United States Department of the Interior

FISH AND WILDLIFE SERVICE
San Francisco Bay-Delta Fish and Wildlife Office
650 Capitol Mall, Suite 8-300
Sacramento, California 95814

In Reply Refer to:
08FBDT00-2020-
F-0010

DEC 30 2019

Mr. Guy Romine
Environmental Branch Chief
Military Ocean Terminal Concord
Department of the Army
Military Surface Deployment and Distribution Command
834th Transportation Battalion
410 Norman Ave
Concord, CA 94520-1142

Subject: Biological Opinion for the Proposed Maintenance Dredging at Military Ocean Terminal Concord Project, Contra Costa and Solano Counties, California

Dear Mr. Romine:

This letter is in response to the U.S. Department of the Army's (Army) October 9, 2019 request for initiation of formal consultation with the U.S. Fish and Wildlife Service (Service) on the Proposed Maintenance Dredging at Military Ocean Terminal Concord (MOTCO) Project (proposed project) in Contra Costa and Solano Counties, California. Your request was received by the Service on October 15, 2019. At issue are the proposed project's effects on the federally threatened delta smelt (*Hypomesus transpacificus*) and its designated critical habitat. This response is provided under the authority of the Endangered Species Act of 1973, as amended (16 U.S.C. 1531 *et seq.*) (Act), and in accordance with the implementing regulations pertaining to interagency cooperation (50 CFR 402).

The Federal action on which we are consulting is the maintenance dredging of the Department of the Army's MOTCO's Piers 2, 3, and 4. Pursuant to 50 CFR 402.12(j), you submitted a biological assessment for our review and requested concurrence with the clarified findings presented therein. These findings conclude that the proposed project may affect, and is likely to adversely affect delta smelt and is not likely to adversely affect delta smelt designated critical habitat.

In considering your request, we based our evaluation on the following: (1) the Army's October 9, 2019 initiation letter; (2) the Army's October 2019, *Biological Assessment for Military Ocean Terminal Concord Pier Maintenance Dredging Contra Costa and Solano County, California*

(BA); (3) emails and telephones conversations; and (4) other information available to the Service.

The Service has reviewed the proposed project and its effects to the delta smelt's designated critical habitat. In designating critical habitat for the delta smelt, the Service identified the following Primary Constituent Elements (PCEs) essential to the conservation of the species:

PCE #1 is physical habitat for spawning. Reduction in overall spawning substrate is not expected to occur. The reduction is not expected because dredging will be conducted at depths deeper than the assumed spawning habitat of delta smelt (i.e. shallow water habitat).

PCE #2 is suitable water quality for all life stages. Water quality in the action area will be temporarily affected by mechanical clamshell dredging and by sediment disposal activities at the SF-16, in-bay disposal site (SF-9 is not within designated critical habitat). Maintenance dredging of the navigation channel may affect water quality surrounding the area being dredged through the creation of the sediment plumes. The sediment plumes are temporary in nature and typically dissipate within the same day of activity. Sediment plumes are also discountable in size in relation to the Delta and would not be expected to affect the overall water quality of the Delta ecosystem. In-bay disposal adjacent to the channel is beneficial specific to delta smelt critical habitat over other forms of disposal by not removing sediment from the Delta.

PCE #3 is river flow. The proposed dredging is limited to the piers and does not permanently divert water out of or away from the surrounding aquatic environment and therefore is not expected to diminish river flow.

PCE #4 is salinity for rearing. The proposed project is not expected to have any significant effect on salinity, since the river flows will not be affected, thus not affecting the position of X2.

Based on the analysis above, the Service concurs that the proposed project is not likely to adversely affect the delta smelt's critical habitat. The remainder of this document represents the Service's biological opinion on the effects of the proposed project on the delta smelt.

Consultation History

September 18, 2019: The Army hosted a multi-agency conference call to discuss the dredging project. Part of the discussion focused on proposing maintenance dredging in more than one consultation. Dredging as proposed under the MOTCO Piers 2 and 3 Modernization Project biological opinion (Service file number: 08FBT00-2014-F-0002-5) was not conducted and the Army acknowledged the need to withdraw dredging from that consultation.

October 15, 2019: The Service received the Army's initiation letter and biological assessment.

November 2019: The Service and Army exchanged emails regarding clarification on determinations and consultation time frame.

BIOLOGICAL OPINION

Description of the Proposed Action

Overview

MOTCO proposes to perform dredging practices to maintain operational and mission capacity for Piers 2,3, 4, and Barge Pier (totaling 38 acres). Dredging would be conducted under the Long Term-Management Strategy (LTMS) for the Placement of Dredged Material for San Francisco Bay Region. As required by the 1999 LTMS biological opinion and 2004 amendment (Service file numbers: 1-1-98-F-62 and 1-1-04-F-0199), any dredging in Suisun Bay and its tidal marshes from the Carquinez Bridge east to Collinsville would require separate endangered species consultation. The frequency of dredging to be conducted, and volumes dredged would maintain suitable depths for navigability and cargo operations at piers 2-4 (35 feet Mean Lower Low Water (MLLW)) and the barge pier (20 feet MLLW). Maintenance dredging includes dredging to the respective pier's regulatory depth, plus up to 2 feet of overdepth. MOTCO dredging operations would use a clamshell dredge depending on the Dredged Material Management Office (DMMO) permit and equipment availability. Local water velocities appear to slow sediment deposition, therefore, MOTCO currently expects to dredge every 2 years when necessary to maintain navigability from 2020 to 2030. Current conditions and estimated dredge event volume and area are provided in Table 1.

Table 1. Pier area conditions with proposed dredging actions

Pier	Hydrographic Survey Date	Proposed Dredge Parameters Year	Depth (Feet)	Volume (CY)	Area (acres)
Barge	13-Mar-2019	2020	-22	7,835	2.57
2	13-Mar-2019	2020	-37	75,225	29.26
3	13-Mar-2019	2020	-37	2,602	1.03
4	7-Jun-2018	Post-2020	-37	12,571	4.73
Proposed 2020 Dredging				85,662	32.87
Post-2020 Dredging				12,571	4.73

Dredging would be conducted using mechanical dredges, with material being placed in a bottom-dumping scow. Once full, the scow will be transported by a tug to the dredged material placement site for disposal. The maximum anticipated volume of material proposed for maintenance dredging the first year is approximately 85,662 cubic yards (cy). If the dredging is continuous (24 hours a day) and the maximum daily rate of approximately 7,000 cubic yards is achieved, the project could be completed in 13 full days. However, dredging typically does not occur 24 hours per day; rather, the effective work time (actual digging of shoaled material) is often 12 to 16 hours per day. Additionally, crew changes, relocation of the dredge, and other activities (e.g. breakdowns) limit the amount of dredging that occurs. Therefore, completing the proposed action's first year dredging could require anywhere from 30 to 60 days. Future dredging maintenance events are anticipated to be completed in shorter time periods.
Dredging would be conducted during the August 1 through November 30 work window.

Sediment disposal would occur at one or more of these locations: LTMS Carquinez Strait (SF-9), LTMS SF-16, the Montezuma Wetlands Restoration Project (MWRP), the Cullinan Ranch Restoration Project (CRRP), or the Antioch Dunes National Wildlife Refuge (ADNWR). Sediment testing would be performed to identify appropriate placement sites for dredge material. These proposed dredged material placement sites are already fully permitted to accept dredged material from Bay Area dredging projects.

Table 2 identifies the preferred Federal standard placement site and proposed alternate placement sites that would be used for each location, as well as expected dredge volumes. MOTCO would beneficially reuse dredged material to the maximum extent its authorities allow. Although it is assumed for the purpose of this consultation that placement would occur at the identified Federal standard sites, MOTCO would place dredged material at beneficial reuse sites when costs are equivalent to the Federal standard.

Table 2. Summary of the proposed dredging action.

Location	Dredge Type	Initial Dredge Volume (CY)	Dredge Frequency	Range of Volume Dredged (CY)	Median Volume Dredge (CY)	Proposed Action Placement Site
Piers 2, 3, 4, and Barge Pier	Clamshell	85,662	1-2	2,602-75,225	28,000	MWRP,CRRP, ADNWR, SF-9, SF-16

Dredging Methods

The clamshell bucket capacity would range between 20 to 50 cy, depending on dredge availability. Up to seven scows, with a capacity of 2,000 to 4,000 cy, and four 1,800 horsepower (hp) tugs would be used to transport dredged material to placement sites. In addition, one 1,000 hp tender tug would be required to maneuver each dredge plant.

The estimated daily production rate would range between 3,100 and 6,600 cy, depending on the location of dredging and the placement site being used. For example, the production rate would be approximately 5,000 cy if dredged material were placed at the upland beneficial use sites. The production rate would decrease if material were transported to one of the federal standard disposal sites.

A mechanical clamshell dredge consists of a crane mounted on a floating deck barge, with a clamshell bucket on the end of the crane boom (Figure 1). The deck barge has two to four spud piles attached to the platform, generally at the corners. The spud piles are long pipes that are driven vertically into the bay bottom by hydraulic assistance. The spud piles are used to anchor the dredge barge. Clamshell dredges are not self-propelled so they require a tug boat to tow or push the dredge to and from the dredge sites. Once a tug moves the dredge into place, the spuds are driven into the bay bottom anchoring the dredge. Once the dredge is anchored in place, dredging can begin. Relocating the dredge requires approximately 1 hour to complete. On average, the mechanical clamshell dredge plant for this project would need to be relocated approximately every 3 hours. In addition, when working adjacent to the ship channel, the dredge

would need to be moved out of the shipping channel to allow deep draft vessels to transit the channel.

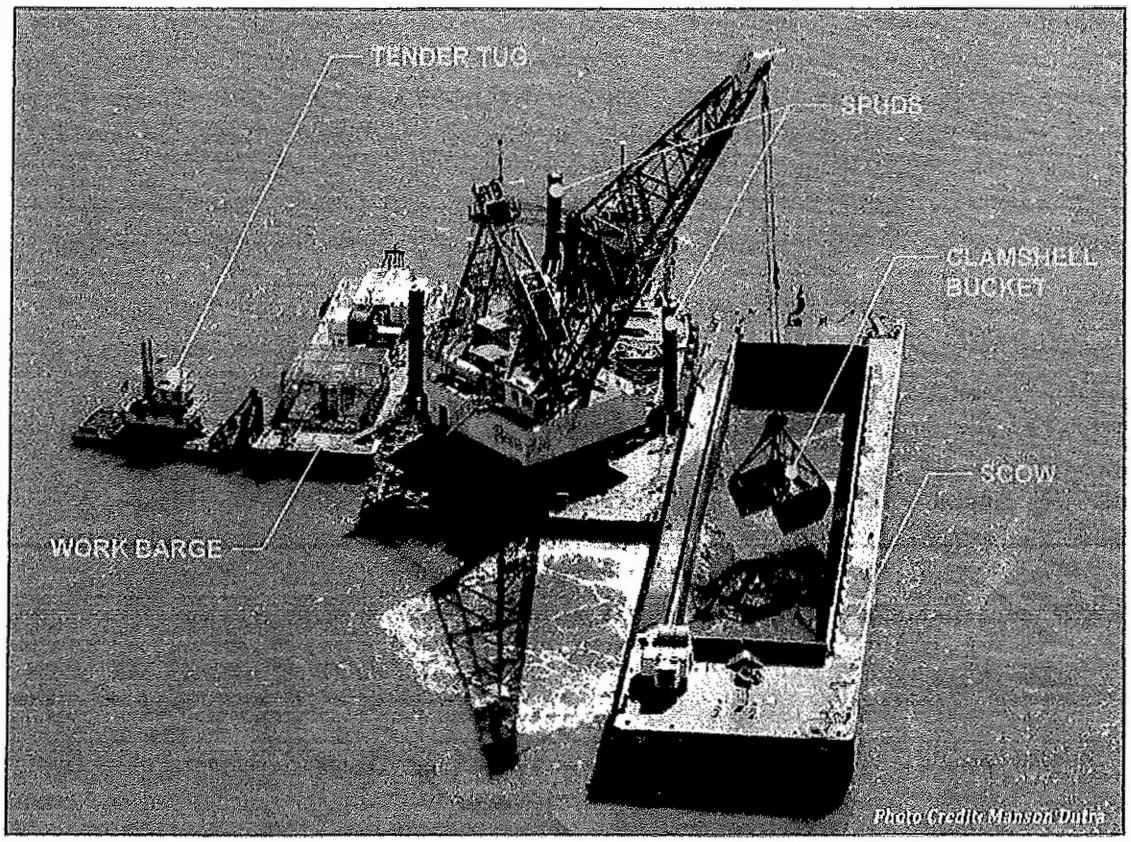

Figure 1. Typical Mechanical Clamshell Dredge and Scow

The crane has a boom that is long enough to extend out beyond the end of the work barge in any direction and is able to swivel 360 degrees on its mount. A large clamshell bucket is attached to the end of a series of cables at the end of the boom, which allows the bucket to be raised and lowered into the water. The cables also open and close the bucket as it is filled with sediment and then emptied into scows. The scows are open barges that can carry large quantities of sediment and are towed with tug boats to and from disposal sites. As soon as one scow is filled and hauled away, another empty scow is maneuvered into place alongside the dredge and the digging continues.

Clamshell buckets are raised from and lowered to the bottom using a system of cables. The weight of the bucket is sufficient for it to fall through the water column into the bottom sediment. The cables restrict the clamshell from going too deep, or beyond the maximum allowable overdepth. The clamshell then closes and is pulled up through the water column to above the scow. Once over the scow, the clamshell opens and deposits the dredged material into the scow. When all the material within reach of the clamshell is dredged, the spuds are raised and the tender tug transports the dredge and scow to the next area requiring dredging. The process is repeated until all material is dredged from the channel. Following dredging, hydrographic surveys would be conducted to ensure that the entire area is dredged to the desired depth.

During dredging, clamshells place a slurry of sediment and water in the scows. Depending on the sediment type being dredged, the sediment-to-water ratio of the slurry is expected to be approximately 60 to 70 percent sediment and 30 to 40 percent water. To increase the sediment volume in the scows, the scows may decant water back to the water column in a process called overflow. Overflowing the scows increases the sediment volume, compared to water, which can decrease the number of scow-tug trips to placement sites, thereby decreasing construction costs. The San Francisco Bay Regional Water Quality Control Board allows unrestricted overflow in San Francisco Bay when sediment is greater than 80 percent sand. When sediment is less than 80 percent sand, overflow is only allowed if turbidity monitoring is conducted within 500 feet of dredging operations to demonstrate that the turbidity plume generated by overflow activities does not increase the ambient turbidity by more than 10 percent, does not reduce dissolved oxygen concentrations to below 7.0 mg/L in Suisan Bay, or result in the pH going below 6.5 or above 8.5.

Sediment proposed for dredging in front of the MOTCO Piers is anticipated to classify as clay, silt, and sand. The alternating layers of silty clay, clayey silt, sandy silt, silty sand, sand, and inter-bedded clay and sand are discontinuous and of varying thickness. Shells, wood debris (e.g., branches, twigs, and rootlets), and organic soils grading to peat also are expected to be encountered. Sediment directly in front of MOTCO Piers 2, 3 and 4, and Barge Pier was <80 percent sand when analyzed for pier renovations. Therefore, overflow turbidity monitoring would be required to demonstrate that the turbidity plumes are not adversely affecting water quality in the vicinity of the dredge.

Dredge Material Transport and Placement

When the scows are full, they would be transported to the dredged material placement site by diesel-powered tug boats. When the scow arrives at an open water disposal site, the doors at the bottom of the scow would open and dredged sediment would fall through the scow doors to the bottom of the placement site (Figure 2). As material falls through the water column, some sediment is stripped from the descending plume, creating turbidity around the scow. However, most sediment would fall to the bottom of the placement site. Scows transported to beneficial use sites would moor to an offloader at the respective site, such that sediment could be pumped out of the scow and onto the restoration site. Pumping out the sediment, or offloading, typically involves the use of a modified hydraulic pipe dredge, which serves as an offloader. A Liberty offloader (Figure 3), which is on a floating barge, is typically used at MWRP. A land-based offloader (Figure 4) is used at CRRP. Once moored, the offloader would insert a snorkel into the scow, simultaneously injecting water into the scow to create a water-sediment slurry and pumping the slurry from the scow to a designated cell within the site. The offloader's water intake system must be screened in accordance with the California Department of Fish and Wildlife's screening criteria. It takes approximately 2 hours to completely offload dredged sediment from a scow. Scows-tugs from the MOTCO would travel an average of 12 miles to MWRP. The distance from MOTCO to CRRP is approximately 19 miles. Scows-tugs would travel approximately 7 knots (8 miles per hour) from dredge sites to the beneficial use sites. On average, each scow-tug trip to and from the beneficial use sites, including offloading, would take approximately 6 hours.

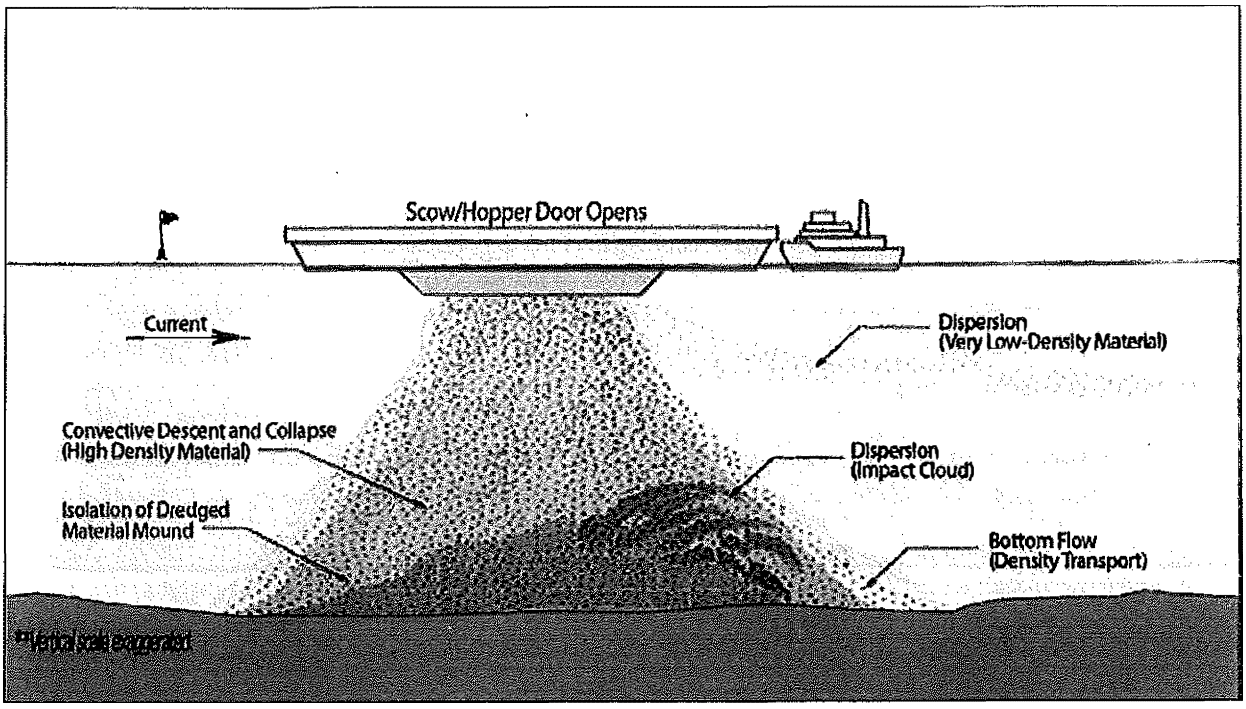

Figure 2. Aquatic Placement of Dredged Material

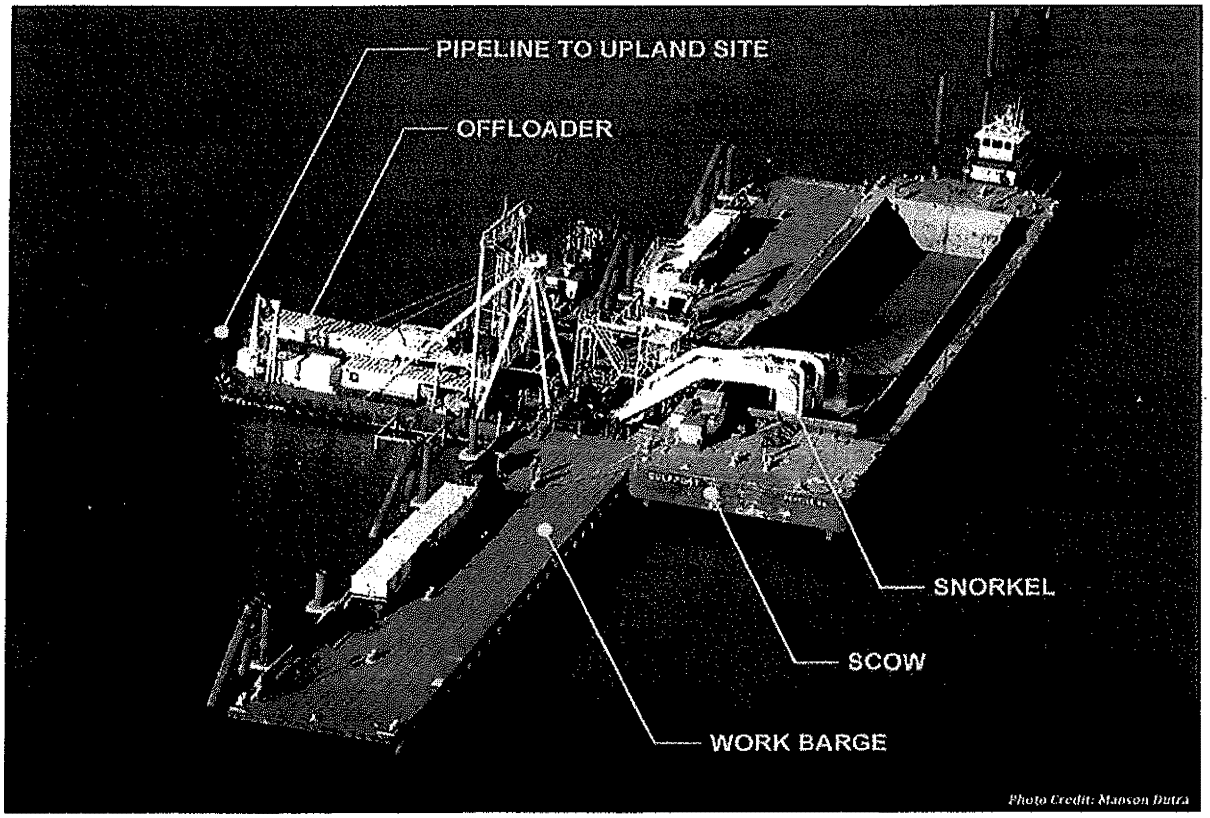

Figure 3. Liberty Offloader during Typical Offloading at Montezuma Wetlands Restoration Project

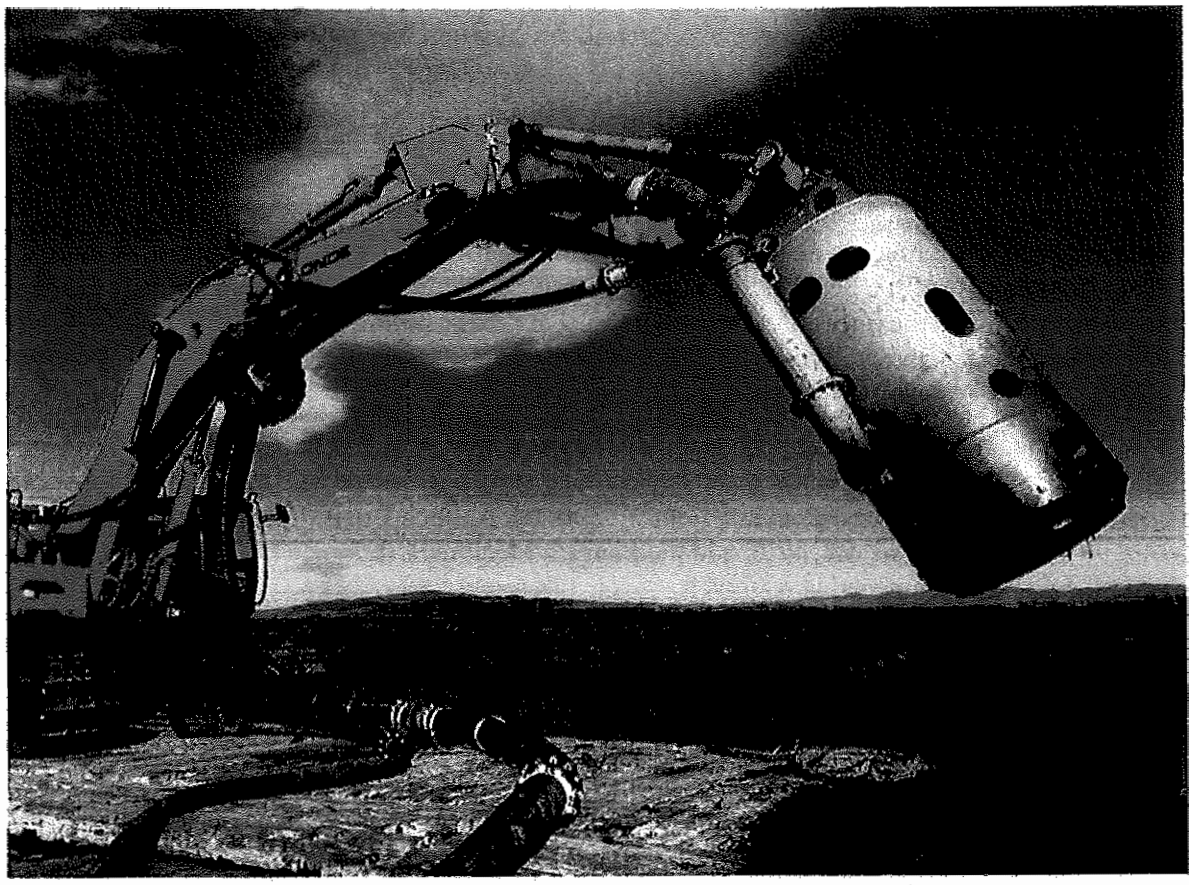

Figure 4. Modified Offloader Currently Offloading Dredged Material at Cullinan Ranch (Dutchman Slough)

Conservation Measure

- All dredging will be accomplished during the Service's recommended in-water work window for delta smelt August 1st to November 30th.

