Appendix G Biological Resources – Fisheries

This appendix describes the environmental setting for fisheries resources.

G.1 Environmental Setting

G.1.1 Regional Setting

Historical Habitat

Typical of Central Valley rivers and a semiarid climate, the natural or "unimpaired" flow regime of the San Joaquin River historically varied greatly in the magnitude, timing, duration, and frequency of streamflows, both interannually and seasonally (San Joaquin River Restoration Program [SJRRP] 2011a). Streamflow variability created conditions that partially helped create and sustain multiple salmonid life history strategies and life history phases of numerous other resident and anadromous native fish and other aquatic species.

The San Joaquin River originates in the Sierra Nevada at an elevation greater than 13,000 feet above mean sea level (SJRRP 2011a). It rapidly descends and exits mountainous terrain in the area now occupied by Friant Dam. The San Joaquin River downstream from Friant Dam consists of a deeply incised channel that discharges to the valley floor near Gravelly Ford. Before the influx of settlers in the 1860s, and subsequent agricultural development, the San Joaquin River and its main tributaries meandered across alluvial fans, deposits of river sediments resulting from a decrease in velocity, along the main axis of the San Joaquin Valley floor in their natural state. Historically, the San Joaquin River in Reach 1 was moderately sinuous with a gravel bed and planform morphology with numerous split channels, side channels, and high flow scour channels (McBain and Trush 2002). In Reach 2 the river transitioned into being sand bedded with a meandering morphology with large sinuosity and a single primary channel (McBain and Trush 2002). High flow scour channels at the downstream end of Reach 2 transported high flows south to Fresno Slough which were then conveyed back to the San Joaquin River at Mendota (McBain and Trush 2002). Reach 3 had similar morphology to Reach 2 with large exposed point bars and riparian vegetation present on the top of the point bars and on the floodplains (McBain and Trush 2002).

Near Mendota, the San Joaquin River merged with Fresno Slough, a wider and deeper waterway than the San Joaquin River (SJRRP 2011a). Fresno Slough was part of an intricate slough system that exchanged water between the Tulare Lake Basin and the San Joaquin River. Downstream from Mendota, in the present area of the Reach 4B/ESB Project study area, the San Joaquin River was a meandering sand-bedded channel with numerous anabranching sloughs with base flows being conveyed by both the San Joaquin

River channel and the sloughs (McBain and Trush 2002). Narrow riparian levees provided moderate confinement of the river on both banks, with large areas of tule marsh flood basins being present past the riparian levees (The Bay Institute 1998, McBain and Trush 2002). Oxbow lakes and off-channel ponds within the flood basins were likely present (McBain and Trush 2002). The flood basins extended for miles on both sides of the San Joaquin River in Reach 4B (McBain and Trush 2002). Channel migration and avulsion were likely very slow and infrequent due to the low sediment supply, as a result of deposition in upstream reaches, and low stream energy as high flows spilled over the narrow riparian levees into the flood basins (McBain and Trush 2002). With the limited channel confinement provided by the riparian levees, overbank inundation of the flood basins probably occurred most years and was of long duration, on the order of months (McBain and Trush 2002). The prolonged inundation of sloughs and flood basins likely provided high flow refugia and rearing habitat for juvenile salmonids and other native fishes (McBain and Trush 2002).

Although historic water quality data (i.e., data from before construction of Friant Dam) are not available, the river provided sufficient water quality conditions for native fish, including anadromous salmonids (SJRRP 2011a). Cold, clear snowmelt runoff flowing from the granitic upper basins of the southern Sierra Nevada provided optimal conditions for freshwater life history stages of salmonids in the upper San Joaquin River and its tributaries and for invertebrate production, the primary food resource for salmonids. The abundant cold water in the upper San Joaquin River basin had high (saturated) concentrations of dissolved oxygen (DO), low salinity, and neutral pH levels. Levels of suspended sediment and turbidity likely were relatively low, even during high runoff events, because of the upper basin’s mainly granitic geology and relatively low rates of primary productivity (algae growth). In the Reach 4B/ESB Project area, primary productivity likely increased historically as a result of the river meandering through sloughs, flood basins, and long, slow pools with minimal shading from riparian vegetation. However, the extensive tule marshes in the flood basins may have provided extensive shade in locations where the tules were dense.

The San Joaquin River in Reach 4B was historically a gaining reach with shallow groundwater being very close or above the river surface and discharging to the river and surrounding marshes (McBain and Trush 2002). During periods of low surface flow, the shallow unconfined aquifer of the San Joaquin Valley trough would contribute significant baseflows to the San Joaquin River in Reach 4B (McBain and Trush 2002). The shallow groundwater pumping close to the river has changed portions of the San Joaquin River within Reach 4B from a gaining reach to a losing reach (McBain and Trush 2002).

Existing Habitat

The San Joaquin Valley, part of the San Joaquin Basin, and the associated Tulare Basin, once had a wide variety of terrestrial and aquatic habitats that provided rich resources for Native Americans and early settlers (Brown 2000). However, as the San Joaquin Valley was converted to agricultural land use, native ecological communities declined. On the valley floor, invasive species, intensive agricultural activity, and increasing urbanization, have resulted in changes to water quality and aquatic habitats. Invasive species have caused changes in aquatic and riparian plant communities resulting in reduced habitat quality. Intensive pesticide and fertilizer use, which enter surface waters in various ways, has impacted water quality (Kuivila and Foe 1995, Domagalski et al. 1997, Kratzer and Shelton 1998, Brown et al. 1999). Pesticide concentrations sometimes reach concentrations acutely toxic to sensitive invertebrates (Kuivila and Foe 1995). Agricultural return flows also may contain high concentrations of dissolved solids (salinity) and trace elements (Saiki 1984, see Brown 2000) that can degrade water quality. Clearing of land for agriculture or flood control activities has resulted in the loss of over 90% of wetland and riparian habitat (Brown 2000).

Today, water resource systems of the San Joaquin River region are among the most constrained in the nation as managers try to meet water supply, water quality, flood control, ecosystem, and recreation objectives (Brekke et al. 2004). During the irrigation season (usually March to October), irrigation water from the Delta-Mendota Canal and return flows from irrigated fields usually contribute most of the discharge in downstream portions of the San Joaquin River above the Merced River confluence (Reaches 3-5) (Saiki and Palawski 1990). In contrast, the west-side tributaries, some of which originate on the San Joaquin Valley floor, derive most of their discharge from groundwater seepage and irrigation return flows. The section of San Joaquin River between Friant Dam and the Merced River confluence (i.e., Reaches 1A through 5) provides generally poor fish habitat conditions (SJRRP 2010a). Physical barriers and reaches with poor water quality or no surface flow have reduced habitat connectivity. Under current operations, approximately 60 miles of the San Joaquin River are dewatered for the majority of the year. Tributaries to these reaches support little or no available spawning habitat for anadromous salmonids and lamprey and, under certain conditions, potentially create straying opportunities that hinder the ability of fish to complete their life cycles, especially adult salmonids. Habitat complexity between Friant Dam and the confluence with the Merced River is reduced, with limited secondary habitat (e.g., side channels and floodplains) or instream habitat structure, and contains highly altered riparian vegetation. Bypasses in these reaches receive water sporadically, as necessary for flood control.

G.1.2 Reach 4B/ESB Project Area Setting

The Reach 4B/ESB Project area includes Reaches 4B1 and 4B2, a 32.5-mile stretch of the San Joaquin River, the Middle Eastside Bypass, the Lower Eastside Bypass, and the Mariposa Bypass in Merced County, California (see Figure 1-2). A wide variety of aquatic and upland habitats occur within the Reach 4B/ESB Project area, but the habitats that most directly impact fishery resources include: riverine/open water, lacustrine, freshwater emergent wetland, seasonal wetland (if connected hydrologically to the main channel so that fish have access), riparian/willow scrub, and valley foothill riparian. The distribution, species compositions, and abundance of these habitats are described in detail in Chapter 6 of this EIS (Biological Resources-Vegetation and Wildlife).

Reach 4B

Reach 4B of the San Joaquin River begins at the Sand Slough Control Structure (River Mile [RM] 168.5) and extends downstream to the confluence of the Eastside Bypass and San Joaquin River (RM 136) (see Figure 1-2). Reach 4B has been further divided into two sub-reaches, Reach 4B1 and Reach 4B2. Reach 4B1 begins at the Sand Slough

Control Structure and continues to the Mariposa Bypass, and Reach 4B2 extends from the Mariposa Bypass to the confluence of the Eastside Bypass and the San Joaquin River.

The section of river directly upstream of Reach 4B (Reach 4A) is dry in most months because all flows in the San Joaquin River are diverted at Sack Dam to the Arroyo Canal. Any flows reaching the Sand Slough Control Structure are diverted to the Eastside Bypass via the Sand Slough Control Structure, leaving Reach 4B1 dry, with the exception of agricultural return flows, local runoff, natural pooling due to shallow ground water in wet years, and when it is used to convey water by land owners (SJRRP 2010a). As a result, the Reach 4B1 channel has become poorly defined and has filled in with dense vegetation and other fill material. In addition, Reach 4B1 is confined by anthropogenically modified narrow levees. Reach 4B2 begins at the confluence of the Mariposa Bypass, where flood flows in the bypass system rejoin the main stem of the San Joaquin River, and this reach extends to the confluence of the Eastside Bypass (SJRRP 2011b). As a result of differences in manmade levee configuration, Reach 4B2 contains wider floodplains and a more sinuous channel, including side channels and oxbows, because of a wider levee configuration than Reach 4B1. Additionally, it contains vast areas of grasslands and riparian vegetation stands. A portion of Reach 4B2 flows through the San Luis National Wildlife Refuge (NWR), which is managed to support a wide variety of native plant and animal species. Unlike Reach 4B1, Reach 4B2 is perennially wet because of agricultural return flow (SJRRP 2010a).

Eastside Bypass and Mariposa Bypass

The study area for the Reach 4B/ESB Project also includes the Eastside and Mariposa bypasses. The Eastside Bypass extends from the confluence of Ash Slough and Chowchilla Bypass to the confluence with the San Joaquin River at the head of Reach 5. In the Grasslands Wildlife Management Area, riparian trees and shrubs have a patchy distribution along the banks of the Eastside Bypass. The Lower Eastside Bypass has some side channels and sloughs that support remnant patches of riparian vegetation. Outside of the refuge areas, the Eastside Bypass is managed for flood conveyance and does not currently support extensive riparian habitat. The Mariposa Bypass conveys flows from the end of the Middle Eastside Bypass to the San Joaquin River at the upstream end of Reach 4B2. The Mariposa Bypass is also managed for flood conveyance and does not currently support riparian habitat. The bypasses are routinely cleared of vegetation to maintain flood capacity and are regularly used to dispose of agricultural drain water.

The flood season for the Lower San Joaquin Levee District (LSJLD) typically lasts from November 15 to June 15 of each water year, with rainfall contributing to higher flows during the early part of the flood season, and snowmelt contributing to flows at the later part of the flood season.

Key flood control structures within the study area include the Reach 4B Headgate on the San Joaquin River at the beginning of Reach 4B1, the Sand Slough Control Structure at the beginning of the Middle Eastside Bypass, the Eastside and Mariposa bypass control structures where the Middle Eastside Bypass transitions to the Lower Eastside Bypass, and the Mariposa Drop Structure at the end of the Mariposa Bypass near the confluence with the San Joaquin River at the upstream end of Reach 4B2 (SJRRP 2011b).

G.1.3 Environmental Stressors

This section describes the major environmental stressors currently affecting native fish species in the San Joaquin River. Stressors are defined as physical, chemical, or biological perturbations to a system that adversely affect ecosystem processes, habitats, and species (SJRRP 2010b). The following summarizes information from a literature review of overall San Joaquin River Restoration Area (Restoration Area) stressors (SJRRP 2010b, SJRRP 2011a), and findings from recent SJRRP investigations. When SJRRP actions enable anadromous salmonids to use the Reach 4B/ESB Project area then many of these stressors will also occur within the project area or affect fish in upstream or downstream locations after they have passed through Reach 4B/ESB.

Disease

The fish diseases in downstream locations may occur in Reach 4B/ESB once fish passage improvement allows Chinook Salmon and other fishes to consistently use and migrate through the reach. The United States Fish and Wildlife Service (USFWS) conducted a survey of the health and physiological condition of juvenile fall-run Chinook salmon (*Oncorhynchus tshawytscha*) in the San Joaquin River and its primary tributaries, the Stanislaus, Tuolumne, and Merced rivers, during spring 2000 and 2001 (Nichols and Foott 2002). *Renibacterium salmoninarum*, the causative agent of bacterial kidney disease (BKD), was detected in naturally produced juveniles caught in rotary screw traps from the Stanislaus and Tuolumne rivers and juveniles caught with a Kodiak trawl at Mossdale in the San Joaquin River. No gross clinical signs of BKD were seen in any of the fish examined. However, these low-level infections might remain active after infected fish enter the ocean where clinical symptoms might develop.

