Appendix D –
Biological Resources – Aquatic

September 2021

Delta Stewardship Council

A CALIFORNIA STATE AGENCY

This page intentionally left blank.

D.1 Introduction

This appendix contains accounts of special-status fish species that have potential to occur in the Primary and Extended Planning Areas. “Special-status species,” as defined in this document, are fish species legally protected under the federal Endangered Species Act (ESA), California Endangered Species Act (CESA), or other State regulations, and species considered sufficiently rare by the scientific community to warrant conservation concern.

Special-status fish species considered in this appendix are those animal species included in at least one of the following categories:

- Federally listed as threatened or endangered
- Proposed for federal listing as threatened or endangered
- Candidate for federal listing
- State listed as threatened or endangered
- Candidate for State listing
- Fully protected species under the California Fish and Game Code
- State species of special concern
- Species on California Department of Fish and Wildlife’s (DFW’s) watch list

Descriptions of these potentially occurring special-status fish species are provided below. Sources used include California Natural Diversity Database (CNDDB) records; existing species accounts available from DFW, U.S. Fish and Wildlife Service (USFWS), and other agencies; recovery plans for special-status species with potential to occur in the Delta; critical habitat designations; and relevant scientific literature.

D.2 Fish Species

The species accounts in this appendix provide an overview of special-status fish species that are known to occur or that have an appreciable likelihood of occurring in the Delta and Suisun Marsh and the Extended Planning Area, and are likely to be affected by the implementation of the proposed Delta Plan Amendments. The special-status species that occur, or that have the potential to occur in, the Primary Planning Area and Extended Planning Area are presented in Table D-1.

Table D-1
Special-status Fish Species with the Potential to Occur within the Primary and Extended Planning Areas

Common Name	Scientific Name	Status (Federal/State)	Primary Habitat and Critical Seasonal Periods	Occurrence in Primary and Extended Planning Areas
Central Valley Steelhead	*Oncorhynchus mykiss*	FT/—	Anadromous species using riverine, estuarine, and saltwater habitat. Migration potentially occurs year-round.	Sacramento River, American River, San Joaquin Valley, Delta
California Central Coast/ South-Central Coast	*Oncorhynchus mykiss*	FT/—	Anadromous species using riverine, estuarine, and saltwater habitat. Migration potentially occurs year-round.	Coastal Mountains, San Francisco Bay Area; documented in SCVWD Service Area in Upper Penitencia, Pacheco, and Coyote creeks and Guadalupe River
Central Valley Chinook salmon, fall/late fall-run	*Oncorhynchus tshawytscha*	SC/CSC	Anadromous species using riverine, estuarine, and saltwater habitat. Adult migration occurs mainly from September through December but has been observed as late as June. Primary juvenile outmigration occurs from January through June.	Sacramento River, American River, Delta, San Francisco Bay Area, San Joaquin Valley; also known to occur in the Guadalupe River and Coyote Creek
Central Valley spring-run Chinook salmon	*Oncorhynchus tshawytscha*	FT/ST	Anadromous species using riverine, estuarine, and saltwater habitat. Adult migration potentially occurs from March through May. Juvenile outmigration occurs from November through April.	Sacramento River, Delta, San Joaquin Valley
Sacramento River winter-run Chinook salmon	*Oncorhynchus tshawytscha*	FE/SE	Anadromous species using riverine, estuarine, and saltwater habitat. Adult migration potentially occurs from January through May. Juvenile outmigration occurs from November through mid-March.	Sacramento River, Delta
Green sturgeon	*Acipenser medirostris*	FT/CSC	Green sturgeon are an anadromous species, migrating from the ocean to freshwater to spawn. They exist in the Sacramento River system, as well as in the Eel, Mad, Klamath, and Smith rivers in the northwest portion of California.	Sacramento River, American River, San Francisco Bay Area, Delta, San Joaquin Valley

Table D-1 (continued) Special-status Fish Species with the Potential to Occur within the Primary and Extended Planning Areas

Common Name	Scientific Name	Status (Federal/State)	Primary Habitat and Critical Seasonal Periods	Occurrence in Primary and Extended Planning Areas
Delta smelt	*Hypomesus transpacificus*	FT/SE	Spends most of its life in the Sacramento–San Joaquin estuary. Spawns in shallow, fresh or slightly brackish water upriver from the mixing zone, including in the Sacramento River, Mokelumne River system, Cache Slough region, San Francisco Bay Delta, and Montezuma Slough area.	Sacramento River, American River, Delta
Longfin smelt	*Spirinchus thaleichthys*	—/ST	The longfin smelt is an anadromous species that spawns in the Delta and rears in the brackish areas of the San Francisco Bay and Delta.	Delta, San Francisco Bay Area
California/San Joaquin Roach	*Lavinia symmetricus* ssp.	—/CSC	Occurs in small, warm tributaries, to larger streams that flowed through open foothill woodlands of oak and foothill pine. Located in the foothills in much of the same region that contains the pikeminnow- hardhead-sucker assemblage.	Occurs upstream of large reservoir or in tributary streams that would not be affected by the project.
Riffle Sculpin	*Cottus gulosus*	SC/—	Riffle sculpins live in permanent, cool, headwater streams where riffles and rocky substrates predominate.	Riffle sculpin are found in many increasingly isolated watersheds in the Central Valley drainage and the central coast. They are mostly present in mid-elevation reaches, although they are present below dams with coldwater releases
Sacramento Hitch	*Lavinia exilicauda exilicauda*	SC/—	Sacramento hitch inhabit warm lowland waters including clear streams, turbid sloughs ,lakes and reservoirs.	In the Sacramento River, hitch appear to be spread across much of their native range up to and including Shasta Reservoir.
Hardhead	*Mylopharodon conocephalus*	—/CSC	Hardhead are often found at low to mid elevations in relatively undisturbed habitats of larger streams with high water quality (clear, cool).	In the Sacramento River they are common in both the mainstem and tributaries up to 1500 m in elevation.

Table D-1 (continued)
Special-status Fish Species with the Potential to Occur within the Primary and Extended Planning Areas

Common Name	Scientific Name	Status (Federal/State)	Primary Habitat and Critical Seasonal Periods	Occurrence in Primary and Extended Planning Areas
River Lamprey	*Lampetra ayresii*	—/CSC	Adults need clean, gravelly riffles in permanent streams to spawn successfully. Ammocoetes live in silty backwaters and eddies with muddy or sandy substrate into which they burrow.	Occur in the lower Sacramento and San Joaquin River drainages, including the Stanislaus and Tuolumne Rivers.
Pacific Lamprey	*Lampetra tridentata*	SC/—	Adults need clean, gravelly riffles in permanent streams to spawn successfully. Ammocoetes live in silty backwaters and eddies with muddy or sandy substrate into which they burrow.	Occur in both the lower Sacramento and San Joaquin Rivers and many of their tributaries including the Stanislaus, Tuolumne, Merced, and King Rivers
Sacramento Splittail	*Pogonichthys macrolepidotus*	—/CSC	Splittail spawn in shallow water over flooded vegetated habitat with a detectable water flow. Splittail larvae and juveniles remain in riparian or annual vegetation along shallow edges on floodplains	The Sacramento splittail is endemic to the San Francisco Estuary and watershed.
Sacramento perch	*Archoplites interruptus*	—/CSC	Historically found in the sloughs, slow moving rivers, and lakes of the central valley. Prefer warm water. Aquatic vegetation is essential for young. (Within native range only)	Found in isolated quarry lakes in the Livermore Valley and would not be affected by the Project.

Sources: CDFW 2012; Moyle 2002
Federal Status:
SC: Species of Concern
FE: Endangered
FT: Threatened
State Status:
SE: Endangered
ST: Threatened
CSC: Species of Special Concern

D.2.1 Anadromous Salmonids

The term anadromous salmonids refers to a group of fishes, including salmon and trout, that spend a portion of their life at sea, but return to spawn in fresh water. In the Central Valley, Chinook salmon and steelhead, the primary anadromous salmonids, share a common life history that typically includes passage through the Delta twice during their lifetime: once as juveniles emigrating to the ocean from the Sacramento and San Joaquin rivers and their tributaries where they were born, and again as adults on their return migration to their natal streams to spawn. Salmon die after spawning, but adult steelhead may return to the ocean after spawning and make the journey more than once. The timing of upstream migration and spawning varies, with runs of Chinook salmon identified by their spawning migration period. Four runs of Chinook salmon occur in the Sacramento River system: fall-run, late-fall-run, winter-run, and spring-run. Only spring- and winter-run Chinook salmon and Central Valley steelhead are listed under the federal and/or ESA and are described below.