Action Area

The Action Area is defined in 50 CFR § 402.02, as "all areas to be affected directly or indirectly by the Federal action and not merely the immediate area involved in the action." For the proposed project, the Action Area encompasses both the dredged reaches of MOTCO's Barge Pier and Piers 2 through 4 in Suisun Bay (38 acres) and the disposal sites. Figure 5 shows the dredging locations and the aquatic disposal sites and MWRP. The MWRP, CRRP, and ADNWR have existing biological opinions that address the effects placement of dredged materials on listed species. Those actions are considered part of the *Environmental Baseline* and will not be discussed in the *Effects of the Action.* The two aquatic disposal sites were part of the LTMS biological opinion project description but not specifically analyzed for effects to delta smelt.

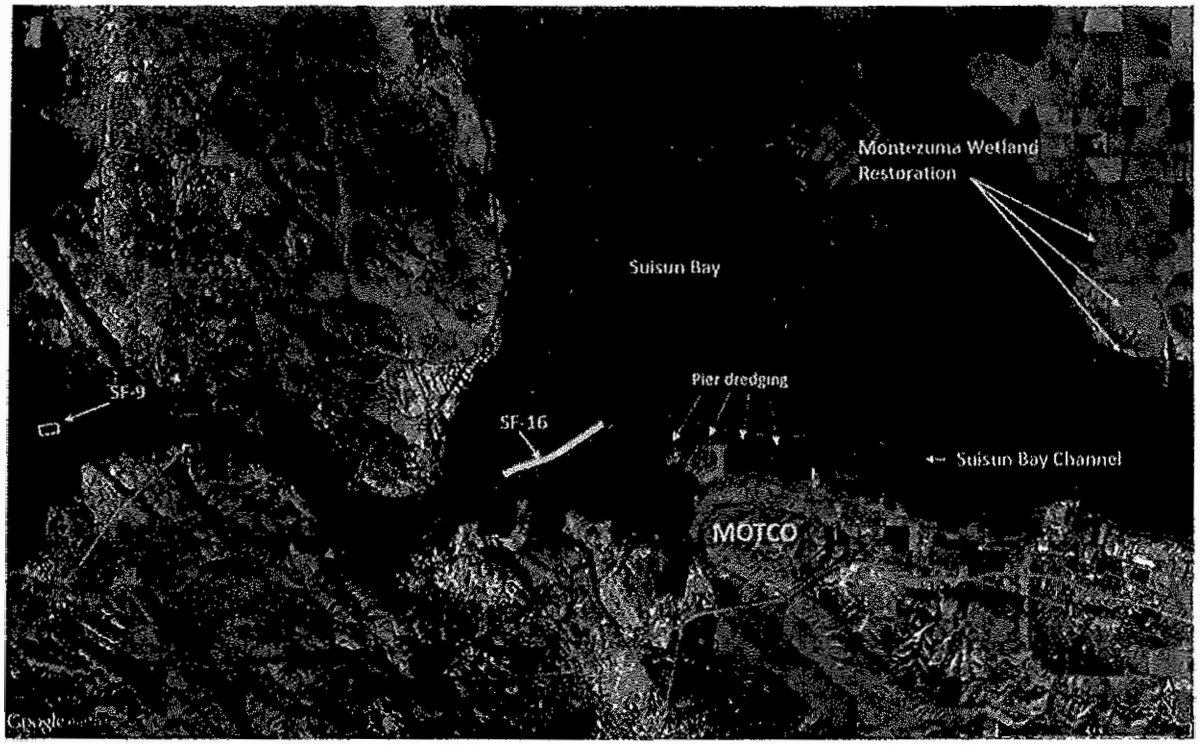

Figure 5. Dredging and Material Placement Sites

Analytical Framework for the Jeopardy Determination

Section 7(a)(2) of the Act requires that Federal agencies ensure that any action they authorize, fund, or carry out is not likely to jeopardize the continued existence of listed species. "Jeopardize the continued existence of" means to engage in an action that reasonably would be expected, directly or indirectly, to reduce appreciably the likelihood of both the survival and recovery of a listed species in the wild by reducing the reproduction, numbers, or distribution of that species (50 CFR § 402.02).

The jeopardy analysis in this biological opinion considers the effects of the proposed Federal action, and any cumulative effects, on the rangewide survival and recovery of the listed species. It relies on four components: (1) the *Status of the Species*, which describes the current rangewide condition of the species, the factors responsible for that condition, and its survival and recovery needs; (2) the *Environmental Baseline*, which analyzes the current condition of the species in the Action Area without the consequences to the listed species caused by the proposed action, the factors responsible for that condition, and the relationship of the Action Area to the survival and recovery of the species; (3) the *Effects of the Action*, which includes all effects that are caused by the proposed Federal action; and (4) the *Cumulative Effects*, which evaluates the effects of future, non-Federal activities in the Action Area on the species. The *Effects of the Action* and *Cumulative Effects* are added to the *Environmental Baseline* and in light of the status of the species, the Service formulates its opinion as to whether the proposed action is likely to jeopardize the continued existence of listed species.

Status of the Species

Species Legal Status and Life Cycle Summary

The Service proposed to list the delta smelt as threatened with proposed critical habitat on October 3, 1991 (Service 1991). The Service listed the delta smelt as threatened on March 5, 1993 (Service 1993), and designated critical habitat for the species on December 19, 1994 (Service 1994). The delta smelt was one of eight fish species addressed in the *Recovery Plan for the Sacramento–San Joaquin Delta Native Fishes* (Service 1996). A 5-year status review of the delta smelt was completed on March 31, 2004 (Service 2004). The review concluded that delta smelt remained a threatened species. A subsequent 5-year status review recommended uplisting delta smelt from threatened to endangered (Service 2010a). A 12-month finding on a petition to reclassify the delta smelt as an endangered species was completed on April 7, 2010 (Service 2010b). After reviewing all available scientific and commercial information, the Service determined that re-classifying the delta smelt from a threatened to an endangered species was warranted but precluded by other higher priority listing actions (Service 2010c). The Service reviews the status and uplisting recommendation for delta smelt during its Candidate Notice of Review (CNOR) process. Each year it has been published, the CNOR has recommended the uplisting from threatened to endangered. Electronic copies of these documents are available at https://ecos.fws.gov/ecp0/profile/speciesProfile?sId=321.

The delta smelt is a small fish of the family Osmeridae. In the wild, very few individuals reach lengths over 3.5 inches (90 mm; Damon *et al.* 2016). At the time of its listing, only the basics of the species' life history were known (Moyle *et al.* 1992). In the intervening 26 years, it has become one of the most studied fishes in the United States. Enough has been learned about the delta smelt to support its propagation in captivity over multiple generations (Lindberg *et al.* 2013), to support the development of complex conceptual models of the species life history (Interagency Ecological Program (IEP) 2015), and mathematical simulation models of its life cycle (Rose *et al.* 2013a). Any synthesis of the now extensive literature on the delta smelt requires drawing conclusions across studies that had disparate objectives, but several syntheses have been compiled from existing information (Moyle *et al.* 1992; Bennett 2005; IEP 2015; Moyle *et al.* 2016). In this biological opinion, the Service relied on these previous syntheses where it remains appropriate to do so. We also relied on source study results and analyses of our own to synthesize across a rapidly growing body of scientific information.

The delta smelt has a fairly simple life history because a large majority of individuals live only one year (Bennett 2005; Moyle *et al.* 2016) and because it is an endemic species (Moyle 2002), comprising only one genetic population (Fisch *et al.* 2011), that completes its full life cycle in the northern reaches of the San Francisco Bay-Delta (Merz *et al.* 2011; Figure 6). The schematic of this simple life cycle developed by Moyle *et al.* (2016) and published again by Moyle *et al.* (2018) is shown in Figure 7. Most spawning occurs from February through May in various places from the Napa River and locations to the east including much of the Sacramento-San Joaquin Delta. Larvae hatch and enter the plankton primarily from March through May, and most individuals have metamorphosed into the juvenile life stage by June or early July. Most of the juvenile fish continue to rear in habitats from Suisun Bay and marsh and locations east principally along the Sacramento River-Cache Slough corridor (recently dubbed the 'North Delta Arc'; Moyle *et al.* 2010). The juvenile fish (or 'sub-adults') begin to develop into maturing adults in the late fall. Thereafter, the population spatial distribution expands with the onset of

early winter storms and the first individuals begin to reach sexual maturity by January in some years, but most often in February (Damon *et al.* 2016; Kurobe *et al.* 2016). Delta smelt do not reach sexual maturity until they grow to at least 55 mm in length (~ 2 inches) and 50% of individuals are sexually mature at 60 to 65 mm in length (Rose *et al.* 2013b). In captivity delta smelt can survive to spawn at two years of age (Lindberg *et al.* 2013), but this appears to be rare in the wild (Bennett 2005; Damon *et al.* 2016; Figure 7). The spawning microhabitats of the delta smelt are unknown, but based on adult distribution data (Damon *et al.* 2016; Polansky *et al.* 2018) and the evaluation of otolith microchemistry (Hobbs *et al.* 2007a; Bush 2017), most delta smelt spawn in freshwater to slightly brackish-water habitats under tidal influence. Most individuals die after spawning, but as is typical for annual fishes, when conditions allow, some individuals can spawn more than once during their single spawning season (Damon *et al.* 2016). In a recent study spanning 2 to 3 months, captive males held at a constant water temperature of 12°C (54°F) spawned an average of 2.8 times and females spawned an average of 1.7 times (LaCava *et al.* 2015).

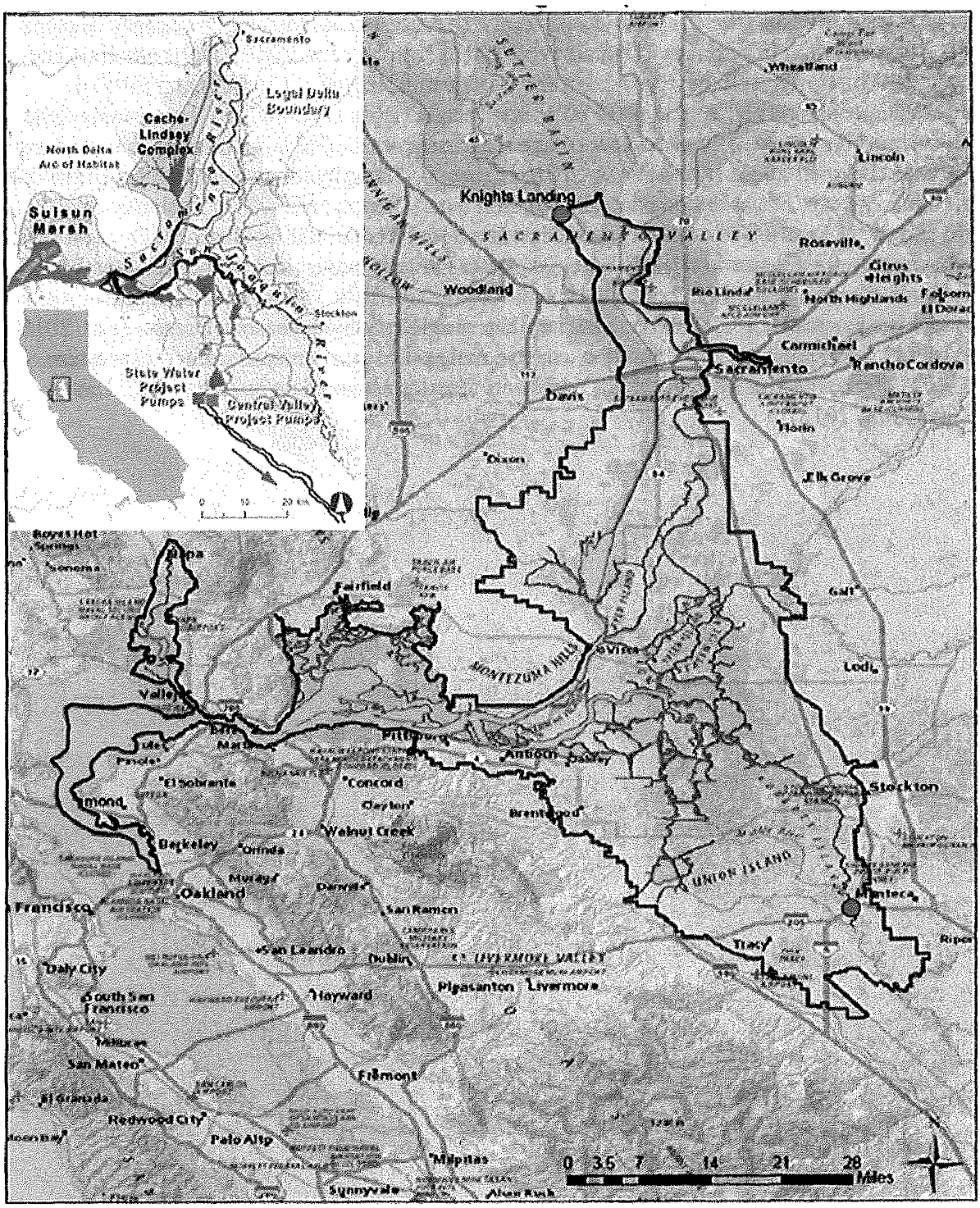

Figure 6. Delta smelt range map. Waterways colored in purple depict the delta smelt distribution described by Merz *et al.* (2011). The Service has used newer information to expand the transient range of delta smelt further up the Napa and Sacramento rivers than indicated by Merz *et al.* (2011). The red polygon depicts the boundary of delta smelt's designated critical habitat. The inset map shows the region known as the North Delta Arc shaded light green.

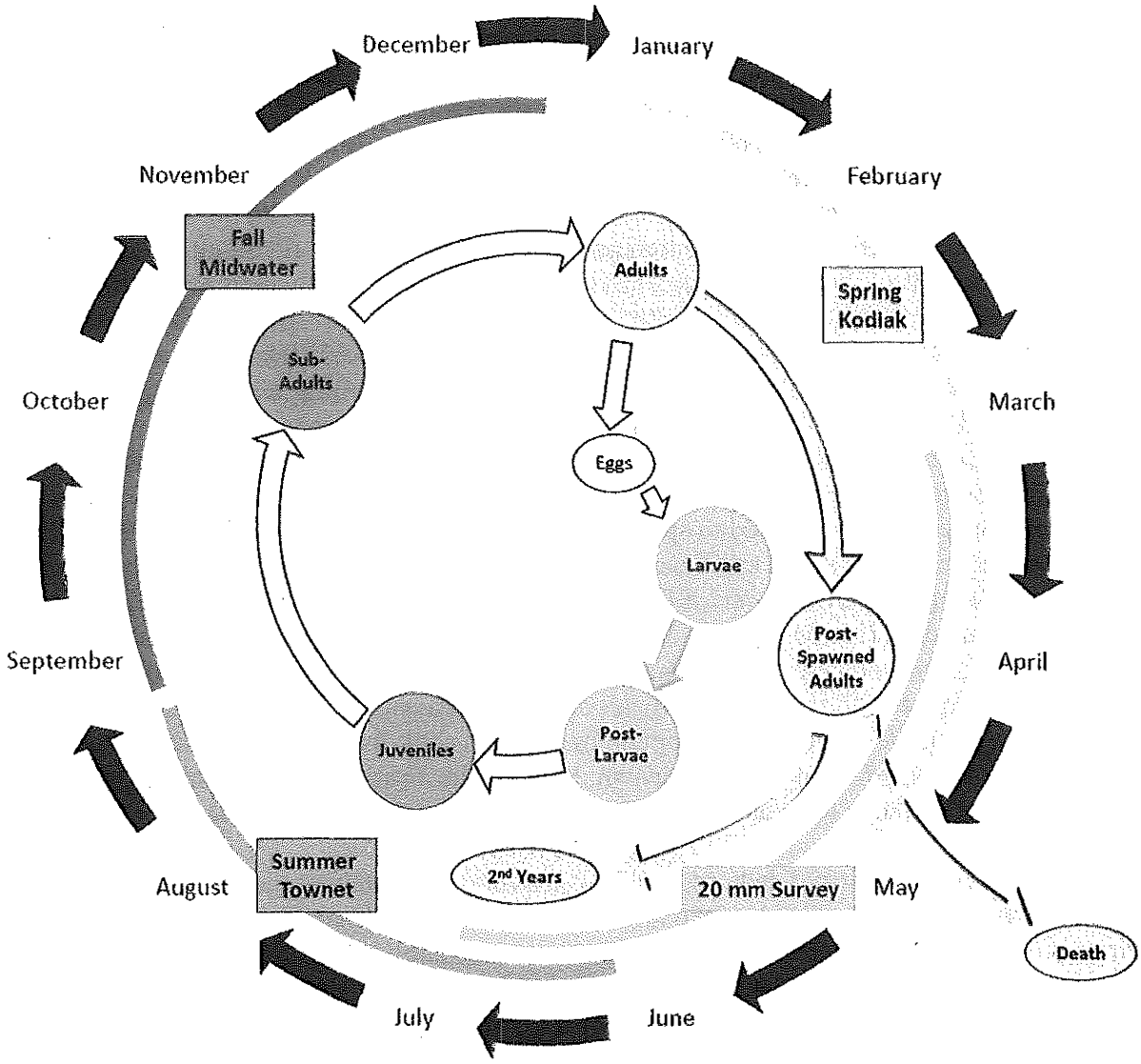

Figure 7. Schematic representation of the delta smelt life cycle. This conceptual model crosswalks delta smelt life stages with calendar months and current monitoring programs (prior to Enhanced Delta Smelt Monitoring) used to evaluate the species' status. Source: Moyle *et al.* 2016

Detailed Review of the Reproductive Biology of Delta Smelt

Delta smelt spawn in the estuary and have one spawning season for each generation, which makes the timing and duration of the spawning season important every year. Delta smelt are believed to spawn in fresh and low-salinity water (Hobbs *et al.* 2007a; Bush 2017). Therefore, freshwater flow affects how much of the estuary is available for delta smelt to spawn (Hobbs *et al.* 2007a). This is one mechanism in which interannual variation in Delta outflow could play a role in the population dynamics of delta smelt. Given the timing of delta smelt reproduction, Delta outflow during February through May would be most important for this mechanism. During this time of year, variation in Delta outflow is largely driven by weather variation and regulated by the California State Water Resources Control Board Decision-1641 (D-1641).

The locations of delta smelt spawning are thought to be influenced by salinity (Hobbs *et al.* 2007a), but the duration of the spawning season is thought to be driven mainly by water temperature (Bennett 2005; Damon *et al.* 2016), which is largely a function of regional air temperature (Wagner *et al.* 2011). Thus, the spawning season duration does not appear to be a freshwater flow mechanism, but rather, a climate-driven mechanism (Brown *et al.* 2016a). Delta smelt can start spawning when water temperatures reach about 10°C (50°F) and can continue until temperatures reach about 20°C (68°F; Bennett 2005; Damon *et al.* 2016). The ideal spawning condition occurs when water temperatures remain between 10°C and 20°C throughout February through May. Few delta smelt ≤ 55 mm in length are sexually mature and 50% of delta smelt reach sexual maturity at 60 to 65 mm in length (Rose *et al.* 2013b). During January and February, many delta smelt are still smaller than these size thresholds (Damon *et al.* 2016). Thus, if water temperatures rise much above 10°C in January, the "spawning season" can start before many individuals are mature enough to actually spawn. If temperatures continue to warm rapidly toward 20°C in early spring, that can end the spawning season with only a small fraction of 'adult' fish having had an opportunity to spawn, and perhaps only one opportunity to do so. Delta smelt were initially believed to spawn only once before dying (Moyle *et al.* 1992). It has since been confirmed that delta smelt can spawn more than once if water temperatures remain suitable for a long enough time, and if the adults find enough food to support the production of another batch of eggs (Lindberg *et al.* 2013; Damon *et al.* 2016; Kurobe *et al.* 2016). In a recent study spanning 2 to 3 months, captive males held at a constant water temperature of 12°C (54°F) spawned an average of 2.8 times and females spawned an average of 1.7 times (LaCava *et al.* 2015). As a result, the longer water temperatures remain cool, the more fish have time to mature and the more times individual fish can spawn. Most adults disappear from monitoring programs by May, suggesting they have died (Damon *et al.* 2016; Polansky *et al.* 2018).

The reproductive behavior of delta smelt is only known from captive specimens spawned in artificial environments and most of the information has never been published, but is currently being revisited in new research. Spawning likely occurs mainly at night with several males attending a female that broadcasts her eggs onto bottom substrate (Bennett 2005). Although preferred spawning substrate is unknown, spawning habits of delta smelt's closest relative, the Surf smelt (*Hypomesus pretiosus*), are sand or small gravel (Hirose and Kawaguchi 1998; Quinn *et al.* 2012).

The duration of the egg stage is temperature-dependent and averages about 10 days before the embryos hatch into larvae (Bennett 2005). It takes the fish about 30-70 days to reach 20-mm in length (Bennett 2005; Hobbs *et al.* 2007b). Similarly, Rose *et al.* (2013b) estimated that it takes delta smelt an average of slightly over 60 days to reach the juvenile life stage. Metamorphosing "post-larvae" appear in monitoring surveys from April into July of most years. By July, most delta smelt have reached the juvenile life stage. Thus, subtracting 60 days from April and July indicates that most spawning occurs from February-May.

Hatching success is highest at temperatures of 15-16°C (59-61°F) and lower at cooler and warmer temperatures and hatching success nears zero percent as water temperatures exceed 20°C (Bennett 2005). Water temperatures suitable for spawning occur most frequently during the months of February-May, but ripe female delta smelt have been observed as early as January and larvae have been collected as late as July, suggesting that spawning itself may extend into June in years with exceptionally cool spring weather.

