EDF Exhibit 1

A Focal Species and Ecosystem Functions Approach for Developing Public Trust Flows in the Sacramento and San Joaquin River Delta

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February 2010

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Cover Photo: Charlie Nguyen

Suggested citation:
Stillwater Sciences. 2010. A Focal Species and Ecosystem Functions Approach for Developing Public Trust Flows for the Sacramento and San Joaquin River Delta. Prepared for Environmental Defense Fund, San Francisco, California by Stillwater Sciences, Berkeley, California. February.

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1 INTRODUCTION

The Sacramento-San Joaquin Delta Reform Act of 2009 directs the State Water Resources Control Board (SWRCB or Board) to develop public trust flow criteria for the San Francisco Bay-Delta Estuary. Various regulatory regimes establish overlapping environmental protection mandates for the Estuary including but not limited to endangered species statutes, clean water statutes, and laws requiring the "doubling" of anadromous fisheries. However, no single regime has required the Board or other public agency to take a comprehensive look at the Estuary as a whole to determine the flows needed to ensure the Bay-Delta ecosystem's long-term ecological health and stability. To address information needs outlined in the Act, this report provides a brief overview of the state of the science and then develops a functional approach to flows addressing habitat needs for a suite of selected focal species intended to represent the broader Sacramento-San Joaquin River delta ecosystem.

It should be noted that time constraints limited the number of focal species we could examine, thus this report is intended to support, but by itself does not constitute, a complete public trust flow assessment. Nevertheless, there are considerable scientific data and evidence supporting the need for substantially higher freshwater flows than have been made available to the delta and greater San Francisco Bay-Delta Estuary over the last few decades. Although much of the relevant data and literature regarding biological resources in the delta has been developed within the context of current water export operations, we have attempted to identify the flows necessary for maintaining ecosystem functions in an idealized setting (i.e., in the absence of water exports from the delta). As a companion to this document, the Bay Institute of San Francisco (TBI) has independently developed a set of flow recommendations based on maintaining the viability[1] of species using the San Francisco Bay-Delta Estuary that include flows necessary to mitigate a number of direct effects of diversion (e.g., fish entrainment in the export pumping facilities) as well as indirect effects (e.g., altered hydrodynamics and water quality in the interior of the delta). Rosenfeld and Swanson (2010) make use of existing regression analyses between delta outflow, abundance, productivity of representative species, In addition, they examine the effects of flow upon the habitat distribution of key life-history stages of these species as well as the provision of genetic and age-class diversity.

This paper supplements the broader approach addressed by TBI (Rosenfeld and Swanson 2010) by examining physical habitat requirements of key life stages of focal species inhabiting the delta using a review of the primary literature as well as the numerous ecosystem restoration analyses that have been conducted by public agencies over the last two decades. We have reviewed the primary materials below in developing recommended flow criteria:

1. Biological opinion on the effects of the long-term operations of the Central Valley Project and State Water Project on Chinook salmon (NMFS 2009a)
2. Recovery plan for Chinook salmon and Central Valley steelhead (NMFS 2009b)
3. Biological opinion on the effects of the proposed coordinated operations of the Central Valley Project and State Water Project on delta smelt (USFWS 2009)

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[1] In recent endangered species consultations by the National Marine Fisheries Service, an independent population that has a negligible probability of extinction over a 100-year time frame is considered "viable" using four key demographic parameters: 1) abundance, 2) productivity (i.e., population growth rate), 3) population spatial structure, and 4) diversity (McElhany et al. 2000).

4. Anadromous Fish Restoration Program working paper (USFWS 1995)
5. Final restoration plan for the Anadromous Fish Restoration Program (USFWS 2001)
6. CALFED (2000) EIS/EIR and supporting Ecosystem Restoration Program Plan
7. Water Right Decision 1630 - Establishing terms And conditions for interim protection of public trust uses of the San Francisco Bay/Sacramento-San Joaquin Delta Estuary (SWRCB 1993)

The flow assessment below addresses ecological needs and make use of these and many other relevant sources in an aim to identify the “volume, quality, and timing of water necessary for the Delta ecosystem under different conditions” as required under the Delta Reform Act. After a brief overview of the historical and current physical setting of the delta, as well as relevant recent research, we develop flow objectives using a focal species approach to represent broader linkages to their supporting ecosystem.

1.1 Geographic Setting

The San Francisco Bay estuary and Sacramento and San Joaquin River delta comprise the largest estuary on the west coast of North America, stretching from the San Francisco Bay to the west slope of the Sierra Nevada Range. Small streams drain rocky and unforested uplands, grasslands, and forests in the Sierra Nevada and run through the foothills to the Central Valley. Of the 3,600 mi^2 (9,324 km^2) of wetland and riparian habitat in the Central Valley that existed prior to European settlement, about 2,400 mi^2 (6,216 km^2) of the lowland floodplain was dominated by freshwater tule (*Scirpus* spp.) (Hall 1887), whereas about 1,200 mi^2 9,324 km^2) of riparian forest flanked the Sacramento and tributary rivers in the Central Valley within the 100-year floodplain (Katibah 1984). The “legally defined delta” is defined in Section 12220 of the California Water Code (CWC) and includes land and water bounded by the Cities of Sacramento to the north, Tracy to the south, Stockton to the East, and Pittsburg to the west. For the purposes of this report, the “Delta” extends westward from the legally defined delta to Suisun Bay and the Carquinez Strait (Figure 1).

The channels of the Delta were first surveyed by the U.S. Navy in the 1840s. These surveys opened up the Delta and communities along the mainstem channels to interact and trade with communities surrounding the San Francisco Bay. As travel to the area became easier and less expensive, communities in the Delta and northern California began to establish rapidly. In the late 1850s, the Swamp Land Act transferred ownership of swamp and overflow land from the federal government to the State. Proceeds from the State’s sale of these swamplands were to go toward reclaiming them and a Board of Swamp and Overflowed Land Commissioners was created in 1861 to manage reclamation projects. Small-scale reclamation projects began was early as 1870, although developers quickly learned that the natural peat soils were inadequate levee material and that manual labor could not maintain the reclaimed Delta islands. Steam-powered dredges were used to move large volumes of alluvial soils to construct the large levees seen today, isolating nursery areas for aquatic and bird species from tidal exchanges. Most of the Delta wetlands had been “reclaimed” by the 1920s, with some 30 islands currently managed for intensive agriculture and urban development.

Today, the Delta encompasses about 60,000 acres (25,900 ha) of water surface exclusive of Suisun Bay, 520,000 acres (210,400 ha) of agricultural lands, 64,000 acres (26,000 ha) of towns and cities, and 75,000 acres (30,300 ha) of undeveloped areas. Much of the rich Delta farmland has lost soil from oxidation, compaction, and wind erosion, resulting in lowered elevations of some islands up to 25 feet below sea level (CDWR 1993). The Delta is interlaced with hundreds of miles of waterways, and relies on more than 1,000 miles (1,600 km) of levees for protection against flooding (Kahrl 1979, Moore and Shlemon 2008). These levees have largely eliminated access to tidal exchanges with marsh habitats used as nursery areas for Delta fishes (Kimmerer et al 2008), while completion of large dams on the major rivers of the Central Valley (Table 1-1) has led to other ecological effects, including altering flow regimes and water clarity.

Table 1-1. Major dams on rivers draining into the Delta.

River	Dam	Year completed	Reservoir Maximum capacity (million acre-feet)	Operating agency[1]
American	Folsom	1956	0.98	USBR
Clear Creek	Trinity	1962	2.4	USBR
Feather	Oroville	1968	3.5	CDWR
N. Fork Feather	Lake Almanor	1927	1.3	PG&E
Kings River	Pine Flat	1954	1.0	USACE
Merced	New Exchequer	1967	1.0	MID
Mokelumne	Pardee	1929	0.2	EBMUD
Sacramento	Shasta	1945	4.5	USBR
Stanislaus	New Melones	1979	2.4	USBR
Tuolumne	New Don Pedro	1971	2.0	TID/MID
Yuba	Bullards Bar	1971	0.97	YCWA

[1] **USBR**-United States Bureau of Reclamation; **CDWR**-California Department of Water Resources; **PG&E**-Pacific Gas and Electric; **USACE**-United States Army Corps of Engineers; **MID**-Modesto Irrigation District; **EBMUD**-East Bay Municipal Utilities District,: **TID**-Turlock Irrigation District; **YCWA**-Yuba County Water Agency

1.2 Delta Water Budget

Annual inflow to the Delta comes from the Sacramento River (76%), San Joaquin River (15%), eastside tributaries, including the Mokelumne and Cosumnes rivers (5%), and to a lesser degree direct precipitation (4%) (Kahrl 1979). Precipitation varies seasonally, and the region is characterized by dry summers and wet winters; however, there is high annual variation overall. Tidal and variations in Delta inflows bring salt water to the Delta from the greater San Francisco Bay to the west. The transition zone between fresh and salt water is generally located near Chipps Island, but can move out into the Bay during floods and deep into the Delta during droughts (CDWR 1993) as well as due to exports from the Delta (Monsen et al 2007). For example, on average in recent years, 44% percent of all flows that would have naturally passed through the Delta are diverted (based on data from 1995–2005 shown in Table 6.1 in Lund et al. 2007).

Figures 2 through 4 show the historical inflows (WY 1956–2003)[2] from the Sacramento River basin, the San Joaquin River basin and eastside tributaries, and net Delta outflow to San Francisco bay using data summarized by CDWR (2007). The differences in area of these curves accounts for the annual volumes of water exported from the Delta at the North Bay Aqueduct, the Contra Costa Water District South Bay Aqueduct, the Central Valley Project (CVP) federal pumps at Tracy (Jones Pumping Plant), and the State Water Plan (SWP) pumps at Tracy (Banks Pumping Plant). Although average annual precipitation has declined slightly over the past decades, Lund et al. (2007) report that CVP and SWP water exports from the San Joaquin and Sacramento Rivers and their tributaries have increased dramatically, from 0.7 MAF in WY 1956 to a record high of 6.5 MAF in 2006. As would be expected, the proportion of Delta exports to

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[2] Note that although actual flow data have been compiled through WY 2009, unimpaired flow estimates have been calculated and published only through WY 2003 (DWR 2007)

Delta inflows have also increased, ranging from as low as 1.5% of Delta inflow in WY 1956 to 53% of Delta inflow in 1990 (http://www.iep.ca.gov/dayflow/index.html). The increases in Delta exports in recent decades are discussed further in Section 1.6.5, as a causative factor in the Pelagic Organism Decline (POD) in the Delta.

Below we summarize major inflows to the Delta, Delta exports to the CVP and SWP, agricultural diversions within the Delta, and the influence of daily tidal exchanges with San Francisco Bay.

1.2.1 River inflow

The rivers and their tributaries that empty into the Delta drain over 40% of California. The Sacramento River drains the northern Central Valley; its major tributaries are the American, Yuba, and Feather rivers. The San Joaquin River drains much of the southern portion of the Central Valley; its major tributaries are the Merced, Tuolumne, and Stanislaus rivers. The principal east-side tributaries to the Delta are the Mokelumne, Cosumnes, and Calaveras rivers. The majority of the water in these rivers is derived from the Sierra Nevada Range, where precipitation (both rain and snow) is much greater than in the Central Valley (where average precipitation is on the order of 10–12 inches per year).

