may be associated with rivers draining into San Pablo Bay as well as the eastern portion of the LTMS planning area and beyond into the Delta.

3.7.1.5 Salt Ponds

Salt pond habitat did not exist under pre-settlement conditions within the Planning Area and was created by diking and draining tidal marshes and mudflat habitats (LTMS 1994g). Salt ponds are isolated and are little used by native Bay fish species.

3.7.2 Offshore Habitats

The offshore habitats of the Bay fall into two categories: water column and benthic.

3.7.2.1 Water Column Habitat

The term "habitat" is applied to the water column in this report for consistency. Two major biotic elements occur in this habitat in the Bay: planktonic and nektonic species. Water column habitats may also be utilized, under certain conditions, by species typically classified as demersal or even benthic, particularly in large estuarine systems such as the Bay. The distribution of nektonic fish has been correlated to bathytypic habitats (Baxter et al. 1999; see discussion in the following section).

3.7.2.2 Benthic Habitats

Benthic habitats have not been well characterized in much of San Francisco Bay, especially offshore, because low visibility and strong currents make direct observation difficult. Furthermore, the dynamic nature of the system undoubtedly results in changes to benthic habitats over time. However, the National Oceanic and Atmospheric Administration (NOAA) has recently conducted highly detailed bottom surveys of the Bay which will soon be available (Mulvey 2003). Benthic habitats of the Bay have been characterized generally by depth (bathytypic habitats) and substrate (geotypic habitats). In addition, one biotypic habitat (formed by marine plants) has been recognized in the Bay. Certain demersal and epibenthic species may or may not have fidelity to depth and/or substrate "habitats." Pelagic/nektonic species may utilize certain benthic habitats. An important example of this is the spawning of Pacific herring on certain shallow geotypic habitats and other substrata.

3.7.2.2.1 Bathytypic Habitats

Benthic habitats in the Bay often have been divided somewhat arbitrarily into two bathytypic habitats. Deeper areas of the Bay, e.g., over 7 meters depth, are referred to as the "channel" or "spine of the Bay." In a two-dimensional projection, the channel habitat occupies more than half of the Central Bay, while occupying much narrower areas in the South, San Pablo, and Suisun Bays. Overall, in a two-dimensional projection, the channel habitat occupies less than one half of the water surface of the Bay in the LTMS planning area (Baxter et al. 1999, Figure 1). Those areas less than 7 meters deep are referred to as the shallows or shoals. Some fish distribution trends may be related to these bathytypic habitats (Baxter et al. 1999).

3.7.2.2.2 Geotypic Habitats

Geotypic habitats are those that are characterized by the nature of the substrate, which is typically native rock, shell, and sediments. Although not strictly geogenic, artificial substrate, such as seawalls, riprap, piers, and pilings may be included in this category. Generally, rock, shell and coarse sediments are typically found in the areas of the Bay where currents are rapid, such as in the channel areas (USACE et al. 1998, Figure 3.2-2) and certain shorelines that experience relatively high currents. Such habitats may also occur along shorelines where sediment deposition is reduced. Fine sediments occur throughout the system in the water column and deposit preferentially in the low current areas, particularly on the shoals. In many of these areas, there may be an ill-defined transition from water column to benthos where extremely fine particles form a colloidal layer near the bottom. Most of the fine sediment areas should be considered a dynamic rather than a static habitat.

3.7.2.2.3 Biotypic Habitats

Biotypic habitats are established when one or more species populations creates a physical/structural environment different from that in the absence of the population, resulting in the establishment of a defined community. Biotypic habitats are often referred to as biotopes (Kennish 1990). Coral reefs are perhaps the most widely known example of a biotypic habitat. Only one biotypic habitat has been identified in the Bay: eelgrass beds. Eelgrass beds are of limited extent and are largely confined to the Central Bay region where salinity is highest (USACE et al. 1998). Certain species may only occur in eelgrass beds while only certain life stages of other species may depend on eelgrass habitat.

3.8 Biological Communities of the San Francisco Bay Estuary

The Estuary supports a complex array of biological communities. The biological communities of the Estuary that are associated with the main bodies of water can be grouped into four major categories: phytoplankton, zooplankton, benthos, and fish. A similar but slightly different set of communities is associated with five distinct habitat types within the transition zones between the purely aquatic environment and upland areas: intertidal mudflats, rocky shore; salt marsh (including salt ponds), brackish marsh, freshwater marsh, and floodplains.

3.8.1 Phytoplankton and Zooplankton

Phytoplankton production is the major source of organic matter in the Bay/Delta, accounting for about 50 percent of the total (SFEP 1992b). In wet years, river transport of detrital material is another important source of organic matter, at least for the Delta and Suisun Bay. Phytoplankton dynamics are influenced by currents, light availability, and aquatic organisms living in the system. Light and nutrients (from the rivers, waste treatment plants, and decomposition) are sufficient to support much larger blooms of phytoplankton than are typically observed. Results from several studies suggest that much of the phytoplankton produced in the water column settles to the bottom, where it is consumed by a variety of organisms from bacteria to large clams and worms. Benthic diatoms growing on the sediment surface throughout the Bay, together with temporarily or permanently settled phytoplankton, may represent the most readily available food resource for bottom organisms. Recent declines in observed phytoplankton and suspended material concentrations in Suisun Bay and other parts of the northern reach have been attributed, at least in part, to high benthic grazing by a recently introduced species of clam, *Potamocorbula amurensis*. The organic matter produced in or transported to the Bay is ingested directly by planktonic invertebrates (zooplankton) who digest and metabolize it to carbon dioxide, water, and dissolved nutrients. There are estimated to be over 200 species of zooplankton in the Estuary, most of which have not been well-studied. Important species include the opossum shrimp (*Neomysis mercedis*) that ranges from Suisun Bay down into San Pablo Bay during periods of high riverine flow, and the copepod *Eurytemora* that also resides in the northern reaches. Recently introduced species of copepod, *Sinocalanus doerri* and *Pseudodiaptomous forbesi*, have also been found in increasing numbers. Zooplankton are consumed by larval and juvenile stages of most fish species; by adult stages of fish species such as anchovy, smelt, and shad; and by macro-invertebrates such as bay shrimp.

3.8.2 Macroalgae and eelgrass

Macroalgae are most commonly found growing in hard bottom areas (rock outcrops, coarse sediments, and human-made structures) in the central and northern regions of the Estuary. Eelgrass is also found in the Bay, but is largely limited to the Central Bay region where salinity is highest. The marshes of the Bay/Delta, because of their greatly reduced size following more than 130 years of reclamation, are probably only a minor source of organic matter to the Bay system. The amount of organic matter washed into the Bay from the marshes may be only about 5 percent of the amount produced by phytoplankton in the Bay. Nevertheless, within marshes and other shallow areas, dense zones of macroalgae such as eelgrass beds provide an important source of organic matter, substrate, and a nutrient-rich habitat for smaller organisms. Disposal of dredged material has the potential to physically alter/cover the substrate upon which macroalgae grow (coarse sediments and rocky shorelines) and to affect eelgrass beds.

3.8.3 Benthos

Benthic organisms dwell on the Estuary's mudflats, on the bottom of tidal marshes and openwater areas, and on hard surfaces below the intertidal zone. Benthic organisms have adopted a variety of life strategies. Some, such as worms, burrow into the bottom sediment; some, such as crabs and oysters, live on the sediment surface (epibenthic);

others such as mussels live on rock pilings or other hard objects. Most benthic species are either filter-feeders or grazers, although some are active predators. Benthic invertebrates are an important component of the food chain as they are an important food source for demersal fishes, crabs, and shorebirds. Most benthic organisms in the Estuary are introduced species, arriving attached to imported commercial species, attached to ship bottoms, or in ballast water. New species entering the system have led to complete changes in community structure, particularly in San Pablo and Suisun bays. The most striking example of such an introduction has been the Asian clam, *Potamocorbula amurensis*, which was first discovered in the Estuary in 1986. Since that time it has spread rapidly and now dominates most of the benthic communities in San Pablo and Suisun bays (SFEP 1992a). The ecological (and economic) impacts of these introduced species have been extensive, from reducing the availability of food to higher trophic levels to damaging various water-related structures. Factors affecting the abundance, composition, and health of the benthic community include outflow from the Delta, substrate, salinity, and pollution. In general, diversity is lowest in the Delta where, of the more than 82 benthic species recorded, only five species account for 90 percent of the individuals at most sites (SFEP 1992a). In the more saline waters of San Pablo Bay, the number of benthic species increases to more than one dozen. In the South Bay, where there are several substrate types, diversity is even greater. Mollusks comprise the greatest biomass of larger benthic species in the Bay (Thompson and Nichols 1981), with the most abundant species including *Mytilus galloprovinciallis*, *Macoma balthica*, *Mya arenaria*, *Tapes japonica*, and the recently introduced Asiatic clam, *Potamocorbula amusrensis*. Other important components of the benthos include numerous polychaete and amphipod species as well as crabs and shrimp.

3.8.4 Fish and Shellfish

This section includes a general discussion of fish and shellfish in the Bay. Detailed discussions of the windows fish species are presented in the following section.

The fish and shellfish of the Estuary can be placed into four categories: true estuarine species, freshwater species, marine species, and anadromous species. Many of these fish and shellfish are commercially and/or recreationally important. In addition, some of them are threatened or endangered, or otherwise special status species. This section briefly describes the life history, status, and distribution of these four categories of fishes and invertebrates, with particular attention paid to those that are special status and/or are commercially/ recreationally important. Fisheries of the Estuary include anadromous and resident species, crab and shrimp. All areas of the Bay/Delta support commercially and/or recreationally important fisheries. Climatic changes in oceanic and continental conditions, and physical features such as salinity, temperature, and bathymetry affect the distribution, abundance, and composition of fishes in the Estuary. In addition, human activities such as introduction of non-native species, pollution, changes to the freshwater inflow and outflow regime, and modification of waterways and wetlands from dredging and disposal have also controlled the distribution and abundance of fish species in the Estuary (SFEP 1992a; USFWS 1994). Most fish described in this section are species introduced to California. Introductions of nonnatives into the Estuary are primarily a result of attempts by resource agencies to enhance the fishery by providing game fishes or new forage for game fishes, and ballast water release from overseas cargo ships (USFWS 1994; SFEP 1992a; Leidy 1984). The introduction of non-native species to the Estuary has created a shift in the food web. This could ultimately drive some native species to extinction or inhibit their recovery (SFEP 1992a). The potential impacts from dredging and disposal on fish in the Estuary vary according to the location of the activity, time of year when the activity occurs, and the location of each fish species during their respective life cycle. Impacts on fishes include, but are not limited to, interference with migration, degradation of water quality, habitat loss or degradation, and interference with foraging habitat and food resources. The greatest potential for impacts occurs in affected habitats within each embayment that support sensitive lifestages of important species. Negligible impacts are expected where habitats are not significantly altered. In general, disruption of the benthic and near-bottom waters at and immediately adjacent to disposal sites, and disruption of sensitive habitats (e.g, eelgrass) and key migratory corridors are of greatest concern.

3.8.4.1 True Estuarine Species

The Delta smelt (*Hypomseus transpacificus*) is the only true estuarine species of fish in San Francisco Bay. Longfin smelt (*Spirinchus thaleichthys*) has been identified, albeit rarely, outside the Golden Gate; all other species maintain part of their populations outside the Estuary. Sacramento splittail (*Pogonichthys macrolepidotus*) had a historical distribution that included the Central Valley. However, due to habitat alterations in the Central Valley drainages, this species is now primarily found in the Delta and is now considered an estuarine species.

3.8.4.2 Freshwater Species

Freshwater fishes consist of native and introduced species. Native freshwater species found in the Estuary include the Sacramento splittail, Sacramento squawfish (*Ptychocheilus grandis*), hitch (*Lavinia exilcauda*), Sacramento blackfish (*Orthodon microlepidotus*), hardhead (*Mylopharodon conocephalus*), Sacramento sucker (*Catostomus occidentalis*), prickly sculpin (*Cottus asper*), and the live-bearing tule perch (*Hysterocarpus traski*). The Sacramento perch (*Archoplites interruptus*) is now believed extirpated from the Delta (USFWS 1994; SFEP 1992a). Introduced species include centrarchids such as sunfish (*Lepomis* sp.), crappie (*Pomoxis* sp.), and bass (*Micropterus* sp.), as well as catfish (*Ameirus*). These species are most abundant in channels dominated by San Joaquin River waters (SFEP 1992a).

3.8.4.3 Marine Species

Marine species can be separated into two categories: those species that maintain part of their population in the Estuary and can be referred to as seasonal species, and those species that reside in the Estuary year-round. Northern anchovy (*Engraulis mordax*) and the Pacific herring (*Clupea harengeus*) are the most abundant of the seasonal species. Northern anchovy enter the Estuary as adults and, while there is evidence of all life stages using the Bay, none reside all year. The Pacific herring enters as adults to spawn, but is only present in large numbers for a few months. Other seasonal species include the Starry flounder (*Platichthys stellatus*), English sole (*Parophrys vetulis*), and white croaker (*Genyonemus lineatus*), which enter the Bay through bottom currents and tidal forces (SFEP 1992a). Most of the resident species are benthic fishes. These species include shiner perch (*Cymatogaster aggregata*), bay goby (*Lepidogobius lepidus*), and the staghorn sculpin (*Leptocottus armatus*). They are known to show strong parental care and have a high tolerance of environmental change. Other resident marine species include introduced species such as the yellowfin goby (*Acanthogobius flavimanus*) and the chameleon goby (*Tridentiger trigonocephalus*; SFEP 1992a).

3.8.4.4 Anadromous Species

The native anadromous species found in the Estuary include chinook salmon (*Oncorhynchus tshawytscha*), steelhead trout (*Oncorhynchus mykiss mykiss*), green sturgeon (*Acipenser medirostris*), and white sturgeon (*Acipenser transmontanus*). Introduced species include American shad (*Alosa sapidissima*) and striped bass (*Morone saxatilis*). These species have commercial and recreational value in the Estuary. Anadromous species are highly sensitive to environmental change that may affect their migration, spawning habitat, and habitat for nurseries (USFWS 1994; SFEP 1992a). The coho salmon (*Oncorhynchus kisutch*) was historically found in the Estuary, but is now believed to be extirpated (Brown et al. 1994).

4.0 BIOLOGY AND ECOLOGY OF WINDOWS FISH SPECIES

This section provides detailed general information, regulatory status, reproduction, growth and development, behavior, distribution and migration, and other information for the windows fish species.

4.1 Chinook Salmon (*Oncorhynchus tshawytscha*)

4.1.1 General Information and Status

Chinook salmon belong to the family Salmonidae and are one of eight species of Pacific salmonids in the genus *Oncorhynchus*. Chinook salmon are easily the largest of any salmon, with adults often exceeding 40 pounds; individuals over 120 pounds have been reported. Chinook salmon are anadromous (adults migrate from a marine environment into the fresh water streams and rivers of their birth) and semelparous (spawn only once and then die; NOAA 2004a).

Along the U.S. West Coast, there are 17 distinct groups, or ESUs, of chinook salmon, from southern California to the Canadian border and east to the Rocky Mountains. In 1994, Sacramento River winter-run chinook were listed as endangered and this run is also State endangered. The Central Valley spring-run is listed as federal threatened and State species of special concern, the Central Valley fall and late fall run is a candidate/not warranted, and the California coastal population is threatened (NOAA 2004a). USFWS (1996) produced a recovery plan for juvenile habitat for this species.

Armor and Herrgesell (1985) classified chinook salmon of San Francisco Bay as a “mixed response” (to wet and dry years) anadromous species.

4.1.2 Reproduction

The Chinook salmon typically spends 3 to 6 years maturing in the ocean before returning as adults to their natal streams (Moyle 2002, Eschmeyer et al. 1983, Allen and Hassler 1986). Most Sacramento-San Joaquin Chinook salmon returning to spawn have been four years of age (Clark 1929). Chinook spawn upstream in tributaries of the Bay, generally not in proximity to dredging activities. Accordingly, direct effects of dredging on spawning are not anticipated.

4.1.3 Growth and Development

Estuaries, such as San Francisco Bay, appear to play a vital role in Chinook salmon life history. Tidal marsh habitat is especially important to juvenile salmonids. For instance, juvenile Chinook salmon forage in the intertidal and shallow subtidal areas of tidal marsh, tidal flat, channel habitats, and open bay habitats of eelgrass and shallow sand shoal areas (Maragni 2000, BCDC 2002, Allen and Hassler 1986). These productive habitats provide both a rich food supply and protective cover within shallow turbid waters. The distribution of juvenile Chinook salmon changes tidally, with fry moving from tidal channels during flood tides to feed in nearshore marshes (Maragni 2000, BCDC 2002, Allen and Hassler 1986).

Juvenile Chinook salmon migration into estuaries has been reported to occur at night and during daylight (Seiler et al. 1981, Dawley et al. 1986). Juveniles may move quickly through estuaries or reside there for up to 189 days (Dawley et al. 1986, Simenstad et al. 1982). Juvenile Chinook salmon gain significant growth in estuarine habitats as they smolt and prepare for the marine phase of their life (MacDonald et al. 1987).

Juveniles have been found on the floodplain of the Cosumnes River, Sacramento County, although they are mostly associated with flowing water. High growth rates were achieved within this flooded area by feeding on abundant zooplankton and insects. Juveniles left this area as flood waters receded, with minimal stranding. This particular floodplain was used for juvenile rearing (Moyle et al. 2000a, 2000b). Importantly, studies have shown that juvenile fall-run, ocean-type Chinook salmon use wetlands extensively, revealing a strong connection between the health of wetland habitats and the well-being of Chinook salmon (Maragni 2000, BCDC 2002).

Once Chinook salmon reach the juvenile stage and begin their migration to the ocean, certain habitats become critical to their survival. In riverine areas, both submerged cover (such as boulders, woody debris, and aquatic vegetation) and overhead cover (such as continuous riparian vegetation canopies, undercut banks, and turbulent water) provide shade, food, and protection against predation to juvenile Chinook salmon (Maragni 2000, BCDC 2002).

Juvenile fish mature in the ocean off the California coast, with fall and winter-run fish remaining in continental shelf waters and spring-run moving into the high seas (Allen and Hassler 1986).

4.1.4 Behavior

While in estuaries, juveniles feed in intertidal and subtidal habitats of tidal marshes. In these habitats, juveniles prey upon insects, gammarid amphipods, harpacticoid copepods, mysids, chironomids, decapod larvae, and small (larval and juvenile) fish (Levy and Levings 1978, Levy et al. 1979, Northcote et al. 1979, Healey 1980, Levy and Northcote 1981, Healey 1982, Kjelson et al. 1982, Simenstad et al. 1982, Simenstad 1983, McCabe et al. 1986). In low-flow years when juveniles are larger, their food source will include crab megalops, squid, and small fish (e.g., northern anchovy, Pacific herring, rockfish; Beauchamp et al. 1983).

4.1.5 Distribution and Migration

Chinook salmon are found in all estuaries north of San Francisco Bay in California, except Tomales Bay (Monaco et al. 1990). California's largest populations of Chinook salmon originate in the Sacramento-San Joaquin River system. In 1992, an estimated 10 to 50 million smolts migrated through the Delta annually (Herbold et al. 1992). Four distinct kinds of Chinook salmon exist, based on the timing of adult spawning migration: winter, spring, fall, and late fall. In addition, two types of Chinook salmon exist, based on their life histories: stream-type and ocean-type. Ocean-type spend less time in freshwater as juveniles than do stream-type. Chinook salmon of the Sacramento-San Joaquin River system are predominantly ocean-type (Maragni 2000, BCDC 2002). 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. Spring-run Chinook salmon are extinct in the San Joaquin River and only remnant runs remain in a few Sacramento River tributaries (Fry 1973). Historically, spring-run Chinook salmon spawned in small tributaries that have essentially all been blocked to migration by large dams. Fall and late-fall runs continue as they spawn in the main stems of the Sacramento and San Joaquin Rivers. Winter-run Chinook salmon are unique to the Sacramento River and formerly spawned in cold water tributaries above the present Shasta Dam prior to its construction (Sacramento River Winter-Run Chinook Salmon Recovery Team 1996). While distribution of out-migrating juvenile Chinook salmon in San Francisco Bay is not well known, they have been found throughout, including in the South Bay, in high outflow years (Maragni 2000, BCDC 2002).

4.1.6 Other Information

Multiple and complex factors have affected the well-being of Chinook salmon during every stage of their lives. During the early freshwater stages of life, mortality is caused by destruction of spawning grounds, fluctuations in water temperature, low dissolved oxygen, loss of cover, food availability, and competition (Reiser and Bjornn 1979). Besides the above factors, human impacts such as river flow reductions, the construction of dams and the consequent creation of reservoirs, water diversions, logging practices, and pollution have affected population abundance (Raymond 1979, Netboy 1980, Stevens and Miller 1983). In the ocean, adult salmon are affected by oceanographic conditions, food availability, predation, and overfishing (Fraidenburg and Lincoln 1985, Emmett et al. 1991). In freshwater, adults are subject to natural factors such as drought and flood, and to human impacts, such as fishing, dams, road construction, flood protection, dredging, gravel mining, timber harvest, grazing, and pollution (USFWS 1995, Maragni 2000, BCDC 2002).

Species associated with and dependent upon Chinook salmon are numerous. Sacramento squawfish, riffle sculpin, channel catfish, steelhead trout, striped bass, rockfish, egrets, and herons all eat juvenile salmon. Harbor seals, California sea lion, North American river otter, and Pacific lamprey all eat adult Chinook salmon. Juvenile Chinook salmon prey on a variety of invertebrates, including bay shrimp and terrestrial and aquatic insects. Adults prey on squid, Pacific herring, northern anchovy and rockfish, among others. Critical to the survival of Chinook salmon is good water quality, adequate flows, productive spawning and rearing habitat, state-of-the-art positive barrier screens on water diversions, protection from excessive harvest, and free access to upstream migration, or well-designed ladders for adult passage. Restoration efforts in San Francisco Bay also will continue to study and focus on the benefit of tidal marshes to the health and well-being of the salmon fishery (Maragni 2000, BCDC 2002).

4.2 Coho Salmon *(Oncorhynchus kitsutch)*

4.2.1 General Information and Status

Coho salmon belong to the family Salmonidae and are one of eight species of Pacific salmonids in the genus *Oncorhynchus*. Coho salmon are anadromous (adults migrate from a marine environment into the fresh water streams and rivers of their birth) and semelparous (spawn only once and then die). Coho spend approximately the first half of their life cycle rearing in streams and small freshwater tributaries. The remainder of the life cycle is spent foraging in estuarine and marine waters of the Pacific Ocean prior to returning to their stream of origin to spawn and die. Most adults are three-year-old fish, however, some precocious males known as "jacks" return as two-year-old spawners. A returning adult may measure more than two feet in length and weigh an average of eight pounds (NOAA 2004b).

Along the U.S. West Coast, there are six distinct groups, or ESUs, of coho salmon. Three of these ESUs, Central California, Southern Oregon/Northern California Coasts, and Oregon Coasts, were listed as threatened under the ESA in October 1996, May 1997, and August 1998, respectively (NOAA 2004b).

4.2.2 Reproduction

In California, upstream migration of coho salmon coincides with large increases in streamflow, especially in streams in which the flow is low in the summer. Spawning usually peaks from November to January and occurs in riffles (Hassler 1987).

4.2.3 Growth and Development

In some areas of the Pacific northwest, coho salmon fry rear in estuaries. In southeast Alaska, coho salmon fry entered the stream/estuary ecotone in the spring and reared there during summer, growing faster than in freshwater areas upstream (Murphy et al. 1984). Most fish moved out of the estuary to upstream freshwater areas to overwinter. In fall, most fish emigrated seaward with the first seasonal freshets. Coho fry that reared in the estuaries contributed to the populations of spawning fish that returned to the systems (Hassler 1987).

Coho salmon fry undergo a characteristic transformation from parr to smolts before they migrate to the ocean. Distinct morphological, physiological, and behavioral changes accompany this transformation (Hoar 1976, Folmar and Dickhoff 1980). The onset of smoltification and migration is associated with fish age and size, and environmental conditions (primarily increasing day length and water temperatures; Wedemeyer et al. 1980). The characteristic changes associated with smoltification and migration are reversible if coho salmon are prevented from entering seawater (Zaugg and McLain 1970, Woo et al. 1978, Hassler 1987).

4.2.4 Behavior

Coho salmon grow rapidly in the ocean, where they feed on both invertebrates and fishes. The food of juvenile coho salmon along the Oregon and Washington coasts in 1980 comprised seven major prey groups (Emmett et al. 1986). In late May to early June, the salmon fed mostly on fish. In early July, fish and the euphausiid *Thysanoessa spinifera* were of primary importance. In late August to early September, hyperiid amphipods and the pelagic gastropod *Limacina* spp. were the primary forage. The intensity of feeding increased from May to September. One study found that the major foods of juvenile coho salmon along the Oregon coast were the euphausiid *T. spinifera*, hyperiid amphipods, and fishes (Peterson et al. 1982).

4.2.5 Distribution and Migration

Coho salmon were rare in the Sacramento River system until the California Department of Fish and Game stocked large numbers of fry into the system in 1956-1958 (Hallock and Fry 1967). The coho salmon stocked in the Sacramento River initially returned to spawn but did not maintain a run. Over time, the fish have again become scarce and any that enter the Sacramento River should be regarded as strays. Coho salmon do not enter the San Joaquin River (Hassler 1987). Coho also have been artificially stocked in reservoirs of the Sacramento drainage (Fuller et al. 1999).

Coho has thousands of semi-isolated populations in coastal streams over a wide geographic range. The California populations are southernmost for the species (Moyle 2002) but are infrequently found as far south as Chamalu Bay, Baja California (Fuller et al. 1999).

No populations are thought to exist currently either within the Bay or its tributaries (Moyle 2002). Fish recently reported from the Sacramento River are regarded as strays. Coho do not enter the San Joaquin River (Hassler 1987). Native coho populations currently inhabit coastal streams adjacent to the Bay, and their return to Bay streams is quite possible, particularly if nearby coastal coho populations are successfully restored in the future.

4.2.6 Other Information

Coho salmon fry in estuaries have rates of growth and survival that are better than and independent of those of fry residing in streams (Tschaplinski 1982). Estuaries may produce large, fast growing fry, which help maintain the adult stock. Therefore, to maintain healthy coho stocks, practices that destroy or alter estuarine habitat should be avoided or minimized (Hassler 1987).

4.3 Steelhead Trout (*Oncorhynchus mykiss irideus*)

4.3.1 General Information and Status

Steelhead trout (*Oncorhynchus mykiss irideus*) has the greatest diversity of life history patterns of any Pacific salmonid species, including varying degrees of anadromy, differences in reproductive biology, and plasticity of life history between generations. Within the range of west coast steelhead, spawning migrations occur throughout the year, with seasonal peaks of activity. In any given river basin there may be one or more peaks of migration activity; since these runs are generally named for the season in which they occur, some rivers may have runs known as winter, spring, summer, or fall steelhead. In northern California, some biologists have retained the terms spring and fall steelhead to name what others would call summer steelhead.

North American steelhead commonly spend two years in the ocean before entering freshwater to spawn. Summer steelhead enter fresh water up to a year prior to spawning. Steelhead may spawn more than once. In some cases, the separation between anadromous steelhead and rainbow or redband trout is obscured (NOAA 2004c).

Steelhead trout is federal listed threatened in central coastal California and in the central Valley (NOAA 2004c).

Armor and Herrgesell (1985) classified steelhead trout of San Francisco Bay as a “wet response” (to wet and dry years) anadromous species.

4.3.2 Reproduction

Steelhead are a polymorphic species and as such populations within a stream may be anadramous, resident, or mixtures of the two forms that interbreed. Polymorphic salmonids exhibit a high degree of life history variation. Steelhead within San Francisco Bay may be classified as “ocean-maturing” or “winter” steelhead that typically begin their spawning migration in the fall and winter, and spawn within a few weeks to a few months from when they enter freshwater (McEwan and Jackson 1996, Barnhart 1986). Releases of cold water from several large Central Valley reservoirs on the Sacramento River system may induce steelhead to move into upstream tributaries as early as August and September. This means that upstream migrating steelhead may be observed within San Francisco Bay and Suisun Marsh/Bay between December and April, with most spawning occurring between January and March (Leidy 2000, BCDC 2002).