Detailed Review of the Habitat Use and Distribution of Delta Smelt

Because the delta smelt only lives in one part of one comprehensively monitored estuary, its general distribution and habitat use are well understood (Moyle *et al.* 1992; Bennett 2005; Hobbs *et al.* 2006; 2007b; Feyrer *et al.* 2007; Nobriga *et al.* 2008; Kimmerer *et al.* 2009; Merz *et al.* 2011; Murphy and Hamilton 2013; Sommer and Mejia 2013; Mahardja *et al.* 2017a; Simonis and Merz 2019). The delta smelt has been characterized as a semi-anadromous species (Bennett 2005; Hammock *et al.* 2017) and Sommer *et al.* (2011) characterized the species as a partial diadromous migrant, recognizing individual variation in its life-history. However, both terms emphasize a life cycle in which delta smelt spawn in freshwater and volitionally move 'downstream' into brackish water habitat, which is only one endpoint among several individual life cycle strategies that have recently been confirmed through the use of otolith microchemical analyses (Bush 2017). In addition, semi-anadromy and partial diadromy are scale-dependent terms which have caused confusion among researchers and managers alike. For instance, some individual delta smelt clearly migrate between fresh and brackish water during their lives (Bush 2017). Other individuals could appear to have done so based on otolith microchemistry but in reality have moved very little and simply experienced annual salinity variation, which can be very high in much of the range of delta smelt (see Hammock *et al.* 2019). Other individual delta smelt are clearly freshwater and brackish-water resident throughout their lives (Bush 2017). As a result, there are both location-based (*e.g.*, Sacramento River around Decker Island) and conditions-based (low-salinity zone) habitats that delta smelt permanently occupy. There are habitats that some delta smelt occupy seasonally (*e.g.*, for spawning), and there are habitats that a few delta smelt occupy transiently, which we define here as occasional use. Transient habitats include distribution extremes from which delta smelt have occasionally been collected, but were not historically collected every year or even in most years. Thus, the Service suggests the delta smelt may be best characterized as an upper estuary resident species with a population-scale distribution that expands and contracts as freshwater flow seasonally (and interannually) decreases and increases, respectively. This influence of freshwater flow inputs on delta smelt distribution could in turn influence mechanisms that affect the species' population dynamics when those mechanisms are linked to where the fish reside or how they are distributed in the estuary. We note that water temperature, turbidity, water diversion rates, prey availability, and possibly other factors would also affect these spatial recruitment and survival mechanisms.

Delta smelt have been observed as far west as San Francisco Bay near the City of Berkeley, as far north as Knight's Landing on the Sacramento River, as far east as Woodbridge on the Mokelumne River and Stockton on the Calaveras River, and as far south as Mossdale on the San Joaquin River (Merz *et al.* 2011; Figure 6). These extremes of the species' distribution extend beyond the geographic boundaries specified in the critical habitat rule. However, most delta smelt have been collected from locations within the critical habitat boundaries. In other words, observations of delta smelt outside of the critical habitat boundaries reflect transient habitat use rather than permanent or seasonal habitat use. The Napa River is the only location outside of the critical habitat boundaries that may be used often enough to be considered a seasonal habitat rather than a transient one.

The fixed-location habitats that delta smelt permanently occupy span from the Cache Slough complex down into Suisun Bay and Suisun Marsh (Figure 8). The reasons delta smelt are believed to permanently occupy this part of the estuary are the presence of fresh- to low-salinity water year round that is comparatively turbid and of a tolerable water temperature. These

appropriate water quality conditions overlap an underwater landscape featuring variation in depth, tidal current velocities, edge habitats, and food production (Nobriga *et al.* 2008; Feyrer *et al.* 2011; Murphy and Hamilton 2013; Sommer and Mejia 2013; Hammock *et al.* 2015; 2017; 2019; Bever *et al.* 2016; Mahardja *et al.* 2019; Simonis and Merz 2019). Field observations are increasingly being supported by laboratory research that explains how delta smelt respond physiologically and behaviorally to variation in water quality that can vary with changes in climate, freshwater flow and estuarine bathymetry (e.g., Hasenbein *et al.* 2013; 2016b; Komoroske *et al.* 2014; 2016).

The principal variable-location habitat that delta smelt permanently occupy is the low-salinity zone (LSZ) (Moyle *et al.* 1992; Bennett 2005). The LSZ is a dynamic habitat with size and location that respond to changes in tidal and river flows (Jassby *et al.* 1995; Kimmerer *et al.* 2013; MacWilliams *et al.* 2015; 2016; Bever *et al.* 2016). The LSZ generally expands and moves downstream as river flows into the estuary increase, placing low-salinity water over a larger and more diverse set of nominal habitat types than occurs under lower flow conditions. As river flows decrease, the LSZ contracts and moves upstream. This is perhaps the most frequently assumed freshwater flow mechanism in discussions about X2 regulations, but as shown by Kimmerer *et al.* (2009; 2013), it does not appear to be a major explanatory mechanism for most fishes including the delta smelt.

The LSZ often encompasses many of the permanently occupied fixed locations discussed above. It is treated separately here because delta smelt distribution tracks the movement of the LSZ somewhat (Moyle *et al.* 1992; Dege and Brown 2004; Feyrer *et al.* 2007; 2011; Nobriga *et al.* 2008; Sommer *et al.* 2011; Bever *et al.* 2016; Manly *et al.* 2015; Polansky *et al.* 2018; Simonis and Merz 2019). Due to its historical importance as a fish nursery habitat, there is a long research history into the physics and biology of the LSZ. The LSZ is frequently defined as waters with a salinity range of about 0.5 to 6 ppt (Kimmerer 2004). This and similar salinity ranges reported by different authors were chosen based on analyses of historical peaks in chlorophyll concentration and zooplankton abundance. Most delta smelt collected in California Department of Fish and Wildlife's (CDFW) 20-mm Survey and Summer Townet Survey (TNS) have been collected at salinities of near 0 ppt to 2 ppt and most of the (older) delta smelt in the Fall Midwater Trawl (FMWT) have been collected from a salinity range of about 1 to 5 ppt (Kimmerer *et al.* 2013). These fish of different life stages do not tend to be in dramatically different places (Murphy and Hamilton 2013; Figure 8), suggesting that some of the change in occupied salinity with age is due to the seasonal increases in salinity that accompany lower outflow in the summer and fall.

Each year, the distribution of delta smelt seasonally expands when adults disperse in response to winter flow increases that also coincide with seasonal increases in turbidity and decreases in water temperature (Sommer *et al.* 2011; Figure 8). The annual range expansion of adult delta smelt extends up the Sacramento River to about Garcia Bend in the Pocket neighborhood of Sacramento, up the San Joaquin River from Antioch to areas near Stockton, up the lower Mokelumne River system, and west throughout Suisun Bay and the larger sloughs of Suisun Marsh. Some delta smelt seasonally and transiently occupy Old and Middle rivers in the south Delta each year, but face a high risk of entrainment when they do (Kimmerer 2008; Grimaldo *et al.* 2009). The expanded adult distribution initially affects the distribution of the next generation because delta smelt eggs are adhesive and not believed to be highly mobile once they are spawned (Mager *et al.* 2004). Thus, the distribution of larvae reflects a combination of where spawning occurred and freshwater flow when the eggs hatch.

In summary, the delta smelt population spreads out in the winter and then retracts by summer into what is presently a bi-modal spatial distribution with a peak in the LSZ and a separate peak in the Cache Slough complex. Most individuals occur in the LSZ at some point in their life cycle and the use of the Cache Slough complex diminishes in years with warm summers (Bush 2017).

Microhabitat Use: The delta smelt has been historically characterized as a pelagic fish, meaning one with a spatial distribution that is skewed away from shorelines (Moyle *et al.* 1992; Sommer *et al.* 2007). This has led to some confusion among researchers and managers alike – usually perpetuating a strawman argument that delta smelt either occupy deep-water habitats or shallow-water habitats. Then, catch data from shallow habitats get used to refute the pelagic characterization, but catches in shallow-water say nothing more about a pelagic tendency than catches in deep water would say about a nearshore habitat tendency. The long-term monitoring programs used to characterize delta smelt status and trend are offshore sampling programs – meaning pelagic sampling programs, and surface-trawling appears to be particularly effective at capturing delta smelt away from shorelines (Mitchell *et al.* 2017). However, numerous studies have reported collecting delta smelt from nearshore environments using fishing gear like beach seines and fyke nets from locations that often had a water depth less than or equal to 1 meter (just over three feet) (e.g., Matern *et al.* 2002; Nobriga *et al.* 2005; Gewant and Bollens 2012; Mahardja *et al.* 2017b). Further, it has been established that onshore-offshore movements are one behavior option delta smelt and other fishes can use to maintain position or move upstream in a tidal-flow influenced estuary (Bennett *et al.* 2002; Feyrer *et al.* 2013; Bennett and Burau 2015). Captive delta smelt have been shown to avoid in-water structure like submerged aquatic vegetation (SAV) (Ferrari *et al.* 2014). SAV tends to grow where tidal current velocities are low, which is a habitat attribute that has also been associated with wild delta smelt (Hobbs *et al.* 2006; Bever *et al.* 2016). Thus, the proliferation of SAV in areas that might otherwise be attractive to delta smelt represents a significant habitat degradation, not only because it creates structure in the water column, but also because it is associated with higher water transparency (Hestir *et al.* 2016), and a fish fauna that delta smelt does not seem to be able to coexist with (Nobriga *et al.* 2005; Conrad *et al.* 2016). Based on our review, the Service suggests that the characterization of delta smelt as an open-water fish appears to be accurate and does not imply occupation of a particular water column depth. The species does appear to have some affinity for surface waters (Burau and Bennett 2015; Mitchell *et al.* 2017), but like any microhabitat descriptor, this is not intended to reflect the location of all individuals because delta smelt are not limited to surface waters (Feyrer *et al.* 2013).

Although the delta smelt is generally an open-water fish, depth variation of open-water habitats is an important habitat attribute (Moyle *et al.* 1992; Hobbs *et al.* 2006; Bever *et al.* 2016). In the wild, delta smelt are most frequently collected in water that is somewhat shallow (4-15 ft deep) where turbidity is often elevated and tidal currents exist, but are not excessive (Moyle *et al.* 1992; Bever *et al.* 2016). For instance, in Suisun Bay, the deep shipping channels are poor quality habitat because tidal velocity is very high (Hobbs *et al.* 2006; Bever *et al.* 2016), but in the Delta where tidal velocity is slower, offshore habitat in Cache Slough and the Sacramento Deepwater Shipping Channel is used to a greater extent (Feyrer *et al.* 2013; CDFW unpublished data).

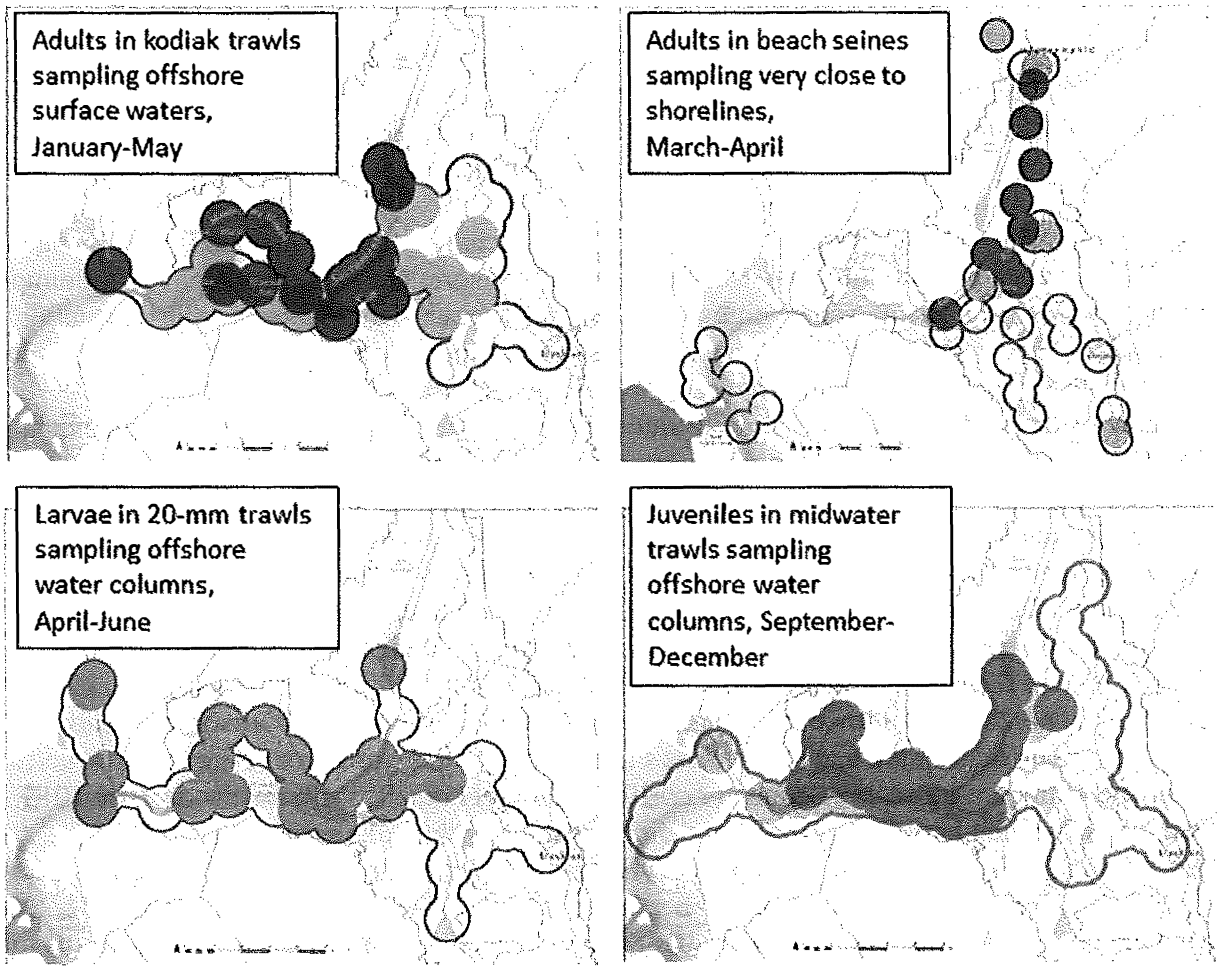

Figure 8. Maps of multi-year average distributions of delta smelt collected in four monitoring programs. The sampling regions covered by each survey are outlined. The areas with dark shading surround sampling stations in which 90 percent of the delta smelt collections occurred, the areas with light shading surround sampling stations in which the next 9 percent of delta smelt collections occurred. Note the lack of sampling sites in Suisun Bay and marsh for the beach seine (upper right panel). Source: Murphy and Hamilton (2013).

Environmental Setting and History of Ecological Change in the Bay-Delta

This section briefly reviews environmental changes that have occurred since 1850; i.e., the California Gold Rush to the present. This section is subdivided into three parts. The first describes the condition that is believed to have existed in 1850. The second covers a period from about 1920 to 1967, which is the year prior to the initiation of State Water Project (SWP) water exports from the Delta. The third sub-section covers 1968, the first year of Central Valley Project (CVP) and SWP dual operations, to the present.

Over the past few years, the scientific information developed to understand pre- and post-water project changes to the estuary's landscape and flow regime has grown substantially. However, as with most scientific endeavors, there are some discrepancies that may affect some conclusions. For instance, Whipple *et al.* (2012) showed the difference between contemporary estimates of unimpaired Delta outflow that were used in the modeling studies reviewed below and measured

data from the latter 19th century. These discrepancies can affect the conclusions about the natural hydrograph of the Bay-Delta ecosystem and should be kept in mind when reviewing what follows. The information on ecosystem changes that have accrued through time provides context for the current status of the delta smelt.

The 1850 Bay-Delta estuary: The historical Delta ecosystem was a large tidal marsh at the confluence of two floodplain river systems (Whipple *et al.* 2012; Andrews *et al.* 2017; Gross *et al.* 2018; Figure 9). The Delta itself experienced flooding over spring-neap tidal time scales and seasonal river runoff time scales. This variability in freshwater input to the estuary was likely important to seasonal and interannual variability in the productivity of the ecosystem for the same reasons that smaller-scale tidal marsh plain and floodplain inundation are today. Specifically, these flood cycles deliver organic carbon, but also increase the production of lower trophic levels due to lengthened water residence times and greater shallow, wetted surface areas (Sommer *et al.* 2004; Grosholz and Gallo 2006; Howe and Simenstad 2011; Enright *et al.* 2013). When freshwater flows out of the Delta and into the estuary, it can generate currents that aggregate particulate matter like sediment and phytoplankton (Monismith *et al.* 1996; 2002; MacWilliams *et al.* 2015) – and presumably also did so in the pre-development ecosystem. Prior to the invasion of the overbite clam, these sediment and phytoplankton aggregations, which occurred near the 2 parts per thousand (ppt) isohaline, demarcated an important fish nursery region (Turner and Chadwick 1972; Jassby *et al.* 1995; Bennett *et al.* 2002).

The estuary's natural hydrograph reached its annual base flows (annual minimum inputs of fresh water) in August or September toward the end of California's dry summers (Figure 10). Freshwater inputs would generally increase during the fall as precipitation in the watershed resumed. Delta outflow reached a broad winter through spring peak fueled first by precipitation followed by additional contributions from melting snow. The annual peak of Delta outflow often spanned January through May before declining back to base flow conditions by the late summer. The year-to-year variation in Delta outflow was considerable, often varying by about an order of magnitude during each month of the year. Water flowing from the Delta mixed into larger open-water habitats in Suisun and San Pablo bays, which themselves were fringed with marshes and tidal creeks. This pre-development ecosystem was shallower than the modern system. As a result, salinity responded more rapidly to changes in freshwater flow than it does now and less freshwater flow was needed to move salinity isohalines than is presently the case (Andrews *et al.* 2017; Gross *et al.* 2018). Like most native fish, the delta smelt evolved its life history to take advantage of this flow regime (Moyle 2002). In particular, its spawning period and early life stages overlap the months in which historical marsh-floodplain inundation and freshwater inputs to the estuary were highest, and water temperatures were cool, but not as cold as they are in the winter before spawning commences (see above for details of what is known about spawning and early life stages of delta smelt).

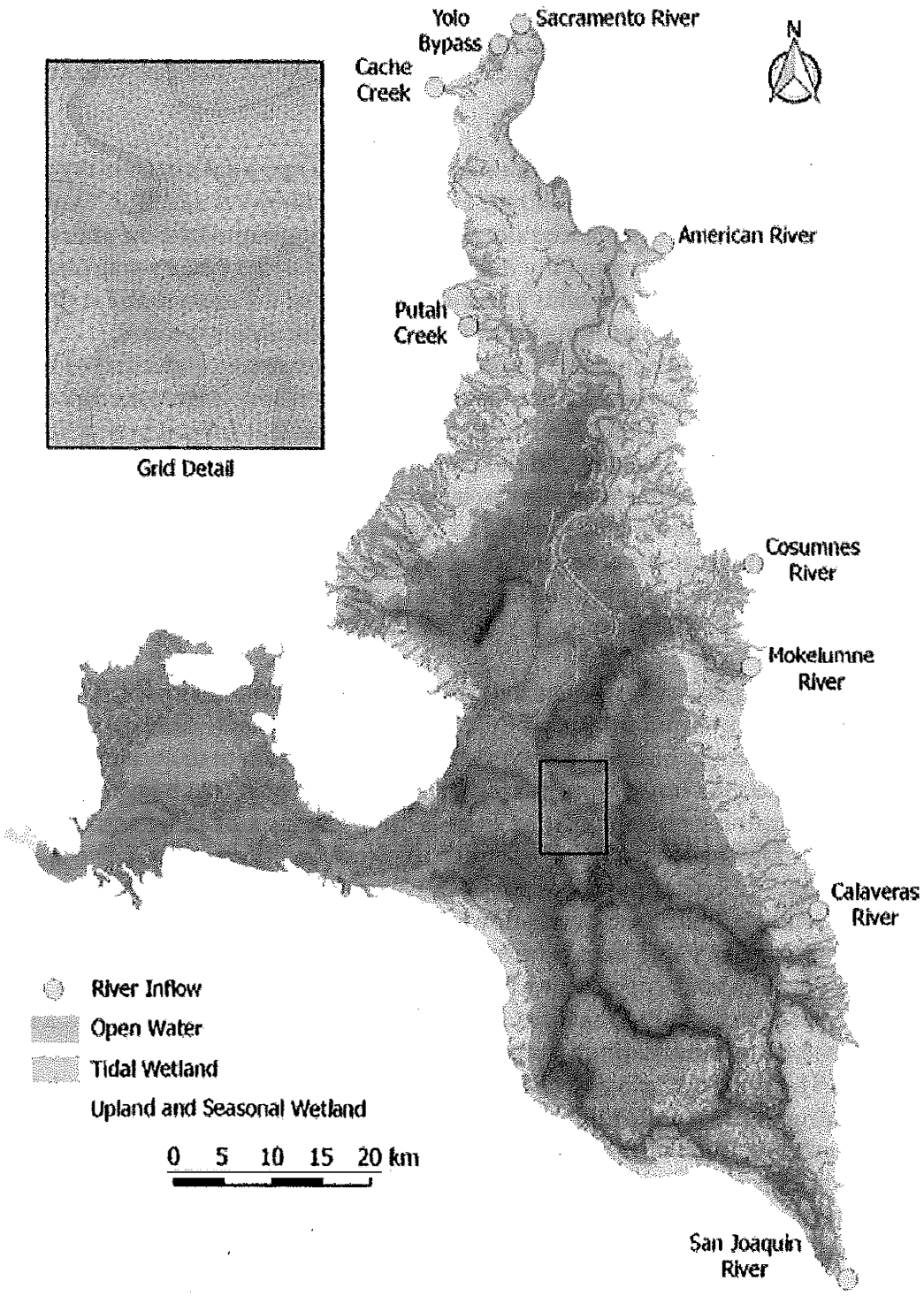

Figure 9. The circa 1850 Delta as depicted in the version of the UnTRIM 3-D hydrodynamic model described by Andrews *et al.* (2017). The model depicts an expansive tidal marsh area of approximately 2,200 square kilometers (km) or 850 square miles. Source: Andrews *et al.* (2017).

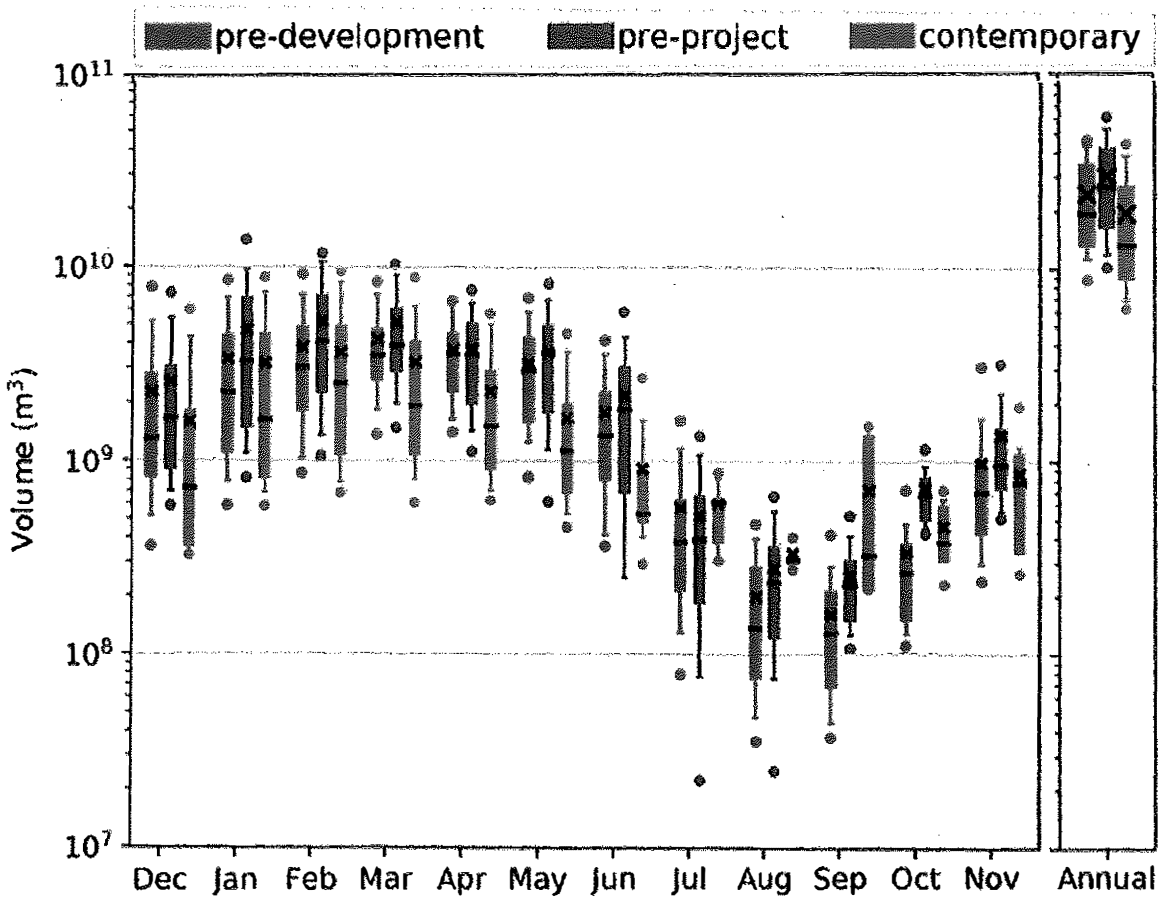

Figure 10. Boxplots of estimated Delta outflow by month for a pre-development Bay-Delta (circa 1850; red boxes), a pre-Central Valley Project and State Water Project Bay-Delta (circa 1920; green boxes), and a contemporary Bay-Delta (blue boxes; precise year not stated by the authors). Source: Gross *et al.* (2018). The inset labeled "Annual" on the x-axis is the boxplot summary of the sum of monthly outflows. Gross *et al.* (2018) attributed the higher outflow in the pre-project era relative to the pre-development era to the levees that had been constructed in the system by 1920.

