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Supplement to the "Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay"

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Contents

Tables

Acronyms

BCDC	Bay Conservation and Development Commission
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife (formerly California Department of Fish and Game, CDFG)
EIS/EIR	Environmental Impact Statement/Environmental Impact Report
EPA	U.S. Environmental Protection Agency
FESA	Federal Endangered Species Act
LTMS	Long-term Management Strategy for Placement of Dredged Material
NOAA	National Oceanic and Atmospheric Administration
NMFS	National Marine Fisheries Service
RWQCB	Regional Water Quality Control Board
SLC	State Lands Commission
USACE	U.S. Army Corps of Engineers
USFWS	U.S. Fish and Wildlife Service

1.0 Summary

This document is a supplement to the *Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay* (Framework) (LFR 2004). The Framework evaluates data needs and issues of concern to the agencies involved in the Long-term Management Strategy (LTMS) for Placement of Dredged Material in the San Francisco Bay Region. In this supplement, we provide information about the potential effects of dredging activities on commercially important or state and federally listed species that were not included in the original Framework document. These species include the California Least Tern (*Sterna antillarum browni*), California Clapper Rail (*Rallus longirostris obsoletus*), salt marsh harvest mouse (*Reithrodontomys raviventris*), green sturgeon (*Acipenser medirostris*), longfin smelt (*Spirinchus thaleichthys*), and Dungeness crab (*Cancer magister*).

Work for this project consisted of gathering information on the life history and potential effects of dredging activities for the six species listed above, as well as identifying management concerns and data gaps for each of these species. This review was based on several sources of information, including San Francisco Bay LTMS documents and symposia, agency reports, peer-reviewed publications, and interviews with stakeholders and researchers. Staff from regulatory agencies was interviewed to identify management concerns and rank the importance of potential topics of study for each of the six species. The potential study topics discussed were identical to those presented in the 2004 Framework document. In addition, the rankings of potential study topics were reassessed for those species considered in the 2004 Framework document.

2.0 Introduction

This document is a supplement to the *Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay* (LFR 2004). This work is being conducted under the auspices of the participants of the Long-Term Management Strategy (LTMS) for the Placement of Dredged Material in the San Francisco Bay Region. The LTMS is led by two federal and three state agencies that have the primary responsibility and authority to regulate dredging and dredged material disposal in the Bay Area: the Francisco Bay Conservation and Development Commission (BCDC), the San Francisco Bay Regional Water Quality Control Board (RWQCB), the San Francisco District of the U.S. Army Corps of Engineers (USACE), the State Lands Commission (SLC), and the U.S. Environmental Protection Agency (EPA). The LTMS also includes the resource agencies with regulatory authority over sensitive species: the California Department of Fish and Wildlife (CDFW, formerly CDFG), the National Marine Fisheries Service (NMFS), and the U.S. Fish and Wildlife Service (USFWS).

The LTMS program has used environmental work windows as a key tool in managing dredging and dredged material disposal in an economically and environmentally sound manner in San Francisco Bay. In 1999, under the authority of the Federal Endangered Species Act (FESA), NMFS and USFWS developed temporal and geographically based environmental work windows for dredging and disposal projects to minimize or avoid adverse impacts to state and federally listed fish species in San Francisco Bay. The California Department of Fish and Game (CDFW) concurred with the federal biological opinions and also added environmental work windows for state species of special concern.

As part of their original workplan in 2002, the LTMS Science and Data Gaps Workgroup (Science Workgroup) requested the development of a document to identify and assess information needed to refine the environmental work windows. Phil Lebednik developed the original *Framework for Assessment of Potential Effects of Dredging on Sensitive Fish Species in San Francisco Bay* (hereafter referred to as "the Framework") with assistance from the Science Workgroup members and other agency representatives. The species reviewed in the original document were those fish species that were state or federally listed (chinook and coho salmon, steelhead trout, delta smelt) or were state species of special concern (Pacific herring) at the time that the study was undertaken. The Framework compiled existing information about the life histories of these fish species within San Francisco Bay, identified the potential impacts on these species related to dredging or aquatic disposal, and summarized and prioritized the specific management concerns and research questions that resources agency staff had identified for each species.

The Science Workgroup initially focused on those fish species for which there were the most immediate management concerns. Therefore, the Framework did initially not include any of the non-fish species for which environmental work windows had been developed.

This supplement provides information about the potential effects of dredging on state and federally listed avian and mammalian species that were not included in the original document: the California Least Tern (*Sterna antillarum browni*), California Clapper Rail (*Rallus longirostris obsoletus*), and salt marsh harvest mouse (*Reithrodontomys raviventris*). The Southern distinct population segment (DPS) of the green sturgeon (*Acipenser medirostris*) and the longfin smelt (*Spirinchus thaleichthys*) are also included since they are now federally and state-listed threatened species, respectively. Dungeness crab (*Cancer magister*) is included because of its commercial importance.

This supplement to the Framework (1) provides species and life history information for the six species listed above; (2) assesses the potential impacts to these species from dredging and dredged material placement; and (3) identifies management concerns, data gaps, and potential studies for these species. The supplement also includes an annotated bibliography of all LTMS-funded studies related to the four fish species in the original Framework Document and the additional species reviewed here.

2.1 Document Organization and Approach

The organization of the supplement differs slightly from the original document. Given that there is less information to present, and in order to avoid redundancy, the supplement consolidates information for each species that had been separated into different document sections in the original document. The original Framework separated the discussion of life history information and the potential impacts of dredging and dredged material disposal for each species into two different document sections: Sections 4.0 and Section 6.0. Section 6.0 of the original document is further sub-divided to address; (1) the general potential effects of dredging and dredged material disposal to the environment as described in the LTMS EIS/EIR (Section 6.1); (2) species-specific potential impact information from the various LTMS documents (section 6.2); and (3) species-specific potential impact information from the literature (Section 6.3). In this supplement, the types of information contained in Section 4 and Section 6.1, 6.2, and 6.3 of the original Framework are all consolidated into one single section per species.

Species-specific potential impact information includes both a review of the relevant scientific literature and a summary of the potential study topics ranked as a high priority by the LTMS agencies (Tables 1 - 6). A series of interviews was conducted with representatives of agencies involved in the LTMS. The interviews included all of the resource agencies (NOAA Fisheries, USFWS, CDFG) as well as two of the three LTMS lead agencies (BCDC and USACE) that are actively involved in the Science Workgroup. The selection of interviewees was based on consultations with the Chair of the LTMS Science Group and several other key members of the Science Group. The Regional Water Quality Control Board-San Francisco Bay Region abstained from ranking study topics because their Basin Plan does not prioritize individual species. While persons interviewed consulted with other staff in their respective agencies, it is important to note that interview results may not necessarily reflect all potential concerns that a more formal review may include. Nevertheless, it was considered that this collective cross-section of stakeholder feedback would likely identify the most significant concerns. High priority study topics are discussed in terms of potential studies and study questions related to these topics (Table 7). Agency staff ranked study topics as high, medium, or low priority for each species. Topics that were ranked as a high or medium priority by all agencies or as a high priority by a majority are discussed in detail below.

The Framework contains information on the San Francisco Bay environment and dredging equipment and operations. In order to avoid redundancy, this supplement will not include information on these topics. Since there are two fish species being added in this update, some discussion of general impacts from the Framework may be repeated in the section on green sturgeon and longfin smelt. Additional discussion of the more general potential effects from dredging and disposal on piscivorous birds as found in the literature is included in Section 4.0.

This update to the Framework has been developed based on several sources of information:

- San Francisco Bay LTMS Documents (including technical reports, the LTMS EIS/EIR, LTMS biological opinions, and related agency documents);
- Reports and publications on the species of interest;
- Reports and publications on the potential effects of dredging and disposal on the species of interest;

- Interviews with agency staff, stakeholders, and researchers; and
- Materials from LTMS symposia on the effects of dredging on longfin smelt and green sturgeon.

3.0 Additional Window Species

3.1 Dungeness Crab (Cancer magister)

3.1.1 General Information and Status

The Dungeness crab is a member of the family Cancridae and is found in nearshore waters and major estuaries along the California coast. Tagging experiments on the coast of California have identified five subpopulations in and around the following regions: Avila-Morro Bay, Monterey Bay, San Francisco Bay, Fort Bragg, and Eureka-Crescent City (Hankin and Warner 2001).

The Dungeness crab is currently not listed as a state or federal species of concern but is a commercially valuable species in San Francisco Bay.

3.1.2 Reproduction

In California, mating can occur anytime between February and July (Hankin and Warner 2001) and usually happens between March and May (Poole and Gotshall 1965) but sometimes as late as July (Wild and Tasto 1983). Mating occurs between recently molted (soft-shell) females and non-molting (hard-shell) males (Snow and Neilson 1966). Eggs are not fertilized until the fall, when they are extruded in a sponge-like mass of up to two million eggs held beneath the abdominal flap of the female. Hatching occurs from late December to mid-January (Wild and Tasto 1983). Eggs hatch in 60 to 120 days (Pauley et al. 1986). A female will have about three to four broods and may produce up to five million eggs during her lifetime (MacKay 1942).

3.1.3 Growth and Development

The life stages of the Dungeness crab include the egg, larvae, juvenile, and adult. (Hankin and Warner 2001). Local adult Dungeness crabs mate and lay eggs offshore in the Gulf of the Farallones. After hatching, young crabs go through five free-swimming larval stages. During the end of their last larval stage, ocean currents transport larvae into San Francisco Bay, typically between April and June. The crabs then metamorphose into first stage, bottom-dwelling juveniles. In California, both males and females molt an average of twelve times before they reach adulthood (when their carapace width reaches approximately 4 inches) and sexual maturity is reached at two years of age. Once maturity is reached, the growth of females slows as compared to males and the frequency of molts decreases for both sexes (Hankin and Warner 2001). Crabs reared in San Francisco Bay molt more frequently than those found in near-coastal marine waters and typically can reach sexual maturity at one year of age (Wild and Tasto 1983).

3.1.4 Behavior

Dungeness crabs in the larval stage are pelagic (living in the water column) and feed on plankton. Juvenile and adult stage crabs are epibenthic (living on the bottom surface) and are opportunistic foragers that feed on larger bottom-dwelling organisms such as clams, crustaceans, and small fishes (Tasto 1983). In some cases, cannibalism occurs among all age groups (Warner 1992).

3.1.5 Distribution and Migration

Dungeness crabs are found along the west coast of the North America. Their range extends from Alaska's Aleutian Islands to Point Conception, California (Warner 1992). The pelagic larval forms are found in both nearshore and offshore waters. The juvenile and adult organisms are found in both nearshore waters and bays and estuaries from the intertidal zone to approximately 300 feet of depth (Hatfield 1983, Reilly 1983a, Reilly 1983b, Warner 1992).

San Francisco Bay is an important nursery area for the coastal stock of crabs. Growth of juveniles is faster in estuaries than offshore, likely due to warmer temperatures (Armstrong and Gunderson 1985). The majority of Dungeness crabs in the Bay are juveniles of a single year-class. They congregate in tidal and navigational channels in early summer and spread out over mudflats and protected shoreline areas, where they mature into adults, before migrating out of the Estuary into coastal waters (Tasto 1983, McCabe et al. 1988). The abundance of juveniles in San Francisco Bay varies significantly from year to year and is often highest in San Pablo Bay (Tasto 1983, CDFG 1987).

Juvenile crabs are more common on sandy or sandy-mud substrate but can be found on almost any bottom type (e.g., shell debris). They prefer vegetated areas that provide cover from predators (such as eelgrass or drift macroalgae) to bare mud or open sand (Fernandez et al. 1993, Iribarne et al. 1995, Eggleston and Armstrong 1995, McMillan et al. 1995).

3.1.6 Other Information

The Dungeness crab has been commercially fished in the San Francisco Bay Area since 1848. Currently, harvesting of Dungeness crabs is permitted exclusively outside of the Golden Gate (Goals Project 2000). In addition, fishing regulations prohibit the catch of female crabs and specify that the carapace size of landed crabs must be at least 6.25 inches, to ensure that a sufficient number of crabs can mature and reproduce before capture.