All of the major rivers and tributaries that supply water to the Delta are dammed for flood control, water storage, and diversion (Table 1-1). Prior to the construction of large storage dams, flow arrived as large pulses during winter storms or spring snowmelt events. Damming has altered the natural hydrograph; regulation and diversion decrease peak flows in the winter and spring, while irrigation requires a predictable summer water supply that is above low flows that would naturally occur at this time.

1.2.2 Delta exports

Although water is diverted from the Delta in a variety of methods and locations, for the purposes of this report, Delta exports principally refer to CVP and SWP operations and diversions. A network of upstream and downstream storage reservoirs and aqueducts allow for water from the Delta to be delivered from federal and state pumping plants at Tracy to various parts of the state. Water to be exported from the Delta generally originates from rainfall runoff, flood control at upstream reservoirs, or planned release from upstream reservoirs. Depending on time of year, water takes approximately seven days to reach the Delta from the Shasta Dam on the Sacramento River, three days from the Oroville Dam on the Feather River, and as little as one to two days from the Folsom Dam on the American River. Some Delta exports are delivered to satisfy immediate water supply demands, while some exports are pumped to San Luis Reservoir near Los Banos for storage. San Luis Reservoir has a storage capacity of 2 million acre feet, and is used by both facilities.

The CVP pumping plant at Tracy has a maximum capacity of 4,600 cfs, although the Delta-Mendota Canal leading from the pumps is often limited to 4,200 cfs. The Clifton Court forebay provides a temporary storage pool for the Tracy Pumping Plant, minimizing the operating inefficiencies resulting from tidal fluctuations and local draw-down by the pumps. The forebay has a capacity of approximately 32,000 acre-feet and opens to the Delta in the southeastern corner. Water is withdrawn through a 0.8 mi (1.3 km) channel paralleling the western edge of the forebay. Water from the CVP is sent south through the 500 mi (800 km) California Aqueduct for agriculture use in the San Joaquin basin. The SWP pumping plant has a capacity of 10,300 cfs, but under present operational constraints is generally limited to 6,680 cfs. The SWP supplies water to the South Bay Aqueduct and the California Aqueduct for water deliveries south of the Delta, for mostly domestic use.

During periods of high pumping rates relative to Delta inflows, the export facilities draw Sacramento River water into the central and southern Delta via the Delta Cross Channel (constructed as part of the CVP), a natural connection through Georgiana Slough, and other interior Delta channels. During high demand, Sacramento River water also flows through Three-Mile Slough and the western end of Sherman Island, and up the San Joaquin River toward the pumps (Arthur et al. 1996).

1.2.3 Agricultural diversions

In addition at the large export facilities, water is removed from Delta channels by approximately 2,500 pumps, siphons, and floodgates to irrigate agricultural lands surrounding and within the Delta. Because the elevation of island land surfaces is below the channel surface elevation, approximately half of the diversions are siphons (with the remainder divided evenly between pumps and floodgates) and most of the return drains require pumping over levees into channels.

Although precise measures of agricultural diversions are unavailable, current estimates of collective summer diversion are based on estimates of channel depletion, which is a measure of net consumptive use and does not factor in water returned to channels via agricultural drainage pumping from the Delta islands. Channel depletion between June and September averages about 1% of total Delta volume, and ranges from 10 to 35% of total inflow during that period, with a median of 18% (Kimmerer 2000).

Almost all Delta agricultural diversions are rated to less than 250 cfs (Cook and Buffaloe 1998). In an effort to reduce fish entrainment, CDFG stipulates screening requirements for three classes of diversions (over 250 cfs, under 250 cfs, and those installed after 1971), but CDFG data indicate that fewer than a tenth of the 2,500 floodgates, siphons and pumps are screened (CDFG unpublished data, 2000). Using data from 1978 to 1979 when approximately 1,900 diversions were operating, Brown (1982) estimated that 2,000 to 5,000 cfs were collectively pumped by in-Delta diversions from late March to September, with the highest rate occurring in July (Brown 1982). Water is diverted at other times of year for other purposes, including leaching salts from soils, breaking down post-harvest corn stubble, and flooding land to attract waterfowl (Cook and Buffaloe 1998).

1.2.4 Tidal exchanges

Daily tidal fluctuations affect flow direction and magnitude to a far greater degree than freshwater inflows to the Delta. The average tidal flow at Chipps Island (full ebb or flood) is about 170,000 cfs, approximately 5 times average inflow (CDWR 1993). Flows past Chipps Island can reach 330,000 cfs upstream and 340,000 cfs downstream during a single tidal cycle in the summer. Although tidal flows are typically an order of magnitude larger than Delta inflows or net outflow (Burau et al. 2000), depending on inflow and location in the Delta (CDWR Delta Atlas), the lag time in the system is high in response to freshwater inputs. Freshwater inflow pulses must be large and long-lasting to affect overall Delta flow patterns (Burau et. al. 2000).

The magnitude of tidal flows is a function of distance upriver and local channel geometry. For example, tidal flow ranges from nearly 340,000 cfs around Brown's Island at the western end of the Delta, to approximately 75,000 cfs in the lower Sacramento River near Decker Island, to

1,500 cfs in the San Joaquin River, near Upper Roberts Island (CDWR 1993). Although the net displacement of water due to tidal influences may be small, the total distance traveled by hypothetical water particles can be large, as much as 8–12 miles during one tidal cycle according to models run for the western Delta (Denton and Hunt 1986). Both the variations in tide height and this tidal east-to-west tidal excursion become smaller further up the Delta and away from the ocean boundary. As discussed below, this pattern of natural tidal exchange and water displacement can be altered by export operations at the SWP and CVP, which can further displace water from the Delta and can create periods of net "reverse flow" in south Delta channels.

1.3 Delta Hydrodynamics

The hydrodynamics of the Delta influence the quality and abundance of water, food, and habitat in the Delta. Flow patterns within the Delta affect temperature and salinity gradients, which determine biologically productive and unproductive habitats for focal species addressed in this report. The Delta provides habitat for various life stages of many species, each often having their own specific tolerance ranges for salinity, temperature, depth, seasonality, and other habitat characteristics. The hydrology and hydrodynamics of the Delta are a function of the amount and timing of runoff from precipitation and snowmelt within the drainage area, tidal cycles, water outflow, and water management, including export, barrier operations and reservoir releases.

Within the central and southern Delta, the CVP and SWP diversion facilities have a large effect on channel net flow direction and magnitude, including within the Old and Middle rivers, Grant Line Canal, and San Joaquin River. Data collected by USGS and CDWR document that when a net positive flow exists at the San Joaquin River at Stockton, approximately 33% of the water exported by the projects is drawn down Old River, 45% through Middle River, and 22% through upper Old River and Grant Line Canal. Net reverse flows occur in the San Joaquin River at Stockton when the quantity of water drawn to the pumps through the upper Old River and Grant Line Canal exceeds San Joaquin River flow entering the Delta upstream (Oltman 1996), Given that juvenile and smolting salmonids orient their movements with the prevailing flow direction (Harden-Jones 1968), net reverse flows under current operations will result in increased entrainment, predation and salvage related mortality. For example, NMFS (2009a) examined losses of juvenile Chinook salmon *(Oncorhynchus tshawytscha)* at the CVP and SWP export facilities between 1995–2007 and found that losses increased dramatically when estimated reverse flows in Old and Middle Rivers (i.e., flows towards the pumps) exceeded 5,000 cfs.

1.3.1 Barrier operations

Physical and mechanical barriers are operated within the Delta to control the path of flow towards the CVP and SWP export pumps, improving water quality of the exported water, as well as to reduce entrainment and mortality of resident and migratory fish. In low freshwater outflow years (and particularly when export pumping is high), Sacramento River water mixes with saline ocean water, and then is drawn upstream into the San Joaquin River by the export pumping operations, creating "reverse flow" conditions. Periods of reverse flow have been shown to deteriorate water quality (Monsen et al 2007) and harm fisheries in the lower San Joaquin River (NMFS 2009a). Two 60-foot gates near Walnut Grove control the flow from the Sacramento River to the Delta Cross Channel (DCC). Gate operation is coordinated with tidal cycles and river flow to improve water quality in the central Delta and allow cleaner Sacramento River water to flow to the pumps. The gates are also used as a barrier to fish migration to prevent Sacramento River salmon from being drawn toward the interior Delta and the pumps at Tracy.

For the protection of outmigrating Fall-run Chinook salmon in years when spring flow in the San Joaquin River is less than 5,000 cfs, a temporary barrier has been typically placed at the head of Old River (Head of Old River Barrier) from April 15th to May 15th to prevent drawing these fish towards the pumps near Tracy. The barrier is constructed with rock along the mainstem bed in combination with overflow weirs and gate culverts that can transport water to agricultural diversions downstream in Old River, while allowing fish to migrate down the San Joaquin River. The HORB has also typically been placed in the fall from early September to late November along with additional temporary rock barriers along the Grant Line Canal, and on the Old and Middle rivers near Tracy to improve water levels and water quality for upmigrating salmon. Without the barrier in place, approximately 60% of the water flows down Old River, and 40% flows down the San Joaquin River, with flows down Old River often exceeding 100% of San Joaquin River inflow to the Delta, with the remaining water provided by reversed flow in the lower San Joaquin River (CDWR 1986, Monsen et al 2007).

Barrier operations and other alterations of Delta hydrodynamics can lead to increase risk of predation, particularly by introduced predatory fish that now occur in the Delta (see Sections 1.6.4 and 2.2.1.4). Recently, an experimental Non-Physical Barrier (NPB) was installed at the confluence of Old and San Joaquin rivers in the spring of 2009, consisting of strobe lights, acoustics, and a bubble curtain. Initial results show a 50% improvement in the number of Chinook salmon smolts guided away from Old River, and CDWR plans on installing the NPB in spring of 2010 (CDWR 2009). Although the NPB may eventually replace the rock barrier on a permanent basis, the resulting impacts of increased reverse flows in Old and Middle Rivers on salmon outmigrant survival and subsequent spawner returns is unknown. For example, Monsen et al (2007) found that removal of the HORB in fall increases the flushing time of the Stockton Ship Channel from days to weeks, contributing to a depletion of dissolved oxygen, with potential impacts upon the upmigration of returning Chinook salmon spawners.

1.3.2 Delta hydrodynamic models

Before examining the influences of Delta hydrodynamics on fish ecology, we describe several quantitative and physical models have been developed over the past 50 years to describe flow patterns in the Delta. Because of the complexity of Delta hydrodynamics in response to changing hydrology and the tremendous pressure on scarce water resources to meet multiple objectives, these models have been developed to allow operational decisions across the Delta and the State. The majority of these models are driven primarily by differences in stage between areas of the Delta, have been used to examine water transfers, water quality, fish entrainment, and other critical issues surrounding the CVP and SWP export operations. While not a comprehensive list, the most widely-used models are described below.