Many tidal river estuaries form frontal zones where inflowing fresh water begins mixing with seawater (Peterson 2003). In the Bay-Delta, a frontal zone of biological importance is the LSZ (Jassby *et al.* 1995). The LSZ is a mobile and variable habitat region that frequently overlaps the parts of the estuary where many delta smelt reside (as described above). In the Bay-Delta the location and associated function of the LSZ have historically been indexed using a statistic called X2, which is the geographic location of 2 ppt salinity near the bottom of the water column measured as a distance from the Golden Gate Bridge (Jassby *et al.* 1995; MacWilliams *et al.* 2015; Figure 11). When Delta outflow is high, saline water is pushed closer to the Golden Gate, resulting in a smaller distance from the Golden Gate Bridge to X2. Conversely, when Delta outflow is low, salinity intrudes further into the estuary resulting in a larger distance from the Golden Gate Bridge to X2. These changes in how salinity is distributed affect numerous physical and biological processes in the estuary (Jassby *et al.* 1995; Kimmerer 2002a,b; Kimmerer 2004; MacWilliams *et al.* 2015).

X2, rather than another salinity isohaline, was chosen as the low-salinity zone habitat metric because it is a frontal zone or boundary upstream of which, salinity tends to be the same from the surface of the water to the bottom, and downstream of which, salinity varies from top to bottom (Jassby *et al.* 1995). That variability in the vertical distribution of salinity is indicative of currents that help to aggregate sinking particles like sediment and phytoplankton, and as recently modeled, zooplankton (Kimmerer *et al.* 2014), near X2.

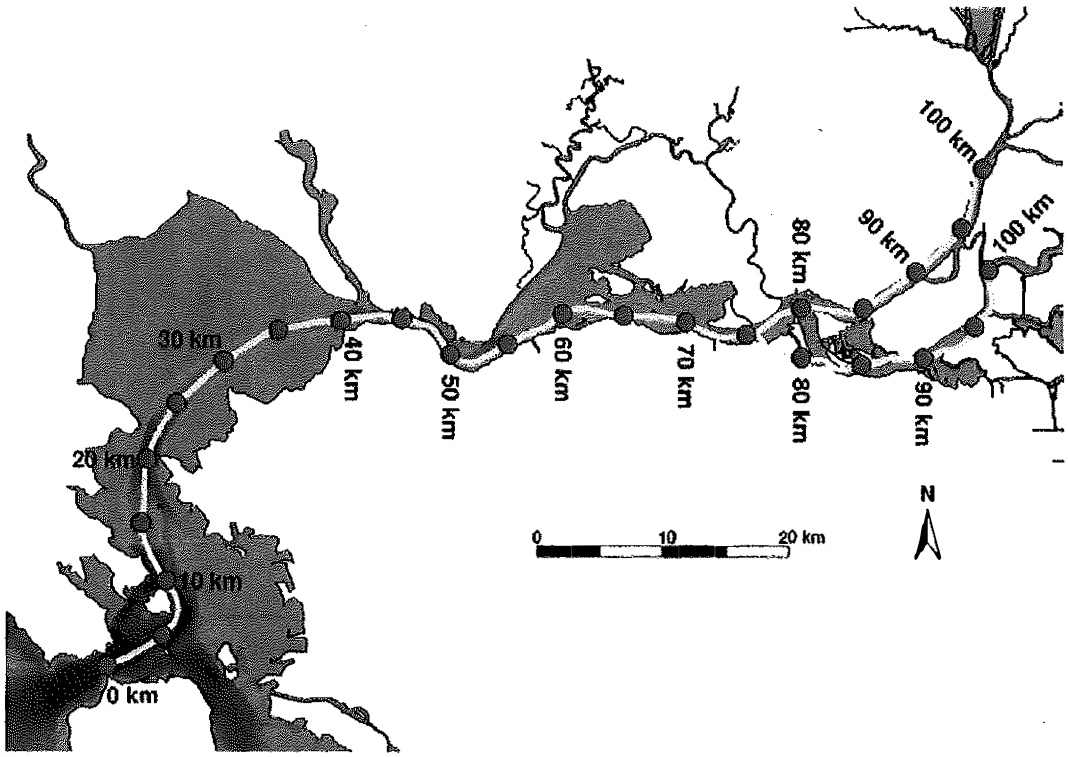

Figure 11. The northern reach of the Bay-Delta as depicted in the UnTRIM 3-D contemporary Bay-Delta model; greener colors represent shallower water and bluer colors represent deeper areas. The yellow lines depict the transect along which the location of X2 is estimated in the model and the associated red circles depict selected km distances from the Golden Gate Bridge along the northern axis of the estuary into the Sacramento and San Joaquin rivers for use in interpreting the variable locations of X2. Source: MacWilliams *et al.* (2015).

Pre-development outflows from the Delta were higher in the winter and spring than they are now while summer and fall outflows may have been lower (Andrews *et al.* 2017; Gross *et al.* 2018; Figure 10). Thus, X2 also varied more within years in the circa 1850 estuary than it now does. In the pre-development estuary, X2 would remain in San Pablo Bay for months at a time in the winter-spring of Above Normal and wetter water year types before retreating landward (upstream) in the summer-fall. In the contemporary estuary, X2 spends nearly all of its wet season time in Suisun Bay (landward or 'upstream' of historical) and dry season time between Collinsville and Rio Vista (~ 80 to 95 km; Figure 11). These contemporary dry season locations of X2 may be seaward or 'downstream' of historical locations (Gross *et al.* 2018).

There are no data on the timing and magnitude of biological productivity in the circa 1850 Bay-Delta, nor are we aware of any information on how delta smelt used the estuary at the time. However, inferences can be made based on general ecosystem function in the northern hemisphere temperate zone and contemporary information. The input of basal food web materials like nutrients and detritus likely co-varied with the timing, duration, and magnitude of freshwater flows (e.g., Delta inflow; Jassby and Cloern 2000), which would likewise have affected the timing, magnitude, and duration of inundation of the system's expansive floodplains (e.g., Whipple *et al.* 2012; Figure 9). The production of planktonic and epibenthic invertebrates from floodplains, tidal wetlands, and open-water habitats that fuel the production of juvenile fishes that feed in open waters may have generally increased during the spring and peaked during the summer in concert with seasonal variation in water temperature (e.g., Heubach 1969; Orsi and Mecum 1986; Merz *et al.* 2016). The summer months are the warmest months in the Bay-Delta region and thus, they support the highest *average* metabolic rates of invertebrates and fish, which rely on water temperature to control their body temperature and metabolic rates. However, there was likely to have been considerable species-specificity to this generalization (e.g., Ambler *et al.* 1985; Gewant and Bollens 2005) because the Bay-Delta's native biotic community includes numerous cold-water adapted species.

The seasonal timing of delta smelt reproduction (February-May; detailed below) would have more broadly coincided with the general timing of peak freshwater flow into the Bay-Delta (Figure 10). The higher outflow and shallower average depth of the system resulted in frequent occurrence of the LSZ in San Pablo Bay during the wet season. Thus, it is likely that delta smelt reared in San Pablo Bay, taking advantage of its greatly expanded low-salinity habitat area (see MacWilliams *et al.* 2015), to much greater extent prior to development of the system than they are able to now. Lower flows in the summer-fall likely caused delta smelt distribution to seasonally retract back into Suisun Bay/marsh and the Delta; ecosystems which were likely much more productive at the time due to the expansive tidal marshes and greater connection between land and water (Whipple *et al.* 2012). Delta smelt's population-level demand for prey annually peaks at some combination of water temperature and growth of the population's biomass. This timing could be estimated from the model developed by Rose *et al.* (2013a), but we are not aware that such a calculation exists.

<u>1920-1967:</u> By 1920, most of the Delta's tidal wetlands had been reclaimed (Whipple *et al.* 2012; Figure 12). The data provided by Gross *et al.* (2018; Figure 9) suggest that Delta outflow may have been a little higher circa 1920 than it had been circa 1850 due to levee construction. However, this may (Hutton and Roy 2019) or may not be consistent with historical observations (Whipple *et al.* 2012). Regardless, Delta outflow and several other net flow metrics from within the Delta did begin to decline between the early 1920s and 1967 (Hutton *et al.* 2017a; 2019). These changes occurred because of four factors: (1) water storage in the Bay-Delta watershed increased from about 4 million acre feet (MAF) to about 40 MAF because of the construction of dams upstream of the Delta, (2) the CVP began exporting water from the Delta in 1951, (3) non-project water diversions within and upstream of the Delta increased, and (4) shipping channels were dredged through the estuary and into the Sacramento and San Joaquin rivers. These changes facilitated a general water management strategy in California to store water during the wet season and re-distribute it during the dry season to provide a more reliable supply than was available naturally. In addition, the CVP and SWP have had to offset a considerable summertime water deficit to protect the quality of their exported water and to protect water quality for senior

water rights holders in the Delta. These uses would be highly impaired without water released from CVP and SWP reservoirs during the summer and fall (Hutton *et al.* 2017b).

During the 1930s to 1960s, the navigation channels were dredged deeper (~12 meters) to accommodate shipping traffic from the Pacific Ocean and San Francisco Bay to ports in Sacramento and Stockton and to increase the capacity of the Delta to convey floodwaters. Channel deepening interacted with the simultaneously increasing water storage to change the Bay-Delta ecosystem into one in which Suisun Bay and the Sacramento-San Joaquin River confluence region became the largest and most depth-varying places in the typical range of the LSZ. Even with these changes, the LSZ remained a highly productive fish nursery habitat for many decades (Stevens and Miller 1983; Moyle *et al.* 1992; Jassby *et al.* 1995).

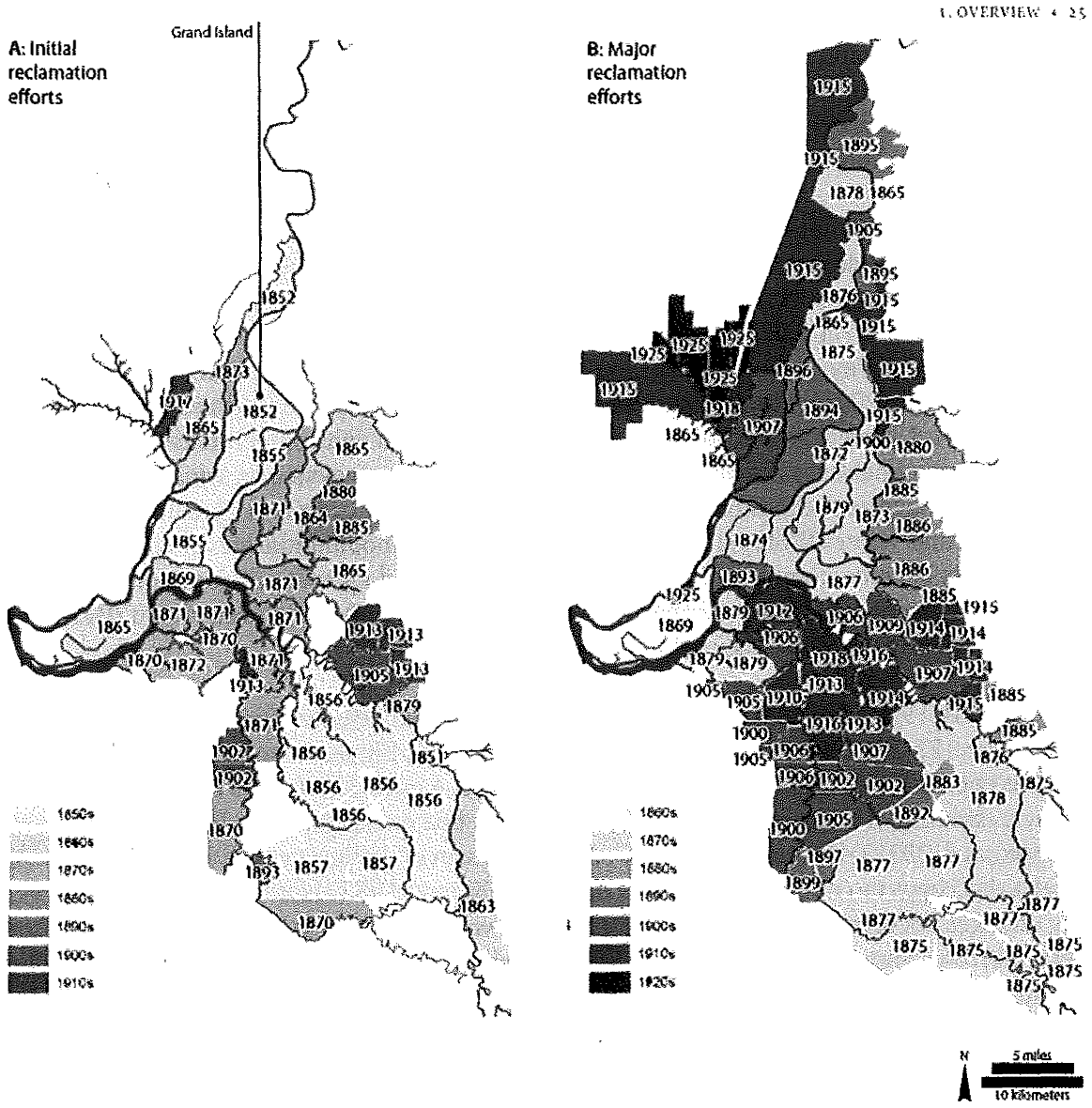

Figure 12. Maps of the Delta showing years of initial land reclamation attempts on the left and major land reclamation efforts on the right. Note that a large majority of the major reclamation efforts were underway by 1915 and the last efforts in the vicinity of Liberty Island began in 1925. Source: Whipple *et al.* (2012).

1968-present: The SWP began exporting water from the Delta in 1968 and its exports generally increased until about 1989 (Figure 13). CVP exports reached present-day levels by the end of the 1970s. During the 1980s water storage capacity in the Bay-Delta watershed reached its present-day level of a little over 50 MAF (Cloern and Jassby 2012; Hutton *et al.* 2017a). Thereafter, combined CVP-SWP exports began to increase in year-to-year variability, which increased the uncertainty about how much water would be supplied south of the Delta annually. This has combined with the increasing human demand for fresh water to result in a conflict between human water demand and environmental water uses, including the maintenance of the hydraulic salinity barrier needed to protect exported water and other in-Delta water users from salinity intrusion (Hutton *et al.* 2017b; Reis *et al.* 2019).

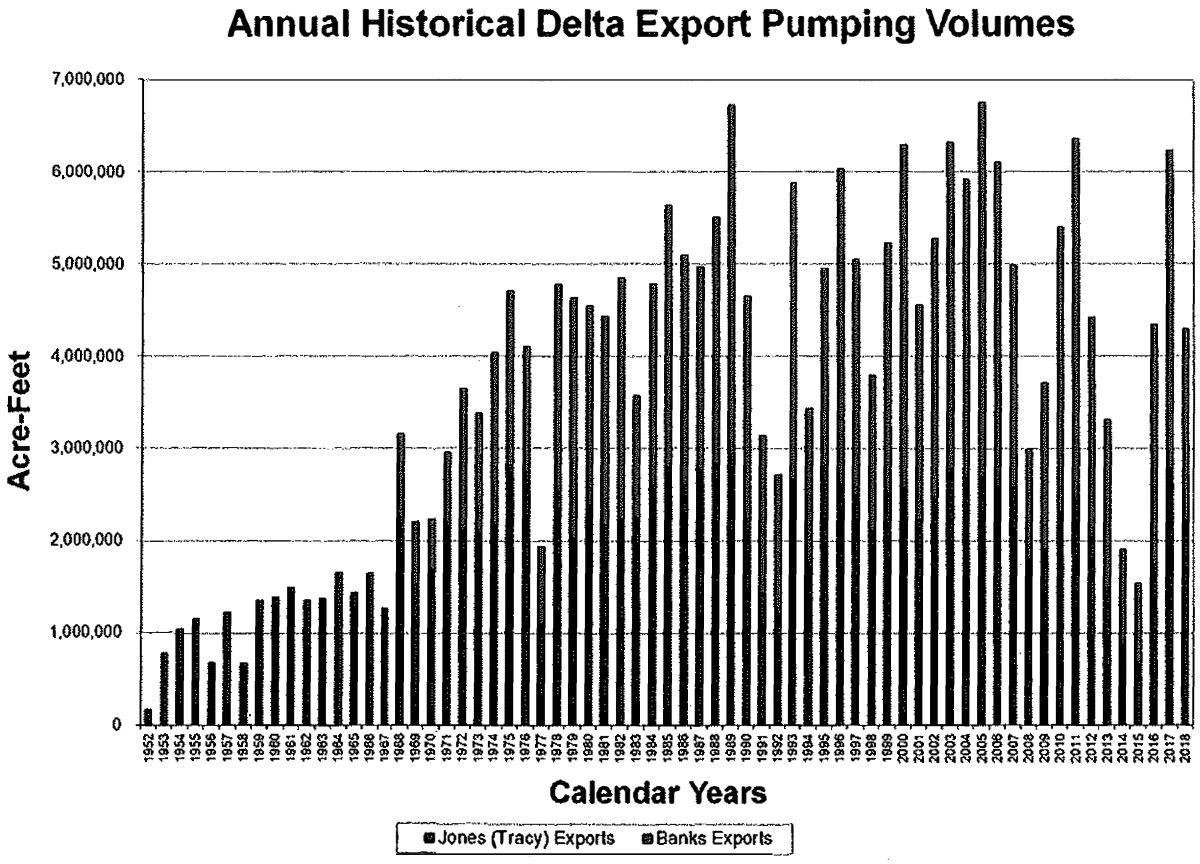

Figure 13. Time series of Central Valley Project and State Water Project exports from the Delta for 1952 through 2018. State Water Project exports began in water year 1968. Source: DAYFLOW data base.

The changes discussed above have continued to lower Delta outflow (Hutton *et al.* 2017a,b; Reis *et al.* 2019; Figures 14 and 15), though D-1641 appears to have halted the trend for years in which the eight river index is lower than 20 MAF (middle panel of Figure 14). In Figure 14, exports were modeled as depletions of water from the system, so the more negative the number on the y-axis of the middle panel, the higher the exports. Thus, the graphic shows that in years when the eight river index is more than 20 MAF, exports continue to increase, but in years when the eight river index is lower than 20 MAF, exports have been trending lower. Both of these trends cause the higher year-to-year variability in water exports shown in Figure 13.

In general, major changes to the flow regime of an aquatic ecosystem are expected to be accompanied by ecological change (Benson 1981; Bunn and Arthington 2002; Poff and Zimmerman 2010; Gillson 2011), and that is what has been observed over time in the Bay and Delta (e.g., Matern *et al.* 2002; Moyle and Bennett 2008; Winder *et al.* 2011; Feyrer *et al.* 2015; Conrad *et al.* 2016). Delta outflow is a driver of many ecological mechanisms in the Bay-Delta and an indicator of several others (Kimmerer 2002a). Thus, the changes to the estuary's freshwater flow regime have likely interacted with the changes to the estuary's landscape, specifically its deeper channels and greatly reduced land-water connections (Andrews *et al.* 2017), to lower the total biological productivity of the estuary. In addition, changes to the freshwater flow regime detailed above appear to have affected the reproductive success of fishes that use the Delta and Suisun Bay as rearing habitats. The evidence for this is that the native fish assemblage had reproductive seasons timed to winter-spring peak flows, whereas currently dominant non-native species generally spawn later in the spring and into the summer when inflows to the Delta are generally high to support human water use, but outflow from the Delta is generally low (Moyle 2002; Moyle and Bennett 2008). Reis *et al.* (2019) recently described super-critical water years with respect to Delta outflow. Several studies have indicated that low flow years and droughts in particular result in low native fish production in the Bay-Delta (Meng *et al.* 1994; Jassby *et al.* 1995; Kimmerer 2002b; Feyrer *et al.* 2015). Droughts recur and may contribute to cumulative impacts to native fishes like delta smelt. For instance, recent droughts have been particularly problematic for delta smelt (Moyle *et al.* 2018). Thus, the frequency of these super-critical water years, which has been much higher since 1968 than it was from 1920-1967 (Figure 15), is a conservation challenge that the Service and its partners have to contend with.

There are several fish species in the Bay-Delta that have historically been shown to have demonstrable positive population responses to freshwater flows into or out of the Delta. These include the well-described relationships for the survival of emigrating Sacramento basin Chinook salmon (*Oncorhynchus tschawytscha)* smolts with Sacramento River inflows (Kjelson and Brandes 1989; Perry *et al.* 2010), the relationship of Sacramento splittail (*Pogonichthys macrolepidotus*) production to Yolo Bypass flow (Moyle *et al.* 2004; Feyrer *et al.* 2006), and the 'fish-X2' relationships for striped bass (*Morone saxatilis*), longfin smelt (*Spirinchus thaleichthys*), and starry flounder (*Platichthys stellatus*) (Turner and Chadwick 1972; Jassby *et al.* 1995; Kimmerer 2002b). The life-history of delta smelt with its affinity for fresh and low-salinity waters seems consistent with that of a fish one could expect to respond similarly to variation in Delta outflow or X2. Researchers searched for some form of analogous relationship for the delta smelt for several decades, but no persistent relationship was found (Stevens and Miller 1983; Moyle *et al.* 1992; Jassby *et al.* 1995; Kimmerer 2002b; Bennett 2005; Mac Nally *et al.* 2010; Thomson *et al.* 2010; Miller *et al.* 2012). Further, Rose *et al.* (2013a,b) did not find salinity variation *per se* to have much impact on predictions of delta smelt population growth rate. The larger predicted impact in their individual-based model related to flow was due to simulated entrainment in exported water (Rose *et al.* 2013b; Kimmerer and Rose 2018). Although entrainment was predicted to lower the population growth rate, in and of itself, it could not convert a strongly positive growing population into a declining one without at least one additional factor impacting survival at the same time.

The IEP (2015) reported a correlation between February-May X2 and ratios of the 20-mm Survey index for delta smelt and either the Spring Kodiak Trawl (SKT) or FMWT indices of the parental stock that produced the 20-mm fish. This relationship emerged in data beginning at the

time of the pelagic organism decline (POD) in 2002. This relationship is stronger when considered in terms of salinity at Chipps Island (He and Nobriga 2018), possibly because salinity can be measured more accurately than Delta outflow when net freshwater flow is very low (Monismith 2016). Castillo *et al.* (2018) used a simulation based on SKT data to suggest a link between Delta outflow and adult delta smelt abundance. In addition, several teams have reported statistical associations of delta smelt spatial distribution and salinity that imply the population spatial distribution co-varies with Delta outflow, X2, or similar indices of freshwater input to the estuary (Feyrer *et al.* 2007; 2011; Nobriga *et al.* 2008; Kimmerer *et al.* 2009; 2013; Bever *et al.* 2016; Polanksy *et al.* 2018; Simonis and Merz 2019). The strength of this covariation and its management utility have been contested (e.g., Murphy and Hamilton 2013; Manly *et al.* 2015; Latour 2016; Polanksy *et al.* 2018) and supported (Sommer *et al.* 2011; Bever *et al.* 2016; Feyrer *et al.* 2016; Mahardja *et al.* 2017a) in several recently published papers.