Populations of Dungeness crab began declining in the early 1960s, most likely due to changes in ocean climate, increased predation, and possibly pollution (Wild and Tasto 1983). Dungeness crab populations undergo significant annual variation and few current estimates have been generated for populations along the Pacific coast (Goals Project 2000).

Factors affecting Dungeness crab populations in the San Francisco area (i.e., the Gulf of the Farallones from Half Moon Bay to Bodega Bay, including San Francisco Bay) include ocean temperatures (which affect hatching success), ocean currents (which affect larval drift), predation, and commercial fishing. Water and sediment quality issues, such as low dissolved oxygen (below 5 ppm), ammonia, pesticides, oiled sediments, and other contaminants, may have an impact on nursery habitat (Wild and Tasto 1983, Emmett et al. 1991).

3.1.7 Potential Impacts

The LTMS EIS/EIR concluded that Dungeness crabs, which live in the benthic environment, are susceptible to direct entrainment by dredging equipment (LTMS 1998). Crab abundance tends to be higher in the Central Bay and North Bay (especially San Pablo Bay) in shallow berthing areas and channels between May 1st and June 30th (LTMS 2001). Therefore, these locations and times of year are especially critical for potential impacts. The EIS/EIR also identifies concerns regarding disposal of dredged material at the Carquinez or San Pablo Bay designated disposal sites, where Dungeness crabs may be present during the most sensitive life stages (LTMS 1998).

Most of the studies on entrainment of Dungeness crabs are from the Pacific Northwest region, with a geographic focus on the Gray's Harbor and Columbia River estuaries in Washington State. Studies at Gray's Harbor concluded that entrainment is a function of the type of dredging equipment used. Hopper and pipeline dredges are much more likely to entrain crabs than clamshell dredges, since these hydraulic dredges create a strong suction field that crabs and other benthic organisms cannot escape (Reine and Clarke 1998; Nightingale and Simenstad 2001). Several studies have found Dungeness crabs to be particularly susceptible to hopper dredging (Reine and Clark 1998, Nightingale and Simenstad 2001). Stevens (1981) attributed low rates of entrainment by clamshell dredges to the fact that crabs tend to avoid both the increased suspended sediment associated with clamshells and the low-frequency vibrations caused by the lowering of the bucket into the water (Nightingale and Simenstad 2001).

Entrainment may also be influenced by other factors like bottom depth, advance speed of the draghead or cutterhead, the flow-field velocities generated by these devices, volume of material being dredged, and the direction of dredging with regard to tidal flow (Nightingale and Simenstad 2001). In one study, Larson and Patterson (1989) identified the latter as the most important factor. They found that entrainment rates were highest when dredging occurred against an ebb flow. However, this observation could not be duplicated in three years of follow-up studies (Reine and Clark 1998).

While Dungeness crabs are found throughout the Estuary, they tend to congregate in navigation channels, particularly during low tides or while migrating into or out of the Estuary, which makes them more susceptible to entrainment during channel dredging events (Reine and Clarke 1998).

Several studies in Gray's Harbor have found that juvenile crabs are much more susceptible to entrainment than adults (Nightengale and Simenstad 2001). Studies by the U.S. Army Corps of Engineers (1986) on the Columbia River found that young-of-year crabs (crabs in their first post-larval instar stage) were entrained at high rates by hopper dredges compared to older crabs (Armstrong et al 1987). There is little information as to why this happens. One study suggests that the high entrainment rates might be due to the fact that there are a larger numbers of crabs in younger life stages in estuaries (McGraw et al 1998). Generally, when there is an abundance of crabs in the Estuary, entrainment rates are higher. Armstrong et al. (1989) and Larson and Patterson (1989) suggest that the overall impact on populations may be minor, because the higher entrainment rates affect mostly crabs in younger life stages, which have high natural mortality rates to begin with (Larson and Patterson 1989, Armstrong et al. 1989).

Predicting the impact of entrainment on Dungeness crab populations in an Estuary is difficult, since there is great natural variability in seasonal numbers and natural mortality rates. Also, not all Dungeness crabs that are entrained are killed. The causes of mortality of entrained crabs are physical trauma, burial or crushing under excessive sediment weight, or disposal into a Confined Disposal Facility. According to Wainwright et al (1992), mortality rates of entrained crabs depend on the type of equipment used, the disposal method, the size of the crab, its condition, and whether it is molting (McGraw et al 1998, Reine and Clark 1998, Armstrong et al 1987). Stevens (1981) found that hopper dredge mortality due to entrainment increased with crab size and ranged from 5% mortality for crabs measuring 7-10mm in length to 86% mortality for crabs over 75mm (Nightengale and Simenstad 2001). Entrainment rates in the outer Columbia River Estuary ranged for adult crabs ranged from 0.040 to 0.592 crabs/cubic yard of dredged material (Nightengale and Simenstad 2001). McGraw et al. (1988) also found higher mortality due to entrainment for larger crabs. They suggest that smaller crabs pass more easily through pump mechanisms without being harmed and are less likely to come into contact with rocks and other large debris that may be contained in the dredged material (McGraw et al., 1998).

As discussed in the original framework document (LFR 2004), dredging and disposal activities may also result in the direct burial of organisms or benthic communities with dredged material. According to a study by Keegan et al (1989), Dungeness crabs are prevalent in and around the Carquinez disposal site for dredged material (accounting for nearly eight percent of the crustacean catch in the study sampling area) and therefore may be susceptible to burial (LTMS 1998).

Mortality rates for buried crabs are likely related to the abundance of crabs, their level of activity, and the rate of deposition of the dredged material. The disposal footprint depends upon vessel speed, water depth, currents, and ambient bathymetry. Currents, the speed of the vessel, and the water depth would also determine whether the material settles compactly or diffusely on the ocean bottom. Strong currents and flow at the disposal site may disperse disposal material and greatly decrease the potential for crab burial. Also, surge currents created by the dredge material disposal often force the crabs out of the area where the material is being deposited, further minimizing potential for burial. The surge currents themselves have been found to cause no significant injury to the crabs. Crabs that were tumbled around by currents were able to quickly right themselves (Vavrinec et al. 2007).

Crabs that cannot dig out of deposited dredge material usually suffer mortality. In one lab study, Chang and Levings (1978) found that all Dungeness crabs buried by five cm of sediment or less were able to re-establish respiratory pathways quickly. Crabs buried underneath ten cm of material could quickly re-establish breathing pathways and still dig themselves out of the sediment. Underneath 20 cm of material, however, crabs were unlikely to emerge from burial and suffered high mortality rates (Pearson 2005). Another study in the Columbia River concluded that crabs three years and older (carapace width >150 mm) are highly likely to survive (less than 2% mortality) a burial depth of up to 12 cm of sediment, which the study states is a typical maximum deposit depth for dredge material disposal operations (Vavrinec et al. 2007). However, crabs around two years of age and younger were likely subject to significant mortality (Vavrinec et al. 2007). This suggests that younger crabs may be more susceptible to mortality by burial.

Dredging activities may affect crabs indirectly by reducing eelgrass cover. Crab density increases have been found to correlate with increases in percent eelgrass cover. Studies by Nelson (1981) and Heck and Thoman (1984) determined that a minimum, or threshold, vegetation density is required for significant reduction of predation impacts (Nightengale and Simenstad 2001). Dredging activities may have direct impacts on eelgrass cover by physically damaging eelgrass beds. Dredging activities may also indirectly impact eelgrass cover by impacting eelgrass productivity. Increased turbidity due to dredging activities can potentially limit the growth and distribution of eelgrass and other aquatic plants by reducing available light (Batiuk et al. 1992; Dennison et al., 1993).

3.1.8 Priority Study Topics, Research Topics and Potential Studies

Distribution, displacement, avoidance, and entrainment were ranked as high or medium priority study topics for Dungeness crab by all agencies interviewed or as a high priority topic by a majority of the agencies interviewed for this project (Table 1).

Table 1. Priority ranked topics of study for the Dungeness crab (1=highest, 2=moderate, 3=lowest priority; j = juveniles only; all other entries = adults and juveniles.).

Topic	Dungeness Crab				
	NOAA	**FWS**	**CDFW**	**BCDC**	**USACE**
Distribution	1		2j	1	3
Behavior	3		3j	1	3
Migration	3		3j	1	3
Food sources	1		3j	3	3
Feeding	1		3j	3	3
Spawning	1			3	3
Development	3			3	3
Disturbance	1		3j	3	3
Displacement	1		3j	1	3
Avoidance	1		3j	1	3
Entrainment	1		2j	1	3
Burial	3		3j	2	3
Sedimentation	1		2j	3	3
Noise	3		3j	3	3
Sediment type	3		3j	3	3
Habitat modification/loss	2		3j	1	3
Turbidity (optical)	3		3j	2	3
Suspended sed. conc.	3		2j	2	3
Water quality (pH, NH3, etc.)	3		2j	3	3
Toxicity	3		2j	2	3
Pathway	3		3	2	3
Exposure	3		2j	2	3
Bioavailability	1		3	2	3
Bio-accumulation	3		2j	2	3

3.1.8.1 Distribution
Study Topic: Spatial and temporal distributions of Dungeness crab in San Francisco Bay
Study question: What is the overlap between Dungeness crab distribution and areas of dredging impact?

Potential Study: Distribution of Dungeness crab is generally well known in the San Francisco Estuary. The purpose of this study would be to determine the overlap of dredging with the spatial and temporal distribution of Dungeness crab in the Bay. The first phase of this study could involve a review of the available literature and unpublished data on the distribution of Dungeness crab and mapping the overlap with the location of dredging operations. Depending on the results of this literature review, future field studies might be recommended, if dredging is conducted in areas or habitats not previously sampled or studied.

3.1.8.2 Displacement and Avoidance
Study Topic: Displacement effects on Dungeness crab
Study questions: Do Dungeness crab avoid areas where dredging occurs? Are Dungeness crab displaced by dredging projects?

Displacement and avoidance are similar effects that are defined in the Framework document. Displacement refers to an effect that causes a species to leave an area that is normally occupied. Avoidance refers to an effect that causes a species not to use an area that is only occasionally or infrequently occupied. In practice, these two terms may not represent different effects on species and are therefore discussed together.

Potential Study: Perform a literature review on displacement/avoidance responses in Dungeness crab and a comparison with dredging conditions. If displacement/avoidance appears likely, a plan could be developed to conduct additional evaluation using field or laboratory studies.

3.1.8.3 Entrainment
Study Topic: Entrainment risk to Dungeness crab.
Study question: What is the risk of direct mortality or injury to Dungeness crab due to entrainment?

Studies on entrainment by dredging indicate that entrainment risk for benthic organisms varies significantly with the type of dredge (LTMS 2004). Most of the studies on the effects of dredging on Dungeness crab were conducted in the State of Washington. However, the result of these studies may not be fully transferrable to the San Francisco Estuary, due to differences in the type of dredge used and the habitat dredged. In addition, Dungeness crab are smaller in Washington estuaries than in this Estuary (DFG pers. comm.) and size differences would be a consideration.

Potential Study: Review Dungeness crab and dredging entrainment literature for hydraulic and mechanical dredging to evaluate the risk of entrainment. This study would be informed by an evaluation of the distribution of crabs within dredging locations using the results of the study proposed in section 3.1.8.1.

3.1.9 Lower priority topics

Behavior, migration, food sources, habitat modification, feeding, spawning, disturbance, sedimentation, and bioavailability were rated as high priority topics by only one of the agencies interviewed. Study questions related to these topics include:

- Does increased turbidity affect foraging success of Dungeness crab?
- Does dredging impact food resources for Dungeness crab?
- Does dredging modify Dungeness crab habitat critical for predator avoidance?
- Does dredging increase Dungeness crab contaminant exposure to through re-suspension and increased bioavailability of contaminants?
- Does the suspended sediment plume from dredging cause physiological stress or tissue damage to Dungeness crab?

