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Fisheries and Aquatic Ecosystems Technical Report

Shasta Lake Water Resources Investigation

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Abbreviations and Acronyms

ºC	degree Celsius
ºF	degree Fahrenheit
ACID	Anderson-Cottonwood Irrigation District
Bay	San Francisco Bay
BO	Biological Opinion
CALFED	CALFED Bay-Delta Program
CESA	California Endangered Species Act
cfs	cubic foot per second
CVP	Central Valley Project
CVPIA	Central Valley Project Improvement Act
DCC	Delta Cross Channel
Delta	Sacramento-San Joaquin Delta
DEM	Digital Elevation Model
DFG	California Department of Fish and Game
DO	dissolved oxygen
DPS	distinct population segment
DWR	California Department of Water Resources
EIS	Environmental Impact Statement
ESA	Federal Endangered Species Act
ESU	Evolutionarily Significant Unit
FR	Federal Register
GIS	geographic information system
KMP	Klamath Mountain Province
MAF	million acre-feet
mg/l	milligram per liter
NGO	nongovernmental organization
NMFS	National Marine Fisheries Service
ppt	part per thousand
RBDD	Red Bluff Diversion Dam
Reclamation	U.S. Department of the Interior, Bureau of Reclamation
RK	river kilometer
RM	river mile
RPA	Reasonable and Prudent Alternative
SONCC	Southern Oregon/Northern California Coast

State	State of California
STNF	Shasta-Trinity National Forest
SWP	State Water Project
TCD	temperature control device
UKT	Upper Klamath Trinity
USFS	U. S. Forest Service
USFWS	U.S. Fish and Wildlife Service
WSEL	water surface elevation
X2	salinity isopleth

Chapter 1 Affected Environment

1.1 Environmental Setting

This chapter describes the affected environment as it relates to fisheries and the aquatic ecosystem in the study area.

The primary study area includes Shasta Lake and the lower reaches of its major and minor tributaries, and the Sacramento River from Shasta Dam to Red Bluff Diversion Dam (RBDD). Because of the potential for a project at Shasta Dam to affect resources outside the primary study area, information on an extended study area is also included. For the purpose of fisheries and the aquatic ecosystem, this extended study area includes the Sacramento River downstream to the Sacramento-San Joaquin River Delta (Delta). It also includes portions of the lower Feather River, lower American River, lower Stanislaus River, and lower San Joaquin River basins, and the water service areas of the Central Valley Project (CVP) and State Water Project (SWP). The Trinity River is also included in the affected environment because operation of the CVP and SWP in response to project operation alternatives has the potential to affect Trinity River flows.

Descriptions of fisheries and the aquatic ecosystem were derived primarily from the following sources:

- *Assessment of Fisheries Impacts Within the Sacramento-San Joaquin Delta* (Attachment 13)
- *Shasta Lake Water Resources Investigation Mission Statement Milestone Report* (Reclamation 2003)
- *Shasta Lake Water Resources Investigation Initial Alternatives Information Report* (Reclamation 2004)
- Chapter 3, "Biological Environment," in *Draft Shasta Lake Water Resources Investigation Plan Formulation Report* (Reclamation 2007)

1.1.1 Aquatic Habitat

This section briefly describes the aquatic habitats in the primary and extended study areas and CVP and SWP service areas. Factors affecting the abundance and distribution of fish populations are described under a separate section titled "Fisheries Resources" below.

Primary Study Area

The primary study area includes Shasta Lake and primary upstream tributaries and the Sacramento River from Shasta Dam to Red Bluff. The Sacramento River supports the largest contiguous riverine and wetland ecosystems in the Central Valley and yields 35 percent of the State of California's (State) water supply. Most of the Sacramento River flow is controlled by the U.S. Department of the Interior, Bureau of Reclamation's (Reclamation), Shasta Dam, and river flow is augmented in average water years by transfer of up to 1 million acre-feet (MAF) of Trinity River water through Clear Creek and Spring Creek tunnels to Keswick Reservoir (Reclamation 2004).

Shasta Lake and Vicinity Shasta Dam and Shasta Lake are located on the upper Sacramento River in northern California. Shasta Dam is located about 9 miles northwest of the city of Redding, and the dam and entire reservoir are within Shasta County. As mentioned, the primary study area is composed of Shasta Dam and Shasta Lake, the lower reaches of the tributaries draining into Shasta Reservoir, and the Sacramento River downstream to Keswick Dam. Thirteen representative tributaries to Shasta Lake were selected for focused examination as part of this assessment, including the Sacramento River, McCloud River, Pit River, Squaw Creek, and Big Backbone Creek. Water resources development, including the construction of dams and diversions, has affected the hydrology, geomorphology, and ecology of the watershed. Before the construction of Shasta Dam, the Sacramento River typically experienced large fluctuations in flow driven by winter storms, with late-summer flows averaging 3,000 cubic feet per second (cfs) or less. These fluctuations and periodic flows moved large amounts of sediment and gravel out of the mountainous tributaries and down the Sacramento River. The completion of Shasta Dam in 1945 resulted in general dampening of historic high and low flows, reducing the timing, magnitude, and duration of winter floods while maintaining higher summer flows between 7,000 and 13,000 cfs. The annual volume of flow in the Sacramento River continues to vary significantly from year-to-year. However, average monthly flows following the construction of Shasta Dam no longer exhibit pronounced seasonal winter highs and summer lows. This is primarily because of winter flood control operations that have reduced peak flood flows, and summer releases made for water supply purposes.

Today, the current composition and distribution of fish species inhabiting the study area reflect the historic fishery, the operational effects of Shasta Dam as well as dams on several of the upstream tributaries, and the introduction of nonnative fish species. Shasta Lake fish species include native and nonnative species, which are dominated by mostly introduced warm-water and cold-water species (Weidlein 1971; DFG, unpublished data). Shasta Lake tributary fish species comprise several native and nonnative species and have been managed to favor naturally produced ("wild") and stocked (hatchery-cultured) native and nonnative trout species (Rode 1989, Moyle 2002, Rode and Dean 2004, DFG unpublished data). Major assemblages of non fish aquatic animal species include benthic macroinvertebrates and zooplankton communities.

The distribution and productivity of organisms and aquatic habitats of Shasta Lake are greatly affected by the reservoir's dynamic seasonal surface elevation fluctuations and thermal stratification. The reservoir's flood control, water storage, and water delivery operations typically result in declining water elevations during the summer through the fall months, rising or stable elevations during the winter months, and rising elevations during the spring months and sometimes into the early-summer months, while storing precipitation and snowmelt runoff. During summer months, the epilimnion (relatively warm surface layer) is 30 to 50 feet deep and warms up to 80 degrees Fahrenheit (°F). Water temperatures above 68°F favor warm-water fishes such as bass and catfish. Deeper water layers, which include the hypolimnion and the metalimnion (transition zone between epilimnion and the hypolimnion), are cooler and suitable for cold-water species. Shasta Lake is classified as a cool-water, mesotrophic, monomictic reservoir because it is moderately productive and has one period of mixing each year, although it never completely turns over (Bartholow et al. 2001).

Cold-water habitat provided by Shasta Lake is a function of the total storage and associated surface area provided by Shasta Lake. This relationship is influenced by variation in the water surface elevation (WSEL) throughout the year. Variation in WSEL is a function of water demand, water quality requirements, and inflow, and WSEL can change based on the water year type. Typically, primary production in reservoirs is associated with storage volumes when all other factors are held constant (Stables et al. 1990). Increased storage and the corresponding increase in surface area results in a greater total biomass and a greater abundance of plankton and fish, because available habitat area is increased.

Upper Sacramento River (Shasta Dam to Red Bluff) The Sacramento River flows for approximately 10 miles between Shasta Dam and Keswick Dam and 59 miles between Keswick Dam and RBDD. The river in this reach has cool water temperatures because of regulated releases from Shasta and Keswick dams, and a stable, largely confined channel with little meander. Riffle habitat with gravel substrates and deep pool habitats are abundant in comparison with downstream reaches, although the habitats are still insufficient to support healthy salmonid populations. Immediately below Keswick Dam, the river is deeply incised in bedrock with very limited riparian vegetation and limited functioning riparian ecosystems. Water temperatures are generally cool, even in late summer, because of regulated releases from Shasta Lake and Keswick Reservoir. Near Redding, the river flows into the valley and the floodplain broadens. Historically, this area appears to have had wide expanses of riparian forests, but much of the river's riparian zone is currently subject to urban encroachment and noxious weed problems. This encroachment becomes quite extensive in the Anderson/Redding area, with homes placed directly within or adjacent to the riparian zone.

Despite net losses of gravel since construction of Shasta Dam, substrates in much of this reach contain gravel needed for spawning by salmonids, mostly derived from the Central Valley Project Improvement Act (CVPIA) gravel augmentation program. This reach provides much of the remaining spawning and rearing habitat of several listed anadromous salmonids, even though the amount of gravel available is insufficient. For this reason, it is one of the most sensitive and important stream reaches in the State.

Three water control structures, Keswick Dam, Anderson-Cottonwood Irrigation District (ACID), and RBDD, are located along the Sacramento River in this reach. Currently, revisions are being made at RBDD to improve fish passage. The main tributaries to the Sacramento River between Shasta Dam and Red Bluff are Battle, Bear, Clear, Cow, and Cottonwood creeks. The primary land uses along the Sacramento River between Shasta Dam and RBDD are urban, residential, and agricultural.

Water resources development, including the construction of dams and diversions, has affected the hydrology, geomorphology, and ecology of the watershed. Many of these effects have been detrimental to local habitats and species. Before the construction of Shasta Dam, the Sacramento River typically experienced large fluctuations in flow driven by winter storms, with late-summer flows averaging 3,000 cfs or less. These fluctuations and periodic flows moved large amounts of sediment and gravel out of the mountainous tributaries and down the Sacramento River. The completion of Shasta Dam in 1945 resulted in general dampening of historic high and low flows, reducing the timing, magnitude, and duration of winter floods while maintaining higher summer flows between 7,000 and 13,000 cfs. The annual volume of flow in the Sacramento River continues to vary significantly from year to year. However, average monthly flows following the construction of Shasta Dam no longer exhibit pronounced seasonal winter highs and summer lows. This is primarily because of winter flood control operations that have reduced peak flood flows, and summer releases made for water supply purposes.

Extended Study Area

The extended study area consists of the lower Sacramento River and Delta (including major tributaries and floodplain bypasses), Trinity River, and the CVP and SWP service areas. Each of these areas/water bodies is described separately below.

Lower Sacramento River The roughly 300 miles of the Sacramento River can be subdivided into distinct reaches. These reaches are discussed separately because of differences in morphology, water temperature, and aquatic habitat functions. This section focuses on the reaches of the mainstem Sacramento River from RBDD to Colusa, from Colusa to the Delta, and on the Delta. Each of these reaches is discussed individually along with the main tributaries and floodplain bypasses to the Sacramento River.

Red Bluff Diversion Dam to Colusa In this reach, the Sacramento River functions as a large alluvial river with active meander migration through the valley floor. The river is classified as a meandering river, where relatively stable, straight sections alternate with more sinuous, dynamic sections (Sacramento River Conservation Area Forum 2003). The active channel is fairly wide in some stretches and the river splits into multiple forks at many different locations, creating gravel islands, often with riparian vegetation. Historic bends in the river are visible throughout this reach and appear as scars of the historic channel locations with the riparian corridor and oxbow lakes still present in many locations. The channel remains active and has the potential to migrate in times of high water. Point bars, islands, high and low terraces, instream woody cover, early successional riparian plant growth, and other evidence of river meander and erosion are common in this reach. The channel takes on varying widths, and aquatic habitats consist of shallow riffles, deep runs, deep pools at the bends, glides in the straight reaches, and shallow vegetated floodplain areas that become inundated during high flows.

Colusa to the Delta The general character of the Sacramento River changes drastically downstream from Colusa from a dynamic and active meandering channel to a confined, narrow channel restricted from migration. While setback levees exist along portions of the river upstream from Colusa, the levees become much narrower along the river edge as the river continues south to the Delta. Surrounding agricultural lands encroach directly adjacent to the levees, which have cut the river off from the majority of its riparian corridor, especially on the eastern side of the river. The majority of the levees in this reach are lined with riprap, allowing the river no erodible substrate. The channel width is fairly uniform and river bends are static as a result of confinement by levees. Therefore, aquatic habitats are fairly homogenous because depth profiles and substrate composition are fairly uniform throughout the reach. Multiple water diversion structures in this reach move floodwaters into floodplain bypass areas during high-flow events. Primary floodplain bypass areas include the Butte Basin, Sutter Bypass, and Yolo Bypass, all of which are fed by overflow weirs along the Sacramento River (see additional discussion below).

Primary Tributaries to Lower Sacramento River Lower reaches of primary tributaries are included because of the potential for project effects on flows and associated flow-related effects on fish species of management concern. However, potential changes in flows are diminished in these areas because of operation of upstream CVP and SWP reservoirs and increasing effects of inflows from tributaries, as well as diversions and flood bypasses.

Lower Feather River Aquatic habitats found in the lower Feather River vary as the river flows from releases at the California Department of Water Resources (DWR) Oroville Dam facilities down to the confluence with the Sacramento

River at Verona. At the upper extent, the approximate 8-mile low-flow (about 600 cfs) section contains mainly riffles and runs, which provide spawning habitat for the majority of Feather River Chinook salmon (*Oncorhynchus tshawytscha*) and steelhead (*O. mykiss*). Also present in the low flow channel is a series of remnant gravel pit pools/ponds that connect to the main channel. This stretch is fairly confined by levees as it flows through the city of Oroville. From the downstream end of the low flow channel, the Feather River is fairly active and meanders its way south to Marysville. However, this stretch is bordered by active farmland, which confines the river into an incised channel in certain stretches. Relatively large areas of adjacent farmlands are in the process of being restored to floodplain habitat with the relocation of levees to become setback levees.

Lower American River   Flows in the lower American River (below Folsom and Nimbus Dams) are generally cold and clear, providing habitat for anadromous and resident fish species. The river is fairly low gradient and is composed of riffle, run, glide, and pool habitats. Dams along the watershed have reduced gravel inputs to the system, but the lower American River contains large gravel bars and forks in many locations, leaving gravel/cobble islands within the channel. The majority of the lower American River is surrounded by the American River Parkway, preserving the surrounding riparian zone. The river channel does not migrate to a large degree because of the geologic composition that has allowed the river to incise deep into sediments, leaving tall cliffs and bluffs adjacent to the river.

Sacramento River Floodplain Bypasses   As described above, there are three major floodplain bypasses – Butte Basin, Sutter Bypass, and Yolo Bypass – with a total of 10 overflow structures along the mainstem Sacramento River (six weirs, three flood relief structures, and an emergency overflow roadway) that provide access to broad, inundated floodplain habitat during wet years.

Unlike other Sacramento River and Delta habitats, floodplains and floodplain bypasses are seasonally dewatered (as high flows recede) during late spring through autumn. This prevents introduced fish species from establishing year round dominance except in perennial water sources (Sommer et al. 2003). Moreover, many of the native fish are adapted to spawn and rear in winter and early spring (Moyle 2002) during the winter flood pulse. Introduced fish typically spawn during late spring through summer when the majority of the floodplain is not available to them.

Butte Basin   The Butte Basin lies east of the Sacramento River and extends from the Butte Slough outfall gates near Meridian to Big Chico Creek near Chico Landing. Flood flows are diverted out of the Sacramento River into the Butte Basin and Sutter Bypass via several designated overflow areas (i.e., low points along the east side of the river) that allow high flood flows to exit the Sacramento River channel.

Sutter Bypass The Sutter Bypass is a narrow floodwater bypass conveying Sacramento River flood flows from the Butte Basin and the Tisdale Weir. The bypass area is an expansive land area in Sutter County used mainly for agriculture. In times of high water, Sacramento River water enters the bypass through the Butte Slough outfall and the Tisdale Weir (when the stage exceeds 45.45 feet) and inundates the bypass with as much as 12 feet of water. The Sutter Bypass, in turn, conveys flows to the lower Sacramento River region at the Fremont Weir near the confluence with the Feather River and into the Sacramento River and the Yolo Bypass (USACE and The Reclamation Board 2002).

Yolo Bypass The Yolo Bypass is an approximate 59,000-acre land area that conveys Sacramento River flood waters around Sacramento during times of high runoff. Flow is diverted from the Sacramento River into the bypass when the stage exceeds 33.5 feet (corresponding to 56,000 cfs at Verona). Diversion of the majority of Sacramento River, Sutter Bypass, and Feather River floodwaters to the Yolo Bypass from Fremont Weir controls Sacramento River flood stages at Verona. During large flood events, up to 80 percent of Sacramento River flows are diverted into the bypass.