Proliferative kidney disease (PKD) was detected in both natural and hatchery juveniles from the Merced and main stem San Joaquin rivers in 2000 and 2001 (Nichols and Foott 2002), and in natural juveniles from the Merced River in 2002 (Nichols 2002). The myxozoan parasite *Tetracapsula bryosalmonae,* which causes PKD, was detected in the kidney samples of only 2 percent of juvenile Merced River fish sampled in April 2000, but 90 percent of April 2001, 100 percent of May 2001, and 51 percent of April 2002 samples. Heavy infections were observed in 22 percent of samples in 2002 (Nichols 2002). These data suggest that the incidence of pathogen infection is low in above-normal water years, such as 2000, compared to dry water years such as 2001 and 2002. PKD has been described at the Merced River Fish Hatchery since the 1980s and in California since at least 1966. It compromises fish swimming, saltwater entry performance, and disease resistance (Nichols and Foott 2002). Nichols and Foott (2002) suggest that PKD could be a significant contributor to mortality in natural fish.

The pathogen *Ceratonova* (previously *Ceratomyxa*) is present in the Central Valley, and studies indicate it can cause high mortality rates in Chinook smolts (Hendrickson et al. 1989, Foott and Imrie 2016). This disease relies on tubifex worms for an intermediate host, and the worms flourish in organic sediments. It is likely the worms multiply, and the disease spreads in years when organic sediments are not flushed by high flows. There are indications that mortality of smolts due to this disease increases in drought years and decreases in wet years (Foott and Imrie 2017).

Whirling disease is found in salmonid populations in the Central Valley (NMFS 2014). The disease is caused by the parasite *Myxobolus cerebralis,* which has a two-aquatic host life cycle consisting of an oligochaete worm *Tubifex tubifex* and a salmonid fish (Steinbach Elwell et al. 2009). Very young fish are the most vulnerable to whirling disease with susceptibility decreasing with age and growth (Steinbach Elwell et al. 2009). The response of salmonids to infection by *M. cerebralis* varies among genera, species, strains, and individuals (Steinbach Elwell et al. 2009). Within the genus *Oncorhynchus*, most species experience high prevalence and severity of disease, and high mortality rates if exposed to a sufficient parasite dose when susceptible (Steinbach Elwell et al. 2009). Highly susceptible species include rainbow trout with Chinook salmon being more resistant (Steinbach Elwell et al. 2009). The clinical signs of whirling disease include: 1) whirling behavior resulting from spinal cord constriction and brain stem compression, 2) blackened tail caused by pressure on nerves that control pigmentation, 3) skeletal deformities caused by cartilage damage and interference with normal bone growth, and 4) mortality as a result of direct physical damage or inability to feed or avoid predation (Steinbach Elwell et al. 2009). In addition, infection can reduce fitness by decreasing growth rate and reducing swimming performance (Steinbach Elwell et al. 2009).

Habitat Degradation

The San Joaquin River within the Restoration Area has a sediment budget imbalance as a result of the elimination by Friant Dam of most sediment supply from the upper watershed in combination with the modified flow regime and land use downstream from Friant Dam (SJRRP 2010b). Loss of alluvial features in the Restoration Area has contributed to the reduction in frequency of floodplain inundation, which has probably caused a substantial reduction in potential food resources and predator refuge for juvenile salmonids in the Restoration Area (SJRRP 2010b). The loss of flow and encroachment of levees, structures, flood control, and farming practices have also contributed to the reduction in floodplain presence and frequency of floodplain inundation. Historically, these inundation areas (flood basins, shallow sloughs, and side channels) may have provided excellent rearing opportunities for juvenile salmonids and other species (Sommer et al. 2001, Sommer et al. 2005, Jeffres et al. 2008, Limm and Marchetti 2009). Rearing juvenile salmonids prefer shallow, relatively slow velocity habitat within or close to cover such as LWM, inundated riparian vegetation, and submerged aquatic vegetation (Beakes et al. 2014). During high flows, the shallow and slow velocity habitat with cover is found on floodplains, in seasonal side channels, and other off channel habitat (Sommer et al. 2001, Limm and Marchetti 2009). Shallow floodplains can also be very productive resulting in fast growth rates for juvenile salmonids rearing on them (Sommer et al. 2001, Jeffres et al. 2008, Katz et al. 2017). Channel incision resulting from substantially diminished sediment supply reduces the availability of alternating bars and riffles as well as side channels that juvenile Chinook salmon use for feeding and predator avoidance during low flow periods (Beechie et al. 2005, Sellheim et al. 2015). During low flow periods, side channels can provide the shallow, complex habitat that juvenile salmonids prefer for rearing (Bellmore et al. 2013). Low water flows as a result of water regulation are a major source of habitat degradation for native fishes in Reach 4B and the impacts of low water flows are discussed in detail in the "Inadequate Flows" section below.

A separate but connected bypass system, consisting of the Chowchilla Bypass Channel, Eastside Bypass Channel, and Mariposa Bypass Channel, was constructed to divert and carry flood flows from the San Joaquin River and eastside tributaries upstream of the Merced River (SJRRP 2010b). These bypasses are confined by manmade levees and have limited floodplain access, habitat structure, nearshore habitat, and riparian habitat required by Chinook salmon and other species.

Large quantities of downed trees are a functionally important component of many streams (National Oceanic and Atmospheric Administration National Marine Fisheries Service [NMFS] 1996, Beechie and Sibley 1997, Collins et al. 2002). Large woody debris (LWD) influences channel morphology by affecting longitudinal profile, pool formation, channel pattern and position, and channel geometry (SJRRP 2010b, Gurnell et al. 2002). Downstream transport rates of sediment and organic matter are controlled in part by storage of this material behind LWD. LWD also affects the formation and distribution of habitat units, provides cover and complexity, and acts as a substrate for biological activity (Collins et al. 2002, Roni et al. 2015). Wood enters streams inhabited by salmonids, either directly from adjacent riparian zones, or from riparian zones in adjacent nonfish-bearing tributaries (Latterell and Naiman 2007). Removal of riparian vegetation and LWD from the streambank results in the loss of a primary source of overhead and instream cover for juvenile salmonids. The removal of riparian vegetation and LWD, and the replacement of natural bank substrates with rock revetment, can adversely affect important ecosystem functions (Florsheim et al. 2008). Living space and food for terrestrial and aquatic invertebrates is lost, eliminating an important food source for juvenile salmonids. Loss of riparian vegetation and soft substrates reduces inputs of organic material to the stream ecosystem in the form of leaves, detritus, and woody debris, which can affect biological production at all trophic levels. The magnitude of these effects depends on the degree to which riparian vegetation and natural substrates are preserved or recovered during the life of the project.

Like many Central Valley rivers, the amount of LWD and potential recruitment into the San Joaquin River below Friant Dam and specifically in Reach 4B has been severely degraded by anthropogenic activities. Agricultural conversion, flood control, and water development in addition to other anthropogenic activities have directly impacted the LWD resources in Reach 4B. The riparian forests in Reach 4B as well as in upstream reaches are substantially reduced from historical conditions (McBain and Trush 2002) which has a direct impact on LWD. In addition, Friant Dam as well as smaller dams downstream prevent or reduce the downstream movement of LWD.

Like LWD, shaded riverine aquatic habitat (SRA) is an important component of alluvial river habitat for juvenile salmonids. SRA as defined by the USFWS (1992) is the nearshore aquatic habitat occurring at the interface between a river and adjacent woody riparian habitat and occurs from the edge of the bank to the limit of overhanging riparian canopy or vegetation present within the water. The key attributes of SRA are: 1) the river bank consisting of natural, eroding substrates supporting riparian vegetation that either overhangs or protrudes into the water, and 2) the river containing varying amounts of woody debris, often substantial detritus, and varying water velocities, depths, and flows (USFWS 1992). Studies have demonstrated the importance of SRA in the Central Valley for rearing juvenile salmonids with high juvenile salmonid densities associated with SRA (USFWS 1998, USFWS 2010, USFWS 2011, Beakes et al. 2014).

The construction of levees and dikes to convert land for agricultural production tends to channelize riverine habitats and reduces channel migration and avulsion (McBain and Trush 2004). Reduced channel migration in the Restoration Area has eliminated off-channel habitats, reduced complex side channels, and reduced instream habitat complexity including large woody debris and riparian vegetation, particularly SRA, which all serve to provide suitable conditions for juvenile salmonids over a wide range of flows (SJRRP 2010b). Agricultural conversion also has directly reduced the amount of floodplains, and levees and dikes have further isolated historic floodplains from the channel. It is likely that the loss of floodplain habitats has substantially reduced food resources and predator refuge for juvenile salmonids.

Hatchery Operations

Seven hatcheries in the Central Valley raise anadromous salmonids, including in the Sacramento River Basin, the Coleman National Fish Hatchery (Battle Creek), Feather River Fish Hatchery, Nimbus Fish Hatchery (American River), Mokelumne River Hatchery, Livingston Stone Hatchery (Sacramento River); and in the San Joaquin River Basin, the: Merced River Fish Hatchery and the Salmon Conservation and Research Facility (San Joaquin River) (McEwan 2001, SJRRP 2016). The Salmon Conservation and Research Facility (SCARF), which is adjacent to the San Joaquin River below Friant Dam, is being built to help meet the SJRRP goal of restoring self-sustaining runs of Chinook Salmon (SJRRP 2016). SCARF is being designed and will be operated as a conservation facility which will reduce or eliminate many of the negative impacts associated with production/mitigation hatcheries. Hatchery production can negatively affect fish populations by leading to a loss of genetic integrity primarily through hybridization, inbreeding, and random genetic change (SJRRP 2010a). Hybridization presumably creates individuals that are less well-adapted to local conditions than either parent (Araki et al. 2008, Laikre et al. 2010). Inbreeding results from the breeding of closely related individuals and is likely to develop from hatchery production because eggs and milt are obtained from relatively few individuals (Wang et al. 2002). A small breeding population also may lead to genetic drift. Both inbreeding and genetic drift can lead to the production of individuals that are less adapted than naturally produced fish to the natural environment in which the species evolved (Wang et al. 2002).

The following are other potentially negative effects of producing hatchery fish:

- Displacement of wild salmonid juveniles through competition and predation (Levin et al. 2001, Tatara and Berejikian 2012)

- Competition between hatchery adults and wild adults for limited spawning habitat (Kostow 2009)

- Stimulation of sport and/or commercial harvest efforts, which could increase the harvest rate of naturally produced salmonids (NMFS 2016)

- Increase in disease rate among naturally produced fish (Miller et al. 2014)
- Negative social interaction between hatchery salmonids and wild salmonids (Berejikian et al. 1996, Weber and Fausch 2005)

Impaired Water Quality

High Water Temperatures

Release temperatures from Friant Dam under existing Friant operations typically fluctuate between 48 to 58°F (8.9 to 14.4°C), and water temperatures are expected to be suitable for juvenile rearing except in the downstream reaches (Reaches 2B to 5) as water temperatures increase. However, release temperatures during recent drought years were higher than typical with temperatures in the late summer through early winter ranging into the upper 60s and low 70 degrees Fahrenheit (USGS gage 11251000 San Joaquin River below Friant Dam). Critical to lethal water temperatures and exaggerated fluctuations in water temperature result from a combination of factors, including seasonally high air temperatures (May through September), low flow releases, groundwater pumping that eliminated the inflow of cool groundwater throughout the Restoration Area (thermal refugia), removal of large woody riparian forests that provided shade, warm agricultural runoff, and warm flood flows from the Kings River through the James Bypass (SJRRP 2010b). It is also possible that high flow releases during summer and fall could exhaust the cold-water pool in Millerton Lake, thereby causing release temperatures to substantially increase above 58°F (14.4°C). Many of these impacts would directly affect the in-river life stages of anadromous salmonids. In the Fisheries Management Plan, the SJRRP established monthly water temperature objectives for the in-river life stages of Chinook salmon (SJRRP 2010b) based on water temperature criteria presented in the U.S. Environmental Protection Agency's (EPA) Region 10 Guidance for Pacific Northwest State and Tribal Temperature Water Quality (EPA 2003), Rich (2007) Impacts of Water Temperature on Fall-run Chinook Salmon (*Oncorhynchus tshawytscha*) and Steelhead (*O. mykiss*) in the San Joaquin River System, and Pagliughi (2008) Lower Mokelumne River Reach Specific Thermal Tolerance Criteria by Life Stage for Fall-Run Chinook Salmon and Winter-Run Steelhead. The water temperature objectives are summarized below for the adult migration, juvenile rearing, and juvenile outmigration life stages that are relevant to the Reach 4B/ESB Project. Adult Chinook salmon during migration start to experience stress from high water temperatures between 62.6 and 68°F (17 to 20°C), with lethal temperatures being greater than 68°F (20°C) (SJRRP 2010b). However, the migration data collected by Strange (2010) suggest that the lethal temperature is higher than this. Rearing and outmigrating juveniles start to experience stress at water temperatures between 64.4 and 70°F (18 to 21.1°C), with the prolonged exposure lethal temperature being greater than 75°F (23.9°C) (Pagliughi 2008, SJRRP 2010b). Although floodplain-rearing temperatures can exceed 17 to 20°C, these, floodplains can benefit growth given an adequate food supply, even in the presence of stress inducing temperatures (Jeffres et al. 2008).