3.2 Green Sturgeon (*Acipenser medirostris*)

3.2.1 General Information and Status

The green sturgeon belongs to the family Acipenseridae and is the most widely distributed sturgeon species. Green sturgeons are anadromous (adults migrate from a marine environment into the fresh water streams and rivers of their birth to spawn) and spend more time in the ocean than other species of sturgeon (Adams et al 2007).

There are two distinct green sturgeon populations on the U.S. West Coast: a northern population that is found in the Eel River and northward; and a southern population that is found in the Sacramento River through the San Francisco Bay Estuary. These two populations have been characterized based on the sturgeon's strong spawning site fidelity and the preliminary genetic evidence that indicates differences between individuals in the Klamath River and those in San Pablo Bay (Adams et al. 2002).

The southern population of green sturgeon was listed as a federal threatened species in 2006 and may become endangered in the future, due to substantial loss of spawning habitat, its highly concentrated spawning only in one area of the Sacramento River, and multiple other environmental risks to the species (Adams et al. 2007). The northern population is considered more stable and unlikely to be listed in the near future (Adams et al. 2007).

3.2.2 Reproduction

Female green sturgeons are thought to spawn once every two to five years (Moyle 2002). Adults migrate upstream to spawn in deep pools of large, turbulent rivers. Their spawning season spans from April to July, with peak spawning occurring between May and June (Erickson et al. 2002).

As green sturgeon spawn, they are thought to broadcast their eggs over large cobble substrate where the eggs settle into the spaces between the cobbles. Green sturgeons produce fewer young (lower fecundity) but have a larger egg size than other sturgeons (Deng 2000).

3.2.3 Growth and Development

Like other sturgeons, green sturgeons are long-lived and slow-growing (Moyle 2002). Males typically first spawn at 15 years and females first spawn at 17 years of age (Adams et al. 2002). Green sturgeons can live up to 70 years.

Larvae start feeding approximately ten days after hatching and grow rapidly to approximately 300 mm by the end of the first year (NMFS 2007). Juveniles spend one to four years in the Estuary before migrating downstream and out into the Pacific Ocean.

3.2.4 Behavior

Green sturgeons are benthic feeders (Moyle 2002). Juveniles in San Francisco Bay usually consume opossum shrimp (*Neomysis mercedis*) and amphipods (*Corophium spp.)*, and adults in the Sacramento-San Joaquin Delta feed mainly on invertebrates, including shrimp, mollusks, amphipods, and on small fish (Adams et al. 2002).

3.2.5 Distribution and Migration

Green sturgeons commonly occur nearshore in coastal waters from San Francisco Bay to Canada (Adams et al. 2002). While green sturgeons have been observed in many estuaries and river systems, actual spawning locations (based on the presence of juveniles) have only been documented in the Rogue (Erickson et al. 2002), Klamath (Scheiff et al. 2001), Trinity (Scheiff et al. 2001), Sacramento (DFG 2002), and Eel (Pucket 1976) Rivers.

Current and historical populations and spawning distributions of the green sturgeon are difficult to assess. While green sturgeons spawn in rivers in the spring and summer, they tend to congregate in coastal bays and estuaries in late summer and early fall (Adams et al. 2006). The reasons for this behavior are not entirely clear, since they seem to neither feed nor spawn in these locations (Adams et al. 2002). The original spawning distribution for green sturgeon may have been reduced due to harvest and other impacts and smaller, less productive populations may have been eradicated by harvest and habitat degradation, before there was any documentation of their existence (Adams et al. 2006).

Green sturgeons have been detected in both shallow nearshore areas and channels. They return upstream to spawn at time intervals ranging from one to three years. In the summer, green sturgeons are more concentrated near the Golden Gate, while in winter they are distributed more widely throughout the Estuary (Stanford et al. 2010)

3.2.6 Other information

Loss of spawning habitat appears to be a very significant factor in the reduction of the southern population of green sturgeon (NMFS 2007). Spawning areas have been eliminated from the area above Shasta Dam on the Sacramento River and Oroville Dam on the Feather River, because the placement of these structures has prevented the fish from accessing these upstream sites (Adams et al 2007). Entrainment of individuals by water diversion projects is an additional threat to the population (Adams et al 2006). It is noteworthy, however, that the number of green sturgeon entrained at water diversion facilities since 1986 has actually decreased, even though water exports have increased significantly. This suggests that the abundance of green sturgeon has decreased greatly (NMFS 2007).

3.2.7 Potential Impacts

Currently, there is limited information in the literature about the potential effects of dredging and disposal on green sturgeon. According to a recent biological opinion written by NMFS, dredging degrades the benthic invertebrate community by removing prey organisms upon which green sturgeon feed. If dredging happens yearly or on a regular basis in a given area, the recovery rate of the benthic community in that area is often decreased and communities may not recover fully between dredging episodes (NMFS 2007).

LFR (2004) noted that increased turbidity in dredging plumes could potentially affect the foraging ability of adult fish by reducing visibility and adversely affecting feeding rates. LFR also stated that bottom dwelling fish species are less likely to be affected by increased suspended sediments than salmonids. There is the potential that the feeding behavior of green sturgeon may be affected by increased turbidity, but they are probably less likely to be affected than other species, since they are bottom-feeders that are normally exposed to higher concentrations of suspended sediments as they forage (NMFS 2007).

Increased suspended sediments have the potential to affect egg-hatching success (Wilbur and Clark 2001 in LFR 2004). However, this may not be the case for all fish species. A study by Hanson and Walton (1990) on the hatching success and survival for striped bass eggs and larvae did not show reduced breeding success (LFR 2004). Suspended sediments may affect green sturgeon eggs, which are broadcast along river bottoms and attach to substrates. Moyle et al (1992) and Conte et al (1998) concluded that increases in fine sediment can inhibit the attachment of eggs on the bottom following spawning (EPIC 2001).

There is also the potential for green sturgeon to be entrained during dredging activities (especially by suction dredges). Demersal fish, such as sand lance, gobies, sculpins, and pricklebacks are likely to have the highest rates of entrainment of any fish species as they reside on or in substrates on the bottom of the Estuary (Nightingale and

Simenstad 2001). While green sturgeon are larger than other fish and may be better able to swim away from suction dredges, they do tend to spend more time in the benthic environment and have a longer residence time in the Estuary than other anadromous fish (like salmonids). Therefore, they may be more likely to come into contact with a suction dredge intake pipe (NMFS 2007).

The 2010 Green Sturgeon Symposium identified the major threats to sturgeon from dredging to be hydraulic entrainment, re-suspension of contaminated sediment, underwater noise, changes to habitat due to bed leveling, and impacts to the prey base (Stanford et al 2010).

3.2.8 Priority Study Topics and Potential Studies

Distribution, behavior, entrainment, habitat, and bioaccumulation were ranked as high or medium priority study topics for green sturgeon by all agencies interviewed or as high priority by a majority of the agencies interviewed for this project (Table 2).

3.2.8.1 Distribution
Study Topic: Spatial and temporal Distribution of green sturgeon in San Francisco Bay.
Study Question: What is the overlap between green sturgeon distribution and areas of dredging impact?

Potential Study: This study could focus more on the distribution of juvenile green sturgeon, whose movements are not as well understood as those of adults. This study would expand on recent telemetry work done with this species.

3.2.8.2 Behavior
No specific behavioral studies have been proposed.

3.2.8.3 Food Sources
Study Topic: Effect of dredging on green sturgeon food sources
Study Question: How does dredging impact food resources for green sturgeon?

Dredging has the potential to affect food resources for green sturgeon through alteration of habitat and water quality parameters important to their benthic prey.

Potential Study: The first phase of this study would be to conduct a literature review of the effect of dredging on prey species important to green sturgeon. If negative effects appear likely, a plan could be developed to conduct additional evaluation using field or laboratory studies.

3.2.8.4. Entrainment
Study Topic: Entrainment risk to green sturgeon
Study Question: What is the risk of direct mortality or injury to green sturgeon due to entrainment?

Potential Study: This study could evaluate the risk of entrainment, by reviewing the literature for relevant information on green sturgeon and potential entrainment effects of hydraulic and mechanical dredging. This study would be informed by an evaluation of the distribution of green sturgeon within dredging locations using the results of proposed study on green sturgeon distribution (See Section 3.2.8.1).

Table 2. Priority ranked topics of study for the green sturgeon (1=highest, 2=moderate, 3=lowest priority; a=adult, j=juvenile).

	Green Sturgeon				
Topic	**NOAA**	**FWS**	**CDFW**	**BCDC**	**USACE**
Distribution	1		1	1	2
Behavior	1		1	2	2
Migration	3		2	1	2
Food sources	1		2	2	2
Feeding	1		3	3	2
Spawning	3		3	3	2
Development	2		3	3	2
Disturbance	2		3	3	1
Displacement	3		2	2	2
Avoidance	3		2	2	1
Entrainment	1		3	1	1
Burial	3		3	1	1
Sedimentation	3		3	2	2
Noise	2		3	3	2
Sediment type	3		3	3	2
Habitat modification/loss	1		2	2	2
Turbidity (optical)	3		3	2	2
Suspended sed. conc.	3		3	2	2
Water quality (pH, NH3, etc.)	2		2	2	3
Toxicity	1		2	2	3
Pathway	2		3	1	3
Exposure	2		3	1	3
Bioavailability	2		3	2	3
Bio-accumulation	1		2	2	3

3.2.8.5 Burial
Study Topic: Determine burial risk to green sturgeon
Study Question: What is the risk that green sturgeon will be buried by placement of dredged sediment?

Potential Study: The first phase of this study could be to conduct a literature review of the risk of burial to green sturgeon. If negative effects appear likely, a plan could be developed to conduct additional evaluation using field or laboratory studies.

3.2.8.6 Habitat modification
Study Topic: Effects of habitat modification by dredging on the green sturgeon
Study Questions: How will habitat modification by dredging affect green sturgeon?

Dredging has the potential to affect the green sturgeon by altering channel habitat, which could result in changes in bed form morphology and habitat structural complexity, potentially interfering with daily vertical migrations of sturgeon.

Potential Study: This study could conduct a review of current literature and synthesis of current tracking data to infer habitat preferences and assess the potential impacts of dredging-related habitat modifications on green sturgeon.

3.2.9 Lower Priority Topics

Migration, feeding, disturbance, toxicity, pathway, exposure, and bioaccumulation were rated as medium priority study topics by all agencies interviewed. Study questions related to these topics include:

- Determine the distribution of juvenile green sturgeon in San Francisco Bay relative to dredging projects.
- How does dredging impact food resources for green sturgeon?
- How does increased turbidity affect foraging success of green sturgeon?
- Does increased suspended sediment concentration affect development of eggs and larvae?
- Does increased suspended sediment concentration cause physiological stress or tissue damage to green sturgeon?
- Do dredging activities increase green sturgeon exposure to contaminants through increased accumulation in the food web?

3.3 Longfin Smelt (*Spirinchus thaleichthys*)

3.3.1 General Information and Status

The longfin smelt belongs to the Osmeridae family. They are anadromous fish that spawn in freshwater and disperse to marine environments as they mature (Moyle 2002). San Francisco Bay is home to the southern-most breeding population, once considered a separate species from the rest of the range, which extends north to Alaska (Moyle 2002). Recognition of the Estuary population as a genetically distinct population could result in a Federal decision to list the population. Recent genetic work found no evidence of gene flow between the San Francisco Bay population and the Lake Washington population (Israel and May 2010).

On March 4, 2009, the California Department of Fish and Game (CDFG) listed the longfin smelt as threatened under the California Endangered Species Act (CESA; Fish and Game Code §§ 2050 et seq.). On March 29, 2012 the U.S. Fish and Wildlife Service designated the San Francisco Bay-Delta population a candidate for Endangered Species Act protection.