4.3.3 Growth and Development

Steelhead remain in freshwater for one to four years (usually two years) before downstream migration as smolts (Moyle 2002). With a few exceptions, most Sacramento River juvenile steelhead emigrate as 1-year-old fish during spring and early summer (Barnhart 1986, Reynolds et al. 1993, Shapovalov and Taft 1954).

4.3.4 Behavior

Rearing juvenile steelhead are primarily drift feeders utilizing a variety of terrestrial and aquatic insects, including emergent aquatic insects, aquatic insect larvae, snails, amphipods, opossum shrimp, and various species of small fish (Moyle 2002, Barnhart 1986). Larger steelhead will feed on newly emergent steelhead fry. Emigrating adult and juvenile steelhead may be found foraging in and migrating throughout the open water of estuarine subtidal and riverine tidal habitats within all areas of San Francisco (Leidy 2000, BCDC 2002).

4.3.5 Distribution and Migration

Although the life-history characteristics of steelhead are generally well known, the polymorphic nature of the subspecies has resulted in much confusion over the status and distribution of steelhead in San Francisco Estuary and its tributaries. Historically, the Sacramento-San Joaquin River systems supported large runs of steelhead (McEwan and Jackson 1996). Presumably, most streams with suitable habitat within the San Francisco Estuary also supported steelhead, however accurate population estimates for individual streams are not available (Skinner 1962, Leidy 1984). USACE et al. (1998) reported that steelhead make spawning runs into several rivers and small creeks of the Bay, including the Napa, Petaluma, and Guadalupe Rivers and Sonoma Creek. Small steelhead runs of unknown size are known to exist in many creeks tributary to San Francisco Bay (Leidy 2000, BCDC 2002).

4.3.6 Other Information

General factors influencing steelhead population numbers during upstream migration, spawning, and incubation include barriers to passage, diversions, flow fluctuations, water temperature, and other water-quality parameters, such as sedimentation of spawning habitats. Factors affecting juvenile rearing habitat and emigration within the San Francisco Estuary and its tributary streams include low summer flows combined with high water temperatures. Within Suisun Bay/Marsh, the downstream migrating steelhead are adversely affected by altered flows; entrainment; and mortality associated with trapping, loading, and trucking fish at state and federal pumping facilities. Leidy (2000) and BCDC (2002) stated that dredging and dredged material disposal within San Francisco Bay may contribute to degradation of steelhead habitat and interfere with migration, foraging, and food resources; however, no studies were cited that documented these potential effects.

Some other important factors that are critical to maintaining optimal steelhead habitat include water quality and quantity, habitat heterogeneity, migration barriers, and introduced salmonids. Steelhead require relatively "good" water quality (e.g., low suspended sediment and contaminant loads and other forms of pollution), as well as sufficient flows for spawning, rearing, and migration. Diverse stream habitats consisting of shallow riffles for spawning and relatively deep pools, with well-developed cover, for rearing are important factors. The importance of estuarine or riverine tidal wetlands within the San Francisco Estuary for rearing/foraging or migrating steelhead is not well understood (Leidy 2000).

4.4 Delta Smelt (*Hypomesus transpacificus*)

4.4.1 General Information and Status

Delta smelt is a species of the family Osmeridae that is endemic to the San Francisco Estuary. Species in this family are small and silvery and may occur in large numbers in marine and freshwaters of the Northern Hemisphere. Delta smelt has experienced marked population declines (Moyle 2002).

Delta smelt (*Hypomesus transpacificus*) is a federal- and state-listed threatened species (USACE 1998). The delta smelt is a small, short-lived native fish found only in the Bay-Delta estuary. The species was listed as threatened in 1993 under the federal Endangered Species Act. Locations throughout San Francisco Bay have been designated as Critical Habitat (Federal Register Vol. 59 No. 242, December 19, 1994). Habitat loss is thought to be one of the most important elements in causing its decline. New water-quality standards adopted by the state in 1995 are aimed, in part, at improving habitat conditions. USFWS (1996) produced a recovery plan for this species.

Armor and Herrgesell (1985) classified delta smelt of San Francisco Bay as a “mixed response” (to wet and dry years) estuarine species.

4.4.2 Reproduction

The delta smelt female does not produce many young (i.e., it has low fecundity). The smelt is primarily an annual species, although a few individuals may survive a second year. The location and season of spawning is generally known, but spawning has not been directly observed. Spawning apparently occurs in shallow freshwater sloughs and evidently occurs within the Delta, including the lower Sacramento and San Joaquin Rivers and Suisun Marsh. Delta smelt larvae have also been found in the Napa River, Montezuma Slough, and the San Joaquin River as far upstream as Stockton (CDWR and USBR 1994, BCDC 2002, Sommer and Herbold 2000, Moyle et al. 1992).

Spawning may occur from late winter (December) to early summer (July) in tidally influenced rivers and sloughs, including dead-end sloughs and shallow edge waters of the upper Delta. Most spawning apparently occurs in fresh water, but evidence indicates that some may occur in brackish water in or near the entrapment zone (Wang 1991). The demersal, adhesive eggs sink and attach to hard substrates, such as submerged tree branches and roots, gravel or rocks, and submerged vegetation. Survival of adhesive eggs and larvae is probably significantly influenced by hydrology at the time of spawning (CDWR and USBR 1994, Sommer and Herbold 2000, Moyle et al. 1992).

Spawning stock does not appear to have a major influence on Delta smelt year class success. However, the low fecundity of this species, combined with planktonic larvae, which likely have high rates of mortality, requires a large spawning stock if the population is to perpetuate itself. This may not have been an important factor in the decline of Delta smelt, but it may be important for its recovery (CDWR and USBR 1994, CDFG 1992c, Sommer and Herbold 2000, Moyle et al. 1992).

4.4.3 Growth and Development

xxxxx Newly hatched larvae are planktonic and drift downstream near the surface to the freshwater/saltwater interface in nearshore and channel areas. Growth is rapid through summer, but slows in fall and winter. Delta smelt become sexually mature in the fall at approximately seven to nine months of age. The majority of adults die after spawning (CDWR and USBR 1994, Sommer and Herbold 2000).

4.4.4 Behavior

Newly hatched larvae feed on rotifers and other microzooplankton. Older fish feed almost exclusively on copepods. Prior to 1988, Delta smelt ate almost solely the native *Eurytemora affinis* (Herbold 1987). During the 1980s, *Eurytemora affinis* was displaced by the introduced copepod *Pseudodiaptomus forbsii* throughout Suisun Bay, and Delta smelt shifted to a diet of *Pseudodiaptomus forbsii* (Sommer and Herbold 2000).

4.4.5 Distribution and Migration

Delta smelt are endemic to the Sacramento-San Joaquin Estuary. They have been found as far north as the confluence of the American and Sacramento Rivers and as far south as Mossdale on the San Joaquin River. Their upstream range is greatest during periods of spawning. Larvae subsequently move downstream for rearing. Juvenile and adult Delta smelt commonly occur in the surface and shoal waters of the lower reaches of the Sacramento River below Isleton, the San Joaquin River below Mossdale, through the Delta, and into Suisun Bay (Moyle 2002, Moyle et al. 1992, Aasen 1999). Downstream distribution is generally limited to western Suisun Bay. During periods of high Delta outflow, Delta smelt populations do occur in San Pablo Bay, although they do not appear to establish permanent populations there (Herbold et al. 1992). Recent surveys, however, show that Delta smelt may persist for longer periods in the Napa River, a tributary to San Pablo Bay (BCDC 2002, Sommer and Herbold 2000).

4.4.6 Other Information

Delta smelt experienced reduced population levels during the 1980s, and this trend was consistent throughout the Delta and Suisun Bay. However, declines may have occurred as early as the mid-1970s in the eastern and southern portions of the Delta.

No single factor appears to be the sole cause of the Delta smelt decline; however declines have been attributed primarily to restricted habitat and increased losses through entrainment by Delta diversions (CDWR 1992, Herbold et al. 1992, USFWS

1994). Reduced water flow may intensify entrainment at pumping facilities as well as reduce the quantity and quality of nursery habitat. Outflow also controls the location of the entrapment zone, an important part of the habitat of Delta smelt (Sommer and Herbold 2000, BCDC 2002). Reduced suitable habitat and increased entrainment occurs when the entrapment zone moves out of the shallows of Suisun Bay and into the channels of the lower Sacramento and San Joaquin Rivers as a result of low Delta outflow. The movement of the entrapment zone to the river channels not only decreases the amount of area that can be occupied by Delta smelt, but also decreases food supply (BCDC 2002).

Although the effects of the recent high diversions of fresh water, especially when coupled with drought conditions from 1987-1992, are the most likely causes of the decline in the Delta smelt population, other contributing factors may include the presence of toxic compounds in the water, competition and predation, food supply, disease, very high outflows, and low spawning stock (Sommer and Herbold 2000, BCDC 2002).

In a study of interannual effects of freshwater flow into the Estuary, Kimmerer (2002) reported that delta smelt abundance was higher during high-flow than during low-flow years prior to 1981-82, but was higher during low-flow years after that period.

Toxic contaminants have also been identified as a factor that could affect Delta smelt survival (USFWS 1991). Possible pollutants include heavy metals, pesticides, herbicides, and polycyclic aromatic hydrocarbons. An inverse relationship has been found between copper applications to ricefields and Delta smelt abundance, but no toxicity studies have been conducted to verify the degree to which pollutants in water and sediments affect Delta smelt (Goals Project 2000).

Research suggests that competition with inland silversides, a non-native fish that arrived in the Bay around 1975, working synergistically with low flows, has contributed to Delta smelt decline as well (Bennett 1995). Inland silversides were found to be voracious predators of larval fish in both field and laboratory experiments. In addition, smelt and silversides may compete for copepods and cladocerans. Hatching and larval smelt may be extremely vulnerable to schools of foraging silversides, especially in low-outflow years when Delta smelt are forced into narrower, upstream channels, where silverside competition and predation may be increased. Evidence suggests that other non-native species, such as chameleon goby and striped bass, are either direct predators or compete with Delta smelt for food or habitat (CDWR and USBR 1994). However, it is questionable if striped bass is an important factor when both striped bass and Delta smelt were abundant in the 1960s, and the smelt was not a significant prey of the bass (CDFG 1992c, Sommer and Herbold 2000).

4.5 Pacific Herring (*Clupea pallasi*)

4.5.1 General Information and Status

Pacific herring (*Clupea pallasi*) is a member of the Clupeidae, one of the most abundant families of fishes (Moyle 2002). Species in this family are typically marine, but anadromous and freshwater species also occur. Pacific herring ranges from San Diego Bay to the Bering Sea and Japan (Barnhart 1988). It is a commercially harvested species in San Francisco Bay (USACE et al. 1998). Adults, juveniles and roe deposited on kelp and red algae are harvested. Armor and Herrgesell (1985) classified Pacific herring of San Francisco Bay as a "wet response" (to wet and dry years) marine-estuarine species.

4.5.2 Reproduction

Adult herring congregate outside San Francisco Bay before entering and generally spend about two weeks in the Bay before spawning (CDFG 1987). Spawning takes place from early November through March, with peak activity in January (Spratt 1981, CDFG 1992b, Watters 1998). The timing of spawning is believed to coincide with increased levels of plankton production as a food source for larvae (Lassuy 1989), as well as the presence of freshwater flows (Cherr et al. 2001, Emmett et al. 1991). Pacific herring spawn primarily on vegetation, rock riprap, pier pilings, and other hard substrates in intertidal and shallow subtidal waters (Spratt 1981, Lassuy 1989, Emmett et al. 1991). Spawning occurs in waves of 1 to 3 days, occasionally up to a week in length, and often at night in conjunction with high tides (Spratt 1981). Waves are separated by one to several weeks over the length of the season with larger fish tending to spawn first (Lassuy 1989). The number and size of the waves is related to the distribution of the dominant year classes (CDFG 1992b, Tasto 2000).

Watters (1998) and Watters et al. (2001) reported that herring in San Francisco Bay spawned from as far north as Paradise Cay near the Richmond–San Rafael Bridge to as far south as the Port of Redwood City. Most spawning occurred between the bridge and Candlestick Point. According to Haegele and Schweigert (1985),herring egg mortality results mostly from suffocation due to high egg densities and silting, predation, and (in intertidal spawn) exposure stresses and wave action. Dickson et al. (1972) reported that herring can be captured and transplanted to experimental spawning locations in the field. Laboratory studies on the effects of oil on herring spawning and reproduction were reported by Pearson et al. (1985). They successfully obtained spawning in the laboratory. They also demonstrated active substrate testing by adults and definite substrate preference for spawning.

4.5.3 Growth and Development

Optimum development and hatching of embryos occur at about half-strength seawater (Cherr et al. 2001). Metamorphosis to the juvenile stage takes place over two to three months (Emmett et al. 1991). The fish are free swimming at this stage and begin to form shoreline-oriented schools (CDFG 1992b). Juveniles vary in sizes depending upon regional growth rates, which in turn are affected by population size and environmental conditions (Emmett et al. 1991). In the Bay Area, there are no apparent differences in the growth rates of males and females (Spratt 1981). Adults vary in size as well, and locally it takes two to three years to reach maturity (Spratt 1981, Emmett et al. 1991). It is possible that some Pacific herring in more northern climates may exceed 15 years in age, but few have been noted to live longer than 9 years (Emmett et al. 1991, Tasto 2000).

Schweigert et al. (2002) concluded that Pacific herring populations (including San Francisco Bay stocks) fluctuate significantly as a result of environmental forcing. Recent decreases in food (plankton) availability likely led to herring population declines. They indicated that there appear to be threshold effects associated with population density, ocean production, and plankton availability, and El Niño–Southern Oscillation–mediated sea surface temperatures.

4.5.4 Behavior

Pacific herring larvae, juveniles, and adults are selective pelagic planktonic feeders and move toward the water's surface to feed at dusk and dawn (Emmett et al. 1991). Generally, prey items will change with growth and geographic distribution. Larvae feed on diatoms, invertebrate and fish eggs, crustacean and mollusk larvae, bryzoans, rotifers, and copepods (Hart 1973). Juveniles consume a variety of crustaceans, as well as mollusk and fish larvae; while adults eat mostly planktonic crustaceans and fish larvae (Hart 1973, Emmett et al. 1991). In winter, there is an overall reduction in adult Pacific herring feeding as stored energy is used for ripening reproductive products and, during their spawning migration and inshore "holding" period, herring may severely limit or stop feeding entirely (Lassuy 1989, Tasto 2000).

Herring eggs are eaten by various species of fish (e.g., sturgeon), ducks (e.g., surf scoter), and gulls (CDFG 1992b). Larvae are often prey for large pelagic invertebrates and various fishes, while juveniles and adults are consumed by a variety of fishes (e.g., spiny dogfish shark, Chinook salmon, Pacific staghorn sculpin, and striped bass), seabirds (e.g., Brandt's cormorants, brown pelicans, and western gulls), and marine mammals, such as harbor seals (Hart 1973, Lassuy 1989, Emmett et al. 1991). Predation is considered to be the greatest source of natural mortality for juvenile and adult Pacific herring (CDFG 1992b).

4.5.5 Distribution and Migration

San Francisco Bay population levels fluctuate widely, with predation as the single most important factor affecting the population levels of Pacific herring. In addition to commercial and recreational fishing, humans influence herring survival by altering Pacific herring habitat and water quality (BCDC 2002, Tasto 2000).

Major populations exist in the eastern Pacific between San Francisco Bay and central Alaska (Hart 1973). Within San Francisco Bay, the principal spawning areas are found along the Marin County coastline (i.e., Sausalito, Tiburon Peninsula, and Angel Island), at the San Francisco waterfront and Treasure Island, on the east side of the Bay from the Port of Richmond to the Naval Air Station at Alameda, and on beds of vegetation in Richardson Bay and the South Bay (Spratt 1981, CDFG 1992b, Tasto 2000).

After hatching, the larvae are clumped and controlled largely by tidal factors, and following disappearance of the yolk sac and the onset of feeding, their distribution becomes patchy (CDFG 1992b). Larvae and young juveniles are found in the Bay between November and April and their greatest densities are in the shallow waters of the upper South Bay, Central Bay, and San Pablo Bay. Juveniles are found in the deeper areas of the Bay (peak in Central Bay) between April and August, and, for the most part, have left the Bay by late June (CDFG 1987). They eventually move to offshore or nearshore areas and do not return to the Bay until they are mature and ready for spawning. There is conflicting evidence of a strong correlation between juvenile abundance, as measured by young-of-the-year surveys, and recruitment to the adult spawning population two years later (Herbold et al. 1992, Tasto 2000).

4.5.6 Other Information

Surfperches, topsmelt, jacksmelt, rock crabs, and white sturgeon eat Pacific herring eggs. California halibut, young salmon, California sea lion, harbor seal, and striped bass eat juvenile and adult Pacific herring (BCDC 2002, Tasto 2000).

Critical habitat to the health of Pacific herring is, first and foremost, appropriate spawning habitat. This habitat includes seagrass or algae, as well as substrate that is rigid, smooth in texture, and lacking sediment. In addition, young Pacific herring need quiescent and productive shallow subtidal areas as rearing habitats. Water quality is an important factor because eggs may be affected by high levels of suspended particulate matter, particularly if the sediments are laden with contaminants. Additionally, larvae have been shown to be sensitive to hydrocarbons from spilled oil or other sources (BCDC 2002, Tasto 2000).

Egg mortality can result from tidal exposure and desiccation, abrupt or severe temperature or salinity changes, low oxygen levels, wave action, suffocation by high egg densities or siltation, pollution, and predation (Lassuy 1989, Emmett et al. 1991). Factors related to natural mortality of larvae in the Bay include competition and other density dependent mechanisms, as well as starvation during their initial feeding period and changes in dispersal patterns. Juveniles and adult survival is affected by competition, predation, disease, spawning stress, and fishing (Emmett et al. 1991).

Predation appears to be the single most important factor affecting population levels (Lassuy 1989). In addition to commercial and recreational fishing, humans influence herring survival by affecting water and habitat quality. Spawning habitat quantity and

Delta outflows are not thought currently to be limiting factors in determining the Bay's herring population size (CDFG 1987 and 1992b).

In a study of interannual effects of freshwater flow into the Estuary, Kimmerer (2002) reported that Pacific herring egg/juvenile survival was higher during high-flow than during low-flow years.

5.0 DREDGING EQUIPMENT AND OPERATIONS

The following description of dredging equipment and operations is primarily taken from USEPA and USACE (1992).

Dredging equipment and dredging operations resist precise categorization. As a result of specialization and tradition in the industry, numerous descriptive, and often overlapping terms categorizing dredges have developed. For example, dredges can be classified according to the basic means of moving material (mechanical or hydraulic); the device used for excavating sediments (clamshell, cutterhead, dustpan, and plain suction); the type of pumping device used (centrifugal, pneumatic, or airlift); and others (see Figure 2). However, for the purposes of this document, dredging is actually accomplished basically by only two mechanisms:

- Hydraulic dredging: removal of loosely compacted materials by cutterheads, dustpans, hoppers, hydraulic pipeline plain suction, and sidecasters, usually for maintenance dredging projects.
- Mechanical dredging: removal of loose or hard, compacted materials by clamshell, dipper, or ladder dredges, either for maintenance or new work projects.

Hydraulic dredges remove and transport sediment in liquid slurry form. They are usually barge mounted and carry diesel or electric-powered centrifugal pumps with discharge pipes ranging from 6 to 48 inches in diameter. The pump produces a vacuum on its intake side, and atmospheric pressure forces water and sediments through the suction pipe. The slurry is transported by pipeline to a disposal area. Hopper dredges are included in the category of hydraulic dredges for this report, even though the dredged material is simply pumped into the self-contained hopper on the dredge rather than through a pipeline. It is often advantageous to overflow hopper dredges to increase the load; however, this may not always be acceptable due to water-quality concerns near the dredging site.

Mechanical dredges remove bottom sediment through the direct application of mechanical force to dislodge and excavate the material at almost in situ densities. Backhoe, bucket (such as clamshell, orange-peel, and dragline), bucket ladder, bucket wheel, and dipper dredges are types of mechanical dredges. Sediments excavated with a mechanical dredge are generally placed into a barge or scow for transportation to the disposal site.

6.0 POTENTIAL EFFECTS OF DREDGING ON FISH

The following sections provide an overview of potential effects on fish from dredging. Most of the effects are illustrated in Figures 3 through 9.

Sections 6.1 through 6.3 include discussions of effects of dredging as reported in the literature. The reader is advised that this literature review was not intended to be comprehensive but was limited to documents that were easily obtained by the authors. As discussed in the introduction to this report, the review of literature was primarily intended to identify issues for consideration by the Work Group and was limited to information contained in major reviews of this subject. Furthermore, there was no attempt by the authors to perform an independent evaluation of statements made in the literature or to verify statements cited from other publications. Based on our reading of some of the source material and comments from contemporary experts on dredging effects, it appears that certain statements about potential or theoretical effects of dredging may have become repetitively cited from secondary sources (e.g., other review articles). Perhaps of more concern, it appears that certain statements about dredging effects may have been based upon citations to studies not directly investigating dredging effects. The reader is cautioned, therefore, to consider these effects statements as potentially relevant but, unless cited directly from a study clearly related to dredging conditions, subject to detailed review of the primary literature source and/or further research before assuming that the effect does in fact occur in the environment during dredging operations.

6.1 General Effects of Dredging as Described in the EIS/EIR

This section describes briefly the types of impacts associated with dredging activities as described in the EIS/EIR. Most of the impacts from dredging are temporary and localized and, with the exception of impacts associated with a changed bottom topography (potential change in local hydrodynamics and in the makeup of the benthic resources present in the dredge area), the impacts end when the dredging ends. The most substantial impacts tend to be on water quality, the potential for resuspension of contaminants buried in the sediments, and the impacts on biological resources in the dredge area. These types of impacts are therefore discussed in more detail below.

6.1.1 Potential Impacts on Water Quality

Water quality variables that can be affected by dredging operations include turbidity, suspended solids, and other variables that affect light transmittance, dissolved oxygen, nutrients, salinity, temperature, pH, and concentrations of trace metals and organic contaminants if they are present in the sediments (U.S. Navy 1990). Dredging resuspends bottom sediments and thus temporarily increases the turbidity of surface waters. Chemical reactions can occur between the suspended materials and the surrounding Bay water. The primary controlling factors would be the redox potential of the seawater, the pH of the seawater and, to a lesser degree, the salinity (Pequegnat 1983). ("Redox potential" refers to the reduction-oxidation potential, which is a measure of the availability and activity of oxygen to enter into and control chemical reactions.) The fine-grained sediment fractions (clay and silt) have the highest affinity for several classes of contaminants, such as trace metals and organics, and tend to remain in the water column longer than sand because of their low settling velocities (U.S. Navy 1990). Oxygen in the seawater would promote oxidation of the organic substances in the suspended materials. This, in turn, can release some dissolved contaminants, particularly the sulfides (U.S. Navy 1990). Depending on the dredging method used, dissolved oxygen concentrations in the water column can be substantially reduced during dredging if the suspended dredged material contains high concentrations of oxygen demanding substances (e.g., hydrogen sulfide). The reduction of dissolved oxygen during dredging is minimal (1 to 2 ppm) and transitory in surface waters, but can be more severe in bottom waters (reduction of up to 6 ppm for 4 to 8 minutes). Most estuarine organisms are capable of tolerating low dissolved oxygen conditions for such short periods. Reduced dissolved oxygen concentrations would be expected to be localized and short term, with minimal impacts (U.S. Navy 1990). Nutrient enrichment can increase turbidity in the water column by enhancing the growth of phytoplankton. If this occurs, it is typically a transient phenomenon with minimal local impact. In the Bay area, nutrients would be flushed out of the dredging area by tidal currents. Effects of nutrients on phytoplankton in the Bay would generally not be detectable (U.S. Navy 1990). Depending on the location of the dredging, deepening navigation channels can increase saltwater intrusion into the Delta (since saline water is heavier than freshwater), potentially impacting freshwater supplies and fisheries. Dredging can also increase saltwater intrusion into groundwater aquifers (e.g., the Merritt Sand/Posey formation aquifer in the Oakland Harbor area), with consequent degradation of groundwater quality in shallow aquifers (U.S. Navy 1990).

6.1.2 Potential Impacts on Sediments

The impacts on sediments at the dredging site may include increased post-dredging sedimentation in the newly deepened areas for new work projects, local changes in air-water chemistry, and possible slumping of materials from the sides of the dredging areas.

6.1.3 Potential Resuspension of Contaminants

Dredging will resuspend contaminants if contamination is present in the surface sediments. Metal and organic chemical contamination is widespread in San Francisco Bay sediments due to river run-off and municipal/ industrial discharges. Contaminants of particular concern in various parts of the Bay include silver, copper, selenium, mercury, cadmium, PCBs, DDT and its metabolites, pesticides, PAHs, and tributyltin. Dredging of contaminated sediments does present the potential for release of contaminants to the water column, and for the uptake of contaminants by organisms contacting resuspended material. However, most contaminants are tightly bound in the sediments and are not easily released during short-term resuspension. Chemical reactions that occur during dredging may change the form of the contaminant and thus alter its bioavailability to organisms. These chemical reactions are determined by complex interactions of environmental factors, and may either enhance or decrease bioavailability, particularly of metals.

6.1.4 Potential Impacts on Biological Resources

The impacts of dredging on biological resources can be short term or long term, direct or indirect. There can be short-term impacts from the dredging, and long-term impacts associated with habitat modification. Short-term impacts could include local changes in species abundance or community diversity during or immediately after dredging. Long-term impacts could include permanent species abundance or community diversity changes caused by changes in hydrodynamics or sediment type, or a decline or erratic trend beyond the normal range of variability in the years following new dredging (U.S. Navy 1990). Direct impacts would be directly attributable to the dredging activity, such as a direct loss of mudflat habitat or a temporary turbidity-induced reduction in productivity in an eelgrass bed immediately adjacent to a dredging site. Indirect effects on organisms include those effects which are not immediately measurable as a consequence of dredging operations. Such effects might, for example, involve population changes in one species that are caused by dredging's effects on its predators, prey, or competitors. Indirect effects may be manifested over extended periods of time and/or at some distance away from the dredging site. The differentiation between direct and indirect effects is not always clear. Dredging involves the removal of substrate and benthic organisms at the dredging site, resulting in immediate localized effects on the bottom life. Besides the decimation of organisms at the dredging site, there is the removal of the existing natural or established community with widely varying survival of organisms during dredged material excavation. Aside from the initial physically disruptive effects, a long- term environmental concern is the recovery (repopulation) of bottom areas where dredging has occurred (Hirsch et al. 1978). Dredging thus opens the area for recolonization on a new substrate that may resemble the original substrate or be completely different in physical characteristics. Recolonization may include the same organisms or opportunistic species that have environmental requirements that are flexible enough to allow them to reoccupy a disturbed site (Reilly et al. 1992). Recolonization of the dredging site can begin quickly, although reestablishment of a more stable benthic community may take several months or years after the dredging operation has occurred (Oliver et al. 1977; Conner and Simon 1979). Oliver et al. (1977) found that most of the infauna were destroyed at the center of the dredging area. Communities inhabiting highly variable and easily disrupted environments, such as those found in shallow water, recovered more quickly from dredging operations than communities in less variable environments such as in deep or offshore waters. Seasonal changes in the environment were considered most important in shallower water where the organisms are more likely to be affected by the changing seasons (Reilly et al. 1992). Oliver et al. (1977) noted two phases of succession after a disturbance. In the first phase, opportunistic species such as some polychaetes would move into a disturbed area. The second phase involved recruitment of organisms associated with undisturbed areas around the disturbed site. Recovery at the disturbed dredging site depends on the type of environment and the speed and success of adult migration or larval recruitment from adjacent undisturbed areas (Hirsch et al. 1978). The effects of habitat loss or alteration at the dredge site may extend beyond the boundaries of the dredging operations. However, dredging-induced habitat alterations are minor compared to the large-scale disturbance of benthic habitat in San Francisco Bay from naturally occurring physical forces (Reilly et al. 1992). The result of these forces is a state of non-equilibrium in benthic species composition typical of shallow estuaries. Naturally occurring habitat disturbances arise from seasonal and storm-generated waves, and from seasonal fluctuations of riverine sediment transport into San Francisco Bay. Human influences on benthic habitat include not only dredging and disposal, but also waste discharges, sediment deposition from hydraulic mining, filling of Bay margins, fresh water diversions, and introduction of exotic species. When the disturbance ceases, recolonization of the benthic substrate occurs; reestablishment of a more or less stable benthic community can take several months or years (Reilly et al. 1992). The suspension of sediments during dredging will generally result in localized, temporary increases in turbidity that are dispersed by currents or otherwise dissipate within a few days, depending on hydrodynamic and sediment characteristics (e.g., USACE and Port of Oakland 1998). Where dredging occurs in relatively polluted areas, contaminants in the sediments are likely to be dispersed into the water column, resulting in localized, temporary increases in contaminant concentrations that may affect fish and invertebrates. Although the increases in turbidity are transient, they can have several types of longer-term consequences for sensitive biological resources. Increased turbidity can reduce the survival of herring eggs, which are attached to hard surfaces on Central Bay shorelines, potentially resulting in reduced recruitment and, ultimately, reduced abundance of this important resource species in the Bay. In certain locations, at critical times of year, increased turbidity can affect the survival of the larval or juvenile stages of sensitive fish species, as well as the feeding and migration of adults. Short-term impacts on critical foraging areas, such as eelgrass beds, during the nesting season of marine birds such as the endangered California least tern, can affect the birds' nesting success. The effect of dredging on fish varies to some degree with the life stage of the fish. Early life stages of fish are more sensitive than adults. Adult fish would be motile enough to avoid the areas of activity; it is assumed that fish will leave the affected areas until dredging is done. Turbidity could reduce visibility, causing difficulty in locating prey. Suspended sediments can have other impacts, including abrasion of the body and clogging of the gills. Generally, bottom-dwelling fish species are most tolerant to suspended solids, and filter feeders are the most sensitive. In San Francisco Bay, dredging between December and February could disrupt the spawning of the Pacific herring and result in mortality to eggs. Depending on the location of dredging, such activity could affect the migration of steelhead and chinook salmon. Dredging in the Central Bay during summer can affect juvenile Dungeness crabs, for which the Central Bay provides an important nursery habitat. Larval and juvenile fishes and invertebrates are also vulnerable to entrainment in dredging equipment.