D.2.1.1 Legal Status

D.2.1.1.1 Spring-run Chinook Salmon

The Central Valley Evolutionarily Significant Unit (ESU) of spring-run Chinook salmon is federally listed as Threatened and listed as Threatened by the State of California. Critical habitat for Central Valley spring-run Chinook salmon has been designated within specified stream reaches in Tehama, Butte, Glenn, Shasta, Yolo, Sacramento, Solano, Colusa, Yuba, Sutter, Trinity, Alameda, San Joaquin, and Contra Costa counties (70 FR 52488). Critical habitat includes the stream channels within the designated stream reaches, and includes a lateral extent as defined by the ordinary high-water line (33 CFR 329.11). Critical habitat in estuaries (e.g., San Francisco-San Pablo-Suisun Bay, Humboldt Bay, and Morro Bay) is defined by the perimeter of the water body as displayed on standard 1:24,000 scale topographic maps or the elevation of extreme high water, whichever is greater (70 FR 52488).

Essential Fish Habitat (EFH) has been designated for a number of species managed under a variety of fishery management plans and the Magnuson-Stevens Fishery Conservation and Management Act. For Chinook salmon, EFH overlaps and extends Critical Habitat designated for the individual ESUs. Essential Fish Habitat for Chinook salmon in California includes all streams, lakes, ponds, wetlands, and other water bodies currently or historically accessible to salmon in California. Chinook Salmon EFH excludes areas upstream of longstanding naturally impassible barriers (i.e., natural waterfalls in existence for several hundred years), but includes aquatic areas above all artificial barriers except specifically named impassible dams. Chinook Salmon EFH also extends from the nearshore and tidal submerged environments within State territorial waters out to the full extent of the exclusive economic zone (200 miles or 370.4 km) offshore of California north of Point Conception.

D.2.1.1.2 Winter-run Chinook Salmon

The Sacramento River ESU of winter-run Chinook salmon is federally listed as Endangered and listed as Endangered by the State of California. Critical habitat for Central Valley winter-run Chinook salmon has been designated and includes the following waterways and adjacent riparian zones: the Sacramento River from Keswick Dam, Shasta County to Chipps Island at the westward margin of the Delta; all waters from Chipps Island westward to the Carquinez Bridge, including Honker Bay, Grizzly Bay, Suisun Bay, and Carquinez Strait; all waters of San Pablo Bay westward of the Carquinez Bridge; and all waters of San Francisco Bay (north of the San Francisco/ Oakland Bay Bridge) from San Pablo Bay to the Golden Gate Bridge (58 FR 33212). Essential Fish Habitat for winter-run Chinook salmon is the same as described above for spring-run Chinook.

D.2.1.1.3 Central Valley Steelhead

The Central Valley Distinct Population Segment (DPS) of steelhead is federally listed as Threatened. Critical habitat for this DPS of steelhead has been designated within specified stream reaches in Tehama, Butte, Glenn, Shasta, Yolo, Sacramento, Solano, Yuba, Sutter, Placer, Calaveras, San Joaquin, Stanislaus, Tuolumne, Merced, Alameda, Contra Costa (70 FR 52488). Critical habitat includes the stream channels within the designated stream reaches, and includes a lateral extent as defined by the ordinary high-water line (33 CFR 329.11). Critical habitat in estuaries (e.g. San Francisco-San Pablo-Suisun Bay, Humboldt Bay, and Morro Bay) is defined by the perimeter of the water body as displayed on standard 1:24,000 scale topographic maps or the elevation of extreme high water, whichever is greater (70 FR 52488).

D.2.1.1.4 Central California Coast Steelhead

The Central California Coast Distinct Population Segment (DPS) of steelhead is federally listed as Threatened. Critical habitat for this DPS of steelhead has been designated within specified stream reaches in Lake, Mendocino, Sonoma, Napa, Marin, San Francisco, San Mateo, Santa Clara, Santa Cruz, Alameda, Contra Costa, and San Joaquin counties (70 FR 52488). Critical habitat includes the stream channels within the designated stream reaches, and includes a lateral extent as defined by the ordinary high-water line (33 CFR 329.11).

D.2.1.2 Distribution

D.2.1.2.1 Spring-run Chinook Salmon

Historically, spring-run Chinook salmon were found in the upper and middle elevation (1,000 to 6,000 feet) reaches of the San Joaquin, American, Yuba, Feather, Sacramento, McCloud, and Pit rivers, with smaller populations in most tributaries with sufficient habitat for over-summering adults (NMFS 2009:93). Naturally spawning populations of spring-run Chinook salmon spring-run have become restricted to only two self-sustaining populations (Mill and Deer Creek, Butte Creek) and anecdotal occurrences in other tributaries of the Sacramento (NMFS 2016). A restoration program has been underway since 2014 to re-establish spring-run Chinook salmon in the mainstem San Joaquin River below Friant Dam (NMFS 2016).

D.2.1.2.2 Winter-run Chinook Salmon

The historical distribution of winter-run spawning and rearing was limited to the upper Sacramento River and its tributaries, where spring-fed streams provided cold water throughout the summer, allowing for spawning, egg incubation, and rearing during the mid-summer period (Yoshiyama et al. 1998:490). The construction of Shasta Dam in 1943 blocked access to all of these waters except Battle Creek (NMFS 2009:79). The Battle Creek population was likely extirpated due to hydroelectric operations (Lindley et al. 2007). Currently only a single population exists in the reach of the Sacramento River between Keswick Dam near Redding and Red Bluff Diversion (Lindley et al. 2007, NMFS 2016b). Recent studies based on analyses of otolith isotopes as revealed that rearing habitat may include habitats not previously considered, including tributaries of the Feather and American Rivers, as well as Mill Creek and Deer Creek (Phillis et al. 2018).

D.2.1.2.3 Central Valley Steelhead

Prior to dam construction, water development and watershed perturbations, Central Valley steelhead were widely distributed throughout the Sacramento and San Joaquin rivers (McEwan 2001:13). Existing wild steelhead stocks in the Central Valley are mostly confined to the upper Sacramento River and its tributaries, including Antelope, Deer, and Mill creeks and the Yuba River. A few wild steelhead are produced in the American and Feather rivers (McEwan 2001:15). Until recently, steelhead were thought to be extirpated from the San Joaquin River system. Recent monitoring has detected small self-sustaining populations of steelhead in the Stanislaus, Mokelumne, and Calaveras rivers (NMFS 2014).

D.2.1.3 Relevant Natural History

D.2.1.3.1 Spring-run Chinook Salmon

Adult spring-run Chinook salmon enter freshwater in the spring, hold over the summer, and spawn in the fall. Adult spring-run Chinook salmon leave the ocean to begin their upstream migration in late January and early February (DFG 1998:III-6) and enter the Sacramento River between March and September, primarily in May and June (Fisher 1994:871 Table 1; Yoshiyama et al. 1998, p.489 Table 1). Adult spring-run Chinook salmon migrate from the Sacramento River into spawning tributaries primarily between mid-April and mid-June. Peak spring-run spawning generally occurs in September but may occur from mid-August to mid-October depending on water temperatures (NMFS 2009:94-95 Table 4-4).

Spring-run Chinook salmon fry emerge from the gravel from November to March (Yoshiyama et al. 1998:489 Table 1) and the emigration timing is highly variable, as they may migrate downstream as young-of-the-year, as juveniles, or as yearlings. Depending on flow conditions in their natal streams and the Sacramento River, spring-run Chinook salmon fry may enter the Delta as early as January and as late as June; yearlings can enter the Delta from October to March or April (DFG 1998:III-9). Spring-run juveniles have been observed rearing in the lower reaches of non-natal tributaries and intermittent streams in the Sacramento Valley during the winter months (Maslin et al. 1997:17 Table 2).

D.2.1.3.2 Winter-run Chinook Salmon

Adult winter-run Chinook salmon enter freshwater in winter or early spring, and delay spawning until spring or early summer; juvenile winter-run Chinook salmon emigrate to the sea after only 5 to 9 months of river and estuary life (NMFS 1997:II-1). Adults enter San Francisco Bay from November through June, enter the Sacramento River basin between December and July, and migrate past the Red Bluff Diversion Dam (RBDD) from mid-December through early August (NMFS 1997:II-3). Spawning occurs primarily in the reach between Keswick Dam and RBDD primarily from mid-April to mid-August, with the peak occurring in May and June (Yoshiyama et al. 1998:489 Table 1).