3.3.2 Reproduction

Most longfin smelt exhibit a two-year semelparous (spawning once before dying) life cycle. Some individuals have been observed spawning after one year or three years. Longfin smelt spawn from November to June, although the majority of spawning occurs between February and April (Moyle 2002). Females lay 2,000 to 18,000 eggs, their fecundity increasing with age (CDFG 2009). Longfin smelt in the San Francisco Estuary have not been directly observed spawning and their exact microhabitat preferences are unknown. However, longfin smelt in Lake Washington are known to spawn on sand or gravel (CDFG 2009). The distribution of yolk-sac larvae in the San Francisco Estuary suggests spawning occurs at the interface between fresh and brackish water (Moyle 2002).

3.3.3 Growth and Development

Longfin smelt grow to standard lengths of 60 to 70 mm in the first year of life, followed by a second period of growth in the summer and fall of the second year, to obtain standard lengths of 90 to 111 mm. Rare individuals that survive to year three reach 120 to 150 mm standard length (CDFG 2009). Egg development lasts approximately one month in longfin smelt (CDFG 2009). The young smelt then hatch and exist as yolk-sac larvae for one to two weeks. The yolk-sac larvae float near the water surface and move with the prevailing current. Larvae reach juvenile length ($\geq$20 mm) approximately 90 days after hatching (CDFG 2009).

3.3.4 Behavior

Smelt in San Francisco Bay undergo tidal migrations to maintain their position relative to habitat (Bennett et al. 2002). Longfin smelt exhibit daily vertical migrations, appearing higher in the water column at night and lower during the day, related to the movement of their prey (Moyle 2002). Smelt larvae and young juveniles feed predominantly on calanoid copepods, including *Eurytemora affinis* (Baxter et al 2010). Older juveniles and adults feed principally on opossum shrimp and copepods (Feyrer et al 2003, Hobbs et al. 2006).

3.3.5 Distribution and Migration

Distribution of adult longfin smelt changes seasonally, with the majority of adults found in Central, San Pablo, and Suisun bays in the summer, and moving upstream in early fall. Adult distribution is the most widespread in the winter and spring, extending from the South Bay through the Delta, with the greatest concentrations in San Pablo Bay, Suisun Bay, and the West Delta (Rosenfeld 2009). Both juveniles and adults are uncommon in the Delta in the fall (CDFG 2009).

3.3.6 Other Information

The longfin smelt was once one of the most abundant fish species in the San Francisco Estuary. The species has declined severely in abundance in recent decades. Previous declines were strongly correlated with low Delta water outflow. However, recent declines have persisted even in years of high Delta outflow (Moyle 2002, Rosenfeld 2009). These recent declines, beginning in the early 2000s, are considered part of the Pelagic Organism Decline (POD) in the Estuary. Major causes believed to be contributing to the recent decline of the longfin smelt are reduced freshwater outflow during the incubation and larval rearing period, entrainment of larvae and adults in water delivery intakes, and the changing of the food web due to introduced species (Moyle 2002, CDFG 2009).

3.3.7 Potential Impacts

Potential impacts of dredging include direct mortality due to entrainment or burial of eggs, removal of spawning habitat, changes in water quality due to increased suspended sediment, and indirect effects resulting from habitat alteration.

Entrainment by hydraulic dredging has been directly monitored in several studies, and little entrainment has been observed (Swedberg and Zentner 2009, Gold 2009, McGowen 2010). Dredging in spawning habitat poses a risk of removing eggs or spawning habitat directly, burying eggs, or increasing suspended sediment to an extent that prevents the adhesion of eggs to proper substrate (USACE 2004).

Increased turbidity from dredging activities is a potential concern for aquatic species in the Bay. However, longfin smelt are an estuarine species, adapted to turbid waters and changing water clarity. For new dredging projects, changes to hydrodynamics and habitat have the potential to benefit or harm longfin smelt, depending on the project-specific outcome. Longfin smelt may be particularly sensitive to changes in hydrodynamics, as they appear to use channel depth and the pattern of water flow through a channel to maintain position near the entrapment zone (Hobbs 2009).

Potential indirect effects of dredging pertaining to the creation and maintenance of shipping channels include the introduction of invasive species, as well as harm by commercial vessel wave action and propeller damage (Stanford et al. 2009).

3.3.8 Priority Study Topics and Potential Studies

Distribution, food source, feeding, spawning, disturbance, displacement, avoidance, and entrainment were ranked as high or medium priority study topics for longfin smelt by all agencies interviewed or as high priority by a majority of the agencies interviewed for this project (Table 3).

Table 3. Priority ranked topics of study for the longfin smelt (1=highest, 2=moderate, 3=lowest priority; a=adult, j=juvenile).

	Longfin Smelt				
Topic	**NOAA**	**FWS**	**CDFW**	**BCDC**	**USACE**
Distribution	1	3	1	3	2
Behavior	1	1	3	2	2
Migration	1	1	3		2
Food sources	1		2	1	2
Feeding	1	3	2	1	2
Spawning	1	1	1	3	2
Development	3	3	2	3	1
Disturbance	1	1	3	1	1
Displacement	1	1	3	1	2
Avoidance	1	2	3	1	1
Entrainment	1	1	2	1	1
Burial	3	3	1	2	1
Sedimentation	3	2	1	2	2
Noise	3	2	3	3	2
Sediment type	1	3	2	0	2
Habitat modification/loss	3	1	3	2	2
Turbidity (optical)	3	2	3	2	2
Suspended sed. conc.	3	2	3	2	2
Water quality (pH, NH3, etc.)	3	1	3	2	3
Toxicity	3	1	3	2	3
Pathway	3	2	3	2	3
Exposure	3	1	3	2	3
Bioavailability	3	1	3	3	3
Bio-accumulation	3	2	2	3	3

3.3.8.1 Food Sources
Study Topic: Effect of dredging on longfin smelt food sources
Study Question: How does dredging impact food resources for longfin smelt?

Dredging has the potential to affect food resources for longfin smelt through alteration of habitat and water quality parameters important to the copepod and shrimp species that make up the majority of the longfin smelt diet.

Potential Study: The first phase of this study would be to conduct a literature review of the effect of dredging on prey species important to the longfin smelt. If negative effects appear likely, a plan could be developed to conduct additional evaluation using field or laboratory studies.

3.3.8.2 Spawning
Study Topic: Spawning location of longfin smelt and effects of dredging on longfin smelt spawning.
Study Question: Where in San Francisco Bay do longfin smelt spawn? Does dredging remove or alter spawning habitat?

Potential Study: The purpose of this study would be to determine where in the Bay longfin smelt are spawning and whether these areas overlap with areas of dredging activity. Spawning location could be determined by substrate sampling or through the use of artificial substrates.

3.3.8.3 Disturbance
No specific studies have been proposed. "Disturbance" is a general term that includes topics such as displacement and avoidance or noise, which are addressed in subsequent sections.

3.3.8.4 Displacement and avoidance
Study Topic: Determine displacement effects on the longfin smelt
Study questions: Do longfin smelt avoid areas where dredging occurs? Are longfin smelt displaced by dredging projects?

Potential Study: Perform a literature review on avoidance responses in longfin smelt and a comparison with dredging conditions. If displacement appears likely, a plan could be developed to conduct additional evaluation using field or laboratory studies.

3.3.8.5 Entrainment
Study Topic: Determine entrainment risk to longfin smelt.
Study Question: What is the risk of direct mortality or injury to longfin smelt due to entrainment?

Potential Study: A first phase of this study could be to evaluate the risk of entrainment, by searching the literature for relevant information on longfin smelt and potential entrainment effects of hydraulic and mechanical dredging. This study would be informed by an evaluation of the distribution of longfin smelt within dredging locations. Later stages of this study could involve monitoring entrainment rates for different dredging methods.

3.3.9 Lower priority topics

Distribution, feeding, development, burial, sediment type, sedimentation, migration, development, habitat modification, water quality, toxicity, exposure, and bioavailability were rated as high priority study topics by at least one agency interviewed. Sediment type is of particular concern because of spawning, and the concern that dredging may remove spawning habitat. The proposed study of longfin smelt spawning locations will help to address this topic. Study questions related to these lower priority topics include:

- What is the overlap between longfin smelt distribution and areas of dredging impact?
- How does increased turbidity affect foraging success of longfin smelt?
- Does increased sedimentation impact egg attachment?
- Do suspended sediment plumes cause physiological stress or tissue damage to longfin smelt?
- How is longfin smelt habitat modified by dredging?

3.4 California Clapper Rail (*Rallus longirostris obsoletus*)

3.4.1 General Information and Status

The California Clapper Rail is a member of the family Rallidae that is endemic only to the San Francisco Bay region. It is one of three subspecies of *R. longirostris* found in California: the California Clapper Rail (*Rallus longirostris obsoletus*), the 'Light-footed' Clapper Rail (*R. l. levipes)* and the 'Yuma' Clapper Rail (*R. l. ymanensis*; AOU 1957).

The Clapper Rail was federally listed as endangered in 1970 (35 FR 16047, 13 October 1970) and listed as a state endangered species in 1971 (USFWS 1984). The U.S. Fish and Wildlife Service produced a recovery plan for the species in 1984.

3.4.2 Reproduction

The Clapper Rails nesting period usually begins in March and extends into July (DeGroot 1927, Harvey 1980, Evens and Page 1983), with the peak nesting period occurring in April and May. Clapper Rails lay between five and 14 eggs at a time with the average being seven eggs per clutch (DeGroot 1927, Zucca 1954). Clapper Rail pairs are monogamous, territorial, and show strong site fidelity from year to year (Applegarth 1938, Massey and Zembal 1987, Zembal et al. 1989, Albertson 1995).Incubation responsibility is shared by both adults over a period of 18 to 29 days (Applegarth 1938, Zucca 1954, Taylor 1996). The majority of hatching occurs from mid-April to early June (Applegarth 1938, Zucca 1954, Harvey 1988, Foerster et al. 1990).

3.4.3 Growth and Development

Clapper Rails are one of the largest rail species. Adults grow to approximately 31-40 cm in length and weigh approximately 250-350 grams, with the males usually being larger than the females (Taylor 1996). Clapper Rail chicks leave the nest soon after hatching (Applegarth 1938). Young rails then accompany the parents for approximately eight weeks, learning to forage for food (DeGroot 1927, Zembal 1991). Juveniles fledge at approximately ten weeks (Johnson 1973) and may breed as early as their first spring after hatching.

3.4.4 Behavior

The California Clapper Rail primarily inhabits emergent salt marsh and brackish tidal marsh throughout San Francisco Bay. Clapper rails favor habitats that are dominated by pickleweed (*Salicornia virginica*) with extensive stands of Pacific cordgrass (*Spartina foliosa*) that are subject to direct tidal circulation. These habitats provide an intricate network of tidal sloughs and abundant numbers of benthic invertebrates for foraging (Grinnell et al 1918, DeGroot 1927, Harvey 1988, Collins et al 1994) and also serve as escape routes from predators (Zembal and Massey 1983, Foerster et al 1990).

In the South Bay, nests can be in gumplant (*Grindelia humilis*), pickleweed clumps, cordgrass stands, saltgrass patches (*Distichlis spicata*), and wrack (DeGroot 1927, Applegarth 1938, Zucca 1954, Harvey 1988, Foerster et al 1990). In the North Bay, nests have been found in alkali bulrush (*Scirpus robustus*), gumplant, or pickleweed. Nests are primarily located less than two meters from first-order channels and at least 100 meters landward from the marshland shoreline (Evens and Page 1983, Evens and Collins 1992, Collins and Evens 1992).

Clapper Rails tend to forage at low tide on exposed mudflats and in tidal sloughs (Applegarth 1938, Foerster and Takekawa 1991). They feed on benthic invertebrates, including mussels, clams, crabs, snails, amphipods, and worms, in addition to spiders, insects, and fish (Williams 1929, Applegarth 1938, Moffitt 1941).