6.2 Effects of Dredging on Fish Windows Species as Described in the EIS/EIR and Biological Opinions

The following sections describe the potential impacts of dredging on individual windows fish species as contained in Table F-1 of the Management Plan, which, according to Goeden and Goldbeck (2003) is a corrected version of Table J-2 (USACE et al. 1998). Also described are "critical locations." The effects described in this section were mitigated by establishment of the work windows for fish.

6.2.1 Chinook Salmon

The EIS/EIR identified the following potential effects of dredging on chinook salmon. Dredging may interfere with migration of adults. Water quality degradation could affect adults and juveniles. Juveniles could also be affected by direct habitat loss or degradation, interference with foraging or food resources, and entrainment by the dredge.

Critical locations and times for adults were Pinole Shoal (San Pablo Bay) and Suisun Bay Channel (December 1 to May 31), and east of Sherman Island, along migratory corridors to and from the Sacramento River (November 1 to May 15). Critical locations for juveniles were the area upstream from the Bay Bridge to Sherman Island, including sloughs (December 1 to May 31), and east of Sherman Island, along migratory corridors to and from the Sacramento River (October 1 to May 31).

The NMFS biological opinion (Whitlock 1999) identified the following potential impacts to both salmon species and steelhead trout:

1. redistribution of pollutants and/or release of contaminants which may result in chronic or acute toxicity, particularly those that rear for prolonged periods in affected areas,
2. burial of bottom-dwelling organisms which may reduce feeding opportunities for rearing juvenile salmon [most likely this statement applies to disposal]
3. resuspension of sediment particles which could interfere with visual foraging, abrade gill tissues, or interfere with migration. Increased turbidity may also interfere with primary productivity
4. sediment alterations associated with in-Bay disposal.

NMFS concluded that turbidity levels generated are likely low enough in concentration and short enough in duration to avoid significant effects on fish health, foraging, or migration. In open areas, salmon and steelhead are likely to avoid dredging areas and utilize similar areas. Regarding toxins, NMFS concluded that body burdens of juvenile salmon and steelhead in the Bay were below chronic toxicity levels even with the pre-LTMS dredging regime. Dredging in areas with depths less than 20 feet may pose an entrainment risk to smaller salmon and steelhead juveniles. LTMS mitigation measures were deemed to minimize this risk. New dredging projects potentially could reduce available shallow water rearing habitat, but such projects would be subject to consultation and beneficial re-use projects were deemed to mitigate this effect. NMFS emphasized that beneficial re-use projects that create tidal wetland habitat may provide a valuable conservation program providing an important food supply and rearing area for juvenile salmonids. NMFS estimated that any incidental take would be de minimis. CDFG concurred that dredging activities were not likely to jeopardize this species (Lollock 1998).

6.2.2 Coho Salmon

Coho salmon was not included in Table J-2 of the EIS/EIR or Table F-1 of the Management Plan. The work window for coho is June 1 to October 31 in the waters of Marin County from the Golden Gate to the Richmond-San Rafael bridges.

Potential impacts to coho salmon identified in the NMFS biological opinion (Whitlock 1999) are essentially the same as those described for chinook salmon (see Section 6.2.1). CDFG concurred that dredging activities were not likely to jeopardize this species (Lollock 1998).

6.2.3 Steelhead Trout

The EIS/EIR identified the following potential effects of dredging on steelhead trout. In the the area upstream from the Bay Bridge to Sherman Island, including sloughs, (December 1 to May 31), east of Sherman Island, along migratory corridors to and from the Sacramento River (October 1 to May 31) and in Central Bay (December 1 to May 31), dredging may interfere with migration, degrade water quality, cause direct habitat loss or degradation, and interfere with foraging or food sources. In the Napa and Petaluma rivers and Sonoma Creek, dredging may degrade habitat and cause adverse effects on life stages (October 15 to July 31).

Potential impacts to steelhead trout identified in the NMFS biological opinion (Whitlock 1999) are essentially the same as those described for chinook salmon (see Section 6.2.1). CDFG concurred that dredging activities were not likely to jeopardize this species (Lollock 1998).

6.2.4 Delta Smelt

The EIS/EIR identified the following potential effects of dredging on delta smelt. In all critical locations, dredging could directly entrain fish and degrade spawning ground habitat. Critical locations were: Suisun Bay and marshes, from the Carquinez Bridge east to Colinsville (all year); and the southern (February 1 to June 30), central (December 1 to June 30) and northern (September 15 to July 31) Delta.

USFWS identified the following potential effects of dredging on delta smelt and critical habitat designated for delta smelt (Goude 1999). Dredging in shallow waters of sloughs and rivers (less than 3 m) potentially could remove eggs, impede fertilization, or reduce survival as a result of sedimentation on eggs. If dredging permanently removed shallow water habitat, fish may have to utilize less desirable areas. Clamshell dredge operations in intertidal areas could leave depressions in which smelt could be trapped at low tide and experience mortality. No cumulative effects on delta smelt were attributed to dredging. USFW concluded that any incidental take would not be likely to result in jeopardy to the smelt nor result in destruction of adverse modification of its critical habitat. CDFG concurred that dredging activities were not likely to jeopardize this species (Lollock 1998).

6.2.5 Pacific Herring

The EIS/EIR identified the following potential effects of dredging on Pacific herring. Dredging could interfere with spawning activity and cause reduced hatching success and reduced larval survival. Critical locations were historical spawning areas in Central Bay and Richardson Bay (December 1 to February 28).

As stated in Section 3.5.1, Pacific herring is not a listed species and therefore no consultations were conducted for this species. The environmental work window and dredging restrictions for herring incorporated into the EIS/EIR preceded that process and were initiated by CDFG in 1993 (Turner 1993 [developed by Robert Tasto]). Dredging was identified as potentially having a negative effect on reproductive success when conducted in the vicinity of herring spawning activity and deposits. Adverse effects on eggs or early larval forms could result from either the physical or chemical nature of the sediments that become suspended, including interference with attachment, fertilization, or respiration, sulfide effects, and lowered dissolved oxygen. Potential effects resulting from exposure to fine particle-bound chemical contaminants was also identified. Potential effects of dredging on herring spawning activities are illustrated on Figure 9.

6.3 Effects of Dredging on Fish as Described in the Literature

This section includes a brief summary of literature on the effects of dredging on fish. This literature review is not comprehensive, but includes a number of the recent publications that summarize dredging effects as well as a number of papers assembled by the Work Group that are particularly relevant to issues of concern in the Bay.

6.3.1 Biological Effects

6.3.1.1 Distribution

Suspended sediments can affect Bay fishes in a variety of ways. One such effect is that juvenile fishes may be more abundant in turbid than in less turbid coastal waters (Gregory 1990). There are also reports of underyearling sockeye salmon frequently being observed at the surface during bioassays with high suspended sediment concentrations (Servizi 1990).

6.3.1.2 Behavior

Suspended sediments have been shown to affect fish behavior such as avoidance responses, territoriality, feeding, and homing behavior. Short-term pulses of sediments trigger changes in social organization of coho salmon. When turbidity returns to lower levels, reestablishment of previous social organization occurs. One study demonstrated that particular levels of increased turbidity caused pronounced behavioral changes in prey reaction and predator avoidance. Coho salmon territorial, gill flaring, and feeding behaviors have been disrupted in presence of higher turbidity levels (Nightingale and Simenstad 2001). Wilber and Clarke (2001) found that suspended sediments result in cough reflexes, swimming activity, gill flaring, and territoriality. Short-term pulses of suspended sediments disrupt dominance hierarchies of juvenile coho salmon, and increased swimming behavior of rainbow smelt, thus disrupting schooling behavior (Wilber and Clarke 2001).

Social behavior was found to have been disrupted by high turbidities, with a breakdown in dominance hierarchy among juvenile coho salmon (Servizi 1990). Reports have also shown that short-term pulses of suspended sediments caused breakdown of dominance hierarchies of coho salmon, with more frequent gill-flaring activity and territorial defense cessation (Sigler 1990). Suspended sediments have also been shown to affect territoriality in salmonids (Sigler 1990). Young steelhead trout and coho salmon emigrated from channels with elevated turbidity during experiments using continuous clay turbidities (Sigler et al. 1984).

Suspended sediments cause alarm reaction, cover abandonment, and attraction (as potential food source or cover). There are also changes in light penetration/scattering effects alarm reaction, increased swimming, altered school behavior, avoidance, displacement, attraction, and changes in prey capture rates (Anchor Environmental 2003). Gregory (1990) speculated that suspended sediments affect reduction in vulnerability to predation. He noted decreases in intraspecific aggression in stream resident coho in turbid conditions (Gregory 1990).

6.3.1.3 Migration

Suspended sediment has been shown to affect homing behavior in salmonids. Adult male chinook salmon exhibited significantly reduced preference for home water contaminated with ash (Sigler 1990). However, volcanic ash may generate different responses than dredged sediments.

Servizi (1990) reported that turbid water interferes with the migration of Arctic grayling, Pacific salmon and trout (Servizi 1990). Allen and Hardy (1980) found that suspended sediments (dredging in riverine systems) impact the migration of salmonids (Allen and Hardy 1980). Outmigrating juvenile chinook salmon were significantly affected by chemical contaminants in the San Francisco Bay, according to a study by Varanasi et al. (1993). Given opportunity, juvenile coho salmon and steelhead trout migrate to clearer water when exposed to high concentration of suspended sediment (NMFS 1998).

Nightingale and Simenstad (2001) reported that juvenile salmonid migration was more susceptible to dredging than adult migration because of potential entrainment effects.

6.3.1.4 Feeding

A study by Anchor Environmental (2003) stated that increased turbidity can affect feeding of adult fishes. Bottom dwelling fish species are most tolerant to suspended solids, while the filter feeders are most sensitive.

Suspended sediments have been shown to affect feeding behavior in salmonids. Reaction distance to prey and capture success were reduced in waters with notable levels of suspended sediments. Food habits of chinook salmon changed as result of suspended sediment. Feeding rates of yearling coho salmon and steelhead trout were reduced as a result of high exposure of suspended sediments (Sigler 1990). Another study speculated that larval foraging success could be reduced as a result of increased suspended sediment levels (Hanson and Walton 1990).

According to Everhart et al. (1970), the decrease in visibility as a result of high turbidity makes feeding difficult, and coho salmon experienced a reduction in feeding rate with high concentrations of suspended sediments (NMFS 1998).

Larval and juvenile salmonids are visual feeders. High concentration of suspended sediments and high turbidity limit the light entering habitat and inhibit vision. One study demonstrated that at particular levels of increased turbidity, juvenile salmon increase feeding rates as a result of cover from predation (Nightingale and Simenstad 2001). In a different study, short-term pulses of suspended sediments disrupt feeding behavior of juvenile coho salmon. The results of studies on the effects of higher turbidity are variable. Some studies indicated decreases in foraging success, while others indicated increased feeding rates (e.g., Pacific herring; Wilber and Clarke 2001).

Messieh et al. (1981), in a study of the effects of disposal, determined that suspended sediments could inhibit feeding of herring larvae at low levels. Reduced feeding rates have been documented at sublethal levels for several stream resident salmonids, and reduction of reaction distance to prey for juvenile chinook salmon were also reported (Gregory 1990).

Larval Pacific herring were reported to feed at a greater rate under moderate suspensions of fine-grained sediment and volcanic ash, but feeding ability decreased with increasing suspension level (Boehlert and Morgan 1985).

6.3.1.5 Spawning

Salmonids undergo the smoltification process in estuarine waters. This process is tied to hormone levels regulating their developmental process, and visual acuity in estuarine waters is part of this process. High concentration of suspended sediments and high turbidity limit the amount of light entering their habitat and inhibit vision (Nightingale and Simenstad 2001).

Everhart et al. (1970) concluded that chinook salmon were diverted from a main river because of turbidity and selected a small clear tributary. Salmon were so concentrated that superimposition of redds destroyed much of natural production (Everhart et al. 1970).

Suspended sediments have been found to smother spawning areas (Wilber and Clarke 2001). Messieh et al. (1981), in a study of the effects of dredged material disposal, concluded that sediment deposited on or around spawn increased egg mortality (Messieh et al. 1981). Anchor Environmental (2003) also identified suspended sediments as causing a reduction in the hatching success of eggs.

However, a report by Hanson and Walton (1990) concluded that no significant differences in the densities or distribution of striped bass eggs and larvae were detectable in areas of increased turbidities associated with dredging activities (Hanson and Walton 1990).

6.3.1.6 Development

According to Everhart et al. (1970) eggs and fry are more susceptible to harm by higher turbidities than any other stage, and are often damaged by suffocation. In another study, eggs and larvae of nonsalmonid estuarine fishes were shown to exhibit sensitivity to suspended sediment (Wilber and Clarke 2001). Locally, increased turbidity can reduce the survival of herring eggs and can affect the survival of the larval or juvenile stages of this sensitive fish species. Although Messieh et al. (1981) concluded that increased suspended sediments could result in earlier hatching and shorter hatching lengths (Messieh et al. 1981).

Suspended sediments have also been found to cause reduced larval growth/development, and abnormal larval development (Anchor Environmental 2003). Sigler (1990) reports a reduction in growth/maturation rates. This study noted statistically significant reductions in growth, density, and increased rates of out migration for coho salmon. Survival of eggs and larvae of white perch and striped bass was reduced when exposed to high concentrations of suspended sediments (Sigler 1990).

In one study, young steelhead trout and coho salmon subjected to continuous clay turbidities grew less well than those living in clear water (Sigler et al. 1984). The NMFS (1998) concluded that juvenile coho salmon and juvenile steelhead exposed to high concentrations of suspended sediment for long periods was non-lethal, but caused a reduction in growth rate. Gregory (1990) showed that reduced growth rates have been documented at sublethal levels for several other stream resident salmonids (Gregory 1990), and the fitness of coho salmon may also be impaired (Servizi 1990).

However, one review reported no significant impact of suspended sediment on hatching success of striped bass eggs, as well as no significant impact on striped bass larvae by increased suspended sediments (Hanson and Walton 1990).

6.3.1.7 Fish Injury

Studies have shown that suspended sediments can cause changes in respiration rate, choking, coughing, abrasion, and puncturing of structures (e.g., gills/epidermis), reduced water filtration rates, and reduced response to physical stimulus (Anchor Environmental 2003). In another study, turbidity was believed to cause excessive mucus secretion and excretory interference, respiratory interference, adaptations that either prevent or permit survival (Wallen 1951).

Everhart et al. (1970) concluded that coarser particles in suspension as a result of high turbidity may harm fish by abrasion or crushing (if large enough). Furthermore, abrasion of body surface of fish can remove protective mucus, increasing susceptibility to invasion by parasites or disease. High turbidity will also cause solids to settle out on the gill filaments, resulting in a decrease in respiration (Everhart et al. 1970). In riverine systems, suspended sediments have affected respiration, caused abrasion to gills, resulted in pathological changes to gill structures, and changed blood chemistry for salmonids (Allen and Hardy 1980).

According to Nightingale and Simenstad (2001), the size and shape of suspended sediments (as well as duration of exposure) can be important factors in determining the risks to salmonid populations. High concentrations of suspended sediments elicit stress responses, cause gill damage, increase mucus production, and decrease oxygen transfer. There was a 20 percent mortality of Arctic grayling and coho salmon when exposed to high concentrations of suspended sediments, and juvenile coho salmon showed clogged gill epithelia under exposure to high concentrations of suspended sediments. Sockeye, chinook, coho, four-spine stickleback, cunner, and sheephead minnow experienced high mortality in suspended sediment as a result of reduced oxygen uptake (Nightingale and Simenstad 2001).

The NMFS (1998) indicated that histological damage to chinook salmon gills occurs during extreme exposure to suspended sediments, and 50 percent mortality of juvenile coho salmon and rainbow trout may result when exposed to high levels of suspended sediments. Juvenile sockeye salmon survived long exposure to suspended sediment, but experienced hypertrophy (swelling) and necrosis (cell death) of gill tissue in a study by Servizi (1990). This study also reported that juvenile coho had died during exposure to soil-derived suspended sediments, and suspended sediments reduced tolerance among yearling steelhead. Other conclusions included elevated levels of plasma glucose that are considered a secondary response to stressors, a report of elevated cortisol levels in yearling steelhead and coho with suspended sediment, and a significant rise in gill-flaring among juvenile coho salmon (Servizi 1990).

Although suspended sediments did not cause mortality in this study, induced elevation of plasma cortisol levels and blood hematocrits (reduced tolerance to infection) was also reported (Sigler 1990). According to Simenstad (1990), principal mechanisms of potential near-field injury were through histopathological effects (e.g., hypertrophy and necrosis) on the fishes' gills when in high suspended sediment concentrations.

6.3.2 Physical Effects

6.3.2.1 Disturbance

Reilly et al. (1992) has concluded that dredging activities open areas for recolonization on new substrate that may be similar to or different from pre-dredging communities. This recolonization may include the same species or opportunistic species. Most infauna is destroyed at the center of a dredging disturbance (Reilly et al. 1992). Hirsch et al. (1978) showed that communities in dredging areas are removed initially, but that populations recover with time (Hirsch et al. 1978).

6.3.2.2 Displacement

A study conducted at the Alcatraz disposal site by Burcynski (1991) concluded that fish disappeared from the area for up to two to three hours following discharge. Wilber and Clarke (2001) showed that short-term pulses of suspended sediments may disrupt juvenile coho salmon and elicit alarm reactions that may cause fish to relocate downstream to undisturbed areas. Hirsch et al. (1978) determined that dredging activities may result in the removal of organisms or communities.

6.3.2.3 Avoidance

Suspended sediments have been shown to affect avoidance responses. Changes in light penetration and/or scattering can cause avoidance in fishes (Anchor Environmental 2003).

Rainbow smelt and Altlantic herring avoid suspended sediments at low concentrations, whereas juvenile chum salmon show avoidance of particular levels of turbidity during dredging operations (Nightingale and Simenstad 2001, Sigler 1990). Messieh et al. (1981) concluded that juvenile herring avoid suspended sediment. Juvenile coho avoided high turbidity areas as well (Servizi 1990).

6.3.2.4 Entrainment

According to Nightingale and Simenstad (2001), benthic infauna are particularly vulnerable to entrainment, but mobile epibenthic and demersal organisms can also be susceptible. Rates are usually described as number of organisms entrained per cubic yard of dredged sediment. Dungeness crabs and demersal fish are most likely to have the highest rates as they reside on or in bottom substrates with life-history strategies of burrowing or hiding in bottom substrate. White sturgeon (juvenile and adult) are susceptible to entrainment because of their small size, limited swimming ability, and tendency to orient with bottom habitats. Juvenile salmonids and eulachons were dominant entrained taxa in a Canadian study, and juvenile salmonid migration was concluded to be more vulnerable than adult migration (Nightingale and Simenstad 2001).

McGraw and Armstrong (1990) concluded that the total mortality rate for pipeline dredges in Gray's Harbor, Washington was estimated at 99 percent for those fish entrained. Using dip nets to sample overflow ports on a hopper dredge, this study reported recovery rates of only 1 percent for juvenile salmon. Histopathologic studies of surviving entrained fish revealed that salmon smolts suffered internal lesions and other conditions, indicating that overall mortality was 100 percent. They reported that juvenile longfin smelt, threespine stickleback, and many other species had been observed entrained in dredges in an earlier study. In their study, only one chum salmon was entrained, whereas in a previous study, 858 pink salmon were entrained (McGraw and Armstrong 1990).

Dredging in areas less than 20 feet deep may pose a risk to smaller salmon and steelhead juveniles (NMFS 1998).

Larson and Moehl (1990) reported that longfin smelt were observed in hopper dredges during past studies. There were a total of 14 species or species groups of fish that were encountered during this study. Most species were demersal. Eulachon was the only anadromous species collected. No juvenile or adult salmonids were collected. It is unlikely that anadromous fish are entrained in any significant amount by hopper dredging in channels through estuaries, or large river mouths. However, dredging in river channels where the river is constricted, particularly during periods of peak outmigration, may entrain juvenile salmonids or smelt (Larson and Moehl 1990).

6.3.2.5 Burial

In 1978, Hirsch et al. found that dredging activities may result in the burial of organisms or communities (Hirsch et al. 1978). In a study of the effects of dredged material disposal, the authors concluded that sediment may be deposited in spawning areas (Messieh et al. 1981).

6.3.2.6 Sedimentation

According to Hirsch et al. (1978), dredging activities may change local sedimentation patterns.

6.3.2.7 Noise

Noise has been documented to influence fish behavior. Fish detect and respond to sound utilizing its cues to hunt for prey, avoid predators, and for social interaction. Based on known range of salmonid hearing, underwater noise from pile-driving is expected to be heard by salmonids within a 600-meter radius. Pile-driving operations affect distribution and behavior of pink and chum salmon. Atlantic and Pacific herring show similar "startle" or "start" responses to noise stimuli. High intensity sounds can also permanently damage fish hearing (Nightingale and Simenstad 2001).

Pile-driving operations result in more intense bursts of sound energy. Dredging operations generally produce lower levels of sound energy and often last around the clock for extended periods of time (Nightingale and Simenstad 2001). However, more research is required before the effect of dredging noise on salmonids and other fishes can be evaluated (Nightingale and Simenstad 2001).

6.3.2.8 Turbidity (Optical Properties)

According to Schoellhamer and Warner (2001), suspended sediments result in high turbidity, thus limiting light availability and photosynthetic capabilities. Turbidity at natural levels is generally not harmful to fish, but high concentrations of suspended sediments may have detrimental effects (Everhart et al. 1970). Fish are affected directly by a decrease in visibility, which may make feeding difficult.

Nightingale and Simenstad (2001) discussed the importance of light transmission to the fitness and survival of larval and juvenile estuarine fish. They stated that light transmission is affected by increased levels of suspended sediment and concluded that suspended sediments temporarily increase at varying levels near operating dredges. This increase is a function of a combination of factors, including substrates, currents and operational parameters. Suspended sediments vary throughout the water column, with larger plumes typically occurring closer to the dredging equipment. The plume sizes decrease exponentially as one moves away from dredging site (both horizontally and vertically; Nightingale and Simenstad 2001).

Gregory (1990) concluded that visual constraints have the potential to severely affect the growth and survival of estuarine fishes. In riverine systems, slightly turbid water resulted in an increased activity level, as well as less reliance on overhead cover by brook trout and creek chub (Gregory 1990). Wilber and Clarke (2001) concluded that suspended sediment may act as a source of cover for juvenile salmonids. However, this reduces the avoidance response of juvenile chinook salmon in bird and fish predator models, and may reduce the surfacing response by juvenile coho salmon, thus increasing their vulnerability to predation (Wilber and Clarke 2001). Increased levels of suspended sediment has been shown to reduce the reaction distance of visually foraging fish toward their prey (Gregory 1990).

6.3.2.9 Habitat and Food Source Modification

Similar studies have shown that dredging activities may result in the alteration of habitat, changed water flow regimes, and alteration of local salinity (Hirsch et al. 1978). New dredging projects in shallow water areas have the potential to reduce available shallow water rearing habitat (NMFS 1998). Potential ecosystem effects are assumed to include loss or change in critical habitat, reduction of primary and secondary production (food web effects), and changes in hydrology and sedimentation (Simenstad 1990).

Anderson et al. (1993) conducted studies in outer Los Angeles Harbor on benthic invertebrate communities in dredged and undredged locations. They concluded that communities gradually return to previous population levels at dredged sites.

6.3.2.10 Suspended Sediments

Suspension of sediment in the water column is the most direct result of dredging activities (LaSalle 1990). The magnitude and spatial extent of suspended sediment is related to the type of dredge used, physical/biotic characteristics of the dredged material, and site-specific hydrological conditions (LaSalle 1990). Reilly et al. (1992) stated that the amount of suspended sediment produced varies with type of dredge used. The amount of loading is also determined by physical factors including particle size distribution, percent moisture, and degree of cohesion (Reilly et al. 1992).

Suspended sediments were found to affect Suisun Bay by limiting light availability and photosynthesis and by providing a transport pathway for contaminants (Schoellhamer and Warner 2001). Concentrations can be much greater in the immediate vicinity of dredging operations than ambient conditions, however, natural physical processes account for the variability of suspended sediment at Point San Pablo (Schoellhamer 2002).

Segar (1990) concluded that, while dredged sediment disposal at the Alcatraz site in Central Bay contributed significantly to the suspended sediment loading and turbidity, the resulting suspended sediment concentrations and turbidity were below levels (of uncontaminated sediments) known to adversely affect fish and other organisms.

According to Everhart et al. (1970) abundant amounts of suspended sediment may have detrimental effects. Large quantities of suspended sediment have proven to be detrimental to aquatic life of salmon and trout streams (Everhart et al. 1970). Hirsch et al. (1978) found lethal or sublethal effects as a result of smothering or physiological stress, as well as aesthetic impacts.

Hayes (2002) provided a brief review of controls that have been used to minimize suspended sediment plumes ("turbidity plumes") that result from dredging. Swing speeds, rotation speeds, and cutting depths were identified as parameters that affect plume size or intensity with cutterhead dredges. Fall speed, bucket design, and barge overflows were identified as parameters that affect plume size or intensity with bucket dredges. Silt screens or curtains have also been used to limit plume size, based on surface plume extent. Hayes also concluded that physical and operational controls have costs associated with them and more research is needed to document their efficacy (Hayes 2002).

Watters (1998) stated that sediments (i.e., from a suspended sediment plume associated with dredging) can kill herring embryos by: 1) not allowing oxygen to pass through the membrane of the egg, 2) introducing contaminants, and 3) preventing excretion of wastes.