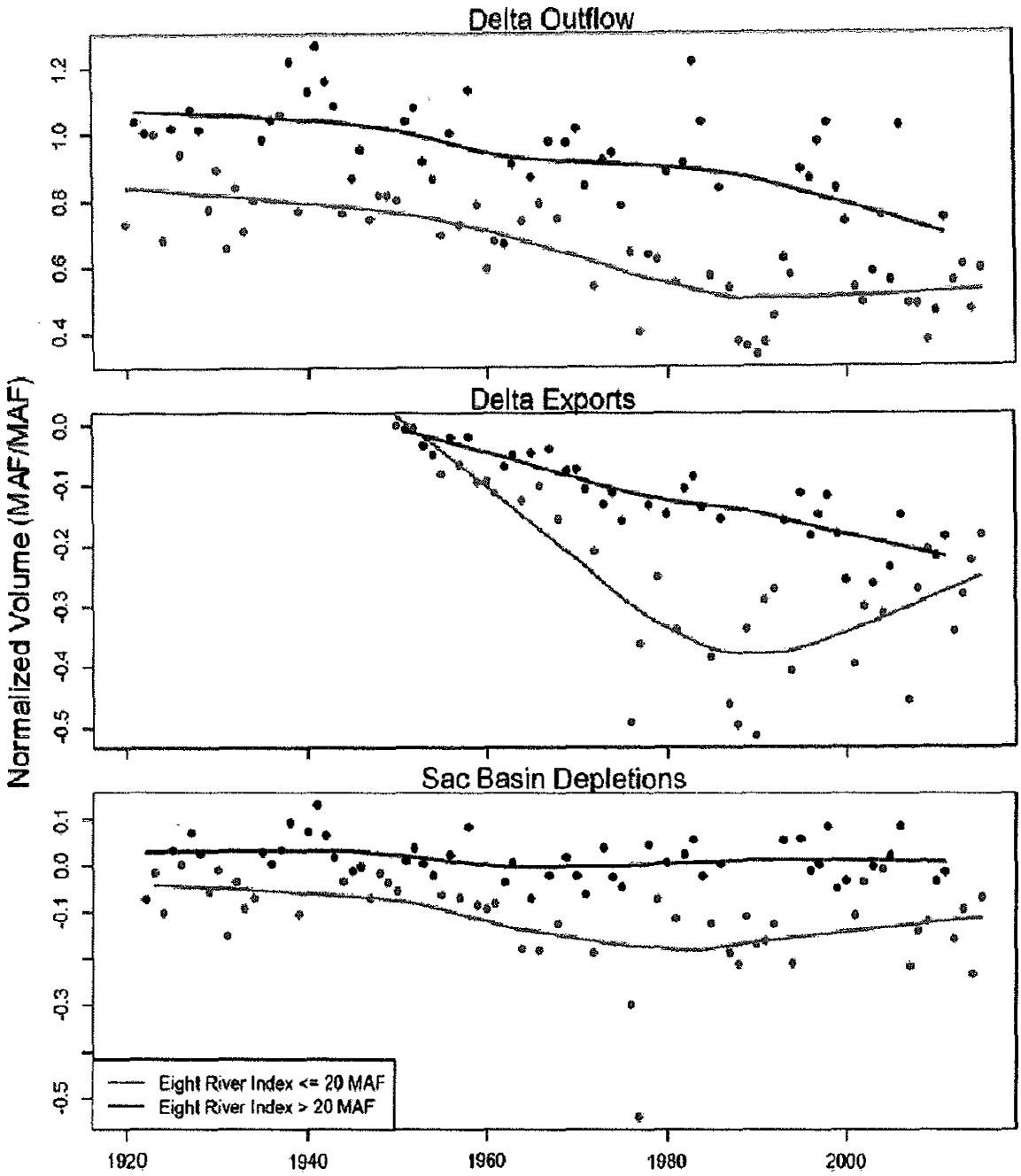

Figure 14. Time series (1922-2015) of statistical trend outputs of annual Delta outflow (top panel), Delta exports treated as depletions so increasing exports are represented by more negative values (middle panel), and water diversions from the Sacramento River basin upstream of the Delta (bottom panel). Black symbols and lines are for years in which the eight river index, a measure of water availability in the Bay-Delta watershed, was greater than 20 million acre-feet (MAF). Red symbols and lines are for years in which the eight river index was less than or equal to 20 MAF. Source: Hutton *et al.* (2017b).

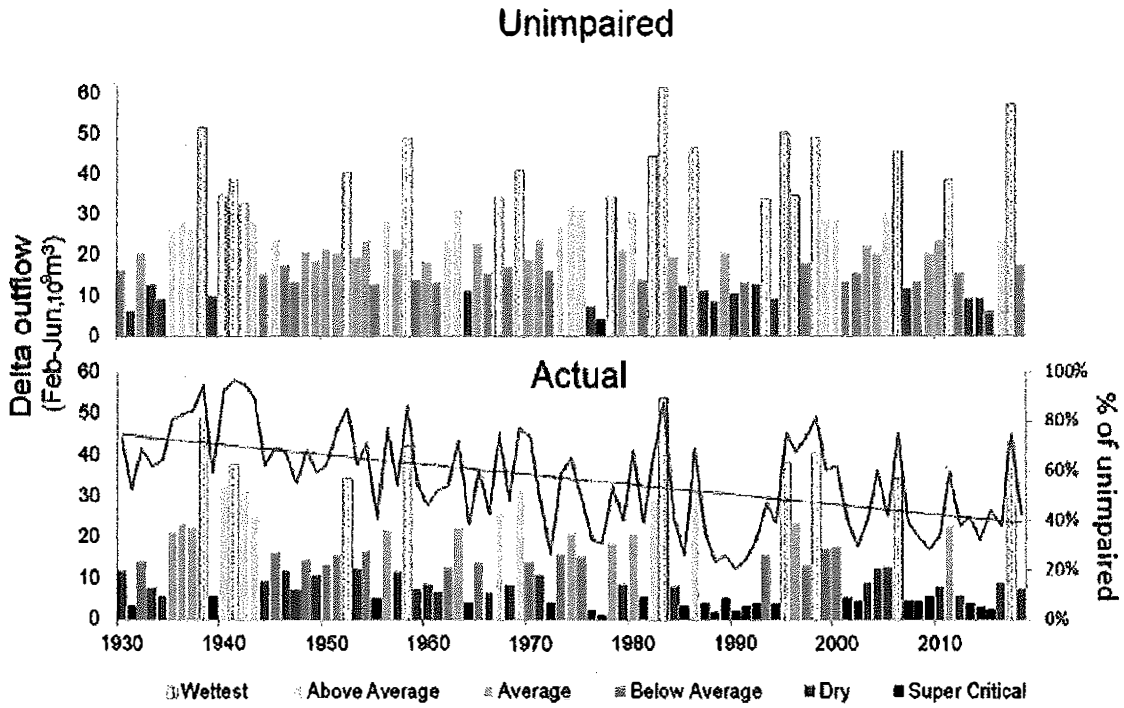

Figure 15. Time series of estimates of unimpaired (upper panel) and actual (lower panel) Delta outflow (February-June) color-coded according to six water year types, 1930-2018. The water year types based on basin precipitation are shown in the upper panel. In the lower panel, the water year types were re-assessed based on their fraction of the estimated unimpaired outflow. The long-term trend in this fraction as "% of unimpaired" is shown on the second y-axis of the bottom panel. Source: Reis *et al.* (2019).

Delta Smelt Population Trend

The CDFW's TNS (http://www.dfg.ca.gov/delta/data/townet/indices.asp?species=3) and FMWT Survey (http://www.dfg.ca.gov/delta/data/fmwt/indices.asp) are the two longest running indicators of the delta smelt's abundance trend. Indices of delta smelt relative abundance from these surveys date to 1959 and 1967, respectively (Figures 16 and 17). The FMWT index has traditionally been the primary indicator of delta smelt trend because it samples later in the life cycle, providing a better indicator of annual recruitment than the TNS (Service 1996). It has also sampled more consistently and more intensively than the TNS. The FMWT deploys more than 400 net tows per year over its four-month sampling season (September through December). The highest FMWT index for delta smelt (1,673) was recorded in 1970 and a comparably high index (1,654) was reported in 1980 (Figure 17). The last FMWT index exceeding 1,000 was reported in 1993. The last FMWT indices exceeding 100 were reported in 2003 and 2011. In 2018, the FMWT index was zero for the first time. The TNS index for delta smelt has been zero four times since 2015. Thus, the TNS and FMWT have recorded a 40-50 year decline in which delta smelt went from a minor (but common) species to essentially undetectable by these long-term surveys (Figures 16 and 17).

Following the listing of the delta smelt, the CDFW launched a 20-mm Survey (1995) and a SKT Survey (SKT; 2002) to monitor the distribution and relative abundance of late larval stage and

adult delta smelt, respectively. These newer indices have generally corroborated the trends implied by the TNS and the FMWT (Figures 16 and 17). The CDFW methods generate abundance indices from each survey but each index is on a different numeric scale. This means the index number generated by a given survey only has quantitative meaning relative to other indices generated by the same survey. Further, the CDFW indices lack estimates of uncertainty (variability) which limits interpretation of abundance changes from year to year even within each sampling program. The Service recently completed a new delta smelt abundance indexing procedure using data from all four of these surveys (Polansky *et al.* 2019). The Service method improves upon the CDFW method because it generates abundance indices in units of numbers of fish, including attempts to correct for different sampling efficiencies among surveys, and the method includes measures of uncertainty. Service indices of spawner abundance based on combined January and February SKT sampling are listed with their confidence intervals in Table 3. The estimates show the most recent 18 years of the delta smelt's longer-term decline in numbers of fish as best as they can be approximated with currently available information. The 2019 abundance estimate of 5,610 is the lowest on record, though the upper confidence limit for the 2019 estimate overlaps the lower confidence limits from 2016 and 2018. This indicates there is more than a five percent chance that the 2019 abundance index is not different from 2016 and 2018. Regardless of this recent year uncertainty, the 2019 abundance index is much lower than peak abundance estimates in Table 3 which themselves are all based on data streams that started after the species had already declined considerably (Figures 16 and 17).

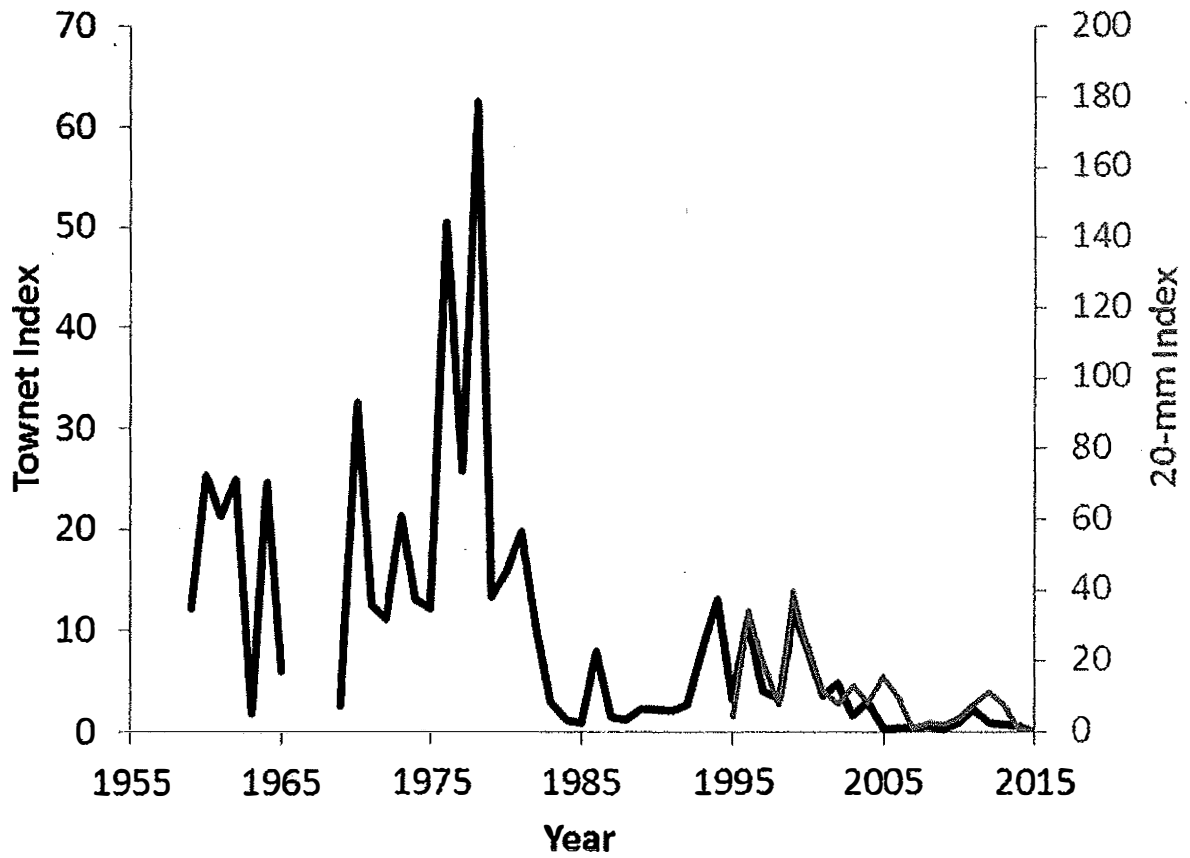

Figure 16. Time series of juvenile and larval delta smelt relative abundance as depicted by the California Department of Fish and Wildlife's Summer Townet Survey and 20-mm Survey, respectively. The townet survey began in 1959 and the 20-mm Survey began in

1995. The second y-axis was scaled to better align the indices which are calculated on different numeric scales.

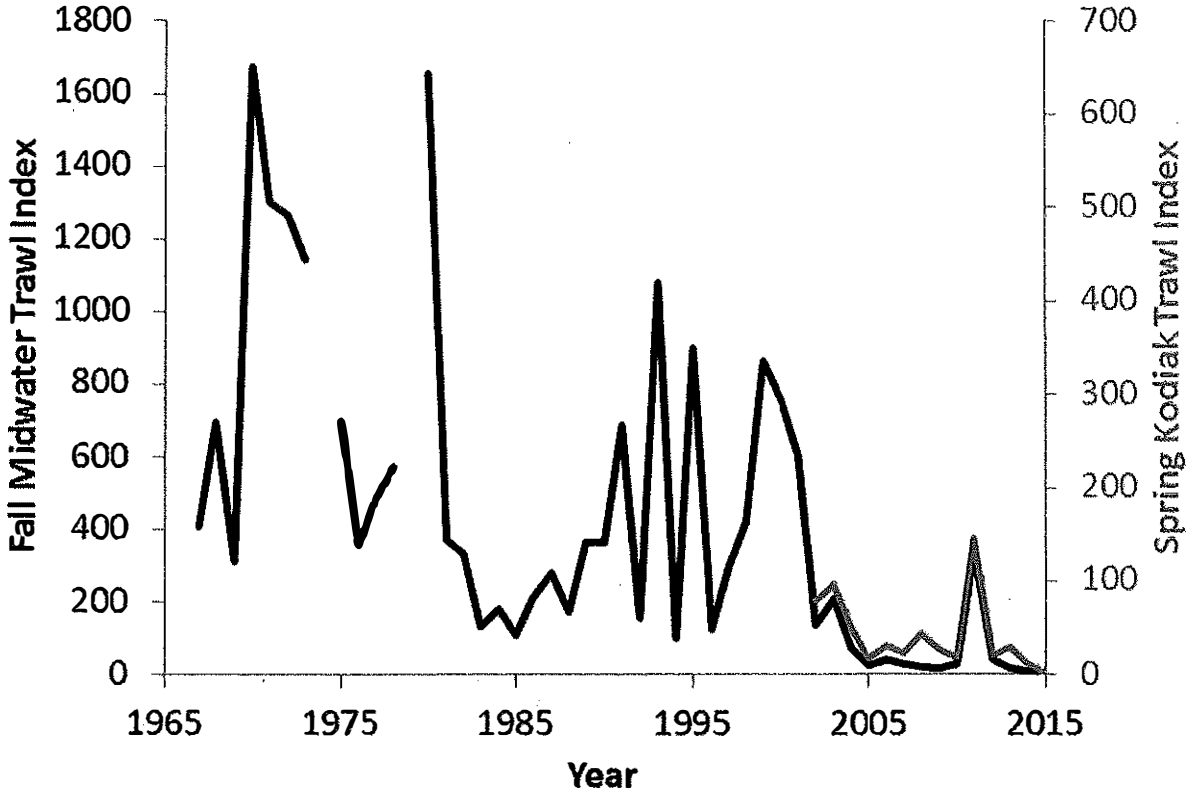

Figure 17. Time series of juvenile and larval delta smelt relative abundance as depicted by the California Department of Fish and Wildlife's Fall Midwater Trawl Survey and Spring Kodiak Trawl Survey, respectively. The midwater trawl survey began in 1967 and the Kodiak trawl survey began in 2002. The second y-axis was scaled to better align the indices which are calculated on different numeric scales.

Table 3. Estimates of adult delta smelt population size during January-February of 2002 through 2019 with 95% confidence intervals.

			95% Confidence Interval		Number of Delta Smelt Caught in the SKT Survey		
Year	Abundance Estimate	Standard Error	Lower Bound	Upper Bound	January	February	Year-to-Year Ratio
2002	1,093,244	195,329	760,332	1,523,294	262	394	NA
2003	996,055	261,205	581,197	1,597,198	NA	232	0.91
2004	966,981	262,190	553,729	1,573,002	380	300	0.97
2005	715,858	147,190	470,572	1,044,828	220	218	0.74
2006	272,327	42,400	198,681	364,438	44	84	0.38
2007	449,466	128,731	249,216	749,168	109	107	1.65
2008	509,428	188,396	236,859	963,839	132	36	1.13
2009	1,166,145	523,856	459,083	2,464,804	579	61	2.29
2010	251,863	54,580	161,753	374,582	88	57	0.22
2011	461,599	202,547	185,712	962,088	177	128	1.83
2012	1,177,201	328,682	662,728	1,939,836	320	287	2.55
2013	333,682	89,809	191,886	541,064	100	125	0.28
2014	308,972	91,474	167,858	522,884	148	55	0.93
2015	213,345	76,639	101,434	397,439	21	68	0.69
2016	25,445	9,584	11,661	48,622	7	6	0.12
2017	73,331	23,342	38,010	128,459	18	8	2.88
2018	26,649	21,397	5,215	82,805	10	4	0.36
2019	5,610	4,395	1,138	17,135	1	1	0.21

Climate Change

Climate projections for the San Francisco Bay-Delta and its watershed indicate that changes will be substantial by mid-century and considerable by the year 2100. Climate models broadly agree that average annual air temperatures will rise by about 2°C at mid-century and about 4°C by 2100 if current atmospheric carbon emissions accelerate as currently forecasted (Dettinger *et al.* 2016). It remains highly uncertain whether annual precipitation in the Bay-Delta watershed will trend wetter or drier (Dettinger 2005; Dettinger *et al.* 2016). The warmer air temperature projections suggest more precipitation will fall as rain rather than snow and that storms may increase in intensity, but will have more dry weather in between them (Knowles and Cayan 2002; Dettinger 2005; Dettinger *et al.* 2016). The expected consequences are less water stored in spring snowpacks, increased flooding and an associated decrease in runoff for the remainder of the year (Hayhoe *et al.* 2004). Changes in storm tracks may lead to increased frequency of flood and drought cycles during the 21st century (Dettinger *et al.* 2015).

As of 2009, sea level rise had not had much effect on X2 (Hutton *et al.* 2017b). However, additional sea level rise is another anticipated consequence of a warming global climate and if it

is not mitigated, sea level rise will likely increase saltwater intrusion into the Bay-Delta (Rath *et al.* 2017). During the summer of 2015, variation in sea level interacted with very low Delta inflows to cause frequent recurrence of net negative Delta outflow (Monismith 2016).

Since the early 1980s, climate change is thought to have increased wind speed along the central California coast, resulting in a more frequent and longer lasting upwelling season (Garcia-Reyes and Largier 2010). Coastal upwelling causes colder deep water to rise to the ocean surface, bringing with it nutrients that stimulate the coastal food web. One effect of wind blowing over the estuary is that it resuspends sediment deposited in shallow areas like San Pablo Bay, Grizzly Bay, and Honker Bay (Ruhl *et al.* 2001). Thus, higher wind speeds blowing onto the coast might be expected to result in higher turbidity of the water in parts of the estuary. In contrast to this expectation, Bever *et al.* (2018) reported a recent reduction in wind speed over the Bay-Delta during 1995-2015, which these authors associated with lower turbidity in Suisun Bay. The Service notes these contrasting results for completeness but we cannot reconcile these opposing trends in wind speed at this time. We show below that Secchi disk depth (an indicator of water turbidity) have not increased since the mid-1980s near the (mobile) location of X2 even though suspended sediment concentrations in Suisun Bay have decreased since about 2000 (Schoellhamer 2011; Bever *et al.* 2018).

Central California's warm summers are already a source of energetic stress for delta smelt and warm springs can already severely compress the duration of their spawning season (Rose *et al.* 2013a,b). We expect warmer estuary temperatures to present a significant conservation challenge for delta smelt in the coming decades (Brown *et al.* 2013; 2016a; Figure 18). Feyrer *et al.* (2011) and Brown *et al.* (2013; 2016a) have evaluated the anticipated effects of projected climate change on several delta smelt habitat metrics. Collectively, these studies indicate the future will bring chronically compressed fall habitat, fewer 'good' turbidity days (defined by the authors as a mean turbidity greater than or equal to 18 Nephelometric Turbidity Units (NTU)), a spawning window of similar duration but that is shifted 2 to 3 weeks earlier in the year, and a substantial increase in the number of days delta smelt will need to endure lethal or near lethal summer water temperatures.

The delta smelt lives at the southern limit of the inland distribution of the family Osmeridae along the Pacific coast of North America. The anticipated effects of a warming climate are expected to create increasing temperature related challenges for delta smelt at some future point. The amount of anticipated change to the regional climate expected in the near term is lower than it is for the latter half of the century (Figure 18). Therefore, it is less certain that any measurable change from current conditions will occur in the next approximately 10 years than by 2050 or 2100. For the time being, water temperatures are stressful to delta smelt, but not of themselves lethal in most of the upper estuary (Komoroske *et al.* 2015).