Winter-run fry begin to emerge from the gravel in late June to early July and emergence continues through October (Fisher 1994:871 Table 1). Emigration of juvenile winter-run past RBDD may begin as early as mid-July, typically peaks in September, and can continue through March in dry years (NMFS 1997:II-4). Juvenile winter-run Chinook salmon occur in the Delta primarily from November through early May (USFWS 2001. p. 16 Table 3). The timing of migration may vary somewhat due to changes in river flows, dam operations, and water year type (NMFS 2009:81). Winter-run juveniles remain in the Delta until 5 to 10 months of age, and then begin emigrating to the ocean from November through May (Fisher 1994:871 Table 1). Recent analyses of isotopes in juvenile otoliths suggest that a wide diversity of previously unknown habitats are used as rearing locations including Mill Creek, Deer Creek, Feather River and the American River (Phillis et al. 2018). Chinook typically will spend two to three years in the ocean, before returning to spawn.

D.2.1.3.3 Central Valley Steelhead

Central Valley steelhead generally leave the ocean and begin their upstream migration in August and September (Busby et al. 1996:22 Table 3). They spawn from December through April, with peak spawning activity from January through March, in small headwater streams and tributaries where cool, well oxygenated water is available year-round (Hallock et al. 1961:16; McEwan and Jackson 1996:19). Timing of upstream migration is correlated with higher flow events, such as freshets, with associated lower water temperatures (NMFS 2009:104). Steelhead fry usually emerge from the gravel about 4 to 6 weeks after hatching, but factors such as redd depth, gravel size, siltation, and temperature can affect emergence timing (Shapovalov and Taft 1954:156). Newly emerged fry move to the shallow, protected areas associated with the stream margin (McEwan and Jackson 1996), but soon move to other areas of the stream and establish and defend feeding territories (Shapovalov and Taft 1954:156).

Juvenile steelhead in the Sacramento River basin migrate downstream during most months of the year, but the peak period of emigration occurs in the spring, with a much smaller peak in the fall (Hallock et al. 1961, p.14; Nobriga and Cadrett 2001:32-33 Figure 3). Emigrating Central Valley steelhead use the lower reaches of the Sacramento River and the Delta for rearing and as a migration corridor to the ocean. Some juvenile steelhead may rear in tidal marsh areas, and connected non-tidal freshwater marshes and other shallow water areas in the Delta for short periods prior to their final emigration to the ocean (NMFS 2009:106).

D.2.1.4 Threats

Access to most of the historical upstream spawning habitat for Chinook salmon and steelhead has been eliminated or degraded by manmade structures (e.g., dams and weirs) associated with water storage, conveyance, flood control, and diversions and exports for municipal, industrial, agricultural, and hydropower purposes (Yoshiyama et al. 1998:500; McEwan 2001:15; Lindley et al. 2006:2). Upstream diversions and dams have decreased downstream flows and altered the seasonal hydrologic patterns. Reduced flows from dams and upstream water diversions result in spawning delays, increased straying, and increased mortality of outmigrating juveniles (Yoshiyama et al. 1998:501; DWR 2005).

Channel margins throughout the Delta have been leveed, channelized, and fortified with riprap for flood protection and island reclamation, which generally degrades the quality of habitat available for juvenile rearing. Modification of natural flow regimes due to upstream reservoir operations has resulted in a reduction in the extent and duration of seasonal floodplain inundation and other flow dependent habitat used by migrating juvenile Chinook salmon (70 FR 52488, Sommer et al. 2001:326; DWR 2005). Reduced flows have also resulted in increased water temperatures, increased residence times, and reductions in dissolved oxygen levels in localized areas of the Delta (e.g., Stockton Deep Water Ship Channel) that adversely affect the quality of rearing habitat for juvenile salmonids.

Predation on juvenile salmon by nonnative fish has been identified as an important threat to salmon and steelhead in areas with high densities of nonnative fish (e.g., smallmouth and largemouth bass, striped bass, and catfish) that prey on outmigrating juveniles (Lindley and Mohr 2003:321). The invasion of nonnative aquatic vegetation, such as Brazilian waterweed and water hyacinth, has provided suitable habitat for nonnative fish that prey on juvenile salmon and steelhead (Brown and Michniuk 2007:196). Channelized waterways (e.g., riprap-lined levees) provide virtually no cover protection from predators and little spatial diversity.

Juvenile salmonids are also subject to entrainment at the SWP and CVP export facilities, various smaller facilities, and agricultural diversions in the Delta, although the level of entrainment at the SWP and CVP facilities is regulated by the resource agencies. Changes in environmental cues as a result of SWP and/or CVP export operations during the migration period may contribute to delays in migration, attraction to false migration pathways, or increased movement of migrating salmon toward the export facilities, which increases the risk that these fish will be entrained into the fish salvage facilities. For example, net water movement in the central and southern Delta towards the pumping facilities may alter the migratory cues for emigrating fish in these regions (NMFS 2009). Unscreened or insufficiently screened intakes can result in the entrainment of juvenile salmonids into these agricultural diversions. Many juvenile salmon migrate downstream through the Delta during the late winter or early spring when many of the agricultural irrigation diversions are not operating or are only operating at low levels. The effect of entrainment mortality on salmonid population dynamics and overall adult abundance is not well understood.

Operation of the CVP and SWP water projects alter flow patterns in the Delta and create entrainment issues in the Delta at the pumping and fish facilities (NMFS 2009:131). At the SWP and CVP export facilities, multiple factors influence the vulnerability of juvenile salmonids to entrainment, including their geographic distribution within the Delta and hydrodynamic factors such as reverse flows in Old and Middle rivers. Salmonids respond behaviorally to various cues (e.g., water currents, salinity) during both upstream adult and downstream juvenile migration through the Delta. Changes in these cues as a result of SWP and/or CVP export operations during the migration period may result in delays in their migration. This can increase their time of residence in the Delta, which may make them more vulnerable to entrainment into the central and southern Delta waterways, and increase their exposure to predation within the central and southern Delta waterways (NMFS 2009:313).

As a result of the extensive agricultural development within the Central Valley, exposure to pesticides and herbicides has been identified as a significant concern for salmon and other fish species (Bennett et al. 2001, p.2). Other contaminants of concern for salmonids include, but are not limited to, mercury, copper, oil and grease, ammonia, and localized areas of depressed dissolved oxygen (e.g., Stockton Deep Water Ship Channel). In addition, sublethal concentrations of toxics may interact with other stressors on salmonids, increasing their vulnerability to mortality as a result of exposure to seasonally elevated water temperatures, predation, or disease (Werner 2007, slide 25).

Chinook salmon and steelhead are subject to illegal harvest (poaching) in inland waters. Adult spring-run Chinook salmon are particularly vulnerable because they hold in pool habitat within streams where they are easily accessible during the summer months. The level and effect of illegal harvest on salmon abundance and reproduction is unknown.

Hatchery produced salmon and steelhead in the Central Valley also present multiple threats to wild salmonid populations, including competition for food and habitat, direct predation on wild fish, and interbreeding with wild fish that can reduce their genetic fitness (NMFS 2009:143; Goodman 2005; p. 374). Hatchery production has been shown to negatively affect the genetic diversity and fitness of wild salmonid populations. Moderate to high numbers of hatchery fish may impact the genetic diversity of wild populations of Central Valley salmon. Hatchery fish compete with wild fish for food, habitat, and mates. Hatchery fish are frequently less productive than wild fish. Nonetheless, a very large portion of the existing genetic diversity in Central Valley salmonids is contained in hatchery origin stocks and, in some cases, properly managed hatchery stocks may be important contributors to recovery of the species.

D.2.1.5 Relevant Conservation Efforts and Guidance

Current conservation efforts and guidance for anadromous salmonids are provided primarily by National Marine Fisheries Service (NMFS) in its 2019 Biological Opinion for the Reinitiation of the Long-term Operation of the Central Valley Project (CVP) and State Water Project (SWP) and the 2014 Recovery Plan for the Evolutionarily Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the Distinct Population Segment of Central Valley Steelhead (NMFS 2019; NMFS 2014).