6.3.2.11 Sediment Type

Literature regarding sediment type was reviewed in the LTMS EIS/EIR (see Section 6.2).

6.3.3 Water Quality and Contaminants

6.3.3.1 Water Quality

Effects on water quality vary, and may include the following parameters: turbidity, suspended solids, other variables that affect light transmittance, dissolved oxygen, nutrients, salinity, temperature, pH, concentrations of trace metals and organic contaminants. Although typically short lived, dissolved oxygen concentrations can be reduced substantially if high concentrations of oxygen-demanding substances are mixed into the water column.

Studies have shown direct effects on dissolved oxygen, nutrient and the ammonia content of water (Hirsch et al. 1978). Reduction in dissolved oxygen and release of natural and industrially derived chemicals may be a short-lived result of dredging activities (LaSalle 1990). Kohn et al. (1994) determined that median lethal concentrations (96-hour exposure) for marine or estuarine amphipods ranged from about 50 to 148 mg/l total ammonia.

Water column impacts at dredging sites include increased oxygen demand, releases of contaminants and nutrients (Allen and Hardy 1980). Dredging operations that involve suspension of sediments can also increase the concentration of associated chemical contaminants in the water column (McFarland et al. 1989a). Anchor Environmental (2003) found that resuspended sediments can cause changes in ambient water chemistry such as pH and dissolved oxygen content.

Wakeman (1977) reported that concentrations of heavy metals increased near dredging and disposal operations in San Francisco Bay.

6.3.3.2 Acute Toxicity

Wakeman et al. (1988) found that dredging operations have the potential to redistribute and release contaminants to the biota of San Francisco Bay. This may result in an acute or subacute toxic effect to organisms (Hirsch et al. 1978).

Dredged material from harbors or other heavily industrialized waters may also contain substantial amounts of heavy metals, oils, greases, pesticides, PCBs, other toxic substances (Allen and Hardy 1980).

Studies have shown that concentrations of PCBs are significantly higher in juvenile chinook salmon from the San Francisco Bay (when compared to hatchery fish in Delta), while concentrations of PAHs are not significantly higher. However, concentrations of high molecular weight aromatic hydrocarbons are significantly higher (Casillas 1993). However, there is no evidence that the elevated contaminant concentrations in San Francisco Bay biota are directly attributable to dredging operations.

6.3.3.3 Pathways

Contaminants may be released to the water column and made available for uptake by organisms through contact with suspended material. Studies have shown that suspended sediments can provide a transport pathway for contaminants (Schoellhamer and Warner 2001).

6.3.3.4 Exposure Points

Information on exposure points in the Bay was provided in the LTMS EIS/EIR (1998; see Section 6.2).

6.3.3.5 Bioavailability

Contaminants associated with resuspended sediments become bioavailable to organisms when released in dissolved state to the water column (Gambrell et al. 1976, Anchor Environmental 2003). Allen and Hardy (1980) reported that the presence of contaminants in dredged material provides a potential for uptake. Studies by McFarland et al. (1989a) showed that dredging operations that cause suspension of sediments can increase the concentration of chemical contaminants in the water column. On the other hand, particulate organic matter can act as a scavenger of metals and organic chemicals from solution, thereby reducing the bioavailable fraction in the water column. Suspension of uncontaminated sedimentary material has been demonstrated to reduce the bioavailability of contaminants by adsorbing them from solution (McFarland et al.

1989a). In 1988, Wakeman et al. showed that disturbance of the bottom by dredging equipment during excavation process has the potential of affecting sediment chemistry and increasing contaminant bioavailability.

O'Connor (1992) discussed molecules that are absorbed to or present in particulate matter (e.g., suspended solids, detritus, other organisms) and have a higher chemical affinity for the epithelium of the "target" organism than for the source material. The physiochemical changes resulting from suspension may influence transformations of mercury, lead, and zinc into more bioavailable chemical forms (Gambrell et al. 1980).

6.3.3.6 Bioaccumulation

Suspension of contaminated sediments in contaminant-free water has been reported to result in bioaccumulation by exposed organisms (McFarland et al. 1989b). Hirsch et al. (1978) described bioaccumulation of toxicants through the food web. Allen and Hardy (1980) indicated that pesticides, PCBs, and ketones biomagnify in organisms as compounds are transported to higher trophic levels. Concerns regarding bioaccumulation of mercury in aquatic organisms following a dredging operation were expressed by Lee and McFarland (2000).

Nightingale and Simenstad (2001) briefly discussed the long-term affects of contaminants and bioaccumulation associated with dredging activities. A local study found dredging activities related to quantities of suspended sediment in Central Bay waters and their associated burdens of chemical contaminants (O'Connor 1992).

6.4 Current Stakeholder Concerns Related to Dredging

A key element in development of this framework has been the goal of addressing concerns about the effects of dredging on the five currently designated windows fish species as expressed by the resource and other agencies and stakeholder participants in the Work Group. Information about these concerns was obtained from a priority matrix (Section 6.4.1) and interviews of stakeholders (Section 6.4.2).

6.4.1 Priority Matrix

To identify and focus agency concerns associated with dredging, the Work Group developed a matrix of effects topics and windows fish species. Early versions of the matrix were denominated a "data matrix." The topics contained in the matrix were compiled from stakeholder input in the initial meetings of the Work Group. After agreement on the final version, four agencies (NOAA Fisheries, USFWS, CDFG, and BCDC) populated the matrix with a simple priority ranking (see Figure 10). In this "Priority Matrix," "1" indicates a high priority, "2" indicates a moderate priority, and "3" indicates a low priority rating given to each topic for each species (and in some cases, different life stages of a species). The ranking values were intended to indicate a priority of sequencing for the topics, i.e., topics ranked "1" are indicated as those which should be evaluated in initial studies. The rankings were not intended to indicate greater or lesser perceived effects.

6.4.2 Stakeholder Interviews

To obtain more specific information about stakeholder concerns than was practicable in Work Group meetings, a series of interviews was conducted with representatives of stakeholders involved in the LTMS process. The organizations interviewed included all of the resource agencies (NOAA Fisheries, USFWS, CDFG) as well as three of the LTMS agencies (BCDC, USEPA, and USACE). The fourth LTMS agency, the Regional Water Quality Control Board-San Francisco Bay Region, was not interviewed because its representative had recently retired and a new representative to the Work Group had not been identified. Thus, input from this organization will be incorporated at a later time. Additionally, representatives of the two largest ports in the Bay were interviewed.

It is important to note that, although the persons interviewed were participating in the Work Group and were involved directly in dredging issues in the Bay on behalf of their respective organization, the information obtained in the interviews did not arise from a full organizational review. Therefore, the interview results may not necessarily reflect all concerns which could be identified if such an expanded and formal review were to be conducted. Nevertheless, it was considered that this collective cross-section of stakeholder feedback would likely identify the most significant concerns and that any topics of interest that may not have been listed initially would be identified as the process of the Work Group advanced.

The interview process employed was as follows. Interviewees were provided with information in advance of the meeting, including the list of topics identified in the priority matrix. The interviewee was asked to spend some time before the interview to consider what their concerns were and to identify any study topics that could address one or more issues. The interviewer brought to the meeting several resources, including the list of topics, copies of biological opinions, references on species biology and key references on the effects of dredging. However, for the most part, the interviewees did not need to examine the resource materials. The interview format was informal and the interviewee was encouraged to guide the conversation. The only request from the interviewer was that all of the topics and all of the fish species of concern to the interviewee should be discussed. As the interview progressed, the interviewer asked questions to clarify concerns or provoke additional response. In most interviews, the interviewee sequentially commented on the topics in the list. In some interviews, the discussion focused on various species, regions of the Bay or more specific locations or dredging projects. The interviewer recorded topics of concern and particularly took note of ideas for studies that could assist in the evaluation.

7.0 EVALUATION AND SCIENCE FRAMEWORK

The information presented in previous sections indicates that the dredging scenarios with the greatest potential to produce significant direct effects on windows fish species have been for the most part mitigated by the existing work windows and associated restrictions. There was no indication that the work windows have failed in their overall objective to protect sensitive species and there is no clear evidence (e.g., direct fish mortality during dredging operations) suggesting that such protection is grossly ineffective.

The focus of this evaluation is therefore on addressing existing data gaps and remaining uncertainties that if better resolved could result in more informed and effective protection of sensitive fish species. Better information about these topics would enable agency personnel to more effectively protect the species by focusing on the most critical issues. Better information about dredging effects may also provide insights concerning additional protective measures. At the same time, such information could further facilitate the permitting and operation of dredging projects. Furthermore, it is possible that better information could lead to more flexibility for dredging operations in locations or at times when the species is not present or unlikely to be affected by dredging operations.

This section includes discussions of the subjects of concern identified by the stakeholders and descriptions of studies that could be conducted to evaluate the high priority effects of dredging on each of the windows fish species.

7.1 General Stakeholder Concerns

Before discussing current stakeholder concerns in more detail, the following discussion of general concerns will assist the reader place the detailed discussions that follow into a broader context.

One of the concerns of the resource agencies (given that the work windows are in effect) involve indirect, sublethal or subtle potential effects that could significantly affect species populations in a variety of ways, but which may not be easily detected. Many of these concerns are associated with environmental parameters where there are ambient (i.e., non-dredging induced) levels present in the Bay. In these instances, the potential effects of dredging must be evaluated as an incremental change in ambient ("background") conditions. An example of this type of concern is the effect of suspended sediment plumes produced by dredges in the Bay, which is characterized by high and highly variable ambient suspended sediment concentrations.

Another major concern expressed by the resource agencies is the uncertainty associated with the distribution of fish in the Bay, both spatially and temporally. The premise of the work windows concept is that if dredging operations do not occur when the species is seasonally present, then there will be no effects. The effectiveness of this approach is therefore directly dependent on accurate knowledge of the seasonal presence of species in various regions of the Bay. If the species is in fact present when the work window is open, the window may be insufficiently protective. The available information reviewed in previous sections indicates that, while there is reasonably good information on seasonal timing for some species (e.g., adult salmonid inmigration), there is considerable uncertainty (or lack of information) for others. Furthermore, even if acceptable information is available (i.e., for prior periods) there may be uncertainty associated with predictions based on such information, especially in a highly dynamic estuarine system, on interannual or decadal timescales.

Some of the stakeholders associated with the ports and dredging community expressed concern that the work windows and/or restrictions associated with permits for work during closed window periods may be too restrictive. For the most part, this perception arises because the information upon which such decisions were made appears tenuous to these stakeholders. They maintain that certain restrictions appear overly precautionary as a result. In reference to the uncertainty associated with the presence of windows species in the Bay as discussed in the preceding paragraph, these stakeholders have a different perspective. If the species is not present when the window is closed, the window may be overly protective and unjustifiably restrictive of dredging activities.

Another issue expressed in the Port of Oakland and Port of San Francisco interviews concerned the herring window. The interviewees felt that the restrictions placed on dredging related to the herring window were similar to those imposed for the threatened and endangered species. However, herring is a commercially exploited species in the Bay. Because this issue relates to policy questions, it is not addressed in this report. A number of herring studies are identified later in this chapter.

A key point regarding the discussion of work windows is that in reality most, if not all, dredging projects are subject to more than one work window with variable timeframes. Therefore, from a project perspective, if more than one applicable work window is overly narrow, the restriction on the project is potentially compounded.

Perhaps the most important question left unanswered in the work windows scheme, for both open and closed periods, is: If the species is present, will dredging operations have an adverse effect? During closed periods, this question is addressed via individual project consultations; however, agency personnel expressed concerns that in some instances there is little information upon which to make such determinations.

There are three general criteria by which any potential condition associated with dredging may be determined to be acceptable:

1) The species is not present at the time of the condition and the condition has no residual effect on habitat quality by the time the species is present.

2) The species is present, but the condition has no effect on the species or its habitat.

3) The species is present and the condition likely has an adverse effect on the species and/or its habitat, but the degree of adverse effect is considered acceptable under regulatory criteria.

These criteria reveal a key point associated with the dredging effects evaluations discussed later in this chapter: there may be more than one investigative approach available to resolve a particular uncertainty. Returning to the example described above, concerning the effects of dredging plumes on fish, this question might be resolved either by better information on the presence of fish or by an evaluation of plume effects.

The specific concerns of the agencies are addressed below and, based on the information presented in the foregoing sections, potential study topics are described for addressing those concerns. The two primary purposes of this report were to identify the agencies' concerns and to identify those study topics associated with the greatest concerns so that a series of studies could be initiated. Accordingly, the following discussion focuses on the highest priority topics identified by resource agency and BCDC staff. Moderate and low priority topics are noted but detailed discussion of lower priority topics is deferred to a later time.

7.2 Specific Concerns and Study Topics

This section includes discussions of agency concerns expressed in the interviews associated with the topics that were ranked as high priority. Based on that information, studies are identified and described. Dredging effects topics identified by the Work Group (including the agencies) are grouped into three major categories: biological effects (Section 7.2.1), physical effects (Section 7.2.2), and water quality and contaminant effects (Section 7.2.3). Toxicological effects are included in the latter section.

Development of a comprehensive framework of potential studies comprising the wide range of topics identified by the Work Group was challenging because of the interrelationships of many of the topics. Some topics, such as suspended sediment plumes, would contribute crucial information to a number of other study topics. In other cases, study topics may be most appropriately combined into a single study, e.g., plume geochemistry (discussed under the water quality topic) and suspended sediments. After careful consideration of various alternatives, it was decided to address each topic identified by the Work Group as a separate subject of discussion and within which study topics are identified. Some concerns associated initially by the agencies with certain topics are referred to other topics for consistency.

Each topic section begins with a review of the Priority Matrix developed using input from four agencies (USFWS, NOAA Fisheries, CDFG, and BCDC). The purpose of the matrix was to focus initial discussion on the topics of greatest concern for each windows species; accordingly, those species or life stages that were ranked high priority are addressed in the section. Next, a summary discussion identifies the specific issues associated with each species. Species were grouped together, as appropriate, when an issue had substantially similar effect or shared a study approach.

Following the issue discussion, potential study topics were identified. Each study topic was assigned a code based on the category and subject (e.g., the first study topic recommended for Distribution in the Biological category was coded "B-Dist-1"). The study topic was also assigned a title. For each topic, a description is provided of the broad scope that the study would encompass. In some descriptions, follow-on studies are identified.

As stated above, the study topics are frequently interrelated, sometimes in complex ways, and it is likely that some studies described under different topics would be combined when they are implemented. To assist in understanding the interconnections of the studies, references are made to other studies, as appropriate. Study topics and their relationships are presented in Table 7-1.

7.2.1 Biological Effects

This section includes topics that were grouped into the biological effects category: distribution, behavior, migration, feeding, spawning, development, and fish injury.

7.2.1.1 Distribution

Dredging effects associated with distribution were rated a high priority for juvenile chinook and coho salmon, juvenile steelhead, and herring larvae and juveniles. These stages are known to occupy the Bay for rearing periods before migrating to coastal waters. Information exists indicating the general periods that these fish are in the Bay, but there is little information concerning spatial distribution and residence periods are not well defined. Better information on the spatial and temporal distribution of fish could contribute to a refinement of the windows and enable more effective (i.e., more focused) protection of populations.

Study Descriptions:

<u>Study Topic B-Dist-1. Spatial and temporal distributions of chinook and coho salmon in the Bay</u>. The purpose of this study would be to determine the spatial and temporal distributions of salmon in the Bay. Limited information is available, and this study would identify data gaps, determine data needs, and collect additional data.

Phase 1 – Literature and Existing Information Review. A first phase could involve review of the literature and available unpublished data on the distribution of both adult and juvenile chinook and coho salmon in the Bay to determine the state of current knowledge. Because there are no known extant populations of coho in the Bay, as a practical matter, this study will focus on chinook salmon. The geographic focus of this study could be on the central and north bays eastward to the boundary of the study area. As discussed previously, adult salmon migrating upstream are thought to be more limited spatially and temporally in the Bay. The spatial and temporal distribution of juveniles is less well known. The study could be complex because of the various runs of chinook which have different timing and may have different periods of residence. The relative rearing periods in tributaries versus the Bay would be important information for this study. Habitat preference could provide useful information, if juvenile salmon were shown to occur primarily in tidal marshes, or in Bay shoal areas with defined characteristics. Elements of study topic B-Migr-1 may be incorporated into this study. Overlap of distributions of this species with dredging operations could be determined by comparison with the results of support activity Tech-Sup-5.

Phase 2 – Field Data Collection. A second phase could involve collection of field data. The scope of this phase could be developed following completion of phase 1. Because chinook is a sensitive species, destructive sampling should be avoided. Therefore, if field data collection is considered desirable, the feasibility of using non-destructive methods, such as sonic tagging or ultrasonic telemetry (Quinn 1990), should be investigated. Any of a variety of study scales (e.g., habitat-related, local, regional or Bay-wide) would provide useful information.

<u>Study Topic B-Dist-2. Spatial and temporal distributions of adult and juvenile steelhead in the Bay</u>. The purpose of this study would be to determine the spatial and temporal distributions of steelhead in the Bay. Significant data gaps likely exist, and the low density of populations may present challenges to filling those gaps.

Phase 1 – Literature and Existing Information Review. A first phase could involve review of the literature and available unpublished data on the distribution of both adult and juvenile steelhead in the Bay to determine the state of current knowledge. The spatial and temporal distribution in the Bay of juveniles and adults is not well known. For adults, the geographic focus of this study could be on known or suspected steelhead streams in the study area, which may include all regions of the Bay. Habitat preference could provide useful information, if juvenile steelhead were shown to occur primarily in tidal marshes (Leidy 2000), or in Bay shoal areas with defined characteristics. Elements of study topic B-Migr-1 may be incorporated into this study. Overlap of distributions of this species with dredging operations could be determined by comparison with the results of support activity Tech-Sup-5.

Phase 2 – Field Data Collection. A second phase could involve collection of field data. The scope of this phase could be developed following completion of phase 1. Because steelhead is a sensitive species, destructive sampling should be avoided. Therefore, if field data collection is considered desirable, the feasibility of using non-destructive methods, such as sonic tagging, should be investigated. Any of a variety of study scales (e.g., habitat-related, local, regional, or Bay-wide) would provide useful information.

<u>Study Topic B-Dist-3. Spatial and temporal distributions of herring larvae and juveniles in the Bay</u>. The purpose of this study would be to determine the distribution of herring larvae and juveniles in the Bay. Very little published information is available on this topic.

Phase 1 - Literature and Existing Information Review. A first phase could involve review of the available literature and unpublished data (particularly DFG data) on distribution of both stages in the Bay. Key unpublished sources of this information include historical fish sampling and particularly the data and knowledge of the DFG staff that manage the fishery. Overlap of distributions of this species with dredging operations could be determined by comparison with the results of support activity Tech-Sup-5.

Phase 2 – Field Data Collection. A second phase could involve collection of field data. The scope of this phase could be developed following completion of phase 1. Because herring is a managed species, limited destructive sampling could be considered. Key objectives of such a study would be to determine the relationship of larval distribution to water masses in the Bay and relationships between juvenile fish and preferred prey, as well as coastal out-migration timing.

<u>Lower Priority Topics:</u> Moderate priority was assigned to determining the distribution of delta smelt and herring eggs in the Bay. DFG's concern regarding herring spawning activity is addressed in Section 7.2.1.5. Detailed consideration of delta smelt distribution is deferred to a later planning phase.

7.2.1.2 Behavior

Dredging effects associated with behavior was rated a high priority for all species (including juveniles and adults of herring). Behavior is a general term that includes topics such as distribution, migration, feeding, avoidance, noise and exposure to plumes. These effects are addressed under those topics.

<u>Study Description</u>:

Refer to related topics for study descriptions.

7.2.1.3 Migration

Migration was rated a high priority for chinook and coho salmon, and steelhead. The temporal and spatial distributions of these species are addressed under study topics B-Dist-1 and B-Dist-2. The primary concerns expressed by NOAA Fisheries included fish avoidance of locations where dredging is occurring which could result in blocking migration or altering migration to less desirable routes. Blockage is likely to occur (if at all) only in very restricted locations where dredging activity could substantially occupy the migration route, such as narrow channels and tributary mouths. Completion of the study topics referenced above would identify such restricted locations where project-specific mitigation requirements could be developed (such as not dredging during the migration period in the location).

Study Description:

Study Topic B-Migr-1. Determine Constricted Migration Routes and Periods for Salmonids. The purpose of this study is to determine the location of narrow migration routes for chinook and coho salmon, and steelhead in the Bay that could be constricted as a result of dredging activity.

Phase 1 – Review Existing Information. A first phase could involve review of the literature and available information to determine known and potential migration routes and times of migration for juveniles and adults. Information on juveniles may be similar to that addressed under habitat modification discussed in Section 7.2.2.9 because the Bay may serve as a rearing habitat for juvenile salmonids. Related subjects that could be included in this review are behavioral attributes, environmental cues, habitat preferences (e.g., coarse sediments), and historic or potential future spawning areas (the latter particularly related to coho salmon and steelhead trout).

Phase 2 – Evaluate Spatial Relationship Between Migration Routes and Dredging Sites. This phase could identify which areas are in close proximity to dredging locations. This study could be included as an element in study topics B-Dist-1 and B-Dist-2. Overlap of distributions of migration routes with dredging operations could be determined by comparison with the results of support activity Tech-Sup-1.

Phase 3 – Conduct Field Studies. Depending on the results of the first two phases, a third phase could include further analysis of existing data or field studies to obtain new information. This could include sonic tagging techniques.

Lower Priority Topics: Moderate priority was assigned to determining the effects of disposal on delta smelt and effects of dredging were rated low priority for that species. Herring Larval, juvenile and adult effects were rated moderate by DFG and low by BCDC. Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.1.4 Feeding

Food sources were included in the Work Group's priority matrix. In this report, food sources are addressed in the habitat and food sources Section 7.2.2.9. "Feeding" in this discussion is considered to include adverse effects on fish feeding behavior as well as increased predation success on the species, primarily as a result of increased suspended sediment concentrations associated with dredging. Consideration of feeding activity of fish species was rated a high priority for chinook and coho salmon by NOAA. Because there are no known extant populations of coho in the Bay, as a practical matter, this study will focus on chinook salmon. It is generally thought that in-migrating adults either do not feed or feed very little when passing through the Bay. However, juvenile chinook may spend a longer period of rearing in the Bay. In the interview, BCDC expressed concern about increased predation on juveniles. The spatial and temporal distribution of juvenile chinook in the Bay may provide insights about the significance of temporary disruption of feeding (if any) in a location being dredged. Feeding effects were rated a high priority for both dredging and disposal effects on delta smelt.

Study Descriptions:

Study Topic B-Feed-1. Determine Effects of Dredging on Feeding by Juvenile Chinook Salmon. The purpose of this study would be focused on the effects of suspended sediment plumes on feeding by juveniles and predation of juveniles.

Phase 1 – Perform Literature Review. The first phase could involve review of the literature on effects of turbidity and suspended sediments on juvenile salmonid feeding and predation.

Phase 2 – Evaluate Effects of Dredging Plumes. The purpose of a Phase 2 study could be to determine the effect of turbidity and suspended sediments associated with dredging plumes on feeding by and predation upon juvenile salmonids. Results of study topics P-Sup-1 and –2 relative to turbidity would be inputs to this study.

Study Topic B-Feed-2: Determine Effects of Plumes on Feeding and Predation of Delta Smelt. The purpose of this study is to determine how dredging plumes affect feeding activities by and predation on delta smelt.

Phase 1 – Conduct Literature Review. This study could involve review of literature on delta smelt and related species regarding feeding behavior and avoidance of predators in sediment plumes. Additional phases would depend on the results of the first phase.

Lower Priority Topics: Feeding concerns relative to steelhead were rated moderate (BCDC) or low (NOAA, DFG - adults). Feeding concerns relative to herring larvae and juveniles were rated moderate and for adults low by DFG. BCDC rated herring as a moderate concern. Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.1.5 Spawning

Dredging effects associated with spawning were rated a high priority for delta smelt (dredging and disposal) and herring adults. This section addresses the behavioral aspects of spawning. Spawning success as measured by hatching is addressed under sedimentation and toxicity. Spawning habitat effects are addressed under habitat.

USFWS concerns regarding delta smelt spawning primarily relate to sedimentation and associated contaminants.

Dredging effects associated with spawning were rated a high priority for herring by DFG. DFG has expressed concerns about the potential for dredging operations to modify spawning behavior when dredging occurs in close proximity to potential spawning habitat. Modified spawning activity could result in adverse affects on the spawning process, reduced amount of spawn and/or prevention of spawning. The characteristics of dredging most likely to cause such effects are noise and increased suspended sediment concentration, water quality, and toxicity effects associated with the sediment plume. Descriptions of studies for addressing these topics are described in the relevant sections of this chapter.The concern of DFG regarding adult herring relates to adults avoiding a spawning area because of dredging operations. This issue is addressed in Section 7.2.2.3 under study topic P-Av-1. Another DFG issue was a desire to obtain better information on herring spawning in locations deeper than those that are currently monitored.

Study Descriptions:

Study Topic B-Spawn-1. Determine Effects on Spawning of Delta Smelt. The purpose of this study would be to evaluate the effects of suspended sediment plumes on delta smelt.

Phase 1 – Literature Review. This phase could involve review of literature on effects of plumes on spawning activity in delta smelt. Because little is known about spawning in this species, literature of related and/or similar species would need to be reviewed.

Phase 2 – Evaluate Suspended Sediment Effects. This phase could use information developed in Section 7.2.2.10 for likely delta smelt spawning habitat together with the results of the literature review to determine potential effects of plumes on spawning in this species.

Study Topic B-Spawn-2. Determine Extent of Herring Spawning in Deeper Water. The purpose of this study would be to obtain more information on spawning activity that occurs below DFG's current monitoring sites (i.e., below wadeable depths at low tide). Fishermen have provided anecdotal reports of spawning at those depths. DFG has indicated that the presence of more extensive spawn than is currently recorded would assist in evaluating risk to the population.

Lower Priority Topics: Spawning concerns were rated a low priority for chinook and coho salmon and steelhead. Because dredging rarely if ever occurs near spawning habitat for these species, no further evaluation may be needed for this topic.

7.2.1.6 Development

Dredging effects associated with development was rated a high priority for herring larvae, juveniles and adults by DFG and BCDC. DFG expressed concern that dredging operations in the Bay could reduce herring larval and juvenile development if those life stages were exposed to the operations. However, before this subject can be evaluated, the distribution of these life stages in the Bay may need to be determined, as recommended in study topic B-Dist-3. Clarification is needed from DFG regarding the effects of dredging on the development of adults.

Study Descriptions:

Study Topic B-Dev-1. Determine Effects of Suspended Sediment Plumes on Herring Larvae and Juveniles. The purpose of this study would be to determine the effects of suspended sediment plumes on herring larvae and juvenile feeding and predation.

Phase 1 – Review and Evaluate Literature. In phase 1 of this study, the literature on herring larvae and juveniles could be assembled and evaluated, particularly regarding effects of suspended sediments.

Phase 2 – Evaluate Potential Effects of Suspended Sediment Plumes. In this phase, the results of the first phase could be evaluated together with the results of study B-Dist-3 and studies P-Susp-1 to –3.

Study Topic B-Dev-2. Determine Effect of Suspended Sediment Plumes on Herring Adults. Before this study can be described, further clarification from DFG is needed regarding their concerns about the effects of dredging on the development of adults.

Lower Priority Topics: Effects of dredging on development of chinook and coho salmon were rated low by NOAA Fisheries and BCDC and moderate by DFG. Ratings for delta smelt were moderate. Effects on steelhead were rated high by BCDC, moderate by DFG and low by NOAA Fisheries. Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.1.7 Fish Injury

Dredging effects associated with fish injury was not included in the priority matrix because the Work Group did not consider this topic to be of concern; however, it is included in this report for completeness because this topic has been addressed in the literature on dredging effects on fish. Effects of entrainment (including fish injury associated with entrainment) is addressed in Section 7.2.2.4. Fish injury could result from direct contact of the fish with the dredge unit. The species and life stages of concern in the Bay environmental windows are most likely either nektonic or, if demersal, are thought to occur primarily in shallow and/or sensitive habitats in the Bay. Dredging occurs on the bottom and ordinarily would be permitted in such habitats only after careful evaluation. Consequently, this topic was not considered to be of sufficient likely importance to be evaluated.