Water temperature is a primary limiting factor for natural steelhead production on many Central Valley streams (NMFS 2009). Although many Central Valley dams provide downstream water releases intended to benefit fall-run Chinook salmon, most do not provide cool water temperatures for steelhead during summer and fall, especially during extended droughts (Moyle et al. 2008). Many dams are not able to provide cool water because they were not designed for deep-water reservoir releases or they lack adequate cold-water pool storage (McEwan 2001). Where releases of cold water occur throughout the summer, resident populations of trout often develop and remain, limiting anadromous behavior (SJRRP 2011a, Sogard et al. 2012). The SJRRP did not establish monthly water temperature objectives for steelhead like was done for Chinook Salmon (SJRRP 2010b). General temperature guidelines for steelhead would be based on a DFG proposal to assess temperature impairment (DFG 2007), EPA guidelines (EPA 2003), and a report on temperature impacts on fall-run Chinook salmon and steelhead (Rich 2007).

Water temperature is a primary limiting factor for natural production of spring-run Chinook salmon on Central Valley streams (NMFS 1999). Appropriate water temperature regimes below many dams cannot be maintained at levels comparable to temperature regimes that were achieved naturally in the upper watersheds that previously provided holding, spawning, incubation, and rearing habitat (SJRRP 2011a).

Contaminants

Both natural and anthropogenic factors influence water quality within the San Joaquin River (Quinn and Karkoski 1998). For instance, the Grasslands Basin is a hydrologic unit situated west of the San Joaquin River that naturally drains the area between the Westlands Water District and Highway 140 to the San Joaquin River. The Basin soils are naturally high in salts and of low permeability (Quinn and Karkowski 1998). The low permeability combined with water importation has resulted in a shallow groundwater table. To maintain productivity, the installation of artificial drainage was necessary in low-lying agricultural areas (Quinn and Karkowski 1998). Drainage from the southern part of the basin (41,000 hectares) contains high concentrations of trace elements and soluble salts that are harmful to fish and wildlife. The primary constituents of concern are salt, boron, and selenium (Quinn and Karkoski 1998). Water quality in the valley floor of the San Joaquin River Basin has been impaired because of contamination from a variety of other sources, including 1) aquatic and terrestrial herbicide application, 2) urban and agricultural pesticide application, 3) trace elements from industrial and agricultural activities and those naturally present in soils, and 4) effluent from wastewater treatment plants and livestock operations, particularly dairy farms (SJRRP 2010b). Point sources of pollution originate from single identifiable sources, whereas nonpoint sources originate from many different sources. Examples of nonpoint sources are agricultural runoff (e.g., excess fertilizers, herbicides, and pesticides) and urban stormwater containing oil, grease, heavy metals, polycyclic aromatic hydrocarbons, and other organics (Central Valley Regional Water Quality Control Board [RWQCB] 1998). Impervious surfaces (e.g., concrete) tend to reduce water infiltration and increase stormwater runoff (NMFS 1996). Recent studies suggest that chronic or sublethal effects of contaminants may be subtle and difficult to detect. For example, early experimental studies indicated that hatchery-reared juvenile Chinook salmon exposed to undiluted agricultural subsurface drainwater from the west side of the San Joaquin River had greater than 75 percent mortality, whereas there were no chronic detrimental effects on the growth and survival of the study fish exposed to agricultural return flows that were diluted by greater than or equal to 50 percent (Saiki et al. 1992). However, other studies suggest that juvenile fall-run Chinook salmon died in the laboratory after eating selenium-contaminated invertebrates and prey fish over a 90-day period that were collected from the San Joaquin River Basin (Beckon 2007).

A recent study has also indicated a serious potential risk of pesticides/insecticides/ fungicides to exposed early life stages of Chinook salmon and aquatic invertebrates in the Central Valley (Viant et al. 2006). A large number of pesticides/insecticides/fungicides have been detected by water quality sampling programs in the San Joaquin River Basin, including aldrin, carbaryl, chlorpyrifos, diazinon, dieldrin, diuron, heptachlor, lindane, malathion, metribuzin, and trifluralin (Domagalski et al. 2000). Most contaminant water quality problems occur in the lower Restoration Area (Reaches 3 through 5) where water quality is influenced by a lack of freshwater inflow with the majority of water being imported from the Sacramento and San Joaquin River Delta (Delta) and by agricultural drainage, particularly from Mud and Salt sloughs. Multi-year studies by Domagalski et al. (2000) and others (Brown 1997, Panshin et al. 1998) assessed a wide array of contaminants. The growing number of chemical pesticides/insecticides/fungicides found in the San Joaquin Valley is too large to encompass in this review. Furthermore, accurately quantifying risks of individual pesticides/insecticides/fungicides or synergistic effects of multiple pesticides/insecticides/fungicides is not easily validated; most studies rely on comparing contaminant levels (from biota or the environment) to literature values, regional or national statistics, or suitable reference sites.

The San Joaquin-Tulare study unit (essentially the San Joaquin Valley) was among the first basins chosen for the United States Geological Survey (USGS) National Water Quality Assessment Program (NAWQA) and recently has focused considerable attention on pesticide contamination in the San Joaquin River Basin (Dubrovsky et al. 1998, Panshin et al. 1998, Kratzer and Shelton 1998, Brown and May 2000). Generally, toxicity within the San Joaquin River has been attributed to pesticides/insecticides/fungicides from agricultural nonpoint sources, substantiated by the lack of detection of pesticide compounds in reference sites on the upper Kings River and Tuolumne River, situated above agricultural influences (Dubrovsky et al. 1998). In the NAWQA studies, available drinking water standards were not exceeded at San Joaquin River monitoring sites, but the concentrations of several pesticides/insecticides/fungicides exceeded the criteria for the protection of aquatic life. As mentioned previously, regional or national contamination levels are used to interpret San Joaquin River study results. Gilliom and Clifton (1990, from Brown 1998) reported that the San Joaquin River had some of the highest concentrations of organochlorine residues in bed sediments among the major rivers of the United States. Although the organochlorine pesticide DDT (dichloro-diphenyl-trichloroethane) was banned in the United States in 1973, DDT concentrations have continued to be detected in biota of the San Joaquin Valley streams at lower levels (Goodbred et al. 1997, Dubrovsky et al. 1998), as contaminated soils are transported to streams and sediment is resuspended from riverbeds. The most recent 303(d) list of impaired waterbodies presented by the Central Valley RWQCB identifies Reaches 3, 4, and 5 of the San Joaquin River study area, Mud Slough, and Salt Slough, all as impaired due to pesticides and unknown toxicity.

Selenium and mercury are two environmental contaminants of primary concern in aquatic environments, and the San Joaquin River is not an exception (SJRRP 2010b). Selenium and mercury are trace elements that can be harmful to aquatic life because they undergo biomagnification after being converted to organic forms in reducing (i.e., low oxygen) conditions by methylating bacteria. Because of this conversion to an organo-metallic compound, methylated selenium and mercury are absorbed preferentially into fatty tissues and can biomagnify through the food chain despite low ambient concentrations. Central Valley RWQCB water quality objectives for selenium are currently being exceeded for Mud Slough and downstream reaches. While the reported background concentrations for selenium for the San Joaquin River above Salt and Mud sloughs are about 0.5 micrograms per liter (µg/L), selected sites along the river have selenium concentrations from 1 to 5 µg/L (Central Valley RWQCB 2001). The input of selenium from the Grasslands area into the San Joaquin River represents a major risk for larval fish, including Chinook salmon (Beckon 2007).

In past surveys, fish from several locations within the study area were shown to contain elevated concentrations of arsenic (Rasmussen et al 1995, Saiki 1989), mercury (Rasmussen et al. 1995, Saiki and May 1988), and selenium (Saiki 1989, Saiki and Lowe 1987, Saiki and May 1988, White et al. 1988). A study by Saiki et al (1992), found that arsenic, mercury, and selenium measured in composite whole-body samples of five fishes — bluegill (*Lepomis macrochirus*), common carp (*Cyprinus carpio*), mosquitofish (*Gambusia affinis*), largemouth bass (*Micropterus salmoides*), and Sacramento blackfish (*Orthodon microlepidotus*) — from the San Joaquin River system were elevated; however, only selenium approached concentrations that may adversely affect survival, growth, or reproduction in warm water fishes. Moreover, only selenium among the four measured elements exhibited a geographic (spatial) pattern that coincided with known inflows of tile drainage to the San Joaquin River and its tributaries (Saiki et al. 1992). Historical data from the Grassland Water District (a region exposed to concentrated tile drainage) suggested that concentrations of selenium in fishes were at maximum during or shortly after 1984, and have been slightly lower since then. The decline of selenium concentrations in fishes from the Grasslands Water District area could be temporary if additional acreages of irrigated lands in this portion of the San Joaquin Valley must be tile-drained to protect agricultural crops from rising groundwater tables.

The 2010 SJRRP Annual Technical report presented water quality monitoring results for compounds that could have potential effects on Chinook salmon and other fish native to the San Joaquin River (SJRRP 2011c). Prominent findings included concentrations of bifenthrin in sediment samples with the potential to cause mortality in certain organisms and bioaccumulate up the food web and 30 water quality samples with copper exceeding the United States Environmental Protection Agency (EPA) aquatic-life acute benchmark for invertebrates.

Inadequate Flows

Adult salmon passage below Friant Dam during the 1940s was inhibited by low flows in the channel. In 1944 and 1947, California Department of Fish and Game (CDFG, now the California Department of Fish and Wildlife [CDFW]) (1955a) observed 5,000 to 6,000 spring-run Chinook salmon migrating up the San Joaquin River as far as Mendota Dam with flow that was estimated to be 100 cubic feet per second (cfs) in the reach between Sack Dam and the confluence with the Merced River. CDFW (CDFG 1955a) observed that many of these fish had rubbed themselves raw going over the shallow sandbars between Sack Dam and the confluence with the Merced River (approximately 50 miles). Such abrasions may increase the risk of mortality from disease for spring-run Chinook salmon since they must spend an extended period of time holding in pools throughout the summer before spawning in early fall (SJRRP 2010b). Abrasions on fish can increase the probability of disease infection (Bader et al. 2006). Passage for the San Joaquin River adult spring-run Chinook salmon has been blocked completely in the Restoration Area since the 1950s when the river was dewatered below Sack Dam except during uncontrolled flow releases in wet years (SJRRP 2010b).

Suitable flows are necessary year-round for juvenile salmon rearing. As flow increases, the area preferred by juvenile Chinook salmon shifts from the center of the channel to submerged terrestrial vegetation on the edge of the channel and within the floodplain (SJRRP 2011b). Deeper inundation provides more overhead cover and protection from avian and terrestrial predators than shallow water (Everest and Chapman 1972). In broad low-gradient rivers, changes in flows can greatly increase or decrease the lateral area available to juvenile Chinook salmon, particularly in riffles and shallow glides.

The Central Valley stream reaches (Mill, Deer, Butte creeks) that are presently accessible to spring-run Chinook salmon often lack the summer habitat conditions needed to sustain juvenile spring-run demonstrating the yearling life history in their lower reaches and during drought years (SJRRP 2011b). These conditions can be exacerbated by reservoir operations and water diversions that reduce summer flows and can be particularly severe in drought years.

Reduced flows also interact with other stressors such as temperature, contaminants, other water quality parameters, and disease to exacerbate conditions. A reduced volume of water flow generally increases in temperature faster. Contaminants are less diluted in a reduced flow volume. Disease transmission is increased when reduced flows reduce the area of suitable habitat and cause fish to become more concentrated in the available habitat.

Passage Impediments

Fish migrate to spawn, feed, avoid predators, and escape stressful environmental conditions. The success of migration, whether upstream, downstream or laterally (to floodplain and off channel habitat) is limited by aquatic conditions and the presence of barriers that can impede fish passage.

According to NMFS (2008), a passage impediment is defined as any artificial structural feature or project operation that causes adult or juvenile fish to be injured, killed, blocked, or delayed in migration, to a greater degree than in a natural river setting.

Direct and indirect impacts related to creating passage issues for migrating fish include:

- Blockage – Both complete and partial physical prevention of further migration. Complete blockages prevent migration at all flow levels while partial blockages only prevent migration at certain flow levels or only a portion of the fish are able to pass (for example a blockage of a certain height that only 25% of Chinook Salmon are able to jump over to continue their migration).

- Migration Delay- Opportunities to veer off course delaying migration, adding stress, reducing energy stores, and potentially experiencing high temperatures
- Fatigue – Cannot complete immediate passage or reduces ability to complete migration or life strategy
- Vulnerability – Predation and disease
- Injury – Impact, scrapes, and abrasions
- Desiccation – Tissue damage or reduction in gill function due to being out of water for prolonged periods
- Disorientation – Fish cannot find pathway or access to passage, impeding or reducing migration success

Velocity, depth, and elevational changes (hydraulic drops) can block or impede fish movement. Whether a structure is an impediment to fish movement depends on the physical and hydraulic features of the structure, and the physiology and behavior of the fish; this can change with fish species and age. Barriers may create velocity, depth, and slope conditions that fish cannot physically overcome, and these factors may disorient fish or cause fish to avoid such conditions. In addition, turbulence, depth, and fall can injure or otherwise incapacitate fish, increasing their vulnerability to predation, disease, and fatigue. Multiple impediments along a migratory path may fatigue fish as they migrate upstream or downstream and the cumulative effect of these impediments may decrease the physical abilities of individual fish to migrate and successfully complete their life history (Jones and Stokes 2001; Gallagher 1999).