D.2.2 Delta Smelt

D.2.2.1 Legal Status

Delta smelt were listed as a threatened species under both the federal ESA and the California ESA in 1993. In 2009, the California Fish and Game Commission elevated the status of delta smelt to Endangered under the California ESA in response to an emergency petition. Critical habitat for Delta smelt was designated by USFWS in 1995 (59 FR 65256). The designated critical habitat extends throughout Suisun Bay (including Grizzly and Honker bays), the length of Goodyear, Suisun, Cutoff, first Mallard and Montezuma sloughs, and the contiguous waters of the legal Delta.

D.2.2.2 Distribution

The Delta Smelt is restricted to an area extending from the Sacramento River at the confluence of Feather, south to the fork of the San Joaquin and Old rivers, and west into the San Pablo Bay, an area of approximately 51,800 ha (Moyle et al. 2016). Delta Smelt distribution is highly dependent on life stage, however it is usually confined within or upstream of the estuary's low salinity zone (<7psu) (Bennet 2005, Komoroske et al. 2015). The distribution is variable, based on life stage. This variability has led to rare observations of Delta Smelt North to Knights Landing on the Sacramento River, East in to Woodbridge on the Mokelumne River, South down to Mossdale on the San Joaquin, and West out to the San Francisco Bay (USFWS 2017). Recently their distribution, especially during summer and fall, has become restricted to the north, east and west Delta as warmer temperatures and clearer water in the central and south Delta likely cause survival to drop (Merz et al. 2011, Moyle et al. 2016). Distribution is often referred to in relation to X_2, the physical location of the 2ppt salinity isohaline along the axis of the Delta Estuary (Jassby et al. 1995).

D.2.2.3 Relevant Natural History

Delta smelt spawn in the freshwater reaches of the San Francisco estuary, primarily in the Delta. Adult delta smelt spawn during the late winter and spring months, with most spawning occurring during April through mid-May (Moyle 2002:229). After hatching, larvae disperse into low salinity habitats, generally moving into Suisun Bay, Montezuma Slough, and the lower Sacramento River below Rio Vista as they mature (Grimaldo et al. 1998:27). In general, delta smelt prefer to rear in or just above the region of the estuary where fresh water and brackish water mix as a result of tidal and river currents; this region is typically in Suisun Bay (Bennett 2005:11).

D.2.2.4 Threats

Because of their short life span (one or two years), low fecundity, current low abundance and limited geographic range, changes in the Delta have influenced the distribution and abundance of delta smelt in complex and synergistic ways. Delta smelt have been affected by loss of habitat and reductions in the quality of their habitat, largely as a result of changes in Delta inflows that affect salinity and human activities such as wetland and floodplain reclamation. The amount of spawning habitat may have been reduced as a result of reclamation, channelization, and riprapping of historical intertidal and shallow subtidal wetlands.

Delta smelt are lost to entrainment in the CVP and SWP water export facilities, various smaller facilities, and agricultural diversions in the Delta, most of which are unscreened or inadequately screened (Herren and Kawasaki 2001:343). The risk of entrainment to delta smelt varies seasonally and among years. Modeling has shown that up to 25% of larval or juvenile smelt and as much as 50% of the adult population may be entrained by increased pumping activities during high export years (Kimmerer 2008). In addition, the CVP and SWP water export facilities and other diversions export phytoplankton, zooplankton, nutrients, and organic material that would otherwise support the base of the food web in the Delta, thus reducing food availability for delta smelt (Jassby and Cloern 2000:345; Resources Agency 2007:21).

The introduction and invasion of nonnative species has also contributed to adversely affecting delta smelt. Introduced clams have reduced phytoplankton and zooplankton abundance throughout the region (Thompson 2007, slide 8) and altered the abundance and species composition of the zooplankton (Jassby et al. 2002:699). Changes in the zooplankton species composition have affected the quality of food resources available to delta smelt because some of the nonnative zooplankton species are less suitable as a food resource than the native species (Resources Agency 2007:16). Delta Smelt are likely not particularly susceptible to predation due to their low abundances and habitat requirements which are not favored by predators. While Largemouth Bass will consume Delta Smelt in aquaculture (Ferrari et al. 2014), there is limited habitat overlap and like many other potential predators for Delta Smelt, their ambush predatory tactics and generalist diet makes them a low risk for the rare smelt (Moyle et al. 2016). Mississippi silverside (*Menidia beryllina*) is a more likely predator for smelt eggs and larvae as their abundances are high in habitats and areas where Delta Smelt may spawn (Bennett 2005, Baerwald et al. 2012).

Brazilian waterweed and water hyacinth (both introduced plants) grow in dense aggregations and can indirectly affect delta smelt by reducing dissolved oxygen levels, suspended sediment concentrations and turbidity within the water column. Reduced turbidity as a result of these plants and filter feeding by the introduced clams may reduce foraging efficiency and increase the vulnerability of delta smelt to predation. Because of the structure and shade they provide, these aquatic plants also create excellent habitat for bass and sunfish, nonnative predators of delta smelt.

Numerous toxic chemicals including agricultural pesticides, herbicides, heavy metals, and other agricultural and urban product can enter delta smelt habitat from a variety of sources. Chemicals, such as pesticides, herbicides, endocrine disrupting compounds, and metals may have lethal and sublethal effects on delta smelt that make them more vulnerable to other sources of mortality (Werner 2007).

D.2.2.5 Relevant Conservation Efforts and Guidance

Current conservation efforts and guidance for Delta smelt are provided primarily by USFWS in its 2019 Biological Opinion for the Reinitiation of the Long-term Operation of the Project CVP and SWP (USFWS 2019). The 1996 Delta Native Fishes Recovery Plan provided initial guidance on recovery of delta smelt; however, that document is out of date and currently under revision by USFWS.

D.2.3 Green Sturgeon

D.2.3.1 Legal Status

The southern DPS of green sturgeon is federally listed as Threatened. Critical habitat for this green sturgeon DPS has been designated and includes the Sacramento River, lower Feather River, and lower Yuba River in California; and the Sacramento-San Joaquin Delta and Suisun, San Pablo, and San Francisco bays in California (74 FR 52300).

D.2.3.2 Distribution

In the Pacific Ocean, green sturgeon range from the Bering Sea, Alaska, to Ensenada, Mexico. Green sturgeon occupy freshwater rivers from the Sacramento River up through British Columbia (Moyle 2002:110), but spawning has been confirmed in only three rivers: the Rogue River in Oregon and the Klamath and Sacramento rivers in California. Based on genetic analyses and spawning site fidelity (Adams et al. 2002:12; Israel et al. 2004:926), NMFS determined that are at least two distinct population segments of green sturgeon. Green sturgeon in the Delta and Sacramento River Basin belong to the southern DPS, consisting of populations originating from coastal watersheds south of the Eel River ("Southern DPS"). Spawning of Southern DPS Green Sturgeon primarily occurs in the mainstem Sacramento River although a spawning event was documented in 2011 in the lower Feather River at the Thermalito Afterbay Outlet (Seesholtz et al. 2012).Relevant Natural History

Green sturgeon spend a large portion of their lives in coastal marine waters as subadults and adults. Subadult male and female green sturgeon spend at least approximately 6 and 10 years at sea, respectively, before reaching reproductive maturity and returning to freshwater to spawn for the first time (Nakamoto et al. 1995:iv, 14). Adult green sturgeon spend as many as 2 to 4 years at sea between spawning events (70 FR 17386, April 6, 2005; Erickson and Webb 2007:264). Adults typically begin their upstream spawning migration in the spring and either migrate downstream after spawning, or reside within the river over the summer (Erickson et al. 2002:568; Benson et al. 2007:10-12). Subadults may also migrate upstream, but for unknown purposes. Adults and subadults occupy the San Francisco Bay, San Pablo Bay, Suisun Bay, and the Delta adjacent to the Sacramento River. Adults and subadults primarily inhabit the Delta and bays during summer months, most likely for feeding and growth (Kelly et al. 2007:292).

D.2.3.3 Threats

Like the anadromous salmonids, access to historical spawning habitat for green sturgeon has been reduced by construction of migration barriers, such as major dams, that block or impede access. The locks at the end of the Sacramento River Deep Water Ship Channel at the connection with the Sacramento River block migration of fish from the deep water ship channel back to the Sacramento River (DWR 2005:3-49). In addition, green sturgeon are attracted by high floodwater flows into the Yolo Bypass basin and then concentrate behind Fremont Weir, which blocks passage and may strand sturgeon when flood flows recede (DWR 2005:4-16). Larval and juvenile sturgeon are susceptible to entrainment in multiple diversions along the Sacramento and Feather rivers.