Study Description:

No further evaluation may be needed on this topic unless the results of the B-Dist studies indicate that life stages unable to avoid contact with dredge equipment occur frequently in dredging locations.

7.2.2 Physical Effects

This section includes topics that were grouped into the physical effects category: disturbance, displacement, avoidance, entrainment, burial, sedimentation, noise, turbidity, habitat and food source modification, suspended sediments, and sediment type.

7.2.2.1 Disturbance

Dredging effects associated with disturbance were rated a high priority for chinook and coho salmon by NOAA Fisheries and BCDC but moderate by DFG. NOAA indicated in the interview that this rating referred to changes in sediment type; therefore, this concern is addressed in study P-Hab-2. Disturbance was rated high for delta smelt (dredging) and all stages of herring. "Disturbance" is a general term that includes such effects as displacement, avoidance, noise and other more specific topics that are addressed in other sections. The same high priorities were given for these species in one or more of those topics.

<u>Study Description</u>:

Refer to related topics for study descriptions.

<u>Lower Priority Topics:</u> Disturbance was rated a moderate concern of disposal on delta smelt. Ratings for steelhead were high (BCDC), moderate (DFG), and low (NOAA Fisheries). Detailed consideration of this topic is deferred to the related topics identified above or to a later planning phase for these species.

7.2.2.2 Displacement

Dredging effects associated with displacement were rated a high priority for chinook and coho salmon, delta smelt, and herring (eggs, juveniles, and adults). "Displacement" is similar to "avoidance" but in this discussion, displacement is defined as an effect that causes fish to leave an area that is normally occupied. In practice, these two terms may not represent different effects on fish. Displacement effects associated with migration routes and spawning activities are addressed under those topics.

This discussion focuses on effects associated with fish rearing in the Bay. Temporary displacement of fish at the point of dredging (i.e., "near-field" effects) is presumed to occur if fish are present. This temporary displacement probably does not represent a concern. Long-term displacement resulting from changes in the site as a result of dredging (i.e, increased depth, surface sediment changes, etc.) are addressed under the habitat discussion. The remainder of this discussion considers the temporary displacement of fish outside of the immediate location of the dredge (i.e., "far-field" effects). A study conducted at the Alcatraz disposal site by Burcynski (1991) concluded that fish disappeared from the area for up to two to three hours following discharge. It is not known whether or not the fish detected in that study included any of the species addressed in this report. The disposal plume is different from a dredging plume and the authors were not certain that the fish movement was attributable to the discharge or to changes associated with tidal mixing.

Delta smelt occur at shallow depths in the northeast portion of the LTMS management area. Based on the interview, USFWS is concerned about the potential for displacement of delta smelt, particularly from dredging in marinas. If marinas can be shown not to be habitat for delta smelt, there would be less concern about dredging in these locations.

Study Descriptions:

Study Topic P-Disp-1. Determine Displacement Effects on Juvenile Chinook Salmon. The purpose of this study would be to determine the temporary far-field displacement effects of dredging on juvenile chinook salmon.

Phase 1 – Perform Literature Review. This phase could involve assembly and review of literature on avoidance responses and a comparison with dredging conditions. If displacement appears likely, a plan could be developed to conduct additional evaluation.

Phase 2 – Perform Additional Evaluation. Depending on the results of phase 1, additional evaluation could be conducted.

Study Topic P-Disp-2. Determine Displacement Effects on Delta Smelt. The purpose of this study is to determine if dredging causes far-field displacement of delta smelt.

Phase 1- Evaluate Marinas as Habitat. The initial focus of this study could be on determining whether or not marinas in the northeast portion of the LTMS management area represent a permanent habitat for delta smelt.

Phase 2 – Determine Reactions to Dredging. Literature and other information could be gathered to determine whether or not smelt would be displaced by dredging activities.

Phase 3 - Conduct Additional Evaluations. If marinas are determined to be permanent habitat and dredging could result in displacement, additional evaluations could be conducted focusing on minimizing displacement.

Lower Priority Topics: Effects of disposal on delta smelt were of moderate concern. Effects of dredging on steelhead were high (BCDC), moderate (DFG), or low (NOAA Fisheries); and moderate for larval herring. Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.2.3 Avoidance

Dredging effects associated with avoidance were rated a high priority for chinook and coho salmon, steelhead and herring (larvae, juveniles, and adults). "Avoidance" is similar to "displacement" but in this discussion, avoidance is defined as an effect that causes fish to not occupy an area that is periodically or infrequently occupied. In reality, these two terms may not represent different effects on most fish. Most agency concerns for chinook and coho salmon and steelhead are associated with dredging operations causing avoidance of migration routes. This issue is addressed in Section 7.2.1.3, study topic B-Migr-1.

Avoidance effects on herring larvae and juveniles would be most effectively evaluated after the results of study topic B-Dist-3 are available. The potential for dredging to cause herring to avoid spawning in nearby locations is of great concern to DFG and this issue was also given high importance in the Port of San Francisco interview. The characteristics of dredging most likely to cause avoidance are noise and increased suspended sediment concentration, water quality, and toxicity effects associated with the sediment plume. Study Descriptions for addressing these topics are described in the relevant section of this chapter.

Study Descriptions:

Study Topic P-Av-1. Determine Adult Herring Avoidance Responses. The purpose of this study would be to determine whether or not herring adults approaching a spawning area would avoid the area as a result of dredging operations, and if so, to what degree. Most likely, there is little or no literature that would resolve this issue. Accordingly, a literature review could be incorporated as part of a field study. A study design could be crafted working closely with DFG biologists and using interviews of dredgers, fishermen, and others who may be able to provide anecdotal information that could inform the design. The Port of Oakland revealed in the interview that dredgers have reported herring spawning on dredging equipment. This information could be collected and incorporated into the evaluation. One possible approach could conduct an intensive monitoring study based on the existing requirements for dredging monitors in spawning areas. Another approach could simulate dredging conditions on a small scale in a spawning area as a pilot test. A third approach could document environmental conditions (e.g., suspended sediment concentrations, noise levels) in nearshore spawning areas and compare the results to conditions during dredging operations. The results of studies identified in the sections on suspended sediment concentration, water quality, and toxicity may also provide input to this study.

Study Topic P-Av-2. Determine Avoidance Response of Herring Juveniles. The purpose of this study could be to determine the effect of dredging on juvenile herring that rear in the Bay. This study could be approached in two different ways. The distribution of juveniles in the Bay could be determined and if they do not occur in areas that are dredged, there would be no avoidance effect. Alternatively, an evaluation could be performed to determine if juveniles would avoid conditions associated with dredging. In either approach, the results of study B-Dist-3 would provide important input to this study. The results of studies identified in the sections on suspended sediment concentration, water quality, and toxicity may also provide input to this study.

Study Topic P-Av-3. Determine Larval Herring Avoidance Response. The purpose of this study could be to determine the effect of dredging on larval herring that rear in the Bay. This study could be approached in two different ways. The distribution of larvae in the Bay could be determined and if they do not occur in areas that are dredged, there would be no avoidance effect. Alternatively, an evaluation could be performed to determine if larvae would avoid conditions associated with dredging. In either approach, the results of study B-Dist-3 would provide important input to this study.

The results of studies identified in the sections on suspended sediment concentration, water quality, and toxicity may also provide input to this study.

Lower Priority Topics: Avoidance was rated a moderate priority for delta smelt. Detailed consideration of this topic is deferred to a later planning phase for this species.

7.2.2.4 Entrainment

Dredging effects associated with entrainment were rated a high priority for chinook and coho salmon, steelhead, and herring larvae and juveniles. The concerns expressed by NOAA Fisheries and DFG on salmonids were primarily associated with juveniles and hydraulic dredging. Studies on entrainment by dredging generally indicate that entrainment risk varies significantly with the type of dredge but that the greatest risk is associated with benthic-associated fish (i.e., sediment-dwelling or strictly demersal species – see Section 6.3.2.4). Juvenile salmonids rearing in the Bay are likely to be sufficiently mobile that they can generally avoid entrainment; however, the literature could be reviewed to provide more detail regarding this issue. Also, the results of the B-Dist-1 study topic could assist in evaluating the potential exposure of juveniles to entrainment risk.

Similarly for herring larvae and juveniles, what is known about larval and young herring juvenile mobility could be reviewed and the results of study topic B-Dist-3 could be considered to determine if further studies are needed.

Study Descriptions:

Study Topic P-Ent-1. Determine Entrainment Risk to Juvenile Salmonids. This study could involve a review of juvenile salmonid and dredging entrainment literature for hydraulic dredging to evaluate the risk of entrainment. Included could be an evaluation of the distribution of the fish with dredging locations using the results of study topic B-Dist-1.

Study Topic P-Ent-2. Determine Entrainment Risk to Larval and Young Juvenile Herring. This study could involve a review of herring and dredging entrainment literature to evaluate the risk of entrainment. Included could be an evaluation of the distribution of the larvae and juveniles with dredging locations using the results of study topic B-Dist-3.

Lower Priority Topics: Entrainment was rated a moderate concern by USFWS for delta smelt. Detailed consideration of this topic is deferred to a later planning phase for this species.

7.2.2.5 Burial

Dredging effects associated with burial were rated a high priority for delta smelt (disposal) and herring eggs. Burial can be a major topic of concern relative to disposal of dredged materials (as expressed by USFWS). With respect to dredging, there is less potential for burial. Essentially all burial from dredging would occur as a result of sedimentation (i.e., deposition of solids suspended during dredging operations). Priorities assigned to burial were very similar to those assigned to sedimentation. For these reasons, burial effects for herring eggs are addressed in study P-Sed-1 in Section 7.2.2.6.

Study Description:

Refer to studies under the sedimentation topic.

Lower Priority Topics: Burial was rated a moderate concern for delta smelt (dredging) and herring larvae. It was ranked as low priority for chinook and coho salmon, and herring juveniles and adults. Detailed consideration of this topic is deferred to a later planning phase for these species/life stages.

7.2.2.6 Sedimentation

For reasons discussed above, sedimentation and burial are considered together in this section. Dredging effects associated with burial and sedimentation were rated a high priority for delta smelt associated with disposal (burial), steelhead, and herring eggs. However, in the NOAA interview, sedimentation was indicated not to be of high priority for steelhead. Burial is considered to be primarily a suffocation effect in this report. Sedimentation effects include gill clogging, abrasion, and related effects. Sedimentation was of concern relative to delta smelt spawning as indicated in Section 7.2.1.5.

DFG is very concerned about the potential adverse effects of burial on herring eggs as a result of increased sedimentation from dredging plumes. Studies on herring egg survival in the laboratory have demonstrated that high levels of sedimentation result in increased mortality (see Section 6.3.1.5). (For this discussion, egg mortality and abnormal development are considered equivalent.) There is also an indication that mortality of eggs buried deep in the egg mass may occur without sedimentation (see Section 4.4.2). The most important factor in this mortality may be low rates of oxygen diffusion to the eggs; however, other factors could also play a role (e.g., reduced ability for diffusion of waste products, increased pathogenic activity, or toxicity resulting from biogeochemical changes at low oxygen levels). Ambient levels of suspended sediment in the Bay are relatively high when compared with other large Pacific Coast estuaries. Herring generally spawn in shallow areas where water movement may mitigate sedimentation effects. These factors indicate that comprehensive evaluation of the potential effects of dredging on herring egg mortality would be complex and would need to involve a multi-faceted approach.

Study Descriptions:

Study Topic P-Sed-1. Determine Sedimentation Effects on Delta Smelt Spawning. The purpose of this study would be to determine the effects of suspended sediment plumes on spawning activity and eggs of delta smelt; however, as discussed above, it is not currently known where delta smelt spawn.

Phase 1 – Determine Location of Spawning. This phase could conduct field research to determine where smelt spawn; however, despite extensive research, this information is not available. Therefore, it may not be feasible to obtain this information.

Phase 2 – Determine Sedimentation Effects on Surrogate Species. Pending availability of information on delta smelt spawning, an alternative option could be to select a surrogate species and conduct a literature review or laboratory studies on the effects of sedimentation on that species.

Study Topic P-Sed-2. Determine Sedimentation Effects on Herring Eggs. A first phase in this study could involve review of information on herring eggs, sedimentation rates, and factors affecting egg mortality, with special emphasis on Bay conditions associated with known spawning areas. Subsequent phases could include the following investigation topics (Note: The intent of presenting these topics is not to suggest that all may need to be conducted. A variety of potential study topics is presented to assist the stakeholders in selecting an appropriate approach.):

1) Laboratory studies on the effects of sedimentation on Bay herring eggs, using Bay sediment. Determination of the relationship of sedimentation to mortality, factoring in egg mass (egg depth or other appropriate parameter).

2) Field experiments on sedimentation effects on herring eggs. One approach would be to transplant eggs from natural spawning areas to comparable but non-spawning areas where dredging is occurring. Another approach would be to transplant eggs into a variety of locations with different sedimentation rates

3) Characterization (via field measurements or modeling) of suspended sediment plumes associated with dredging in areas near known herring spawning areas. Field measurements could take place in such locations during periods when herring are not

spawning. This may include determination of sedimentation rates. Appropriate parameters would need to be recorded so that environmental differences between the study period and herring spawning season could be accounted for.

4) Characterization of ambient suspended sediment concentrations in herring spawning areas during spawning season. This may include determination of sedimentation rates. This study would indicate the range of natural sedimentation on herring eggs. Another purpose of this study would be to assess the potential effect of excessive sedimentation on exploring adults to determine its effect on rejecting otherwise acceptable spawning habitat.

5) Determination of the co-factors associated with sedimentation in areas of the Bay where herring spawn (i.e., particle size, water movement, etc.). This study would provide information to assist in interpreting the effects of various sedimentation rates on herring egg mortality.

6) Determination of herring egg mortality under natural conditions. Understanding the natural levels of egg mortality (and factors associated with mortality) would assist in the overall evaluation of dredging effects. Furthermore, understanding egg mortality could be an important parameter in monitoring and managing the stock.

Lower Priority Topics: Burial and sedimentation were considered to be of low priority for chinook and coho salmon (moderate for sedimentation for chinook and coho salmon by DFG), moderate for delta smelt (dredging, and disposal for sedimentation), moderate (burial) or low (sedimentation) for herring larvae and low for herring juveniles and adults. Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.2.7 Noise

Dredging effects associated with noise were rated a high priority for chinook and coho salmon by DFG (moderate by BCDC and low by NOAA Fisheries), high for steelhead by DFG (moderate by BCDC and NOAA Fisheries), and high for herring larvae, juveniles and adults. The dredging literature indicates that noise associated with dredging operations may affect fish behavior.

Study Description:

Study Topic P-Noise-1. Prepare Review of Literature on Noise Effects on Fish. Recently, a workshop was conducted on noise effects of pile-driving on fish in the Bay with special emphasis on exceptionally large pile drivers for bridge construction. This and other literature could be reviewed and information relevant to dredging noise and its effects could be summarized in a report. Any subsequent evaluations would depend on the outcome of this review.

Lower Priority Topics: Noise was rated moderate (dredging) or low (disposal) priority for delta smelt. Detailed consideration of this topic is deferred to a later planning phase for this species.

7.2.2.8 Turbidity (Optical Properties)

Dredging effects associated with turbidity were rated a high priority for chinook and coho salmon, and all stages of herring. Although turbidity is an optical measurement and is therefore a different parameter than suspended sediments which is a mass measurement, turbidity generated by dredging operations is essentially associated with the suspended sediment plume.

Study Description:

Turbidity may be evaluated in conjunction with suspended sediments. Evaluation of turbidity is included in the suspended sediment section.

Lower Priority Topics: Turbidity effects were rated moderate priority for delta smelt and steelhead (high by BCDC). Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.2.9 Habitat and Food Source Modification

Dredging effects associated with habitat and food source modification were rated a high priority for delta smelt (dredging and disposal), steelhead (moderate by DFG), and all life stages of herring. The concern expressed in the USFWS interview was to obtain better information on habitat requirements for delta smelt. In addition, NOAA's concern regarding disturbance from sediment changes for chinook and coho salmon are included in this section. USFWS indicated in the interview a concern regarding the effect of suspended sediment plumes on habitat for delta smelt. Sedimentation aspects for these species are discussed in Section 7.2.2.10. Contaminant aspects are addressed in Section 7.2.3.6. DFG's concerns regarding herring as discussed in the interview are associated with habitat modification. One concern is the effect of dredging on spawning habitat selection by adults. The potential for this effect to be expressed as avoidance or displacement is addressed in those sections. Another potential effect is excessive sedimentation, which could cause exploring adults to reject otherwise acceptable spawning habitat. This effect is addressed in the sedimentation section. DFG also indicated that better information on spawning in deeper areas than those the Department currently surveys would provide a more complete estimate of total Bay spawning activity. Another strong interest of DFG was to conduct a genetic study to determine whether there are identificable gene pools related to individual spawning schools or sites. There is some support for this idea in the literature. Hay and McKinnell (2002) concluded, based on a tagging study, that herring exhibit non-random association during periods of six months to several years.

Study Descriptions:

Study Topic P-Hab-1. Determine Effects of Habitat Modification on Steelhead. The purpose of this study would be to identify the potential effects of dredging on juvenile steelhead in the Bay.

Phase 1 – Review Existing Information and Evaluate Dredging Proximity. Phase 1 of this study could involve a review of existing information to determine the habitat preferences and uses of juveniles. The study could also examine the potential overlap between habitat and dredging operations. The latter could be accomplished by using the information provided by Tech-Sup-5.

Study Topic P-Hab-2. Determine Effects of Surface Sediment changes on Salmonid Smolt Habitat Preference. The purpose of this study could be to determine the effects of changes in surficial sediments from dredging relative to habitat preference for chinook smolts. NOAA indicated in the interview that a high priority for disturbance referred to changes in sediment type as a habitat preference.

Phase 1 – Perform Literature Review. The first phase of this study could entail review of the literature on habitat preferences of salmonid smolts. If habitat differences are indicated, phase 2 could be conducted.

Phase 2 – Evaluate Surficial Sediment Changes Resulting from Dredging. The purpose of this phase could be to determine whether dredging results in surficial sediments that are less preferable for smolts. Depending on the results, additional phases could be conducted. The results of support activity Tech-Sup-6 would assist in this phase.

Study Topic P-Hab-3. Determine Habitat Requirements for Delta Smelt. The purpose of this study would be to determine the specific habitat requirements for delta smelt and to determine whether habitat is likely to occur in areas that are dredged. Bureau of Reclamation, IEP and DFG data may facilitate this study.

Lower Priority Topics: Priorities for habitat and food source modification were moderate or low for chinook and coho salmon (some aspects rated high by BCDC). Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.2.10 Suspended Sediments

This topic considers only the physical effects of suspended sediments. Chemical effects associated with suspended sediment plumes are discussed in Section 7.2.3. Dredging effects associated with suspended sediments were rated a high priority for chinook and coho salmon, delta smelt, steelhead, and all life stages of herring. Concern regarding spawning effects on delta smelt (referred to this topic from Section 7.2.2.9) is also included here.

Increased suspended sediments resulting from dredging could adversely affect a wide range of topics discussed in other sections, including migration, feeding, spawning, development, displacement, avoidance, sedimentation, water quality, toxicity, and various other contaminant effects. Thus it is evident that suspended sediments is perhaps the most important consideration in evaluating the effects of dredging on fish. However, it is very important that consideration of the potential effects of suspended sediments from dredging on these aspects of fish biology and ecology be evaluated in the appropriate context. As previously discussed, Bay waters have high and highly varying ambient concentrations of suspended sediments. Dredging plumes generally need to be addressed as an incremental increase over ambient conditions, unless the dredging plume is qualitatively different from ambient suspended sediments. Secondly, dredging takes place in a limited portion of the shallow areas of the Bay and at any one time, in an even smaller fraction of the Bay. Finally, at any one location, dredging events are short-lived and occur at most annually and often at multi-year intervals.

Before addressing any other aspect of this topic, a clear understanding of the 3-dimensional extent of dredging plumes is desirable. This understanding should encompass the various dredging equipment (and other operational practices that affect plumes) used in the Bay and the range of site characteristics in which each type of equipment is used in the Bay (i.e., depths, currents, physical restrictions, sediment types).

Study Descriptions:

Study Topic P-Susp-1. Determine Extent of Suspended Sediment Plumes.

Phase 1 – MEC/ERDC 2003 Study. A first step in this study was completed in 2003 using an acoustic backscatter technique for a single dredging event.

Phase 2 - Calibrate ERDC's Plume Models. A second phase could calibrate ERDC's plume models using the results of the study conducted in Phase 1.

Phase 3 - Design Additional Studies. A third phase could evaluate the need for additional field data to more fully calibrate the model (i.e., different dredging equipment and different types of sites) and design an appropriate series of studies. This study could specifically address sedimentation in nearshore delta smelt habitat. One concern that was mentioned in the NOAA interview related to the suspended sediment plume from overflow discharge.

Phase 4 - Collect Additional Field Data. A fourth phase could carry out the additional field studies.

Phase 5 - Complete Calibration of the Model. A final phase could involve complete calibration of the model. Turbidity information could be obtained as well as input to study topic B-Feed-1.

Study Topic P-Susp-2. Determine Bay Ambient Suspended Sediment Concentrations. A clear understanding of Bay ambient suspended sediment concentrations is desirable before the effects of dredging plumes can be evaluated.

Phase 1 - Conduct Literature and Informaton Review. A first phase could involve review of the literature and other information and evaluation of the range of ambient conditions to which fish species occurring at dredging sites are exposed in the Bay.

Phase 2 – Collect Additional Data. Depending upon the results of Phase 1, additional data collection and/or analyses may be needed. Turbidity information could be obtained as well as input to study B-Feed-1.

Study Topic P-Susp-3. Determine the Effects of Suspended Sediment Plumes on Fish. The effects of suspended sediment plumes on fish could be evaluated. This would be a multi-phased study.

Phase 1 - Review Literature and Informaton. A first phase could involve review and summarization of the literature on the effects of suspended sediments on fish. This review could, to the extent possible, discuss the relationship between study conditions investigated in the literature and Bay conditions. Additionally, the review could discuss the relationship between study species investigated in the literature and those of concern in the Bay. Finally, the review could provide the parameters associated with suspended sediments that are needed to evaluate effects on fish and those parameters need to be incorporated into the data collection efforts of study topics P-Susp-1 and –2.

Phase 2 - Evaluate of Effects on Fish. In a final phase, the results of Phase 1 and studies P-Susp-1 and P-Susp-2 could be incorporated into an evaluation of effects on fish.

Lower Priority Topics: Moderate priority was assigned to disposal effects on delta smelt. Detailed consideration of this topic is deferred to a later planning phase for this species.

7.2.2.11 Sediment Type

Dredging effects associated with sediment type were rated a high priority for steelhead trout and all stages of herring. Sediment type is an important factor associated with burial, sedimentation, turbidity, suspended sediments, and a variety of water quality and contaminant issues. Sediment physical properties, particle size distribution, organic carbon content, and contaminant concentrations are among the characteristics of sediments that may need to be evaluated. In evaluating the effects of dredging in the Bay, an important question is the difference, if any, between sediments suspended by dredging and those present in the water column under ambient conditions. Another issue involves the differences in sediment quality between shallow and deep sediments (i.e., maintenance versus “new” dredging). Evaluations of sediment type could be incorporated, as appropriate in the topics listed above when studies address sediment quality.

Study Description:

Study Topic P-Sed Type-1. Determine Sediment Characteristics. The literature on sediment quality in the Bay should be reviewed and summarized to facilitate understanding of differences in suspended sediment plumes from different projects. This effort would be facilitated by analysis of the results of testing required by the USACE as provided by support activity Tech-Sup-6.

Determination of appropriate sediment characteristics may be made when considering the effects of burial, sedimentation, turbidity, suspended sediments, water quality and contaminant issues on steelhead and herring.

Lower Priority Topics: Sediment type was ranked a moderate priority for chinook and coho salmon and delta smelt. Detailed consideration of this topic is deferred to a later planning phase for these species.

7.2.3 Water Quality and Contaminants

This section includes topics that were grouped into the water quality and contaminants effects category: water quality, acute toxicity, pathways, exposure, bioavailability, and bioaccumulation. There are some differences in agency perspectives relative to toxic and bioaccumulative effects from dredging. NOAA and USFWS tend to be concerned about these subjects. DFG, USEPA, and Port of Oakland indicated that the testing protocols for dredged materials and the disposal options based on those results were developed specifically to address these issues and satisfactorily mitigated most concerns on those topics.

7.2.3.1 Water Quality

Dredging effects associated with water quality were rated a high priority for essentially all windows fish species. The term "water quality" for this discussion is limited to naturally occurring chemicals and other conditions that could adversely affect water quality, primarily as a result of sediment suspension caused by dredging operations. Such factors include increased ammonia and sulphides, decreased pH, etc. Water quality issues specifically associated with sediment particles are addressed under Section 7.2.2.10. Water quality issues associated with contaminants is addressed in Sections 7.2.3.2 through 7.2.3.6.

Evaluation of water quality parameters would be closely associated with suspended sediment plume and sediment type studies. The effects of water quality changes resulting from dredging are short-lived as a result of oxygenation and diffusion in the water column. Such changes may be acutely toxic but are more likely to be sublethal, leading to avoidance. This is particularly likely because most of the species and life stages are mobile and able to avoid undesirable water masses. Herring adults spawning in a specific location at a specific time and the spawn itself are exceptions to this generalization.

Study Descriptions:

Study Topic WQ-WQ-1. Evaluate Water Quality Effects from Suspended Sediments. The purpose of this study could be to determine the potential for suspended sediment plumes to adversely affect water quality.

Phase 1 - Review Literature and Informaton. The first phase in this study could summarize the existing information to identify the factors that influence water quality changes and the relationship between water quality alterations and suspended sediment plumes. Among the topics that could be evaluated are increased ammonia and sulphides, decreased pH, etc. Development of a conceptual model may be appropriate. Some of the literature on this topic indicated that water quality changes are very ephemeral; therefore, an exposure evaluation may resolve this issue. It may be appropriate for other studies related to suspended sediment plumes and sediment type to include evaluation of the potential for water quality degradation.

Study Topic WQ-WQ-2. Evaluate Fish Responses to Water Quality Alterations. Following completion of the preceding study, or in parallel with it, an evaluation could be made of the responses of fish to altered water quality conditions associated with dredging. This evaluation could consider most of the biological effects (distribution, behavior, migration, feeding, spawning, and development) and physical effects (disturbance, displacement, avoidance, habitat and food sources) as endpoints and, depending on the outcome of the first study, the results may be evaluated together with results from the suspended sediment and sediment type studies. As a subtopic, this study could incorporate the results of acute toxicity evaluation, study WQ-Tox-1. The study could address all species and life stages identified in the priority matrix.

7.2.3.2 Acute Toxicity

Dredging effects associated with acute toxicity were rated a high priority for essentially all fish species of concern. However, in the interview, BCDC indicated that acute toxicity should not be a problem for most dredged materials. Acute toxicity could occur primarily as a result of sediment suspension caused by dredging operations. Toxicity is related to the presence of chemicals, such as ammonia and sulphides, decreased pH, and toxic inorganic and organic chemicals. Although Bay sediments have been documented to have high levels of a wide variety of contaminants, reports of acute toxicity such as fish kills associated with dredging plumes, are absent. However, the possibility exists that such plumes could be acutely toxic and an evaluation may be warranted. Acute toxicity evaluations would be informed by the results of study topics P-Susp-1 to –3.

Study Description:

Study Topic WQ-Tox-1. Determine Effects of Acute Toxicity in Suspended Sediment Plumes.

Phase 1 - Review Literature. The literature on acute toxicity of dredging plumes to fish could be reviewed and summarized. Particular emphasis could be placed on discussion of testing in the EIS/EIR and the USACE's testing manual. The results may indicate the need to modify the following study topics.

Study Topic WQ-Tox-2. Conduct Chemical Identification and Exceedence Screening.