All six weirs (Moulton, Colusa, Tisdale, Fremont, Sacramento, and Cache Creek) have a fixed-level, concrete overflow section, followed by a concrete, energy-dissipating stilling basin, with a rock and/or concrete erosion blanket across the channel beyond the stilling basin and a pair of training levees that define the weir's flow escape channel. All overflow structures except the Sacramento Weir pass floodwaters by gravity once the river reaches the overflow water surface elevation. The Sacramento Weir has gates on top of the overflow section that hold back floodwaters until opened manually by DWR's Division of Flood Management.

Lower San Joaquin and Stanislaus Rivers The lower San Joaquin River is characterized by a relatively wide (approximately 300 feet) channel with little canopy or overhead vegetation and minimal bank cover. Aquatic habitat in the San Joaquin River is characterized primarily by slow-moving glides and pools, is depositional in nature, and has limited water clarity and habitat diversity. Many of the fish species using the lower San Joaquin River use this lower segment of the river to some degree, even if only as a migratory pathway to and from upstream spawning and rearing areas. The lower river also is used by certain fish species (e.g., delta smelt *(Hypomesus transpacificus)*) that make little to no use of areas in the upper segment of the river (see Delta discussion below). Aquatic habitats in the lower Stanislaus River vary longitudinally and provide fish spawning, rearing, and/or migratory habitat for a diverse assemblage of common Central Valley native and nonnative fish species. Aquatic habitats include riffles, runs, pools, and glides. Floodplain and associated riparian habitat also varies with the development of levees and encroachment of agriculture and urban uses. Flows in both river systems are highly altered and are managed for flood control and water supply purposes.

Sacramento-San Joaquin Delta The Delta and San Francisco Bay (Bay) make up the largest estuary on the west coast (EPA 1993). The Delta and Suisun Bay, on the western edge of the Delta, are located at the confluence of the Sacramento and San Joaquin rivers and may be considered to represent the most important, complex, and controversial geographic area for both anadromous and resident fisheries production and distribution of California water resources for numerous beneficial uses (Hanson, pers. comm., 2009). The Delta comprises of a network of channels through which water, nutrients, and aquatic food resources are moved and mixed by tidal action. The Delta is shown in Figure 1-1.

The San Francisco Bay-Delta (Bay-Delta) is a complex estuarine ecosystem, a transition zone between inland sources of freshwater and saltwater from the ocean. Along the salinity gradient extending from the Golden Gate upstream into the central Delta and tributaries, the species composition of the aquatic community changes dramatically, although the basic functional relationships among organisms (e.g., predator-prey) remain similar throughout the system.

The Delta's channels are used to transport water from upstream reservoirs to the south Delta, where Federal and State facilities (C.W. "Bill" Jones Pumping Plant and Harvey O. Banks Delta Pumping Plant, respectively) pump water into CVP and SWP canals, respectively.

Environmental conditions in the Delta depend primarily on the physical structure of Delta channels, inflow volume and source, Delta Cross Channel (DCC) operations, Delta exports and diversions, and tides. The CVP affects Delta conditions primarily through control of upstream storage and diversions, Delta exports and diversions, and DCC operations. These factors also determine outflow and the location of the entrapment zone, which is an area of high organic carbon that is critically important to a number of fish and invertebrate species, as well as to the overall ecology of the Delta and Suisun Bay. In addition to these physical factors, environmental conditions such as water temperature, predation, food production and availability, competition with introduced exotic fish and invertebrate species, and pollutant concentrations all contribute to interactive, cumulative conditions that have substantial effects on Delta fish populations.

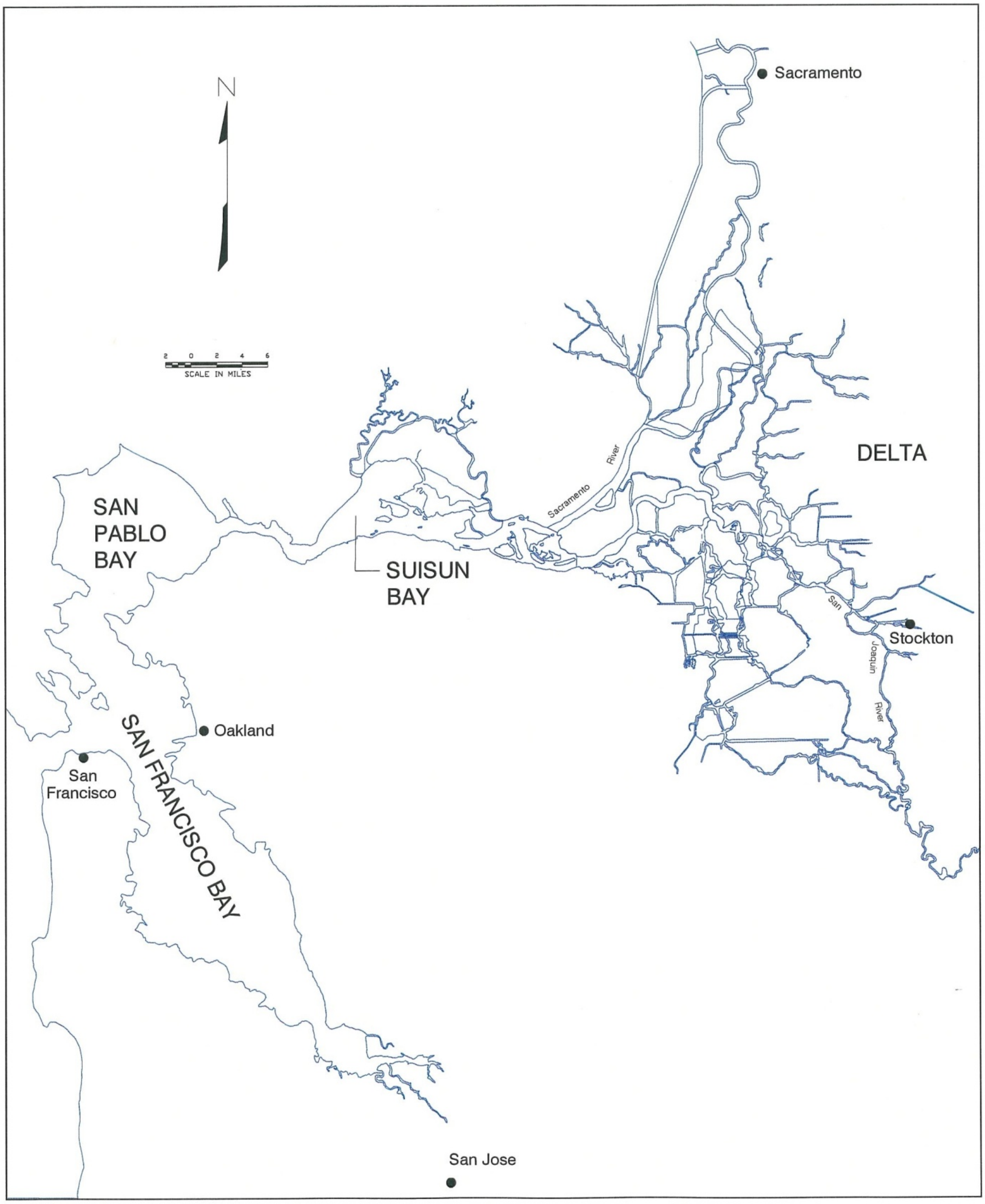


Figure 1-1. San Francisco Bay and Sacramento-San Joaquin River Delta

Delta habitat is of key importance to fisheries, as illustrated by the more than 120 fish species that rely on its unique habitat characteristics for one or more of their life stages (EPA 1993). Fish species found in the Delta include anadromous species, as well as freshwater, brackish water, and saltwater species. The Delta provides spawning and nursery habitat for more than 40 resident and anadromous fish species, including delta smelt, Sacramento splittail, American shad, and striped bass. The Delta is also a migration corridor and seasonal rearing habitat for all four runs of Chinook salmon steelhead, and green sturgeon.

Adult Chinook salmon move through the Delta during most months of the year. Salmon and steelhead juveniles depend on the Delta as transient rearing habitat during migration through the system to the ocean, and could remain for several months, feeding in marshes, tidal flats, and sloughs. All life stages of striped bass and American shad (*Alosa sapidissima*) are found in the Delta; approximately 45 percent of striped bass (*Morone saxatilis*) spawn in the Delta, as do some American shad. Numerous resident species live in the Delta year-round, including delta smelt, Sacramento splittail (*Pogonichthys macrolepidotus*), and introduced threadfin shad (*Dorosoma petenense*).

Delta inflow and outflow are important for species residing primarily in the Delta (e.g., delta smelt, longfin smelt) (USFWS 1994), as well as juveniles of anadromous species (e.g., Chinook salmon) that rear in the Delta before ocean entry. Seasonal Delta inflows affect several key ecological processes, including (1) the migration and transport of various lifestages of resident and anadromous fishes using the Delta (EPA 1992); (2) salinity levels at various locations within the Delta, as measured by the location of the salinity isopleths (X2) (i.e., the position in kilometers eastward from the Golden Gate Bridge of the 2 parts per thousand (ppt) near-bottom isohaline); and (3) the Delta's primary (phytoplankton) and secondary (zooplankton) production.

The San Francisco Bay region is predominantly developed for urban and industrial uses with limited anadromous fisheries. The region contains numerous small streams and reservoirs used primarily for domestic water supply. All anadromous species use these habitats, with the exception of some American shad and striped bass that complete their entire life cycles within the Delta and upstream. The four runs of Chinook salmon and steelhead migrate as adults from the Pacific Ocean, through San Francisco Bay and into their natal rivers, while Chinook salmon and steelhead smolts migrate downstream through the Bay on their way to the ocean.

More than 200 fish species, mostly marine, exist in the Bay (Miller and Lea 1972). The Bay is an important nursery area for marine and estuarine species, including bay shrimp (*Cragon* spp.), dungeness crab (*Cancer magister*), northern anchovy (*Engraulis mordax*), Pacific herring (*Clupea harengus*), and English sole (*Pleuronectes vetulus*). The Bay provides a protective, highly productive habitat that enhances early survival and growth of these species.

Delta outflow influences abundance and distribution of fish and invertebrates in the bay through changes to salinity, currents, nutrient levels, and pollutant concentrations. The response of organisms to outflow depends on species and life stage. The variability in the response of organisms to variable volume outflow levels is important in the dynamics of the estuarine community. The effect of Delta outflow on San Bay organisms is determined by its timing, magnitude, and duration. The cause-and-effect relationship between Delta outflow and organism abundance and distribution is complex and often dictated by a chain or web of events rather than by specific, direct effects. Although correlations between flows and organism abundance have been identified, the mechanisms of the relationships are largely unknown. Water residence time in the Bay, determined by tides, local inflow, Delta outflow, and bathymetry, also affects fish species abundance (Smith 1987).

In many segments of the estuary, but particularly in Suisun Bay and the Delta, salinity is controlled by the balance of salt water intrusion from San Francisco Bay and freshwater flow from the tributaries to the Delta. By altering the timing and volume of flows, water development has affected salinity patterns in the Delta and in parts of the Bay (SFEP 1992). Historically, under natural conditions, the Carquinez Strait/Suisun Bay region marked the approximate boundary between salt water and fresh water in the estuary during much of the year. In the late summer and fall of drier years, when Delta outflow was minimal, seawater moved into the Delta from the Bay. Beginning in the 1920s, following several dry years, and because of increased upstream storage and diversions, salinity intrusions became more frequent and extensive.

Since the 1940s, releases of fresh water from upstream storage facilities have increased Delta outflows during summer and fall. These flows have correspondingly limited the extent of salinity intrusion into the Delta. Reservoir releases have helped to ensure that the salinity of water diverted from the Delta is acceptable during the summer and late fall for farming, municipal, and industrial uses (SFEP 1992).

Salinity is an important habitat factor in the estuarine environment of the Delta. All estuarine species are assumed to have optimal salinity ranges, and their survival may be affected by the amount of habitat available within the species' optimal salinity range. Because the salinity field in the Estuary is largely controlled by freshwater outflows, the level of outflow may determine the surface area of optimal salinity habitat that is available to the species (Hieb and Baxter 1993, Unger 1994).

The transition area between saline waters within the Bay and freshwater within the rivers, frequently referred to as the low salinity zone, is located within Suisun Bay and the western Delta. The low salinity zone has also been associated with the entrapment zone, a region of the estuary characterized by higher levels of particulates, higher abundances of several types of organisms, and a turbidity maximum. It is commonly associated with the position of the 2 ppt X2, but actually occurs over a broader range of salinities (Kimmerer 1992). Originally, the primary mechanism responsible for this region was thought to be gravitational circulation, a circulation pattern formed when freshwater flows seaward over a dense, landward-flowing marine tidal current. However, recent studies have shown that gravitational circulation does not occur in the entrapment zone in all years, nor is it always associated with X2 (Burau et al. 1998). Lateral circulation within the Estuary or chemical flocculation may play a role in the formation of the turbidity maximum of the entrapment zone.

As a consequence of higher levels of particulates, the entrapment zone may be biologically significant to some species. Mixing and circulation in this zone concentrates plankton and other organic material, thus increasing food biomass and production. Larval fish such as striped bass, delta smelt, and longfin smelt may benefit from enhanced food resources. Since about 1987, however, the introduced Asian overbite clam population has cropped much of the primary production in the Estuary and there has been virtually no enhancement of phytoplankton production or biomass in the entrapment zone (CUWA 1994).

Although the base of the food chain may not have been enhanced in the entrapment zone during the past decade, this region continues to have relatively high levels of invertebrates and larval fish. Vertical migration of these organisms through the water column at different parts of the tidal cycle has been proposed as a possible mechanism to maintain high abundance in this region, but recent evidence suggests that vertical migration does not provide a complete explanation (Kimmerer, pers. comm.).

Although recent evidence indicates that X2 and the entrapment zone are not as closely related as previously believed (Burau et al. 1998), X2 continues to be used as an index of the location of the entrapment zone and area/or of increased biological productivity. Historically, X2 has varied between San Pablo Bay (river kilometer (RK) 50) during high Delta outflow and Rio Vista (RK 100) during low Delta outflow. In recent years, it has typically been located between approximately Honker Bay and Sherman Island (RK 70 to 85). X2 is controlled directly by the volume of Delta outflow, although changes in X2 lag behind changes in outflow. Minor modifications in outflow do not greatly alter X2.

Jassby and Powel (1994) showed that when X2 is in the vicinity of Suisun Bay, several estuarine organisms tend to show increased abundance. However, it is by no means certain that X2 has a direct effect on any of the species. The observed correlations may result from a close relationship between X2 and other factors that affect these species.

Trinity River Sacramento River flow is augmented in average water years by transfer of up to 1 MAF of Trinity River water through the Clear Creek and Spring Creek tunnels to Keswick Reservoir (Reclamation 2004). Flows in the Trinity River (below Lewiston Dam) are generally cold, providing habitat for anadromous and resident fish species. Aquatic habitats in the river consist of riffle, run, glide, and pool habitats. Fish habitat values have increased in quantity and quality through restoration activities that have taken place over the last several years. Implementation of the Trinity River Restoration Program is expected to further increase the value of the habitat below Lewiston Dam over the next 10 to 15 years (NMFS 2000).

CVP/SWP Service Areas The CVP and SWP service areas contain several highly altered aquatic habitat types, including reservoirs, canals, ditches, and other manmade water conveyance structures/facilities. Agricultural land and urban development are the dominate land uses within these service areas. As a result of all these factors, the aquatic communities that occupy the habitats are highly adapted to these disturbed environments and are dominated by nonnative species.

1.1.2 Fisheries Resources

This section describes the life history, habitat requirements, and factors that affect the abundance of species selected for the assessment of impacts of the proposed project alternatives. A separate discussion on aquatic macroinvertebrates in the primary and extended study areas is presented after this section.

Primary Study Area

Water bodies within the primary study area contain a large and diverse assemblage of resident and anadromous fish species, including recreationally and commercially important species, and species that are listed as threatened and endangered (see Table 1-1).