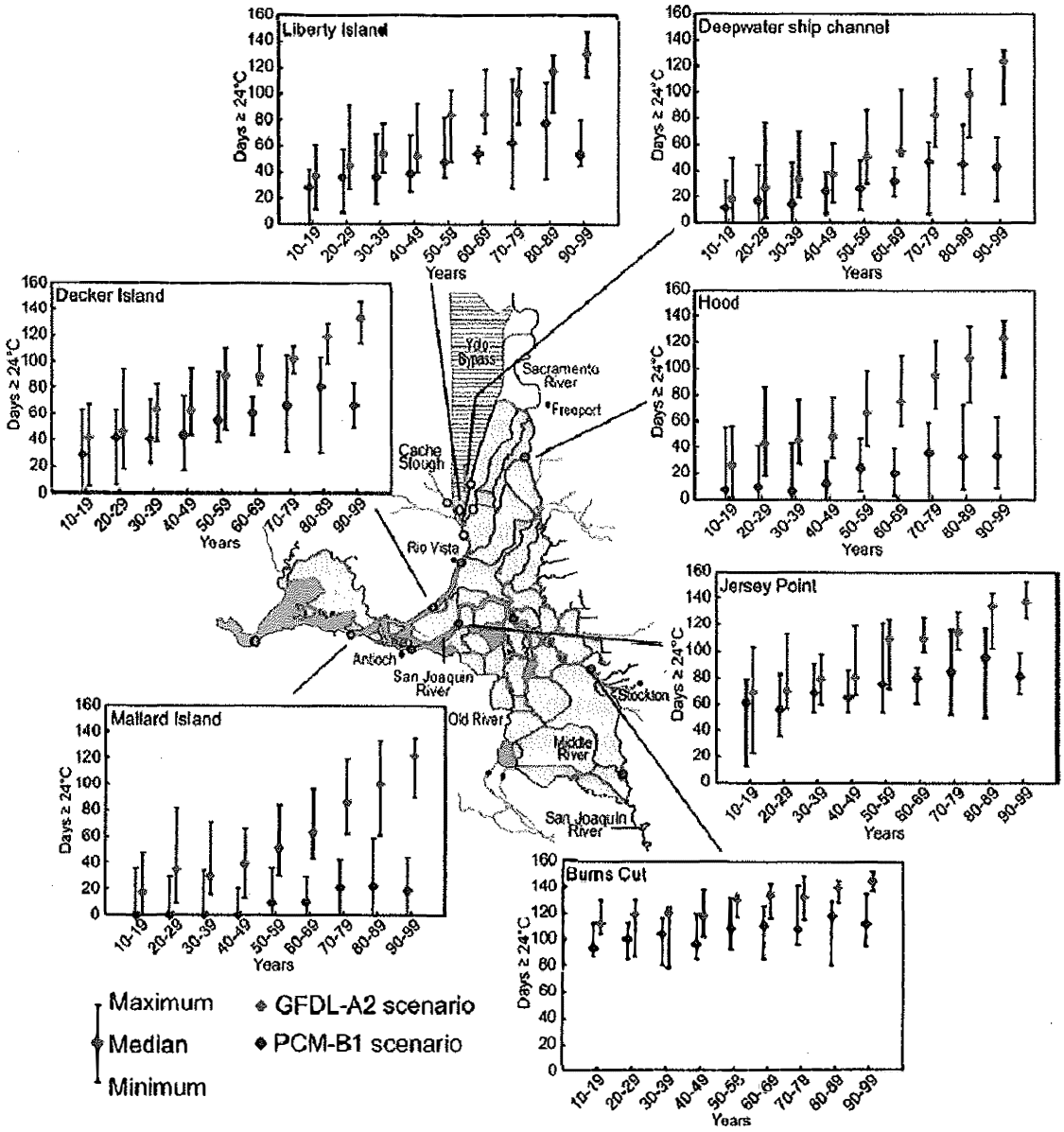

Figure 18. Plots of median, maximum, and minimum number of days each year with an estimated average daily water temperature greater than or equal to 24°C (75°F) at selected sites in the Delta by decade for the 21st century. The water temperature threshold reflects one chosen by the authors to represent near lethal conditions for delta smelt. Source: Brown *et al.* (2016a).

Recovery and Management

Following Moyle *et al.* (1992), the Service (1993) indicated that SWP and CVP exports were the primary factors contributing to the decline of delta smelt due to entrainment of larvae and juveniles and the effects of low flow on the location and function of the estuary mixing zone (now called the low-salinity zone). In addition, prolonged drought during 1987-1992, in-Delta water diversions, reduction in food supplies by nonindigenous aquatic species (specifically overbite clam and nonnative copepods), and toxicity due to agricultural and industrial chemicals were also factors considered to be threatening the delta smelt. In the Service's December 15,

2008 *Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP)* (2008 BiOp), the Reasonable and Prudent Alternative (RPA) required protection of all life stages from entrainment and augmentation of Delta outflow during the fall of Wet and Above-Normal years as classified by the State of California (Service 2008). The expansion of entrainment protection for delta smelt in the 2008 BiOp was in response to large increases in juvenile and adult salvage in the early 2000s (Kimmerer 2008; Brown *et al.* 2009). The fall X2 requirement in the 2008 RPA was in response to increased fall exports that had reduced variability in Delta outflow and lowered habitat suitability during the fall months and the 2008 proposed action was anticipated to reduce it further (Feyrer *et al.* 2011).

The Service's (2010c) recommendation to uplist delta smelt from threatened to endangered included a discussion of threats related to reservoir operations and water diversions upstream of the estuary as additional water operations mechanisms interacting with exports from the Delta to restrict the LSZ and concentrate delta smelt with competing and predatory fish species. In addition, Brazilian waterweed (*Egeria densa*) and increasing water transparency were considered new detrimental habitat changes. Predation was considered a low-level threat linked to increasing waterweed abundance and increasing water transparency. Additional threats considered potentially significant by the Service in 2010 were entrainment into power plant diversions, contaminants, and reproductive problems that can stem from small population sizes. Conservation recommendations included: establish Delta outflows proportionate to unimpaired flows to set outflow targets as fractions of runoff in the Central Valley watersheds; minimize reverse flows in Old and Middle rivers; and, establish a genetic management plan for captive-reared delta smelt with the goals of minimizing the loss of genetic diversity and limiting risk of extinction caused by unpredictable catastrophic events. The Service (2012) recently added climate change to the list of threats to the delta smelt.

Maintaining protection of the delta smelt from excessive entrainment, improving the estuary's flow regime, suppression of nonnative species, increasing zooplankton abundance, and improving water quality are among the actions the Service has previously indicated are needed to recover the delta smelt.

There have been several recent papers suggesting it is time to consider supplementation of the wild delta smelt population with captive-bred fish as part of a broad-based conservation strategy to avoid extinction in the wild, also known as extirpation (Moyle *et al.* 2016; 2018; Hobbs *et al.* 2017; Lessard *et al.* 2018). This year, pilot research conducted by the California Department of Water Resources (DWR) has demonstrated that captive-bred delta smelt held within steel enclosures can survive in the Delta for at least 30 days. This is long enough to show that the fish can feed themselves and did not die from acute water toxicity in either of two locations tested thus far. The fish will be evaluated for chronic toxic exposure, but that work is not finished. These results are promising and similar research is planned for later this year and next.

The status of the delta smelt is poor. The current estimated delta smelt population sizes are so low that it seems unlikely the species can be habitat- or food-limited even though both physical and food web-related habitat attributes have degraded over time. It is more likely that delta smelt have been marginalized by non-native fishes and invertebrates that compete with and prey on them. When fish populations reach very low levels, they can fall victim to demographic problems (often termed Allee effects in the scientific literature). These include problems

concentrating enough individuals in particular locations for successful spawning, successful feeding, or maintaining large enough egg supplies, or shoals and schools of juvenile and adult fish to provide effective protection from predators (Liermann and Hilborn 2001; Keith and Hutchings 2012).

Summary of the Status of Delta Smelt

The relative abundance of delta smelt has reached very low numbers for a small forage fish in an ecosystem the size of the Bay-Delta and the species is approaching extinction in the wild (Moyle *et al.* 2016; 2018; Hobbs *et al.* 2017). The extremely low 2018-2019 abundance indices reflect decades of habitat change and marginalization by non-native species that prey on and out-compete delta smelt. The anticipated effects of climate change on the Bay-Delta and its watershed such as warmer water temperatures, greater salinity intrusion, lower snowpack contribution to spring outflow, and the potential for frequent extreme drought, indicate challenges to delta smelt survival will increase.

Environmental Baseline

Environmental baseline refers to the condition of the listed species or its designated critical habitat in the Action Area, without the consequences to the listed species or designated critical habitat caused by the proposed action. The environmental baseline includes the past and present impacts of all Federal, State, or private actions and other human activities in the Action Area, the anticipated impacts of all proposed Federal projects in the Action Area that have already undergone formal or early section 7 consultation, and the impact of State or private actions which are contemporaneous with the consultation in process. The consequences to listed species or designated critical habitat from ongoing agency activities or existing agency facilities that are not within the agency's discretion to modify are part of the environmental baseline.

MOTCO

MOTCO is located on Suisun Bay, 30 miles northeast of San Francisco, in Contra Costa County. MOTCO's infrastructure was constructed by the U.S. Navy beginning in WWII and operated as a Navy installation. The U.S. Army MOTCO began operations in 1997. Under a Base Realignment and Closure (BRAC) process, the installation was transferred to the Army in 2008. This installation is the primary West Coast common-user transshipment terminal, home to the SDDC's 834th Transportation Battalion.

The MOTCO installation accounts for 72% of the Army's West Coast ammunition handling and approximately 25% of the nation's total ammunition throughput capability. The U.S. Navy dredged the piers, pier navigation approach, and the South Seal Island Channel on average every two years from 1943 through 1981. More than 1.8 million cubic yards was dredged over this time period averaging 87,000 cubic yards per dredge event. Since 1981, additional dredging events are documented from 1986 and 1994. MOTCO does not have any documentation of dredge events between 1994 and 2008. Dredging has not occurred since the Army assumed the

property in 2008 at the conclusion of the Base Realignment and Closure process. Sediment accumulation around the piers has resulted in sediment elevations above the proposed depth of 35 feet (MLLW) at Piers 2-4, and 20 feet (MLLW) at the Barge Pier, and is currently impacting military operations by restricting the times that the MOTCO piers can be used. Dredged material from MOTCO was historically placed on upland levee sites and infrequently at the Carquinez Straight (SF-9) and Suisun Bay disposal sites (SF-16).

On February 4, 2015, the Service issued a biological opinion for the modernization and repair of Piers 2 and 3 which included maintenance dredging (Service file number 08FBTD00-2014-F-0002-5). Dredging was not actually conducted during pier modernization and the Army, per the September 18, 2019 conference call, discussed withdrawing dredging from the previous consultation in order to consult on this broader maintenance dredging program.

Dredged Material Placement Sites

The MWRP is a privately-owned restoration project located on the eastern edge of Suisun Marsh, north of the confluence of the Sacramento and San Joaquin Rivers near the town of Collinsville, in Solano County. A detailed description of the restoration activities and associated impacts to special status species and critical habitat are fully described in the Montezuma Wetland Restoration Project's biological opinions (Service file numbers: 1-1-99-F-12; 1-1-02-F-0175 and 1-1-04-F-0270). Approximately 17.5 million cubic yards of dredged material are needed to raise site elevations. As of August 2017, approximately 4 million cy of dredged material have been placed at Montezuma Wetlands, contributing to the restoration of over 350 acres of wetlands (https://www.waterboards.ca.gov/sanfranciscobay/water_issues/programs/dredging.html).

The CRRP is located along the northern shoreline of San Pablo Bay near the city of Vallejo in Solano and Napa Counties. A detailed description of the restoration activities and associated impacts to special status species and critical habitat are fully described in the May 7, 2010 intra-Service biological opinion (Service file number: SFB-1010-01; TAILS number: 81420-2010-F-0182). In 2014, regulatory permits were revised to increase the volume of dredged sediment authorized for placement in support of tidal marsh habitat restoration at Cullinan Ranch (DMMO 2015 as cited in the BA). Specifically, the amount was increased from 450,000 cy to restore 50 acres to 2.8 million cy to restore 290 acres of the 1,575-acre site to elevations suitable for marsh plain establishment. As of December 2017, approximately 800,000 cy had been placed at Cullinan Ranch (Ducks Unlimited 2017 as cited in the BA), leaving a remaining capacity of approximately 2 million cy.

The ADNWR is an approximately 55-acre refuge managed by the Service that consists of two parcels separated by a Georgia-Pacific Gypsum Plant and a Pacific Gas & Electric utility easement. The refuge was founded in 1980 and is located along the shoreline of the San Joaquin River in Antioch, California. The western parcel, the 41- acre Stamm Unit, is the only unit proposed to receive dredge sediment for this project. The ADNWR is located about 12 miles east of MOTCO. As part of the Comprehensive Conservation Plan (CCP) for the ADNWR, dune restoration is one of the primary objectives for habitat restoration (Service 2002) and described in the intra-Service biological opinion for the CCP (Service file number: 1-1-01-F-291). Beginning in 1991, the Service has imported sand to the ADNWR in order to create additional habitat. The CCP specifies identifying potential sources of clean sand, specifically from the

Stockton DWSC, and importing the sand for habitat restoration. Due to the sandy substratum in the areas surrounding Antioch Dunes, the shoaling that typically occurs in this section of the San Joaquin River is sand. In 2013, the Port of Stockton and the Service at Antioch Dunes partnered with the U.S. Army Corps of Engineers (Corps) to begin restoration efforts using dredged material. This site was used as a DMPS in 2013, 2015, and is planned to be used in 2019 and is consistent with the intent of the CCP and the biological opinion on the CCP.

The SF-9 placement site is a 1,000-foot by 2,000-foot rectangle, approximately 10 to 55 feet deep, 0.9 miles west of the entrance to Mare Island Strait in eastern San Pablo Bay in Solano County (Figure 5). Disposal is limited to 1 million cy of dredged material per month and a maximum of 3 million cy per year during wet or above-normal water flow years, and 2 million cy per year during all other years.

The SF-16 placement site is a single-user, in-Bay, unconfined disposal site reserved for sand dredged from the Suisun Channel and New York Slough projects only. SF-16 is a 500-foot by 11,200-foot rectangle adjacent to the northern side of Suisun Bay Channel, approximately 1 mile upstream of the Interstate 680 Bridge (Figure 5). The depth at this site is approximately 30 feet MLLW. Currently, the site is authorized to receive 200,000 cy of dredged sand per year.

Delta Smelt

The project occurs within Suisun Bay within the range of delta smelt. Delta smelt are located in the Suisun Bay year-round and are known to utilize the action area as habitat. The project also occurs within the low salinity zone (LSZ) where smelt are known to rear, feed and breed. The Suisun Bay and the Confluence of the Sacramento and San Joaquin Rivers are considered critical areas within delta smelt habitat and the San Francisco Bay Estuary for the survival of this species. Delta smelt are often observed in the highest densities in these areas (Merz *et al.* 2011).

As detailed in the *Status of the Species* section of this biological opinion, the delta smelt abundance is at its historical low. The latest surveys to detect delta smelt within Suisun Bay were the Service's Enhanced Delta Smelt Monitoring Survey, which encountered delta smelt this December. These studies monitor the juvenile and adult delta smelt distribution and relative abundance throughout their historical spring range in the Sacramento-San Joaquin Delta and San Francisco Estuary. It can be anticipated that delta smelt will be in the juvenile and subadult lifestages and located in the Action Area during the duration of the proposed project.

Bever *et al.* (2016) combined long-term fish sampling data from the Suisun Bay and a detailed three-dimensional hydrodynamic modeling to investigate the relationship between historical fish catch and hydrodynamic complexity of the Suisun Bay. They concluded that delta smelt presence (i.e., delta smelt caught in the FMWT) during wetter years, in this area, overlaps with the regions of low salinity, low maximum velocity, and high turbidity. While Bever *et al.* (2016) concluded that the high maximum velocity of the navigation channels reduced the likelihood of delta smelt presence, it also demonstrated that delta smelt presence increases from west to east in the navigation channel. Thus, in low outflow years delta smelt are concentrated above the confluence of the Sacramento and San Joaquin rivers, whereas in higher outflow years the distribution extends through Suisun Bay (Sweetnam 1999; Adib-Samii 2011).

Effects of the Action

Effects of the Action are all consequences to listed species or critical habitat that are caused by the proposed action, including the consequences of other activities that are caused by the proposed action. A consequence is caused by the proposed action if it would not occur but for the proposed action and it is reasonably certain to occur. Effects of the action may occur later in time and may include consequences occurring outside the immediate area involved in the action.

The proposed maintenance dredging of the MOTCO piers is likely to result in adverse effects to delta smelt in the Action Area by interfering with feeding, movement, and/or other essential behaviors. To minimize adverse effects of the proposed project, the Army has proposed to complete the work during the Service's recommended in-water work window for delta smelt. This scheduling will reduce the likelihood that life stages other than juveniles and adults will be present during the proposed project activities.

Direct Contact with Dredging Equipment

Delta smelt have the potential to be injured by the dredging equipment. The most likely cause of injury would be from the clamshell bucket falling through the water column until reaching the substrate. However, as the mechanical clamshell bucket travels though the water column, it is expected to generate a pressure wave which would likely force small fish away and avoiding contact. General disturbance from barges, dredging crew and tugs is expected to disturb delta smelt in the surrounding area and likely cause the fish to exhibit a startled response, followed by escapement from the area.

Entrainment

The entrainment of aquatic organisms is possible with a mechanical clamshell dredge. As the bucket of a mechanical clamshell dredge collects material from the bottom, aquatic organisms can be physically collected within the water and sediment material. However, mechanical clamshell dredging is considered to have a very low risk of fish entrainment, typically the lowest of all dredge types (Corps DOER 1998). Again, general disturbance from barges, dredging crew and tugs is expected to disturb any delta smelt in the surrounding area and likely cause the fish to exhibit a startled response, followed by escapement from the area.

Increased Hydroacoustics

Mechanical clamshell dredge equipment and associated dredge actions generate underwater noise and sound pressure waves that may adversely affect delta smelt. Underwater sound pressure waves can harass and harm fish species (Reyff 2003; Abbott and Bing-Sawyer 2002; California Department of Transportation 2001; Longmuir and Lively 2001; Stotz and Colby 2001). As the pressure wave passes through a fish, the swim bladder is rapidly squeezed due to the high pressure, and then rapidly expanded as the under-pressure component of the wave passes through the fish. This can cause adverse effects including: rupture of the swim bladder, rupture of capillaries, internal hemorrhage, neurological stress, and auditory damage. Extreme sound waves can cause instantaneous death, latent death within minutes after exposure, or can occur several days later. Increase in sound waves can also result in reduced fitness of fish; making it susceptible to predation, disease, starvation, or inability to complete its life cycle.

To quantify the level of sound expected to cause harm, the Fisheries Hydroacoustic Working Group, an interagency working group that includes the Service, established interim criteria for evaluating underwater noise impacts from pile driving on fish. These criteria are defined in the document entitled "*Agreement in Principal for Interim Criteria for Injury to Fish from Pile Driving Activities*", dated June 12, 2008 (Fisheries Hydroacoustic Working Group 2008). This agreement identifies a peak sound pressure level (SPLs) of 206 decibels (dB) and an accumulated sound exposure level of 187 dB as thresholds for injury to fish ≥ to 2 grams (g). For fish less than 2 g, the accumulated sound exposure level threshold is reduced to 183 dB. Although there has been no formal agreement on a "behavioral" threshold, National Marine Fisheries Service (NMFS) uses 150 dB-root mean square (rms) as the threshold for adverse behavioral effects (NMFS 2009). Even though the above criteria were developed for pile driving, and the proposed action is dredging, it provides a reasonable means to analyze the expected increase in underwater sound pressures waves to the species.

The noise from a clamshell dredge is punctuated by its entry into the water, contact with bottom substrate and the closing of the jaws of the clamshell. There are also periods of quiet between the events when the clamshell enters the water. In 2001, the Corps' Engineer and Research Development Center prepared an analysis of increased SPLs produced by clamshell dredging in Cook Inlet, Alaska. In that analysis, the most extreme peak SPLs (dB rms) was produced by the dredge bucket striking the channel bottom in mixed coarse sand and/or gravel. Peak sound pressures levels measured during mechanical dredging have been recorded at 124 dB from 150 meters away (Dickerson *et al.* 2001). Ambient noise conditions, in the Action Area during the proposed work window, are comprised primarily of commercial and military ship traffic, wind and wave turbulence, and hydrodynamic noise associated with variable tidal flow condition. The ambient noise conditions in the Action Area are expected to be similar to that of Cook Inlet Alaska, ergo the peak SPLs at 150 meters are expected to be higher than ambient. The proposed project is expected to produce peak SPLs of 124 dB as determined in the Cook Inlet study, which is below all of the thresholds described above. Therefore, the noise from the proposed project is not expected to adversely affect listed species greater than 150 meters from the clamshell dredge plant. Effects on fish closer than 150 meters are unclear, but likely to involve behavioral avoidance of the area.

Increased Suspended Sediment

The proposed project could produce increased suspended sediments, otherwise known as turbidity, in the Action Area from clamshell dredging operations and placement of spoils at the disposal site. A sediment plume results from excess sediment and other material entrained (e.g. air bubbles) being discharged back into the water during operations. Plumes typically have an increased suspended sediment concentration, thus elevated turbidity. The degree of sediment resuspension depends on the material, size and composition of the sediment being resuspended. Plume size, concentration, and duration of the plume depend on environmental and operational specific factors. The materials removed from the Federal navigation channel in Suisun Bay have historically been approximately 90 percent sand.

During clamshell dredging, sediments may become suspended because of the clamshell bucket's impact to the channel bottom, material washing from the top and side of the bucket as it passes through the water column, sediment spillage as it breaks the water surface, spillage of material

during barge loading, and intentional overflow in an attempt to increase the barge's effective load which is only permissible for material that is 90 percent or more sand. Finally, placement of dredged materials at the in-Bay disposal sites (i.e., SF-9 and SF-16), will result in resuspended sediments in the water column.

Exposure to excessive suspended sediment concentrations could lead to physiological stresses such as clogged gills, eroded gill and epithelial tissues, impaired foraging activity and feeding success, and altered movement and migration patterns of juvenile and adult fish (Clarke and Wilber 2000; Newcombe and Jensen 1996; Newcombe and MacDonald 1991). Exposure of fish to elevated suspended sediment concentrations could result in behavioral avoidance and exclusion from otherwise suitable habitat, disrupt movement and migration patterns, reduce feeding rates and growth, result in sublethal and lethal physiological stress, habitat degradation, or delayed hatching; and, under severe circumstances, could result in mortality (Newcombe and Jensen 1996; Clarke and Wilber 2000). The response of fish to suspended sediments varies among species and lifestages as a function of suspended particle size, particle shape, water velocities, suspended sediment concentrations, water temperature, depressed dissolved oxygen concentrations, contaminants, and exposure duration (O'Connor 1991; Sherk 1971; Newcombe and Jensen 1996). Short-duration exposure to associated elevated suspended sediment concentration could result in sublethal effects; however, potential exposure and dosage of suspended sediment concentrations drops exponentially from the source of the plume.

The Corps have stated that sediment plumes from the sandy material dredging operations are temporary in nature and typically disperse within the same day of activity. The range of the increased turbidity is expected to be approximately 200 feet from dredging operations and spoil placement in all directions. The Corps studies have shown turbidity plumes at placement sites last only 20 minutes, and plume duration is even less during placement of sandy material due to coarse sediments settling out of the water column more quickly than fine sediments (Corps 1976; LTMS 1998; Anchor Environmental 2003).

While adult delta smelt already live in an environment with high background levels of turbidity and increased turbidity generally correlates with higher abundance of delta smelt (Feyrer *et al.* 2007; Nobriga *et al.* 2008), it is possible that excessive sedimentation may exceed turbidity levels ideal for delta smelt. If juvenile or adult delta smelt were present within the plume, the behavioral avoidance response of this life stage is expected to substantially reduce or eliminate the risk of lethal or sublethal exposure the farther they are from the plume source.

Removal and Smothering of Benthic Organisms

Dredging of the Suisun Bay Channel will result in removal of benthic organisms from the bottom of the channels. Sediment disposal at in-bay disposal site SF-16 will cover benthic organisms and benthic habitat with dredged material at the floor of the disposal site possibly reducing food availability for delta smelt near the disposal areas. It is not clear how quickly benthic species in the project area will re-colonize the channel bed between dredging episodes.

Cumulative Effects

Cumulative effects include the effects of future State, Tribal, local, or private actions that are reasonably certain to occur in the Action Area considered in this biological opinion. Future Federal actions that are unrelated to the proposed action are not considered in this section because they require separate consultation pursuant to section 7 of the Act.

Adverse effects to delta smelt may result from point and non-point source chemical contaminant discharges within the Action Area. These contaminants include, but are not limited to, ammonia and free ammonium ion, numerous pesticides and herbicides from agricultural activities, and oil and gasoline product discharges. Oil and gasoline product discharges may be introduced into Delta waterways from shipping and boating activities and from urban activities and runoff. Implicated as potential stressors of delta smelt, these contaminants may adversely affect fish reproductive success and survival rates.

Conclusion

After reviewing the current status of the delta smelt, the environmental baseline for the Action Area, the effects of the proposed project, and the cumulative effects, it is the Service's biological opinion that the Proposed Maintenance Dredging at Military Ocean Terminal Concord Project, as proposed, is not likely to jeopardize the continued existence of the delta smelt. The Service reached this conclusion because the project-related effects to the species, when added to the environmental baseline and analyzed in consideration of all potential cumulative effects, will not rise to the level of reducing the likelihood of survival or recovery of the species based on the following: (1) implementation of the conservation measure proposed to minimize adverse effects to delta smelt and (2) the low number of individuals subject to mortality with the mechanical clamshell dredging method.