In 2001, a fish passage evaluation of the entire Restoration Area classified potential passage impediments as (Jones and Stokes 2001):

1. Entrainments
    - Diversions/returns (diversions may or may not have a mechanical pump)
    - Confluences
2. Barriers
    - Structures (e.g., dams, headgates, control structures)
    - Bridges
    - Road crossings (e.g., mounded dirt, with or without culvert, spans channel)

The evaluation used past reports and documents, along with aerial photographs and ground-truthing, to identify 90 potential impediments to migrating fish within Reach 4B.

A decade later, the California Department of Water Resources (DWR) performed another fish passage evaluation for the SJRRP (SJRRP 2011b, 2012). This fish passage evaluation was broken up into two tasks. Task 1 was an initial evaluation of structures in the Restoration Area and included identification and data collection of potential fish passage barriers, identification of fish passage criteria for the evaluation, and identification of potential barriers for future study (SJRRP 2011b). Task 2 consisted of data collection and hydraulic evaluation of the potential fish passage barriers identified in Task 1 (SJRRP 2012).

Task 1 only evaluated structures that would have an impact on migration of fish in the San Joaquin River and bypasses, and did not consider off-channel structures such as diversions or gravel mining pits (SJRRP 2011b). DWR reviewed existing reports on potential fish passage barriers, which resulted in the identification of 61 structures that were reviewed for inclusion in the Task 1 evaluation. Of these 61structures, only 18 were included for analysis in Task 2 based on the Task 1criteria. In addition to previously identified structures, DWR identified other potential fish passage barriers through examination of aerial photographs, and built structural models in the San Joaquin Hydrologic Engineering Center River Analysis System (HEC-RAS), as part of the Task 1 analyses. These analyses resulted in the identification of 50 new structures for a total of 68 structures that were evaluated in Task 1. A total of 45 of the 68 structures were field surveyed using the First Pass method, with the remaining structures not surveyed due to access issues (SJRRP 2011b). The First Pass method consisted of physical data collection of each structure including measurements and photographs (SJRRP 2011b). An additional structure was added based on the field observation and several more structures were evaluated based on existing field data or data collected at a distance (SJRRP 2011b). The data from the First Pass survey were analyzed with ArcGIS GeoDatabase using the fish passage criteria identified for use in this analysis (SJRRP 2011b). The ArcGIS GeoDatabase categorized the structures as Green (not a barrier to fish migration and will not be further analyzed), Gray (placed on a list for Second Pass analysis), and Red (fish passage barrier). This resulted in the identification of 28 structures that were Green, 13 as Gray, and 8 as Red (SJRRP 2011b).

In Task 2, the 13 structures identified as potential fish passage barriers (Gray) in Task 1, as well as two Red barriers (Eastside Bypass and Mariposa Bypass control structures), were evaluated using data collection and hydraulic evaluation (SJRRP 2012). In addition, the Merced NWR weirs in the Eastside Bypass were identified as potential barriers by United States Department of the Interior, Bureau of Reclamation (Reclamation) and evaluated in Task 2. In evaluating fish passage for Task 2, criteria were identified based on guidelines developed by CDFW, NMFS, and others for adult salmonids (SJRRP 2011b, SJRRP 2012). Due to the complexity of developing criteria and evaluating every structure for all fish species potentially present in the reach, adult Chinook salmon were selected as the focal species of the evaluation (SJRRP 2012). However, the SJRRP Native Fish Attributes Table with fish passage criteria was also considered (SJRRP 2012). Fish passage at all identified structures was evaluated based on three main criteria: jump height into the structure, depth in the structure, and velocity in the structure. Second Pass data collection was focused on the data needed to create hydraulic models for the sites and included flow, velocities, and depth. Hydraulic data and models were evaluated in relation to fish capabilities in order to determine Chinook salmon passage success at each potential San Joaquin River fish barrier. The flow ranges used in the model for fish passage was 25 – 4,500 cfs for the San Joaquin River and 25-8,500 cfs for the bypasses with the flow being the actual flow at the structure and not the release from Friant (SJRRP 2012).

Entrainment

Herren and Kawasaki (2001) found 298 diversions in the San Joaquin River Basin. More than 95 percent of these diversions were unscreened at the time of the study with unscreened diversions increasing the likelihood of fish entrainment. The precise impacts of these diversions across life stages of Chinook salmon or other fishes are unknown (SJRRP 2010a). No studies have been conducted to determine the entrainment rates at pumps and weirs within the Restoration Area (SJRRP 2010a). In a laboratory experiment, smolt sized juvenile Chinook Salmon were found to have an entrainment risk of 0.3 to 2.3 percent when encountering a simulated unscreened water diversion (Mussen et al. 2013). In a juvenile Chinook Salmon entrainment study of agricultural pumps in the Sacramento River, an average of 0.05 percent (range 0 to 1.0 percent) of marked salmon released upstream of the diversion were recaptured (Hanson 2001).

Water diversions can reduce survival of emigrating juvenile salmonids by causing direct losses at unscreened or inadequately screened diversions; these diversions can also cause indirect losses associated with reduced streamflows (SJRRP 2010a). Fish screening and salvage efforts at major agricultural diversions have met with variable levels of success, and many smaller unscreened or inadequately screened diversions continue to operate. Unscreened diversions continue to be operated due to the lengthy fish screen regulatory permitting process and they can be expensive to install. Fish losses at diversions can result from physical injury, impingement, entrainment, or predation. Delayed passage, increased stress, and increased vulnerability to predation also contribute to mortality caused by diversions. Diversion impacts on migratory fish depend on diversion timing and magnitude, river discharge, fish species and life stage, and other factors.

Diversions/returns (Diversions may or may not have a mechanical pump) Sixty diversion/returns within the 4B Reach were identified using aerial photographs (Jones and Stokes 2001). Three of those locations were visited by the 4B Fisheries Team in 2010. One location was a pipe culvert with a flap gate, and the other two locations were pumping stations. These facilities appeared to have the potential to entrain juvenile fish. At all three locations, culvert configurations indicate that once fish were diverted from the channel, they could not return (Figure G-1). Debris screening was observed at two of the three locations, providing a barrier to adult fish, but could entrain most sizes of juvenile fish. All three locations had large cut ditches from the channel to the diversion or return. These areas were relatively deep, and had low flow velocity, indicating a potential for harboring piscivorous predators.

Figure G-1.
Example of Pump Diversion within Reach 4B

Tributary Confluences (False Pathways) using aerial photographs, five confluence connections were identified within Reach 4B with the main confluences being with Bear and Owens creeks, and all were located on the Eastside Bypass (Jones and Stokes 2001). During high flows, there could be the potential to attract migrating adult fish from the main channel, which could create negative consequences like migration delays, missed cues, or exposure to elevated temperatures. Juveniles might also traverse these tributaries, but this may or may not have negative consequences, depending on whether these areas provide beneficial rearing habitat, and if juveniles could freely return to the main channel.

Barriers As described above, DWR performed a fish passage evaluation for the SJRRP throughout the Restoration Area (SJRRP 2011b, 2012b). In evaluating fish passage, criteria were selected based on guidelines developed by CDFW, NMFS, and others for adult salmonids (SJRRP 2011b, SJRRP 2012). Due to the complexity of developing criteria and evaluating every structure for all fish species that may be present in the reach, adult Chinook salmon was the focus species of the evaluation but passage for all native fish species was considered (SJRRP 2012). Fish passage potential at all identified structures, at flows ranging from 25 to 4,500 cfs at the potential barriers in the San Joaquin River and 25 to 8,500 cfs for potential barriers in the bypass, was evaluated based on three main criteria: jump height into the structure, water depth within the structure, and flow velocity within the structure. Hydraulic data were evaluated in relation to fish capabilities in order to determine Chinook salmon passage success at each potential San Joaquin River fish barrier.

The results of the Task 2 evaluation conducted by DWR, suggested that adult Chinook salmon would not be able to pass structures at most flows in Reach 4B, or the Eastside

Bypass, unless improvements are completed to allow passage (SJRRP 2012). The following eight structures in the Reach 4B/ESB Project study area were identified as either partial or complete barriers for adult migration of salmon and would be evaluated further to develop passage alternatives (SJRRP 2012):

- Merced Refuge Weir #2
- Merced Refuge Weir #1
- Dan McNamara Road
- Eastside Bypass Control Structure
- Mariposa Bypass Control Structure
- Mariposa Drop Structure
- Eastside Bypass Rock Weir

The restriction of spawning to a limited area below impassable barrier is considered one of the primary factors that explains the decline of Central Valley anadromous fish species, including Chinook salmon and steelhead (SJRRP 2010a). Barriers can also impede the movement of numerous other native and non-native fish species.

Flow Structures

Reach 4B Headgates The Headgates are located at RM 168. They consist of an earth fill dam with four, square concrete headgate culverts controlling flow into Reach 4B. When the gates are closed, this structure is a complete barrier to flow and fish. The gates have not been operational for many years (and may no longer be operational) but would be a fish passage barrier if they could be operated (Figure G- G-2). If the gates could be opened the structure would require consistent maintenance due to the small diameter of each culvert and there is a high probability that the culverts will become plugged with debris.

Figure G-2.
Four Culverts Associated with the Reach 4B Headgates

There also appears to be an elevation gradient that would be an impediment to upstream and downstream migration. The structure also would have debris load issues that would further impede fish movement. Energy dissipation would create a potential pool in conjunction with the concrete basin, providing holding areas for predators of small fish moving downstream. Depending on velocities, fish might impact concrete energy dissipation structures, causing injury or disorientation. High concentrations of invasive aquatic vegetation could potentially influence water quality (i.e., dissolved oxygen) adjacent to the structure, creating an additional physiochemical barrier for some fish.

Sand Slough Control Structure Located adjacent to the Reach 4B Headgates is the Sand Slough Control Structure (RM 168). This is a low head control structure in Sand Slough between the San Joaquin River and the Eastside Bypass (Figure G-3). Task 2 determined that this structure is not a fish barrier (SJRRP 2012). However, the large scour pools above and below the concrete structure could provide potential predator holding areas. Predation on juvenile salmon can be quite high within energy dissipation pools located below control structures (Sabal et al. 2016).

Figure G-3.
Sand Slough Control Structure

Mariposa Bypass Control Structure This structure is located at ~RM147 within the Mariposa Bypass. The concrete has 14 bays (6 open in the middle and 4 gated on either side; Figure G-4). Each of the bays has concrete energy dissipation structures that would create upstream fish barriers under a variety of flows. The Mariposa Bypass Control Structure is a barrier at all flows (SJRRP 2012). Manipulation of the gates would likely not improve passage. Dissipation structures most likely would create hydraulic drops that could potentially injure and disorient downstream moving fish. A combination of scour holes and dissipation sills could create stranding and predation issues for juvenile fish. At lower flows, the pool just downstream of the structure would greatly dissipate velocities, creating an energy sink for juvenile fish and potentially disorient fish searching for upstream and downstream passage. This pool also might create water quality issues, including temperature and dissolved oxygen barriers as well as elevated risk of predator holding.

Figure G-4.
Mariposa Bypass Control Structure

Mariposa Bypass Drop Structure This structure is located at ~ RM147 in the Eastside Bypass and diverts flow from the Eastside Bypass to the Mariposa Bypass. The structure consists of a concrete wall spanning the channel and two concrete walls framing the downstream channel. The channel-spanning wall is over 6 feet tall on the upstream side and well over 15 feet on the downstream side. The wall is likely a barrier at all flows even when completely inundated during flood flows. The concrete basin on the downstream side concentrates high flows, creating a very large scour pool (well over 1 acre in size). At lower flows, this pool would greatly dissipate velocities, creating an energy sink for juvenile fish and potentially disorient fish searching for upstream and downstream passage and create an elevated risk of predator holding (Figure G-5).

**Figure G-5.
Scour Hole Associated with the Mariposa Bypass Drop Structure**

The downstream hole could also create potential water quality issues during lower flow situations (e.g., temperature and dissolved oxygen). Scour holes at the top and bottom of the structure could create potential predator holding areas.

Eastside Bypass Control Structure This structure is in the Eastside Bypass immediately adjacent to the Mariposa Bypass Bifurcation Structure. The structure constricts flow through six radial gates. Each of the bays has concrete energy dissipation structures that would create upstream fish barriers under a variety of flows (see Figure G-6). The energy dissipating blocks create physical passage barriers to large fish (i.e., adult anadromous salmonids). There are weep holes, small holes designed for water release at low flows (see Figure G-6), across the wall face, but their utility in passing fish appears minimal. Manipulation of the gates might improve some passage but may also cause potential impingement issues. Structures most likely would create hydraulic drops that could potentially injure and disorient downstream moving fish.

Figure G-6.
Energy Dissipation Sills, Radial Arms, and Weep Holes within the Eastside Bypass Control Structure

A combination of scour holes and dissipation sills could create stranding and predation issues for juvenile fish. At lower flows, the lower pool would greatly dissipate velocities, creating an energy sink for juvenile fish and potentially disorient fish searching for upstream and downstream passage. This pool also might create water quality issues, including temperature and dissolved oxygen barriers.