Table 1-1. Fish Species Known to Occur in Primary Study Area

Common Name	Scientific Name	Distribution Within Primary Study Area		
		Shasta Lake Tributaries	Shasta Lake/ Keswick Reservoir	Sacramento River—Keswick to Red Bluff
Chinook salmon	*Oncorhynchus tshawytscha*		X	
winter-run				X
spring-run				X
fall-run				X
late fall-run				X
Rainbow trout	*Oncorhynchus mykiss*	X	X	X
Steelhead trout	*Oncorhynchus mykiss*			X
Brown trout	*Salmo trutta*	X	X	X
Green sturgeon	*Acipenser medirostris*			X
White sturgeon	*Acipenser transmontanus*	X	X	X
Pacific lamprey	*Lampetra tridentata*			X
Western brook lamprey	*Lampetra richardsoni*			X
Sacramento sucker	*Catostomus occidentalis*	X	X	X
Sacramento pikeminnow	*Ptychocheilus grandis*	X	X	X
Hardhead	*Mylopharodon conocephalus*	X	X	X
Sacramento blackfish	*Orthodon microlepidotus*	X	X	
California roach	*Hesperolecus symmetricus*	X		X
Speckled dace	*Rhinichthys osculus*	X	X	
Golden shiner	*Notemigonus crysoleucas*	X	X	
Carp	*Cyprinus carpio*	X	X	X
Channel catfish	*Ictalurus punctatus*	X	X	X
White catfish	*Ameiurus catus*		X	X
Brown bullhead	*Ameiurus nebulosus*		X	X
Black bullhead	*Ameiurus melas*		X	X
Riffle sculpin	*Cottus gulosus*	X	X	
Prickly sculpin	*Cottus asper*			X
Rough sculpin	*Cottus asperrimus*	X		
Pit sculpin	*Cottus pitensus*	X		
Bigeye marbled sculpin	*Cottus klamathensis macrops*	X		
Largemouth bass	*Micropterus salmoides*		X	
Smallmouth bass	*Micropterus dolomieui*	X	X	X
Spotted bass	*Micropterus punctulatus*	X	X	
Black crappie	*Pomoxis nigromaculatus*		X	
White crappie	*Pomoxis annulauris*		X	
Bluegill sunfish	*Lepomis macrochirus*		X	
Green sunfish	*Lepomis cyanellus*	X	X	
Threadfin shad	*Dorosoma petenense*		X	
Tule perch	*Hysterocarpus traski*	X	X	X
Tui chub	*Siphateles bicolor*	X	X	

Source: Moyle 2002; Reclamation 2004

Shasta Lake and Vicinity Shasta Lake fish species include native and nonnative species, which are dominated by mostly introduced warm-water and cold-water species (Weidlein 1971; DFG, unpublished data) (Table 1-1). Major assemblages of aquatic non-fish animal species include benthic macroinvertebrates and zooplankton communities.

Cold-Water Species Shasta Lake and its tributaries provide very productive habitats for cold-water fish species, which typically prefer or require temperatures cooler than 70°F. During the cooler months, cold-water species such as rainbow trout, brown trout, and landlocked Chinook salmon may be found rearing throughout the lake; however, these species do not spawn in the lake, preferring to spawn in tributary streams. During the summer months, these cold-water species may be found rearing in association with the cold, deep hypolimnion and metalimnion layers within the reservoir, although the fish may make frequent forays into the epilimnion to feed on small prey fish and return to cooler depths to digest their prey (Finnell and Reed 1969, Koski and Johnson 2002, Moyle 2002, Quinn 2005).

Native species such as white sturgeon, hardhead, riffle sculpin, Sacramento sucker, and Sacramento pikeminnow tend to reside in cooler water strata in the reservoir and in and near tributary inflows (Moyle 2002). Trout may also congregate near the mouths of the reservoir's tributaries, including the upper Sacramento River, McCloud River, Pit River, and Squaw Creek, at various times of the year for various purposes, including thermal refuge, foraging, and spawning, when conditions are favorable for these species.

Hatchery- and pen-reared trout and salmon are stocked in Shasta Lake several times each year to support the sport fishery. About 60,000 pounds of juvenile rainbow trout and about 50,000 subcatchable Chinook salmon are planted annually (Baumgartner, pers. comm., 2008).

Climate conditions and reservoir storage volume are the two most influential factors affecting cold-water habitat and primary productivity in Shasta Lake (Bartholow et al. 2001). Cold-water habitat provided by Shasta Lake is a function of the total storage and associated surface area provided by Shasta Lake. This relationship is influenced by variation in the WSEL throughout the year. Variation in WSEL is a function of water demand, water quality requirements, and inflow, and WSEL can change based on the water year type. Typically, primary production in reservoirs is associated with storage volumes when all other factors are held constant (Stables et al. 1990). Increased storage and the corresponding increase in surface area results in a greater total biomass and a greater abundance of plankton and fish, because available habitat area is increased.

Warm-Water Species The warm-water fish habitats of Shasta Lake occupy two ecological zones: the littoral (shoreline/rocky/vegetated) and the pelagic (open water) zones. The littoral zone lies along the reservoir shoreline down to the maximum depth of light penetration on the reservoir bottom, and supports populations of spotted bass, smallmouth bass, largemouth bass, black crappie, bluegill, channel catfish, and other warm-water species.

The upper, surface layer of the pelagic zone is the principal plankton-producing region of the reservoir. Plankton comprises the base of the food web for most of the reservoir's fish populations. Operation of the Shasta Dam temperature control device (TCD), which helps conserve the reservoir's cold-water pool by accessing warmer water for storage releases in the winter, spring, and early summer, may reduce zooplankton biomass in the epilimnion. However, operations of the TCD may result in some increased plankton production at deeper levels as a result of a slight warming of the hypolimnetic layers within the reservoir during the fall months (Bartholow et al. 2001).

Warm-water species, such as largemouth bass, smallmouth bass, spotted bass, and other sunfishes, were introduced into Shasta Lake and have become well established with naturally sustaining populations. Spotted bass are currently the dominant warm-water species in Shasta Lake (S. Baumgartner, pers. comm.., 2006). These warm-water fishes feed primarily on invertebrates while young and become predaceous on other fishes, including engaging in some cannibalism, as they grow. In Shasta Lake, threadfin shad, crayfish, and other invertebrates are most abundant in the diets of these fish (Saito et al. 2001). Spawning activity usually begins during late March or April when temperatures rise to around 60°F. Males generally build the nests in sand, fine gravel, rubble, or debris-covered bottoms at depths between 1 and 20 feet, which varies by species. Spotted bass and catfishes typically spawn at greater depths than the other warm-water species in Shasta Lake. Eggs generally hatch in 3 to 5 days at the predominant springtime water temperatures in Shasta Lake, and males guard the eggs and larvae for up to 4 weeks (Moyle 2002). Fry and juveniles disperse into shallow water and prefer areas with vegetation and large rubble as protective cover from predators (Moyle 2002, Ratcliff 2006).

The primary factors affecting warm-water fish abundance and production in Shasta Lake include seasonal reservoir fluctuations, availability of high-quality littoral habitat, and annual climate variations (Ratcliff 2006). The effect of sport fishery harvests on Shasta Lake fish populations is not well understood, although it is generally thought that overfishing of naturally reproducing populations by sport fisheries seldom limits fish abundance (Moyle 2002).

Reservoir level fluctuations, associated shoreline erosion, and suppression of shoreline and emergent vegetation are thought to generally be the most significant factors affecting warm-water fish production in reservoirs, including Shasta Lake (Moyle 2002, Ratcliff 2006). Water level variations influence physical, chemical, and biological processes, which in turn affect fish populations. Reservoir drawdowns reduce water depths and influence thermal stratification and the resulting temperature, dissolved oxygen (DO), and water chemistry profiles.

The typical seasonality of reservoir fluctuations on Shasta Lake can affect year-to-year reproductive success of littoral-spawning fishes, especially the black bass species, by influencing nesting behavior (e.g., abandonment of nests) and dewatering of nests containing eggs in years when reservoir levels decline during the spring and early summer months. Under these same conditions, juveniles may be forced to move to areas with less protection from predation or lower food production. In years when the reservoir rises rapidly and/or extensively during the spring and early summer months, submergence of active bass nests by more than 15 to 20 feet often results in high egg mortality (Stuber et al. 1982, Moyle 2002).

Shoreline and littoral vegetation are important warm-water fish habitat components for sustainable fishery production (Ratcliff 2006). Structural diversity (e.g., submerged trees, brush, rock, boulders, and rubble) provides shelter and feeding areas for fish. During construction of the reservoir, many trees and brush fields were cleared prior to inundation. Portions of the Pit River and Squaw Creek arms were not cleared, as evidenced by the large number of inundated trees observable in certain areas. Clearing efforts reduced the potential structural diversity of the inundated habitat. Vegetative clearing in many reservoirs has resulted in rocks, boulders, and man-made features (e.g., bridge pilings, riprap, marinas) being the only structural habitat features available, especially for bass and other warm-water fishes.

Annual reservoir fluctuations create highly variable conditions for establishment and maintenance of shoreline and littoral-zone vegetation and aquatic invertebrate communities that subsequently impose limitations on warm-water fish production. Exposed shoreline reservoir areas generally require 3 to 4 years to reestablish terrestrial vegetation. The absence of established, rooted aquatic vegetation is a common aquatic habitat factor that limits populations and fishery production for many fish species in reservoirs (Ploskey 1986, Moyle 2002).

The Shasta-Trinity National Forest (STNF), in cooperation with other Federal and State agencies and local nongovernmental organizations (NGO), has implemented a habitat improvement program at Shasta Lake. The objective of this program is to increase cover for warm-water fish. As the fishery management agency for Shasta Lake, California Department of Fish and Game (DFG) prepared a Draft Management Plan for Shasta Lake in 1991. This plan, which has not been finalized, acknowledges the benefit to warm-water fish of structural enhancement projects.

STNF, DFG, and NGOs have used a variety of materials and techniques to construct structural enhancements (e,g., willow planting, brush structures) to provide warm-water fish habitat within the drawdown zone of Shasta Lake. The materials and techniques have varied because of differences in funding, available materials, site conditions (reservoir levels), longevity, and desired outcome.

According to STNF aquatic biologists, brush structures constructed from whiteleaf manzanita (*Arctostaphylos manzanita)* have been the STNF's preferred means of structural enhancement since about 1990. These structures have been constructed in areas where manzanita is available near the shoreline, typically in manner that provides varying degree of structural habitat as water levels change over time. The biologists have indicated that these structures have typically resulted in a threefold to tenfold increase in the abundance of warm-water fish in the treated areas (Joe Zustak, pers. comm. 2007).

Tributary Species The lower reaches of the tributaries draining to the reservoir provide spawning habitat for adfluvial fishes (i.e., fish that spawn in streams, but rear and grow to maturity in lakes) residing in Shasta Lake, as well as, stream-resident fishes, with rainbow trout the principal game species. Most native fish species found in Shasta Lake may also inhabit the lower reaches of the tributaries. Several tributaries to Shasta Lake (e.g., Squaw Creek, Little Backbone Creek) have been subjected to discharge from abandoned upslope copper mines. The *Shasta Lake West Watershed Analysis* (Bachmann 2000) suggests that these creeks are "biologically dead" as a result of acid mine discharge from these mines. This watershed analysis also stated that "fish kills" have occurred in Shasta Lake in the vicinity of such tributaries during high runoff conditions.

The four main tributaries to Shasta Lake, which include the Sacramento River, McCloud River, Squaw Creek, and Pit River, are renowned for their high-quality recreational trout fisheries. Each of these streams drains considerable watershed areas comprising mixed conifer forests in the reaches above Shasta Lake. With the exception of the Pit River, which has a series of hydroelectric project dams that begin immediately upstream from Shasta Lake, each of these tributaries has more than 30 miles of high-quality, fish-bearing riverine habitat between the Shasta Lake and upstream dams on the Sacramento and McCloud rivers and steep headwater reaches on Squaw Creek.

For the most part, land use along the main Shasta Lake tributaries upstream from the reservoir is a mix of Federal and privately managed forest and timberlands and except for sparse residential development, several small municipalities, and the hydropower projects on the Pit, McCloud, and Sacramento rivers much of the area is lightly developed. The Sacramento River above Shasta Lake is paralleled by a major interstate highway and railroad transportation corridor. In July 1991, a railroad accident spilled 19,000 gallons of the fumigant pesticide metam sodium into the Sacramento River near the town of Dunsmuir, approximately 35 stream miles upstream from Shasta Lake. Metam sodium is highly toxic and killed aquatic and riparian vegetation, aquatic macroinvertebrates, and fish and amphibians along the entire length of the river to Shasta Lake, where a massive chemical containment and neutralization effort was mounted. Ecological recovery efforts were implemented shortly after this spill incident and populations of fish, aquatic macroinvertebrates, and the vegetation adjacent to the stream have attained levels that appear to be in a natural dynamic equilibrium consistent with full recovery, although some amphibian and mollusk population remained depressed at least 15 years later (Cantara Trustee Council 2007).

There are about 2,903 miles of ephemeral, intermittent, and perennial stream channels that contribute to the main Shasta Lake tributaries within the study area. Most of these sub-tributaries are relatively short and steep and may be classified as confined, headwater channels that contribute water, sediment, and organic and inorganic material to Shasta Lake. Most (64 percent) of these stream channels are intermittent and have a slope greater than 10 percent. About 14 percent of the stream channels are perennial, with slopes of less than 7 percent. In the Pacific coast and Cascade ranges, stream channels with gradients up to about 4 to 7 percent and possessing sufficient flows typically exhibit a good potential to support habitation by fish and other aquatic organisms; although, steeper slopes do not necessarily, in and of themselves, preclude habitation by fish, particularly trout, sculpins, and dace (Naiman 1998; Reeves et al. 1998). About 79 percent of the tributaries with good fish-bearing potential in the study area occur within the Sacramento River, Squaw Creek, and Pit River arms (see Chapter 4 for more detail).

Most of the lower gradient, potentially fish-bearing reaches of tributary streams to Shasta Lake are near their confluence with the reservoir. The gradient of most of these tributaries rapidly increases upstream from the shoreline, and natural barriers to fish are common. These barriers are most often created by cascades, waterfalls, and steep reaches of stream channel (i.e., greater than 7 percent slope) that are more than one-quarter mile in length. Stream channel data generated from field inventories and analysis using Reclamation's geographic information system (GIS) Digital Elevation Model (DEM) indicate that most barriers on the perennial tributaries occur near the reservoir

Upper Sacramento River (Shasta Dam to Red Bluff) The upper Sacramento River (Shasta Dam to Red Bluff) provides vital fish spawning, rearing, and/or migratory habitat for a diverse assemblage of native and nonnative species. Native species present in this reach of the river can be separated into anadromous (i.e., species that spawn in freshwater after migrating as adults from marine habitat) and resident species. Native anadromous species include four runs of Chinook salmon, steelhead trout, green and white sturgeon (*Acipenser medirostris* and *A. transmontanus*), and Pacific lamprey (*Lampetra tridentata*). Native resident species include Sacramento pikeminnow (*Ptychocheilus grandis*), Sacramento splittail, Sacramento sucker (*Catostomus occidentalis*), hardhead (*Mylopharodon conocephalus*), California roach (*Lavinia symmetricus*), and rainbow trout (*O. mykiss*). Nonnative resident species include largemouth bass (*Micropterus salmoides*), smallmouth bass (*Micropterus dolomieu*), white and black crappie (*Pomoxis annularis* and *P. nigromaculatus*), channel catfish (*Ictalurus punctatus*), white catfish (*Ameiurus catus*), brown bullhead (*Ictalurus nebulosus*), bluegill (*Lepomis macrochirus*), green sunfish (*Lepomois cyanellus*), and golden shiner (*Notemigonus crysaleucas*).

Keswick Reservoir The U.S. Fish and Wildlife Service (USFWS) conducts a propagation and captive broodstock program for endangered winter-run Chinook salmon at the Livingston Stone National Fish Hatchery located at the base of Shasta Dam on the Sacramento River upstream from Keswick Reservoir. The program consists of collecting adult winter-run Chinook salmon from the mainstem Sacramento River, holding and spawning the adults, rearing the juveniles in the hatchery environment, then releasing them back into the mainstem Sacramento River downstream from Keswick Dam. The overriding goal of the programs is to supplement the endangered population and provide an “insurance policy” against extinction. The propagation program (initiated in 1989), and the captive broodstock program (initiated in 1991) are recognized in the National Marine Fisheries Service (NMFS) Draft Recovery Plan (1993b) for this endangered species. Water is supplied to the hatchery from Shasta Dam.