3.4.5 Distribution and Migration

The historical distribution of California Clapper Rails included tidal marshes from Humboldt Bay to Morro Bay (Grinnell et al. 1918, Grinnell and Wythe 1927, Grinnell and Miller 1944, AOU 1957, AOU 1983, Gill 1979). Presently, they are found only in tidal marshes within San Francisco Bay (Evens 1985, Baron and Takekawa 1994). Current observations of Clapper Rails in estuaries outside of San Francisco Bay are sporadic and the birds sighted are presumed to be vagrants (USFWS 1994). Clapper Rails are distributed fairly evenly between the South Bay and the North Bay (Goals Project 2000).

California Clapper Rails are considered non-migratory, although they have been documented to demonstrate post-breeding dispersal, up to several kilometers from the breeding site, during the fall and early winter (Orr 1939, Wilber and Tomlinson 1976). Historical data suggest that there may be a fairly regular fall dispersal period from August to November; however, Clapper Rails may not disperse every year (Goals Project 2000).

3.4.6 Other Information

The decline of the California Clapper Rail first occurred from the mid-1800s to the early 1900s due to commercial and sport hunting (Wilbur and Tomlinson 1976, Gill 1979). The passage of the International Migratory Bird Treaty Act in 1913 curbed overhunting. Since that time, however, populations have continued to decline significantly due to habitat destruction, the introduction of the red fox in the South Bay, and significant levels of mercury and other contaminants in the eggs (Schwarzbach et al. 2006, Goals Project 2000, Davis et al. 2003).

As of 1988, the total population in San Francisco Bay was estimated to be approximately 700 rails (Foerster and Takekawa 1991). While there is substantial information on current populations by sub-region, total population data are somewhat varied and may indicate a fairly wide fluctuation (USFWS unpubl. data, Collins et al 1994). More recent estimates suggest the total population has increased slightly to approximately 1,040-1,260 individuals (Goals Project 2000).

3.4.7 Potential Impacts

The LTMS EIS/EIR found that dredging might cause destruction of breeding and nesting habitat, and/or loss of upland refugial cover. Nearshore or upland disposal and placement of dredged material for beneficial reuse may also result in direct habitat loss (LTMS 1998). Since Clapper Rails are non-migratory, they may be potentially affected year round but are especially vulnerable between February 1st and August 31st when they may be breeding (LTMS 2001). Clapper rails may be impacted by dredging and disposal activities occurring in and around diked and tidal salt marshes throughout San Francisco Bay and Suisun Marsh (LTMS 2001).

The USFWS biological opinion also found dredging activities may directly and indirectly result in temporary and permanent loss of suitable Clapper Rail habitat. Dredging may result in the direct removal of vegetated habitat as well as mudflats used by foraging Clapper Rails. In addition, suitable Clapper Rail habitat could be temporarily lost through the direct placement or incidental slippage of dredged materials. An indirect loss of Clapper Rail habitat could occur if dredging activities cause slumping of the habitats used by the species from the sides of dredged areas. Dredged materials placed on adjacent levees could result in increased predation by eliminating important upland hiding cover used by Clapper Rails and harvest mice during high tides. Evens and Page (1986) observed that predation on several species of rails appeared to be greatest during high tides when flooded marshes provided minimal vegetative cover.

Maintenance dredging, such as in tidal sloughs which also serve as county flood control channels, can result in temporary impacts to Clapper Rails. These periodic, temporary impacts, which can repeatedly diminish habitat value and prevent the full development of tidal marsh, result in sustained impacts to the Clapper Rail (Goude 1999).

The LTMS EIS/EIR concluded that dredging and disposal activities could cause disturbance to Clapper Rails during the breeding season (without direct habitat loss) (LTMS 1998).

The LTMS EIS/EIS concluded further that California Clapper Rails are susceptible to mercury exposure, especially in the South Bay (Schwarzbach et al. 2006). They are exposed to mercury through their diet, which consists largely of benthic invertebrates that forage on detritus and plankton (Eddleman and Conway 1994; Varoujean 1972; Test and Test 1942; Moffitt 1941; Williams 1929). Dredging of contaminated sediments could potentially release contaminants to the water column and result in their uptake by organisms contacting resuspended materials (LTMS 1998; Oram and Melwani 2006). According to the USFWS biological opinion, the USFWS conducted a study in 1995 and 1996 that found increased mercury concentrations in prey items of the Clapper Rail as a result of dredging and placing sediment in tidal marsh. However, since the LTMS will not authorize placement of dredged materials in tidal marsh except through separate formal ESA Section 7 consultation, USFWS expected that the effects of dredging and disposal on the bioavailability of mercury to Clapper Rails would be minimal (Goude 1999).

There is very little available information in the literature on the potential impacts from dredging and disposal on the California Clapper Rail.

3.4.8 Priority Study Topics and Potential Studies

Distribution, behavior, disturbance, displacement, avoidance, noise, and habitat modification were ranked as high priority study topics for the California Clapper Rail by agencies interviewed for this project (Table 4).

3.4.8.1 Distribution

Study Topic: Spatial distribution of the California Clapper Rail in San Francisco Bay.
Study Question: What is the overlap between Clapper Rail distribution and areas of dredging impact?

Potential Study - The purpose of this study would be to determine the overlap of dredging with the distributions of Clapper Rails in the San Francisco Bay. The distribution of Clapper Rails in the San Francisco Bay is well know from studies that have used call-count and airboat surveys (Pitkin et al. 2011). The first phase of the proposed study could involve a review of the literature and available unpublished data on the distribution of Clapper Rails and potential overlaps with the location of dredging operations. Depending on the results of the literature review, future field studies might be recommended, if dredging is conducted in areas where Clapper Rails may occur that have not been previously sampled or studied.

Table 4. Priority ranked topics of study for the California Clapper Rail (1=highest, 2=moderate, 3=lowest priority; a=adult, j=juvenile).

Topic	California Clapper Rail				
	NOAA	FWS	CDFW	BCDC	USACE
Distribution		1	3	3	3
Behavior		1	1	2	3
Migration		3			3
Food sources		2	2	2	2
Feeding		2	2	2	2
Spawning		3			3
Development		3		2	3
Disturbance		1	1	1	1
Displacement		1	1	1	2
Avoidance		1	3	1	2
Entrainment		3			3
Burial		2			3
Sedimentation		3			3
Noise		1	3	1	2
Sediment type		2		3	3
Habitat modification/loss		1	3	2	2
Turbidity (optical)		3	3	3	3
Suspended sed. conc.		3		3	3
Water quality (pH, NH3, etc.)		2	2	3	3
Toxicity		2	2	2	3
Pathway		2	3	2	3
Exposure		2	3	2	3
Bioavailability		2	2	2	3
Bio-accumulation		2	2	2	3

3.4.8.2 Behavior

Behavior is defined in the Framework as a general term encompassing changes in distribution, migration, and feeding, or avoidance in response to noise, increased suspended sediment, or other disturbances. Specific concerns for Clapper Rails relate to the effects of noise on behavior and displacement or avoidance of areas near dredging operations. These concerns are discussed in the relevant sections below.

3.4.8.3 Disturbance

No specific studies have been proposed. "Disturbance" is a general term that includes topics such as displacement and avoidance or noise, which are addressed in subsequent sections.

3.4.8.4 Displacement and avoidance

Study Topic: Displacement effects on the California Clapper Rail
Study Questions: Do Clapper Rails avoid areas where dredging occurs? Are Clapper Rails displaced by dredging projects?

Proposed Study: This study could involve a review of literature on avoidance responses in Clapper Rails and a comparison with dredging conditions. If displacement appears likely, a plan could be developed to conduct additional evaluation using radio-telemetry or other field methods.

3.3.8.5 Noise

Study Topic: Effects of noise on the California Clapper Rail
Study Question: Does the noise from dredging operations interfere with Clapper Rail vocalizations?

The Clapper Rail is a highly vocal species and calls between conspecifics are critical to social interactions within the species.

Proposed Study: The first phase of this study could be to conduct a literature review on the effects of noise on Clapper Rail interactions. If warranted, field studies could be conducted.

3.4.9 Lower priority topics

Distribution, food sources, feeding, and habitat modification were rated as medium priority study topics by all agencies interviewed. Study questions related to these topics include:

- What is the overlap between Clapper Rail distribution and areas of dredging impact?
- Will dredging affect prey resources and foraging habitat available to the Clapper Rail?
- Does dredging increase Clapper Rail exposure to contaminants through increased bioavailability and bioaccumulation? Mercury and DDT (and its metabolites) are of particular concern because of their potential to impact bird species.
- Will foraging, nesting, or refuge habitat be altered either through direct removal or through changes in sedimentation and hydrology?

3.5 California Least Tern (*Sterna antillarum browni*)

3.5.1 General Information and Status

The California Least Tern (*Sterna antillarum brownii)* is a member of the gull family (Laridae) and is one of three subspecies of Least Terns found in the United States, together with *S. antillarum antillarum and S. antillarum athalassos*. *S. antillarum antillarum* is found on the East Coast (Lessons 1847), and *S. antillarum athalassos* is found in interior river systems of the United States (Burleigh and Lowery 1942). Least Terns are the smallest members of the gull family (Olsen and Larsson 1995), with an average length of 23 cm and an average wingspan of about 51 cm (Goals Project 2000).

The breeding population of the California Least Tern is distributed in five clusters along the coast: San Francisco Bay, San Luis Obispo/Santa Barbara County, Ventura County, Los Angeles/Orange County, and San Diego (HMS 2007).

The California Least Tern was listed as a federal endangered species in 1970 (Federal Register 35:16047 October 13, 1970; Federal Register 35:8495 June 2, 1970) and as a state endangered species in 1980 (DFG 1980).

3.5.2 Reproduction

Least Terns typically arrive at California breeding sites in middle or late April and begin courting immediately (Goals Project 2000). Nesting occurs in two waves, one from early May through early June, and the second from mid-June through early July (Goals Project 2000).

Least Terns are colonial nesters, although single pairs can sometimes nest on their own. Least Terns prefer to build their nests on open sand or fine gravel substrate with sparse vegetation. They are opportunistic nesters and will sometimes use newly filled or graded lands and airports. Nests are usually found near open water, usually along coastal beaches and estuaries with adequate food sources (Goals Project 2000). Nests consist of a shallow scrape in the ground that is sometimes decorated with shells, sticks, or other material. Typically, Least Terns will lay two or three (occasionally one or four) eggs during the breeding season.

The majority of breeding birds are aged 2-7 years, although some older birds have also been observed breeding (Masey et al.1992). The degree of natal- and year-to-year site fidelity in Least Terns is relatively high, but is strongly influenced by geomorphic stability, predation level, and amount of human disturbance at the site (Burger 1984).

3.5.3 Growth and Development

Eggs require approximately 21 days of incubation and both parents participate (Goals Project 2000). Adults will brood chicks for the first couple of days after hatching to protect them from exposure to fluctuating temperatures (Thompson et al. 1997). Within a few days of hatching, chicks are able to move about on their own. Least Terns fledge at 17 to 21 days, although complete flight skills typically take longer to develop (Goals Project 2000).

After fledging, Least Terns eventually leave breeding sites and disperse to local areas that offer young birds opportunities to develop foraging skills and consume ample prey to build reserves for migration. These sites are thought to be as important to the survival of juvenile terns as the nesting areas (Massey and Atwood 1984). In San Francisco Bay, there are several post-breeding sites, such as the South Bay Salt Ponds "intake" salt ponds, the E. B. Roemer Bird Sanctuary in Alameda, and Robert's Landing in San Leandro. California Least Terns usually leave post-breeding areas by late September (Goals Project 2000).

Least Terns reach reproductive maturity at approximately two to three years of age (Goals Project 2000).

3.5.4 Behavior

California Least Terns forage in both shallow and deep water by hovering and diving onto the surface of the water to catch prey. At times, they will also forage trapped prey in pools of water left on mudflats during low tides. California Least Terns have been known to feed on a wide variety of fish species, but they appear to prefer northern anchovy (*Engraulis mordax*), smelt, and silversides (*Atherinidae sp.*; Atwood and Kelly 1984, Chase and Paxton 1965). In rare cases, they may feed on invertebrates, such as the waterborne larvae of drone flies (Goals Project 2000). Eelgrass beds provide very important foraging habitat for California Least Terns (LTMS 1998). Both adults provide food to the chicks, typically delivering 1-2 fish per hour, and continue to feed them even after they fledge (Thompson et al. 1997).