Reclamation of wetlands and islands have reduced and degraded the availability of rearing habitat for green sturgeon. The impacts of channelization and riprapping are thought to affect all life stages. Dredging operations to maintain commercial and recreational vessel passage in the Sacramento and San Joaquin rivers, and the navigation channels within the Delta, and Suisun, San Pablo, and San Francisco bays pose risks to bottom dwelling fish such as green sturgeon through entrainment. In addition, dredging operations can decrease the abundance of locally available prey species, contribute to resuspension of toxics such as ammonia, hydrogen sulfide, and copper during dredging and dredge spoil disposal, and alter bathymetry and water movement patterns.

Green sturgeon are vulnerable to recreational sport fishing within the Bay-Delta estuary and Sacramento River. Regulations require the release of green sturgeon caught incidentally, but illegal harvest may still occur. High water temperatures in the Feather River and San Joaquin River may affect sturgeon migration, spawning, and egg development. Water temperatures in the Sacramento River may no longer be a major concern for green sturgeon because temperatures in the upper Sacramento River are actively managed for Sacramento River winter-run Chinook salmon. Juvenile sturgeon are also exposed to increased water temperatures in the Delta during the late spring and summer due to the loss of riparian shading and by thermal inputs from municipal, industrial, and agricultural discharges.

Subadults and adults feeding in bays and estuaries may be exposed to contaminants that may affect their growth and reproduction (Fairey et al. 1997:1063 Table 2; Greenfield et al. 2005:33 Table 2). Studies on white sturgeon in estuaries indicate that the bioaccumulation of pesticides and other contaminants adversely affects growth and reproductive development and may result in decreased reproductive success (Kruse and Scarnecchia 2002:437; Feist et al. 2005:1681). Green sturgeon are believed to experience similar risks from contaminants (70 FR 17386, April 6, 2005). Because green sturgeon spend more time in marine waters than white sturgeon, they may have less exposure to contaminants in estuaries compared to white sturgeon. However, green sturgeon may be more sensitive than white sturgeon to certain contaminants found in coastal estuaries, including methylmercury and selenium, that affect their routine and active metabolic rates, swimming performance, and ability to avoid predators (Kaufman et al. 2008, slide 20).

D.2.3.4 Relevant Conservation Efforts and Guidance

Current conservation efforts and guidance for green sturgeon are provided primarily by National Marine Fisheries Service (NMFS) in its 2019 Biological Opinion for the Reinitiation of the Long-term Operation of the CVP and SWP (NMFS 2019).

D.2.4 Longfin Smelt

D.2.4.1 Legal Status

Longfin smelt are listed as Threatened by the State of California. In 2009, the USFWS issued a 12-month finding concluding that the Delta population of longfin smelt did not meet the definition of a distinct population segment, and therefore did not qualify for listing under the federal ESA. Shortly thereafter, the Center for Biological Diversity and The Bay Institute filed a lawsuit challenging the Service’s decision. On February 2, 2011, the United States District Court for the Northern District of California approved a settlement agreement between the USFWS, the Center for Biological Diversity, and The Bay Institute, obligating the USFWS to reconsider the status of the longfin smelt, including the San Francisco Bay-Delta population. Under the terms of the settlement, the USFWS must conduct a rangewide review of the species and issue a new listing determination by September 30, 2011. No critical habitat for this species has been designated.

D.2.4.2 Distribution

The historical and current range of the longfin smelt is from Alaska southward to the San Francisco Bay-Delta in California (77 FR 19756). In California, longfin smelt are known from the Klamath River, Humboldt Bay and its tributaries, the Eel River, the Van Duzen River, the Russian River, and the San Francisco Bay-Delta (Moyle 2002:235-236). During its life cycle, the longfin smelt uses the entire estuary from the freshwater Sacramento-San Joaquin Delta downstream to South San Francisco Bay and out into coastal marine waters (Baxter 1999:180; Moyle 2002:236; Rosenfield and Baxter 2007:1590). Longfin smelt are dispersed broadly in the San Francisco Bay-Delta estuary by high outflows and currents, which could transport larvae or small juveniles long distances before they mature and start living near the bottom of the water column (77 FR 19756).

D.2.4.3 Relevant Natural History

The longfin smelt is a euryhaline (tolerant of variable salinities) pelagic fish that inhabits various depths of the water column depending on the individual's life stage. Longfin smelt reportedly cannot tolerate water temperatures greater than 68 ºF (20 ºC) (Moyle 2002:236), and will move farther downstream (west) during the summer months when water temperatures in the Delta are higher. Longfin smelt have been found throughout the year in fresh and brackish waters with salinities ranging from 14 to 28 parts per thousand (ppt) (DFG 2001:477).

Longfin smelt may spawn as early as November and as late as June, although spawning typically occurs from February to April (Moyle 2002:236). However, longfin smelt at various life stages are detected in the San Francisco Bay estuary trawl surveys in numerous months of the year (Rosenfield and Baxter 2007:1587), suggesting that the spawning period may not be restricted to November to June or that growth and development between individuals varies. Spawning occurs in areas of relatively low salinity, which are considered essential nursery habitat for estuarine organisms. Spawning usually occurs over rocky or gravelly substrates and aquatic plants (Moyle 2002:236). Newly hatched embryos are transported in the upper portion of the water column downstream (west) into more brackish parts of the San Francisco Bay-Delta system (Moyle 2002:236). Longfin smelt usually live for 2 years, although some individuals may spawn as 1- or 3-year-old fish, and die soon after spawning (Moyle 2002:236).

Longfin smelt first begin feeding on copepods and cladocerans. With subsequent growth, their diet expands to include mysids and amphipods among a variety of lesser food items (Slater 2008:418). Longfin smelt are preyed upon by fishes, birds, and mammals (Barnhart et al. 1992:44). A composite index of predatory fish density in Central Bay and San Pablo Bay was found to be negatively associated with trends in Longfin Smelt abundance in population dynamics modeling by Maunder et al. (2015).

D.2.4.4 Threats

Due to their similarity in habitat use, longfin smelt are subject to many of the same stressors and population threats as delta smelt (see discussion above).

Additionally, Jeffries et al. (2016) examined physiological performance in larval/young juvenile Longfin Smelt in relation to water temperature in a laboratory study and concluded that Longfin Smelt may be more susceptible than Delta Smelt to increases in temperature, and therefore Longfin Smelt may have little tolerance for future warming in California under climate change. By comparison to Delta Smelt (Brown et al. 2013, 2016), climate change could result in detrimental effects on Longfin Smelt ecology related to factors such as maturation and spawning season length and timing, as well as reduction in habitat extent.

D.2.4.5 Relevant Conservation Efforts and Guidance

Longfin smelt are being managed through a protective State regulation that governs SWP and CVP operations in the south Sacramento-San Joaquin Delta, research and monitoring, local water diversions and the State water Project North Bay Aqueduct, dredging, and sand mining.

D.2.5 Sacramento Splittail

D.2.5.1 Legal Status

Sacramento splittail are not listed under the State (CESA) or federal ESA, but are considered a California species of special concern.

D.2.5.2 Distribution

Adult splittail spawn within the mainstem rivers and major tributaries to the Delta upstream in the Extended Planning Area. Adult splittail spawn on inundated floodplains of the Yolo Bypass and Cosumnes River. Collection of larvae and young juveniles indicates that inundation of terrestrial habitat within the levees of the San Joaquin River also provides suitable spawning habitat (Moyle et al. 2004). Larvae and young juveniles begin their migration downstream through the Delta with rising water temperatures during the spring; such migrations often occur in late-April, May, or even June of high flow years (Moyle et al. 2004). In low flow years, juvenile splittail are most abundant in the northern and western regions of the Delta; in high flow years, their distribution is more even throughout the Delta (Sommer et al. 2009). Most late stage juveniles and non-reproductive adults inhabit moderately shallow (<4 m) brackish and freshwater tidal sloughs and shoals, such as those found in Suisun Marsh and the margins of the lower Sacramento River (Moyle et al. 2004).