Keswick Reservoir is operated by Reclamation as a reregulating facility. Levels in Keswick Reservoir are subject to operational changes at Whiskeytown and Shasta lakes. The reservoir provides habitat for a variety of aquatic organisms, including native and nonnative fish. Table 1-1 includes the fish species known to occur in Keswick Reservoir. In addition to water released from Shasta Dam and Whiskeytown Lake, this reservoir is the recipient of water and sediment from Spring Creek, emanating from the Iron Mountain Mine. Additional information on the relationship between Spring Creek and Keswick Reservoir is provided in the Hazards and Hazardous Materials Technical Report.

Extended Study Area

Lower Sacramento River and Delta The extended study area includes the middle and lower Sacramento River, tributaries, Delta, and CVP and SWP water service areas. Like the primary study area, habitats in the extended study area also provide vital fish spawning, rearing, and/or migratory habitat for a diverse assemblage of native and nonnative species, many of which are the same as those found in the primary study area (see Table 1-2).

Table 1-2. Central Valley Fish Species Potentially Affected by Project Alternatives

Common Name	Scientific Name	Distribution
Native Species		
Hitch	*Lavinia exilicauda*	Central Valley rivers; Delta
Blackfish	*Orthodon microlepidotus*	Central Valley rivers; Delta
California roach	*Lavinia symmetricus sp.*	Central Valley rivers; Delta
Hardhead	*Mylopharodon conocephalus*	Central Valley rivers; Delta
Sacramento splittail	*Pogonichthys macrolepidotus*	Central Valley rivers; Delta
Pikeminnow	*Ptychocheilus grandis*	Central Valley rivers; Delta
Sacramento sucker	*Catostomus occidentalis*	Central Valley rivers; Delta
Delta smelt	*Hypomesus transpacificus*	Delta; San Francisco Bay
Longfin smelt	*Spirinchus thaleichthys*	Delta; San Francisco Bay
Steelhead/rainbow trout	*Oncorhynchus mykiss*	Central Valley rivers; Delta; San Francisco Bay; Pacific Ocean
Chinook salmon	*Oncorhynchus tshawytscha*	Central Valley rivers; Delta; San Francisco Bay; Pacific Ocean
Threespine stickleback	*Gasterosteus aculeatus*	Central Valley rivers; Delta
Prickly sculpin	*Cottus asper*	Central Valley rivers; Delta
Tule perch	*Hysterocarpus traski*	Central Valley rivers; Delta; San Francisco Bay
White sturgeon	Acipenser transmontanus	Central Valley rivers; Delta; San Francisco Bay; Pacific Ocean
Green sturgeon	*Acipenser medirostris*	Central Valley rivers; Delta; San Francisco Bay; Pacific Ocean
Introduced Species		
American shad	*Alosa sapidissima*	Central Valley rivers; Delta; San Francisco Bay; Pacific Ocean
Threadfin shad	*Dorosoma petenense*	Central Valley rivers; Delta
Goldfish	*Carassius auratus*	Central Valley rivers; Delta
Red shiner	*Cyprinella lutrensis*	Central Valley rivers; Delta
Carp	*Cyprinus carpio*	Central Valley rivers; Delta
Golden shiner	*Notemigonus chrysoleucas*	Central Valley rivers; Delta
Rosyface shiner	*Notropis rubellus*	Central Valley rivers; Delta
Fathead minnow	*Pimephales promelas*	Central Valley rivers; Delta
White catfish	*Ameiurus catus*	Central Valley rivers; Delta
Black bullhead	*Ameiurus melas*	Central Valley rivers; Delta
Channel catfish	*Ictalurus punctatus*	Central Valley rivers; Delta
Wakasagi	*Hypomesus nipponensis*	Delta; San Francisco Bay
Western mosquitofish	*Gambusia affinis*	Central Valley rivers; Delta
Inland silverside	*Menidia beryllina*	Central Valley rivers; Delta; San Francisco Bay
Striped bass	*Morone saxatilis*	Central Valley rivers; Delta; San Francisco Bay; Pacific Ocean
Bluegill	*Lepomis macrochirus*	Central Valley rivers; Delta
Redear sunfish	*Lepomis microlophus*	Central Valley rivers; Delta
Smallmouth bass	*Micropterus dolomieu*	Central Valley rivers; Delta
Largemouth bass	*Micropterus salmoides*	Central Valley rivers; Delta
White crappie	*Pomoxis annularis*	Central Valley rivers; Delta
Black crappie	*Pomoxis nigromaculatus*	Central Valley rivers; Delta
Bigscale logperch	*Percina macrolepida*	Delta; San Francisco Bay
Yellowfin goby	*Acanthogobius flavimanus*	Delta; San Francisco Bay
Shimofuri goby	*Tridentiger bifasciatus*	Delta; San Francisco Bay
Chameleon goby	*Tridentiger trigonocephalus*	Delta; San Francisco Bay

Source: Moyle 2002, California Department of Fish and Game unpublished data

Key:

Delta = Sacramento-San Joaquin Delta

Trinity River

The Trinity River provides habitat for Southern Oregon/Northern California Coast (SONCC) coho salmon (*Oncorhynchus kisutch*), Southern Oregon/Northern California Coast Chinook salmon, Klamath Mountains Province (KMP) steelhead, green sturgeon, white sturgeon, Pacific lamprey, resident rainbow trout, speckled dace, three-spine stickleback, Klamath small scale sucker (*Catostomus rimiculus*), prickly sculpin, and riffle sculpin (*Cottus gulosus*), brook trout (*Salvelinus fontinalis*), brown trout (*Salmo trutta*) American shad, brown bullhead, golden shiner, and green sunfish. Coho salmon and KMP steelhead are included in this discussion because they are special-status species and CVP and SWP operations in response to changes at Shasta Dam have the potential to affect Trinity River flows.

CVP/SWP Service Areas The CVP and SWP water service areas contain several highly altered aquatic habitat types, including reservoirs, canals, ditches and other manmade water conveyance structures/facilities. Agricultural land and urban development are the dominant land uses within these service areas. As a result of all these factors, the aquatic communities that occupy the habitats are highly adapted to these disturbed environments and are dominated by nonnative species, some of which are detrimental to survival of native species.

Special-Status Species

Special-status fish species are legally protected or are otherwise considered sensitive by Federal, State, or local resource conservation agencies and organizations. Special-status fish species addressed in this section include:

- Species listed as threatened or endangered under the Federal Endangered Species Act (ESA) or California Endangered Species Act (CESA).
- Species identified by USFWS, NMFS, or DFG as species of special concern.
- Species fully protected in California under the California Fish and Game Code.
- Species identified as priorities for recovery under the CALFED Bay-Delta Program (CALFED) Multi-Species Conservation Strategy (CALFED 2000).
- Considered sensitive or endemic by the U.S. Forest Service (USFS).
- Considered a survey and manage species by USFS.

A total of nine special-status fish species occur or have the potential to occur in the primary and extended study areas and are described below (see also Table 1-3). Of the nine species, Central Valley steelhead distinct population segment (DPS), Sacramento River winter-run evolutionarily significant unit (ESU), Central Valley spring-run Chinook salmon ESU, Southern DPS of North American green sturgeon, and delta smelt are Federally listed as threatened or endangered species. USFWS delisted Sacramento splittail from its Federally listed-as-threatened status on September 22, 2003. NMFS determined that listing is not warranted for Central Valley fall-/late fall-run Chinook salmon. However, it is still designated as a Species of Concern because of concerns over specific risk factors. The two remaining species (hardhead and Sacramento perch) are considered Species of Special Concern by DFG and/or Federal Species of Concern by USFWS. Brief descriptions follow for the special-status species with potential to occur in the primary and extended study areas.

Table 1-3. Fish Species Known to Occur in Primary Study Area

Common Name	Scientific Name	Distribution Within Primary Study Area		
		Shasta Lake Tributaries	Shasta Lake/ Keswick Reservoir	Sacramento River – Keswick to Red Bluff
Chinook salmon	*Oncorhynchus tshawytscha*		X	
winter-run				X
spring-run				X
fall-run				X
late fall-run				X
Rainbow trout	*Oncorhynchus mykiss*	X	X	X
Steelhead trout	*Oncorhynchus mykiss*			X
Brown trout	*Salmo trutta*	X	X	X
Green sturgeon	*Acipenser medirostris*			X
White sturgeon	*Acipenser transmontanus*	X	X	X
Pacific lamprey	*Lampetra tridentata*			X
Western brook lamprey	*Lampetra richardsoni*			X
Sacramento sucker	*Catostomus occidentalis*	X	X	X
Sacramento pikeminnow	*Ptychocheilus grandis*	X	X	X
Hardhead	*Mylopharodon conocephalus*	X	X	X
Sacramento blackfish	*Orthodon microlepidotus*	X	X	
California roach	*Hesperolecus symmetricus*	X		X
Speckled dace	*Rhinichthys osculus*	X	X	
Golden shiner	*Notemigonus crysoleucas*	X	X	
Carp	*Cyprinus carpio*	X	X	X
Channel catfish	*Ictalurus punctatus*	X	X	X
White catfish	*Ameiurus catus*		X	X
Brown bullhead	*Ameiurus nebulosus*		X	X
Black bullhead	*Ameiurus melas*		X	X
Riffle sculpin	*Cottus gulosus*	X	X	
Prickly sculpin	*Cottus asper*			X
Rough sculpin	*Cottus asperrimus*	X		
Pit sculpin	*Cottus pitensus*	X		
Bigeye marbled sculpin	*Cottus klamathensis macrops*	X		

Table 1-3. Fish Species Known to Occur in Primary Study Area (contd.)

Common Name	Scientific Name	Distribution Within Primary Study Area		
		Shasta Lake Tributaries	Shasta Lake/ Keswick Reservoir	Sacramento River – Keswick to Red Bluff
Largemouth bass	*Micropterus salmoides*			
Smallmouth bass	*Micropterus dolomieui*	X	X	X
Spotted bass	*Micropterus punctulatus*	X	X	
Black crappie	*Pomoxis nigromaculatus*		X	
White crappie	*Pomoxis annulauris*		X	
Bluegill sunfish	*Lepomis macrochirus*		X	
Green sunfish	*Lepomis cyanellus*	X	X	
Threadfin shad	*Dorosoma petenense*		X	
Tule perch	*Hysterocarpus traski*	X	X	X
Tui chub	*Siphateles bicolor*	X	X	

Source: Moyle 2002; Reclamation 2004

Fish Species of Primary Management Concern

Evaluating potential project alternative-related impacts on fish and aquatic resources requires an understanding of fish species' life histories and life-stage-specific environmental/habitat requirements. Therefore, this information is provided below for fish species of primary management concern that occur within the primary and extended study areas. Species of primary management concern include special-status species likely to occur in the potentially affected portions of the Sacramento River and tributaries and Delta (e.g., Chinook salmon, steelhead, green sturgeon, delta smelt, longfin smelt, Sacramento splittail, hardhead) and species that are recreationally and/or commercially important (e.g., striped bass).

Because these species collectively represent a diversity of life histories and environmental/habitat requirements, and because they are among the most sensitive to environmental perturbation, the findings from assessments made for these species can be effectively used to make inferences to other fish species using the primary and extended study areas. Species of primary management concern with the greatest potential to be affected by implementation of the proposed project alternatives are discussed below. The seasonal timing of important life stages for these species in the study areas is presented in Table 1-4.

Table 1-4. Life History and Distributions of Evaluation Fish Life Stages in Primary and Extended Study Areas

Life Stage/Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Steelhead												
Adult migration	■	■	■				■	■	■	■	■	■
Spawning	■	■	■	■								■
Egg incubation	■	■	■	■	■	■	■	■				■
Rearing/emigration	■	■	■	■	■	■	■	■	■	■	■	■
Fall-run Chinook salmon												
Adult migration							■	■	■	■	■	■
Spawning										■	■	■
Egg incubation	■	■	■							■	■	■
Rearing/emigration	■	■	■	■	■	■						
Late fall-run Chinook salmon												
Adult migration	■	■	■								■	■
Spawning	■	■	■	■								
Egg incubation	■	■	■	■	■	■						
Rearing/emigration				■	■	■	■	■	■	■	■	■
Winter-run Chinook salmon												
Adult migration	■	■	■	■	■	■						■
Spawning				■	■	■	■	■				
Egg incubation				■	■	■	■	■	■	■		
Rearing/emigration	■	■	■				■	■	■	■	■	■
Spring-run Chinook salmon												
Adult migration			■	■	■	■	■	■	■	■		
Spawning								■	■	■	■	
Egg incubation								■	■	■	■	■
Rearing/emigration	■	■	■	■	■						■	■
Green sturgeon												
Adult migration		■	■	■	■	■	■					
Spawning		■	■	■	■	■	■					
Egg incubation		■	■	■	■	■	■					
Rearing/emigration	■	■	■	■	■	■	■	■	■	■	■	■
Delta smelt												
Adult migration	■	■	■									■
Spawning	■	■	■	■	■	■	■					
Larvae and juvenile rearing	■	■	■	■	■	■	■					
Estuarine rearing	■	■	■	■	■	■	■	■	■	■	■	■
Longfin smelt												
Adult migration	■	■	■									■
Spawning	■	■	■	■	■	■	■					
Larvae and juvenile rearing	■	■	■	■	■	■	■					
Estuarine rearing	■	■	■	■	■	■	■	■	■	■	■	■
Sacramento splittail												
Adult migration	■	■	■									■
Spawning	■	■	■	■	■	■	■					
Larvae and juvenile rearing			■	■	■	■						
Adult and juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■
Hardhead												
Adult foraging and spawning					■	■	■					
Spawning						■	■	■	■	■		
Larvae and juvenile rearing						■	■	■	■	■		
Adult and juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■

Table 1-4. Life History and Distributions of Evaluation Fish Life Stages in Primary and Extended Study Areas (contd.)

Life Stage/Location	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Striped bass												
Adult migration			■	■	■	■	■	■				
Spawning						■	■	■	■	■		
Larvae and juvenile rearing						■	■	■	■	■		
Adult and juvenile rearing	■	■	■	■	■	■	■	■	■	■	■	■

Sources: Vogel and Marine 1991, Moyle 2002, Wang 1986, National Marine Fisheries Service 2005

Key:

■ = period of potential occurrence

Central Valley Steelhead On March 19, 1998, naturally spawned Central Valley steelhead were federally listed as threatened by NMFS (63 Federal Register (FR) 13347, March 19, 1998). The Central Valley ESU includes all naturally spawned populations of steelhead (and their progeny) in the Sacramento and San Joaquin Rivers and their tributaries. Resident rainbow trout were previously included as part of the protected fish, but in January 2006, NMFS directed that only the anadromous form should be listed as threatened, and the resident form did not warrant listing (71 FR 834, January 5, 2006).

The original critical habitat designation for the Central Valley steelhead was withdrawn pending review. The consent decree (U.S. District Court of the District of Columbia Civil Action No. 00-2799 CKK) resulted in the withdrawal of the critical habitat designation for this ESU. On December 10, 2004, NMFS published a new proposal to designate critical habitat for Central Valley steelhead that includes the lower Feather River; Battle, Cottonwood, Antelope, Mill, Deer, Big Chico, and Butte creeks; Sacramento, Yuba, American, Cosumnes, Mokelumne, Calaveras, San Joaquin, Merced, Tuolumne, and Stanislaus rivers; and the Delta. The final designation for Central Valley steelhead critical habitat was published on September 2, 2005, and was in effect on January 2, 2006 (70 FR 52488, September 2, 2005).

In October 2009, NMFS published the Draft Recovery Plan for Central Valley steelhead, which identifies recovery goals, objectives, and criteria, as well as proposed management actions aimed at bringing the populations to a point at which they can be delisted.

Central Valley steelhead historically migrated upstream into the high gradient upper reaches of Central Valley streams and rivers for spawning and juvenile rearing. Construction of dams and impoundments on the majority of Central Valley rivers has created impassable barriers to upstream migration and substantially reduced the geographic distribution of steelhead. Although quantitative estimates of the number of adult steelhead returning to Central Valley streams to spawn are not available, anecdotal information and observations indicate that population abundance is low (NMFS 1996). Steelhead distribution is currently restricted to the mainstem Sacramento River downstream from Keswick Dam, the Feather River downstream from Oroville

Dam, the American River downstream from Nimbus Dam, the Mokelumne River downstream from Comanche Dam, Consumnes River, and a number of smaller tributaries to the Sacramento River system, Delta, and San Francisco Bay. Steelhead have also been reported from tributaries to the San Joaquin River; however, the status of these populations is under investigation.