National Wildlife Refuge Weirs Within the Eastside Bypass, two low weirs control water elevation and flow in the wildlife refuge. Both structures appear to create upstream and downstream barriers to fish due to hydraulic drops. Passage would be further impeded due to high debris loading across both structures from plant production and beaver (*Castor canadensis*) activity (Figure G-7). Predation could be enhanced because of low velocities in and around constricted passage areas.

Figure G-7.
Low Head Weir within the Wildlife Refuge

Other Potential Barriers

Bridges Nine bridges were identified based on aerial photographs of Reach 4B (Jones and Stokes 2001). The bridges do not appear to create any major passage issues. However, high concentrations of bridge abutments could collect debris during high flows, causing backwater conditions and creating passage issues (Figure G-8). Bridges constructed with concrete aprons or energy dissipation structures may create depth and velocity barriers at low flows and scour holes downstream of the structures that could block fish movement. Any blockages that reduce flow velocity or create scour holes could generate conditions advantageous to predators.

Figure G-8.
Example of Bridge and Abutments within Reach 4B

Road crossings (mounded dirt; with or without culvert; spans channel)

Seven road crossings were identified based on a review of aerial photographs (Jones and Stokes 2001). Two of these crossings were visited in 2010 by the 4B Fisheries Team. Both crossings were earthen mounds spanning the entire San Joaquin River channel, with a single, corrugated pipe culvert passing through each. The culverts were significantly under-sized for the channel and would not be able to carry the range of flows expected. Both culverts would have debris loading issues, and the crossings most likely would dam water and then overtop under most flows (Figure G-9). Potential debris and depth barriers are created under this situation. Upstream migrating fish would not be able to negotiate these culverts. If kept clean, downstream passage of some smaller fish (e.g., juvenile salmonids) would be possible. Elevated earthen mounds and undersized pipes most likely would create scour on the downstream side of crossings, creating potential predator holding areas and hydraulic drop barriers under most situations. Some of these road crossings may wash out during high flows (McBain and Trush 2002). The seven crossings identified in 2001 may not be existing currently, particularly after the high flows of 2017.

Figure G-9.
Example of Road Crossing and Associated Culvert

Predation

San Joaquin River fish assemblage monitoring conducted during 2003 to 2005 (CDFG 2007) and 2012 to 2014 (SJRRP 2014, 2017) indicated that the Reach 4B/ESB Project area is inhabited by several non-native species that are known to prey on juvenile salmonids and other native species, including largemouth bass (*Micropterus salmoides*), green sunfish (*Lepomis cyanellus*), warmouth (Lepomis gulosus), black crappie (*Pomoxis nigromaculatus*), white crappie (*Pomoxis annularis*), striped bass (*Morone saxatilis),* bluegill (*Lepomis macrochirus*), pumpkinseed (*Lepomis gibbosus*), redear sunfish (*Lepomis microlophus*), and spotted bass (*Micropterus punctulatus*) (Grossman 2016).

There is an apparent shift in species composition from native to non-native fish assemblages (predominated by predator centrarchid species) with increasing distance downstream from Friant Dam (CDFG 2007, SJRRP 2014, 2017). There was also a corresponding downstream shift in habitat type dominance by area, from glides to pools. In California streams, some species, such as introduced centrarchids, tend to increase their populations with increased human disturbance of habitats, including lowered stream flows, increased number of pools, and increased turbidity (Moyle and Nichols 1973). The more downstream reaches (e.g., the Reach 4B/ESB Project area) were completely dominated by non-native species (including many predator species) in all habitat types (CDFG 2007).

High predation rates on migratory fish, including juvenile salmonids, have been observed below small dams in Central Valley rivers (Tucker et al. 1998, Sabal et al. 2016). As juvenile salmon pass over small dams, the fish are subject to conditions that may disorient them, making them highly susceptible to predation by other fish or birds (Beamesderfer et al. 1996, Wiese et al. 2008). In addition, deep pool habitats tend to form immediately downstream from these dams where Sacramento pikeminnow, striped bass, and other potential predators congregate (Sabal et. al. 2016). Tucker et al. (1998) showed high rates of predation by Sacramento pikeminnow and striped bass on juvenile salmon below the RBDD, and Sabal et al. (2016) demonstrated high predation rates on emigrating salmonids below Woodbridge Dam on the Mokelumne River by striped bass.

Striped bass, an invasive non-native anadromous species, which primarily migrate into the San Joaquin River tributaries during the late-winter and spring (S.P. Cramer and Associates 2004, 2005; Cramer Fish Sciences 2006, 2007), were the primary predators of juvenile fall-run Chinook salmon fitted with radio tags in a Stanislaus River study (Demko et al. 1998). Although more than 90 percent of the radio-tagged fish appear to have been eaten by predators, there is uncertainty as to whether gastrically implanting the radio tags, which had 12-inch-long external whip antennas, impaired the ability of the juvenile salmon to avoid predators (Demko et al. 1998). A recent predation study in the lower San Joaquin River found a mean relative predation rate of 15.3 percent on tethered juvenile Chinook Salmon (Demetras et al. 2016). Of the 12 video documented predation events, 3 were confirmed to be by striped bass with the other predators not identifiable to species (Demetras et al. 2016).

Birds are also known to prey on juvenile salmonids and other fish species (Evans et al. 2012). Caspian terns *Hydroprogne caspia* were documented to prey on juvenile fall-run Chinook salmon migrating in San Francisco Bay (Evans et al. 2011). In addition to terns, double-crested cormorants *Phalacrocorax auritus*, California gull *Larus californicus*, ring-billed gull *L. delawarensis*, and American white pelicans *Pelecanus erythrohynchos* were documented to consume salmonids in the Columbia River basin (Evans et al. 2012). The minimum predation rate of terns and cormorants on Willamete River spring-run Chinook salmon was 2.5% (Evans et al. 2012). Western gulls *Larus occidentalis* consumed juvenile coho salmon *Oncorhynchus kisutch* and steelhead in Central California streams with some of the streams appearing to have high predation rates (Osterback et al. 2013). To date, no avian predation studies on Central Valley salmon have been performed.

G.1.4 Fish Species

Fish communities in the San Joaquin Reach 4B/ESB Project study area have changed markedly in the last 150 years (SJRRP 2011b). Native fish assemblages were adapted to widely fluctuating riverine conditions, ranging from large winter and spring floods to low summer flows, and had migratory access to extensive upstream habitats. These environmental conditions resulted in a broad diversity of fish species, including anadromous species. Fishes that may have historically occurred, as well as those that currently inhabit the Reach 4B/ESB Project area, are listed in Table G-1.

Table G-1.
Fish species with historic or current presence within the Reach 4B/ESB Project study area

Category	Species	Scientific Name	Federal/State Status[1]	Current Presence
Native Anadromous	Central Valley Spring-run Chinook Salmon	*Oncorhynchus tshawytscha*	T/T	Periodic[2]
	Central Valley Fall-run Chinook Salmon	*Oncorhynchus tshawytscha*	SC-/ SC	Periodic
	California Central Valley steelhead	*Oncorhynchus mykiss*	T/SC	Unknown; Rainbow trout observed in Reach 1
	North American Green Sturgeon	*Acipenser medirostris*	T/SC	No; Only anecdotal evidence of historic presence in San Joaquin River
	White Sturgeon	*Acipenser transmontanus*	--/SC	Yes[3]; Observed by DIDSON in Reach 5
	River Lamprey	*Lampetra ayersii*	--/SC	Unknown; have not been observed in Restoration Area during surveys
	Pacific Lamprey	*Entosphenus tridentata*	--/SC	Periodic/ observed in Reach 1
Native Riverine	Sacramento Hitch	*Lavinia exilicauda exilicauda*	--/SC	No; Observed in Reach 2,3, and 5
	Sacramento Blackfish	*Orthodon microlepidotus*		Yes
	Sacramento Splittail	*Pogonichthys macrolepidotus*	--/SC	Periodic
	Sacramento Perch	*Archoplites interruptus*	--/SC	Extirpated
	Hardhead	*Mylopharodon conocephalus*	--/SC	No; Observed in Reach 1
	Sacramento Pikeminnow	*Ptychocheilus grandis*		No; Observed in Reach 1
	Sacramento Sucker	*Catostomus occidentalis occidentalis*		Yes
	Tule Perch	*Hysterocarpus traski*		No; Observed in Reaches 2 and 3
	Prickly Sculpin	*Cottus asper*		Yes
	Riffle Sculpin	*Cottus gulosus*	--/SC	No; Observed in Reaches 1 and 3
	Threespine Stickleback	*Gasterosteus aculeatus*		No; Observed in Reach 1
Native Resident Lamprey	Kern Brook Lamprey	*Lampetra hubbsi*	--/SC	No; Observed in Reach 1

Category	Species	Scientific Name	Federal/State Status[1]	Current Presence
Non-native Invasive Anadromous	Striped Bass	*Morone saxatilis*		Yes
Non-native Invasive Resident	Black Bullhead	*Ameiurus melas*		Yes
	Brown Bullhead	*Ameiurus nebulosus*		Yes
	Channel Catfish	*Ictalurus punctatus*		Yes
	White Catfish	*Ameirurus catus*		Yes
	Bigscale Logperch	*Percina macrolepida*		Yes
	Fathead Minnow	*Pimephelas promelas*		Yes
	Inland Silverside	*Menidia beryllina*		Yes
	Red Shiner	*Cyprinella lutrensis*		Yes
	Golden Shiner	*Notemigonus crysoleucas*		Yes
	Goldfish	*Carassius auratus*		
	Western Mosquitofish	*Gambusia affinis*		Yes
	Common Carp	*Cyprinus carpio*		Yes
	Shimofuri Goby	*Tridentiger bifasciatus*		Yes
	Black Crappie	*Pomoxis nigromaculatus*		Yes
	White Crappie	*Pomoxis annularis*		Yes
	Bluegill	*Lepomis macrochirus*		Yes
	Green Sunfish	*Lepomis cyanellus*		Yes
	Pumpkinseed	*Lepomis gibbosus*		No; observed in Reach 5
	Redear Sunfish	*Lepomis microlophus*		Yes
	Warmouth	*Lepomis gulosus*		Yes
	Spotted Bass	*Micropterus punctulatus*		Yes
	Largemouth Bass	*Micropterus salmoides*		Yes
	Threadfin Shad	*Dorosoma petenense*		Yes

Source: Fish presence information is from San Joaquin River fish assemblage monitoring conducted during 2012 to 2014 (SJRRP 2014, 2017).

[1] SC = California Species of Special Concern, T = Threatened

[2] CV Spring-run Chinook Salmon are a focus of SJRRP reintroduction activities

[3] CDFG report card data 2009

The following species descriptions include a brief account of the current and historical distribution, life history patterns, and habitat requirements of fish species with historic or current presence in the Reach 4B/ESB Project area. This section is subdivided into native anadromous fish, native riverine fish, non-native invasive/introduced anadromous species, and non-native invasive/introduced riverine species.

Native Anadromous Fish Species

Due to the numerous fish barriers present in the Reach 4B/ESB Project area and lack of adequate flows (see Stressors section), native anadromous fish species historically present in the Restoration Area cannot access the Reach 4B/ESB Project area and reaches upstream except in the wettest years. Therefore, all anadromous fish species effectively have been extirpated from the Restoration Area because rare and inconsistent access has not allowed viable populations to persist. Furthermore, extreme habitat degradation and unsuitably high-water temperatures (see Stressors section) has made aquatic habitat in the Restoration Area unsuitable for most life stages of native anadromous fish species. Since there is only anecdotal evidence of the historical use of the San Joaquin River by North American green sturgeon (Beamesderfer et al. 2004, Jackson and Van Eenennaam 2013) this species is not further discussed in this document.

Central Valley Spring-run Chinook Salmon Spring-run Chinook salmon in the Central Valley was once among the largest runs on the Pacific Coast (Yoshiyama et al. 1998). Construction of dams on the Sacramento, American, Mokelumne, Stanislaus, Tuolumne, Merced, and San Joaquin rivers helped lead to the extirpation of spring-run Chinook salmon from these watersheds. Annual abundance estimates of extant Central Valley spring-run Chinook salmon populations display a high level of fluctuation but the overall number of spring-run Chinook salmon remain far below estimates of historic abundance (SJRRP 2011a). On September 16, 1999, NMFS listed the Central Valley spring-run Chinook salmon evolutionarily significant unit (ESU) as threatened under the Federal Endangered Species Act (ESA).