1.3.2.1 CALSIM

The CALSIM model is primarily an operations model developed by CDWR and USBR that allows water resources planning and simulation to examine water demands and transfers throughout the complex system of reservoirs, rivers, and tributary waterways within the Delta. CALSIM-III simulates 82 years of hydrology for the region spanning from water year 1922 to water year 2003 and uses a water supply and water demand relationship to find delivery quantities given available water, operational constraints and desired reservoir carryover storage volumes. The model is designed to evaluate the performance of the CVP and SWP systems for: existing or future levels of land development, potential future facilities, current or alternative operational policies and regulatory environments. Key model output includes reservoir storage, instream river flow, water delivery, Delta exports and conditions, biological indicators, and operational and regulatory metrics (USBR 2008). The regulatory environments consist of the SWRCD D-1485 and D-1641, which are used to determine the Central Valley Project Improvement Act (CVPIA) 3406(b)(2) requirements that implement the primary fish, wildlife, and habitat protection measures (USBR 2008).

1.3.2.2 DAYFLOW

To allow evaluation of Delta hydrodynamics in response to changing hydrological conditions the DAYFLOW was developed in 1978 to estimate historical Sacramento Delta boundary hydrology (Friend 1999). The DAYFLOW program, which is used extensively by the CDWR and CDFG, uses a mass balance approach to calculate historical mean daily flows through the Delta Cross Channel and Georgiana Slough, past Jersey Point, and past Chipps Island to San Francisco Bay (net Delta outflow). The input data include the principal Central Valley stream inflows, Delta precipitation, Delta exports, and Delta consumptive use (principally from in-Delta agricultural and municipal diversions). DAYFLOW has been routinely recalibrated using direct acoustic Doppler current profiling (ADCP) flow measurements initiated in the 1990s and we have used DAYFLOW model outputs extensively in this report to represent daily, monthly, and annual inflows and outflows of the Delta.

1.3.2.3 Delta Simulation Model (DSM)

In order to model flow, velocity, salinity, and particle movement through Delta channels over time, CDWR developed the one-dimensional hydrodynamic Delta Simulation Model (DSM). DSM models all of the major rivers and waterways in the Sacramento – San Joaquin Delta, primary inflows including the Sacramento River, San Joaquin River, Mokelumne River, Cosumnes River, Calaveras River, and Yolo Bypass, and major exports and diversions include Banks Pumping Plant, Jones Pumping Plant, North Bay Pumping Plant, and Contra Costa intake at Old River and Rock Slough. The current version, DSM2, includes simulation of operable gates based on hydrodynamic conditions (USBR 2008). In addition to these inflows and diversions there is also a representation of Delta Island Consumptive Use (DICU), which are the agricultural diversions and return flows throughout the Delta (USBR 2008).

The DSM2-PTM is a particle-tracking module that simulates the transport and fate of neutrally buoyant particles in the Delta channels. The module uses velocity and water elevation information from DSM2-Hydro to simulate the movement of virtual particles in the Delta. If a particle leaves the Delta system by way of an export, diversion, or through any other model boundary, this information is logged for latter analysis and termed the “fate” of the particle. As an example application of DSM2-PTM, the *Biological assessment on the continued long-term operations of the Central Valley Project and the State Water Project* (USBR 2008) used this module to evaluate control of fish larvae entrainment under various operating scenarios by assuming that fish larvae behave similarly to neutrally buoyant particles.

1.3.2.4 Delta TRIM3D

To more accurately evaluate the complex hydrodynamics and associated transport of particles and conservative water quality constituents (e.g., salinity) in the Sacramento-San Joaquin Delta, the Delta TRIM3D model was developed from original hydrodynamic code by Casulli and Cattani (1994) and later applied Delta specific bathymetry and hydraulic operations to the model and compared the results against measured stage, flow, and salinity (Monsen 2001). The model is driven with a tidal boundary condition using observed stage at Martinez and observed flow boundary conditions at the river boundaries on the Sacramento at Freeport and the San Joaquin at Vernalis. Using TRIM3D to illustrate the radical alteration of the Delta ecosystem, Monsen et al (2007) demonstrated that reductions in exports decreases the proportion of Sacramento- to San Joaquin-derived fresh water in the central Delta, leading to rapid increases in salinity, that the DCC dramatically alters seasonal salinity levels in the western Delta and alter the freshwater source distribution in the central Delta. Lastly, Monsen et al (2007) show that removal of the HORB during fall is a causative factor in the depletion of dissolved oxygen at Stockton.

1.3.3 Hydrodynamic influences on Delta fish ecology

The effects of Delta hydrodynamics on conditions for fish are linked to direct entrainment effects as well as the changes in the distribution of resources such as food and habitat, and distribution of hazards such as predators and poor water quality and toxicants. Delta flow patterns are strongly affected by export pumping rates and barrier operations (Monsen et al 2007), but are generally dominated by tidal flows that vary in direction, but also by an order of magnitude above river inflows and exports within a single day. For stronger swimmers such as salmon smolts, fish behavior has a stronger influence on movement and distribution than tidal movements. However, for neutrally-buoyant, weak-swimming organisms such as striped bass (*Morone saxatilis)* larvae, recent simulations suggest that export pumping operations affect entrainment and mortality of weak swimming (larval) fishes, especially in the interior portions of the Delta where smaller, younger fish are presumed to be more abundant (Kimmerer et al 2008).

Kimmerer et al (2009) examined how the quantity of habitat for estuarine nekton, defined by salinity and water depth, responds to changes in freshwater flow in the greater San Francisco Bay Estuary and the extent to which species-specific habitat responses translate to flow responses. For resident fish species in the Delta, flow patterns often influence habitat suitability for spawning and rearing. Flooding of bypasses and floodplains provides key habitat for native fish spawning (e.g., Sacramento splittail [*Pogonichthys macrolepidotus*]) and rearing (e.g., salmonids) in the Delta (Sommer et al. 2007) and floodplain habitat is much reduced from historical availability. The ephemeral nature of floodplain availability restricts its use by centrarchid predators for spawning. Although the shallow depth may prevent larger predatory fish from venturing onto the floodplains, largemouth bass are piscivorous at lengths of just 8–10 cm (3–4 in) and are thus able to exploit relatively shallow floodplain habitat (Nobriga and Feyrer 2007). In addition to these areas having fewer large aquatic predators, shallow-water habitats tend to be warmer than the main channel. The slightly elevated temperatures within the inundated floodplain during winter and spring create vital nursery habitat, with high primary and secondary productivity and abundant terrestrial invertebrate prey for adult and juvenile native fish leading to higher growth rates.

Delta flow patterns also affect adult anadromous fish migrations to upstream spawning areas as well as juvenile outmigration to the sea. River inflow to the Delta is an important migration cue for adult salmonids (Quinn 1990) and for smolts outmigrating to sea from their spawning and rearing areas. Because there are four runs of Chinook salmon that spawn in the tributaries of the Central Valley, river inflow is an important environmental variable for much of the year (Kimmerer and Nobriga 2008).

1.3.4 Fish movement and survival

To examine the influence of water exports on fish survival and movement in the Delta, numerous studies have employed mark recapture techniques, acoustic and radio telemetry, and fish salvage data in an effort to examine the importance of various management alternatives and varying environmental conditions (Kjelson and Brandes 1989, Brandes and McClain 2001, Newman and Rice 2002). Kimmerer (2008) showed the direct losses of delta smelt and Chinook salmon to salvage at the CVP and SWP increased with increasing export flows. Newman (2008) carefully re-analyzed paired release coded-wire-tag (CWT) data collected by the USFWS in four Delta studies conducted since the 1980s to examine the relationship between Chinook salmon smolt survival, exports, pumping facility barrier operations (i.e., DCC, HORB), and San Joaquin River flows. The Newman (2008) reanalysis of two studies ("Interior” and “Delta Action 8”) suggests that export levels have a significant effect upon outmigrant survival, with the two other studies (“VAMP” and “Delta Cross Channel”) showing significant relationships between smolt survival and barrier operations for the State and Federal export pumping facilities.

To examine fish survival and movement in response to inflows, barrier configuration, and export flows more closely, a number of tracking studies have been implemented, beginning with studies by Hallock et al (1970). Recent advances in acoustic telemetry (primarily the miniaturization of transmitters) have allowed the use of this technology to track the movement and mortality of juvenile Chinook salmon in the Delta (Vogel 2008). Studies have been implemented in the North Delta region to investigate fish movement in the Sacramento River, DCC, and Georgiana Slough as well as in the South Delta region to investigate fish movements in the lower San Joaquin River and the Sacramento-San Joaquin Delta (Burau et al. 2007, Vogel 2008, Holbrook et al. 2009).

1.3.4.1 North Delta Chinook salmon tracking studies

A pilot study was conducted by the USGS, CDWR, and Natural Resource Scientists, Inc. in December 2006 and January 2007 to investigate the movement and mortality of juvenile Chinook salmon emigrating through the north Delta including the DCC and Georgiana Slough during two releases (one with the DCC gates closed and one when open) (Burau et al. 2007, Vogel 2008). The study results support the following conclusions: (1) when the DCC gates are closed, the probability that salmon are entrained in Sutter, Steamboat, and Georgiana Sloughs increases, which is consistent with increases in discharge in each of these channels when the gates are closed; (2) survival in every channel (including the mainstem Sacramento River) is higher at higher discharge; and (3) survival in Georgiana Slough is consistently lower than in any other channel where survival was estimated. Based on conclusion (2) above, Burau et al. (2007) hypothesized that the increased travel time through the system associated with the lower Sacramento River flow rates may be responsible for the reduced overall survival. Further investigation of juvenile Chinook movement and mortality was continued with the release of acoustically tagged fish from November 2008 through February 2009.

1.3.4.2 South Delta Chinook salmon tracking studies

As part of the Vernalis Adaptive Management Program (VAMP), survival of juvenile Chinook salmon was assessed in spring 2008 in the San Joaquin River using acoustic telemetry to monitor 915 fish at 16 locations (Holbrook et al. 2009). The goals of the study were to: (1) estimate survival of juvenile Chinook salmon migrating from the San Joaquin River through the Delta by each of three pathways: the mainstem San Joaquin River, Old River, and Turner Cut; (2) quantify route entrainment probabilities where fish leave the San Joaquin River and enter Old River and Turner Cut; and, (3) estimate travel times through the study area (Holbrook et al. 2009). During

2008, the HORB was not installed in Old River and fish could move unimpeded down this pathway.

Although study results were somewhat limited by premature battery failure in several of the implanted fish, study results did indicate: (1) about 22–33% of the tagged fish stayed in the San Joaquin River and this group had the highest survival rate; (2) 4–10% exited the Turner Cut into the Delta but were not detected exiting the Delta, and (3) the majority of the tagged fish (63–68%, depending on week of release) migrated down Old River at about half the survival rate of those in the mainstem San Joaquin River (Holbrook et al. 2009). For those fish entering Old River, the only ones detected exiting the Delta were those collected at CVP and SWP conveyance facilities and transported by truck through the Delta. The rate of fish entrainment into Old River was similar to the proportion of water from the San Joaquin River flowing into Old River. It is unknown whether the current NPB (Section 1.3.1) will influence the proportion of outmigrating salmon relative to flows entering Old River.