The Central Valley steelhead population is composed of both naturally spawning steelhead and steelhead produced in hatcheries. NMFS is continuing to evaluate the status of steelhead and is currently in the process of developing a recovery plan for the species.

Adult steelhead migrate upstream during the fall and winter (September through approximately February) with steelhead migration into the upper Sacramento River typically occurring during the fall, and adults migrating into lower tributaries typically during the late fall and winter. Steelhead spawn in areas characterized by clean spawning gravels, cold-water temperatures, and moderately high velocity. Spawning typically occurs during the winter and spring (December through April) with the majority of spawning activity occurring during January and March. Unlike Chinook salmon, which die after spawning, adult steelhead may migrate downstream after spawning and return to spawn in subsequent years.

Steelhead spawn by creating a depression in the spawning gravels where eggs are deposited and fertilized (redd). Steelhead require relatively clean, cool (less than 57ºF (13.9 degrees Celsius (ºC))) water in which to spawn successfully. The eggs hatch anywhere from 19 to 80 days after spawning, depending on water temperature (warmer temperatures result in faster hatching times), and the young remain in the gravel for several weeks before emerging as fry (Raleigh et al. 1984). The young steelhead emerge from the gravel redd as fry, and rear in the stream system, foraging on insects for 1 to 2 years or longer before migrating to the ocean.

Juvenile steelhead undergo a physiological transformation (smolting) that allows the juvenile steelhead to migrate from the freshwater rearing areas downstream to coastal marine waters. Downstream migration of steelhead smolts typically occurs during the late winter and early spring, (January through May), although based on salvage data at the Federal and State pumping plants in the Delta, the peak months for emigration appear to be March and April in most years. The seasonal timing of downstream migration of steelhead smolts may vary in response to a variety of environmental and physiological factors, including changes in water temperature, changes in streamflow, and increased turbidity resulting from stormwater runoff. The juvenile steelhead rear within the coastal marine waters for approximately 2 to 3 years before returning to their natal stream as spawning 4- or 5-year-old adults.

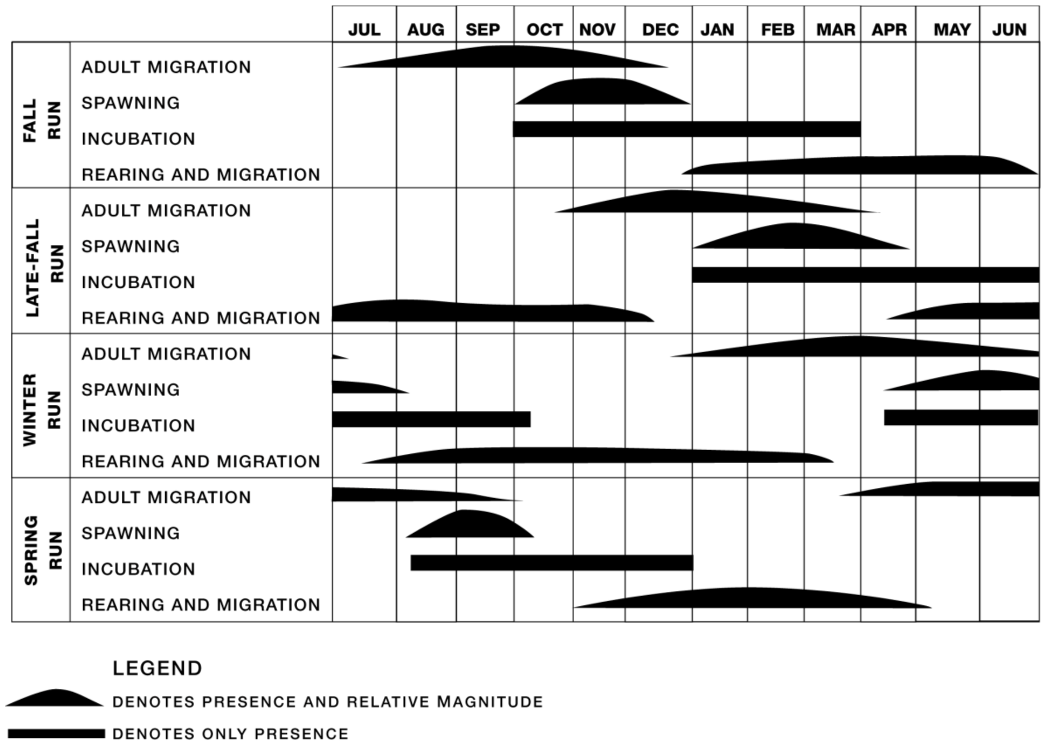
Because steelhead have a mandatory freshwater residency period, it is critical that suitable conditions for juvenile rearing exist year-round. Requirements for optimal juvenile rearing include adequate cover (i.e., greater than 25 percent of stream area), food supply (i.e., enough to sustain growth), and water temperatures of 43ºF to 65ºF (6ºC to 18ºC) (Raleigh et al. 1984). Although juveniles are known to withstand temperatures of up to 77ºF (25ºC), survival at these higher temperatures depends on a number of factors, including exposure duration, acclimation factors, food availability, water quality (specifically DO concentrations), and groundwater dynamics.

The steelhead life cycle is characterized by a high degree of flexibility (plasticity) in the duration of both their freshwater and marine rearing phases. The steelhead life cycle is adapted to respond to environmental variability in stream hydrology and other environmental conditions.

Factors affecting steelhead abundance are similar to those described for winter-run and spring-run Chinook salmon. One of the primary factors affecting population abundance of steelhead has been the loss of access to historical spawning and juvenile rearing habitat within the upper reaches of the Sacramento River and its tributaries and within the San Joaquin River as a result of the migration barriers caused by construction of major dams and reservoirs. Water temperatures within the rivers and creeks, particularly during summer and early fall months, have also been identified as a factor affecting growth and survival of juvenile steelhead. Juvenile steelhead are vulnerable to entrainment at a large number of unscreened water diversions located along the Sacramento River and within the Delta, in addition to entrainment and salvage mortality at CVP and SWP export facilities. Changes in habitat quality and availability for spawning and juvenile rearing, exposure to contaminants, predation mortality, passage barriers and impediments to migration, changes in land use practices, and competition and interactions with hatchery-produced steelhead have all been identified as factors affecting steelhead abundance. Unlike Chinook salmon, steelhead are not vulnerable to recreational and commercial fishing within the ocean, although steelhead support a small inland recreational fishery for hatchery-produced fish. Ocean survival is affected by climatic and oceanographic conditions, and adults are vulnerable to predation mortality by marine mammals.

In recent years a number of changes have been made to improve the survival and habitat conditions for steelhead. Several large previously unscreened water diversions have been equipped with positive barrier fish screens. Improvements to fish passage facilities have also been made to improve migration and access to spawning and juvenile rearing habitat.

Chinook Salmon The Sacramento River supports four separate runs of Chinook salmon: fall-run, late fall-run, winter-run, and spring-run, denoting when adults enter freshwater and begin their upstream migration. Figure 1-2 shows the seasonal occurrence of Chinook salmon in the Delta and tributary waters.



Source: Vogel and Marine 1991

Figure 1-2. Seasonal Occurrence of Different Life Stages of Four Chinook Salmon Runs

Fall-Run Chinook Salmon Fall-run Chinook salmon represent about 80 percent of the total Chinook salmon produced in the Sacramento River drainage (Kjelson et al. 1982). On March 9, 1998 (63 FR 11481), NMFS issued a proposed rule to list fall-run Chinook salmon as threatened, but determined the species did not warrant listing, and identified it as a candidate species (64 FR 50393, September 16, 1999). NMFS also determined that both late fall-run and fall-run comprise a single ESU, but because they are separate in timing and effects, they are distinguished as separate for the purposes of this document.

Although fall-run and late fall-run Chinook salmon inhabit a number of watersheds within the Central Valley for spawning and juvenile rearing, the largest populations occur within the mainstem Sacramento River, Feather River, Yuba River, American River, Mokelumne River, Merced River, Tuolumne River, and Stanislaus River. Fall-run Chinook salmon, in addition to spawning in these river systems, are also produced in fish hatcheries located on the Sacramento River, Feather River, American River, Mokelumne River, and Merced River. Hatchery spawners average more than 25,000 adults. Natural spawners average about 200,000 adults for the Sacramento and San Joaquin river system (Moyle 2002). Hatchery operations are intended to mitigate for the loss of access to upstream spawning and juvenile rearing habitat resulting from construction of dams and reservoirs within the Central Valley, in addition to producing fall-run Chinook salmon as part of the ocean salmon enhancement program to support commercial and recreational ocean salmon fisheries. Fall-run Chinook salmon also support an inland recreational fishery.

Adult fall-run Chinook salmon migrate into the Sacramento River and its tributaries from July through December. Fall-run Chinook salmon spawn during early October through late December and incubation takes place during October through March. The peak of spawning is in October and November as water temperature drops. Fall-run Chinook salmon move upstream from the ocean in the late summer and early fall in mature condition and spawn soon after arriving at their spawning grounds. Juvenile Chinook salmon emerge from the gravel and migrate downstream to the ocean soon after emerging, rearing in the streams for only few months.

Temperature requirements vary according to life stage of Chinook salmon and habitat conditions. The following describes some general requirements for Chinook salmon, including all four runs occupying the Sacramento River. Most adult Chinook salmon migrate upstream when water temperatures are between 51 and 60 ºF (10.5 to 15.5 ºC) (Bell 1990, Hinze et al. 1956, as cited in McCullough et al. 2001). Spring-run Chinook hold in waters typically under 60ºF (15.5 ºC) (NMFS 1997), but because they hold in deep cold pools, surface water temperatures can reach as high as 73ºF (22.8 ºC) (Beauchamp et al. 1983). Adults tend to spawn when water temperatures drop to between 41ºF and 57ºF (5ºC to 13.9ºC) (McCullough 1999, Moyle 2002, NMFS 2002, Slater 1963, Reiser and Bjornn 1979). During spawning, the female digs a nest (redd) with her tail before depositing her eggs while the male(s) alongside her fertilizes them.

The duration of egg incubation is temperature-dependent. Eggs will hatch sooner in warmer water, but water too warm during incubation can either kill the eggs directly or result in deformities and/or mortality post-hatching. The optimal range of water temperatures during egg incubation is between 41ºF and 57ºF (5ºC to 13.9 ºC) (USFWS 1995, NMFS 1997, Slater 1963). Upon hatching, the young fish (alevins) will remain in the nest until their yolk sac has been absorbed, at which time the young fish (now called fry) emerge from the redds. A portion of the fry population migrate downstream soon after emergence, where they rear within the lower river channels, Delta, and Suisun Bay during the spring months (Baker and Morhardt 2001). The remaining portion of juvenile salmon continue to rear in the upstream stream systems through the spring months, until they are physiologically adapted to migrate into saltwater (smolting), which typically takes place between April and early June. A small proportion of the fall-run Chinook salmon juveniles may, in some systems, rear through the summer and fall months, migrating downstream during the fall, winter, or early spring as yearlings.

Water temperatures for rearing fry and juvenile Chinook salmon are optimal between 53ºF and 60ºF (11.7ºC to 15.5ºC) (Rich 1987; Seymour 1956; NMFS 2000, 2002; Banks et al. 1971; Marine 1997). Chinook salmon smolts begin to migrate downstream and through the Delta and San Francisco Bay to the ocean. Studies have shown that smoltification can be hindered and survival compromised when water temperatures exceed 62ºF (16.7ºC) (Zedonis and Newcomb 1997, Marine and Cech 2004, Marine 1997).

The juvenile and adult Chinook salmon rear in coastal marine waters, foraging on fish and macroinvertebrates (e.g., northern anchovy, Pacific herring, squid, krill), until they reach maturation. Adult Chinook salmon spawn at ages ranging from approximately 2 to 5 years old, with the majority of adult fall-run Chinook salmon returning at 3 years old. Chinook salmon, unlike steelhead, die after spawning.

Late Fall-Run Chinook Salmon Late fall-run Chinook salmon mostly inhabit the Sacramento River, with spawning occurring upstream from RBDD. Late fall-run salmon migrate into the Sacramento River from October through April and spawn from January through April. Peak spawning activity in February and March is followed by egg incubation from January through June, and fry emergence from April through June. Rearing and emigration of fry and smolts occur from April through December. Juvenile Chinook salmon rear in the streams during the summer, and in some streams they remain throughout the year.

Sacramento River Winter-Run Chinook Salmon With the possible exception of Battle Creek, the Sacramento River upstream from RBDD is the only spawning stream for winter-run Chinook salmon, which have been in a major decline since the 1960s. The abundance of winter-run Chinook salmon before the construction of Shasta Dam is unknown. Some biologists believe the run was relatively small, possibly consisting of a few thousand fish (Slater 1963). Others, relying on anecdotal accounts, believe the run could have numbered over 200,000 fish (NMFS 1993a). The population during the mid-1960s, more than 20 years after the construction of Shasta Dam, exceeded 80,000 fish (Reclamation 1986). The population declined substantially during the 1970s and 1980s.

In 1989, Sacramento River winter-run Chinook salmon escapement was estimated at less than 550 adults. Escapement continued to decline, diminishing to an estimated 450 fish in 1990 and 191 fish in 1991. The sharp decline in escapement during the late 1980s and early 1990s prompted listing of the winter-run Chinook salmon as endangered under ESA (59 FR 440, January 4, 1994) and CESA. Escapement in 1992 was estimated to be 1,180 fish, indicating good survival of the 1989 class. NMFS data indicate that the population has increased during the late 1990s through 2001. In 1996, returning spawners numbered about 1,000 fish and in 2001, returning adults were estimated to be 5,500 (Pacific Fishery Management Council 2002). From 2001, the number of returning spawners generally increased to about 17,150 in 2006 but dropped again in 2007 through 2009, a trend found to occur for all runs of Chinook salmon spawners (DFG 2009).

The portion of the Sacramento River from Keswick Dam to Chipps Island, all waters westward from Chipps Island to the Carquinez Strait Bridge, all waters of San Pablo Bay, and all waters of the Bay north of the San Francisco-Oakland Bay Bridge have been designated as critical habitat for winter-run Chinook salmon (58 FR 33212, June 16, 1993). Critical habitat includes the river water, river bottom, and adjacent riparian zone (i.e., those adjacent terrestrial areas that directly affect a freshwater aquatic ecosystem).

As with other Chinook salmon stocks, NMFS is continuing to evaluate the status of the winter-run Chinook salmon population and the effectiveness of various management actions implemented within the Sacramento River, Delta, and ocean to provide improved protection and reduced mortality for winter-run salmon, in addition to providing enhanced habitat quality and availability for spawning and juvenile rearing. In October 2009, NMFS published the Draft Recovery Plan for Sacramento River winter-run Chinook salmon, which identifies recovery goals, objectives, and criteria, as well as proposed management actions aimed at bringing the populations to a point at which they can be delisted.

Adult winter-run Chinook salmon spend 1 to 3 years in the ocean. Adult escapement consists of 67 percent 3-year-olds, 25 percent 2-year-olds, and 8 percent 4-year-olds (Hallock and Fisher 1985). Adult winter-run Chinook salmon leave the ocean and migrate through the Delta into the Sacramento River from November through July, passing RBDD on the Sacramento River from mid-December through July, with peak migration occurring during March (Moyle 2002). Most migrating adults have passed RBDD by late June (Moyle 2002). Winter-run Chinook salmon adults prefer water temperatures ranging between 57 and 67°F (14 to 19°C) for upstream migration (NMFS 2009).

Winter-run Chinook salmon spawn from mid-April through August (Moyle 2002). When water temperatures range between 50 and 59°F (10 to 15°C). Egg incubation continues through mid-October. The primary spawning habitat in the Sacramento River is between the RBDD and Keswick Dam. Some fish may spawn below the RBDD, but warm-water temperature below the RBDD kills the eggs during most summers (Yoshiyama et al. 1998).

Juvenile winter-run Chinook salmon rear in the Sacramento River from July through March (Hallock and Fisher 1985). All winter-run Chinook salmon fry pass the RBDD by October; all emigrating pre-smolts and smolts pass the RBDD by March (Martin et al., as cited in NMFS 2009).

Juvenile Chinook salmon move downstream from spawning areas in response to many factors, including inherited behavior, habitat availability, flow, competition for space and food, and water temperature. The number of juveniles that move, and the timing of movement, are highly variable. Storm events and the resulting high flow and turbidity appear to trigger downstream movement of substantial numbers of juvenile Chinook salmon. Juveniles have been observed in the Delta from November through May (NMFS 2009). In general, juvenile abundance in the Delta increases in response to increased Sacramento River flow (USFWS 1995b).