Phase 1 – Develop Chemical List. In phase one of this study, a list could be developed of the chemicals present in Bay sediments that could become acutely toxic to fish when suspended in the water column. Data submitted to the USACE for dredging projects could be examined. Chemicals could include potentially toxic inorganic and organic chemicals as well as the water quality parameters identified in study topic WQ-WQ-1. This phase could examine both water column and sediment data.

Phase 2 – Determine Plume Geochemistry. Information about geochemical changes associated with mixing in the water column could be reviewed and evaluated. Similar information on sediments suspended via natural conditions, such as tidal and wind wave currents, could be evaluated to establish the potential for acute toxicity as a result of background conditions.

Phase 3 – Perform Background Screen. Any chemicals in dredging plumes that are unlikely to exceed background concentrations could be eliminated from further consideration. (Note: Although the additional exposure to these chemicals caused by dredging may contribute some increment of acute toxicity if the chemical is toxic, the quantity of that increment relative to background would be exceedingly small; however, this issue may need to be carefully evaluated for herring spawning areas because Bay background may not be relevant for these purposes to specific locations.) Chemicals that exceed background concentrations could be carried forward into the next study topic.

Study Topic WQ-Tox-3. Perform Acute Toxicity Evaluation. This study could evaluate the potential acute toxicity associated with the chemicals that passed the screen in study topic WQ-Tox-2.

Phase 1 – Identify Benchmarks. The first phase of this study could identify appropriate acute toxicity benchmarks for the species and life stages.

Phase 2 – Determine Concentrations. A second phase could determine the likely ranges and durations of concentrations of chemicals in dredging plumes.

Phase 3 – Evaluate Toxicity. A third phase could use the results of the first two phases to evaluate potential toxicity.

Phase 4 – Evaluate Avoidance. A fourth phase could evaluate potential avoidance mechanisms that could mitigate toxic conditions.

Phase 5 – Evaluate Extent of Dredging. A fifth phase could examine the extent of dredging and the potential for acute toxic effects in the Bay. Herring spawning adults and spawn could be evaluated on a location-specific basis.

7.2.3.3 Pathways

Dredging effects associated with pathways were rated a moderate or high priority for all species and life stages. In this report, "pathways" is related to the exposure of toxic chemicals to windows fish species. Determination of pathways could result from the suspended sediment plume studies and water quality studies described in Sections 7.2.2.10 and 7.2.3.1, respectively. The possibility of dissolved chemicals remaining in the water column or being transported beyond the suspended sediment plume would not be addressed by those studies, however.

<u>Study Description</u>:

<u>Study Topic WQ-Path-1. Perform Pathway Evaluation for Dissolved Chemicals.</u> The literature on transport of dissolved chemicals away from suspended sediment plumes could be reviewed. If substantial transport of toxic and/or bioaccumulative chemicals is likely, the results could be evaluated relative to background concentrations of dissolved chemicals in the Bay. The need for further studies would depend upon the results obtained.

7.2.3.4 Exposure

Dredging effects associated with exposure were rated a moderate or high priority for all species and life stages. Exposure evaluation is one of the most important topics for evaluating the effects of dredging on windows fish species for the following reasons: 1) dredging is an ephemeral activity, 2) dredging occurs in a small fraction of the Bay's total area, and 3) most or all of the changes caused by dredging are potentially present at some level as part of the Bay background. Therefore, with few exceptions, the potential (i.e., probability) for dredging to cause adverse effects in the Bay is directly related to the incremental exposure that results from dredging operations. Possible exceptions include direct dredging effects such as entrainment or fish injury. Exposure point evaluations are incorporated into a number of the foregoing study topics, such as water quality and acute toxicity. Exposure parameters related to larger spatial and time scales would not be included in those studies, however.

<u>Study Description</u>:

<u>Study Topic WQ-Exp-1. Evaluate Spatial and Temporal Distribution of Dredging in the Bay</u>. The purpose of this study could be to develop factors that characterize the spatial and temporal distribution of dredging in the Bay. This evaluation could be stratified by

critical resource site locations, habitats, sub-embayments, embayments, and for the entire Bay. These factors could be employed to more fully evaluate the results of a variety of the studies described elsewhere in this chapter. To illustrate via a hypothetical example, if juvenile chinook are uniformly distributed over shoal areas of the Bay and only 1 percent of that area is exposed to dredging operations, limited sublethal effects of dredging may be deemed an acceptable risk. On the other hand, if limited sublethal effects could be experienced by over 50 percent of the population, further evaluation or development of mitigation options may be appropriate. This study could generate the factors that could be employed in such an evaluation. This evaluation could be conducted most effectively using a geographic information system (GIS). Spatial and temporal factors could be most appropriately applied to species or life stages characterized by Bay-, region-, or habitat-wide distributions. These factors may be less suitable or inappropriate for evaluations of site-specific resources such as herring spawning areas. The above example also illustrates that such exposure evaluations would be dependent on understanding the distribution of the species being evaluated. This topic was addressed in Section 7.2.1.1.

7.2.3.5 Bioavailability

Dredging effects associated with bioavailability were rated a high priority for all species except delta smelt. Bioavailability is a concept that is relatively simple in theory, but highly complex in the environment. It refers to the ease with which a chemical (sometimes occurring in complexes with ligands) at an exposure point may be taken up by an organism to which it is exposed. Acute toxicity associated with bioavailability is discussed in Section 7.2.3.2. This section addresses subacute aspects of bioavailability, particularly those related to bioaccumulation. The most important effect of dredging on bioavailability results from increased water column exposure and geochemical changes that take place when anoxic sediments are mixed into the oxic water column. Such effects could result in increased bioavailability of toxic chemicals.

Study Description:

Study Topic WQ-Bioav-1. Determine Bioavailability Changes. This study could evaluate the geochemical changes associated with suspended sediment plumes which were identified in study topic WQ-WQ-1. The literature could be reviewed to determine the extent and duration of the changes. The results could be incorporated into bioaccumulation study topics.

Lower Priority Topics: Delta smelt was rated a moderate priority. Detailed consideration of this topic is deferred to a later planning phase for this species.

7.2.3.6 Bioaccumulation

Dredging effects associated with bioaccumulation were rated a high priority for herring life stages except adults, and by some agencies for chinook and coho salmon, and steelhead. Concern regarding spawning effects on delta smelt (referred to this topic from Section 7.2.2.9) is also included here. Bioaccumulation is a complex process of uptake and retention of chemicals. The greatest concern associated with bioaccumulative chemicals occurs when they biomagnify in the food web pathway. In reality, bioaccumulation is typically of concern when there is chronic exposure leading to relatively high body burdens. Because bioaccumulation is often time-dependent and dredging events are ephemeral, significant effects are unlikely. Furthermore, materials to be dredged are tested for bioaccumulative properties when certain test data indicate a need. However, an evaluation of this subject may be appropriate given agency concerns, and considering that testing is primarily conducted relative to disposal as opposed to dredging effects.

Study Description:

Study Topic WQ-Bioac-1. Perform Bioaccumulation Exposure Assessment. The purpose of this study could be to estimate the incremental bioaccumulation potential associated with dredging activities. The first phase of this study could be based on available information including testing data submitted to the USACE, the literature and from studies in Sections 7.2.2.10 and 7.2.2.11. Bioaccumulative chemicals potentially present in Bay sediments that could be associated with suspended sediment plumes could be identified. The most significant bioaccumulation pathway in consumers such as fish is typically via prey; therefore, this study could evaluate bioaccumulation in prey items as well as fish. Exposure factors developed in studies identified in Sections 7.2.2.10, 7.2.2.11, and 7.2.3.3 could be applied, as appropriate. The end result could be an estimate of the incremental bioaccumulation potential relative to background. One approach for addressing this issue for adult chinook salmon could be to evaluate data on body burdens in coastal waters and in adults returning to hatcheries. If no significant differences were identified, it could be concluded that uptake in the Bay from all exposures (including dredging) is minimal. Depending on the results, further studies may be needed.

Lower Priority Topics: Delta smelt and herring adults were rated a moderate priority. Detailed consideration of this topic is deferred to a later planning phase for these species/life stage.

7.3 Technical Support for Effects Studies

Several activities could provide important general support for the Work Group and possibly for the studies identified in the preceding chapter. These activities are identified in the following sections.

7.3.1 Work Group Chair Support

Support Activity Tech-Sup-1. Work Group Chair Support: Through 2003 and early 2004, the Chair of the Work Group has volunteered substantial time to coordinate and communicate the Work Group's activities. The agencies expressed a desire to provide financial support for this activity in the future.

7.3.2 Work Group Member Support

Support Activity Tech-Sup-2. Work Group Member Support: Through 2003, non-agency Work Group members participated on a volunteer basis. The agencies expressed support for continued participation of volunteers through financial support as well as adding scientific experts to all or a subset of the Work Group's meetings.

7.3.3 Peer Review Support

Support Activity Tech-Sup-3. Peer Reviewers: The Work Group desires to implement a peer review process to enhance the objectivity and technical quality of the Work Group's products. This support activity would provide funds to engage peer reviewers on an as-needed basis.

7.3.4 Library Support

Support Activity Tech-Sup-4. Library. In 2003, the San Francisco District USACE staff assembled pertinent literature, created a database, and posted the database on the USACE website. This activity could be continued to incorporate additional literature as it becomes available.

7.3.5 Information Management Support

The Work Group evaluations may benefit from a variety of information management support activities, such as GIS and numerical databases. These services could capture key information and facilitate the generation of products to assist the Work Group's decision-making.

Study Descriptions:

Support Activity Tech-Sup-5. Develop GIS Dredging Database. The purpose of this activity could be to identify the locations and timing of current and future dredging projects. The database could encompass Bay-wide base maps and incorporate appropriate Bay characteristics for which spatial distributions are important, such as shoals, sediment types, habitats, etc. Recent NOAA mapping of the Bay could be incorporated into this database. This information could assist studies P-Hab-1, B-Dist-1, B-Dist-2, B-Dist-3, B-Migr-1.

Support Activity Tech-Sup-6. Sediment Quality Database. The purpose of this activity could be to develop a database of sediment quality data submitted to the USACE for dredging projects. This database could provide input to a variety of effects topics.

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Table 7-1. Identified Studies, Phases, and Study Relationships

Effect Category/ Topic	Salmonids	Delta Smelt	Herring	Study Code	Study Title	Phase Title	Studies from which input is needed	Studies to which input should be provided
Biological								
Distribution	●			B-Dist-1	Determine Spatial and Temporal Distributions of Chinook and Coho Salmon in the Bay	Review Literature and Information		P-Hab-2, B-Migr-1
Distribution	●			B-Dist-1	Determine Spatial and Temporal Distributions of Chinook and Coho Salmon in the Bay	Conduct Field Study		
Distribution	●			B-Dist-2	Determine Spatial and Temporal Distributions of Adult and Juvenile Steelhead in the Bay	Review Literature and Information		P-Hab-1
Distribution	●			B-Dist-2	Determine Spatial and Temporal Distributions of Adult and Juvenile Steelhead in the Bay	Conduct Field Study		
Distribution			●	B-Dist-3	Determine Spatial and Temporal Distributions of Herring Larvae and Juveniles in the Bay	Review Literature and Information		
Distribution			●	B-Dist-3	Determine Spatial and Temporal Distributions of Herring Larvae and Juveniles in the Bay	Conduct Field Study		
Behavior								
Migration	●			B-Migr-1	Determine Critical Migration Routes and Periods for Salmonids	Review Existing Information	B-Dist-1 and B-Dist-2	B-Dist-1 and B-Dist-2
Migration	●			B-Migr-1	Determine Critical Migration Routes and Periods for Salmonids	Evaluate Spatial Relationship Between Migration Routes and Dredging Sites		
Migration	●			B-Migr-1	Determine Critical Migration Routes and Periods for Salmonids	Conduct Field Studies		
Feeding	●			B-Feed-1	Determine Effects of Dredging on Feeding by Juvenile Chinook Salmon	Perform Literature Review	P-Susp-3	P-Disp-1
Feeding	●			B-Feed-1	Determine Effects of Dredging on Feeding by Juvenile Chinook Salmon	Evaluate Effects of Dredging Plumes		
Feeding		●		B-Feed-2	Determine Effects of Plumes on Feeding and Predation of Delta Smelt	Conduct Literature Review	P-Susp-3	P-Disp-2
Spawning		●		B-Spawn-1	Determine Effects on Spawning of Delta Smelt	Conduct Literature Review	P-Susp-3, P-Sed-1	
Spawning		●		B-Spawn-1	Determine Effects on Spawning of Delta Smelt	Evaluate Suspended Sediment Effects		
Spawning			●	B-Spawn-2	Determine Extent of Herring Spawning in Deeper Water		Tech-Sup-5	
Development			●	B-Dev-1	Determine Effects of Suspended Sediment Plumes on Herring Larvae and Juveniles	Review and Evaluate Literature	B-Dist-3, P-Susp-3	
Development			●	B-Dev-1	Determine Effects of Suspended Sediment Plumes on Herring Larvae and Juveniles	Evaluate Potential Effects of Suspended Sediment Plumes		
Development			●	B-Dev-2	Determine Effect of Suspended Sediment Plumes on Herring Adults		P-Susp-3	
Fish Injury								

Table 7-1. Identified Studies, Phases, and Study Relationships

Effect Category/ Topic	Salmonids	Delta Smelt	Herring	Study Code	Study Title	Phase Title	Studies from which input is needed	Studies to which input should be provided
Physical Effects								
Disturbance								
Displacement	●			P-Disp-1	Determine Displacement Effects on Juvenile Chinook Salmon	Perform Literature Review	B-Dist-1,-2	B-Feed-1,P-Noise-1
Displacement	●			P-Disp-1	Determine Displacement Effects on Juvenile Chinook Salmon	Perform Additional Evaluation		
Displacement		●		P-Disp-2	Determine Displacement Effects on Delta Smelt	Evaluate Marinas as Habitat	P-Susp-3	B-Feed-2, P-Noise-1
Displacement		●		P-Disp-2	Determine Displacement Effects on Delta Smelt	Determine Reactions to Dredging		
Displacement		●		P-Disp-2	Determine Displacement Effects on Delta Smelt	Conduct Additional Evaluations		
Avoidance			●	P-Av-1	Determine Adult Herring Avoidance Responses to Dredging		B-Dist-3, P-Susp-3, P-Noise-1	
Avoidance			●	P-Av-2	Determine Juvenile Herring Avoidance Responses to Dredging		B-Dist-3, P-Susp-3, P-Noise-1	
Avoidance			●	P-Av-3	Determine Larval Herring Avoidance Responses to Dredging		B-Dist-3, P-Susp-3, P-Noise-1	
Entrainment	●			P-Ent-1	Determine Entrainment Risk to Juvenile Salmonids		B-Dist-1,-2	
Entrainment			●	P-Ent-2	Determine Entrainment Risk to Larval and Young Juvenile Herring		B-Dist-3	
Burial								
Sedimentation		●		P-Sed-1	Determine Sedimentation Effects on Delta Smelt Spawning	Determine Location of Spawning		B-Spawn-1
Sedimentation		●		P-Sed-1	Determine Sedimentation Effects on Delta Smelt Spawning	Determine Sedimentation Effects on Surrogate Species		
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Review Information	P-Susp-1 to -3	B-Dev-1, B-Dev-2
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Conduct Laboratory Studies		
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Conduct Field Experiments		
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Characterize Plumes in Spawning Areas		
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Characterize Ambient SS		
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Determine Sedimentation Mechanisms		
Sedimentation			●	P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Determine Egg Mortality Factors		
Noise	●	●	●	P-Noise-1	Prepare Review of Literature on Noise Effects on Fish			P-Av-1 to -3,
Turbidity								
Habitat /Food	●			P-Hab-1	Determine Effects of Habitat Modification on Steelhead	Review Existing Information and Evaluate Dredging Proximity	Tech-Sup-5	B-Dist-2
Habitat /Food	●			P-Hab-2	Determine Effects of Surface Sediment Changes on Salmonid Smolt Habitat Preference	Perform Literature Review	Tech-Sup-6, P-Susp-3	B-Dist-1
Habitat /Food	●			P-Hab-2	Determine Effects of Surface Sediment Changes on Salmonid Smolt Habitat Preference	Evaluate Surficial Sediment Changes Resulting from Dredging		
Habitat /Food		●		P-Hab-3	Determine Habitat Requirements for Delta Smelt		P-Sed-1	
Habitat /Food			●	P-Hab-4	Determine Genetic Fidelity of Site-Specific Spawning Cohorts for Herring			
Susp. Sed.	●	●	●	P-Susp-1	Determine Extent of Suspended Sediment Plumes	MEC/ERDC 2003 Study		
Susp. Sed.	●	●	●	P-Susp-1	Determine Extent of Suspended Sediment Plumes	Calibrate ERDC's Plume Models		
Susp. Sed.	●	●	●	P-Susp-1	Determine Extent of Suspended Sediment Plumes	Design Additional Studies		
Susp. Sed.	●	●	●	P-Susp-1	Determine Extent of Suspended Sediment Plumes	Collect Additional Field Data		
Susp. Sed.	●	●	●	P-Susp-1	Determine Extent of Suspended Sediment Plumes	Complete Calibration of the Model		
Susp. Sed.	●	●	●	P-Susp-2	Determine Bay Ambient Suspended Sediment Concentrations	Conduct Literature and Information Review		
Susp. Sed.	●	●	●	P-Susp-2	Determine Bay Ambient Suspended Sediment Concentrations	Collect Additional Data		
Susp. Sed.	●	●	●	P-Susp-3	Determine the Effects of Suspended Sediment Plumes on Fish	Review Literature and Information		[many studies]
Susp. Sed.	●	●	●	P-Susp-3	Determine the Effects of Suspended Sediment Plumes on Fish	Evaluate of Effects on Fish		
Sediment Type	●	●	●	P-Sed Type-1	Determine Sediment Characteristics			[many studies]

Table 7-1. Identified Studies, Phases, and Study Relationships

Effect Category/ Topic	Salmonids	Delta Smelt	Herring	Study Code	Study Title	Phase Title	Studies from which input is needed	Studies to which input should be provided
Water Quality and Contaminants								
Water Quality	●	●	●	WQ-WQ-1	Evaluate Water Quality Effects from Suspended Sediments	Review Literature and Information	Tech-Sup-6	
Water Quality	●	●	●	WQ-WQ-2	Evaluate Fish Responses to Water Quality Alterations		WQ-Tox-1, Tech-Sup-6	
Acute Toxicity	●	●	●	WQ-Tox-1	Determine Effects of Acute Toxicity in Suspended Sediment Plumes	Review Literature	P-Susp-1 to –3, Tech-Sup-6	
Acute Toxicity	●	●	●	WQ-Tox-2	Conduct Chemical Identification and Exceedence Screening	Develop Chemical List	P-Susp-1 to –3, Tech-Sup-6	
Acute Toxicity	●	●	●	WQ-Tox-2	Conduct Chemical Identification and Exceedence Screening	Determine Plume Geochemistry		
Acute Toxicity	●	●	●	WQ-Tox-2	Conduct Chemical Identification and Exceedence Screening	Perform Background Screen		
Acute Toxicity	●	●	●	WQ-Tox-3	Perform Acute Toxicity Evaluation	Identify Benchmarks	P-Susp-1 to –3	
Acute Toxicity	●	●	●	WQ-Tox-3	Perform Acute Toxicity Evaluation	Determine Concentrations		
Acute Toxicity	●	●	●	WQ-Tox-3	Perform Acute Toxicity Evaluation	Evaluate Toxicity		
Acute Toxicity	●	●	●	WQ-Tox-3	Perform Acute Toxicity Evaluation	Evaluate Avoidance		
Acute Toxicity	●	●	●	WQ-Tox-3	Perform Acute Toxicity Evaluation	Evaluate Extent of Dredging		
Pathway	●	●	●	WQ-Path-1	Perform Pathway Evaluation for Dissolved Chemicals			
Exposure	●	●	●	WQ-Exp-1	Evaluate Spatial and Temporal Distribution of Dredging			
Bioavailability	●	●	●	WQ-Bioav-1	Determine Bioavailability Changes		Tech-Sup-6	
Bioaccumulation	●	●	●	WQ-Bioac-1	Perform Bioaccumulation Exposure Assessment		Tech-Sup-6	
Support Activities								
Facilitation	●	●	●	Tech-Sup-1	Work Group Chair Support			
Facilitation	●	●	●	Tech-Sup-2	Work Group Member Support			
Technical	●	●	●	Tech-Sup-3	Peer Reviewers			
Technical	●	●	●	Tech-Sup-4	Library			
Technical	●	●	●	Tech-Sup-5	Develop GIS Basemap Showing Dredging Locations			
Inform. Mgmt.	●	●	●	Tech-Sup-6	Sediment Quality Database			P-Sed-2, P-Hab-2

Table 7-1. Identified Studies, Phases, and Study Relationships

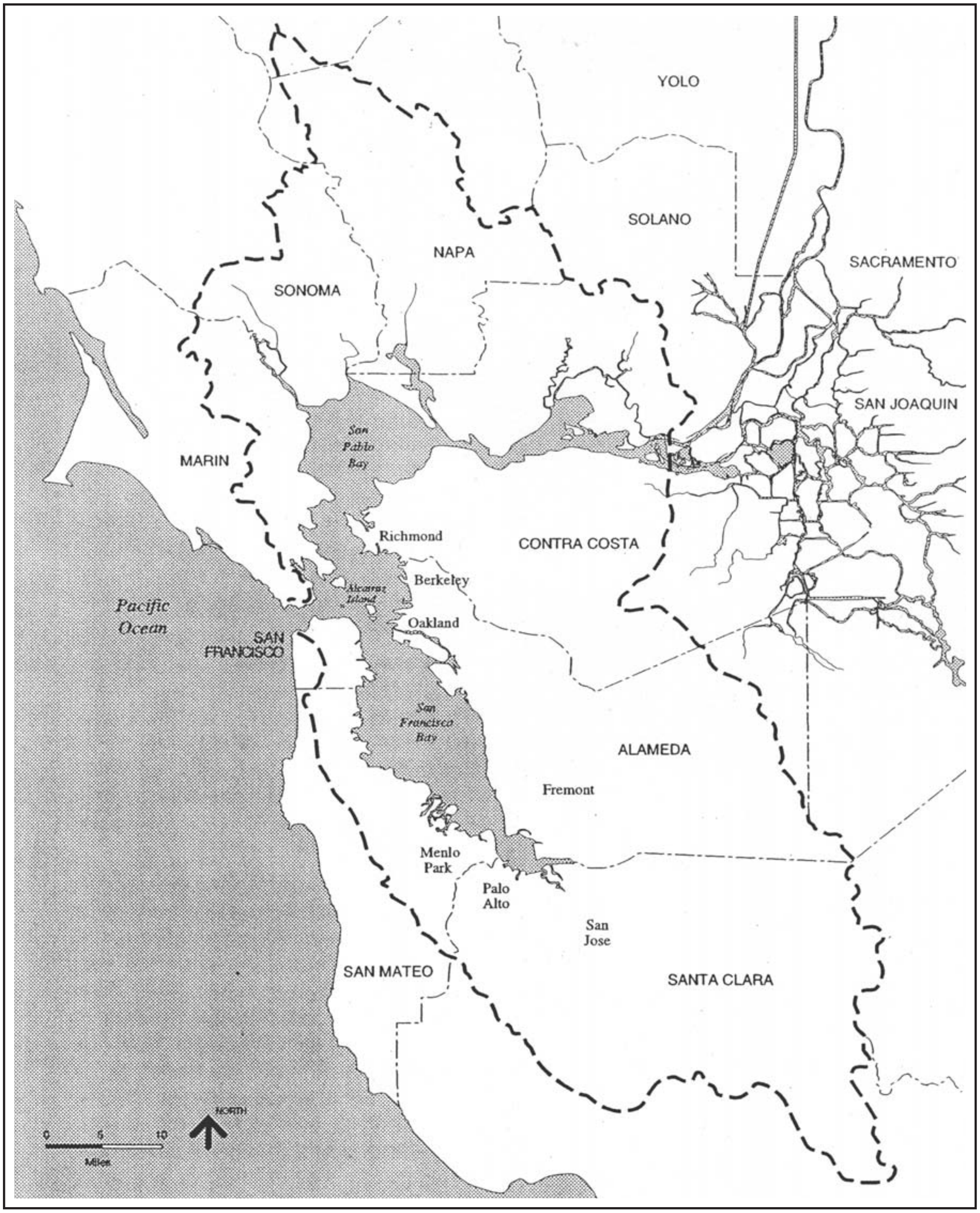
Effect Category/ Topic	Salmonids	Delta Smelt	Herring	Study Code	Comments
Biological					
Distribution	●			B-Dist-1	
Distribution	●			B-Dist-1	
Distribution	●			B-Dist-2	
Distribution	●			B-Dist-2	
Distribution			●	B-Dist-3	
Distribution			●	B-Dist-3	
Behavior					Refer to distribution, migration, feeding, avoidance, noise, and exposure to plumes.
Migration	●			B-Migr-1	
Migration	●			B-Migr-1	
Migration	●			B-Migr-1	
Feeding	●			B-Feed-1	
Feeding	●			B-Feed-1	
Feeding		●		B-Feed-2	
Spawning		●		B-Spawn-1	
Spawning		●		B-Spawn-1	
Spawning			●	B-Spawn-2	
Development			●	B-Dev-1	
Development			●	B-Dev-1	
Development			●	B-Dev-2	Before this study can be described, further clarification from DFG is needed.
Fish Injury					No high priority concerns were identified for this topic.