On January 30, 2014, NMFS designated a nonessential experimental population (NEP) of Central Valley spring-run Chinook salmon under section 10(j) of the Endangered Species Act in portions of the San Joaquin River below Friant Dam (78 FR 79622). The experimental population area includes the San Joaquin River just upstream from its confluence with the Merced River to Friant Dam including all sloughs, channels, floodways, and waterways that CV spring-run Chinook salmon can access along the San Joaquin River as well as portions of the Kings River when it is connected to the San Joaquin River (high water years; 78 FR 79622). The NEP is treated under section 7 as if it is a species proposed for listing. Protective regulations under section 4(d) and 9 apply to the NEP within the experimental population area. The unintentional take of CV spring-run Chinook Salmon in the experimental population area that is caused by otherwise lawful activities is excepted from Section 9 take provisions. Outside of the experimental population area, CV spring-run Chinook salmon will continue to be covered by the take prohibitions and exceptions applicable to the non-experimental part of the ESU but limited take exceptions will apply to meet the *de minimis* conditions of the settlement (78 FR 79622). In the lower San Joaquin River and its tributaries downstream from the Merced River confluence to Mossdale County Park, take of CV spring-run Chinook salmon is excepted if the avoidance of such take would impose more than *de minimis* impact on water supply reductions, additional storage releases, or bypass flows on unwilling third parties (78 FR 79622).

In the San Joaquin River, spring-run Chinook salmon (*Oncorhynchus tshawytscha*) historically spawned as far upstream as the present site of Mammoth Pool Reservoir (RM

322), where their upstream migration historically was blocked by a natural velocity barrier (P. Bartholomew, pers. comm., as cited in Yoshiyama et al. 1996). The San Joaquin River historically supported large runs of spring-run Chinook salmon; (CDFG 1990, as cited in Yoshiyama et al. 1996) suggested that this run was one of the largest Chinook salmon runs on any river on the Pacific Coast, with an annual escapement averaging 200,000 to 500,000 adult spawners (CDFG 1990, as cited in Yoshiyama et al. 1996). Construction of Friant Dam began in 1939 and was completed in 1942, which blocked access to upstream habitat (SJRRP 2011b). Nevertheless, runs of 30,000 to 56,000 spring-run Chinook salmon were reported in the years after Friant Dam was constructed, with salmon holding in the pools and spawning in riffles downstream from the dam. Friant Dam began filling in 1944 and, in the late 1940s, began to divert increasing amounts of water into canals to support agriculture. Flows into the main stem San Joaquin River were reduced to a point that the river ran dry near Gravelly Ford. By 1950, the entire run of spring-run Chinook salmon was extirpated from the San Joaquin River (Fry 1961).

Adult spring-run Chinook salmon historically used the Reach 4B/ESB Project area as a migration corridor during upstream migration in early spring on their way to holding habitat in the upper reaches of the San Joaquin River (Clark 1943). Historical migration through the project area was April through June, with May being the peak time period. Adult migration requires sufficient water depths and velocities to provide barrier-free passage to holding and spawning habitat. CDFW uses a minimum depth of 0.9 feet for passage of adult Chinook salmon in their passage assessments (CDFW 2016). Boles (1988) recommends water temperatures below 65°F (18.3°C) for adult Chinook salmon migration. Lindley et al. (2004) report that adult migration is blocked when temperatures reach 70°F (21.1°C), and fish can become stressed as temperatures approach 70°F (21.1°C). In contrast, Strange (2010) found that adult salmon migration in the Klamath River was blocked at temperatures above about 73°F (22.8°C), with some migration occurring up to temperatures of 75°F (23.9°C).

Spring-run Chinook salmon enter freshwater as sexually immature adult fish, and their holding period can last for several months before individuals are ready to spawn in the fall (Moyle 2002; CDFG 1998). Spring-run Chinook salmon historically spawned in the San Joaquin River upstream from the town of Friant from late August to October, peaking in September and October (Clark 1943). Egg incubation generally lasts between 40 and 90 days at water temperatures of 43 to 54°F (6 to 12°C) (Vernier 1969, Bams 1970, Heming 1982, Bjornn and Reiser 1991). Alevins remain in the gravel for 2 to 3 weeks after hatching and absorb their yolk sac before emerging from the gravels into the water column from November to March (Fisher 1994, Ward et al. 2003).

The length of time spent rearing in freshwater varies greatly among juvenile spring-run Chinook salmon across their range (SJRRP 2011b). Spring-run Chinook salmon may disperse downstream as fry soon after emergence, early in their first summer, in the fall as flows increase, or as yearlings during the spring after overwintering in freshwater (Healey 1991). In contrast to more northern spring-run Chinook salmon populations, many of the current Central Valley populations exhibit fry and smolt downstream migration during the winter and spring of their first year, and relatively few exhibit a yearling life history (NMFS 2014). However, some juveniles likely migrate downstream throughout the year (Nicholas and Hankin 1989).

Historically, spring-run Chinook salmon juveniles likely used the Reach 4B/ESB Project area as a migration corridor and rearing area due to the extensive floodplain habitat present. Juvenile salmonids rear on seasonally inundated floodplains when available. Sommer et al. (2001) found higher growth and survival rates of Chinook salmon juveniles reared on the Yolo Bypass compared with those in the main stem Sacramento River. Jeffres et al. (2008) observed similar results on the Cosumnes River floodplain. Drifting invertebrates, the primary prey of juvenile salmonids, were more abundant on the inundated Yolo Bypass floodplain than in the adjacent Sacramento River (Sommer et al. 2001).

Central Valley Fall-run Chinook Salmon Fall-run Chinook salmon generally spawned lower in the watershed than spring-run Chinook salmon (CDFG 1955b). Although the San Joaquin River also supported a fall-run Chinook salmon run, they historically composed a smaller portion of the river’s salmon runs (Moyle 2002). Fall-run Chinook salmon historically spawned in the main stem San Joaquin River upstream from the Merced River confluence and in the main stem channels of the major tributaries (Yoshiyama et al. 1996). Currently, however, they are limited to the Merced, Stanislaus, and Tuolumne rivers where they spawn and rear downstream from main stem dams (SJRRP 2011b). CDFW has operated a barrier (Hills Ferry Barrier) during the fall-run Chinook salmon spawning season (October to December) at the confluence of the Merced River with the San Joaquin River since the early 1990s to prevent adult fall-run Chinook salmon from migrating further up the San Joaquin River, including the Reach 4B/ESB Project area, into warmer temperatures and impassable barriers that prevent them from accessing suitable spawning habitat in reach 1. However, the Hills Ferry Barrier has been demonstrated to be an ineffective barrier that many adult fall-run Chinook Salmon are able to migrate past (SJRRP 2012, SJRRP 2013).

Fall-run Chinook salmon currently is the most abundant and widespread salmon run in California and is supported by five hatcheries releasing a combined total of approximately 35 million juveniles each year (Mills et al. 1997, Huber and Carlson 2015). NMFS determined that listing this ESU as threatened was not warranted (64 Federal Regulation [FR] 50394–50415, September 16, 1999), but subsequently classified it as a species of concern because of specific risk factors (69 FR 19975, April 15, 2004). In 2008, a collapse of Central Valley fall-run Chinook salmon occurred that has been attributed to several causes, including poor ocean conditions for rearing, freshwater water withdrawals, negative hatchery effects, and ongoing degradation of freshwater and estuarine habitats (Lindley et al. 2009).

Fall-run Chinook salmon exhibit similar life history strategies as spring-run (see spring-run above), with a few differences. Fall-run Chinook salmon do not have a summer holding period; instead, they migrate upstream during the fall and typically spawn from October through December, peaking in early to mid-November in the San Joaquin River tributaries (SJRRP 2011b). Unlike spring-run Chinook salmon, only a small percent of fall-run exhibits a yearling life history strategy, and the majority emigrate as fry or smolts during the winter or spring of the year they were born. Fall-run Chinook salmon fry typically disperse downstream from January through March, whereas smolts primarily migrate between March and June in the Central Valley (Brandes and McLain 2001).

Like spring-run Chinook salmon, fall-run are believed to have historically used the Reach 4B/ESB Project area as an adult upstream migration corridor and as a juvenile rearing and migration corridor during downstream emigration (see spring-run above).

California Central Valley Steelhead Historical rainbow trout/steelhead (*Oncorhynchus mykiss*) distribution in the upper San Joaquin River is unknown; however, in rivers where they still occur, their distribution is skewed further upstream compared to Chinook salmon (Voight and Gale 1998, as cited in McEwan 2001, Yoshiyama et al. 1996) and are typically tributary spawners (SJRRP 2011b). Lindley et al. (2006) predicted the historical distribution of steelhead (the anadromous form of *O. mykiss*), using an Intrinsic Potential habitat model. They found that at least 81 independent populations of *O. mykiss* were widely distributed throughout the Central Valley, but populations were relatively less abundant in San Joaquin River tributaries than in Sacramento River tributaries because of natural barriers to migration. Additionally, many small tributaries to the major San Joaquin River tributaries have too high a gradient or too little flow to have supported steelhead; consequently, they likely were restricted to the main stems and larger tributaries (Lindley et al. 2006). Around 80 percent of the historical spawning and rearing habitat is now behind impassable dams, and 38 percent of the populations identified by the model have lost their entire habitat (Lindley et al. 2006).

Oncorhynchus mykiss has two classifications: steelhead, which refers to the anadromous form, and rainbow trout, which refers to the non-anadromous form. The anadromous distinct population segment of *O. mykiss* was listed under the Federal ESA by NMFS (63 FR 13347, March 19, 1998 and 71 FR 834, January 5, 2006). The California Central Valley steelhead DPS includes all naturally spawned populations of anadromous steelhead below natural and human-made impassable barriers in the Sacramento and San Joaquin rivers and their tributaries, excluding steelhead from San Francisco and San Pablo bays and their tributaries. NMFS has concluded that populations of naturally reproducing steelhead have been experiencing a long-term decline in abundance throughout their range (SJRRP 2011a). Populations in the southern portion of the range have experienced the most severe declines, particularly in streams from the Central Valley south, where many stocks have been extirpated (NMFS 2014). Since the early 20th century, 23 naturally reproducing populations of steelhead are believed to have been extirpated in the western United States. Many more are thought to be in decline in Washington, Oregon, Idaho, and California. The decline of stocks in California has been particularly steep. The only limited data available on steelhead numbers in the San Joaquin River Basin come from CDFW kodiak trawling samples collected on the lower San Joaquin River at Mossdale. These data suggest that steelhead numbers declined in the early 1990s and remained low through 2002 (NMFS 2009).

In the Central Valley, adult steelhead migrate upstream beginning in June, peaking in September, and continuing through February or March (Hallock et al. 1961, Bailey 1954, McEwan and Jackson 1996). Spawning occurs primarily from January through March but may begin as early as late December and may extend through April (Hallock et al. 1961, as cited in McEwan and Jackson 1996). Although most steelhead die after spawning, some adults are capable of returning to the ocean and migrating back upstream to spawn in subsequent years. Eggs hatch after 20 to 100 days, depending on water temperature (Shapovalov and Taft 1954).

Steelhead rear in freshwater before outmigrating to the ocean as smolts. The length of time juveniles spend in freshwater appears to be related to growth rate (Peven et al. 1994). In warmer areas, where feeding and growth are possible throughout the winter, steelhead may require a shorter period in freshwater before smolting (Sogard et al. 2012). Juveniles typically remain in their natal streams for at least one summer, dispersing from fry schools to establish feeding territories (Sogard et al. 2012). Peak feeding and freshwater growth rates occur in late spring and early summer (Sogard et al. 2012). Juveniles either overwinter in their natal streams, if adequate cover exists or disperse to other streams as presmolts to seek more suitable winter habitat (Bjornn 1971; Dambacher 1991). When stream temperatures fall below about 45 °F (7.2°C) in the late fall to early winter, steelhead enter a period of winter inactivity spent, hiding in the substrate or closely associated with instream cover, during which time growth ceases (Everest and Chapman 1972). Juveniles' winter hiding behavior reduces their metabolism and food requirements and reduces their exposure to predation and high flows (Bustard and Narver 1975), but substantial mortality still appears to occur in winter.

Steelhead migrate downstream to the ocean as smolts, typically at a length of 5.85 to 7.80 inches (14.86 to 19.81 cm) (Meehan and Bjornn 1991). A length of 5.46 inches (13.87 cm) is typically cited as the minimum size for smolting (Wagner et al. 1963; Peven et al. 1994). Emigration appears to be more closely associated with size than with age; 6 to 8 inches (15.24 to 20.32 cm) is the most common size of downstream migrants. Downstream migration in unregulated streams has been correlated with spring freshets (Reynolds et al. 1993). Most steelhead spend 1 to 3 years in the ocean, with smaller smolts tending to remain in saltwater for a longer period than larger smolts (Chapman 1958). Larger smolts have been observed to experience higher ocean survival rates (Ward and Slaney 1988, Bond et al. 2008).

Historically, steelhead may have utilized the Reach 4B/ESB Project area for juvenile migration and rearing and as an adult migration corridor on their way to spawning grounds in the upper reaches of the San Joaquin River. Similar to Chinook salmon, the extensive slough and off-channel aquatic habitat present historically in the Reach 4B/ESB Project area (see Historical Habitat section) likely provided excellent steelhead rearing habitat (Jeffres et al. 2008). In the Sacramento River system, drifting invertebrates, the primary prey of juvenile salmonids, have been found to be more abundant on an inundated floodplain than in the adjacent river channel (Sommer et al. 2001).