Winter-run Chinook salmon smolts (i.e., juveniles that are physiologically ready to enter seawater) may migrate through the Delta and San Francisco Bay to the ocean from December through May (Stevens 1989).

A variety of environmental and biological factors have been identified that affect the abundance, mortality, and population dynamics of winter-run Chinook salmon. One of the primary factors that have affected population abundance of winter-run Chinook salmon has been the loss of access to historical spawning and juvenile rearing habitat within the upper reaches of the Sacramento River and its tributaries as a result of the migration barriers caused by Shasta and Keswick dams (Brandes and McLain 2001; Baker and Morhardt 2001). Operation of the RBDD, which impedes adult upstream migration and vulnerability of juvenile winter-run Chinook salmon to predation mortality, has been identified as a factor affecting mortality within the river. In recent years, changes to RBDD gate operations have been made to provide improved access for upstream and downstream migrating winter-run Chinook salmon.

Water temperatures in the mainstem Sacramento River have been identified as a factor affecting incubating eggs, holding adults, and growth and survival of juvenile winter-run Chinook salmon rearing in the upper Sacramento River (Baker and Morhardt 2001). Juvenile winter-run Chinook salmon are also vulnerable to entrainment at a large number of unscreened water diversions located along the Sacramento River and within the Delta in addition to entrainment and salvage mortality at the CVP and SWP export facilities (DWR and Reclamation 2000). Changes in habitat quality and availability for spawning and juvenile rearing, exposure to contaminants and acid mine drainage, predation mortality by Sacramento pikeminnow, striped bass, largemouth bass, and other predators, and competition and interactions with hatchery-produced Chinook salmon have all been identified as factors affecting winter-run Chinook salmon abundance. In addition, subadult and adult winter-run Chinook salmon are vulnerable to recreational and commercial fishing; ocean survival is affected by climatic and oceanographic conditions; and adults are vulnerable to predation mortality by marine mammals (Brandes and McLain 2001).

In recent years, a number of changes have been made to improve survival and habitat conditions for winter-run Chinook salmon. The NMFS biological opinion (BO) for winter-run Chinook salmon (NMFS 1993a) established water temperature objectives for the river upstream from Jellys Ferry (near the RBDD) of 56ºF from April 15 through September 30, and 60ºF for October. Recent changes in reservoir operations, including greater carryover storage, increased imports of cold water from the Trinity River system, and, most importantly, installation of a TCD on Shasta Dam, have substantially improved water temperature conditions in the reach. While NMFS published a BO in 2005, it did not change any of the specific reasonable and prudent alternatives (RPA) designated to protect winter-run Chinook salmon, but incorporated those already presented in the 1993 BO.

Modifications have also been made to RBDD gate operations, and several large previously unscreened water diversions have been equipped with positive barrier fish screens. Modifications to CVP and SWP export operations have also been made in recent years to improve survival of juvenile salmon during migration through the Delta.

Spring-Run Chinook Salmon On September 16, 1999, the Central Valley spring-run Chinook salmon ESU was listed as threatened under the ESA by NMFS. The Central Valley spring-run Chinook salmon ESU includes all naturally spawned populations of spring-run Chinook salmon in the Sacramento River and its tributaries, as well as artificially propagated Feather River spring-run Chinook salmon (70 FR 37177, June 28, 2005).

Critical habitat for Central Valley spring-run was designated on February 16, 2000, but on April 30, 2002, the U.S. District Court for the District of Columbia approved a NMFS consent decree (*National Association of Home Builders v. Evans*) withdrawing the critical habitat designation for this and 18 other ESUs of salmon and steelhead. The consent decree challenged the process by which NMFS established the critical habitat designations, citing that the agency did not take into consideration the economic impacts on the interested parties, as required.

On December 10, 2004, NMFS published a new proposal to designate critical habitat for seven ESUs of Chinook salmon and steelhead in California, including the Central Valley spring-run Chinook salmon. The final designation for critical habitat was published on September 2, 2005, but was in effect on January 2, 2006. The critical habitat includes roughly 1,272 miles of occupied stream habitat and 427 square miles of estuarine habitat, and encompasses the lower Feather River; the Sacramento and Yuba rivers; Beegum, Battle, Clear, Cottonwood, Antelope, Mill, Deer, Butte, and Big Chico creeks; the north Delta (the central and south Delta were excluded); and Suisun, San Pablo, and north San Francisco bays (70 FR 52488, September 2, 2005).

In October 2009, NMFS published the Draft Recovery Plan for Central Valley spring-run Chinook salmon, which identifies recovery goals, objectives and criteria, as well as proposed management actions aimed to bring the populations to a point at which they can be delisted.

Historical records indicate that adult spring-run Chinook salmon enter the mainstem Sacramento River in February and March. Adults hold in deep, cold pools near spawning habitat until spawning commences in late summer and fall. Spring-run Chinook salmon are sexually immature during upstream migration

(Fisher 1994). Spawning occurs in gravel substrates in late August through October. Considerable overlap occurs between spring-run and fall-run Chinook spawning on the mainstem Sacramento River and most of the major tributaries. This overlap has likely resulted in genetic introgression (i.e., loss of genetic purity) of the spring-run stocks (Slater 1963). Genetically pure spring-run Chinook salmon occur mostly only in two spawning tributaries, Mill and Deer creeks.

Juveniles emerge during November and December in most locations but may emerge later when water temperature is cooler. Spring-run Chinook salmon may migrate downstream as young-of-year juveniles or yearlings. Based on observations in Butte Creek and the Sacramento River, young-of-year juveniles migrate during November to June. Yearling spring-run Chinook salmon migrate during October through March, with peak migration in November (Cramer and Demko 1997, Hill and Webber 1999). The downstream migration of both spring-run Chinook salmon fry and yearlings during the late fall and winter typically coincides with increased flow and turbidity associated with winter stormwater runoff.

Juvenile spring-run Chinook salmon rear in their natal streams, the mainstem Sacramento River, and the Delta. Juveniles that remain in their natal streams, especially small, cold tributary streams, may migrate downstream as yearlings. Juveniles migrate downstream to the ocean as yearlings with the onset of the storm season in October of the year following spawning, and migration may continue through March (DFG 1998).

A variety of environmental and biological factors have been identified that affect the abundance, mortality, and population dynamics of spring-run Chinook salmon. The main factor affecting population abundance of spring-run Chinook salmon is the loss of access to historical spawning and juvenile rearing habitat within the upper reaches of the Sacramento River and its tributaries and San Joaquin River as a result of the migration barriers caused by construction of major dams and reservoirs. Operation of the RBDD, which impedes adult upstream migration and vulnerability of juvenile spring-run Chinook salmon to predation mortality, has been shown to cause mortality in the river. Water temperatures have been identified as affecting incubating eggs, holding adults, and growth and survival of juvenile spring-run Chinook salmon.

Juvenile spring-run Chinook salmon are also vulnerable to entrainment at a large number of unscreened water diversions located along the Sacramento River and within the Delta, in addition to entrainment and salvage mortality at the CVP and SWP export facilities. Changes in habitat quality and availability for spawning and juvenile rearing, exposure to contaminants, predation mortality by Sacramento pikeminnow, striped bass, largemouth bass, and other predators, and competition and interactions with hatchery-produced Chinook salmon have all been shown to affect spring-run Chinook salmon abundance. In addition, as for winter-run Chinook salmon, subadult and adult spring-run

Chinook salmon are vulnerable to recreational and commercial fishing; ocean survival is affected by climatic and oceanographic conditions; and adults are vulnerable to predation mortality by marine mammals.

In recent years, a number of changes have been made to improve the survival and habitat conditions for spring-run Chinook salmon. Several large previously unscreened water diversions have been equipped with positive barrier fish screens. Changes to ocean salmon fishing regulations have been made to improve the survival of adult spring-run Chinook salmon. Modifications to CTP and SWP export operations have been made in recent years to improve survival of juvenile Chinook salmon migrating through the Delta. Improvements in fish passage facilities have also been made to improve migration and access to Butte Creek. These changes and management actions, in combination with favorable hydrologic and oceanographic conditions in recent years, are thought to have contributed to the trend of increasing abundance of adult spring-run Chinook salmon returning to spawn in Butte Creek and other habitats within the upper Sacramento River system in recent years.

Coho Salmon General life history information and biological requirements of SONCC coho salmon have been described in various documents (Shapovalov and Taft 1954, Hassler 1987, Sandercock 1991, DFG 1994, Weitkamp et al. 1995), as well as the NMFS final rule listing SONCC coho salmon (May 6, 1997; 62 FR 24588).

Adult coho salmon typically enter rivers between September and February. Spawning occurs from November to January (Hassler 1987), but occasionally as late as February or March (Weitkamp et al. 1995). Coho salmon eggs incubate for 35-50 days between November and March. Successful incubation depends on several factors: DO levels, temperature, substrate size, amount of fine sediment, and water velocity. Fry start emerging from the gravel 2 to 3 weeks after hatching and move into shallow areas with vegetative or other cover. Peak emergence periods in the Trinity River are February through March (USFWS and Hoopa Valley Tribe 1999). As fry grow larger, they disperse upstream or downstream. In summer, coho salmon fry prefer pools or other slower velocity areas such as alcoves, with woody debris or overhanging vegetation. Juvenile coho salmon over-winter in slow-water habitat with cover. Juveniles may rear in freshwater for up to 15 months, then migrate to the ocean as smolts from March to June (Weitkamp et al. 1995). Coho salmon adults typically spend 2 years in the ocean before returning to their natal streams to spawn as 3-year-olds.

Green Sturgeon North American green sturgeon have been separated into two DPSs: the northern DPS (all populations north of, and including, the Eel River) and the southern DPS (Coastal and Central Valley populations south of the Eel River). The southern DPS is currently proposed for listing as threatened under the ESA. On April 15, 2004, NMFS announced that the northern and southern DPSs of green sturgeon would change in listing status from a candidate species to a species of concern (69 FR 117, June 18, 2004). However, litigation challenged the NMFS determination that green sturgeon did not warrant listing as an endangered or threatened species under the ESA and asserted that the agency was arbitrary and capricious in failing to examine whether habitat loss constituted a significant portion of the species' range (70 FR 65, April 6, 2005). The court partially agreed with the plaintiff's motion, and remanded the determination back to NMFS for further analysis and decision as to whether green sturgeon are endangered or threatened in a significant portion of their range. Following this, NMFS listed green sturgeon as threatened (71 FR 17757, April 7, 2006). In April 2009, NMFS designated critical habitat for green sturgeon that includes the Sacramento, lower Feather, and lower Yuba rivers, Yolo and Sutter bypasses, the Delta, and Suisun, San Pablo, and San Francisco bays (74 FR 52300, April 9, 2009)

Not much is known about the life history of green sturgeon because of its low abundance, low sport fishing value, and limited spawning distribution, but spawning and larval ecology are assumed to be similar to that of white sturgeon (Moyle 2002, Beamesderfer and Webb 2002). Green sturgeon are mostly marine fish, spending limited time in estuaries or freshwater (SWRCB 1999). Green sturgeon also make extensive ocean migrations; consequently, most recoveries of individuals tagged in San Pablo Bay have come from the ocean and from rivers and estuaries in Oregon and Washington.

Within estuaries, green sturgeon reportedly tend to concentrate in deep areas with soft bottoms. In rivers, adult (and juvenile) green sturgeon have been observed primarily on clean sand (Environmental Protection Information Center et al. 2001). Adult green sturgeon are benthic, usually found in the Sacramento River in deep, off-channel areas with little current.

Indirect evidence indicates that green sturgeon spawn mainly in the Sacramento River; spawning has been reported in the mainstem as far north as Red Bluff. Migration of green sturgeon begins in late February and continues through July (for both upstream and downstream migration) and may cover as much as 200 miles (Beamesderfer and Webb 2002).Adults and juveniles are opportunistic carnivores, feeding on benthic invertebrates and may also take small fish (Ganssle 1966). Adult green sturgeon are also known to feed on worms, clams, sand lances, callianassid shrimp, crabs, isopods, and anchovies (Environmental Protection Information Center et al. 2001, Moyle 2002). Green sturgeon can withstand long periods of food deprivation during spawning migrations (Environmental Protection Information Center et al. 2001).

Most females reach sexual maturity at 20 to 25 years and 6 to 7 feet in length while males reach sexual maturity at 15 to 17 years and 5 to 6 feet in length (Beamesderfer and Webb 2002). Green sturgeon are thought to spawn every 3 to 5 years (70 FR 65, April 6, 2005). The green sturgeon spawning period is from February to July, with a peak in mid-April to mid-June (Kohlhorst 1976, Moyle 2002, Beamesderfer and Webb 2002). The reported range of preferred/

optimal water temperatures for green sturgeon spawning is unclear, but spawning success is related to water temperature (Beamesderfer and Webb 2002). In the Sacramento River, sturgeon are seen in the river when water temperatures are between 46°F and 57°F (13.9ºC) (Moyle 2002). Spawning occurs in deep pools in large, turbulent river mainstreams (Moyle et al. 1992), and the preferred spawning substrate is likely large cobble-containing crevices in which eggs can become trapped and develop, but may range from clean sand to bedrock (Environmental Protection Information Center et al. 2001, Beamesderfer and Webb 2002).

Sturgeon eggs have been found in the Sacramento River from mid-February through July (Kohlhorst 1976, Moyle 2002, Beamesderfer and Webb 2002). Eggs are broadcast-spawned and externally fertilized in relatively high water velocities (1.5 to 3.0 meters per second) and probably at depths greater than 10 feet (USFWS 1995a). The number of eggs green sturgeon females lay in a spawning season increases with body size, reportedly ranging from 60,000 to 140,000 eggs per female (Moyle et al. 1992) and are the largest egg of any sturgeon (Cech et al. 2000). Green sturgeon eggs are slightly adhesive, adhering to each other and to river substrates (DFG 2002). The importance of water quality is uncertain, but silt is known to prevent green sturgeon eggs from adhering to each other (USFWS 1995a)—sand and silt may suffocate the eggs (Environmental Protection Information Center et al. 2001). The comparatively large egg size, thin chorionic layer on the egg, and other characteristics suggest that green sturgeon probably requires colder, cleaner water for spawning than does the white sturgeon (USFWS 1995a). Water temperatures above 68°F (20ºC) are reportedly lethal to green sturgeon embryos (Beamesderfer and Webb 2002). Eggs hatch approximately 196 hours after spawning, and larvae are 8 to 19 millimeters long. Juveniles range in size from less than 1 inch to almost 5 feet.

Juvenile green sturgeon reportedly occur in shallow water (Radtke 1966) and probably move to deeper, more saline areas as they grow (Environmental Protection Information Center et al. 2001). Rearing juveniles remain in freshwater for 1 to 4 years before returning to their marine environment (Beamesderfer and Webb 2002, Environmental Protection Information Center et al. 2001). Juveniles in the Delta primarily feed on opossum shrimp and amphipods (Radtke 1966, Moyle 2002). The growth rate for green sturgeon juveniles is roughly 3 inches per year until they reach maturity at 4 to 5 feet in length, around age 15 to 20, at which time the growth rate slows (Wang 1986).

The occurrence of green sturgeon in fishery sampling, and CVP/SWP (Jones Pumping Plant and Banks Pumping Plant) fish salvage is extremely low and therefore has not been used to represent the seasonal period of juvenile movement through the Delta. During 2007, for example, green sturgeon were collected in the Jones and Banks fish facilities during one day at each out of the year. Green sturgeon tend to remain near estuaries at first but may migrate considerable distances as they grow larger (SWRCB 1999).

There is no direct evidence of a decline in the numbers of green sturgeon in the Sacramento River. However, the population is so small that a collapse could occur, and it would hardly be noticed because of limited occurrence in conventional fishery sampling programs (SWRCB 1999). In the Delta, major factors that may negatively affect green sturgeon abundance are sport fisheries, modification of spawning habitat, entrainment, and toxic substances.

Delta Smelt Delta smelt is Federally listed as threatened (58 FR 12854, March 5, 1993); critical habitat was designated on December 19, 1994. Critical habitat includes the portion of the Sacramento River from Keswick Dam to Chipps Island, all waters westward from Chipps Island to the Carquinez Bridge, all waters of San Pablo Bay, and all waters of the Bay north of the San Francisco-Oakland Bay Bridge. The status of delta smelt under CESA was upgraded to endangered in January 2010 (DFG 2011).