3.5.5 Distribution and Migration

The California Least Tern is migratory. Winter dispersion patterns are not well documented, but California Least Terns have been found as far south as southern Colima, Mexico (Massey 1981), and Guatemala (Goals Project 2000).

In California, there are about 35 nesting sites from San Diego County to Contra Costa County (Caffrey 1995a). During the breeding season, California Least Terns can be found nesting throughout all of San Francisco Bay up to Pittsburg in Contra Costa and the Montezuma Wetlands Project site near Collinsville. At present, the largest Least Tern colony in Northern California, with approximately 350 nesting pairs, is at the Alameda Naval Base (Goals Project 2000; Marschalek 2008). In the past, Least Terns have been documented to nest on Bair Island (DFG 1981, Anderson 1970) and on various salt pond levees (DFG 1981). In 2007, only the Alameda colony, the Hayward Regional Shoreline colony (approximately 35 nesting pairs), the Montezuma Wetlands Project site colony (approximately 30 nesting pairs), and six to seven nesting pairs at the Pittsburg Power Plant produced fledglings (Marschalek 2008). The Bay Area Least Terns are considered a critical population that is vital to the statewide species recovery effort (Goals Project 2000).

3.5.6 Other Information

Accounts of Least Tern numbers in California prior to 1970 are incomplete; however, abundant numbers of birds (likely in the thousands) were reported at many sites in California at the turn of the century (Caffrey 1995b).

State and federal recovery efforts have been successful in helping the species to rebound in recent years. In 1995, approximately 2,536 pairs of Least Terns were estimated to have nested at approximately 35 California nesting locations. However, surveys have indicated fluctuating numbers, as the numbers of both nesting sites and nesting pairs appear to vary by year (Caffrey 1995a).

Multiple factors have contributed to Least Tern reproductive failures (Edwards 1919, Caffrey 1995b, Feeney 1996). Threats to California Least Tern include human activities (such as highways, development, and beach recreation), contaminant concentrations in eggs (especially mercury; Davis et al. 2003), the introduction of the red fox, and an abundance of feral cats.

3.5.7 Potential Impacts

Both the LTMS EIS/EIR and USFWS biological opinion concluded that dredging and disposal in San Francisco Bay could potentially result in the loss of eelgrass bed foraging habitat (LTMS 1998, Goude 1999). Sediment dispersed during dredging operations could cover eelgrass and reduce light in eelgrass beds outside of dredging boundaries, thus reducing their productivity (Goude 1999). Eelgrass beds are important spawning habitat for topsmelt and jacksmelt, two species upon which Least Terns prey. Reductions in eelgrass productivity could reduce spawning of these species and thus result in depleted food sources for terns. These adverse effects could be most pronounced during June and July each year, when Least Tern adults are feeding unfledged young (Goude 1999).

Critical times and locations for protecting Least Terns in San Francisco Bay were found to be year-round in all eelgrass beds from San Francisco Bay east through Suisun Marsh, coastal waters and sloughs within 1 mile of the coastline from Berkeley Marina south through San Lorenzo Creek (March 15th to July 31st), and coastal waters, sloughs and salt marshes throughout San Francisco Bay south of the Highway 92 bridge (June 1st to September 7) (LTMS 2001).

Both the LTMS EIS/EIR and the USFWS biological opinion identified increased turbidity as a potential adverse effect on foraging success for California Least Terns (LTMS 1998, Goude 1999). Increased turbidity associated with dredging, sediment overflow from barges, and disposal of dredged sediments at locations in the Bay could either individually or collectively reduce in-water visibility for Least Terns at the water surface and at shallow depths, thus reducing their overall foraging effectiveness.

Additionally, increased turbidity could impact the abundance of northern anchovies, the principle prey item for Least Terns. Within San Francisco Bay, northern anchovies spawn in channels, but their larvae mostly occur in shallow water areas (McGowan 1986). While anchovy larvae have been documented to tolerate lower water clarity than anchovy eggs, eggs were found to be most abundant in parts of San Francisco Bay with low concentrations of zooplankton and clearer water (Herbold et al. 1992). This information suggests that decreased water clarity associated with dredging and disposal of dredged sediments could reduce the productivity and availability of northern anchovies and thus adversely affect Least Tern feeding success (Goude 1999).

The USFWS biological opinion found that dredging and disposal of dredged material in the Bay could increase contaminant effects on Least Terns. Contaminants can impact the embryos and larvae of two prey species, topsmelt and jacksmelt, (Singer et al. 1990, Goodman et al 1991, Hemmer et al 1991), which could in turn result in depleted or contaminated food sources for terns. Sediments within the Bay are known to be contaminated with heavy metals, PCBs, PAHs, and DDT (SFEI 2012), and dredging and disposal could result in the dispersal of contaminated sediments in Least Tern foraging areas, which could reduce the productivity and abundance of suitable fish prey. The USFWS biological opinion further noted that increased boat and ship activity associated with dredging operations could increase the risk of spillage events in Least Tern foraging areas (Goude 1999).

Since California Least Terns build their nests on the ground, where they may be susceptible to predators, Least Terns typically feed within two miles of their nesting colony so they can alternate between feeding and protecting their nests. Dredging activities may force Least Terns to feed further away from their nests than they normally would, causing them to spend more time away from the nest and thus increase the risk of predation (LACSTF 2003).

LaSalle et al. (1991) stated that dredging and disposal operations could potentially generate high noise levels that may disrupt the nesting and breeding activities of birds (Reine and Clarke 1998b). Dredging and disposal activities, therefore, may disturb California Least Tern breeding colonies. According to Davis (1974), once Least Terns are disrupted, they may quickly abandon the nest, never to return.

3.5.8 Priority Study Topics and Potential Studies

Distribution, behavior, food sources, disturbance, displacement, avoidance, turbidity, suspended sediment, noise, and bioaccumulation were ranked as high priority study topics for the Least Tern by agencies interviewed for this project (Table 5).

3.5.8.1 Distribution

Study Topic: Spatial and temporal distribution of California Least Tern in San Francisco Bay.

Study Question: What is the overlap between Least Tern distribution and areas of dredging impact?

Potential Study: This study would identify areas of the Bay that Least Terns are using for breeding or foraging. The first phase of this study would be to conduct a review of current literature and unpublished studies of the spatial and temporal distribution of Least Terns in the Bay.

Table 5. Priority ranked topics of study for the California Least Tern (1=highest, 2=moderate, 3=lowest priority).

	California Least Tern				
Topic	**NOAA**	**FWS**	**CDFW**	**BCDC**	**USACE**
Distribution		1	3	1	3
Behavior		1	1	1	3
Migration		2	3	3	3
Food sources		2	1	1	2
Feeding		2	1	3	2
Spawning		3			3
Development		3			3
Disturbance		1	1	2	1
Displacement		1	1	2	2
Avoidance		1	3	2	2
Entrainment		3			3
Burial		3			3
Sedimentation		3			3
Noise		1	3		2
Sediment type		3			3
Habitat modification/loss		3	3		2
Turbidity (optical)		1	1	1	3
Suspended sed. conc.		1		1	3
Water quality (pH, NH3, etc.)		1	2		3
Toxicity		1	2		3
Pathway		2	3	2	3
Exposure		2	3	2	3
Bioavailability		2	2	2	3
Bio-accumulation		2	2	1	3

3.5.8.2 Behavior
No specific behavioral studies have been proposed.

3.5.8.3. Food Sources
Study Topic: Effects of dredging on food sources for California Least Tern

Study Question: How do dredging activities impact food resources for Least Terns?

Possible negative impacts of dredging on tern food resources include removal of eelgrass habitat or prey species avoiding dredging areas due to increased suspended sediment concentration.

Potential Study: The first phase of this study would be to conduct a literature review of the effect of dredging on prey species important to the Least Tern. Phase 2 of this study could involve field or laboratory studies to determine whether dredging causes displacement of prey species.

3.5.8.4 Disturbance

No specific studies have been proposed. "Disturbance" is a general term that includes topics such as displacement and avoidance or noise, which are addressed in subsequent sections.

3.5.8.5 Displacement and avoidance

Study Topic: Displacement effects on California Least Tern
Study Questions: Do Least Terns avoid areas where dredging occurs? Are Least Terns displaced by dredging activities?

Displacement and avoidance are similar effects that are defined in this discussion as they were in the Framework. Displacement refers to an effect that causes a species to leave an area that is normally occupied, while avoidance refers to an effect that causes a species not to use an area that is only occasionally or infrequently occupied. In practice, these two terms may not represent different effects on species and therefore they are discussed together in this report.

Potential Study: A first phase of this study could involve a review of current literature and unpublished studies regarding displacement and avoidance responses in the Least Tern, and the effects of dredging and disposal on foraging and nesting behavior. If displacement appears likely, a study plan could be developed to conduct additional evaluation of tern movement near dredging sites.

3.5.8.6 Turbidity and suspended sediment

Study Topic: Effects of turbidity on California Least Tern
Study Questions: Does increased turbidity affect Least Tern foraging behavior or foraging success? Does increased turbidity decrease food resources available to Least Terns?

Potential Study: This study would be focused on the effects of suspended sediment plumes on Least Tern foraging. Field studies could be conducted to determine whether terns are using areas of higher turbidity near dredging to forage, and if foraging success in these areas is similar to foraging success in less turbid areas. Additionally a literature review of the expected effects of increased turbidity on important prey species could be conducted.

3.5.9 Lower priority topics

Feeding, avoidance, noise, water quality, and bioaccumulation were rated as high priority study topics by at least one agency interviewed. Questions about the effect of dredging on least tern foraging would be informed by a proposed study of the effects of increased turbidity and foraging behavior (see Section 3.5.8.6). Study questions related to these topics include:

- How does increased turbidity affect foraging success of Least Tern?
- Does the noise from dredging operation interfere with Lease Tern vocalizations?
- To what extent are Least Terns exposed to potential negative effects of dredging?
- Does dredging increase bioaccumulation of contaminants in Least Terns?

3.6 Salt Marsh Harvest Mouse (*Reithrodontomys raviventris*)

3.6.1 General Information and Status

The salt marsh harvest mouse is a member of the family Cricetidae and is endemic to the San Francisco Bay region. In San Francisco Bay, there are two distinct subspecies of salt marsh harvest mice: a northern subspecies *(R. r. halicoetes)* found mainly in the North Bay and a southern subspecies *(R. r. raviventris)* found mainly in the South Bay (USFWS 1984). Salt marsh harvest mice are very small rodents and average about 8 to 14 grams in weight and 118 to 175 millimeters in length (Fisler 1965).

The harvest mouse was listed as a federal endangered species in 1970 (35 FR 16047, 13 October 1970) and as a state endangered species in 1971 (USFWS 1984). The U.S. Fish and Wildlife Service produced a recovery plan for the species in 1984.

3.6.2 Reproduction

Salt marsh harvest mice have a low reproduction potential, despite having a long breeding season (March to November). The average litter size is relatively small and (3.72- 4.21) and females of both subspecies are thought to have only one litter per year (Fisler 1965).

Salt marsh harvest mice in the northern subspecies build nests out of balled up grasses (Shellhammer, pers. obs.; Goals Project 2000) or use abandoned bird nests (on which they build caps; Fisler 1965). The southern subspecies often does not build a nest at all (Fisler 1965).

3.6.3 Growth and Development

Salt marsh harvest mice breed primarily in the spring and summer, though a yearly cycle of age classes is not well defined. Individuals live less than 12 months, so there is complete yearly turnover (Fisler 1965)

3.6.4 Behavior

The salt marsh harvest mouse is adapted to salt marshes. The harvest mouse is a strong swimmer and able to drink salt water (Fisler 1965). Harvest mice eat green vegetation from salt marsh plants and seeds (Fisler 1965). In the winter, fresh green grasses appear to be its preferred diet. During the rest of the year, it mainly eats saltgrass (*Distichlis spicata*) and pickleweed (*Salicornia virginica*) (Goude 1999).