1.4 Delta salinity and water quality

Salinity is one of the dominant factors structuring biological communities in the Delta. As a result of tidal influences and seasonal inflows, the boundary between fresh water and salt water in the Delta is in constant flux. Salinity has historically been a primary water quality objective for flow management within the Delta. As Delta outflows decrease due to water exports or low river inflows, salinity intrudes further upstream. Conversely, during sustained high flows, the salinity boundary moves seaward. Prior to the construction of Shasta Dam in 1943, the upper edge of the salinity gradient (picnocline) could be pushed far inland in dry years (Kharl 1979). For example, maximum salinity intrusion in 1931 was as far upstream as Stockton on the San Joaquin River and Courtland on the Sacramento River. With Shasta, Oroville, and Folsom dams in place, salinity intrusion is controlled through upstream releases (particularly during the drier parts of the year) and maximum salinity intrusion does not occur much past Sherman Island in most years. These dams have also reduced much of the natural seasonal variability in the position of the boundary.

1.4.1 Low salinity boundary – X_2

The most widely used salinity index is the position of the X_2 isohaline—the distance upstream from the Golden Gate Bridge where mixing of saltwater from the ocean with freshwater from the Delta results in a salinity of 2 parts per thousand (2,000 mg/L), as measured near the bottom of the channel. X_2 was originally suggested as a management tool because it is highly correlated with Delta outflow, and until recently, accurate outflow measurement was not possible (Oltman 1998). X_2 is a function of both tidal influence and the density of the salt water pushing upstream, along with the amount of river inflow to the Delta, and the amount of water exported via pumping. The location of X_2 is affected by many factors, and the X_2-based standards, such as D-1485, are implemented through real-time monitoring of salinity. For planning purposes, however, the Delta outflow needed to place X_2 in any particular area is estimated through empirical relations traceable to Jassby et al. (1995). Table 1-2 shows the approximate steady-state Delta outflows necessary to maintain the X_2 at various locations in the Delta and the northeastern portion of San Francisco Bay. Note that these are only approximations, because the actual position of X_2 is affected by additional factors, and does not respond instantly to changes in outflow.

Table 1-2. Estimated Delta outflow required to maintain X_2 at various locations.

Distance upstream of Golden Gate Bridge (km)	Mean daily flow (cfs)[1]	Mean monthly flow (cfs)[2]
85	4,882	4,856
80	7,474	7,529
75	11,442	11,672
70	17,516	18,095
65	26,815	28,054
60	41,050	43,492
55	62,842	67,428

1. DAYFLOW documentation. Available: http://www.water.ca.gov/dayflow/documentation/
2. USBR (2008) – Appendix S

1.4.2 Relationship of X_2 and resident fish

There has been a great deal of focus on the "fish – X_2" relationship. X_2, a proxy for outflow, is used as an index of estuarine conditions, and is correlated with a number of variables and effects, including changing physical/chemical processes, habitat, and abundance of organisms at all trophic levels. The effects of X_2 on fish survival is primarily due to the effects of the required Delta outflow to maintain a particular X_2 location upon life-stage specific habitat availability, predation, passive transport, entrainment, temperature, and productivity. Based upon DAYFLOW model outputs of Delta outflows, net Delta exports have been declining in association with the sharp increases in Delta exports in the past two decades. Because of its association with outflow, X_2 displays an inverse relationship with abundance for a number of Delta species and the importance of X_2 for pelagic and estuarine fish populations are discussed in the Estuarine Ecology Team report (Estuarine Ecology Team 1996) and by Kimmerer (2000).

Inverse relationships between X_2 and the abundance of a number of Delta species are significant, at least in some years, for estuarine-dependent copepods, mysids, bay shrimp (*Crangon franciscorum*), and several fish, including longfin smelt (*Spirinchus thaleichthys*), Pacific herring (*Clupea pallasii*), starry flounder (*Platichthys stellatus*), Sacramento splittail, American shad (*Alosa sapidissima*), and striped bass (Kimmerer 1998, Kimmerer 2002b). More recently, Baxter et al. (2008) reported that delta smelt habitat quality in the fall does not increase appreciably until X_2 is <80 km upstream of the Golden Gate Bridge, which is approximately the point at which the delta opens up into Suisun Bay. Herbold (1994) previously found a relationship between the number of days during spring that the low-salinity habitat (X_2) is positioned in Suisun Bay and the abundance of delta smelt in the fall Midwater Trawl Index (MWT). Unlike many other species associated with the low-salinity zone, the abundance of delta smelt as measured by the MWT is not associated with the amount of freshwater flow or average position of X_2 during the spawning or larval season (March-July) (Bennett 2005). This is likely because delta smelt recruitment success can be poor during drought and flood years and variable to high during intermediate flow years when the average position of low-salinity habitat in the spring is in Suisun Bay (Moyle et al. 1992).

1.4.3 Estuarine turbidity maximum

Stratification in Suisun Bay is rare except in the fall, due to its shallow depth and mixing by wind-driven waves. However, this stratification of fresh- and saltwater layers is important for the transport of nutrients and small organisms. The location where net current flowing inland along the bottom reverses direction and sinking particles are trapped in suspension is associated with higher turbidity known as the estuarine turbidity maximum (ETM). Burau et al. (2000) report that in the Delta, ETMs occur near the Benicia Bridge and in Suisun Bay near Garnet Point on Ryer Island. Zooplankton maintain position in this highly productive region of the estuary through vertical movements (Kimmerer 1994).

1.5 Current Delta Operations Criteria

1.5.1 Water Rights Decision 1641

Water Rights Decision 1641 implements the SWRCB 1995 Bay-Delta WQCP and imposes flow and water quality objectives upon the Projects. D-1641 also grants conditional changes to points of diversion for each project. The various flow objectives and export restraints are designed to protect fisheries. These objectives include specific outflow requirements throughout the year, specific export restraints in the spring, and export limits based on a percentage of estuary inflow throughout the year. The water quality objectives are designed to protect agricultural, municipal and industrial, and fishery uses, and they vary throughout the year and by the wetness of the year. These objectives are currently under review by the SWRCB.

1.5.1.1 Export/Inflow requirements

Throughout the year, the combined maximum exports at Clifton Court Forebay (excluding Byron-Bethany pumping) and the Tracy Pumping Plant are calculated as a percentage of the average Delta inflow, which is calculated as the 3-day average for balanced conditions with storage withdrawal of the 14-day average. The maximum diversion is 65% of Delta inflow from July through January, and from February through June the maximum Delta inflow diversion is 35%. However, allowable diversion in February can range up to 45% of Delta inflow depending on the January Eight River Index[3] (8RI) (percent allowable February diversion increases as January 8RI decreases). Allowable inflow diversion percentages can be adjusted upward or downward depending on biological conditions provided there is no net water cost.

In addition to the maximum allowable export to inflow ratio, from April 15 to May 15 flow exports by the CVP and SWP are limited to a maximum 3-day running average of combined export of either 1,500 cfs or 100% of the flow as measured at Vernalis, whichever is greater. The combined export is measured at Clifton Court Forebay (excluding Byron-Bethany pumping) and the Tracy Pumping Plant. This time period may be adjusted to coincide with fish migration timing and the maximum export rate may be varied by the CALFED Operations group.

1.5.1.2 Minimum Delta outflow

Minimum Delta outflow is measured as by the Net Delta Outflow Index (NDOI) for the months of July through January as minimum monthly average flows based on water year types (Table 1-3). Computation of the NDOI is defined in Figure 3 of D-1641 (SWRCB 2000). For minimum monthly standards that are ≤ 5,000 cfs the 7-day average must not fall below 1,000 cfs of the standard, and for minimum monthly standards > 5,000 cfs the 7-day average must be ≥ 80% of the standard. For the months of February through June, often referred to as the "X_2 period",

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[3] The 8RI refers to the sum of the unimpaired runoff as published in the CDWR Bulletin 120 for the following locations: Sacramento River flow at Bend Bridge, near Red Bluff; Feather River, total inflow to Oroville Reservoir; Yuba River flow at Smartville; American River, total inflow to Folsom Reservoir; Stanislaus River, total inflow to New Melones Reservoir; Tuolumne River, total inflow to Don Pedro Reservoir; Merced River, total inflow to Exchequer Reservoir; and San Joaquin River, total inflow to Millerton Lake.

minimum delta outflow is defined by the habitat protection outflow criteria. Calculation of the minimum delta outflow during this period is dependent on several factors, including: the previous months' 8RI, the number of days either the daily average or 14-day average electrical conductivity (EC) is ≤ 2.64 mmhos/cm as measured at Collinsville, and the February starting salinity index. Habitat protection outflows result in 3-day average delta outflows ranging from 7,100 cfs to 29,200 cfs, see Tables 3 and 4 attached to the Order in D-1641 (SWRCB 2000) for a detailed description and calculation of required Delta outflows and EC levels during this period.

Table 1-3. Minimum Delta outflow requirements quantified by the Net Delta Outflow Index as set forth in D-1641.

Month	Water Year Type					
	All	Wet	Above Normal	Below Normal	Dry	Critical
	Minimum monthly average flow (cfs)					
Jan	4,500[1]					
Feb-Jun	Habitat Protection Flows[2], minimum flows range from 7,100 to 29,200 cfs					
Jul		8,000	8,000	6,500	5,000	4,000
Aug		4,000	4,000	4,000	3,500	3,000
Sep	3,000					
Oct		4,000	4,000	4,000	4,000	3,000
Nov-Dec		4,500	4,500	4,500	4,500	3,500

[1] Increase to 6,000 cfs if the Dec 8RI is greater than 800 TAF

[2] Minimum Delta outflow for February through May, the habitat protection period, is calculated from a series of rules that are described in Tables 3 and 4 of the Order in D-1641 (SWRCB 2000)

1.5.1.3 Instream flow requirements

Minimum instream flow requirements for Delta inflow are set for the Sacramento River at Rio Vista for the months of September through December, ranging from 3,000 to 4,500 cfs (Table 1-4). Flow requirements are set at minimum monthly average objectives and vary based on water year type; the 7-day running average can not be less than 1,000 cfs below the monthly objective.

Table 1-4. Sacramento River monthly flow requirements at Rio Vista as set forth in D-1641.

Month	Water Year Type					
	All	Wet	Above Normal	Below Normal	Dry	Critical
	Minimum monthly average flow (cfs)					
Sept	3,000					
Oct		4,000	4,000	4,000	4,000	3,000
Nov-Dec		4,500	4,500	4,500	4,500	3,500

Minimum instream flow requirements for Delta inflow are set for the San Joaquin River at Vernalis for the months of February through June (Table 1-5). Flow requirements are divided into a base flow periods from February 1 through April 14 and May 16 through the end of June, and "pulse" flow periods from April 15 to May 15 for outmigration and in October as an upmigration attraction flow for Fall-run Chinook salmon. Flow requirements are set at minimum monthly average objectives and vary based on water year type; for the base flow period the 7-day running average can not be less than 20% below the monthly objective.

Table 1-5. San Joaquin River monthly flow requirements at Vernalis as set forth in D-1641.