INCIDENTAL TAKE STATEMENT

Section 9 of the Act and Federal regulation pursuant to section 4(d) of the Act prohibit the take of endangered and threatened species, respectively, without special exemption. Take is defined as to harass, harm, pursue, hunt, shoot, wound, kill, trap, capture or collect, or to attempt to engage in any such conduct. Harass is defined by Service regulations at 50 CFR 17.3 as an intentional or negligent act or omission which creates the likelihood of injury to wildlife by annoying it to such an extent as to significantly disrupt normal behavior patterns which include, but are not limited to, breeding, feeding, or sheltering. Harm is defined by the same regulations as an act which actually kills or injures wildlife. Harm is further defined to include significant habitat modification or degradation that results in death or injury to listed species by significantly impairing essential behavior patterns, including breeding, feeding, or sheltering. Incidental take is defined as take that is incidental to, and not the purpose of, the carrying out of an otherwise lawful activity. Under the terms of section 7(b)(4) and section 7(o)(2), taking that is incidental to and not intended as part of the agency action is not considered to be prohibited taking under the Act provided that such taking is in compliance with the terms and conditions of this Incidental Take Statement.

The measures described below are non-discretionary, and must be undertaken by the Army so that they become binding conditions of any grant or permit issued to the applicant, as appropriate, for the exemption in section 7(o)(2) to apply. The Army has a continuing duty to regulate the activity covered by this incidental take statement. If the Army (1) fails to assume and implement the terms and conditions or (2) fails to require the applicant to adhere to the terms and conditions of the incidental take statement through enforceable terms that are added to the permit or grant document, the protective coverage of section 7(o)(2) may lapse. In order to monitor the impact of incidental take, the Army must report the progress of the action and its impact on the species to the Service as specified in the incidental take statement [50 CFR §402.14(i)(3)].

Amount or Extent of Take

The Service expects that incidental take of delta smelt will be difficult to detect or quantify for the following reasons: the small size of juveniles and adults, their turbid aquatic habitat makes them difficult to detect, and the low likelihood of finding dead or impaired specimens. The Service anticipates that the extent of incidental take will be minimized due to the proposed conservation measure as described in this biological opinion and the use of clamshell dredge equipment instead of suction dredging equipment. Due to the difficulty in quantifying the number of delta smelt that will be taken as a result of the proposed action, the number of acres of affected habitat becomes a surrogate for the species that will be taken. The Service anticipates that all individual juvenile and adult delta smelt in the 38 acres of the Action Area may be subject to incidental take in the form of harm, wound, and kill, annually between 2020-2030 as described in this biological opinion. However, the Service believes that actual take in these forms will be minimal with the use of clamshell dredging equipment.

Upon implementation of the following reasonable and prudent measure, incidental take of the delta smelt resulting from the Proposed Maintenance Dredging at Military Ocean Terminal Concord Project in the form of harm, wound, or kill within the project area will become exempt from the prohibitions described under section 9 of the Act. No other forms of take are exempted under this opinion.

Effect of the Take

In the accompanying biological opinion, the Service determined that this level of anticipated take is not likely to result in jeopardy to the delta smelt.

Reasonable and Prudent Measure

The following reasonable and prudent measures are necessary and appropriate to minimize the effects of the Proposed Maintenance Dredging at Military Ocean Terminal Concord Project to the delta smelt:

1. The Army shall ensure that adverse effects to the delta smelt are minimized.

Terms and Conditions

In order to be exempt from the prohibitions of section 9 of the Act, the Army shall comply with the following terms and conditions, which implement the reasonable and prudent measures described above. These terms and conditions are non-discretionary.

1. The following Terms and Conditions implement Reasonable and Prudent Measure Number One (1):

    a. The Army shall minimize the potential for harm of delta smelt resulting from project related activities by implementation of the *Conservation Measure* as described in the *Description of the Proposed Action* in this biological opinion.

    b. The Army shall ensure that the contractors or operators of dredging equipment comply with this biological opinion. The Corps shall educate and inform contractors involved in the project as to the *Conservation Measure* and *Terms and Conditions* in this biological opinion.

    c. The Army shall provide the Service with a final report for the Proposed Maintenance Dredging at Military Ocean Terminal Concord Project, including but not limited to information regarding pre-construction and final dredge volumes, bathymetry surveys, and dredge logs, within 6 months after completing the project.

Salvage and Disposition of Individuals:

Dead individuals of this species shall be placed in a resealable style plastic bag or jar with appropriate preservative solution containing a piece of paper with the date, time, location where the animal was found, and who found it, written in permanent ink. The plastic bag should be placed in a freezer in a secure location. The Service and CDFW must be notified within twenty-four (24) hours of discovery of death or injury to delta smelt that occurs due to project related activities or is observed at the project site. Notification must include the date, time, and location of the incident or of the finding of a dead or injured animal clearly indicated on a United States Geological Survey (USGS) 7.5 minute quadrangle and other maps at a finer scale, as requested by the Service. The Service contact person is Jana Affonso, Assistant Field Supervisor, Endangered Species Division, at the San Francisco Bay-Delta Fish and Wildlife Office at (916) 930-2664; and the Resident Agent-in-Charge of the Service's Office of Law Enforcement, 5622 Price Way, McClellen, California 95562, at (916) 569-8444.

CONSERVATION RECOMMENDATIONS

Section 7(a)(1) of the Act directs Federal agencies to utilize their authorities to further the purposes of the Act by carrying out conservation programs for the benefit of endangered and threatened species. Conservation recommendations are discretionary agency activities to minimize or avoid adverse effects of a proposed action on listed species or critical habitat, to help implement recovery plans, or to develop information. The Service recommends the following actions:

1. Develop study methods for and implement entrainment monitoring during dredging activities that may provide new science and information aiding in a better understanding of the effects of and the prevention of aquatic organism entrainment.

2. Develop and implement noise studies that measure sound pressure waves generated from varying types of dredge equipment in the Suisun Bay Channel and their potential effects to federally listed fish species.

In order for the Service to be kept informed of actions minimizing or avoiding adverse effects or benefiting listed species or their habitats, the Service requests notification of the implementation of any conservation recommendations.

REINITIATION—CLOSING STATEMENT

This concludes formal consultation on the Proposed Maintenance Dredging at Military Ocean Terminal Concord Project. As provided in 50 CFR §402.16, reinitiation of consultation is required and shall be requested by the Federal agency or by the Service, where discretionary Federal involvement or control over the action has been retained or is authorized by law and:

(a) If the amount or extent of taking specified in the incidental take statement is exceeded;

(b) If new information reveals effects of the action that may affect listed species or critical habitat in a manner or to an extent not previously considered;

(c) If the identified action is subsequently modified in a manner that causes an effect to the listed species or critical habitat that was not considered in the biological opinion or written concurrence; or

(d) If a new species is listed or critical habitat designated that may be affected by the identified action.

Please address any questions or concerns regarding this response to Kim Squires, Section 7 Division Chief, at Kim_Squires@fws.gov. Please refer to Service file number 08FBDT00-2020-F-0010 in any future correspondence regarding this biological opinion.

Sincerely,

For
Kaylee Allen
Field Supervisor

cc: Gary Stern, National Marine Fisheries Service, Santa Rosa, CA
Jim Starr, California Department of Fish and Wildlife, Stockton, CA
Elizabeth Christian, Regional Water Quality Control Board, Oakland, CA
Ethan Levine, San Francisco Bay Conservation and Development Commission, San Francisco, CA

Literature Cited

Abbott, R., and Bing-Sawyer, E. 2002. Assessment of pile driving impacts on the Sacramento blackfish (Othodon microlepidotus). Report prepared for Caltrans District 4.

Ambler, J.W., J.E. Cloern, and A. Hutchinson. 1985. Seasonal cycles of zooplankton from San Francisco Bay. Hydrobiologia 129:177-197.

Anchor Environmental, C.A., L.P.). 2003. Literature Review of Effects of Resuspended Sediments Due to Dredging Operations. Prepared for Los Angeles Contaminated Sediments Task Force, Los Angeles, California. June.

Andrews, S.W., E.S. Gross and P. H. Hutton. 2017. Modeling salt intrusion in the Bay-Delta prior to anthropogenic influence. Continental Shelf Research 146:58-81.

(Army) U.S. Department of the Army. 2019. Biological Assessment for Military Ocean Terminal Concord Pier Maintenance Dredging, Contra Costa and Solano County, California.

Bennett, W.A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science 3(2). doi: http://escholarship.org/uc/item/0725n5vk

Bennett, W.A. and J.R. Burau. 2015. Riders on the storm: selective tidal movements facilitate the spawning migration of threatened Delta Smelt in the San Francisco Estuary. Estuaries and Coasts 38(3):826-835. doi: http://dx.doi.org/10.1007/s12237-014-9877-3

Bennett, W.A., W.J. Kimmerer and J.R. Burau. 2002. Plasticity in vertical migration by native and exotic estuarine fishes in a dynamic low-salinity zone. Limnology and Oceanography 47(5):1496-1507. doi: http://dx.doi.org/10.4319/lo.2002.47.5.1496

Benson, N.G. 1981. The freshwater-inflow-to-estuaries issue. Fisheries 6(5):8-10.

Bever, A.J., M.L. MacWilliams, and D.K. Fullerton. 2018. Influence of an observed decadal decline in wind speed on turbidity in the San Francisco Estuary. Estuaries and Coasts 41(7):1943-1967. https://doi.org/10.1007/s12237-018-0403-x

Bever, A.J., M.L. MacWilliams, B. Herbold, L.R. Brown and F.V. Feyrer. 2016. Linking hydrodynamic complexity to delta smelt (*Hypomesus transpacificus*) distribution in the San Francisco Estuary, USA. San Francisco Estuary and Watershed Science 14(1). doi: http://dx.doi.org/10.15447/sfews.2016v14iss1art3

Brown, L.R., W.A. Bennett, R.W. Wagner, T. Morgan-King, N. Knowles, F. Feyrer, D.H. Schoellhamer, M.T. Stacy, and M. Dettinger. 2013. Implications for future survival of Delta smelt from four climate change scenarios for the Sacramento-San Joaquin Delta, California. Estuaries and Coasts 36(4):754-774. doi: http://dx.doi.org/10.1007/s12237-013-9585-4

Brown, L.R., W. Kimmerer and R. Brown. 2009. Managing water to protect fish: a review of California's environmental water account, 2001–2005. Environmental management 43(2):357-368.

Brown, L.R., L.M. Komoroske, R.W. Wagner, T. Morgan-King, J.T. May, R.E. Connon, R.E. and N.A. Fangue. 2016a. Coupled downscaled climate models and ecophysiological metrics forecast habitat compression for an endangered estuarine fish. PloS one 11(1):e0146724.

Bunn, S.E., and A.H. Arthington. 2002. Basic principles and ecological consequences of altered flow regimes for aquatic biodiversity. Environmental Management 30:492-507.

Bush, E.E. 2017. Migratory life histories and early growth of the endangered estuarine Delta Smelt (*Hypomesus transpacificus*). University of California, Davis.

California Department of Transportation. 2001. Fisheries Impact Assessment, Pile Installation Demonstration Project for the San Francisco - Oakland Bay Bridge, East Span Seismic Safety Project, August 2001. 59pp.

Castillo, G. C., Sandford, M. E., Hung, T. C., Tigan, G., Lindberg, J. C., Yang, W. R., and Van Nieuwenhuyse, E. E. 2018. Using natural marks to identify individual cultured adult Delta Smelt. North American Journal of Fisheries Management 38(3):698-705.

Clarke, D.G. and D.H. Wilber. 2000. Assessment of potential impacts of dredging operations due to sediment resuspension. DOER.Technical Note E9. 14 pp.

Cloern, J.E., and A.D. Jassby. 2012. Drivers of change in estuarine-coastal ecosystems: Discoveries from four decades of study in San Francisco Bay. Reviews of Geophysics, 50(4).

Conrad, J. L., A.J. Bibian, K.L. Weinersmith, D. De Carion, M.J. Young, P. Crain, E.L. Hestir, M.J. Santos and A. Sih. 2016. Novel Species Interactions in a Highly Modified Estuary: Association of Largemouth Bass with Brazilian Waterweed *Egeria densa*. Transactions of the American Fisheries Society 145(2):249-263. doi: http://dx.doi.org/10.1080/00028487.2015.1114521

(Corps) United States Army Corps of Engineers. 1976. Dredge Disposal Study, San Francisco Bay and Estuary, Appendix C, Water Column.

(Corps DOER) United States Army Corps of Engineers, U.S. Environmental Protection Agency, San Francisco Bay Conservation and Development Commission, San Francisco Bay Regional Water Quality Control Board, State Water Resources Control Board. 1998. *Final Policy Environmental Impact Statement/Programmatic Environmental Impact Report, Long Term Management Strategy (LTMS) For the Placement of Dredged Material in the San Francisco Bay Region.* USAED, San Francisco. Loose-leaf pub. n.p.

Damon, L.J., S.B. Slater, R.D. Baxter and R.W. Fujimura. 2016. Fecundity and reproductive potential of wild female delta smelt in the upper San Francisco Estuary, California. California Fish and Game 102(4):188-210.

Dege, M. and L.R. Brown. 2004. Effect of outflow on spring and summertime distribution and abundance of larval and juvenile fishes in the upper San Francisco estuary. Pages 49-66 In: Feyrer, F., Brown, L.R., Brown, R.L., Orsi J.J. (eds.). Early life history of fishes in the San Francisco Estuary and Watershed. American Fisheries Society Symposium 39.

Dettinger, M.D. 2005. From Climate-change Spaghetti to Climate-change Distributions for 21st-Century California. San Francisco Estuary and Watershed Science 3(1). http://repositories.cdlib.org/jmie/sfews/vol3/iss1/art4

Dettinger, M., J. Anderson, M. Anderson, L.R. Brown, D, Cayan and E. Maurer. 2016. Climate change and the Delta. San Francisco Estuary and Watershed Science 14(3) http://escholarship.org/uc/item/2r71j15r

Dettinger, M., B. Udall and A. Georgakakos. 2015. Western water and climate change. Ecological Applications 25(8):2069-2093. doi: http://dx.doi.org/10.1890/15-0938.1

Dickerson, C., Reine, K. J., and Clarke, D. G. 2001. Characterization of underwater sounds produced by bucket dredging operations, DOER Technical Notes Collection (ERDC TN-DOER-E14), U.S. Army Engineer Research and Development Center, Vicksburg, MS. www.wes.army.mil/el/dots/doer

Enright, C., S.D. Culberson, and J.R. Burau. 2013. Broad timescale forcing and geomorphic mediation of tidal marsh flow and temperature dynamics. Estuaries and Coasts 36(6): 1319-1339. DOI 10.1007/s12237-013-9639-7

Ferrari, M.C.O., L. Ranåker, K.L. Weinersmith, M.J. Young, A. Sih and J.L. Conrad. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. Environmental Biology of Fishes 97(1):79-90. doi: http://dx.doi.org/10.1007/s10641-013-0125-7

Feyrer, F., J.E. Cloern, L.R. Brown, M.A. Fish, K.A. Hieb and R.D. Baxter. 2015. Estuarine fish communities respond to climate variability over both river and ocean basins. Global change biology 21(10):3608-3619.

Feyrer F., K. Newman, M. Nobriga, T. Sommer. 2011. Modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish. Estuaries and Coasts 34(1):120-128. doi: http://dx.doi.org/10.1007/s12237-010-9343-9

Feyrer, F., K. Newman, M. Nobriga and T. Sommer. 2016. Delta Smelt Habitat in the San Francisco Estuary: A Reply to Manly, Fullerton, Hendrix, and Burnham's "Comments on Feyrer *et al.* Modeling the Effects of Future Outflow on the Abiotic Habitat of an Imperiled Estuarine Fish". Estuaries and Coasts 39(1):287-289.

Feyrer, F, M.L. Nobriga and T.R. Sommer. 2007. Multidecadal trends for three declining fish

species: habitat patterns and mechanisms in the San Francisco Estuary, California, USA. Canadian Journal of Fisheries and Aquatic Science 64(4):723-734. doi: http://dx.doi.org/10.1139/f07-048

Feyrer, F., D. Portz, D. Odum, K.B. Newman, T. Sommer, D. Contreras, R. Baxter, S. Slater, D. Sereno and E. Van Nieuwenhuyse. 2013. SmeltCam: Underwater video codend for trawled nets with an application to the distribution of the imperiled delta smelt. PLoS ONE 8(7). doi: http://dx.doi.org/10.1371/journal.pone.0067829

Feyrer, F., T. Sommer and W. Harrell, W. 2006. Managing floodplain inundation for native fish: production dynamics of age-0 splittail (*Pogonichthys macrolepidotus*) in California's Yolo Bypass. Hydrobiologia 573(1):213-226.

Fisch, K.M., J.M. Henderson, R.S. Burton and B. May. 2011. Population genetics and conservation implications for the endangered delta smelt in the San Francisco Bay-Delta. Conservation genetics 12(6):1421-1434.

García-Reyes, M., and J. Largier. 2010. Observations of increased wind-driven coastal upwelling off central California, J. Geophys. Res., 115, C04011, doi:10.1029/2009JC005576.

Gewant, D.S., and S.M. Bollens. 2005. Macrozooplankton and micronekton of the lower San Francisco Estuary: seasonal, interannual, and regional variation in relation to environmental conditions. Estuaries 28:473-485.

Gewant, D. and S.M. Bollens. 2012. Fish assemblages of interior tidal marsh channels in relation to environmental variables in the upper San Francisco Estuary. Environmental biology of fishes 94(2):483-499. doi: http://dx.doi.org/10.1007/s10641-011-9963-3

Gillson, J. 2011. Freshwater flow and fisheries production in estuarine and coastal systems: where a drop of rain is not lost. Reviews in Fisheries Science 19:168-186.

Grimaldo, L. F., T. Sommer, N. Van Ark, G. Jones, E. Holland, P.B. Moyle, B. Herbold and P. Smith. 2009. Factors affecting fish entrainment into massive water diversions in a tidal freshwater estuary: can fish losses be managed? North American Journal of Fisheries Management 29(5):1253-1270. doi: http://dx.doi.org/10.1577/M08-062.1

Grosholz, E., and E. Gallo. 2006. The influence of flood cycle and fish predation on invertebrate production on a restored California floodplain. Hydrobiologia 568(1):91-109.

Gross, E.S., P.H. Hutton and A.J. Draper. 2018. A Comparison of Outflow and Salt Intrusion in the Pre-Development and Contemporary San Francisco Estuary. San Francisco Estuary San Francisco Estuary and Watershed Science 16(3).

Hammock, B.G., Hartman, R., Slater, S.B., Hennessy, A. and Teh, S.J., 2019. Tidal Wetlands Associated with Foraging Success of Delta Smelt. Estuaries and Coasts:1-11.

Hammock, B.G., J.A. Hobbs, S.B. Slater, S. Acuña and S.J. Teh. 2015. Contaminant and food

limitation stress in an endangered estuarine fish. Science of the Total Environment 532:316-326. doi: http://dx.doi.org/10.1016/j.scitotenv.2015.06.018

Hammock, B.G., Slater, S.B., Baxter, R.D., Fangue, N.A., Cocherell, D., Hennessy, A., Kurobe, T., Tai, C.Y. and Teh, S.J., 2017. Foraging and metabolic consequences of semi-anadromy for an endangered estuarine fish. PloS ONE 12(3):p.e0173497. https://doi.org/10.1371/journal.pone.0173497

Hasenbein, M., N.A. Fangue, J. Geist, L.M. Komoroske, J. Truong, R. McPherson R.E. and Connon. 2016b. Assessments at multiple levels of biological organization allow for an integrative determination of physiological tolerances to turbidity in an endangered fish species. Conservation physiology 4(1) cow004.

Hasenbein, M., L.M. Komoroske, R.E. Connon, J. Geist and N.A. Fangue. 2013. Turbidity and salinity affect feeding performance and physiological stress in the endangered delta smelt. Integrative and Comparative Biology 53(4):620-634. doi: http://dx.doi.org/10.1093/icb/ict082

Hayhoe, K., D. Cayan, C.B. Field, P.C. Frumhoff, E.P. Maurer, N.L. Miller, S.C. Moser, S.H. Schneideri, K.N. Cahill, E.E. Cleland, L. Dale, R. Drapek, R.M. Hanemann, L.S. Kalkstein, J. Lenihan, C.K. Lunch, R.P. Neilson, S.C. Sheridan and J.H. Verville. 2004. Emissions pathways, climate change, and impacts on California. Proceedings of the National Academy of Sciences of the United States of America 101(34):12422-12427. doi: http://dx.doi.org/10.1073/pnas.0404500101

He, L., and M. Nobriga. 2018. Revisiting relationships between salinity and delta smelt abundance. Presentation at the 2018 San Francisco Bay Delta Science Conference, Sacramento, CA.

Hestir, E. L., D.H. Schoellhamer, J. Greenberg, T. Morgan-King and S.L. Ustin. 2016. The effect of submerged aquatic vegetation expansion on a declining turbidity trend in the Sacramento-San Joaquin River Delta. Estuaries and Coasts 1-13. doi: http://dx.doi.org/10.1007/s12237-015-0055-z

Heubach, W. 1969. *Neomysis awatschensis* in the Sacramento-San Joaquin River Estuary. Limnology and Oceanography 14: 533-546.

Hirose, T. and K. Kawaguchi. 1998. Spawning ecology of Japanese surf smelt, *Hypomesus pretiosus japonicus* (Osmeridae), in Otsuchi Bay, northeastern Japan. Environmental biology of fishes 52(1-3):213-223.

Hobbs, J.A., W.A. Bennett and J.E. Burton. 2006. Assessing nursery habitat quality for native smelts (Osmeridae) in the low-salinity zone of the San Francisco estuary. Journal of Fish Biology 69(3):907-922. doi: http://dx.doi.org/10.1577/T06-087.1

Hobbs, J. A., Bennett, W. A., Burton, J., & Baskerville-Bridges, B. 2007b. Modification of the biological intercept model to account for ontogenetic effects in laboratory-reared delta smelt (Hypomesus transpacificus). U.S. Fishery Bulletin 105(1):30-38.

Hobbs, J.A., W.A. Bennett, J. Burton and M. Gras. 2007a. Classification of larval and adult delta smelt to nursery areas by use of trace elemental fingerprinting. Transactions of the American Fisheries Society 136(2):518-527. doi: http://dx.doi.org/10.1577/T06-087.1

Hobbs, J., P.B. Moyle, N. Fangue and R.E. Connon. 2017. Is extinction inevitable for Delta Smelt and Longfin Smelt? An opinion and recommendations for recovery. San Francisco Estuary and Watershed Science 15(2).

Howe, E. R., & Simenstad, C. A. 2011. Isotopic determination of food web origins in restoring and ancient estuarine wetlands of the San Francisco Bay and Delta. Estuaries and Coasts 34:597-617. DOI 10.1007/s12237-011-9376-8

Hutton, P.H., Chen, L., Rath, J.S. and Roy, S.B., 2019. Tidally-averaged flows in the interior Sacramento–San Joaquin River Delta: Trends and change attribution. Hydrological Processes 33(2):230-243.

Hutton, P.H., J.S. Rath, S.B. Roy. 2017a. Freshwater flow to the San Francisco Bay-Delta estuary over nine decades (Part 1): Trend evaluation. Hydrological Processes 31(14):2500-2515.

Hutton, P. H., Rath, J. S., and Roy, S. B. 2017b. Freshwater flow to the San Francisco Bay-Delta estuary over nine decades (Part 2): Change attribution. Hydrological processes 31(14):2516-2529.