Delta smelt are endemic to the Delta. During the spawning season, adults move into the channels and sloughs of the Delta. When Delta outflows are high, delta smelt may occur in San Pablo Bay. Delta smelt have relatively low fecundity and most live for 1 year (Moyle 2002).

Estuarine rearing habitat for juvenile and adult delta smelt is typically found in the waters of the lower Delta and Suisun Bay where salinity is between 2 and 7 ppt. Delta smelt tolerate 0 to 19 ppt salinity. They typically occupy open shallow waters (less than 10 feet) but also occur in the main channel in the region where freshwater and brackish water mix. The zone may be hydraulically conducive to their ability to maintain position and metabolic efficiency.

Adult delta smelt begin a spawning migration, which may encompass several months, toward areas of the upper Delta and toward freshwater during December or January. Spawning occurs between February and July, with peak spawning during April through mid-May. Spawning occurs in shallow edge-waters in the upper Delta channels, including the Sacramento River above Rio Vista, Cache Slough, Lindsey Slough, and Barker Slough. Spawning has not been documented in the Sacramento River upstream from the DCC. Eggs are broadcast over the bottom, where they attach to firm sediment, woody material, and vegetation. Hatching takes approximately 9 to 13 days and larvae begin feeding 4 to 5 days later. Newly hatched larvae contain a large oil globule that makes them semibuoyant and allows them to stay off the bottom. Larval smelt feed on rotifers and other zooplankton. As their fins and swim bladder develop, they move higher into the water column. Larvae and juveniles gradually move downstream toward rearing habitat in the estuarine mixing zone.

Longfin Smelt In April 2010, DFG designated the longfin smelt as a threatened species (DFG 2011). Historically, longfin smelt populations were found in the Klamath, Eel, and San Francisco estuaries, and in Humboldt Bay. From current sampling, populations reside at the mouth of the Klamath River and the Russian River estuary. In the Central Valley, longfin are rarely found upstream from Rio Vista or Medford Island in the Delta. Adults concentrate in Suisun, San Pablo, and North San Francisco bays (Moyle 2002).

Longfin smelt are anadromous, euryhaline, and nektonic. Adults and juveniles are found in estuaries and can tolerate salinities from 0 ppt to pure seawater. After the early juvenile stage, they prefer salinities in the 15 through 30 ppt range (Moyle 2002).

Longfin smelt are found in San Pablo Bay in April through June and disperse in late summer. In the fall and winter, yearlings move upstream into freshwater to spawn. Spawning occurs below Medford Island in the San Joaquin River and below Rio Vista on the Sacramento River, as early as November, and larval surveys indicate spawning may extend into June (Moyle 2002).

While the eggs are adhesive, embryos, which hatch in 40 days at 45°F (7.2ºC), are buoyant. They move into the upper part of the water column and are carried into the estuary. High outflows transport the larvae into Suisun and San Pablo Bays. In low-outflow years, larvae move into the western Delta and Suisun Bay. Higher outflows reflect positively in juvenile survival and adult abundance. Rearing habitat is better in Suisun and San Pablo bays because juveniles require brackish water in the 2 to 18 ppt range. If juveniles stay in the Delta, they become entrained and exposed to more adverse conditions (Moyle 2002). Seasonal occurrence of longfin smelt in CVP and SWP salvage is considered to be representative of the seasonal periods when juvenile and adult longfin smelt would be in the Delta.

Consistently, a measurable portion of the longfin smelt population survives into a second year. During the second year of life, they inhabit San Francisco Bay and, occasionally, the Gulf of the Farallones (Wang 1986). This explains their common identification as anadromous (SWRCB 1999). Because longfin smelt seldom occur in freshwater except to spawn, but are widely dispersed in brackish waters of the Bay, it is likely that their range formerly extended as far up into the Delta as saltwater intruded. The easternmost catch of longfin smelt in fall mid-water trawl samples has been at Medford Island in the Central Delta. The depth of habitat is a pronounced difference between the two species in their region of overlap in Suisun Bay; longfin smelt are caught in greater quantities at deep stations (more than 32 feet), whereas delta smelt are more abundant at shallow stations (less than 10 feet) (SWRCB 1999).

The main food of longfin smelt is the opossum shrimp (*Neomysis mercedi*s), although copepods and other crustaceans are important at times, especially to small fish. Longfin smelt, in turn, are eaten by a variety of predatory fishes, birds, and marine mammals (SWRCB 1999). Recent declines in the abundance of opossum shrimp and other zooplankton have been identified as a factor affecting the abundance of longfin smelt.

Longfin smelt were once one of the most common fish in the Delta. Their abundance has fluctuated widely in the past but, since 1982, abundance has declined significantly (Baxter 1996, The Bay Institute et al. 2007). The abundance of longfin smelt also has declined relative to other fishes, dropping from first or second in abundance in most trawl surveys during the 1960s and 1970s, to seventh or eighth in abundance. Abundance improved substantially in 1995 but was again relatively low in 1996 and 1997. Longfin abundance indices, although variable, were at very low levels in recent years (e.g., 2004 through 2006). The causes of decline are thought to be multiple and synergistic, including reduction in outflows, entrainment losses to water diversions, climatic variation, toxic substances, predation, and introduced species (SWRCB 1999). The longfin smelt is a Federal species of concern, but are being evaluated by USFWS again to see if they warrant listing. California listed longfin smelt as a threatened species in 2009.

Sacramento Splittail. In 1999, after 4 years of candidate status, the splittail was listed as threatened under the ESA (64 FR 25, March 10, 1999). Fall midwater trawl surveys indicate that juvenile splittail abundance has been highly variable from year to year, with peaks and declines coinciding with wet and dry periods, respectively, and correlated with the availability of flooded shallow water habitat. After the listing, the State Water Contractors, San Luis and Delta-Mendota Water Authority, and others challenged the listing, contending that it violated the ESA and the Administrative Procedures Act. On June 23, 2000, the U.S. District Court in Fresno ruled in favor of the plaintiffs and found the listing unlawful. On September 22, 2003, USFWS delisted splittail as a threatened species because habitat restoration actions such as CALFED and the CVPIA are likely to keep the splittail from becoming endangered in the foreseeable future (68 FR 55139, September 22, 2003). Splittail is identified as a species of special concern under CESA.

Splittail are found primarily in the Delta, Suisun Bay, Suisun Marsh, and Napa Marsh, but juveniles have been found in the Sacramento River as far upstream as its tributaries and the RBDD (Sommer et al. 1997). In recent years, splittail appear to have expanded their range because of improved environmental conditions, increased abundance, and increased efforts to detect their presence at the periphery of their known range (Baxter 1999). Sommer et al. (1997, 2002) found that the Yolo and Sutter Bypasses provide important spawning habitat for splittail. Some adults spend the summer in the mainstem Sacramento River rather than return to the estuary (Baxter 1999).

The Sacramento splittail, which has a high reproductive capacity, can live 5 to 7 years, and generally begins spawning at two years of age. Spawning, which seems to be triggered by increasing water temperatures and day length, occurs over beds of submerged vegetation in slow-moving stretches of water (such as flooded terrestrial areas and dead-end sloughs). Adults spawn from February through May in the Delta, upstream tributaries, Napa Marsh, Napa and Petaluma rivers, Suisun Bay and Marsh, and the Sutter and Yolo bypasses

(Baxter et al. 1996). Splittail prefer low water velocities for spawning and early rearing. However, some current is required to keep water temperature and clarity low, keep eggs free of silt, and facilitate suspension and attachment of eggs on vegetation (Jones & Stokes 2001). Adult splittail deposit adhesive eggs over flooded terrestrial or aquatic vegetation when water temperature is between 48 and 68°F (9°C to 20ºC) (Moyle 2002, Wang 1986). Spawning has been observed in depths ranging from 0.5 to 6 feet (Moyle et al. 2000). Splittail spawn in late April and May in Suisun Marsh and between early March and May in the upper Delta and lower reaches and flood bypasses of the Sacramento and San Joaquin Rivers (Moyle et al. 1995). Spawning has been observed to occur as early as January and may continue through early July (Wang 1986, Moyle 2002).

Larval splittail are commonly found in shallow, vegetated areas near spawning habitat. Larvae eventually move into deeper and more open water habitat as they grow and become juveniles. During late winter and spring, young-of-year juvenile splittail (i.e., production from spawning in the current year) are found in sloughs, rivers, and Delta channels near spawning habitat. Juvenile splittail gradually move from shallow, nearshore areas to the deeper, open water habitat of Suisun and San Pablo bays (Wang 1986). Young splittail may occur in shallow and open waters of the Delta and San Pablo Bay, but they are particularly abundant in the northern and western Delta (Sommer et al. 1997; SWRCB 1999). The seasonal occurrence of juvenile splittail in CVP and SWP fish salvage is representative of the periods when juvenile splittail inhabit the Delta. In areas upstream from the Delta, juvenile splittail can be expected to be present in the flood bypasses when these areas are inundated during the winter and spring (Jones & Stokes Associates 1993, Sommer et al. 1997).

Although the Sacramento splittail is generally considered a freshwater species, the adults and subadults have an unusually high tolerance for saline waters (up to 10 to 18 ppt) for a member of the minnow family (Young and Cech 1996). The salt tolerance of splittail larvae is unknown, but they have been observed in water with salinities of 10 to 18 ppt (SWRCB 1999).

Splittail are bottom foragers that feed extensively on opossum shrimp and opportunistically on earthworms, clams, insect larvae, and other invertebrates. They are preyed on by striped bass and other predatory fish in the estuary. In the past, anglers commonly used splittail as bait when fishing for striped bass (SWRCB 1999).

Hardhead Hardhead are widely distributed throughout the low- to mid-elevation streams in the main Sacramento-San Joaquin drainage as well as in the Russian River drainage. Undisturbed portions of larger streams at low to middle elevations are preferred by hardhead. They are able to withstand summer water temperatures above 68°F (20ºC); however, hardhead will select lower temperatures when they are available. They are fairly intolerant of low-oxygenated waters, particularly at higher water temperatures. Pools with sand-gravel substrates and slow water velocities are the preferred habitat; adult fish inhabit the lower half of the water column, while the juvenile fish remain in shallow water closer to the stream edges. Hardhead tend not to do well in areas where introduced centrarchid fish (sunfish and bass) are abundant. Hardhead typically feed on small invertebrates and aquatic plants at the bottom of quiet water (Moyle 2002). Hardhead is a State species of special concern and a Forest Service designated sensitive species.

Striped Bass Striped bass are anadromous fish that have been an important part of the sport fishing industry in the Delta. They were introduced into the Sacramento-San Joaquin estuary between 1879 and 1882 (Moyle 2002). Striped bass will not use fish ladders; therefore, their range in the Sacramento River is limited to the reach of the river below the RBDD. Striped bass may move into the lower reaches of the rivers year-round but probably most often between April and June, when they spawn. The species tends to remain in deep, slow-moving water, where it has access to prey without having to expend a great deal of energy.

Other Important Native Fish Species Present in Study Area

Upper Klamath-Trinity Chinook Salmon Upper Klamath-Trinity (UKT) Chinook salmon are found in the Trinity River within the extended study area (see biological requirements described above for Chinook salmon).

Klamath Mountain Province Steelhead Klamath Mountain Province (KMP) steelhead are found in the Trinity River within the extended study area and have similar biological requirements (see biological requirements described above for steelhead).

California Roach California roach are distributed throughout the State; however, a specific subspecies is found in the Sacramento River drainage (excluding the Pit River), including tributaries to the Bay. California roach occupy small, warm streams with intermittent flow in mid-elevation foothills. Dense populations often occur in isolated pools. They are tolerant of high temperatures (86°F to 95°F (30ºC to 35ºC)) and low oxygen levels, although they also can be found in cold, well-oxygenated systems; human-modified habitats; and the main channels of larger rivers.

The California roach composes multiple subspecies, all of which are included as Federal Species of Concern, and all but one subspecies of which is identified by California as a Species of special concern.

White Sturgeon The white sturgeon, the largest freshwater or anadromous fish species in North America, can reach record sizes over 1,300 pounds. Historically, white sturgeon populations ranged from Alaska to central California (Scott and Crossman 1973); however, major spawning populations are now limited to the Fraser River (British Columbia, Canada), the Columbia River (Washington), and the Sacramento-San Joaquin River system.

Habitat use varies among populations. Portions of populations are considered anadromous, using fresh, brackish, and marine waters during different phases of their life history. White sturgeon are long-lived fish and can live as long as 100 years; however, fish that old are seldom found.

Upstream spawning migrations of white sturgeon in the Sacramento-San Joaquin river system occur between February and May (Miller 1972a, Kohlhorst 1976, Kohlhorst et al. 1991). Only a portion of the total adult sturgeon population migrates upstream from the Delta each year. Sturgeon that do move upstream are believed to be mature and ready to spawn. Kohlhorst et al. (1991) found that the mean size of tagged white sturgeon recaptured upriver was significantly greater (57 inches) than the mean size of all fish tagged (49 inches).

Based on the recoveries of tagged adult sturgeon between 1974 and 1988, and collection of sturgeon eggs, larvae, and juveniles, most white sturgeon migrating up the Sacramento River congregate and spawn between Knights Landing and a point just above Colusa; however, juvenile sturgeon have been found by USFWS as far as the RBDD.

The environmental cues that initiate upstream migration are not well understood. Mature fish could be stimulated to migrate upstream by cues triggering the final stages of gonadal development – such factors as flow, velocity, photoperiod (i.e., the number of daylight hours best suited to the growth and maturation of an organism), or temperature (Pacific States Marine Fisheries Commission 1992).

White sturgeon spawn in the Sacramento River between mid-February and late May, with a peak in spawning (93 percent) occurring between March and April (Kohlhorst 1976). Not all adults migrate upstream to spawn each year. Sexual cycles in sturgeon are complex because these fish mature at a late age and adults do not spawn every year. It is likely that only mature sturgeon migrate upriver to spawn and that most immature fish or fish in resting stages remain in the estuary. Few observations of wild sturgeon spawning have been reported. Apparently, sturgeon broadcast spawn in swift water. The current initially disperses the adhesive eggs, which sink and adhere to gravel and rock on the bottom. The adhesive properties of the eggs are adaptive to spawning and retention of eggs within swift current environments. Sediments can reduce this adhesiveness of eggs (Conte et al. 1988). Optimum temperatures for incubation and hatching range from 52ºF to 63ºF (11.7ºC to 17.2ºC); higher temperatures result in greater mortality and premature hatching (Wang et al. 1985, 1987).

Laboratory studies indicate that larval sturgeon demonstrate three behavioral phases after emergence: swim-up and dispersal, hiding, and feeding (Brannon et al. 1986, Brewer 1987, Duke et al. 1990, Miller et al. 1991). After hatching, yolk sac larvae swim up into the water column. The currents act as a dispersal mechanism, transporting larvae downstream from the spawning area. Larvae swim toward or to the surface, then passively sink to the bottom (Brewer 1987). Either immediately or shortly after touching bottom, the larvae repeat the swimming activity.

When larvae enter the hiding phase, they are still nourished from the yolk sac. To hide, larvae place their heads within substrates (either rock or vegetation) and maintain a constant tail beat to retain their position. Substrate preference of hiding larvae is related to the degree of darkness the substrate provides, a negative phototaxic (i.e., movement away from light) response. This hiding behavior is thought to provide protection from predation as the larvae develop (Brewer 1987).

Larvae develop the mouth and olfactory morphology needed for feeding before the yolk sac is completely absorbed. Although larvae do not appear to forage actively in the hiding phase, they are capable of consuming exogenous food during the later stages of the hiding phase if it is present at the hiding site (Brewer 1987). Exogenous feeding occurs approximately 12 days after hatching at temperatures of 63ºF (17.2ºC) (Buddington and Doroshov 1984). During this phase, the larvae move out of hiding to forage actively for food. Young sturgeon appear to be opportunistic, nonvisual feeders (Miller 1987). The senses of smell and touch appear to be more important than vision for locating prey. Larvae are territorial during this phase (Brannon et al. 1984).

The diet of sturgeon changes as the fish become larger. Young-of-year sturgeon (less than 8 inches long) feed on a number of prey, including small crustaceans and insect larvae, and can potentially consume small fish fry. As the fish grow, the diet becomes more diverse and includes several benthic invertebrates and seasonally abundant food items, such as fish eggs or fry. McKechnie and Fenner (1971) found that adult sturgeon caught in San Pablo and Suisun bays feed primarily on benthic invertebrates, including clams, barnacles, crab, and shrimp. Seasonally, herring eggs and small fish, such as striped bass, flounder, goby, and herring, are important prey items.