Month	Flow Type	Water Year Type					
		All	Wet	Above Normal	Below Normal	Dry	Critical
		Minimum Monthly average flow (cfs)					
Feb-April 14	Base flow [X_2 flow] [1]		2,130 [3,420]	2,130 [3,420]	1,420 [2,280]	1,420 [2,280]	710 [1,140]
April 15 to May 15	Pulse flow [X_2 flow] [1]		7,330 [8,620]	5,730 [7,020]	4,620 [5,480]	4,020 [4,880]	3,110 [3,540]
May 16 to June 30	Base flow [X_2 flow] [1]		2,130 [3,420]	2,130 [3,420]	1,420 [2,280]	1,420 [2,280]	710 [1,140]
October	Pulse flow	1,000[2]					

[1] Each month has two specified flows values and the higher value is required if X_2 is required to be west of Chipps Island.
[2] Up to an additional 28 TAF pulse/attraction flow to bring flows up to a monthly average of 2,000 cfs except for a critical year following a critical year.

1.5.1.4 Salinity standards

In addition to the affects of salinity standards on prescribed minimum delta outflows and instream flow requirements, maximum EC standards are mandated for the San Joaquin River and Suisun Marsh. For the San Joaquin River (measured at Jersey Point and Prisoners Point) from April through June the maximum 14-day mean daily average EC is 0.44 mmhos/cm for all water year types. The San Joaquin River standard does not apply in critical years of when the May 90% forecast of SRI[4] $\leq$ 8.1 MAF.

In the Suisun Marsh, salinity standards are set for the Western Marsh (measured at Chadbourne Slough at Sunrise Duck Club and Suisun Slough 300 ft (91 m) south of Volanti Slough) and Eastern Marsh (measured at Sacramento River at Collinsville and Montezuma Slough at National Steel and Beldon Landing) based on the maximum monthly average of both daily high tide EC values (Table 1-6). Standards for the Eastern Marsh apply to all water year types where as the western marsh has separate standards for deficiency periods, which are defined by: (1) the second consecutive Dry water year following a critical year, (2) a Dry water year following a year in which the Sacramento River Index (See footnote) was less than 11.35 MAF, or (3) a critical water year following a Dry or critical water year.

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[4] Sacramento River Index (SRI) is refers to the sum of the unimpaired runoff in the water year as published in the CDWR Bulletin 120 for the following locations: Sacramento River above Bend Bridge, near Red Bluff; Feather River, total unimpaired inflow to Oroville Reservoir; Yuba River at Smartville; and American River, total unimpaired inflow to Folsom Reservoir.

Table 1-6. Suisun Marsh salinity standards as set forth in D-1641.

Month	Station		
	Eastern Marsh[1]	Western Marsh[2] (normal)	Western Marsh[2] (deficiency)
	Maximum monthly average of twice daily high tide EC (mmhos/cm)		
Oct	19.0	19.0	19.0
Nov	15.5	16.5	16.5
Dec	15.5	15.5	15.6
Jan	12.5	12.5	15.6
Feb-Mar	8.0	8.0	15.6
Apr	11.0	11.0	14.0
May	11.0	11.0	12.5

[1] Measured at Chadbourne Slough at Sunrise Duck Club and Suisun Slough 300 ft south of Volanti Slough.

[2] Measured at Sacramento River at Collinsville and Montezuma Slough at National Steel and Beldon Landing.

The Suisun Marsh Salinity Control Gates (SMSCG) are located on Montezuma Slough about 2 mi (3.2 km) downstream from the confluence of the Sacramento and San Joaquin Rivers, near Collinsville. The objective of Suisun Marsh Salinity Control Gate operation is to decrease the salinity of the water in Montezuma Slough. The facility, spanning the 465 ft (142 m) width of Montezuma Slough, consists of a boat lock, a series of three radial gates, and removable flashboards. The gates control salinity by restricting the flow of higher salinity water from Grizzly Bay into Montezuma Slough during incoming tides and retaining lower salinity Sacramento River water from the previous ebb tide. Operation of the gates in this fashion lowers salinity in Suisun Marsh channels and results in a net movement of water from east to west.

The U.S. Army Corps of Engineers permit for operating the SMSCG requires that it be operated between October and May only when needed to meet Suisun Marsh salinity standards. Historically, the gate has been operated as early as October 1, while in some years the gate was not operated at all. When the channel water salinity decreases sufficiently below the salinity standards, or at the end of the control season, the flashboards are removed and the gates raised to allow unrestricted movement through Montezuma Slough. The approximately 2,800 cfs net flow induced by SMSCG operation is effective at moving the salinity downstream in Montezuma Slough. Salinity is reduced by roughly 100% at Beldons Landing, and lesser amounts further west along Montezuma Slough. At the same time, the salinity field in Suisun Bay moves upstream as net Delta outflow is reduced by gate operation.

1.5.1.5 Additional X_2 requirements

Pursuant to D-1641, diversions by the USBR at Banks Pumping Plant and CDWR at Tracy Pumping Plant are not authorized when the Delta is in excess conditions and such diversions causes the location of X_2 to shift upstream so far that: (1) It is east of Chipps Island (47 mi [75 km] upstream of the Golden Gate Bridge) during the months of February through May, or (2) It is east of Collinsville (50 mi [81 km] upstream of the Golden Gate Bridge) during the months of January, June, July, and August, or (3) During December it is east of Collinsville and Delta smelt are present at Contra Costa Water District's point of diversion under Permits 20749 and 20750 (Application 20245). Similar restrictions also apply to the Contra Costa Water District's (CCWD) ability to refill Los Vaqueros Reservoir.

1.5.2 VAMP requirements

The San Joaquin River Agreement (SJRA) includes a 12-year experimental program providing for increased flows and decreased Delta exports in the lower San Joaquin River during a 31-day pulse flow period during April-May for the benefit of outmigrating Chinook salmon and other species. It also provides for the collection of experimental data during that time to further the understanding of the effects of flows, exports, and the Head of Old River Barrier on salmon survival. This experimental program is commonly referred to as the Vernalis Adaptive Management Program (VAMP). The SJRA also provides water for flows at other times on the Stanislaus, Merced, and lower San Joaquin Rivers. Under the SJRA, Reclamation and CDWR purchase water for VAMP flows from the San Joaquin River water rights holders of up to 110,000 af may be provided for VAMP during April-May with an additional 27,500 af that may be provided at other times. In certain "double-step" years, up to an additional 47,000 af may need to be acquired to fully meet VAMP flow objectives. This water would be provided under supplemental agreements separate from the SJRA. It is anticipated that new SWRCB objectives will be as protective as the current program and that such protections will remain in place through 2030.

1.5.3 Instream flow requirements in upstream spawning and rearing areas

The CVP and SWP must maintain several minimum flow releases in mainstem and tributary reaches upstream of the Delta, often in support of fish and wildlife resources. In addition to the instream flow release requirements within upstream tributaries to the Delta, summaries of the major flow requirements upstream of the CVP and SWP include are provided below (note, there are additional temperature requirements which can necessitate flow releases that are not summarized herein but are described in detail in the *Biological assessment on the continued long-term operations of the Central Valley Project and the State Water Project* (USBR 2008):

- The USBR must release 368,600 to 815,000 af annually from their Trinity River Diversion for Trinity River flows, per the December 19, 2000 Trinity River Mainstem Fishery Restoration ROD. The release schedule of this water volume is scheduled in coordination with the USFWS to best meet habitat, temperature, and sediment transport objectives in the Trinity Basin.
- The USBR maintains minimum flows below Whiskeytown into Clear Creek per a 1960 Memorandum of Agreement with CDFG and an unfinalized 1963 release schedule developed with the USFWS. The release schedule maintains flows of 50 cfs from January through October and 100 cfs in November and December (flow releases are cut to 30 and 70 cfs, respectively, in critical years).
- USBR operates the Shasta, Sacramento River, and Trinity River divisions of the CVP to meet (to the extent possible) the provisions of SWRCB Order 90-05, which maintains a minimum release schedule into the Sacramento River at Keswick Dam. The release schedule maintains a minimum release of 3,250 cfs at Keswick Dam and Red Bluff Diversion Dam (RBDD) from September through the end of February in all water years, except Critically Dry years.
- The CVP must maintain a flow of 5,000 cfs to Wilkins Slough, (gauging station on the Sacramento River), under all but the most critical water supply conditions, to facilitate pumping and use of screened diversions that were installed near this level when navigation existed between Sacramento and Chico Landing.
- Pursuant to SWRCB Decision 893 (D-893), the USBR must maintain a minimum flow downstream of Nimbus Dam on the Lower American River of 250 cfs from January to September 15 and 500 cfs at other times. Although, Nimbus Dam releases are almost

always controlled by flood requirements or coordinated to meet WQCP requirements and CVP water supply demands, and, thus, Nimbus Dam releases are expected to exceed D-893 standards in all but the driest of conditions (USBR 2008).

- Pursuant to SWRCB Decision 1422 (D-1422), the USBR is required to release 98,000 af of water per year, with a reduction to 69,000 af in critical years, to the Stanislaus River downstream of New Melones Reservoir on a distribution pattern to be specified each year by CDFG for fish and wildlife purposes (USBR 2008). Additional instream flow demands from New Melones can also result from needing to meet base flow requirements on the San Joaquin River at Vernalis (Table 1-5).
- As part of SWP operations, CDWR maintains a minimum flow of 600 cfs within the Feather River Low Flow Channel (LFC) downstream from the Thermalito Diversion Dam for fishery purposes. Downstream of the Thermalito Afterbay Outlet, in the High Flow Channel (HFC), a minimum release for flows in the Feather River is 1,000 cfs from April through September and 1,700 cfs from October through March. When the April-to-July unimpaired runoff is less than 55% of normal, the License requires minimum flows of 1,000 cfs from March to September and 1,200 cfs from October to February. It is anticipated that once FERC issues a new operating license to the Oroville Project, minimum flows in the LFC will increase.

1.6 Biotic Interactions

Various potential mechanisms have been proposed to explain the effects of diversions on biotic interactions in the Delta, including changes in freshwater inflow, agricultural diversions, and export pumping on phytoplankton, zooplankton and fish abundance (IEP 1995, Kimmerer 2002b). Biotic interactions in the Delta ecosystem that are affected by flows and water exports include food supply, food-web dynamics, the proliferation of non-native species, competition, and predation. The potential effects of diversions on pathogens and diseases affecting aquatic species were not analyzed for this report.

1.6.1 Food supply

1.6.1.1 Primary production

Freshwater inflows have been shown to affect phytoplankton production in many estuaries (Mallin et al. 1993). Hydrodynamics and estuarine circulation patterns regulate factors important for phytoplankton (algae) growth in the Delta, including nutrient influx, salinity, turbidity, and light penetration. Although hydrodynamic effects of shoal-channel exchange are not addressed in this report, exports generally reduce algal concentrations in the Delta (Arthur et al. 1996), and it has been suggested that diverting water from the upper Delta, rather than through the Delta, could enhance upper estuarine food web productivity due to increased residence time for algal production (Jassby and Powell 1994). The effects of flows and exports on the current distribution and decreased abundance of phytoplankton in the Delta is believed to work through two major pathways: (1) movement of the salinity boundary (X_2) relative to Suisun Bay, as well as (2) direct entrainment of phytoplankton in export flows.