Hutton, P.H. and S.B. Roy. 2019. Characterizing Early 20th Century Outflow and Salinity Intrusion in the San Francisco Estuary. San Francisco Estuary and Watershed Science 17(2). https://escholarship.org/content/qt5jn0f55k/qt5jn0f55k.pdf

(IEP) Interagency Ecological Program. 2015. An updated conceptual model of Delta Smelt biology: our evolving understanding of an estuarine fish. IEP Management, Analysis and Synthesis Team. Interagency Ecological Program for the San Francisco Bay/Delta Estuary. Technical Report 90. California Department of Water Resources. http://www.water.ca.gov/iep/docs/Delta_Smelt_MAST_Synthesis_Report_January%202015.pdf

Jassby, A.D. and J.E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). Aquatic Conservation: Marine and Freshwater Ecosystems 10(5):323-352. https://sfbay.wr.usgs.gov/publications/pdf/jassby_2000_organic.pdf

Jassby, A.D., W.J. Kimmerer, S.G. Monismith, C. Armor, J.E. Cloern, T.M. Powell, J.R. Schubel, and T.J. Vendlinski. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5(1): 272-289. doi: http://dx.doi.org/10.2307/1942069

Keith, D.M., and J.A. Hutchings. 2012. Population dynamics of marine fishes at low abundance. Canadian Journal of Fisheries and Aquatic Sciences 69:1150-1163.

Kjelson, M.A., and P.L. Brandes. 1989. The use of smolt survival estimates to quantify the effects of habitat changes on salmonid stocks in the Sacramento-San Joaquin rivers, California. Canadian special publication of fisheries and aquatic sciences/Publication speciale canadienne des sciences halieutiques et aquatiques.

Kimmerer, W.J. 2002a. Physical, biological, and management responses to variable freshwater flow into the San Francisco Estuary. Estuaries 25(6):1275-1290. doi: http://dx.doi.org/10.1007/BF02692224

Kimmerer, W.J. 2002b. Effects of freshwater flow on abundance of estuarine organisms: physical effects or trophic linkages? Marine Ecology Progress Series 243:39-55. doi: http://dx.doi.org/10.3354/meps243039

Kimmerer, W.J. 2004. Open water processes of the San Francisco Estuary: from physical forcing to biological responses. San Francisco Estuary and Watershed Science 2(1). http://escholarship.org/uc/item/9bp499mv

Kimmerer, W.J. 2008. Losses of Sacramento River Chinook salmon and delta smelt to entrainment in water diversions in the Sacramento-San Joaquin Delta. San Francisco Estuary and Watershed Science 6(2). http://escholarship.org/uc/item/7v92h6fs

Kimmerer, W.J., E.S. Gross and M.L. MacWilliams. 2014. Tidal migration and retention of estuarine zooplankton investigated using a particle-tracking model. Limnology and Oceanography 59(3):901-916.

Kimmerer, W. J., E.S. Gross and M.L MacWilliams. 2009. Is the response of estuarine nekton to freshwater flow in the San Francisco Estuary explained by variation in habitat volume? Estuaries and Coasts 32(2):375. http://www.jstor.org/stable/40663547

Kimmerer, W.J., M.L. MacWilliams and E.S. Gross. 2013. Variation of fish habitat and extent of the low-salinity zone with freshwater flow in the San Francisco Estuary. San Francisco Estuary and Watershed Science 11(4). http://escholarship.org/uc/item/3pz7x1x8

Kimmerer, W.J. and K.A. Rose. 2018. Individual-Based Modeling of Delta Smelt Population Dynamics in the Upper San Francisco Estuary III. Effects of Entrainment Mortality and Changes in Prey. Transactions of the American Fisheries Society 147(1):223-243.

Knowles, N. and D.R. Cayan. 2002. Potential effects of global warming on the Sacramento/San Joaquin watershed and the San Francisco estuary. Geophysical Research Letters 29(18). doi: http://dx.doi.org/10.1029/2001GL014339

Komoroske, L.M., R.E. Connon, K.M. Jeffries and N.A. Fangue. 2015. Linking transcriptional responses to organismal tolerance reveals mechanisms of thermal sensitivity in a mesothermal endangered fish. Molecular ecology 24(19):4960-4981.

Komoroske, L.M., R.E. Connon, J. Lindberg, B.S. Cheng, G. Castillo, M. Hasenbein, and N.

A. Fangue. 2014. Ontogeny influences sensitivity to climate change stressors in an endangered fish. Conservation Physiology 2. http://conphys.oxfordjournals.org/content/2/1/cou008.short

Komoroske, M., K.M. Jeffries, R.E. Connon, J. Dexter, M. Hasenbein, C. Verhille and N.A. Fangue. 2016. Sublethal salinity stress contributes to habitat limitation in an endangered estuarine fish. Evolutionary Applications. doi: http://dx.doi.org/10.1111/eva.12385

Kurobe, T., M.O. Park, A. Javidmehr, F.C. Teh, S.C. Acuña, C.J. Corbin, A.J. Conley, W.A. Bennett and S.J. Teh. 2016. Assessing oocyte development and maturation in the threatened Delta Smelt, *Hypomesus transpacificus*. Environmental Biology of Fishes 99(4):423-432. doi: http://dx.doi.org/10.1007/s10641-016-0483-z

LaCava, M., K. Fisch, M. Nagel, J.C. Lindberg, B. May, and A.J. Finger. 2015. Spawning behavior of cultured delta smelt in a conservation hatchery. North American Journal of Aquaculture 77:255-266. http://dx.doi.org/10.1080/15222055.2015.1007192

Latour, R.J. 2016. Explaining Patterns of Pelagic Fish Abundance in the Sacramento-San Joaquin Delta. Estuaries and Coasts 39(1):233-247. doi: http://dx.doi.org/10.1007/s12237-015-9968-9

Lessard, J., B. Cavallo, P. Anders, T. Sommer, B. Schreier, D. Gille, A. Schreier, A. Finger, T-C. Hung, J. Hobbs, B. May, A. Schultz, O. Burgess, and R. Clarke. 2018. Considerations for the use of captive-reared delta smelt for species recovery and research. San Francisco Estuary and Watershed Science 16(3): https://doi.org/10.15447/sfews.2018v16iss3art3

Liermann, M., and R. Hilborn. 2001. Depensation: evidence, models, and implications. Fish and Fisheries 2:33-58.

Lindberg, J.C., G. Tigan, L. Ellison, T. Rettinghouse, M.M. Nagel and K.M. Fisch. 2013. Aquaculture methods for a genetically managed population of endangered Delta Smelt. North American Journal of Aquaculture 75(2):186-196. doi: http://dx.doi.org/10.1080/15222055.2012.751942

Longmuir, C., and T. Lively. 2001. Bubble curtain systems for use during marine pile driving. Report by Fraser River Pile and Dredge Ltd., New Westminster, BC, Canada.

(LTMS) Long-Term Management Strategy Agencies. 1998. Long-Term Management Strategy for the Placement of Dredged Material in the San Francisco Bay Region, Final Policy Environmental Impact Statement/Environmental Impact Report. Volume I.

Mac Nally, R., J.R. Thomson, W.J. Kimmerer, F. Feyrer, K.B. Newman, A. Sih, W.A. Bennett, L. Brown, E. Fleishman, S.D. Culberson and G. Castillo. 2010. Analysis of pelagic species decline in the upper San Francisco Estuary using multivariate autoregressive modeling (MAR). Ecological Applications 20(5):1417-1430.

MacWilliams, M., A.J. Bever and E. Foresman. 2016. 3-D simulations of the Bay-Delta with subgrid bathymetry to explore long-term trends in salinity distribution and fish abundance. Bay-Delta and Watershed Science 14(2).

MacWilliams, M.L., A.J. Bever, E.S. Gross, G.S. Ketefian, W.J. Kimmerer. 2015. Three-dimensional modeling of hydrodynamics and salinity in the Bay-Delta: An evaluation of model accuracy, X2, and the low–salinity zone. Bay-Delta and Watershed Science 13(1).

Mager, R.C., S.I. Doroshov, J.P. Van Eenennaam and R.L. Brown. 2004. Early life stages of delta smelt. Pages 169-180 in Feyrer, F., Brown, L.R., Brown, R.L., and Orsi, J.J. (eds.). Early life history of fishes in the San Francisco Estuary and Watershed. American Fisheries Society Symposium 39, Bethesda, MD.

Mahardja, B., J.A. Hobbs, N. Ikemiyagi, A. Benjamin and A.J. Finger. 2019. Role of freshwater floodplain-tidal slough complex in the persistence of the endangered delta smelt. PloS ONE 14(1):e0208084.

Mahardja, B., M.J. Young, B. Schreier, and T. Sommer. 2017a. Understanding imperfect detection in a San Francisco Estuary long-term larval and juvenile fish monitoring programme. Fisheries Management and Ecology 24:488-503.

Mahardja, B., M.J. Farruggia, B. Schreier, and T. Sommer. 2017b. Evidence of a shift in the littoral fish community in the Sacramento-San Joaquin Delta. PLOS One 12(1):e0170683. doi:10.1371/journal.pone.0170683

Manly, B.F.J., D. Fullerton, A.N. Hendrix and K.P. Burnham. 2015. Comments on Feyrer *et al.* "modeling the effects of future outflow on the abiotic habitat of an imperiled estuarine fish". Estuaries and coasts 38(5):1815-1820.

Matern, S.A., P.B. Moyle and L.C. Pierce. 2002. Native and alien fishes in a California estuarine marsh: twenty-one years of changing assemblages. Transactions of the American Fisheries Society 131(5):797-816. doi: http://dx.doi.org/10.1577/1548-8659(2002)131<0797:NAAFIA>2.0.CO;2

Meng, L., P.B. Moyle, and B. Herbold. 1994. Changes in abundance and distribution of native and introduced fishes of Suisun Marsh. Transactions of the American Fisheries Society 123:498-507.

Merz, J.E., P.S. Bergman, J.L. Simonis, D. Delaney, J. Pierson, and P. Anders. 2016. Long-term seasonal trends in the prey community of delta smelt (*Hypomesus transpacificus*) within the Sacramento-San Joaquin Delta, California. Estuaries and Coasts 39:1526-1536.

Merz, J.E., S. Hamilton, P.S. Bergman and B. Cavallo. 2011. Spatial perspective for delta smelt: a summary of contemporary survey data. California Fish and Game 97(4):164-189. https://nrm.dfg.ca.gov/FileHandler.ashx?DocumentID=46489

Miller, W.J., B.F.J. Manly, D.D. Murphy, D. Fullerton and R.R. Ramey. 2012. An investigation

of factors affecting the decline of delta smelt (*Hypomesus transpacificus*) in the Sacramento-San Joaquin Estuary. Reviews in Fisheries Science (20)1:1-19. doi: http://dx.doi.org/10.1080/10641262.2011.634930

Mitchell, L., Newman, K., & Baxter, R. 2017. A Covered Cod-End and Tow-Path Evaluation of Midwater Trawl Gear Efficiency for Catching Delta Smelt (Hypomesus transpacificus). San Francisco Estuary and Watershed Science 15(4).

Monismith, S.G. 2016. A note on Delta outflow. San Francisco Estuary and Watershed Science 14(3).

Monismith, S., J.R. Burau, and M. Stacey. 1996. Stratification dynamics and gravitational circulation in northern San Francisco Bay. Pages 123-153 In: Hollibaugh, J.T. (ed). San Francisco Bay: The ecosystem. Pacific Division, American Association for the Advancement of Science.

Monismith, S.G., W. Kimmerer, J.R. Burau, and M.T. Stacey. 2002. Structure and flow-induced variability of the subtidal salinity field in northern San Francisco Bay. Journal of Physical Oceanography 32(11):3003-3019.

Moyle, P.B., 2002. Inland fishes of California: revised and expanded. Univ of California Press.

Moyle, P.B., Baxter, R.D., Sommer, T., Foin, T.C. and Matern, S.A., 2004. Biology and population dynamics of Sacramento splittail (*Pogonichthys macrolepidotus*) in the San Francisco Estuary: a review. San Francisco Estuary and Watershed Science *2*(2).

Moyle, P.B., and W.A. Bennett. 2008. The future of the Delta ecosystem and its fish. Technical Appendix D in Hanak, E., W. Fleenor, and J. Lund, Comparing futures for the Sacramento-San Joaquin Delta. University of California Press.

Moyle, P.B., L.R. Brown and J.R. Durand and J.A. Hobbs. 2016. Delta smelt: life history and decline of a once-abundant species in the San Francisco Estuary. San Francisco Estuary and Watershed Science 14(2). http://escholarship.org/uc/item/09k9f76s

Moyle, P.B., B. Herbold, D.E. Stevens and L.W. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Transactions of the American Fisheries Society 121(1):67-77. doi: http://dx.doi.org/10.1577/1548-8659(1992)121<0067:LHASOD>2.3.CO;2

Moyle, P. B., Hobbs, J. A., & Durand, J. R. 2018. Delta Smelt and water politics in California. Fisheries 43(1):42-50.

Moyle, P. B., Lund, J. R., Bennett, W. A., and W.E. Fleenor. 2010. Habitat variability and complexity in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science 8(3).

Murphy, D.D. and S.A. Hamilton. 2013. Eastern migration or marshward dispersal: exercising survey data to elicit an understanding of seasonal movement of delta smelt. San Francisco

Estuary and Watershed Science 11(3). https://escholarship.org/uc/item/4jf862qz

(NMFS) National Marine Fisheries Service. 2009. Pile driving analysis spreadsheet. http://www.dot.ca.gov/hq/env/bio/files/NMFS%20Pile%20Driving%20Calculations.xls

Newcombe, C.P. and D.D. MacDonald. 1991. Effects of suspended sediments on aquatic ecosystems. N. Amer. J. Fish. Man. 11: 72-81.

Newcombe, C.P. and J. Jensen. 1996. Channel Suspended Sediment and Fisheries: A Synthesis for Quantitative Assessment of Risk and Impact. North American Journal of Fisheries Management, 16(4): 693-727.

Nobriga, M.L., F. Feyrer, R.D. Baxter and M. Chotkowski. 2005. Fish community ecology in an altered river delta: spatial patterns in species composition, life history strategies, and biomass. Estuaries 28(5):776-785. doi: http://dx.doi.org/10.1007/BF02732915

Nobriga, M.L., T.R. Sommer, F. Feyrer and K. Fleming. 2008. Long-term trends in summertime habitat suitability for delta smelt. San Francisco Estuary and Watershed Science 6(1). http://escholarship.org/uc/item/5xd3q8tx

O'Connor, J.M. 1991. Evaluation of turbidity and turbidity-related effects on the biota of the San Francisco Bay-Delta estuary. 84 pp.

Orsi, J.J. and W.L. Mecum. 1986. Zooplankton distribution and abundance in the Sacramento-San Joaquin Delta in relation to certain environmental factors. Estuaries 9(4):326-339. doi: http://dx.doi.org/10.2307/1351412

Perry, R.W., J.R. Skalski, P.L Brandes, P.T. Sandstrom, A.P. Klimley, A. Ammann and B. MacFarlane. 2010. Estimating survival and migration route probabilities of juvenile Chinook salmon in the Sacramento–San Joaquin River Delta. North American Journal of Fisheries Management 30(1):142-156.

Peterson, M.S. 2003. A conceptual view of environment-habitat-production linkages in tidal river estuaries. Reviews in Fisheries science 11(4):291-313. doi: https://doi.org/10.1080/10641260390255844

Poff, N.L., and J.K.H. Zimmerman. 2010. Ecological responses to altered flow regimes: a literature review to inform the science and management of environmental flows. Freshwater Biology 55:194-205.

Polansky, L., Mitchell, L., and Newman, K.B. 2019. Using multistage design-based methods to construct abundance indices and uncertainty measures for delta smelt. Transactions of the American Fisheries Society 148:710-724. https://afspubs.onlinelibrary.wiley.com/doi/full/10.1002/tafs.10166

Polansky, L., K.B. Newman, M.L. Nobriga and L. Mitchell. 2018. Spatiotemporal models of an estuarine fish species to identify patterns and factors impacting their distribution and abundance. Estuaries and Coasts 41(2):572-581. http://dx.doi.org/10.1007/s12237-017-0277-3

Quinn, T., Krueger, K., Pierce, K., Penttila, D., Perry, K., Hicks, T. and Lowry, D., 2012. Patterns of surf smelt, Hypomesus pretiosus, intertidal spawning habitat use in Puget Sound, Washington State. Estuaries and Coasts 35(5), pp.1214-1228.

Rath, J. S., Hutton, P. H., Chen, L., & Roy, S. B. 2017. A hybrid empirical-Bayesian artificial neural network model of salinity in the San Francisco Bay-Delta estuary. Environmental modelling and Software 93:193-208.

Reyff, J. A. 2003. Underwater sound levels associated with construction of the Benicia-Martinez Bridge, acoustical evaluation of an unconfined air-bubble curtain system at Pier 13. Inc., Petaluma, Calif.

Reis, G.J., Howard, J.K. and J.A. Rosenfield. 2019. Clarifying Effects of Environmental Protections on Freshwater Flows to—and Water Exports from—the San Francisco Bay Estuary. San Francisco Estuary and Watershed Science 17(1).

Rose, K.A., W.J. Kimmerer, K.P. Edwards and W.A. Bennett. 2013a. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: I. Model description and baseline results. Transactions of the American Fisheries Society 142(5):1238-1259. doi: http://dx.doi.org/10.1080/00028487.2013.799518

Rose, K.A., W.J. Kimmerer, K.P. Edwards and W.A. Bennett. 2013b. Individual-based modeling of Delta Smelt population dynamics in the upper San Francisco Estuary: II. Alternative baselines and good versus bad years. Transactions of the American Fisheries Society 142(5):1260-1272. doi: http://dx.doi.org/10.1080/00028487.2013.799519

Ruhl, C.A., D.H. Schoellhamer, R.P. Stumpf, and C.L. Lindsay. 2001. Combined use of remote sensing and continuous monitoring to analyse the variability of suspended-sediment concentrations in San Francisco Bay, California. Estuarine, Coastal, and Shelf Science 53:801-812.

Schoellhamer, D.H. 2011. Sudden clearing of estuarine waters upon crossing the threshold from transport to supply regulation of sediment transport as an erodible sediment pool is depleted: San Francisco Bay, 1999. Estuaries and Coasts 34(5):885-899. doi: http://dx.doi.org/10.1007/s12237-011-9382-x

(Service) U.S. Fish and Wildlife Service. 1991. Endangered and threatened wildlife and plants; proposed threatened status for the delta smelt. Federal Register 56:50075-50082. http://ecos.fws.gov/docs/federal_register/fr1938.pdf

(Service) U.S. Fish and Wildlife Service. 1993. Endangered and threatened wildlife and plants; determination of threatened status for the delta smelt; final rule. Federal Register 58(42):12854-12864. https://ecos.fws.gov/docs/federal_register/fr2235.pdf

(Service) U.S. Fish and Wildlife Service. 1994. Endangered and threatened wildlife and plants; final rule critical habitat determination for the delta smelt. Federal Register 59:65256-65277. http://ecos.fws.gov/docs/federal_register/fr2751.pdf

(Service) U.S. Fish and Wildlife Service. 1996. Recovery Plan for the Sacramento-San Joaquin Delta Native Fishes. http://ecos.fws.gov/docs/recovery_plan/961126.pdf

(Service) U.S. Fish and Wildlife Service. 2004. 5-year review of the delta smelt. http://ecos.fws.gov/docs/five_year_review/doc3570.pdf

(Service) U.S. Fish and Wildlife Service. 2008. Formal Endangered Species Act Consultation on the Proposed Coordinated Operations of the Central Valley Project (CVP) and State Water Project (SWP). United States Fish and Wildlife Service, Sacramento, CA. https://www.fws.gov/sfbaydelta/documents/SWP-CVP_OPs_BO_12-15_final_OCR.pdf

(Service) U.S. Fish and Wildlife Service. 2010a. 5-year review delta smelt (*Hypomesus transpacificus*). http://ecos.fws.gov/docs/five_year_review/doc3570.pdf

(Service) U.S. Fish and Wildlife Service. 2010b. Endangered and threatened wildlife and plants; 12-month finding on a petition to reclassify the delta smelt from threatened to endangered throughout its range. Federal Register 75:17667-17680. https://www.gpo.gov/fdsys/pkg/FR-2010-04-07/pdf/2010-7904.pdf

(Service) U.S. Fish and Wildlife Service. 2010c. Notice of Findings on Delta Smelt uplisting. Federal Register 75:69222-69294. https://www.gpo.gov/fdsys/pkg/FR-2010-11-10/pdf/2010-27686.pdf#page=2

(Service) U.S. Fish and Wildlife Service. 2012. Candidate Notice of Review (CNOR) for Delta Smelt. November 21, 2012. Federal Register 77:69994-70060. https://www.gpo.gov/fdsys/pkg/FR-2012-11-21/pdf/2012-28050.pdf

Sherk Jr., A.J. 1971. The effects of suspended and deposited sediments on estuarine organisms. Literature summary and research needs. Chesapeake Biological Laboratory Contribution No. 443. February 1971

Simonis, J.L., and Merz, J.E. 2019. Prey availability, environmental constraints, and aggregation dictate population distribution of an imperiled fish. Ecosphere 10(3) info: doi/10.1002/ecs2.2634.

Sommer, T.R., W.C. Harrell, A. Mueller-Solger, B. Tom, and W.J. Kimmerer. 2004. Effects of flow variation on channel and floodplain biota and habitats of the Sacramento River, California, USA. Aquatic Conservation: Marine and Freshwater Ecosystems 14(3):247-261.

Sommer, T.R., C. Armor, R. Baxter, R. Breuer, L. Brown, M. Chotkowski, S. Culberson, F. Feyrer, M. Gingras, B. Herbold. 2007. The collapse of pelagic fishes in the upper San Francisco Estuary. Fisheries 32:270–277.

Sommer, T. and F. Mejia. 2013. A place to call home: a synthesis of Delta Smelt habitat in the upper San Francisco Estuary. San Francisco Estuary and Watershed Science 11(2). https://escholarship.org/uc/item/32c8t244

Sommer, T., F.H. Mejia, M. Nobriga, F. Feyrer, and L. Grimaldo. 2011. The spawning migration of delta smelt in the upper San Francisco Estuary. Francisco Estuary and Watershed Science 9(2). https://escholarship.org/uc/item/86m0g5sz

Stevens, D.E., L.W. Miller. 1983. Effects of river flow on abundance of young Chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento-San Joaquin River system. North American Journal of Fisheries Management 3(4):425-437. doi: http://dx.doi.org/10.1577/1548-8659(1983)3<425:EORFOA>2.0.CO;2

Stotz, T. and J. Colby. 2001. January 2001 dive report for Mukilteo wingwall replacement Project. Washington State Ferries Memorandum. 5 pp.+ appendices.

Sweetnam, D.A. 1999. Status of delta smelt in the Sacramento-San Joaquin Estuary. California Fish and Game 85(1):22-27. https://www.wildlife.ca.gov/Publications/Journal

Thomson, J. R., W.J. Kimmerer, L.R. Brown, K.B. Newman, R. Mac Nally, W.A. Bennett, F. Feyrer and E. Fleishman. 2010. Bayesian change point analysis of abundance trends for pelagic fishes in the upper San Francisco Estuary. Ecological Applications 20(5):1431-1448. doi: http://dx.doi.org/10.1890/09-0998.1

Turner, J.L. and H.K. Chadwick. 1972. Distribution and abundance of young-of-the-year striped bass, *Morone saxatilis*, in relation to river flow in the Sacramento-San Joaquin estuary. Transactions of the American Fisheries Society 101(3):442-452. doi: http://dx.doi.org/10.1577/1548-8659(1972)101<442:DAAOYS>2.0.CO;2

Wagner, R.W., M. Stacey, L.R. Brown and M. Dettinger. 2011. Statistical models of temperature in the Sacramento–San Joaquin Delta under climate-change scenarios and ecological implications. Estuaries and Coasts 34(3):544-556. doi: http://dx.doi.org/10.1007/s12237-010-9369-z

Whipple, A.A., R.M. Grossinger, D. Rankin, B. Stanford and R.A. Askevold. 2012. Sacramento-San Joaquin Delta historical ecology investigation: Exploring pattern and process. Prepared for the California Department of Fish and Game and Ecosystem Restoration Program. A report of SFEIASC's Historical Ecology Program, publication# 672, San Francisco Estuary Institute-Aquatic Science Center, Richmond, CA. http://www.sfei.org/sites/default/files/biblio_files/Delta_HistoricalEcologyStudy_SFEI_ASC_2012_lowres.pdf

Winder, M., Jassby, A.D. and Mac Nally, R., 2011. Synergies between climate anomalies and hydrological modifications facilitate estuarine biotic invasions. Ecology letters 14(8):749-757.