D.2.5.3 Relevant Natural History

The Adult splittail begin a gradual upstream migration towards spawning areas sometime between late November and late January. The relationship between migrations and river flows is poorly understood, but it is likely that splittail have a positive behavioral response to increases in flows. Feeding in flooded riparian areas in the weeks just prior to spawning may be important for later success of spawning and for post-spawning survival. Evidence of splittail spawning on floodplains has been found on both the San Joaquin and Sacramento Rivers. In the San Joaquin River drainage, spawning has apparently taken place in wet years in the region where the San Joaquin River is joined by the Tuolumne and Merced Rivers. Spawning has also been documented on flooded areas along the lower Cosumnes River (Crain et al. 2004).

Spawning may take place elsewhere in the Delta (e.g., on mid-channel islands) but it has not been documented.

D.2.6 Pacific Lamprey and River Lamprey

D.2.6.1 Legal Status

The river lamprey and pacific lamprey are not listed under the federal or State ESA. River lamprey is considered a species of special concern by the State of California. Pacific Lamprey is considered a Federal species of concern.

D.2.6.2 Distribution

In the Central Valley, river lamprey are found in the lower Sacramento and San Joaquin River drainages, including the Stanislaus and Tuolumne Rivers. They may exist in other tributaries of these rivers, but are easily overlooked and have been the subject of few targeted sampling efforts (Moyle 2002). The species appears to be more abundant in the lower Sacramento-San Joaquin River system than in other streams in California.

D.2.6.3 Relevant Natural History

The Pacific lamprey are anadromous, beginning their migration into freshwater towards upstream spawning areas primarily between early March and late June (Moyle 2002). Most upstream migration occurs at night and occurs in pulses. Spawning habitat requirements are thought to be similar to those of salmonids. There is some evidence that lamprey in larger river systems, such as the Klamath and Eel Rivers, have distinct runs similar to Chinook salmon (Moyle 2002). Both sexes contribute to nest construction by removing larger stones from a gravelly substrate, creating a shallow depression. These simple nests occur in gravelly substrata with moderately swift current, water temperatures typically of 12-18 degrees Celsius, and at a depth of 30-150 centimeters (Moyle 2002). External fertilization of eggs occurs just in front of the nest and are then washed into the nest. Fecundity is unknown. Spawning is repeated until both individuals are spent. Adults typically die after spawning. The eggs hatch into ammocoetes after approximately 19 days at 15 degrees Celsius, spend a short time in the nest, and then drift downstream to suitable area in sand or mud (Moyle 2002).

Ammocoetes remain in freshwater for approximately 5 to 7 years, where they bury into silt and mud and feed on algae, organic material, and microorganisms. Ammocoetes change locations during this stage. Ammocoetes begin metamorphosis into macropthalmia (juveniles) when they reach 14-16 centimeters TL. Individuals develop external features (eyes, oral disc, and color changes) and experience internal and physiological changes that prepare them for their predatory life stage in the ocean (McPhail and Lindsey 1970). Downstream migration begins upon completion of this metamorphosis, generally coinciding with high flow events in winter and spring (Moyle 2002).

Adults spend 3-4 years in the ocean in British Columbia, but this length is thought to be shorter in more southern areas (Moyle 2002). Adult remain close to the mouths of the rivers from which they came, likely because their prey is most abundant in estuaries and other coastal areas (Moyle 2002). Individuals attack a wide variety of fishes, include salmon, Pacific herring, and flatfishes, in the ocean (Beamish 1980). Pacific lamprey are thought to be preyed upon in the ocean by sharks, other fish, otters, seals, and sea lions (Moyle 2002).

D.2.6.4 Threats

Artificial barriers, including dams, culverts, water diversions, tidal gates, and other barriers, can impede or completely block the upstream migration of adults to spawning grounds, resulting in impacts to the distribution and abundance of lamprey (Luzier et al. 2009). Lamprey adults may have difficulty passing over barriers using ladders and other passage structures designed for salmonids, possibly due to high water velocity, sharp angles, culverts with drop-offs, or insufficient resting areas (Kostow 2002).

Artificial barriers, including dams, culverts, water diversions, tidal gates, and other barriers, can impede or completely block the downstream migration of ammocoetes and macropthalmia towards the ocean, resulting in impacts to the distribution and abundance of lamprey (Luzier et al. 2009). Pacific lamprey populations cannot persist for more than a few years above impassable barriers (Beamish and Northcote 1989).

D.2.6.5 Relevant Conservation Efforts and Guidance

Along with several tribes, state and federal agencies are increasingly incorporating of Pacific lamprey into management and monitoring plans to increase the state of knowledge and conserve the species.

D.2.7 Hardhead

D.2.7.1 Legal Status

Hardhead are not listed under the State or federal ESA, but are considered a California species of special concern.

D.2.7.2 Distribution

Hardhead is a native species that is widely distributed in low to mid-elevation streams in the Sacramento and San Joaquin drainages.

D.2.7.3 Relevant Natural History

Stream dwelling juvenile (<150 mm SL) hardhead are often found in small aggregations in pools and runs during the day, actively feeding at the water's surface, holding in moving water to feed on drifting material, or browsing from the benthos (Moyle 2002). Adults tend to school in the deepest part of pools, cruising about slowly during the day. They are most active when feeding, in early morning and evening (Moyle 2002). In small streams, they seldom move more than one kilometer away from home pools, except when spawning.

Hardhead mature following their second year and spawn in the spring, mainly in April and May (Moyle 2002) judging by the upstream migrations of adults into smaller tributary streams during this time of the year. Estimates based on juvenile recruitment suggest that hardhead spawn by April-June in Central Valley streams, although the spawning season may occasionally extend into August in the foothill streams of the Sacramento-San Joaquin drainage.

D.2.7.4 Threats

The apparent ongoing declines in hardhead distribution and abundance are a result of synergistic impacts from habitat loss, decline in water quality, and invasions of alien species (Moyle 2002). The principal threats to hardhead include: (1) dams and diversions, (2) agriculture, (3) urbanization, (4) instream mining, (5) stream modification for transportation, (6) fisheries management ('harvest' associated with past eradication of 'rough fishes' to benefit recreational fisheries), and (7) alien species.

D.2.8 Riffle Sculpin

D.2.8.1 Legal Status

Riffle Sculpin is considered a Federal species of concern.

D.2.8.2 Distribution

Riffle sculpin are found in many increasingly isolated watersheds in the Central Valley drainage and the central coast. In tributaries to the San Joaquin River, they are present from the Mokelumne River south to the Kaweah River. They are mostly present in mid-elevation reaches, although they are present below dams with coldwater releases. In the Sacramento River drainage, they are present in Putah Creek on the west side and most tributaries on the east side, from the American River north to the upper Sacramento and McCloud rivers.

D.2.8.3 Relevant Natural History

Riffle sculpin are found exclusively in permanent cold-water streams. Riffle sculpins eat mainly benthic invertebrates, primarily active insect larvae such as those of caddisflies, stoneflies, and mayflies (Moyle 2002). However, they will consume other prey that is readily available, such as amphipods and small fish, including other sculpins. Riffle sculpins live in permanent, cool, headwater streams where riffles and rocky substrates predominate.

D.2.9 Sacramento Hitch

D.2.9.1 Legal Status

Hardhead are not listed under the State or federal ESA, but are considered a California species of special concern.

D.2.9.2 Distribution

Hitch were once found throughout the Sacramento and San Joaquin valleys in low elevation streams and rivers, as well as in the Delta. Today they are absent from the San Joaquin River and the lower reaches of its tributaries from Friant Dam down to the Merced River. In the Sacramento River, hitch appear to be spread across much of their native range, up to and including Shasta Reservoir.

D.2.9.3 Relevant Natural History

Sacramento hitch are omnivorous and feed upon zooplankton and insects, usually in open waters or at the surface of streams (Moyle 2002). In streams, they feed on filamentous algae, aquatic insects and terrestrial insects. Sacramento hitch inhabit warm, lowland, waters including clear streams, turbid sloughs, lakes and reservoirs. In streams they are generally found in pools or runs among aquatic vegetation, although small individuals will also use riffles.

D.2.9.4 Threats

The Sacramento hitch occur in the lowland reaches of rivers and streams most impacted by human use, as well as in some reservoirs. Given that they persist in some urban streams, it appears hitch are capable of surviving in highly altered habitats although their abundance in such extreme environments is likely limited. Best evidence indicates that their populations are localized and fragmented today which, in turn, suggests that they may be particularly susceptible to a combination of anthropogenic stressors, including dams, polluted run-off from agricultural lands, rural and urban development, and introduction of invasive predator species.