Phytoplankton are found in greater concentrations at or near the estuarine turbidity maximum (ETM), which is dependent on salinities of 1 to 6 psu, and which moves upstream or downstream depending on outflow (Kimmerer 1992). It is the combination of greater light availability and net estuarine flow (vertically and horizontally) that allows for summer phytoplankton maxima in average water years (Cloern et al. 1983). In open waters of the Delta, turbidity limits phytoplankton to the upper 1.5 m (5 ft) of the water column, where effective photosynthesis can take place. If the ETM is positioned in the shallow expanses and shoal areas of Suisun Bay where enough light and nutrients are available, an algal bloom develops in mid-summer. Under high or low outflow conditions, the ETM is positioned in deep (light-limited) channels landward and seaward of Suisun Bay and a bloom does not develop (Arthur and Ball 1979, Cloern et al. 1983). Thus, hydrodynamic conditions (created naturally or via export pumping) causing the entrapment zone to lie upstream or downstream of Suisun Bay may reduce standing crops of phytoplankton in the Delta, effectively decreasing primary production, with potential attendant effects at higher trophic levels.

Water exports from the south Delta have been shown to channel phytoplankton-rich waters (particularly from the San Joaquin River) directly towards the pumps, thereby reducing the standing crop of primary producers in Suisun Bay (Jassby et al. 1996). An important conclusion from much of the work done on phytoplankton in the Delta suggests that algal blooms occur when net outflow through the Delta drops, altering the position of the ETM and increasing residence times for phytoplankton. Interestingly, Interestingly, through about 1995 all regions of the Delta exhibited chlorophyll-a concentrations that had decreased below those measured in 1980 by at least a factor of two (Lehman 1996), with Suisun Bay showing declines by a factor of ten since the multi-year drought in the late 1980s and early 1990s (Kimmerer et al. 1994). Reduced outflow (because of drought conditions and increased exports) may be directly responsible for some of the declines observed through 1995 (Jassby et al. 2002). However, analysis of more recent data indicates that Delta phytoplankton biomass and primary productivity trends were positive from 1996–2005, with freshwater flow variability and its effect on particle residence time likely to have been the main source of interannual phytoplankton variability Jassby (2008). Another recent change in Delta phytoplankton communities is the increased occurrence of blooms of the toxic cyanobacteria *Microcystis aeruginosa*, which “may impact estuarine fishery production through toxic and food web impacts at multiple trophic levels” (Lehman et al. 2010). In contrast to the recent Delta trends, phytoplankton biomass in Suisun Bay did not increase during 1996–2005 (Jassby 2008). Jassby suggests that the non-native clam, *Corbula amurensis*, might be responsible for maintaining low phytoplankton abundance in Suisun Bay (see Section 1.6.5). Reduced outflow creates high-salinity gradients further upstream that can facilitate marine bivalve colonization, which can further deplete phytoplankton abundance (Alpine and Cloern 1992).

1.6.1.2 Secondary production (zooplankton)

Zooplankton abundance, particularly of native species, has declined across seasons and regions of the Delta over the last three decades, and these declines have been more prevalent in the Sacramento and San Joaquin rivers than in Suisun Bay (Orsi and Mecum 1986, Obrebski et al. 1992). Although these declines have not been well associated with changes in Delta outflow, low Delta outflow allows salinity intrusion into the western Delta causing physiological stress on freshwater zooplankton food resources. In addition, salinity intrusion during low inflow years creates patchy distributions of high-quality phytoplankton (food), which could limit or reduce copepod egg production, viability, or larval growth rates (Lehman 1998), particularly important for fish rearing in the western Delta. However, other than their strong dependence on phytoplankton distribution, the underlying mechanisms for the apparent declines in secondary productivity are not well understood (Cloern 1999), but likely result from several factors working in concert, including, but not limited to, changes in nutrient availability, reduced Delta outflow and increased diversions and exports, as well as the presence of non-native species (e.g., *Corbula*) (Kimmerer et al 2008).

1.6.2 Non-native species

Non-native fish and invertebrate species may alter food webs at all trophic levels and may change species composition over the long term. The San Francisco Bay and Delta is recognized as the most invaded ecosystem in North America (Carlton et al. 1990). Although American shad and striped bass were intentionally released into the Delta, other species such as yellowfin goby (*Acanthogobius flavimanus*), the copepods *Psuedodiaptomous* spp. and *Sinoclanus doerrii* and the overbite clam (*Corbula amurensis*) were introduced accidentally in ballast waters. Over 200 non-native species have been introduced and become naturalized, with approximately one-quarter of those species arriving in the last 30 years (Cohen and Carlton 1995).

Throughout the history of the Delta, species invasions have tended to be higher during low outflow or drought conditions, most likely because established native species are stressed or depleted under these conditions (Moyle 1986, Baltz and Moyle 1993). Increasing water diversions during periods of low outflow may further increase the distribution of non-native species or supply conditions suitable for new invasions (Nichols et al. 1990). As described below, a number of invertebrate species (particularly the overbite clam, but also several species of copepods) were able to quickly become established during the drought from 1985 to 1993, and have now increased dramatically in abundance (Kimmerer et al. 1992). Such changes in the abundance and distribution of non-native species may be facilitated by the low-flow conditions created by drought and diversions. The existence of numerous non-native species in the Delta may be an important factor contributing to the decline of some native species populations, including those listed as threatened or endangered. Although invasive aquatic plants (*Eichhornia crassipe*, *Egeria densa*) are not specifically addressed in this report, since they appear to be less influenced by flows in the Delta, other non-native species that potentially pose the greatest impact on native fish species discussed below, especially those that are listed under the federal Endangered Species Act.

1.6.2.1 Overbite clam (*Corbula amurensis*)

The overbite clam appeared in San Francisco Bay in 1986, most likely as a result of a ship releasing ballast water in the Bay, and has rapidly spread through the Delta and Bay (Carlton et al. 1990). It had spread into Suisun Bay by mid-1987, apparently at the expense of other salt-tolerant species, which would have otherwise spread into the Bay under the then-drought conditions (Nichols et al. 1990). *Corbula* is extremely efficient at removing phytoplankton biomass from the water column, filtering channels 10 m (33 ft) deep up to 1.28 times per day (Werner and Hollibaugh 1993). Feyrer and Matern (2000) found that mysid shrimp (*Mysidopsis bahia*) abundance decreased following the overbite clam invasion, which has subsequently lead to a decrease in the importance of mysid shrimp in many fish diets, including splittail and striped bass. Although these shifts may have a negative impact on some fish species (Nobriga 1998, Orsi 2000), more information on the effect of diet shifts, food item quality, and consumption of novel prey is necessary before understanding potential effects on fish populations.

1.6.2.2 Chinese mitten crab (*Eriocheir sinensis*)

First observed in San Francisco Bay in 1992, the Chinese mitten crab (*Eriocheir sinensis*) quickly spread into the Delta by 1996 (Cohen and Carleton 1997, Hieb 1997), with subsequent rapid population-wide fluctuations in abundance (Bergendorf 2005, Rudnick et al. 2005, Hanson and Sytsma 2005). In addition to disrupting commercial shrimp and fishing trawls, one million crabs were entrained at the CVP and SWP salvage facilities in 1998. Juvenile crabs feed on aquatic vegetation, supplemented with macroinvertebrates. Chinese mitten crabs spend the greatest proportion of their life in fresh water, and this seems to be of adaptive significance. Osmotic autoregulation is what allows these animals to compensate for moderate, irregular perturbations of NaCl homeostasis induced by food uptake, land visits, or during molting phases (Onken 1996). This mechanism makes the mitten clam particularly well adapted to Delta conditions and insensitive to the position of X_2. However, low Delta outflow and overcrowded rearing habitat has been hypothesized as causes for the upstream spread of the species (Hieb and Veldhuizen 1998), which may explain their dramatic increase in abundance during 1998–1999, when they were found as far upstream as the San Luis National Wildlife Refuge in the San Joaquin River (CDFG 1998b). However, extensive surveys conducted in the San Joaquin River basin in the year 2000 did not detect the presence of mitten crab (May and Brown 2001). Since this time, populations of the mitten crab have been declining in the Sacramento-San Joaquin River Delta (Heib, pers. comm., 2007). Recent conceptual models suggest that, in addition to zoea (larval crab) development being inhibited at temperatures below 11.7ºC (53.1ºF) (which typically occur between December and January in the Delta), reduced flows to the western Delta and San Francisco Bay may increase salinities and allow marine planktivores such as anchovies to move into the system and prey upon mitten crab larvae (Tsukimura 2008).

1.6.2.3 Non-native fish species

Nearly 30 species of non-native fish in the Delta are now important predators throughout the region. Although little information is available regarding their effects on native fish populations, it is assumed that direct and indirect competition for food, rearing habitat, and breeding sites has had a negative impact on many fish. Evidence for such competition has been found for the non-native carp, catfish, green sunfish, and bluegill (Cohen and Carlton 1995). Competition for food or breeding sites, along with predation by striped bass and largemouth bass likely caused the extirpation of native Sacramento perch (*Archoplites interruptus*) and the extinction of thicktail chub (*Gila crassicauda*) in the Sacramento-San Joaquin basins (Cohen and Carlton 1995). Inland silversides, introduced to Sacramento River reservoirs in 1966, were well-established in the Delta by the early 1980s. Greater silverside abundance in delta smelt spawning areas during low outflow years may be contributing to recent declines in delta smelt (Bennett and Moyle 1996). All of these factors taken together with changes in physical water quality and Delta food webs support the conclusion that increased exports and the loss of seasonal and year-to-year variability in Delta outflows may have influenced the success of invading fish species and their impacts on native populations.

1.6.3 Competition

Exploitative competition, in which species compete for limited resources, may contribute to reduced recruitment in some fish species and/or life stages through density-dependent mortality. Many non-native fish and invertebrate species may rapidly expand in population in response to high resource levels, competing with (or preying upon) resident species within the Delta. In years of reduced Delta outflow, when salinity intrudes farther upstream (particularly into Suisun Bay), suitable rearing habitat may become limiting and increased competition between and among species is possible. The interaction between diversion and Delta outflow primarily affect habitat and food availability through the position of X_2 within the central and western Delta. For example, *Crangon franciscorum* and *Eurythemora* abundance have been shown to be positively related to Delta outflow (Kimmerer et al 2009). For fish species, limitations in available habitat can also influence competition. This is particularly true for juvenile and adult splittail, which prefer low-salinity, shallow-water habitats. Delta smelt also spawn in low-salinity, shallow-water habitat, which can be limiting depending on inflow conditions. Although habitat and food limitation likely lead to increased competition, these impacts are less apparent at low populations than at high populations.

In addition to changes in food web structure due to non-native species (See Section 1.6.5), greater abundance of non-native inland silverside (*Menidia beryllina*) in delta smelt spawning areas during low outflow years may have contributed to recent declines in delta smelt (Bennett and Moyle 1996). The declines of marine copepods and mysid shrimp in the western Delta have been attributed to both marine and freshwater mollusk invasions during extended periods (>2 yrs) of both low and high Delta outflow (Jassby et al. 1995). *Corbula amurensis*, introduced in 1986, may be responsible for many of the declines observed recently of phytoplankton and zooplankton abundances, particularly *Neomysis* in the western Delta. However, all life stages of *Neomysis* are too large to be consumed by *Corbula*, and it is likely that direct competition for food reduced its abundance after the introduction of the clam. Inter-specific competition for food resources (Jassby et al. 1996, Orsi and Mecum 1996) with another mysid shrimp, *Acanthomysis bowmani*, has also been suggested as a factor in *Neomysis* declines (Orsi 2000).