Table 7-1. Identified Studies, Phases, and Study Relationships

Effect Category/ Topic	Salmonids	Delta Smelt	Herring	Study Code	Comments
Physical Effects					
Disturbance					Refer to displacement, avoidance, noise, and other more specific topics that are addressed in other sections.
Displacement	●			P-Disp-1	
Displacement	●			P-Disp-1	
Displacement		●		P-Disp-2	
Displacement		●		P-Disp-2	
Displacement		●		P-Disp-2	
Avoidance			●	P-Av-1	The results of studies identified in the sections on suspended sediment concentration, water quality, and toxicity may also provide input to this study.
Avoidance			●	P-Av-2	The results of studies identified in the sections on suspended sediment concentration, water quality, and toxicity may also provide input to this study.
Avoidance			●	P-Av-3	The results of studies identified in the sections on suspended sediment concentration, water quality, and toxicity may also provide input to this study.
Entrainment	●			P-Ent-1	
Entrainment			●	P-Ent-2	
Burial					Refer to sedimentation studies.
Sedimentation		●		P-Sed-1	
Sedimentation		●		P-Sed-1	
Sedimentation			●	P-Sed-2	
Sedimentation			●	P-Sed-2	
Sedimentation			●	P-Sed-2	
Sedimentation			●	P-Sed-2	
Sedimentation			●	P-Sed-2	
Sedimentation			●	P-Sed-2	
Sedimentation			●	P-Sed-2	
Noise	●	●	●	P-Noise-1	
Turbidity					Refer to suspended sediments topic.
Habitat /Food	●			P-Hab-1	
Habitat /Food	●			P-Hab-2	
Habitat /Food	●			P-Hab-2	
Habitat /Food		●		P-Hab-3	
Habitat /Food			●	P-Hab-4	
Susp. Sed.	●	●	●	P-Susp-1	
Susp. Sed.	●	●	●	P-Susp-1	
Susp. Sed.	●	●	●	P-Susp-1	
Susp. Sed.	●	●	●	P-Susp-1	
Susp. Sed.	●	●	●	P-Susp-1	
Susp. Sed.	●	●	●	P-Susp-2	
Susp. Sed.	●	●	●	P-Susp-2	
Susp. Sed.	●	●	●	P-Susp-3	
Susp. Sed.	●	●	●	P-Susp-3	
Sediment Type	●	●	●	P-Sed Type-1	

Table 7-1. Identified Studies, Phases, and Study Relationships

Effect Category/ Topic	Salmonids	Delta Smelt	Herring	Study Code	Comments
Water Quality and Contaminants					
Water Quality	●	●	●	WQ-WQ-1	
Water Quality	●	●	●	WQ-WQ-2	
Acute Toxicity	●	●	●	WQ-Tox-1	
Acute Toxicity	●	●	●	WQ-Tox-2	
Acute Toxicity	●	●	●	WQ-Tox-2	
Acute Toxicity	●	●	●	WQ-Tox-2	
Acute Toxicity	●	●	●	WQ-Tox-3	
Acute Toxicity	●	●	●	WQ-Tox-3	
Acute Toxicity	●	●	●	WQ-Tox-3	
Acute Toxicity	●	●	●	WQ-Tox-3	
Acute Toxicity	●	●	●	WQ-Tox-3	
Pathway	●	●	●	WQ-Path-1	See also pathway determinations in suspended sediment plume studies and water quality studies described in Sections 7.2.2.10 and 7.2.3.1, respectively.
Exposure	●	●	●	WQ-Exp-1	
Bioavailability	●	●	●	WQ-Bioav-1	
Bioaccumulation	●	●	●	WQ-Bioac-1	
Support Activities					
Facilitation	●	●	●	Tech-Sup-1	
Facilitation	●	●	●	Tech-Sup-2	
Technical	●	●	●	Tech-Sup-3	
Technical	●	●	●	Tech-Sup-4	
Technical	●	●	●	Tech-Sup-5	
Inform. Mgmt.	●	●	●	Tech-Sup-6	



LTMS Planning Area

San Francisco Bay Long Term Management Strategy

LFR LEVINE•FRICKE

Figure 1

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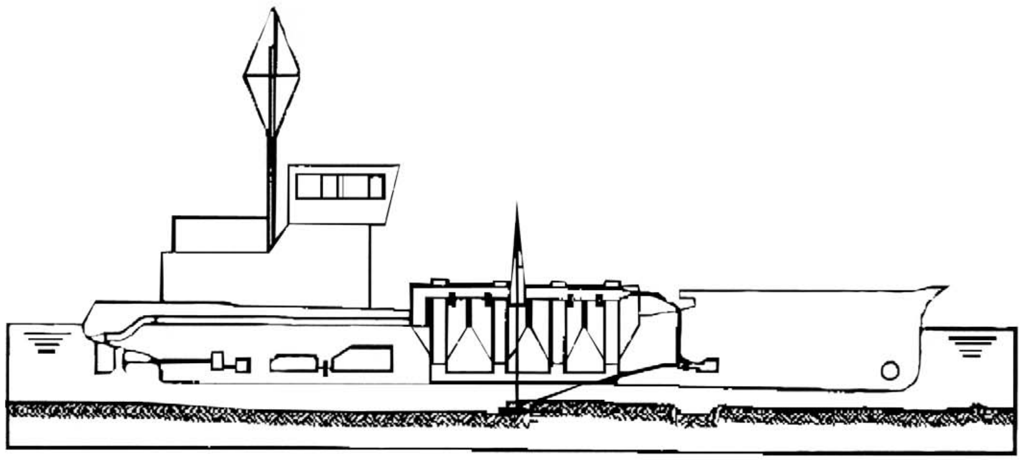
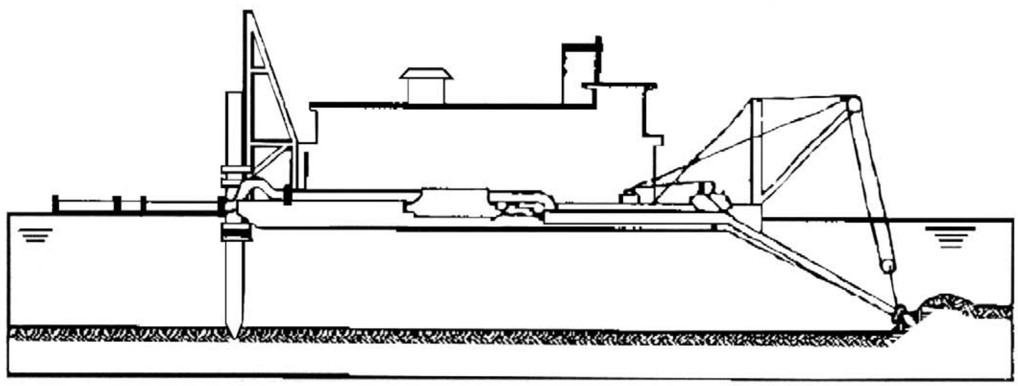
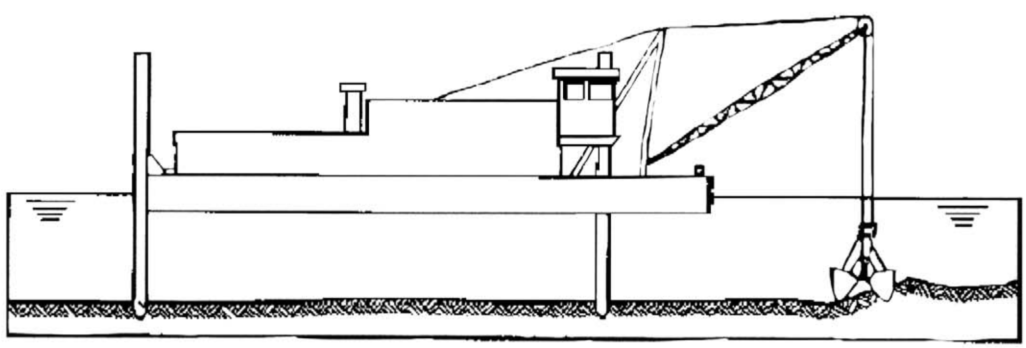


A. SELF PROPELLED HOPPER DREDGE



B. CUTTERHEAD PIPELINE DREDGE



C. CLAMSHELL DREDGE

Source: USEPA & USACE 1992

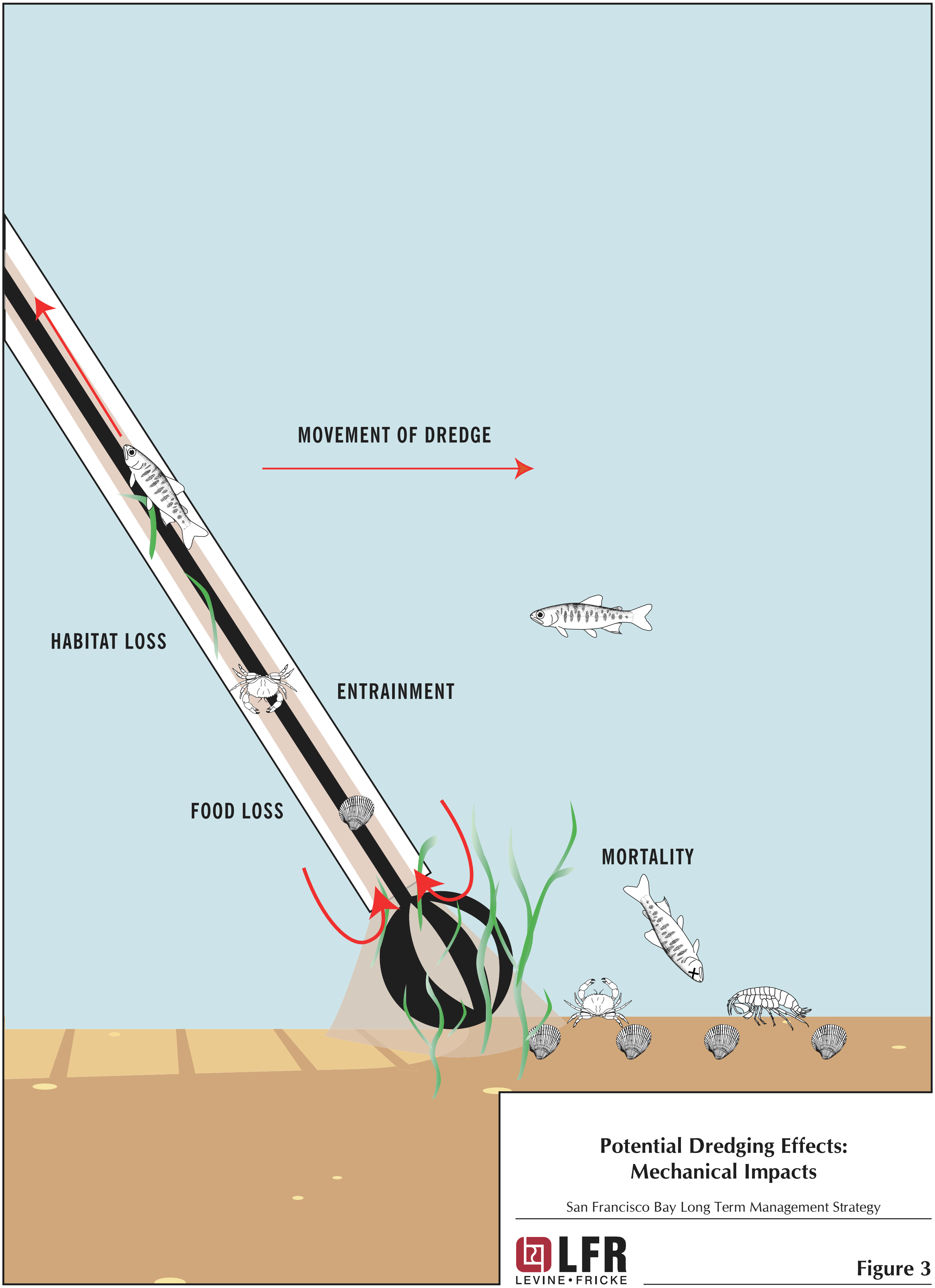
Dredge Types

San Francisco Bay Long Term Management Strategy

LFR
LEVINE•FRICKE

Figure 2

I/Design/09170/00/09170_DredgeType.ai 021704



Potential Dredging Effects: Mechanical Impacts

San Francisco Bay Long Term Management Strategy

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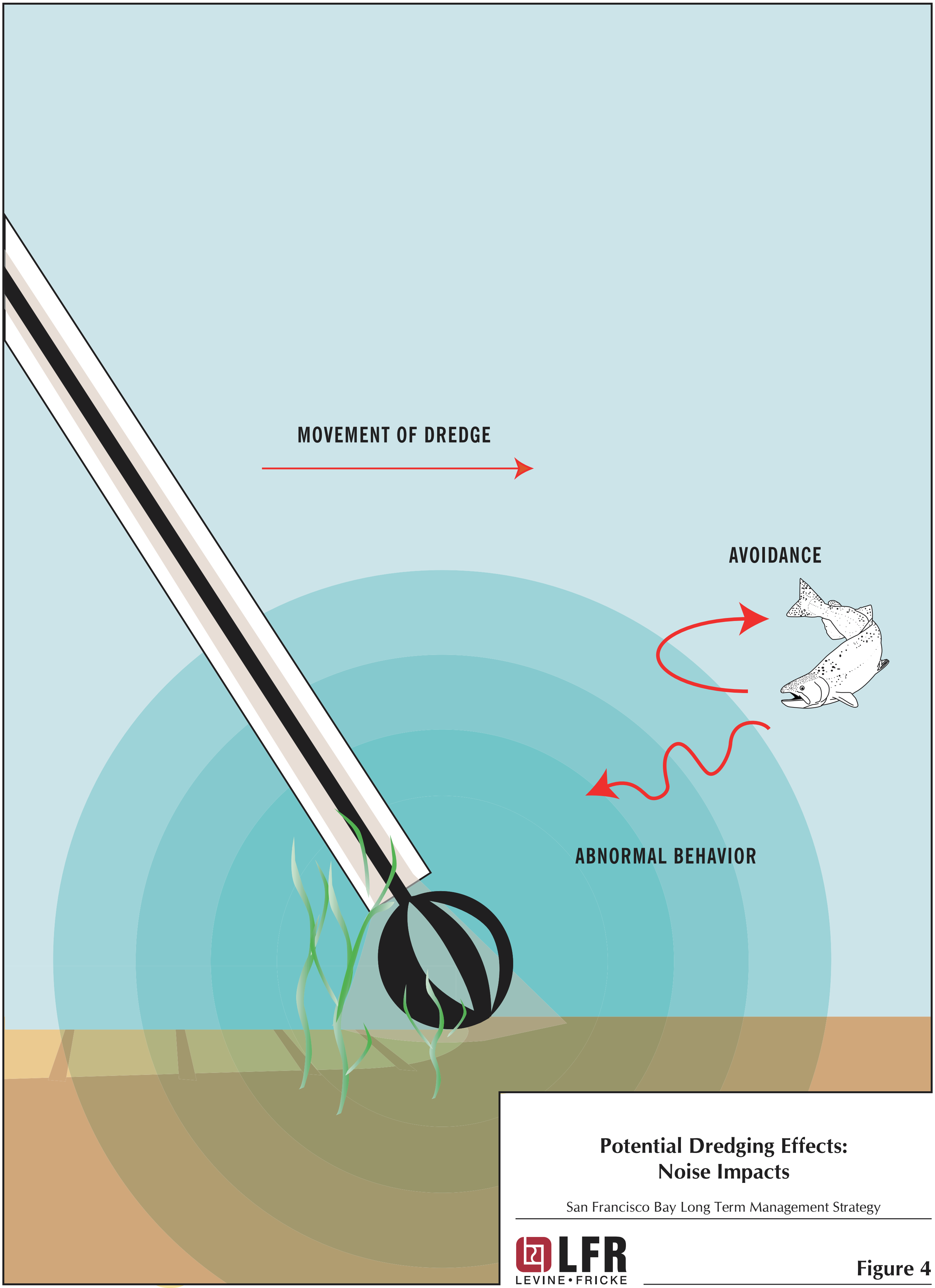
Figure 3

I/Design/09170/00/09170MechanicalEffects.ai 021704



**Potential Dredging Effects:
Noise Impacts**

San Francisco Bay Long Term Management Strategy

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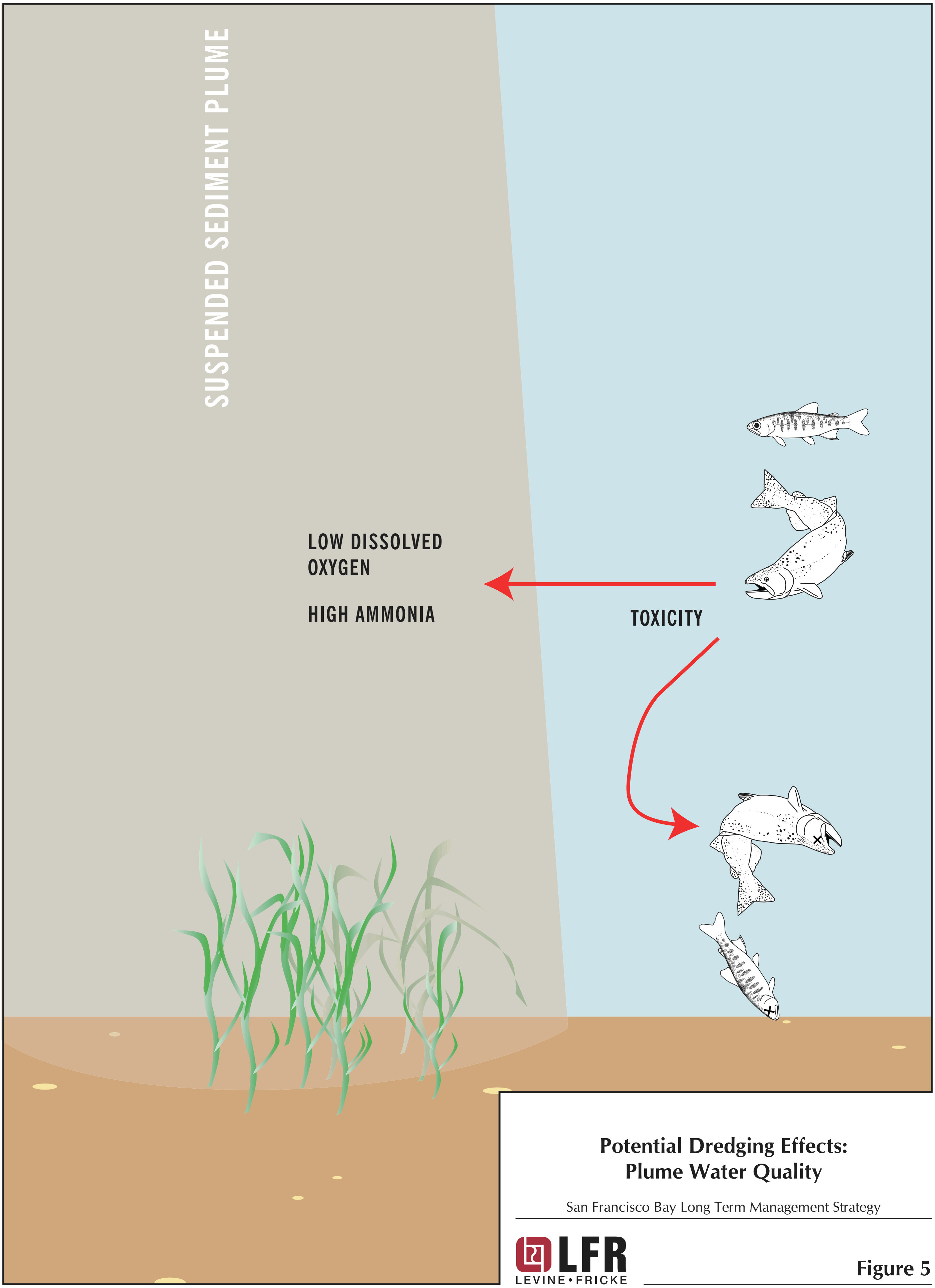
Figure 4

I/Design/09170/00/09170NoiseEffects.ai 092903



Potential Dredging Effects: Plume Water Quality

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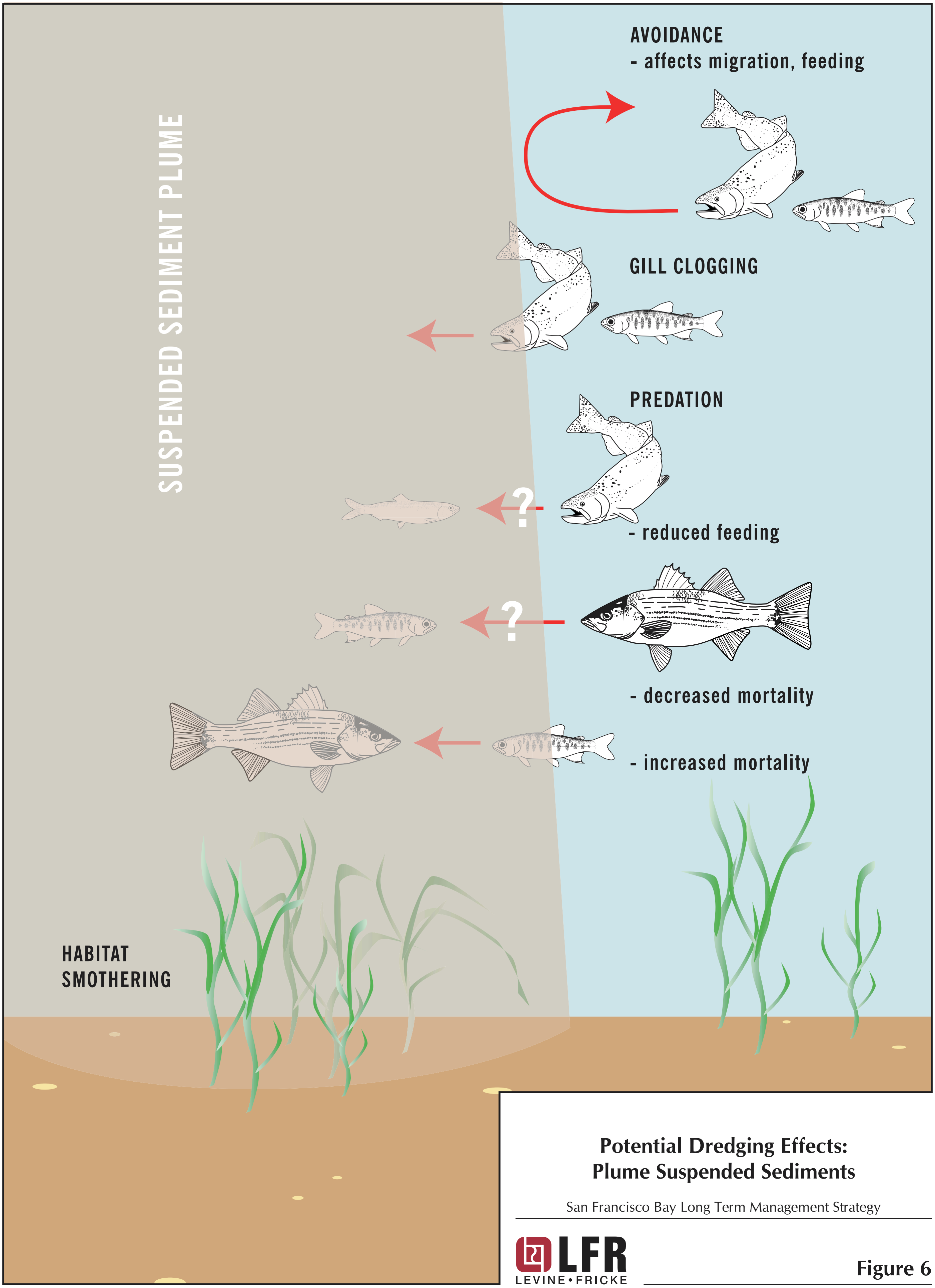
Figure 5

I/Design/09170/00/09170WaterQual.ai 021704



Potential Dredging Effects: Plume Suspended Sediments

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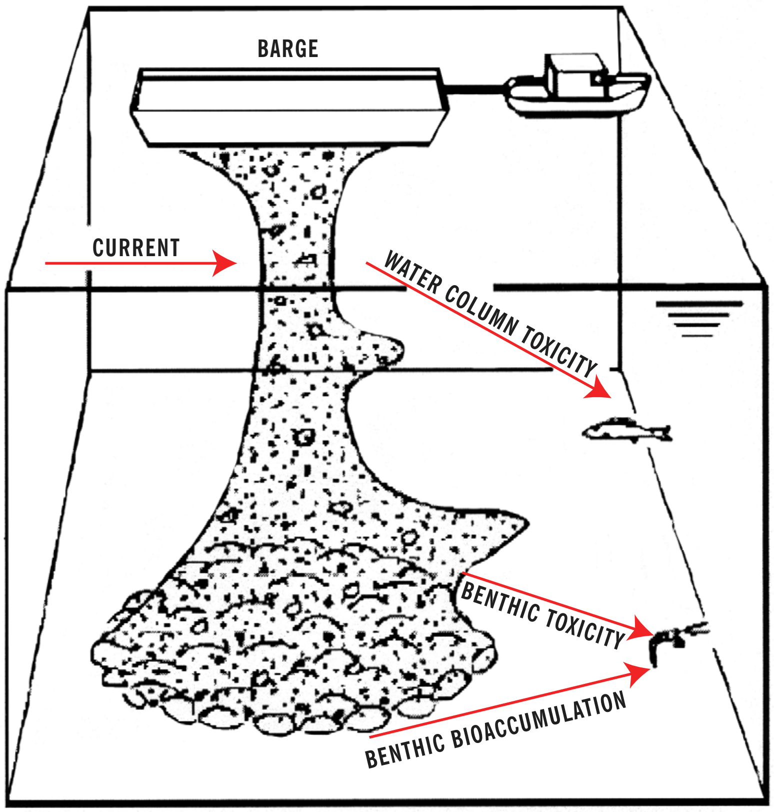
Figure 6

I/Design/09170/00/09170SuspSed.ai 021704



Source: USEPA & USACE 1992

Contaminant Pathways for Open-Water Disposal

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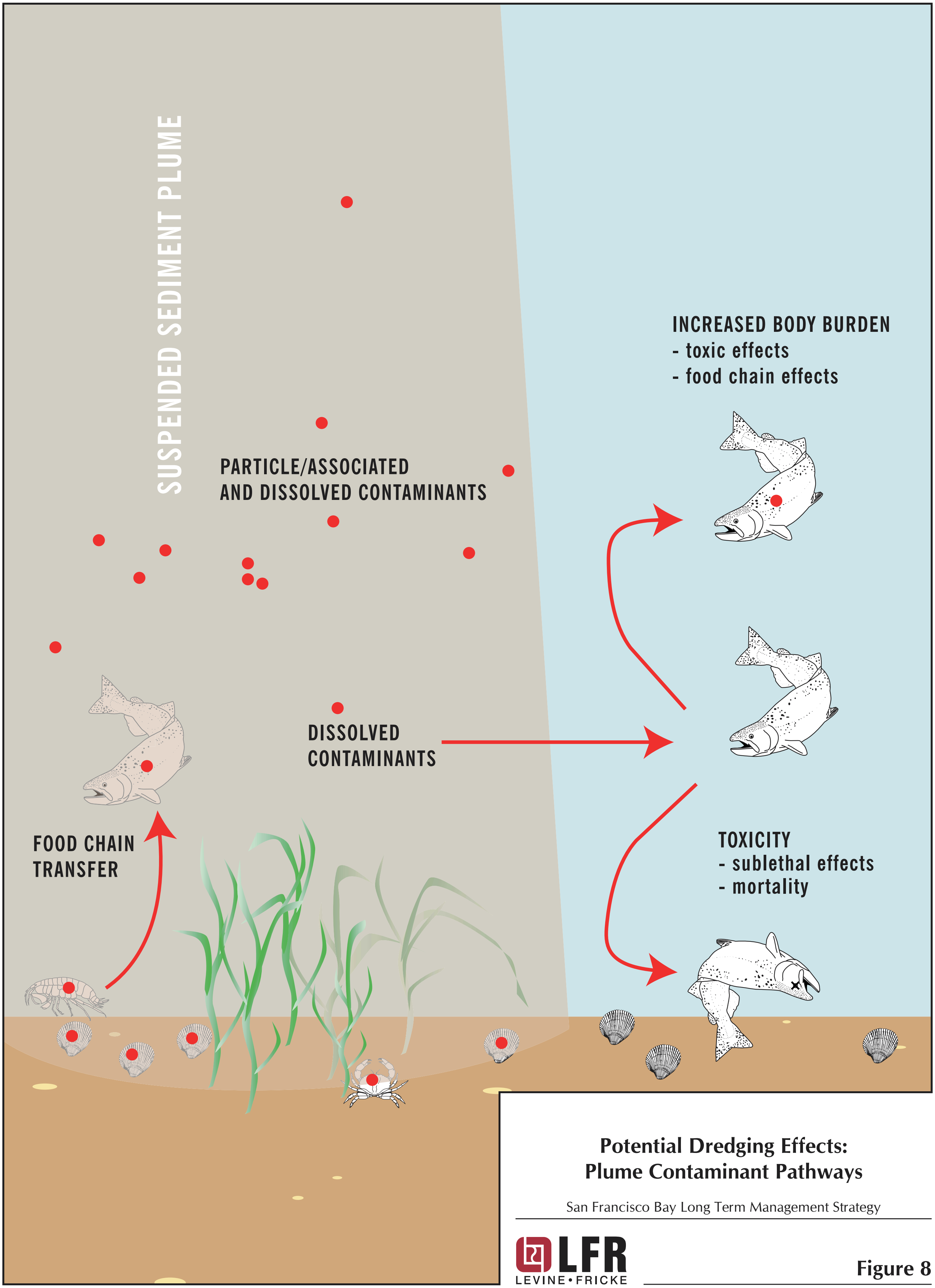
Figure 7