D.3 References

Adams, P. B., C. B. Grimes, S. T. Lindley, and M. L. Moser. 2002. Status review for North American green sturgeon, *Acipenser medirostris*. National Oceanic and Atmospheric Administration, National Marine Fisheries Service, Southwest Fisheries Science Center, Santa Cruz, CA.

Baerwald, M. R., Schreier, B. M., Schumer, G., & May, B. 2012. Detection of threatened Delta Smelt in the gut contents of the invasive Mississippi Silverside in the San Francisco Estuary using TaqMan assays. Transactions of the American Fisheries Society, 141(6), 1600-1607.

Barnhart, R. A., M. J. Boyd, and J. E. Pequegnat. 1992. The ecology of Humboldt Bay, California: An estuarine profile. U.S. Fish and Wildlife Service.

Baxter, R. 1999. Osmeridae. pp. 179-216 in Orsi, J., (ed). Report on the 1980-1995 fish, shrimp, and crab sampling in the San Francisco Estuary, California. Interagency Ecological Program Technical Report 63.

Beamish, R. J., and T. G. Northcote. 1989. Extinction of a population of anadromous parasitic lamprey Lampetra tridentata upstream of an impassable dam. Canadian Journal of Fisheries and Aquatic Sciences 46:420-425.

Bennett, J., J. Hofius, C. Johnson, and T. Maurer. 2001. Tissue residues and hazards of waterborne pesticides for federally listed and candidate fishes of the Sacramento-San Joaquin River Delta, California: 1993–1995. U.S. Fish and Wildlife Service. Environmental Contaminants Division. Sacramento, CA. July 2001.

Bennett, W. A. 2005. Critical assessment of the delta smelt population in the San Francisco Estuary, California. San Francisco Estuary and Watershed Science. Vol. 3, Issue 2 (September 2005), Article 1.

Benson, R. L., S. Turo, and B. W. McCovey Jr. 2007. Migration and movement patterns of green sturgeon (*Acipenser medirostris*) in the Klamath and Trinity rivers, California, USA. *Environmental Biology of Fishes* 79:269–279.

Brown, L. R., W. A. Bennett, R. W. Wagner, T. Morgan-King, N. Knowles, F. Feyrer, D. H. Schoellhamer, M. T. Stacey, 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. Brown, L. R., and D. Michniuk 2007. Littoral fish assemblages of the alien-dominated Sacramento–San Joaquin Delta, California 1980–1983 and 2001–2003. *Estuaries and Coasts* 30: 186–200.

Brown, L. R., L. M. Komoroske, R. W. Wagner, T. Morgan-King, J. T. May, R. E. Connon, and N. A. Fangue. 2016. Coupled Downscaled Climate Models and Ecophysiological Metrics Forecast Habitat Compression for an Endangered Estuarine Fish. PLoS One 11(1):e0146724.

Busby, P. J., T. C. Wainwright, G. J. Bryant., L. Lierheimer, R. S. Waples, F. W. Waknitz, and I. V. Lagomarsino. 1996. Status review of west coast steelhead from Washington, Idaho, Oregon and California. U.S. Department of Commerce, National Oceanic and Atmospheric Administration Technical Memo NMFS-NWFSC-27. 261 pages.

California Department of Fish and Game (DFG). 1998. A status review of the spring run Chinook salmon in the Sacramento River drainage. Report to the Fish and Game Commission. Candidate species status report 98-1. Sacramento, CA. June.

———. 2001. *California's Living Marine Resources: A Status Report*. December.

California Department of Water Resources (DWR). 2005. Bulletin 250. Fish Passage Improvement. Available: http://www.water.ca.gov/fishpassage/publications/B250.cfm.

Crain, P. K., K. Whitener, and P. B. Moyle. 2004. Use of a restored central California floodplain by larvae of native and alien fishes. In Feyrer, F., L. R. Brown, R. L. Brown, and J. J. Orsi, (eds.), Early Life History of Fishes in the San Francisco Estuary and Watershed. American Fisheries Society Symposium 39. Bethesda, Maryland. pp. 125–140.

Erickson, D. L. and M. A. H. Webb. 2007. Spawning periodicity, spawning migration, and size at maturity of green sturgeon, *Acipenser medirostris*, in the Rogue River, Oregon. *Environmental Biology of Fishes* 79: 255–268.

Erickson, D. L., J. A. North, J. E. Hightower, J. Weber, and L. Lauck. 2002. Movement and habitat use of green sturgeon *Acipenser medirostris* in the Rogue River, Oregon, USA. *Journal of Applied Ichthyology* 18: 565–569.

Fairey, R., K. Taberski, S. Lamerdin, E. Johnson, R. P. Clark, J. W. Downing, J. Newman, and M. Petreas. 1997. Organochlorines and other environmental contaminants in muscle tissues of sportfish collected from San Francisco Bay. *Marine Pollution Bulletin* 34: 1058–1071.

Feist, G. W., M. A. H. Webb, D. T. Gundersen, E. P. Foster, C. B. Schreck, A. G. Maule, and M. S. Fitzpatrick. 2005. Evidence of detrimental effects of environmental contaminants on growth and reproductive physiology of white sturgeon in impounded areas of the Columbia River. *Environmental Health Perspectives* 113: 1675–1682.

Ferrari, M. C., Ranåker, L., Weinersmith, K. L., Young, M. J., Sih, A., & Conrad, J. L. 2014. Effects of turbidity and an invasive waterweed on predation by introduced largemouth bass. Environmental biology of fishes, 97(1), 79-90.

Fisher, F. 1994. Past and present status of Central Valley Chinook salmon. *Conservation Biology* 8(3):870–873.

Goodman, D. 2005. Selection equilibrium for hatchery and wild spawning fitness in integrated breeding programs. *Canadian Journal of Fisheries and Aquatic Sciences* 62: 374–389.

Greenfield, B.K., J.A. Davis, R. Fairey, C. Roberts, D. Crane, and G. Ichikawa. 2005. Seasonal, interannual, and long-term variation in sport fish contamination, San Francisco Bay. Science of the Total Environment, 336(1-3):25-43.

Grimaldo L, Ross B, Sweetnam D. 1998. Preliminary results on the age and growth of delta smelt from different areas of the estuary using otolith microstructural analysis. IEP Newsletter 11(1):25–28. Available at: http://www.iep.ca.gov/newsletter.

Hallock, R. J., W. F. Van Woert, and L. Shapovalov. 1961. An evaluation of stocking hatchery-reared steelhead rainbow trout (*Salmo gairdnerii gairdnerii*) in the Sacramento River system. California Department of Fish and Game. Fish Bulletin No. 14. Herren, J. R., and S. S. Kawasaki. 2001. Inventory of water diversions in four geographic areas in California’s Central Valley. In: R.L. Brown, ed., Contributions to the Biology of Central Valley Salmonids. Volume. 2. California Fish and Game. Fish Bulletin 179: 343-355.

Herren, J.R. and S.S. Kawasaki. 2001. Inventory of water diversions in four geographic areas in California’s Central Valley. pp. 343-355 in Brown, R. L., (ed). Contributions to the Biology of Central Valley Salmonids. California Fish and Game. Fish Bulletin 179.

Israel, J. A., J. F. Cordes, M. A. Blumberg, and B. May. 2004. Geographic patterns of genetic differentiation among collections of green sturgeon. *North American Journal of Fisheries Management* 24: 922–931.

Jassby, A. D., J. E. Cloern. 2000. Organic matter sources and rehabilitation of the Sacramento-San Joaquin Delta (California, USA). *Aquatic Conservation: Marine and Freshwater Ecosystems* 10: 323–352.

Jassby, A. D., J. E. Cloern, B. E. Cole. 2002. Annual primary production: patterns and mechanisms of change in a nutrient-rich tidal ecosystem. *Limnology and Oceanography* 47: 698–712.

Jassby, A. D., Kimmerer, W. J., Monismith, S. G., Armor, C., Cloern, J. E., Powell, T. M., & Vendlinski, T. J. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological applications, 5(1), 272-289.

Jeffries, K. M., R. E. Connon, B. E. Davis, L. M. Komoroske, M. T. Britton, T. Sommer, A. E. Todgham, and N. A. Fangue. 2016. Effects of High Temperatures on Threatened Estuarine Fishes During Periods of Extreme Drought. Journal of Experimental Biology 219(11):1705-1716.

Kaufman, R. C., A. G. Houck, and J. J. Cech, Jr. 2008. Effects of dietary selenium and methylmercury on green and white sturgeon bioenergetics in response to changed environmental conditions. 5th Biennial CALFED Science Conference, October 22–24, 2008, Sacramento, CA.