3.6.5 Distribution and Migration

The harvest mouse occurs in salt and brackish habitats of tidal or diked marshes throughout the San Francisco Estuary. The northern subspecies *(R. r. halicoetes)* is found on the upper portion of the Marin Peninsula, and in the Suisun, Petaluma, and Napa marshes and San Pablo Bay. A few, small disjunctive populations are found on the northern coast of Contra Costa County. The southern subspecies *(R .r. raviventris)* occurs primarily in the South Bay with a few, small disjunctive populations on the Marin Peninsula and along the Richmond shoreline (Goals Project 2000). The highest number of persistent populations occurs in marshes on the eastern side of San Pablo Bay and in the dredged material disposal ponds on the Mare Island Shipyard property (Bias and Morrison 1993, Duke et al. 1995).

Salt marsh harvest mice depend on dense cover for protection from predators (Fisler 1965; Shellhammer 1977, 1981; Wondolleck et al. 1976). They prefer the tallest (60-75 cm), most dense pickleweed, mixed with fat hen and alkali heath (Suisun Ecological Workgroup 1997). In addition, they need an upland transition zone to escape the higher tides, and they may even spend a significant portion of their lives there (Goals Project 2000).

Salt marsh harvest mice are non-migratory.

3.6.6 Other Information

The decline of the salt marsh harvest mouse can be mainly attributed to habitat loss, significant fragmentation of remaining marsh habitat, substantial loss of upland and transitional refugia as a result of backfilling, land subsidence, and changes in vegetation and reductions in water salinity due to fresh water inflow (Shellhammer 1982, 1989, USFWS 1994). The main factor in the reduction of this species has been the extensive filling of tidal marshes in San Francisco Bay over the last 150 years (Goals Project 2000).

3.6.7 Potential Impacts

The LTMS EIS/EIR concluded that dredging activities may result in the loss of salt marsh habitat and adjacent upland refugial cover. Nearshore or upland disposal and placement of dredged material for beneficial reuse may also result in direct habitat loss

(LTMS 1998). Given that harvest mice are non-migratory, they are susceptible to these potential impacts year round. Harvest mice may be impacted by dredging and disposal activities occurring in and around diked and tidal salt marshes throughout San Francisco Bay and Suisun Marsh (LTMS 2001).

The USFWS biological opinion for the LTMS also found that dredging could result in temporary and permanent, direct and indirect loss of suitable harvest mouse habitat (Goude 1999). Suitable harvest mouse habitat could be temporarily lost through the direct placement or incidental slippage of dredged materials. An indirect loss of harvest mouse habitat could occur if dredging activities cause slumping of the habitats used by these species from the sides of dredged areas. Dredged materials placed on adjacent levees could result in increased predation by eliminating important upland hiding cover used by harvest mice during high tides. Maintenance dredging, such as in tidal sloughs which also serve as county flood control channels, can result in temporary impacts to harvest mice. These periodic, temporary impacts, which can repeatedly diminish habitat value and prevent the full development of tidal marsh, result in sustained impacts to the harvest mouse (Goude 1999). It is important to note, however, that not all tidal sloughs that serve as flood control channels are adjacent to tidal marsh habitat, and not all tidal marshes provide harvest mouse habitat. Therefore, the impacts of tidal slough dredging should be evaluated on a case-by-case basis with the aid of historic habitat maps and aerial photography.

3.6.8 Priority Study Topics and Potential Studies

Behavior, disturbance, displacement, avoidance, and habitat modification were ranked as high or medium priority study topics for the salt marsh harvest mouse by all agencies interviewed for this project (Table 6).

3.6.8.1 Behavior
Study Topic: Behavior of the salt marsh harvest mouse in response to dredging and disposal of dredge material.
Study Question: How does dredging and disposal of dredged material affect the fine scale movement of salt marsh harvest mouse?

Behavior is defined in the Framework as a general term encompassing changes in distribution, migration, feeding or movement in response to noise, increased suspended sediment, or other disturbances. For the salt marsh harvest mouse, short-term movements and changes of habitat use in response to dredging and disposal are of particular concern.

Proposed Study: Radio telemetry field studies could be conducted to better understand daily movements of the salt marsh harvest mouse, particularly in response to tides, to better understand how dredging and disposal might alter these daily movements.

Table 6. Priority ranked topics of study for the salt marsh harvest mouse (1=highest, 2=moderate, 3=lowest priority).

	Salt Marsh Harvest Mouse				
Topic	**NOAA**	**FWS**	**DFG**	**BCDC**	**USACE**
Distribution		1	3	3	3
Behavior		1	1	2	3
Migration		3			3
Food sources		2	3		2
Feeding		2			2
Spawning		3			3
Development		2	3		3
Disturbance		1	2	1	1
Displacement		1	1	1	2
Avoidance		1	3	1	2
Entrainment		3			3
Burial		2	1		3
Sedimentation		2			3
Noise			3	2	2
Sediment type		2			3
Habitat modification/loss		2	1	2	2
Turbidity (optical)		2			3
Suspended sed. conc.		2			3
Water quality (pH, NH3, etc.)		2	2		3
Toxicity		2	2		3
Pathway		2	2		3
Exposure		2	2	2	3
Bioavailability		2	2		3
Bio-accumulation		2	2		3

3.6.8.2 *Disturbance*
"Disturbance" is a general term that includes such effects as displacement, avoidance, noise and other more specific topics that are addressed in displacement and avoidance below.

3.6.8.3 *Displacement and avoidance*
Study Topic: Salt marsh harvest mouse displacement and avoidance responses

Study questions: Do salt marsh harvest mice avoid areas where dredging occurs? Are they displaced by dredging projects?

Potential Study: A first phase of this study could involve a review of current literature and unpublished studies regarding avoidance responses in the salt marsh harvest mouse and similar species, and the effects of dredging and disposal on mouse distribution. If warranted, radio telemetry or mark-recapture methods could be used to evaluate displacement and avoidance of dredging and disposal areas by the salt marsh harvest mouse.

3.6.8.4 Habitat Modification
Study Topic: Effects of habitat modification on the salt marsh harvest mouse
Study Questions: How will habitat modification affect the salt marsh harvest mouse?

Dredging in or near tidal marsh has the potential to affect the salt marsh harvest mouse by removing foraging, nesting, and refuge habitat directly or altering habitat through changes in sedimentation and hydrology. In addition, modification of habitat through upland placement of dredged material has the potential to affect the foraging, refuge and nesting habitat available to mice. In addition to the potential negative impacts to the species, potential benefits to the species should also be evaluated. Restoration of tidal marsh through beneficial reuse of dredged material has the potential to offset harm to the species caused by habitat loss and climate change.

Proposed Study: The first phase of this study could be to conduct a review of current literature and unpublished studies related to the impacts of habitat modification on the salt marsh harvest mouse.

3.6.9 Lower priority topics

Distribution and burial were ranked as lower priority topics. Study questions related to these topics include:
- What is the distribution of the salt marsh harvest mouse?
- What is the risk that salt marsh harvest mice will be buried by placement of dredged sediment?

3.7 Summary of High Priority Study Topics

Table 7. Summary of High Priority Study Topics

Spatial and Temporal Distributions of Dungeness Crab in the Bay
Displacement Effects on Dungeness crab
Entrainment Risk to Dungeness crab
Behavior of the Salt Marsh Harvest Mouse in Response to Dredging and Disposal
Salt Marsh Harvest Mouse Displacement and Avoidance Responses
Effects of Habitat Modification on the Salt Marsh Harvest Mouse
Spatial Distribution of the California Clapper Rail in the Bay
Displacement Effects on the California Clapper Rail
Effects of Noise on the California Clapper Rail
Effect of Dredging on Longfin Smelt Food Sources
Spawning location of Longfin Smelt and Effects of Dredging on Longfin Smelt Spawning
Displacement Effects on the Longfin Smelt
Entrainment Risk to Longfin Smelt
Spatial and Temporal Distribution of Least Tern in the Bay
Effects of Dredging on Food Sources for California Least Tern
Displacement Effects on California Least Tern
Effects of Turbidity on California Least Tern
Spatial and Temporal Distribution of Green Sturgeon in the Bay
Effect of Dredging on Green Sturgeon Food Sources
Burial Risk to Green Sturgeon
Effects of Habitat Modification on the Green Sturgeon

4.0 Effects of Dredging on Piscivorous Bird Species

According to a literature review conducted by Berry et al. (2003), there are few published reports on the effects of increased suspended sediment concentrations from dredging operations on birds and mammals. Generally, water-dependent birds and mammals are more mobile than the fish, invertebrates, and plants impacted by dredging, and therefore they can avoid most of the direct effects of increased suspended sediments. For example, a bird can avoid turbid areas and choose areas of clearer water for foraging (Berry et al. 2003).

4.1 Feeding

The available literature suggests that the impacts of turbidity on bird are species and site specific. Stevens et al (1997) observed on the Colorado River that waterbirds were most abundant on upstream reaches that were either clear or variably turbid and least abundant on lower reaches where turbidity was higher. The study concluded that turbidity makes it difficult for birds to forage effectively. However, Savard et al (1994) conducted a study in British Columbia ponds and concluded that dabbling duck populations were higher where turbidity was higher (Berry and Hill 2003).

Foraging studies conducted in Los Angeles Harbor suggest that dredging and other construction activities can increase turbidity and affect the California Least Tern's ability to forage in areas adjacent to these activities (Amalong et al. 2003). However, Amalong et al. (2003) concluded that dredging activities conducted in 2003 in Los Angeles Harbor, which included major harbor deepening work, did not adversely affect foraging patterns of California Least Terns. In some locations, terns were actually observed foraging directly in the plumes of dredging operations (Amalong et al. 2003). It should be noted that the study was initiated after most dredging and disposal operations were completed for the season and the rest of this paper involved after-the-fact analysis of data collected for foraging studies from 1994-2002 that were not dredging specific (Amalong et al. 2003). Another study, conducted at the Middle Harbor Enhancement Area (a subtidal habitat restoration project that was part of the Oakland Harbor Deepening Project) from 2002 to 2005, monitored turbidity and the feeding activities of a Least Tern colony in the vicinity of the project site. While it was acknowledged that increased turbidity from the placement of dredged material could potentially affect tern foraging success at the project site, the study concluded that the impact would be spatially and temporally very limited and that there appeared to be no impacts outside of the project area (Erhler et al. 2006).

4.2 Noise

LaSalle et al. (1991) suggest that dredging and disposal operations can generate high noise levels that may disrupt the nesting and/or breeding activities of birds (Reine et al. 1998). Therefore, dredging and disposal activities may disturb nesting and roosting sites for California Least Tern and other waterbirds. Once Least Terns are disrupted, they may quickly abandon the nest, never to return (Davis 1974). Dredging near nest sites has the potential to disrupt reproductive and parental care behaviors, which may lead to lowered hatching success or nest abandonment (Reine et al. 1998).

5.0 Original Window Species

The LTMS has funded several studies which address the data gaps related to the original window species identified in the Framework. These studies include literature reviews, field studies, laboratory experiments, and scientific symposia. Major findings of these studies are summarized in Appendix A. Studies pertain to the following priority study topics (as identified in the Framework document): toxicity, exposure, pathway, bioavailability, and behavior in all species; distribution and migration in salmonids; and suspended sediment and development in herring (Table 8).