Adult anadromous salmonids do not generally feed while migrating through the Delta. Although many populations or runs may be limited by spawning habitat availability, less is known about habitat use and potential limiting factors for juvenile salmonids rearing in the Delta. Because there are few intermediate trapping and trawl locations within the Delta, residence times for juveniles of the various runs are not well known and it is difficult to predict potential relationships between water exports and biotic interactions that may be important for salmonids, such as density-dependent predation in the Delta. Longer residency within the delta and estuary may expose juvenile salmonids to mortality factors operating within these habitats (e.g., entrainment, predation); however, those that do remain for a period before outmigrating to sea likely have higher survival rates due to their larger size at ocean entry.

1.6.4 Predation

As discussed further below, because it is an established intra-guild predator, the overbite clam poses a substantial threat in terms of altering Delta food-webs, including in Suisun Bay. The overbite clam is a filter feeder that consumes phytoplankton, bacterioplankton, and zooplankton, and may effectively reduce zooplankton populations by both direct predation and by depleting their phytoplankton food source. Densities of three common copepod species have declined by 53–91% since the arrival of overbite clam (Kimmerer et al. 1994), although Delta outflow may also be related to decreased abundance (Kimmerer et al 2009). Although springtime abundance has increased since 1997, *Eurytemora* numbers are well below those that pre-date the arrival of the overbite clam (Orsi 2000). Other zooplankton species were probably affected in a similar way (Kimmerer and Orsi 1996). Feyrer and Matern (2000) suggest that there has been a significant decline in the importance of mysid shrimp in diets of splittail and striped bass because of overbite clam predation on plankton.

The mechanisms affecting populations of declining prey species have dominated the literature on biotic interactions in the Delta to some degree, whereas interactions at higher trophic levels, particularly among piscivorous fish, are less well understood. Although non-native striped bass, largemouth bass, and inland silversides may have the greatest impacts on native fish in the Delta, these species also become entrained by Delta export operations. Data from fish salvage facilities suggest that populations of largemouth bass and other predators in the Delta are increasing, which could lead to increased mortality of native fishes in the Delta. Nobriga and Feyrer (2007) found that use of shallow-water habitats by largemouth bass in the Delta is common; their results showed that largemouth bass preyed on more native fish than striped bass or Sacramento pikeminnow and consumed native fish later in the season (July) than the other two species (May); however, all three had very diverse and dynamic diets. Largemouth bass tend to become established in areas of the Delta with submerged macrophytes (Nobriga et al. 2005) and their diet tends to consist of fish and other organisms found in these and other nearshore habitats rather than open-water species. Nobriga and Feyrer (2007) note that striped bass are open-water predators and are probably the most important predator of juvenile Chinook salmon (Lindley and Mohr 2003), and delta smelt (Stevens 1966). A large portion of striped bass predation may occur near water diversions where salmon and smelt are entrained because they tend to aggregate around these structures (Brown et al. 1996, as cited in Nobriga and Feyrer (2007). The most relevant effects of water exports on food-web interactions are those related to phytoplankton and zooplankton and the fish that feed upon them.

1.6.5 Pelagic organism decline

The Interagency Ecological Program (IEP), a consortium of nine state and federal agencies, has been monitoring fish populations in the San Francisco Estuary for decades, and has developed one of the longest and most comprehensive data records on estuarine fishes in the world (Sommer et al. 2007). The surveys, using midwater trawls, sample the pelagic fish assemblage in the upper estuary, the tidal freshwater and brackish portion of the system from the Delta to San Pablo Bay. This long-term dataset (1967 to present) allows the IEP to track changes in pelagic fish abundance in spite of the dynamic nature of the estuary. Three of the most abundant resident pelagic fishes captured in the surveys are two native species (delta smelt, longfin smelt, and striped bass) have shown substantial long-term population declines (Kimmerer et al. 2000, Bennett 2005, Rosenfeld and Baxter 2007). An overall negative trend in habitat quality has occurred for delta smelt, threadfin shad, and striped bass since 1967, with delta smelt and striped bass experiencing the most apparent declines (Feyrer et al. 2007). The reductions in pelagic fish abundance have been recognized as a serious water management issue and have become known as the Pelagic Organism Decline (POD). In response to the POD, the IEP formed a study team in 2005 to evaluate the potential causes of the decline.

The POD has been the subject of an intensive analytical effort by the Interagency Ecological Program (IEP) since the POD was recognized in 2005. The POD investigation has greatly improved our understanding of the ecology of pelagic fishes in the estuary, especially delta smelt. While the mechanisms responsible for long-term and POD-era declines of the species probably vary by species, it appears very unlikely that they are independent of one another. Rather, the decline appears to be the result of multiple interacting causes, including some that are related to water project operations and others that are not (USBLM 2008).

For three pelagic species (delta smelt, longfin smelt, and striped bass), a substantial portion of the abundance patterns has been associated with variation in Delta outflows (Baxter et al. 2008). Sommer et al. (2007) stated that much of the annual variability in the POD species' populations is associated with hydrology, where typically the lowest abundance has been associated with dry years. Fall midwater trawl abundance indices for the pelagic fishes began to decline around 2000. Abundance indices for 2002–2005 included record lows for delta smelt and young-of-the-year striped bass, and near-record lows for longfin smelt. Low abundance of delta smelt and longfin smelt continued even after the Wet 2006 water year when one would have expected a rebound in their populations. Sommer et al. (2007) describe the current conceptual models regarding factors contributing to the POD, including: (1) stock-recruitment effects (the relationship of adult numbers to subsequent year-class strength), (2) habitat changes associated with water quality, disease, and toxic algae blooms limiting estuarine species, (3) top-down effects on mortality, including predation and entrainment at water projects, and (4) bottom-up effects within the food web (e.g., declines in phytoplankton biomass and important zooplankton such as calanoid copepods) limiting fish abundance. Weak stock-recruitment effects have been reported for delta smelt (Bennett 2005), although other environmental variables and impacts are expected to dominate at most population levels (Sommer et al. 2007). Prominent habitat changes include shifts in seasonal flow patterns due to water supply operations, fall salinity encroachment, turbidity and temperature changes, and presence of pesticides.

2 APPROACH AND ASSESSMENT

The physical processes, habitats, and species of the Delta have been the focus of much study, and the volume of available reports and data poses a challenge for synthesizing information and organizing a discussion of ecosystem functioning. Divergent conceptual models about process-habitat-biotic linkages in a highly altered ecosystem further complicate summarizing what is known about Delta ecology. To help overcome these challenges, this report presents an overview of Delta ecology through a focal species approach to explore the functional linkages among ecosystem processes, resultant habitats, and biotic needs. For each focal species, we identify the different life-history stages that occur in the Delta, the habitats used by each of those life-history stages, the ecological processes that create and maintain those habitats, and the management actions (e.g., changes in the flow regime or reconnection of leveed areas to the Delta hydrology) that influence those ecological processes and habitat conditions.

2.1 Focal Species Selection

Stillwater Sciences has developed a set of criteria and a vetting process for selecting focal species, described in the steps below.

2.1.1 Step 1: The species currently exists, or existed historically, within the target system

The first step of the focal species selection involves determining if a candidate focal species currently exists, or existed historically, within the Delta. Species that currently occur in the Delta demonstrate an adaptation to current habitat conditions, so that the conservation and enhancement of existing habitat would likely not pose a threat to an existing population. This step also allows for the potential re-introduction of an extirpated species, which can be a goal of a restoration program.

Because many ecosystems currently support non-native species, the first step of the vetting process does not eliminate non-native species from consideration as a focal species. Non-native species can serve as valuable focal species, especially if they are strong interactors in the system, by clarifying or increasing our knowledge of the environmental changes that have conferred a competitive advantage to them. Such knowledge can assist the design of management actions that reduce that competitive advantage. Though it is often infeasible to eradicate a non-native species once it has become widely established, management actions may help to control the abundance or distribution of targeted non-native species so that their ecological effects are reduced.

2.1.2 Step 2: Is the species listed as endangered or threatened?

The second step of the focal species selection acknowledges that the recovery of listed species constitutes a high social priority, both economically and ecologically. It also recognizes that listed species are often at the center of resource management conflicts, so that recovery of the species can be an important management goal as a means of reducing conflict with, and restrictions on, human activities. The endangered and threatened species that occur in an ecosystem often serve as focal species; however, the number of listed species that occur in the Sacramento River corridor generally precludes the selection of every listed species as a focal species. One of the functions of the focal species approach is to facilitate the synthesis, analysis, and organization of information by engaging a manageable number of species; however, this process can be undermined by the selection of too many focal species.

2.1.3 Step 3: Additional criteria for non-listed species

The third step of the selection process provides much of the information used to compare candidate focal species by applying a series of criteria to non-listed species. It is often important to include non-listed species in the group of focal species in order to capture potential ecosystem changes that are reducing their populations, which could necessitate future protection that would exacerbate resource conflicts.

- **Other special-status designation**. The first criterion queries whether an unlisted species has some other special-status designation (e.g., species of concern). For example, NMFS has designated both the Central Valley Fall-run and Late Fall-run Chinook salmon ESUs as species of concern because of recent population trends, indicating that further reductions in escapements could necessitate future listing and protection (NMFS 2004b).
- **High economic or public interest value**. The second criterion recognizes the economic or social importance of certain species, such as species that are the focus of commercial fisheries (e.g., salmon) and sportfish that are the focus of recreational angling (e.g., steelhead, sturgeon).
- **Narrow habitat requirements**. The third criterion tests whether a species has narrow habitat requirements such that loss of that habitat type would pose a significant threat to the health of the population. For example, delta smelt require a narrow range of salinity during various life stages (Bennett 2005)
- **Weak disperser**. The fourth criterion identifies species that have difficulty dispersing to new areas, which prevents a species from establishing new sub-populations that can help mitigate the loss of an existing breeding/spawning population from a catastrophic event.
- **Strong Interactor**. The fifth criterion indicates that particular species can significantly influence natural communities through ecological interactions with other species. For example, a species may serve as an important prey species for a number of other species, such that a decline in its population can reduce the food base for other species and depress the abundance of an entire community. For example, non-native species can change the very nature of an ecosystem (e.g., overbite clam converting portions of the Bay-Delta estuary from a pelagic to a benthic system).
- **Loss of habitat**. The sixth criterion addresses a factor that often contributes to reductions in the abundance and/or distribution of a species—habitat loss and degradation as a

function of anthropogenic changes to the system. For example, all salmonids in the Central Valley have experienced dramatic losses of spawning habitat as a function of large water supply dams that have eliminated access to historical spawning grounds, as well as losses in food supply in the Delta.

- **Local and/or regional population declines**. The final criterion acknowledges that population abundance and distribution provide two of the key metrics for assessing the health of a species. Local and regional population declines provide a warning signal that a system is undergoing change, thus providing a stimulus for identifying the factors affecting a population. Continued population declines can also necessitate eventual protection under the Endangered Species Act, which often intensifies conflicts over natural resources.