I/Design/09170/00/09170_OpenWater.ai 021704



I/Design/09170/00/09170ContamPath.ai 021704

Potential Dredging Effects: Plume Contaminant Pathways

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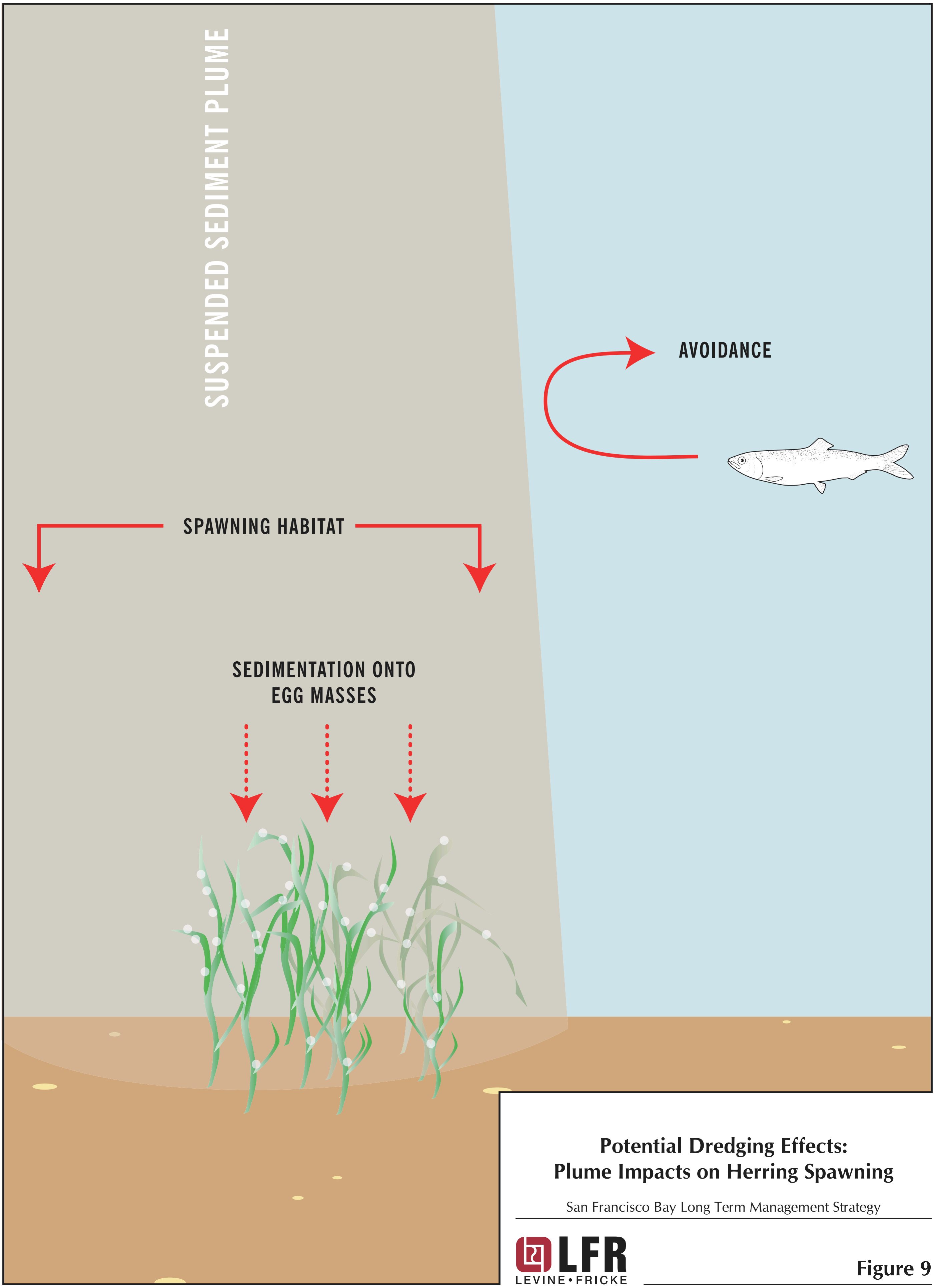
Figure 8



I/Design/09170/00/09170HerrSpawn.ai 021704

Potential Dredging Effects:
Plume Impacts on Herring Spawning

San Francisco Bay Long Term Management Strategy

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Figure 9

Figure 10

San Francisco Bay Long Term Management Strategy (LTMS)

Science Assessment and Data Gaps Work Group

Priority Matrix

Topics Related to Six Environmental Windows Fish Species (1=highest, 2=moderate, 3=lowest priority)

Updated 1/19/04

Topic	Priority Ratings																											
	Chinook Salmon				Coho Salmon				Delta Smelt					Splittail				Steelhead Trout				Herring						
	NOAA	FWS	DFG*	BCDC	NOAA	FWS	DFG*	BCDC	NOAA	FWS		DFG	BCDC	NOAA	FWS	DFG	BCDC	NOAA	FWS	DFG	BCDC	NOAA	FWS	DFG				BCDC
										dredging	disposal													eggs	larvae	juveniles	adults	
Distribution	1		1	2	1		1	1		2	2				2		1	1		1	3			2	1	1	2	3
Behavior	1		3	1	1		3	2		1	1				1		1	1		3	2				2	1	1	1
Migration	1		1	2	1		1	3		3	2				2		1	1		1	3				2	2	2	3
Food sources	3		3(a)	1	3		3(a)	3		1	2				1		2	1		3(a)	3				2	2	3	1
Feeding	1		3(a)	1	1		3(a)	3		1	1				1		2	3		3(a)	2				2	2	3	2
Spawning	3		3	3	3		3	3		1	1				1		1	3		3	3						1	3
Development	3		2	3	3		2	3		2	2				2		1	3		2	1				1	1	1	1
Disturbance	1		2	1	1		2	2		1	1				2		2	2		2	2			1	1	1	1	1
Displacement	1		2	1	1		2	1		1	2				2		1	3		2	1			1	2	1	1	1
Avoidance	1		1	1	1		1	1		2	2				2		2	1		1	1				1	1	1	1
Entrainment	1		1(j)	1	1		1(j)	1		2	3				2		1	1		1(j)	1				1	1	3	2
Burial	3		3	3	3		3	3		2	1				2		3	3		3	3			1	2	3	3	2
Sedimentation	3		2	3	3		2	3		2	2				2		2	1		2	3			1	3	3	3	1
Noise	3		1	2	2		1	2		2	3				2		3	2		1	2				1	1	1	2
Sediment type	2		2	3	2		2	3		2	2				2		2	1		2	3			1	1	1	1	2
Habitat modification/loss	3		2	1	3		2	1		1	1				1		1	1		2	1			1	1	1	1	1
Turbidity (optical)	1		2	1	1		2	1		2	2				2		1	2		2	1			1	1	1	1	1
Suspended sed. conc.	1		1	1	1		1	1		1	2				2		1			1	1			1	1	1	1	1
Water quality (pH, NH3, etc.)	1		3	1	1		3	1		1	1				2		1			3	1			1	1	1	1	1
Toxicity	1		1	1	1		1	1		1	1				2		1			1	1			1	1	1	1	1
Pathway	2		1	1	2		1	2		2	2				2		1			1	1			1	1	1	1	1
Exposure	1		1	1	1		1	1		1	2				2		1			1	1			1	1	1	1	1
Bioavailability	1		1	1	1		1	1		2	2				2		1			1	1			1	1	1	1	1
Bio-accumulation	2		1	2	2		1	1		2	2				2		1			1	1			1	1	1	2	1

*(a)= adults only, (j)=juveniles only, all other entries=juveniles and adults

APPENDIX A

Biology and Ecology of Longfin Smelt
(Spirinchus thaleichthys)

As discussed in Section 2.2, longfin smelt was assigned an environmental window, but this species was not listed as federal threatened or endangered as had been anticipated. Information on the biology and ecology of the species is included in this appendix for completeness.

A.1 General Information and Status

Longfin smelt is an estuarine-anadromous species of the family Osmeridae. Species in this family are small and silvery and may occur in large numbers in marine and freshwaters of the Northern Hemisphere. Populations of this species are recorded from Humboldt Bay and the Eel and Klamath river estuaries, as well as the San Francisco Estuary. Longfin smelt has experienced substantial population declines in California (Moyle 2002). Armor and Herrgesell (1985) classified longfin smelt of San Francisco Bay as a "wet response" (to wet and dry years) estuarine species.

Longfin smelt (*Spirinchus thaleichthys*) is a federal- and state-listed species of concern (USACE 1998). USFWS (1996) produced a recovery plan for this species.

A.2 Reproduction

Maturation of longfin smelt begins late in the second summer of their life in August and September. As they mature, the smelt begin migrating upstream from San Francisco and San Pablo Bays toward Suisun Bay and the Delta. Longfin smelt spawn in fresh water, primarily in the upper end of Suisun Bay and in the lower and middle Delta. In the Delta, they spawn mostly in the Sacramento River channel and adjacent sloughs (Wang 1991). Spawning occurs over sandy-gravel substrates, rocks, or aquatic plants. Spawning may take place as early as November and extend into June, although the peak spawning period is from January to April. Ripe adults, larvae, and juveniles are salvaged at the water export facilities in every below normal or drier water year (Wernette 2000). The eggs are adhesive and are probably deposited on rocks or aquatic plants.

A.3 Growth and Development

Shortly after hatching, longfin smelt larvae develop a gas bladder that allows them to remain near the water surface (Wang 1991). The larvae do not vertically migrate, but instead remain near the surface on both the flood and ebb tides (CDFG 1992c). Larvae are swept downstream into nursery areas in the western Delta and Suisun and San Pablo Bays with larval dispersal farther downstream in years of high outflow than in years of low outflow (CDFG 1992a, Wernette 2000). Early development of gas bladders by longfin smelt causes the larvae to remain near the surface much longer than Delta smelt larvae. That factor and earlier spawning period help explain why the longfin smelt larvae are dispersed much farther downstream in the Estuary than are Delta smelt larvae (Wernette 2000). Larval development occurs primarily in the February through May period and peaks during February-April (CDFG 1992c). Most longfin smelt growth occurs during the first summer and they spawn and die at two years of age (NHI 1992, CDFG 1992c).

A.4 Behavior

The main prey of adult longfin smelt is the opossum shrimp, *Neomysis mercedis* (NHI 1992). There is little information on food habitats of longfin smelt larvae, but fish larvae of most species, including Delta smelt, are known to feed on phytoplankton and small zooplankton (Hunter 1981, USBR 1993). Juvenile longfin smelt feed on copepods, cladocerans, and mysids. The mysid *Neomysis mercedis* is the most important prey of larger juveniles (Wernette 2000).

A.5 Distribution and Migration

Longfin smelt are widely distributed in estuaries on the Pacific Coast. They have been collected from numerous river estuaries from San Francisco to Prince William Sound in Alaska (Moyle 2002). Longfin smelt are euryhaline, meaning they are adapted to a wide salinity range, and they are also anadromous. Spawning adults are found seasonally as far upstream in the Delta as Hood, Medford Island, and the Central Valley Project and State Water Project fish collection facilities in the southern Delta (Wernette 2000). Historically, before construction of Shasta Dam in 1944, saline water intruded in dry months as far upstream in the Delta as Sacramento, so longfin smelt may have periodically ranged farther upstream than they do currently (Herbold et al. 1992). Except when spawning, longfin smelt are most abundant in Suisun and San Pablo Bays (NHI 1992). Pre-spawning adults and yearling juveniles are generally most abundant in San Pablo Bay and downstream areas as far as the South Bay and in the open ocean (Wernette 2000).

A.6 Other Information

In the Bay-Delta Estuary, the decline in longfin smelt abundance is associated with freshwater diversion from the Delta. Longfin smelt may be particularly sensitive to adverse habitat alterations because their 2-year life cycle increases their likelihood of extinction after consecutive periods of reproductive failure due to drought or other factors. Relatively brief periods of reproductive failure could lead to extirpations (Federal Register Vol. 59 No. 4, January 3, 1994, Wernette 2000).

Many exotic species have also invaded the Estuary in recent years. These species may compete with or prey on longfin smelt. However, no single invasion of exotic species parallels the decline the longfin smelt closely enough to suggest that competition from or predation by the species was a primary cause of the longfin smelt’s recent decline. The effects of multiple-species invasion, which have occurred in the Estuary, are extremely difficult to evaluate. The effects of exotic species invasions on longfin smelt is likely not large, because Delta outflow explains over 60 percent of the variation in abundance (Wernette 2000).

Other factors that may affect survival of longfin smelt include food limitation and presence of toxic materials. Abundance of *Neomysis* and other zooplankton prey of longfin smelt has declined in recent years (Obrebski et al. 1992). It is not known what effect the decline in prey abundance has had on longfin smelt. However, food limitation may be important because year class strength of many fish populations, particularly species with planktonic larvae, may be strongly influenced by feeding conditions during the larval life stage (Lasker 1981, Wernette 2000).

In a study of interannual effects of freshwater flow into the Estuary, Kimmerer (2002) reported that longfin smelt abundance is higher during high-flow than during low-flow years.

The short life span of longfin smelt and their relatively low position in the food chain probably reduce the potential for accumulation of toxic materials in their tissues and make them less susceptible to injury than species that live longer (NHI 1992, Wernette 2000).

APPENDIX B

Biology and Ecology of Sacramento Splittail *(Pogonichthys macrolepidotus)*

As discussed in Section 2.2, Sacramento splittail was delisted during the preparation of this report; accordingly, there is no longer a need for an environmental window for this species. Information on the biology and ecology of the species is included in this appendix for completeness.

B.1 General Information and Status

Sacramento splittail (*Pogonichthys macrolepidotus*) is a member of the Cyprinidae or minnow family. This species is unusual for a minnow in its tolerance to mesosaline waters (10-18 ppt; Moyle 2002). Armor and Herrgesell (1985) classified splittail of San Francisco Bay as a “mixed response” (to wet and dry years) freshwater species.

Until recently, the species was a federal-listed threatened species and a state-listed species of special concern (USACE et al. 1998). USFWS (1996) produced a recovery plan for this species. However, the species was delisted by USFWS in September 2003.

B.2 Reproduction

Adult splittail generally reach sexual maturity at about 2 years of age (Caywood 1974). Some males mature at the end of their first year and a few females mature in their third year. An upstream spawning migration occurs from November through May, with a typical peak from January through March. Spawning is thought to peak during February through June, but may extend from January through July. Although submerged vegetation is thought to be the preferred spawning substrate, egg samples have not yet been collected on any substrate. Reproductive activity appears to be related to inundation of floodplain areas, which provides shallow, submerged vegetation for spawning, rearing, and foraging (Caywood 1974, Sommer et al. 1997, Sommer 2000, CDWR and USBR 1994).

B.3 Growth and Development

Although morphological characteristics of splittail eggs, larvae, and juveniles have been described and recent culturing studies are providing preliminary information on early life history requirements and development, very little is known about factors that influence splittail egg and larval development (Bailey 1994, Sommer 2000).

Mature splittail eggs are adhesive or become adhesive soon after contacting water and appear to be demersal; it is assumed that they are laid in clumps and attach to vegetation or other submerged substrates (Bailey 1994, Sommer 2000). Early hatched larvae have not developed eye pigment, and are physically underdeveloped, while the last larvae to hatch have developed eye pigmentation and are morphologically better developed. It is unknown when exogenous feeding actually begins, but preliminary observations indicate that newly hatched larvae may have undeveloped mouths (CDWR and USBR 1994, Sommer 2000).

Sacramento splittail are a relatively long-lived minnow, reaching ages of 5, and possibly, up to 7 years (ID 4283). Studies from Suisun Marsh indicate that young-of-the-year grow approximately 20 millimeters per month (mm/month) from May through September and then decrease to < 5 mm/month through February (Daniels and Moyle 1983). In their second season they grow at about 10 mm/month until the fall, when somatic growth declines and gonadal development begins. The adult growth rate ranges from 5 to 7 mm/month (CDWR and USBR 1994, Goals Project 2000).

B.4 Behavior

Feeding studies describe splittails as opportunistic benthic foragers. Common prey items include opossum shrimp, detritus, insects, and small fish. In Suisun Marsh, opossum shrimp is their main prey item. Food selection studies from Suisun Marsh suggest that splittail specifically select *Neomysis* as their main prey item in the Estuary (Herbold 1987). Fullness indice data indicate that condition factors of splittail are linked to *Neomysis* abundance. Splittail did not switch to alternate and more prevalent food items, as was observed for other native resident species (Sommer 2000).

Striped bass, in turn, commonly prey upon Sacramento splittail (BCDC 2002, Caywood 1974, Sommer 2000).

B.5 Distribution and Migration

The historical range of splittail included all low-gradient portions of all major tributaries to the Sacramento and San Joaquin Rivers, as well as some other freshwater tributaries to San Francisco Bay (Meng and Moyle 1995). A confounding issue is that the collection season and life stage for most of the early observations are unknown, so the relative importance of each location to different age classes of splittail cannot be established (Sommer 2000, BCDC 2002, CDWR and USBR 1994).

Splittail are presently most common in the brackish waters of Suisun Bay, Suisun Marsh, and the Sacramento-San Joaquin Delta (Sommer 2000, BCDC 2002). The data suggest that splittail inhabit much of their historical range and have been located in previously unreported sites. Much of the loss of splittail habitat is attributable to migration barriers, but loss of floodplain and wetlands due to diking and draining activities during the past century probably represents the greatest reduction in habitat (Sommer 2000).

Within the San Francisco Estuary, splittail were collected from southern San Francisco Bay and at the mouth of Coyote Creek in Santa Clara County around the turn of the century (Sommer 2000, BCDC 2002). To our knowledge, no other splittail have been collected in this part of San Francisco Bay (Aceituno et al. 1976). However, splittail are caught in San Francisco Bay and San Pablo Bay in wet years. Adults and young are abundant in two tributaries to San Pablo Bay, the Napa and Petaluma Rivers. The core of distribution of adult splittail during summer appears to be the region from Suisun Bay to the west Delta. Splittail are also present in some of the smaller tributaries and sloughs of Suisun Bay, including Peyton Slough, Hastings Slough, and Pacheco Creek (Sommer 2000, BCDC 2002).

B.6 Other Information

Sacramento splittail are unique in that they are a freshwater species that is able to tolerate brackish water. In addition, they are able to withstand a wide range of temperatures. Both of these characteristics extend their distribution out of the Delta and into portions of San Francisco Bay. Critical habitat for Sacramento splittail are small dead-end channels, freshwater streams, and larger channels such as those found in Montezuma Slough and Suisun Marsh (Daniels and Moyle 1983). Specifically, juveniles and adults utilize shallow edgewater areas lined by emergent aquatic vegetation. Submerged vegetation provides abundant food sources and cover to escape from predators. Shallow seasonally flooded vegetation is also apparently the preferred spawning habitat of adult Sacramento splittail (Caywood 1974, BCDC 2002, Sommer 2000, Moyle et al. 2000a, 2000b, Sommer et al. 2002).

Sacramento splittail abundance is largely dependent upon floodplain inundation associated with high freshwater outflow from the Delta. Higher flows increase inundation of floodplain areas such as Yolo Bypass, which provides spawning, rearing, and foraging habitat (Sommer et al. 2002). Suisun Marsh and Chipps Island both experienced low abundance in the 1980s during periods of low outflow. Attributes that help splittail respond rapidly to improved environmental conditions include a relatively long life span, high reproductive capacity, and broad environmental tolerance (BCDC 2002). In a study of interannual effects of freshwater flow into the Estuary, Kimmerer (2002) reported that Sacramento splittail abundance was higher during high-flow than during low-flow years.

Much of the historical loss of Sacramento splittail habitat is attributable to migration barriers, and to the loss of floodplain and wetlands to diking and draining activities over the last century. Additional factors that may affect population levels include habitat loss, recreational fishing, entrainment, and toxic compounds in the water (BCDC 2002).

Matern et al. (2002) reported that splittail did not exhibit strong concordance with other fish species in Suisun Marsh over a 20-year period.

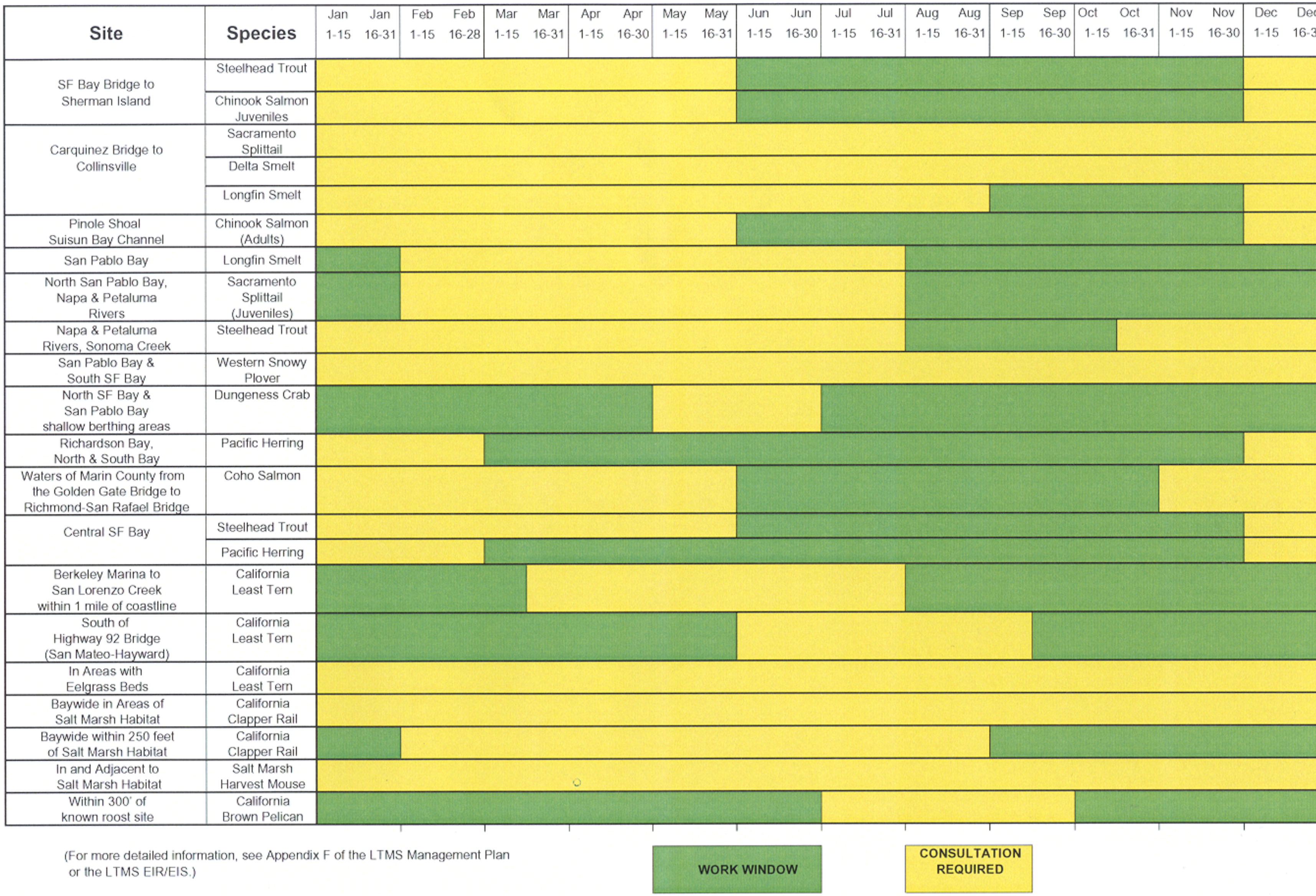
APPENDIX C

Current Environmental Work Windows (Figures 3.2 and 3.3 of the LTMS Management Plan)

Note: Although included in the following version of the work windows table, Sacramento splittail was delisted in 2003 and longfin smelt was not listed as expected when the table was developed. These two species accordingly are not currently designated windows species.

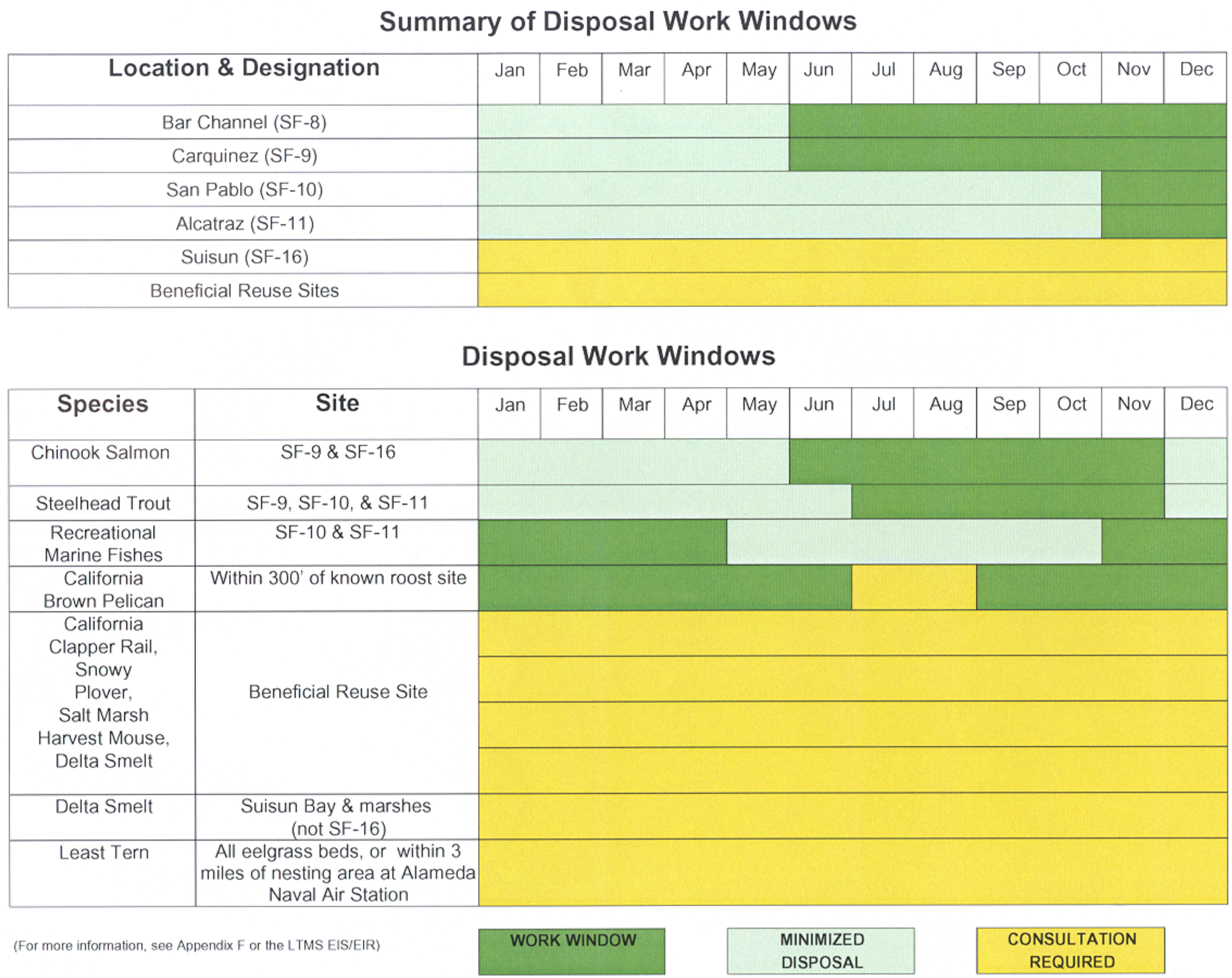
Figure 3.2

Dredging Work Windows by Area



(For more detailed information, see Appendix F of the LTMS Management Plan or the LTMS EIR/EIS.)

Figure 3.3


Summary of Disposal Work Windows
Location & Designation
Jan
Feb
Mar
Apr
May
Jun
Jul
Aug
Sep
Oct
Nov
Dec
Bar Channel (SF-8)
Carquinez (SF-9)
San Pablo (SF-10)
Alcatraz (SF-11)
Suisun (SF-16)
Beneficial Reuse Sites
Disposal Work Windows
Species
Site
Chinook Salmon
SF-9 & SF-16
Steelhead Trout
SF-9, SF-10, & SF-11
Recreational Marine Fishes
SF-10 & SF-11
California Brown Pelican
Within 300' of known roost site
California Clapper Rail, Snowy Plover, Salt Marsh Harvest Mouse, Delta Smelt
Beneficial Reuse Site
Delta Smelt
Suisun Bay & marshes (not SF-16)
Least Tern
All eelgrass beds, or within 3 miles of nesting area at Alameda Naval Air Station
(For more information, see Appendix F or the LTMS EIS/EIR)
WORK WINDOW
MINIMIZED DISPOSAL
CONSULTATION REQUIRED