White Sturgeon White sturgeon (*Acipenser transmontanus*) have a marine distribution spanning from the Gulf of Alaska south to Mexico but a spawning distribution ranging only from the Sacramento River northward (McCabe and Tracy 1994). Currently, self-sustaining spawning populations are only known to occur in the Sacramento, Fraser, and

Columbia rivers. Landlocked populations are located above major dams in the Columbia River basin, and residual non-reproducing fish above Shasta Dam and Friant Dam occasionally have been found (SJRRP 2010a). In California, primary abundance is in the San Francisco Estuary, with spawning occurring mainly in the Sacramento and Feather rivers (Klimley et al. 2015). However, CDFG fisheries catch information obtained from fishery report cards (CDFG 2008, 2009) documented 25 mature white sturgeon encountered by fisherman in 2007 in the San Joaquin River, and 6 mature white sturgeon encountered in 2008 upstream from Highway 140 (Reach 5). In addition, an unknown number of white sturgeon were captured in the Restoration Area in 2009 (CDFG 2010). In 2012, an adult white sturgeon was observed in Reach 5 with a dual frequency identification sonar (SJRRP unpublished data). Adult sturgeon were caught in the sport fishery industry in the San Joaquin River between Mossdale and the confluence with the Merced River in late winter and early spring, suggesting this was a spawning run (Kohlhorst 1976). Kohlhorst et al. (1991) estimated that approximately 10 percent of the Sacramento River system spawning population migrated up the San Joaquin River. According to Gruber et al (2012), white sturgeon were documented spawning in the San Joaquin River just downstream of Laird Park at river kilometer (RK) 142 in April 2011, suggesting the San Joaquin River may be an important source of production for the white sturgeon population in the Sacramento-San Joaquin river system. White sturgeon were also documented spawning within a 24-kilometer reach of the San Joaquin River from Sturgeon Bend (RK 119) to Grayson Road Bridge (RK 143) between March 20 and May 14, 2012 (Jackson and Van Eenennaam 2013). Genetic analysis of wild white sturgeon embryos collected during the 2012 spawning survey suggested that approximately 40 individuals contributed to the 2012 spawning events out of less than 100 adults likely present in the San Joaquin River (Blankenship et al. 2017). However, in subsequent San Joaquin River white sturgeon spawning surveys in the critical dry years 2013, 2014, and 2015, no white sturgeon eggs or larvae were captured despite the presence of mature white sturgeon in the San Joaquin River (Heironomus et al. 2016, Heironomus and Jackson 2017). The apparent negligible recruitment during critical dry years is likely a result of poor water quality conditions in the San Joaquin River in critical dry years, particularly low flows and high water temperatures during the spring spawning period (Heironomus et al. 2016, Heironomus and Jackson 2017). In 2015, at least two of the captured female sturgeon were undergoing atresia, the degeneration and resorption of eggs, likely as a result of mean water temperatures remaining over 18°C for a week prior to their capture (Heironomus and Jackson 2017). The spawning observations in wet 2011 and dry 2012 confirm that white sturgeon do spawn in the San Joaquin River in both wet- and dry-year conditions (Jackson et al. 2016). In dry years, small magnitude, short duration streamflow increases resulting from precipitation events or tributary river flow pulses for juvenile salmonids appear to initiate white sturgeon spawning in the San Joaquin River (Jackson et al. 2016).

White sturgeon spend most of their lives in estuaries of large rivers, only moving into freshwater to spawn (Moyle 2002). Sturgeon migrate upstream when they are ready to spawn in response to flow increases (Moyle 2002, Jackson et al. 2016). Male white sturgeon are at least 10 to 12 years old before sexual maturity (Moyle 2002). Spawning takes place between late February and early June when water temperatures range from 8 to 19°C (Moyle 2002). Telemetry studies in the San Joaquin River suggest a white sturgeon spring migration and spawning from February through May (Heironimus and Jackson 2017). The telemetry studies also suggest some fidelity to the San Joaquin River with 37% (16 out of 43) of previously tagged fish (2012 to 2014) returning to the San Joaquin River in 2015 (Heironimus and Jackson 2017). Large white sturgeon year classes are associated with high outflows through the estuary in spring, presumably due to larval sturgeon being moved quickly downstream to suitable rearing areas in the estuary (Moyle 2002).

Historically, white sturgeon likely only used the Reach 4B/ESB Project area as a migration corridor during upstream spawning runs and downstream juvenile emigration. Currently, numerous barriers in the Reach 4B/ESB Project area (see Stressors section) likely act as complete barriers to adult sturgeon in most years.

River Lamprey River lampreys have been collected from large coastal streams from 20 kilometers north of Juneau, Alaska, to San Francisco Bay (Moyle 2002). In California, most records are for the lower Sacramento-San Joaquin River system, including the Stanislaus and Tuolumne rivers. The biology of river lamprey has not been well studied in California with little primary literature available, so information available is based on studies from British Columbia. Adults migrate into freshwater during the fall and spawn during February through May in tributary streams. They dig saucer-shaped depressions in gravelly riffles for spawning. Juvenile ammocoetes remain in silty backwaters and eddies to feed on algae and microorganisms.

Due to the marshy, low gradient habitat present historically in the Reach 4B/ESB Project area (see Historical Habitat section), river lamprey likely used this Reach for juvenile rearing. However, due to several fish migration barriers present in the Reach 4B/ESB Project area (see Stressors section), river lamprey likely are blocked from migrating through the Reach 4B/ESB Project area or in reaches upstream in most years.

Pacific Lamprey Pacific lamprey (*Entosphenus tridentata*) are anadromous fish that have Pacific coast distributions and have been found in the San Joaquin River (SJRRP 2017, SJRRP unpublished data - DNA barcoding analysis of lamprey). Pacific lamprey does not appear to home to natal streams, as little genetic variation has been observed in populations from British Columbia to southern California (Goodman et al. 2008). Instead, they appear to key in on pheromones released by ammocoetes present in the river such that they will not return to a river that lacks ammocoetes (Goodman and Reid 2012). The result is a source-sink dynamic for Pacific lamprey such that large river systems containing robust populations serve as sources for smaller rivers and streams that can be sinks (Moyle et al. 2015). The Pacific lamprey has diverse life histories with some rivers containing two runs; one run that returns in the spring and spawns immediately after upstream migration and another run that migrates upstream in the fall and will spawn the following spring (Moyle et al. 2015). Most adult Pacific lamprey spawning migrations occur between March and late June, with upstream movement typically occurring during the night (Moyle et al. 2015). Upstream migration seems to take place largely in response to high flows, and adults can move substantial distances unless blocked by major barriers. Due to several fish migration barriers present in the Reach 4B/ESB Project area (see Stressors section), Pacific lamprey likely are blocked from migrating in the Reach

4B/ESB Project area or in reaches upstream in most years. However, Pacific lamprey juveniles were found in Reach 1 during the 2013-2014 sampling demonstrating that Pacific lamprey are able to migrate to Reach 1 in some years (SJRRP 2017).

Pacific lamprey hatching occurs in approximately 17 days at 57°F (14°C) and, after spending an approximately equal period in redd gravels (Meeuwig et al. 2005), ammocoetes (larvae) emerge and drift downstream to depositional areas where they burrow into fine substrates and filter feed on organic materials (Moore and Mallatt 1980). Throughout the ammocoete life stage, individuals will leave their burrows and drift to a new area at night (Moyle et al. 2015). Ammocoetes remain in freshwater for 4 to 7 years before undergoing a metamorphosis into an eyed, smolt-like form (macropthalmia) (Moore and Mallatt 1980, Moyle 2002, Moyle et al. 2015). At this time, individuals migrate to the ocean between fall and spring, typically during winter and spring high-flow events (Goodman et al. 2015), to feed parasitically on a variety of marine fishes and smooth skinned marine mammals (Van de Wetering 1998, Moyle 2002). Pacific lamprey remain in the ocean for approximately 18 to 40 months before returning to freshwater as immature adults (Kan 1975, Beamish 1980). Pacific lampreys die soon after spawning, though there is some anecdotal evidence that this is not always the case (Moyle 2002,).

Due to the marshy, low gradient habitat present historically in the Reach 4B/ESB Project area (see Historical Habitat section), Pacific lamprey likely used this reach for juvenile rearing. However, due to several Reach 4B/ESB Project area fish migration barriers (see Stressors section), Pacific lamprey likely are blocked from migrating through the Reach 4B/ESB Project area or in reaches upstream in some to most years. However, juvenile Pacific lamprey have been observed in Reach 1 (SJRRP 2017) demonstrating that adult Pacific lamprey are able to pass all of the barriers in some years and would have had to pass through reach 4B.

Native Riverine Fish Species

Many of the native riverine species historically present in the Reach 4B/ESB Project area are still present (CDFG 2007; SJRRP2017 Fish Assemblage Monitoring, Unpublished Data), but their abundance trends are unknown. Historically, the San Joaquin River in Reach 4B would have contained had year-round presence of the deep-bodied fishes assemblage in addition to the anadromous salmonids which were migrating through (Moyle 2002). The deep-bodied fish assemblage includes the Sacramento hitch, Sacramento blackfish, Sacramento splittail, and Sacramento perch (Moyle 2002). Some of these species still occur in Reach 4B while others do not (Table G-1). Degradation or complete destruction of historical aquatic habitats due to dewatering, agricultural conversion, levee construction, and channelization (see Stressors section), likely has led to greatly reduced abundances of native riverine species in the Reach 4B/ESB Project area. Furthermore, remaining native riverine species are likely competing with introduced species for limited habitat (see Introduced Fish Species section).

Sacramento Hitch Sacramento Hitch are endemic to the Sacramento-San Joaquin River Basin (SJRRP 2011b). There are three subspecies within this species found in the Clear Lake, Pajaro, and Salinas watersheds and Sacramento-San Joaquin Watershed (Lee et al. 1980). Hitch occupy warm, low-elevation lakes, sloughs, and slow-moving stretches of rivers and clear, low-gradient streams. Among native fishes, hitch have the highest temperature tolerances in the Central Valley. They can withstand water temperatures up to 100°F (38°C) although they prefer temperatures of 81 to 84°F (27 to 29°C). Hitch also have moderate salinity tolerances and can be found in environments with salinities up to 9 parts per thousand (ppt) (Moyle 2002). Hitch require clean, smaller gravel and temperatures of 57 to 64°F (14 to 18°C) to spawn. When larvae and small juveniles move into shallow areas to shoal, they require vegetative refugia to avoid predators. Larger fish are often found in deep pools containing an abundance of aquatic and terrestrial cover (Moyle 2002).

Mass spawning migrations typically occur when flows increase during spring, raising water levels in rivers, sloughs, ponds, reservoirs, watershed ditches, and riffles of lake tributaries. Females lay eggs that sink into gravel interstices (SJRRP 2011b). Hatching occurs in 3 to 7 days at 59 to 72°F (15 to 22°C), and larvae take another 3 to 4 days to emerge. As they grow, they move into perennial water bodies where they would shoal for several months in association with aquatic vegetation or other complex vegetation before moving into open water. Hitch are omnivorous and feed in open waters on filamentous algae, aquatic and terrestrial insects, zooplankton, aquatic insect pupae and larvae, and small planktonic crustaceans (Moyle 2002).

Sacramento blackfish Sacramento blackfish are endemic to low-elevation portions of major tributaries of the Sacramento and San Joaquin rivers (SJRRP 2011b). Although they were abundant in the sizeable lakes of the historical San Joaquin Valley, they are currently common only in sloughs and oxbow lakes of the Delta. Sacramento blackfish are most abundant in warm, turbid, and often highly modified habitats.

They are found in locations ranging from deep turbid pools with clay bottoms to warm, shallow, and seasonally highly alkaline water bodies. Blackfish have a remarkable ability to adapt to extreme environments such as high temperatures and low dissolved oxygen (DO) (Cech et al 1979, Campagna and Cech 1981). Although optimal temperatures range from 72 to 82°F (22 to 28°C), adults frequently can be found in waters exceeding 86°F (30°C). Their ability to tolerate extreme conditions affords them survival during periods of drought or low flows (Moyle 2002).

Spawning occurs in shallow areas with dense aquatic vegetation between May and July when water temperatures range between 54 and 75°F (12 to 24°C). Eggs attach to substrate in aquatic vegetation, and larvae are frequently found in similar shallow areas. Juvenile blackfish are often found in large schools within shallow areas associated with cover and feed on planktonic algae and zooplankton (Moyle 2002).

Sacramento splittail Sacramento splittail are endemic to the Sacramento and San Joaquin rivers, Delta, and San Francisco Bay (SJRRP 2011b). In the San Joaquin River, they have been documented as far upstream as the town of Friant (Rutter 1908). In recent wet years, splittail have been found as far upstream as Salt Slough (Saiki 1984, Baxter 2000) where the presence of both adults and juveniles indicated successful spawning.

Adult splittail move upstream in late November through late January, foraging in flooded areas along the main rivers, bypasses, and tidal freshwater marsh areas before spawning (Moyle et al. 2004). Feeding in flooded riparian areas before spawning may contribute to spawning success and survival of adults after spawning (Moyle et al. 2004). Splittail appear to concentrate their reproductive effort in wet years when potential success is greatly enhanced by the availability of inundated floodplain habitat (Meng and Moyle 1995, Sommer et al. 1997). Splittail are fractional spawners, with individuals spawning over several months (Wang 1995).