Adult and subadult sturgeon inhabit estuarine areas year-round. Adult sturgeon are found in Suisun, San Pablo, and San Francisco bays and in the Delta (Miller 1972b, Shirley 1987, Kohlhorst et al. 1991). Distribution in the Delta is thought to depend primarily on river flow and consequent salinity regimes. The center of the population is upriver during low-flow years and downriver during high-flow years.

Sacramento Sucker The Sacramento sucker is widely distributed throughout the Sacramento River system. Sacramento sucker occupy waters from cold, high-velocity streams to warm, nearly stagnant sloughs. They are common at moderate elevations (600 to 2,000 feet). Sacramento sucker feed on algae, detritus, and benthic invertebrates. They usually spawn for the first time in their fourth or fifth years. When they cannot move upstream, and instead spawn in lake habitat, they typically orient themselves near areas where spring freshets flow into the lake. They typically spawn in stream habitat on gravel riffles from late February to early June. The eggs hatch in 3 to 4 weeks, and the young typically live in the natal stream for a couple of years before moving downstream to a reservoir or large river (Moyle 2002).

Sacramento Pikeminnow Sacramento pikeminnow occupy rivers and streams throughout the Sacramento-San Joaquin river system, mainly at elevations between 300 and 2,000 feet. Sacramento pikeminnow spawn in April and May, with eggs hatching in less than a week. Within a week of hatching, the fry are free-swimming and schooling. Adult pikeminnow may feed on other fish, including juvenile pikeminnow, Chinook salmon, and steelhead, but, according to Moyle (2002), are overrated as predators on salmonid species in natural environments. They can, however, be major predators on juvenile salmon and steelhead in riverine environments modified by dams and fish ladders. Pikeminnow tend to remain in well-shaded, deep pools with sand or rock substrate and are less likely to be found in areas where there are higher numbers of introduced predator species, such as largemouth bass and other centrarchid species.

Pacific Lamprey Similar to Chinook salmon and steelhead, lamprey adults migrate upstream from the ocean during the winter and spring to spawn (Moyle 2002). Spawning occurs over gravel substrates. Larval lamprey rear in sand and mud substrates, gradually moving downstream over the rearing period. Little is known about water quality requirements and other habitat needs.

Important Nonnative Fish Species Present in Study Area

American Shad American shad are an anadromous fish that have been introduced into the Central Valley and have become established as a popular sport fish. American shad are present in the Sacramento River up to Red Bluff and in the lower reaches of the American and Feather rivers. American shad use the San Francisco Estuary after migrating from the ocean in the fall. They move into freshwater where they spawn from March to May. In the Sacramento River basin, the main summer rearing areas are the lower Feather River, the Sacramento River from Colusa to the north Delta and, to some extent, the south Delta. Juvenile shad move to the ocean from September to November, although juvenile migration under high outflow conditions may begin in June.

Catfishes Four species in the catfish family are found in the study area – channel catfish, white catfish, black bullhead and brown bullhead. All were introduced into California. Channel catfish were established in the Sacramento-

San Joaquin system in the 1940s. White catfish were brought into California in a small introduction to the San Joaquin River near Stockton in 1874. The earliest confirmed record of black bullhead in California was 1942. Brown bullhead were also among the earliest (1874) successful transplants to California.

Channel catfish are typically found in main channels of large rivers and streams, but inhabit a wide variety of water bodies, including farm ponds; reservoirs; turbid, muddy-bottom rivers; and large streams with ample riffle habitat. They can tolerate low oxygen levels (1 to 2 parts per million) and high water temperatures (97°F to 100°F (36ºC to 37.8ºC)). They tend to feed on detritus and plant material, but will ingest invertebrates and fish as well. These rapidly growing fish spawn anywhere from 2 to 8 years old, from April to June. They prefer cave-like sites for their spawning nests, such as undercut banks or log jams. Water temperatures between 70 and 84°F (21 and 28.9ºC) are suitable for spawning. Eggs hatch in 6 to 10 days, and the young are actively swimming within 2 days of hatching (Moyle 2002, Wang 1986).

White catfish occupy slow-current habitat, avoiding areas with heavy beds of aquatic plants, or water less than 7 feet deep. They are often found in warm-water lakes, reservoirs, and farm ponds. Water temperatures must exceed 68°F in the summer and, if the lake they occupy stratifies, they will move to the level where the water temperatures exceed 70°F (21ºC). White catfish are carnivorous bottom feeders, feeding primarily on smaller fish such as threadfin shad and silverside, and invertebrates and carrion. Spawning occurs from June to July, and eggs hatch about a week after spawning (Moyle 2002).

Black bullhead prefer ponds, small lake, river backwaters, and small stream pools with warm and turbid water, muddy bottoms, slow currents, and few other fish species. They are capable of surviving water temperatures up to 98°F (35°C) and salinities up to 13 ppt (Moyle 2002). Most foraging occurs at night, feeding mostly on aquatic insects, crustaceans, mollusks, and both live and dead fish. Spawning takes place after water temperatures exceed 68°F (20°C), during June and July, in a mud nest excavated by the female (Moyle 2002).

Brown bullhead are common throughout California, adapting to a large variety of water body types. They prefer water 7 to 16 feet deep with aquatic vegetation and sandy, muddy bottoms. They can survive a wide range of water temperatures (from 32°F to 99°F (0ºC to 37.2 ºC)), although they prefer water temperatures between 68°F and 95°F (20ºC and 35ºC). Brown bullhead feed on invertebrates, crustaceans, and fish, including silversides. Brown bullhead spawn for the first time during their third year, in May and June (Moyle 2002).

Sunfish Sunfish are a popular game fish in California, and almost every species has been introduced into California since the late 1800s. Typically, these fish prefer warm ponds and lakes, or slow moving streams, but can be found in the Sacramento River, including bluegill and green sunfish. A common trait among sunfish is the building of nests and the subsequent defending of the nest by the male of the species.

Bluegill are one of the most abundant fish in California. They prefer warm, shallow lakes, reservoirs, ponds, and sloughs at low altitudes. They can survive in waters with high turbidity and low oxygen levels. They are typically found around rooted aquatic vegetation, where they hide and feed. Substrate is typically silt, sand, or gravel, and they typically do not go deeper than 16 feet. Bluegill feed on whatever is most abundant, including aquatic insect larvae, planktonic crustaceans, terrestrial insects, snails, small fish, fish eggs, and even crayfish. Spawning occurs in the spring when water temperatures reach 64°F to 70°F (17.8°C to 21ºC), and will continue through the summer. Eggs hatch within 2 to 3 days (Moyle 2002).

Green sunfish are aggressive, stout-bodied fish with large mouths that occupy small, warm intermittent streams, ponds, and lake edges. In lake conditions, they stay in shallow weedy areas, where there are few other species. Green sunfish are territorial and opportunistic predators, feeding on more active invertebrates and on small fish, including mosquitofish and other smaller sunfish. They begin spawning in their third year, and the spawning season is from May and June, but sometimes continues until August. Eggs hatch in 5 to 7 days, and the young are soon after free-swimming individuals (Moyle 2002.)

Black Bass Black bass, also in the sunfish family, is a generic name for several bass species, including largemouth and smallmouth bass. Both largemouth and smallmouth bass were introduced into California in 1874; they are some of the most valuable game fish in the state.

Largemouth bass are typically found in warm, quiet water with low turbidity, such as ponds, lakes, sloughs and river backwaters that contain beds of aquatic plants. Optimal growth occurs when water temperatures are between 68°F and 86°F. They typically occupy habitats 3 to 10 feet deep often near the edge of the water. Largemouth bass will feed on nearly everything around them, including crustaceans, frogs, and other fishes. Adults spawn after their second or third year, with the spawning season beginning when water temperatures reach 57°F to 61°F (13.9°C to 16ºC), typically in April, and continuing until June. Males guard the nests. Eggs hatch within 2 to 5 days, and the sac fry remain near the nest for another 5 to 8 days (Moyle 2002).

Smallmouth bass prefer clearer, cooler water than largemouth bass, but can still be found in the same habitat as largemouth bass. Preferred summer water temperatures are from 68°F to 81°F (20°C to 27.2ºC). The dominant food for these fish is crustaceans, aquatic insects, fish, and amphibians. They spawn after 3 or 4 years, in late spring when water temperatures reach 55°F to 61°F (12.8°C to 16.1ºC). As with largemouth bass, males guard the nests. Eggs hatch in 3 to 10 days, and the young remain near the nest for another 3 to 4 days.

1.1.3 Aquatic Macroinvertebrates

Aquatic macroinvertebrates provide an important food base for many fish and wildlife species. In general, published information on the taxonomy, distribution, and abundance of macroinvertebrates in the Sacramento River drainage is limited. Current macroinvertebrate monitoring efforts on the Sacramento River have focused on large-basin scale patterns, and survey sites on the mainstem have been at various locations along the study reach. Under the Sacramento River Watershed program, DFG collected snag samples at two sites, one site near Colusa and one site near Hamilton City. Dominant taxa found in fall 1999 at the Hamilton City site include Orthocladiinae, Naididae, Ephemeroptera (*Baetis* and *Acentrella* sp.) and Trichoptera (*Hydropsyche* sp.) (Sacramento River Watershed Program 2002). Schaffter et al. (1983) found no significant difference in abundance of drifting invertebrates near riprapped and natural habitats on the Sacramento River. More than 50 percent of the drift was composed of chironomids, baetids, and aphids. Analysis of fish diets found the same three families in 72 percent of the guts sampled.

A large-scale monitoring effort in 2001 coordinated by DWR from Keswick Dam to Verona on the Sacramento River found that benthic macroinvertebrate diversity and richness decreased as the river moved downstream. Oligochaetes, chironomids, and mollusks became more prominent in this reach than in the reach from Keswick Dam to Red Bluff (Sacramento River Watershed Program 2002). More recently, the diurnal feeding habits of juvenile Chinook salmon in the upper Sacramento River (river mile (RM) 193 to RM 275) were examined in relation to drifting invertebrates by Petrusso and Hayes (2001). Chironomids and baetids dominated both the drift and stomach contents. Diets of 153 juvenile salmonids were examined; more than 63 percent of the diet was made up of chironomids of all life stages. Baetids comprised 14 percent of the total diet. It was concluded that based on measurements of mean stomach fullness and availability of drifting organisms, there was reasonable feeding opportunity during the sampling period in spring 1996. Mean drift densities ranged from 211 to 2,100 organisms per 100 cubic meters, with an overall mean of 617 organisms per 100 cubic meter (Petrusso and Hayes 2001). Daily mean drift density appeared to show no spatial patterns across the several sites sampled.

The constant flow of water in river systems provides an energetically convenient and economical way to disperse to new habitats; this movement downstream is known as drift. Some invertebrates passively enter the drift (e.g., benthic organisms may be entrained in the water column when a large current sweeps through), and others exhibit active drift behavior (individuals actively enter the water column by voluntary actions) (Waters 1965, 1972; Müller 1974; Wiley and Kohler 1984). Macroinvertebrates drift to colonize new habitats (for dispersal of various life stages or to find suitable resources), or leave unsuitable habitats (in response to habitat quality or predation pressure). Drift is one of the most important downstream dispersal mechanisms for macroinvertebrates. Macroinvertebrates drift more commonly in the evening, usually at dusk (Waters 1972, Müller 1974, Wiley and Kohler 1984, Smock 1996).

Drifting invertebrates are the primary source of prey for juvenile fish, including salmonids (Chapman and Bjornn 1969). Juvenile Chinook salmon will often seek refuge in slow-velocity habitats where they can rest and drifting invertebrates will tend to be deposited.

New Zealand Mudsnail The New Zealand mudsnail (*Potamopyrgus antipodarum*), known to have been introduced to North America since about 1987 (Bowler 1991), was identified in Shasta Lake at the Bridge Bay Marina on September 10, 2007 (USGS NAS 2007). New Zealand mudsnail have also been found lower in the Central Valley, including Sacramento River near Red Bluff, and the American, Mokelumne and Calaveras rivers (Benson 2011). This invasive aquatic mollusk is known from a number of other locations within California and can reach densities of over 500,000 snails per square meter. Densities can fluctuate seasonally, with lowest densities coinciding with the freezing winter months (Proctor et al. 2007). New Zealand mudsnails are highly effective competitors and predators of many native North American benthic macroinvertebrates, including other mollusks, crustaceans, and important aquatic insects. Predators of the New Zealand mudsnail include rainbow trout, brown trout, sculpins, and mountain whitefish (Proctor et al. 2007). Unfortunately, snails are capable of passing through the digestive system of fish alive and intact (Bondesen and Kaiser 1949; Haynes et al.1985).

Possible pathways of introduction into Shasta Lake include contaminated recreational watercraft and trailers and recreational water users (Proctor et al. 2007). Other vectors known to spread the snails, such as contaminated livestock, commercial ships, and dredging/mining equipment, are less likely in the case of Shasta Lake's recent invasion given the lack of commercial activities on the lake. If the particular clone detected in Shasta Lake is tolerant of the local conditions, a rapid colonization of the lake and its tributaries could occur through a variety of vectors.

The potential involvement of recreational watercraft and trailers and recreational water users in the translocation of New Zealand mudsnails between State waters is of immediate concern. Enlargement of Shasta Lake could provide a larger perimeter of shoreline accessibility for the snail, but not necessarily increase preferred lake habitats. In lakes in North America, New Zealand mudsnails do not commonly occupy shoreline habitats. Highest densities of New Zealand mudsnails occur between 20 to 25 meters in Lake Ontario (Proctor et al. 2007).

Quagga Mussel Quagga mussels (*Dressenia bugensis*), an invasive European aquatic mollusk introduced to North America in ship ballast water and first discovered in Lake Erie in 1989 (Spidle et al. 1994), have not been found in Shasta Lake, to date, but were discovered in California at Lake Havasu in 2007 (Cohen 2007). DFG has begun monitoring at Lake Shasta for adult mussels and veligers (S. Baumgartner, pers. comm., 2008). Possible pathways of introduction into Shasta Lake include contaminated recreational watercraft and trailers and recreational water users. The potential involvement of recreational watercraft and trailers and recreational water users in the translocation of quagga mussels between State waters is of immediate concern. Enlargement of Shasta Lake could provide a greater area of deepwater and littoral habitat available for occupation by quagga mussels.

In a 2007 report produced for DFG, Cohen (2007) described the temperature, calcium, pH, DO, and salinity tolerances of quagga mussels in an effort to assess the vulnerability of various California waters to invasion by quagga mussels and zebra mussels. Cohen identified calcium thresholds as the most important environmental factor influencing distribution of zebra mussels in North America and applied similar thresholds for quagga mussels. In an investigation of the upper Sacramento River region, including Whiskeytown Reservoir and the watersheds above Shasta Dam, Cohen found that the McCloud River above Shasta Reservoir and the Pit River near Canby have the proper range of salinity, DO, temperature and calcium (at less than or equal to 12 milligrams per liter (mg/L) to be of low and moderate suitability to invasion by quagga mussels.

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Chapter 2
Impact Assessment

As described in the Environmental Impact Statement (EIS) Chapter 11, the SALMOD was used to support technical analysis. Detailed modeling results are presented in Attachments 1 through 12 in this Technical Report. As well, additional information on the fisheries, hydrology and evaluation results for Delta fisheries are presented in Attachment 13. These Attachment names are:

Attachment 1: Winter-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Future Conditions

Attachment 2: Winter-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Existing Conditions

Attachment 3: Winter-Run Chinook Salmon Production and Mortality from SALMOD AFRP Simulations Under Future Conditions

Attachment 4 Spring-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Future Conditions

Attachment 5: Spring-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Existing Conditions

Attachment 6: Spring-Run Chinook Salmon Production and Mortality from SALMOD AFRP Simulations Under Future Conditions

Attachment 7: Fall-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Future Conditions

Attachment 8: Fall-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Existing Conditions

Attachment 9: Fall-Run Chinook Salmon Production and Mortality from SALMOD AFRP Simulations Under Future Conditions

Attachment 10: Late Fall-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Future Conditions

Attachment 11: Late Fall-Run Chinook Salmon Production and Mortality from SALMOD 1999–2006 Average Simulations Under Existing Conditions

Attachment 12: Late Fall-Run Chinook Salmon Production and Mortality from SALMOD AFRP Simulations Under Future Conditions

Attachment 13 Assessment of Fisheries Impacts Within Sacramento-San Joaquin Delta

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