Table 8. LTMS funded studies which address the data gaps related to the original window species identified in the 2004 LTMS Science Framework

Study Code	2004 Science Framework Document Study Topic	Related LTMS Studies
B-Dist-1	Determine Spatial and Temporal Distributions of Chinook and Coho Salmon in the Bay	Klimley et al. 2009; Chapman et al. 2009
B-Dist-2	Determine Spatial and Temporal Distribution of Adult and Juvenile Steelhead in the Bay	Klimley et al. 2009; Chapman et al. 2009
B-Dist-3	Determine Spatial and Temporal Distribution of Herring Larvae and Juveniles in the Bay	Connor et al. 2005
B-Migr-1	Determine Critical Migration Routes and Periods for Salmonids	Klimley et al. 2009; Chapman et al. 2009
B-Dev-1	Determine Displacement Effects on Juvenile Chinook Salmon	Connor et al. 2005; Griffin et al. 2009
P-Disp-1	Determine Displacement Effects on Juvenile Chinook Salmon	Klimley et al. 2009; Chapman et al. 2009
P-Av-1	Determine Adult Herring Avoidance Responses to Dredging	Connor et al. 2005
P-Av-2	Determine Juvenile Herring Avoidance Responses to Dredging	Connor et al. 2005
P-Sed-2	Determine Sedimentation Effects on Herring Eggs	Connor et al. 2005; Griffin et al. 2009
P-Susp-3	Determine Effects of Suspended Sediment Plumes on Fish	Griffin et al. 2009; Rich et al. 2011
WQ-WQ-1	Evaluate Water Quality Effects from Suspended Sediments	Jabusch et al. 2008
WQ-Tox-1	Determine Effects of Acute Toxicity in Suspended Sediment Plumes	Jabusch et al. 2008

Based on these and other studies, the agencies interviewed recommend changes to the Priority Matrix (Table 9).

USFWS updated several (or “the”) rankings for delta smelt study topics. USFWS now Distribution, feeding, development, and burial were downgraded to lower priority topics for delta smelt. Migration and entrainment were upgraded to higher priority study topics. DFG concurs with the USFWS rankings for delta smelt. No other changes to the original priority matrix were suggested by any of the agencies interviewed.

Table 9. Priority ranked topics of study for delta smelt in the Framework document (left) and updated for 2012 (right).

Topic	Delta Smelt 2004 Rankings					
	NOAA	FWS		DFG		BCDC
		dredging	disposal	dredging	disposal	
Distribution		2	2			
Behavior		1	1			
Migration		3	2			
Food sources		1	2			
Feeding		1	1			
Spawning		1	1			
Development		2	2			
Disturbance		1	1			
Displacement		1	2			
Avoidance		2	2			
Entrainment		2	3			
Burial		2	1			
Sedimentation		2	2			
Noise		2	3			
Sediment type		2	2			
Habitat		1	1			
Turbidity (optical)		2	2			
Suspended sed. conc.		1	2			
Water quality		1	1			
Toxicity		1	1			
Pathway		2	2			
Exposure		1	2			
Bioavailability		2	2			
Bio-accumulation		2	2			

Topic	Delta Smelt Updated 2012 Rankings					
	NOAA	FWS		DFG		BCDC
		dredging	disposal	dredging	disposal	
Distribution		3	3	2	2	
Behavior		1	1	1	1	
Migration		3	3	3	2	
Food sources		1	2	1	2	
Feeding		3	3	1	1	
Spawning		1	1	1	1	
Development		3	3	2	2	
Disturbance		1	1	1	1	
Displacement		1	2	1	2	
Avoidance		2	2	2	2	
Entrainment		1	3	2	3	
Burial		3	3	2	1	
Sedimentation		2	2	2	2	
Noise		2	3	2	3	
Sediment type		2	2	2	2	
Habitat		1	1	1	1	
Turbidity (optical)		2	2	2	2	
Suspended sed. conc.		1	2	1	2	
Water quality		1	1	1	1	
Toxicity		1	1	1	1	
Pathway		2	2	2	2	
Exposure		1	1	1	2	
Bioavailability		1	2	2	2	
Bio-accumulation		2	2	2	2	

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Appendix A. Annotated Bibliography of LTMS Funded Studies

Studies Related to Species Considered in the Original Framework Document

Pacific Herring

1. A Bibliography of Scientific Literature on Pacific Herring (*Clupea pallasi*), with Additional Selected References for Baltic Herring (*Clupea harengus*).
Author: Olge, S., Pacific EcoRisk, Inc.
Year: 2004
Pages: 37 p.

Relevance to Effects of Dredging on Framework Species: The authors compiled a bibliography of literature on Pacific herring, primarily targeting the biology and ecology of herring spawning and early life stages, the effects of suspended sediments and contaminants on herring, and methodologies for performing research using herring early life stages. This bibliography was used as a starting point for further LTMS funded herring studies.

2. A Review of Scientific Information on the Effects of Suspended Sediments on Pacific Herring (*Clupea pallasi*) Reproductive Success
Author: Olge, S., Pacific EcoRisk, Inc.
Year: 2005
Pages: 21 p.

Relevance to Effects of Dredging on Framework Species: The authors describe what is known from the literature about the effects of suspended sediments on the spawning and early life stages of Pacific herring. This review provided background to facilitate subsequent research efforts.

3. The Potential Impacts of Dredging on Pacific Herring in San Francisco Bay.
Authors: Connor, M., J. Hunt, and C. Werme, San Francisco Estuary Institute
Year: 2005
Pages: 82

Relevance to Effects of Dredging on Framework Species: The authors identified factors affecting pacific herring populations based on a review of the relevant scientific literature and input from local experts. This report examined the possible effects of dredging within the context of all factors affecting herring populations at each life stage. The report also identified data gaps and recommended future studies focus on suspended solids and contaminants.

4. Impacts of Suspended Sediments on Fertilization, Embryonic Development, and Early Larval Life Stages of the Pacific Herring, *Clupea pallasi*
Authors: Griffin, F. , E. Smith, C. Vines, G. Cherr

Year: 2009
Journal: Biological Bulletin
Volume: 216
Pages: 175-187

Relevance to Effects of Dredging on Framework Species: The authors conducted two laboratory experiments on the effects of suspended sediment on early life stages of pacific herring. They found that herring eggs were susceptible to sediment adhesion to the chorion during the first 2 hours after the eggs contacted water. After this length of time, sediments that contacted embryos did not have an observable impact. Sediment treatment during the first 2 hours resulted in significantly higher percentages of abnormal larvae and an increase in larval mortality.

Salmonids

5. Interannual variation of reach specific migratory success for Sacramento River hatchery yearling late-fall run Chinook salmon (Oncorhynchus tshawytscha) and steelhead trout (Oncorhynchus mykiss)
Authors: Singer, G., A. Hearn, E. Chapman, M. Peterson, P. LaCivita, W. Brostoff, A. Bremner & A. Klimley
Journal: Environmental Biology of Fishes 96: 363–379
Year: 2013

Relevance to Effects of Dredging on Framework Species: This peer reviewed article reports migration success for Chinook salmon and steelhead trout. Migration success was determined from tracking studies of fish released from hatcheries. Migration success varied by year and by region. For both species, less than 25% of fish tracked reached the Pacific Ocean.

6. Juvenile Salmonid Outmigration and Distribution in the San Francisco Estuary: 2006-2008 Interim Draft Report.
Authors: Klimley, P., D. Tu, A. Hearn, W. Brostoff, P. LaCivita, A. Bremner, T. Keegan; University of California Davis and US Army Corp of Engineers.
Year: 2009

Relevance to Effects of Dredging on Framework Species: This interim report describes the initial findings of fish tracking studies conducted on juvenile salmonids in 2006-2008. The goal of the study was to estimate resident, transit, and migration times and to determine migration pathways. Both juvenile Chinook salmon and steelhead were observed using deep channels and passing dredge material placement sites. Resident times at these sites were relatively short.

7. Juvenile salmonid outmigration and green sturgeon distribution in the San Francisco Estuary: 2008-2009.
Author: Chapman E., A. Hearn, M. Buckhorn, A. Klimley, P. LaCivita, W. Brostoff & A. Bremner, University of California Davis and US Army Corp of Engineers.
Year: 2009
Pages: 90p.

Relevance to Effects of Dredging on Framework Species: This report describes the initial findings of fish tracking studies conducted on juvenile salmonids and green sturgeon in 2009. This study represented an expanded effort of the 2006-2008 fish tracking study described by Kimbley et al (2009) above. A far greater number of salmonids were tagged and tracked, allowing researchers to estimate survival rates as well as transit times. Migrating adult green sturgeons were tagged and detected at sites throughout the Bay. Residence times for tagged sturgeon at disposal sites were relatively short. Juvenile movement patterns were not captured in the study, which was identified as an important data gap.

Tools for evaluating fish behavior

8. Tools for Assessing and Monitoring Fish Behavior caused by Dredging Activities. Final Report.
Author: Rich, A., A.A. Rich and Associates
Year: 2011
Pages: 78 p.

Relevance to Effects of Dredging on Framework Species: This report reviewed recent literature to summarize and evaluate tools available for assessing changes in fish behavior in response to dredging. General approaches for determining fish presence, distribution, and population abundance in response to dredging activities are discussed. The author concludes that studies using a combination of biotelemetry or fish sampling and hydroacoustics hold the most promise, although lab studies might also be useful, as long as bay conditions are accurately replicated.

Water quality

9. Effects of Short-term Water Quality Impacts Due to Dredging and Disposal on Sensitive Fish Species in San Francisco Bay.
Author: Jabusch, T., A. Melwani, K. Ridolfi, M. Connor, San Francisco Estuary Institute.
Year: 2008
Pages: 40p.

Relevance to Effects of Dredging on Framework Species: The authors examined the short-term water quality impacts of dredging operations (dredging and dredged material placement) on sensitive fish species in San Francisco Bay. This study consisted of a literature review of potential short-term water quality impacts and possible effects on fish species of concern and an evaluation of available environmental data. Water quality impacts of concern included dissolved oxygen (DO) reduction, pH decrease, and releases of toxic components such as heavy metals, hydrogen sulfide (H_2S), ammonia, and organic contaminants. The study concluded that most contaminants would likely remain below levels of serious concern for sensitive fish species during dredging or disposal of dredged material. Ammonia was the only contaminant to exceed a biological threshold, based on contaminant concentrations modeled using average Bay sediment concentrations.

10. Symposium: Methylmercury in Dredged Operations and Dredged Sediment Reuse in the San Francisco Estuary
Location: Oakland, CA
Date: January 29, 2010

Relevance to Effects of Dredging on Framework Species: At this one-day symposium, researchers and managers presented talks related to the potential effects of re-suspension and increased bioavailability of Hg as a result of dredging activities. The general consensus reached by symposium participants was that dredging likely wouldn't make much difference to methylmercury levels on regional scale; however, there was concern about possible effects on a local scale because re-suspension of sediment can change the availability of Hg to methylating bacteria. Data available on wetland export of MeHg is very limited, and was identified as an important data gap.

Studies Related to Species Considered in the Update to the LTMS Framework

11. Least Tern Literature Review and Study Plan Development
Author: Burton, R., and S. Terrill, H.T. Harvey
Year: 2012
Pages: 54 p.

Relevance to Effects of Dredging on Framework Species: This report summarizes the current status of Least Terns in the bay and discusses potential impacts of dredging on the species. Potential impacts to terns discussed in the report include disturbance from increased noise, reduced foraging success due to increased turbidity, and decreased water quality. Recommended future studies included GIS-based mapping of Least Tern colony locations and dredging projects, a literature review and modeling of contaminant risk to Least Terns, assessment of contaminant loads in tern eggs, and quantification of turbidity sources in the Bay.

12. Longfin Smelt Literature Review and Study Plan
Author: Robinson, A. and B. Greenfield, San Francisco Estuary Institute

Year: 2011
Pages: 40 p.

Relevance to Effects of Dredging on Framework Species: This report summarizes the life history and current status of longfin smelt in the bay and discusses potential impacts of dredging to the species. Potential impacts to longfin smelt that are discussed in the report include entrainment, removal of spawning habitat, changes in water quality, and habitat modification. The authors recommend future studies of longfin smelt to determine the thermal tolerance of the species, the nearshore distribution of the species, and their spawning habitat requirements.