Eggs begin to hatch in 3 to 7 days, depending on temperature (Bailey 1994). After hatching, the swim bladder inflates and larvae begin active swimming and feeding (Moyle 2002). Most larval splittail remain in flooded riparian areas for 10 to 14 days, most likely feeding in submerged vegetation before moving into deeper water as they become stronger swimmers (Wang 1986, Sommer et al. 1997). Most juveniles move downstream in response to flow pulses into shallow, productive bay and estuarine waters from April to August (Meng and Moyle 1995, Moyle 2002). Floodplain habitat offers high-quality food and production and low predator densities to increase juvenile growth and survival.

Non-breeding splittail are found in temperatures up to 75°F (24°C) (Young and Cech 1996). Juveniles and adults have optimal growth at 68°F (20°C), with physiological distress above 84°F (29°C) (Young and Cech 1996). Splittail have a high tolerance for variable environmental conditions (Young and Cech 1996, Moyle et al. 2015) and are generally opportunistic feeders. Prey includes mysid shrimp, clams, and some terrestrial invertebrates.

Hardhead Hardhead are endemic to larger low- and mid-elevation streams of the Sacramento-San Joaquin river basins (SJRRP 2011b). Hardhead are widely distributed in foothill streams and may be found in a few reservoirs on the San Joaquin River upstream from Millerton Lake. Hardhead prefer water temperatures above 68°F (20°C), with optimal temperatures between 75 and 82°F (24 to 28°C). Their distribution is limited to well-oxygenated streams and the surface water of impoundments. They are often found in clear, deep pools greater than 31.5 inches (800 mm) and runs with slower water velocities. Larvae and post-larvae may occupy river edges or flooded habitat before seeking deeper low-velocity habitat as they increase in size (Moyle 2002).

Hardhead spawn between April and August. Females lay eggs on gravel in riffles, runs, or the heads of pools. The early life history of hardhead is not well known. Juveniles may feed on insects from the surface, whereas adults are benthivores, occupying deep pools. Prey items may include insect larvae, snails, algae, aquatic plants, crayfish, and other large invertebrates (Moyle 2002).

Sacramento pikeminnow Sacramento pikeminnow are endemic to the Sacramento-San Joaquin River Basin (Moyle 2002). Sacramento pikeminnow prefer rivers in low- to mid-elevation areas with clear water, deep pools, low-velocity runs, undercut banks, and vegetation. They are not typically found where centrarchids have become established.

Sacramento pikeminnow prefer summer water temperatures above 59°F (15°C), with a maximum of 79°F (26°C) (Moyle 2002).

Sexually mature fish move upstream in April and May when water temperatures are 59 to 68°F (15 to 20°C). Sacramento pikeminnow spawn over riffles or the base of pools in smaller tributaries. Pikeminnow are slow growing and may live longer than 12 years. Before the introduction of larger predatory fishes, pikeminnows may have been the apex predator in the Central Valley. Pikeminnow prey includes insects, crayfish, larval and mature fish, amphibians, lamprey ammocoetes, and occasionally small rodents (Moyle 2002).

Sacramento sucker Sacramento suckers have a wide distribution in California, including streams and reservoirs of the Sacramento and San Joaquin watersheds (Moyle 2002). Sacramento suckers most commonly are found in cold, clear streams and moderate-elevation lakes and reservoirs. Sacramento suckers can make relatively large migrations related to spawning and flow variability (Jeffres et al. 2006). Shifts in microhabitat use occur with smaller fish using shallow, low-velocity peripheral zones moving to areas of deeper water as they grow (Cech et al. 1990). Sacramento suckers can tolerate a wide range of temperature fluctuations, from streams that rarely exceed 59°F (15°C) to those that reach up to 86°F (30°C). They have high salinity tolerances, having been found in reaches with salinities greater than 13 ppt. Sacramento suckers can colonize new habitats readily (Moyle 2002).

Sacramento suckers typically feed nocturnally on algae, detritus, and small benthic invertebrates. They spawn over riffles from February through June when temperatures are approximately 54 to 64°F (12 to 18°C). After embryos hatch in 2 to 4 weeks, larvae remain close to the substrate until they are swept into warm, shallow water or among flooded vegetation (Moyle 2002).

Tule perch Endemic Sacramento-San Joaquin River subspecies of tule perch historically were widespread throughout the lowland rivers and creeks in the Central Valley (SJRRP 2011b). Currently, in the San Joaquin River watershed, they occur in the Stanislaus River, occasionally in the San Joaquin River near the Delta, and the lower Tuolumne River. Tule perch in riverine habitat usually are found in emergent plant beds, deep pools, and near banks with complex cover. They require cool, well-oxygenated water, and tend not to be found in water exceeding 77°F (25°C) for extended periods. They can tolerate high salinities (i.e., 30 ppt) (Moyle 2002).

Tule perch generally feed on the bottom or among aquatic plants (Moyle 2002). They are primarily adapted to feed on small invertebrates and zooplankton. Females mate multiple times between July and September, and sperm is stored until January when internal fertilization occurs. Young develop within the female and are born in June or July when food is most abundant. Juveniles begin to school soon after birth.

Prickly sculpin Central Valley populations of prickly sculpin (*Cottus asper*) are found in the San Joaquin Valley south to the Kings River (Moyle 2002). Prickly sculpin generally is found in medium-sized, low-elevation streams with clear water and bottoms of mixed substrate and dispersed woody debris. In the San Joaquin Valley, they are absent from warm, polluted areas, implying their distribution is regulated by water quality. Prickly sculpin has been found in abundance in cool flowing water near Friant Dam, in Millerton Lake, and in the small, shallow Lost Lake where bottom temperatures exceed 79°F (26°C) in the summer (Moyle 2002).

Prickly sculpin spawn from February through June when water temperatures reach 46 to 55°F (8 to 13°C). After hatching, larvae move down into large pools, lakes, and estuaries where they spend 3 to 5 weeks as planktonic fry. Prickly Sculpin prey include large benthic invertebrates, aquatic insects, molluscs, and small fish and frogs (Moyle 2002).

Riffle sculpin Riffle sculpin (*Cottus gulosus*) have a scattered distribution pattern throughout California, including the Sacramento-San Joaquin watersheds (Moyle 2002). Riffle sculpin prefer habitats that are fairly shallow with moderately swift water velocities and oxygen levels near saturation (Moyle and Baltz 1985). They move where water temperatures do not surpass 77 to 79°F (25 to 26°C) and temperatures greater than 86°F (30°C) are generally lethal (Moyle 2002).

Riffle sculpins are benthic, opportunistic feeders (Moyle 2002). Spawning occurs between February and April, with eggs deposited on the underside of rocks in swift riffles or inside cavities of submerged logs. Eggs hatch in 11 to 24 days, and when fry Reach approximately 0.25 inches (6 mm) total length, they become benthic (Moyle 2002).

Threespine stickleback Central Valley populations of threespine stickleback (*Gasterosteus aculeatus*) are scattered from the Lower Kings River and the San Joaquin River below Friant Dam to roughly Redding in the Sacramento River drainage (Moyle 2002). Threespine sticklebacks are quiet-water fish, living in shallow, weedy pools and backwaters or among emergent plants at stream edges over bottoms of gravel, sand, and mud. Threespine sticklebacks are capable of completing their entire life cycle in either freshwater or saltwater, migrating between the two environments.

In some areas, pikeminnow predation largely eliminated sticklebacks (Moyle 2002). This may explain in part the scattered distribution of sticklebacks in many California River systems, including those of the Central Valley. For example, in San Francisco Bay streams, they are largely absent from areas containing introduced predatory fish.

Kern brook lamprey Kern brook lamprey (*Lampetra hubbsi*) are endemic to the eastern portion of the San Joaquin Valley and were first collected in the Friant-Kern Canal. They subsequently have been found in the lower Merced, Kaweah, Kings, and San Joaquin rivers. They are generally found in silty backwaters of rivers stemming from the Sierra foothills. The nonpredatory, resident Kern brook lamprey has not been studied extensively, but it presumably has a similar life history and habitat requirements to the western brook lamprey (*Lampetra richardsoni*) and other brook lamprey species. Like other lampreys, the Kern brook lamprey is thought to spawn in the spring and die soon thereafter (Moyle 2002). After eggs hatch, they remain in gravel redds until their yolk sacs are absorbed. At this time, larvae emerge and drift downstream into low-velocity, depositional rearing areas where they feed by filtering organic matter from the substrate.

After reaching approximately 4 to 6 inches (102 to 152 mm), ammocoetes undergo metamorphosis into eyed adults (Moyle 2002). As with other brook lamprey species, adults do not eat and may even shrink following metamorphosis (Moyle et al. 2015). Adults prefer riffles containing small gravel for spawning and cobble for cover (Moyle 2002).

Non-native Introduced/Invasive Anadromous Fish Species

Striped Bass Striped bass were first introduced in the San Francisco Bay in 1879 and are now widely distributed throughout the Sacramento-San Joaquin drainage as far upstream as fish barrier dams (Moyle 2002). Striped bass move regularly between salt and fresh water, and they usually spend much of their life cycle in estuaries. Striped bass are gregarious pelagic predators, reflected in their streamlined body shape, silvery coloration, and feeding habits. Larval and juvenile striped bass are primarily invertebrate feeders. As adults, striped bass are largely opportunistic feeders, with almost any fish inhabiting the same area appearing in their diet. Striped bass are documented predators of juvenile Chinook Salmon in the lower San Joaquin River (Demetras et al. 2016). Predators in the lower San Joaquin River, including striped bass, were associated with pools that were greater than 5 m deep (Cutter et al. 2017). Adult striped bass often reside near diversion dams and other manmade structures which concentrate and may disorient prey fish including juvenile salmonids (Sabal et al. 2016).

Non-native Introduced/Invasive Riverine Fish Species

Catfish species Several species of catfish have been introduced into the Reach 4B/ESB Project area, including black bullhead (*Ameiurus melas*), brown bullhead (*Ameiurus nebulosus*), channel (*Ictalurus punctatus*), and white catfish (*Ameiurus catus*). Catfish prefer slow moving, warm water habitat, are opportunistic omnivores, and scavenge off the bottom of their habitat (Moyle 2002). Juvenile catfish mainly feed on crustaceans and the larvae of aquatic insects. As catfish grow larger, other fish and crayfish become increasingly important food sources. Although their interaction with native fishes has not been studied (Moyle 2002), they likely directly compete for resources with native bottom-feeding species such as hardhead, California roach, and Sacramento Sucker. The common predators of juvenile Chinook salmon in the lower San Joaquin River include channel and white catfish (Cutter et al. 2017).

Forage fish species Several small, forage fish species have been introduced into the Reach 4B/ESB Project area, including bigscale logperch (*Percina macrolepida*), fathead minnow (*Pimephales promelas*), inland silverside (*Menidia beryllina*), red shiner (*Cyprinella lutrensis*), shimofuri goby (*Tridentiger bifasciatus*), golden shiner (*Notemigonus crysoleucas*), goldfish (*Carassius auratus*), and western mosquitofish (*Gambusia affinis*). Introduced forage fish species likely compete most with native Sacramento splittail and the larval and juvenile life stages of many native fish species that rely on zooplankton for prey.

Common Carp In California, common carp (*Cyprinus carpio*) are present across the Sacramento-San Joaquin drainage (Moyle 2002). Common carp are most abundant in warm, turbid water where habitat with silty bottoms and growths of submergent and emergent vegetation dominate. Common carp can tolerate a wide range of turbidities, temperatures, oxygen concentrations, and salinities. In general, common carp are omnivorous bottom feeders, particularly favoring insect larvae and small mollusks. Carp typically root around on silty bottoms, stirring up aquatic insects, which they then pick from the water. Through this foraging behavior, they can decrease local water clarity and prevent dense beds of aquatic plants from growing.

Bass and Sunfish species Several species of bass and sunfish have been introduced into the Reach 4B/ESB Project area, including black crappie (*Pomoxis nigromaculatus*), white crappie (*Pomoxis annularis*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomis cyanellus*), pumpkinseed (*Lepomis gibbosus*), redear sunfish (*Lepomis microlophus*), warmouth (*Lepomis gulosus*), spotted bass (*Micropterus punctulatus*), and largemouth bass (*Micropterus salmoides*). Bass and sunfish species prefer lakes, ponds, or low-velocity habitat in rivers (Moyle 2002). In the lower San Joaquin River, largemouth bass appear to be associated with submerged aquatic vegetation in pools (Cutter et al. 2017). Sunfish prefer habitats with aquatic vegetation and spawn in a variety of substrates. They prefer water temperatures above 27ºC. Juvenile bass tend to feed on invertebrates, whereas adults are predominantly piscivorous. Sunfish are opportunistic feeders and eat a variety of aquatic insects, fish eggs, and planktonic crustaceans. Bass and sunfish species likely prey upon the larval and juvenile life stages of many native fish species present in the Reach 4B/ESB Project area.

Threadfin shad Threadfin shad were first introduced into California waters in the 1950s and have since become established in the Sacramento-San Joaquin drainage (Moyle 2002). Threadfin shad inhabit open waters of reservoirs, lakes, and large ponds as well as sluggish backwaters of rivers. Threadfin shad are planktonic feeders and use their gill rakers to strain small zooplankton, phytoplankton, and detritus particles from the water while also feeding individually on larger zooplankton organisms.

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