Kelly, J. T., A. P. Klimley, and C. E. Crocker. 2007. Movements of green sturgeon, Acipenser medirostris, in the San Francisco Bay Estuary, California. *Environmental Biology of Fishes* 79: 281–295.

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).

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

Kostow, K. 2002. Oregon lamprey: natural history status and analysis of management issues. Oregon Department of Fish and Wildlife, Corvallis, Oregon. 112 pp.

Kruse, G. O. and D. L. Scarnecchia. 2002. Assessment of bioaccumulated metal and organochlorine compounds in relation to physiological bismarkers in Kootenai River white sturgeon. *Journal of Applied Ichthyology* 18: 430–438.

Lindley, S. T., M. S. Mohr. 2003. Modeling the effect of striped bass on the population viability of Sacramento River winter-run Chinook salmon. *Fishery Bulletin* 101: 321–331.

Lindley, S. T., R. Schick, A. Agrawal, M. Goslin, T. E. Pearson, E. Mora, J. J. Anderson, B. May, S. Greene, C. Hanson, A. Low, D. McEwan, R. B. MacFarlane, C. Swanson, J. G. Williams. 2006. Historical population structure of Central Valley steelhead and its alteration by dams. San Francisco Estuary and Watershed Science. Volume 4, Issue 2, (February 2006), Article 3.

Lindley, S. T., R. S. Schick, E. Mora, P. B. Adams, J. J. Anderson, S. Greene, et al. 2007. Framework for assessing viability of threatened and endangered Chinook salmon and steelhead in the Sacramento–San Joaquin Basin. San Francisco Estuary and Watershed Science, 5(1).

Luzier, C. W. et al. 2009. Proceedings of the Pacific Lamprey Conservation Initiative Work Session – October 28–29, 2009. U.S. Fish and Wildlife Service, Regional Office, Portland, OR, USA.

Maslin, P., M. Lennox, and W. McKinney. 1997. Intermittent streams as rearing habitat for Sacramento River Chinook salmon (Oncorhynchus tshawytscha). California State University, Chico, Department of Biological Sciences. 89 pages.

Maunder, M. N., R. B. Deriso, and C. H. Hanson. 2015. Use of State-space Population Dynamics Models in Hypothesis Testing: Advantages Over Simple Log-linear Regressions for Modeling Survival, Illustrated with Application to Longfin Smelt (Spirinchus thaleichthys). Fisheries Research 164:102-111.

McEwan, D. 2001. Central Valley Steelhead. In: Contributions to the Biology of Central Valley Salmonids. Brown, R. L. (ed.), Sacramento, CA: California Department of Fish and Game, Fish Bulletin, Vol. 179, pp 1–43.

McEwan, D. and T. A. Jackson. 1996. Steelhead restoration and management plan for California. California Department of Fish and Game. Sacramento, CA.

Merz, J. E., Hamilton, S., Bergman, P. S., & Cavallo, B. 2011. Spatial perspective for delta smelt: a summary of contemporary survey data. California Fish and Game, 97(4), 164-189.

Moyle, P. B. 2002. Inland fishes of California, 2nd edition. University of California Press, Berkeley and Los Angeles, CA. 502 pp.

Moyle, P. B., R. D. Baxter, T. Sommer, T. C. Foin, and S. A. Matern. 2004. Biology and population dynamics of Sacramento splittail (Pogonichthys macrolepidotus) in the San Francisco Estuary: A review. San Francisco Estuary and Watershed Science. Volume 2, Issue 2. Accessed April 13, 2017.

Moyle, P. B., L. R. Brown, J. R. Durand, & 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).

Nakamoto, R. J., T. T. Kisanuki, and G. H. Goldsmith. 1995. Age and growth of Klamath River green sturgeon (Acipenser medirostris). U.S. Fish and Wildlife Service Project 93-FP-13, Yreka, CA. 20 pp.

National Marine Fisheries Service (NMFS). 1997. National Marine Fisheries Service Proposed Recovery Plan for the Sacramento River Winter-run Chinook Salmon. NMFS, Southwest Region, Long Beach, CA.

———. 2009. Biological Opinion and Conference Opinion on the Long-term Operations of the Central Valley Project and State Water Project. National Marine Fisheries Service, Southwest Region June 4, 2009.

———. 2011. Essential Fish Habitat. Southwest Regional Office. Available: http://swr.nmfs.noaa.gov/hcd/HCD_webContent/EFH/ sanfran_fmp.htm. Accessed January 25, 2011.

———. 2014. Recovery Plan for the Evolitionary Significant Units of Sacramento River Winter-run Chinook Salmon and Central Valley Spring-run Chinook Salmon and the DPS of California Central Valley Steelhead. National Marine Fisheries Service, West Coast Region, Sacramento, CA.

———. 2019. Biological Opinion for the Reinitiation of Consultation on the Long-Term Operation of the Central Valley Project and State Water Project. National Marine Fisheries Service, West Coast Region, Sacramento, CA.

———. 2016a. "California Central Valley Recovery Domain 5-Year Review: Summary and Evaluation of Central Valley Spring-run Chinook Salmon Evolutionarily Significant Unit." 41pp.

———. 2016b. "5-Year Status Review: Summary and Evaluation of Sacramento River Winter-Run Chinook Salmon ESU."

Nobriga, M. L., and P. Cadrett. 2003. Differences among hatchery and wild steelhead: evidence from Delta fish monitoring programs. *Interagency Ecological Program for the San Francisco Estuary Newsletter* 14:3:30–38.

Phillis, C. C., Sturrock, A. M., Johnson, R. C., & Weber, P. K. 2018. Endangered winter-run Chinook salmon rely on diverse rearing habitats in a highly altered landscape. Biological Conservation, 217, 358-362.

Resources Agency. 2007. Pelagic Fish Action Plan. 84 pp.

Rosenfield, J. A. and Baxter, R. D. 2007. Population Dynamics and Distribution Patterns of Longfin Smelt in the San Francisco Estuary. *Transactions of the American Fisheries Society* 136(6): 1577–1592.

Seesholtz, A. M., Manuel, M. J., & Van Eenennaam, J. P. 2014. First documented spawning and associated habitat conditions for green sturgeon in the Feather River, California. Environmental Biology of Fishes, 98(3), 905–912. doi:10.1007/s10641-014-0325-9

Shapovalov, L., and A. C. Taft. 1954. The life histories of the steelhead rainbow trout (*Salmo gairdneri gairdneri*) and silver salmon (*Oncorhynchus kisutch*) with special reference to Waddell Creek, California, and recommendations regarding their management. *California Department of Fish and Game, Fish Bulletin* 98:1–375.

Slater, S. B. 2008. Feeding Habits of Longfin Smelt in the Upper San Francisco Estuary. Presented at the 5th Biennial CALFED Science Conference 2008. October 22–24, 2008, Sacramento Convention Center, Sacramento, CA.

Sommer, T. R., M. L. Nobriga, W. C. Harrell, W. Batham, and W. J. Kimmerer. 2001. Floodplain rearing of juvenile chinook salmon: evidence of enhanced growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58(2):325–333.

Sommer, T., K. Reece, F. Mejia, and M. Morbriga. 2009. Delta smelt life-history contingents: a possible upstream rearing strategy. *IEP Newsletter* 22(1):11–13.

Thompson, J. 2007. Clams – where, how and can we limit the damage. Presentation at the CALFED Science Program workshop: Defining a Variable Delta to Promote Estuarine Fish Habitat. June 11, 2007.

U.S. Fish and Wildlife Service (USFWS). 2001. Abundance and Survival of Juvenile Chinook Salmon in the Sacramento-San Joaquin Estuary: 1997 and 1998. Annual progress report Sacramento-San Joaquin Estuary.

———. 2017. Biological Opinion: For the California WaterFix. U.S. Fish and Wildlife Service.

———. 2019. Biological Opinion for the Reinitiation of Consultation on the Coordinated Operations of the Central Valley Project and State Water Project. U.S. Fish and Wildlife Service, Sacramento, CA.

Werner, I. 2007. Pyrethroids in the water column – is there reason for concern? Seminar, University of California, Davis, November 8.

Yoshiyama, R. M., F. W. Fisher, P. B. Moyle. 1998. Historical abundance and decline of Chinook salmon in the Central Valley region of California. North American Journal of Fisheries Management. 18: 487–521.