2.1.4 Step 4: Availability of information

If a species satisfies at least one of the criteria identified in Step 3 of the selection process, then it passes to Step 4, in which the information about a species is assessed. At a minimum, we must know the general habitat requirements and life history stages of a species for it to function as a focal species. Although it is preferable if this information is specific to the Delta, knowledge of how a species interacts with its environment in a similar system is also of value. The more detailed knowledge that we have of a species, then the greater utility that species can provide as a focal species. Ideally, we will have quantitative data about the abundance, distribution, and habitat preferences of a species. For example, a great deal of study has been focused on Delta smelt populations, distribution, habitat requirements, reliance on Delta inflow and outflow, and other life history requirements.

2.1.5 Step 5: Ranking of species and selection

The information produced for each candidate species in Steps 2, 3 and 4 facilitates a general ranking of species in Step 5 of the selection process. Rankings can be either nominal (e.g., high, medium, low priority) or ordinal (e.g., 1st, 2nd, 3rd). To select focal species for this report, we used nominal rankings. Species receiving high rankings needed to be officially listed (Step 2) or meet one or more criteria listed under Step 3, as well as having adequate information available (Step 4) to be selected (Step 5). A critical aspect of the ranking process in this step was an assessment of whether there was sufficient existing published information on the species (Step 4) that allowed the development of quantitative relationships to Delta inflow or outflow.

2.2 Selected Focal Species

The rankings from Step 5 are used to inform the final selection process in Step 6. Selection of the final suite of focal species can include species that, ideally, represent different assemblages or guilds and species that utilize a broad range of habitat types within the study reach, so that the synthesis and analysis of information will be relevant to a broad range of species.

Selecting too many focal species can undermine the purpose of a focal species approach, which is to focus and organize the discussion and analysis in a manner that is still relevant to a broad array of species. As a result, we determined that a total of four to six species would constitute a manageable suite of focal species that would cover a broad range of habitat types that occur in the river corridor. For this Report, we have selected five focal species that we hypothesized were likely to be responsive to changes in the Delta flow regime:

- Chinook salmon (*Oncorhynchus tshawytscha*)

- striped bass (*Morone saxatilis*)
- delta smelt (*Hypomesus transpacificus*),
- Sacramento splittail (*Pogonichthys macrolepidotus*), and
- overbite clam (*Corbula amurensis*)

It must be emphasized that this is by no means an exhaustive list of all conservation targets within the Delta. However, the selection of these focal species provided a logical starting point for this report while covering a relatively wide range of habitats and ecological processes that occur in the Delta. The life history timing of the focal species addressed in the report are shown in Figure 5 and described further below.

2.2.1 Chinook salmon (*Oncorhynchus tshawytscha)*

2.2.1.1 Species summary and affected life stages

The Sacramento-San Joaquin Delta functions as a migration corridor and potential rearing area for adult and juvenile Chinook salmon originating in the Sacramento and San Joaquin River basins. The Sacramento River basin supports four runs of Chinook salmon: winter, spring, fall, and late-fall. The San Joaquin River basin currently supports fall-run (and possibly late-fall run) Chinook salmon in its lower tributaries, the Merced, Tuolumne, and Stanislaus rivers, supported in part by hatchery stock in the Merced River (Williams 2006). The winter-run consists of a single population spawning in the Sacramento River mainstem below Keswick Dam. The other runs consist of populations that spawn in multiple tributaries. Three Evolutionarily Significant Units (ESUs) are represented in the combined basins: Sacramento River Winter-Run (federally endangered), Sacramento River Spring-Run (federally threatened), and Central Valley Fall and Late-Fall (species of concern). Because these runs exhibit a variety of different life-history strategies, anthropogenic activities in the basin have affected each of the runs differently.

In many systems, juvenile Chinook spend up to several months in estuaries, feeding and growing before entering the ocean (Healey 1991); in productive estuaries, this strategy can result in ocean entry at a larger size and improved survival, likely by reducing predation at this critical juncture. Although and marsh and floodplains may have been extensive enough in the Delta under historical conditions (Atwater et al 1979) to support high juvenile production in an environment where there were fewer predators, Delta marsh habitats and native fish communities have undergone such extreme changes from historical conditions (Kimmerer et al 2008) that few locations in the eastern and central Delta provide suitable habitat for rearing Chinook salmon. Dor example, substantial numbers of fry may be found in the Delta from January through March, but relatively few were found the remaining months of the year during the 20 years of sampling from 1977 to 1997 (Brandes and McLain 2001). The annual abundance of fry (defined as <2.8 in [70 mm] fork length) in the Delta during this period appears related to flow, with the highest numbers observed in wet years (Brandes and McLain 2001).

In the Sacramento/San Joaquin system some juvenile Chinook salmon rear on seasonally inundated floodplains in the winter. Sommer et al. (2001a) found higher growth and survival rates of Chinook juveniles that reared on the Yolo Bypass floodplain than in the mainstem Sacramento River, and Moyle (2000) observed similar results on the Cosumnes River floodplain. On the Yolo Bypass, bioenergetic modeling suggested that increased prey availability on the floodplain was sufficient to offset increased metabolic demands from higher water temperatures (9°F [5°C] higher than mainstem). Sommer et al. (2001a) believe that the well-drained topography (floodplains with few pits and depressions) may help reduce stranding risks when flood waters recede.

Bell (1958, as cited in Healey 1991) suggests that the timing of yearling smolt outmigration corresponds to increasing spring discharges and temperatures. Photoperiod may also be important, although the relative importance of various outmigration cues remains unclear (Bjornn 1971, Healey 1991). High discharge may moderate some predation on juvenile salmon through mechanisms such as increasing turbidity and reducing visibility for sight-oriented predators like largemouth bass. A faster downstream migration rate also shortens the amount of time juvenile salmon are exposed to predators (Berggren and Filardo 1993).

2.2.1.2 Effects of Delta hydrodynamics

Delta flow patterns affect adult Chinook salmon migration to upstream spawning areas and tributaries as well as juvenile outmigration to the sea. River discharge is an important migration cue for adult salmonids attempting to enter their natal streams to spawn, and increases in discharge may improve water quality and habitat conditions in the Bay/Delta, particularly dissolved oxygen in the Stockton Deep Water Ship Channel, allowing adult salmon to successfully migrate through the Delta. Discharge is also a key factor for smolts outmigrating to sea from their spawning and rearing areas.

Sacramento River basin Chinook salmon may experience a number of adverse impacts depending on the operation of the Delta Cross Channel. These gates are periodically closed between November and June to improve survival of salmon migrating down the Sacramento River. Substantial adverse impacts to San Joaquin River basin Chinook salmon also occur in the south Delta due to export operations (NMFS 2009a).

Salmonids produced in San Joaquin River tributaries must migrate through the lower San Joaquin River through the Delta and Bay to the sea. Historically, the Delta consisted of low-lying islands and marshes that flooded during high spring flows. The current Delta consists of islands lying generally below sea level that are surrounded by levees to keep out water. Federal and state pumping plants near Tracy send water from the Delta to various parts of the state utilizing a network of storage reservoirs and aqueducts. Within the central and southern Delta, the diversion facilities have a large effect on channel net flow direction and magnitude, including Old and Middle rivers, the Grant Line Canal, and the San Joaquin River.

Direct losses of juvenile salmonids within the Delta, occur primarily at the CVP and SWP as a result of entrainment into pumping facilities, predation in pump forebays (e.g., Clifton Court Forebay), predation within the Delta, and from fish salvage operations at the pumping facilities. As part of the VAMP, in years when spring flow in the San Joaquin River is less than 7,000 cfs, a temporary barrier is placed at the head of Old River to prevent outmigrating San Joaquin Basin salmon from migrating directly down the Old River channel toward the pumps (See Section 1.3.1). However, under the current USFWS (2008) biological opinion, placement of the HORB is prohibited for the protection of Delta smelt.

Winter Run

Most juvenile winter-run Chinook reach the Delta between January and April, when they can pose a conflict with Delta pumping operations designed to increase South-of-Delta storage during winter months when conflicts with protections for Delta smelt are reduced.

Several studies suggest that juvenile rearing habitat may be a key limiting factor for winter-run Chinook (e.g., Bartholow 2005). Extensive rearing habitat would have been available for winter-run Chinook under historical conditions because of their life history timing. Prior to the construction of large water supply dams in the basin, high flows between January and March often inundated extensive floodplains along the Sacramento River (Sommer et al. 2001b). These shallow-water, low-velocity areas tend to be highly productive (Junk et al. 1989), which confers bioenergetic advantages that promotes higher growth rates and, therefore, higher survival rates. The extent of historical flooding in the Sacramento River valley was vast (Kelley 1989), and the timing of juvenile salmon outmigration would have allowed them to take advantage of these prolonged periods of floodplain inundation.

Previous research in the Sacramento River indicates that inundation of the flood bypasses that flank the Sacramento River enhances growth and survival of juvenile salmonids (Sommer et al. 2001a), but bypass flooding is contingent on infrequent high flow events that are usually tied to flood management operations. Winter-run fry emerge and disperse downstream primarily between August and November when there is relatively little floodplain or bypass inundation, so the population does not benefit from the periodic expansion of shallow water rearing habitat that can contribute to strong year classes of other salmonids.

Spring Run

Spring-run Chinook fry and juvenile rearing takes place in the natal streams, the mainstem of the Sacramento River, inundated floodplains (including the Sutter and Yolo bypasses), and the Delta. Very little information is available on estuarine rearing of spring-run Chinook (NMFS 2004a). NMFS (2004a) postulates that, because spring-run Chinook yearling outmigrants are larger than fall-run Chinook smolts, and ready to smolt upon entering the Delta, they may spend little time rearing in the estuary. Most have presumably left the estuary by mid-May (CDFG, unpublished data).

Fall Run

Fall-run Chinook in the Sacramento River generally exhibit two rearing strategies: migrating to the lower river or Delta as fry, or remaining to rear in the gravel-bedded reach for about three months and then smolting and outmigrating. The highest abundances of fry in the Delta are observed in wet years (Brandes and McLain 2001). Fall Chinook fry rear during a time and in a location where floodplain inundation is most likely to occur, thereby expanding the amount of rearing habitat available. Relative survival of fry appears to be higher in the upper Sacramento River than in the Delta or bay, especially in wet years (Brandes and McClain 2001).

One potential disadvantage of early emergence and emigration and rearing in mainstem channels and the estuary is the possibility of higher predation mortality because of the relatively small size of emigrants. However, fall Chinook fry exhibit several characteristics to combat predation mortality. Predators often occupy deep pools in mainstem channels, so fry generally use shallow water habitat found along channel margins or in runs and riffles to avoid predators. Because rearing habitat is not limiting for fall Chinook fry, they do not exhibit territorial behavior, which allows them to rear, smolt, and out-migrate in higher densities. By emigrating synchronously in schools, rather than as individuals, fall Chinook fry and smolts can swamp potential predators to avoid significant losses to predation, and by emigrating in late spring, they have the advantage of higher discharge fueled by early snowmelt, which can reduce their exposure to predation.

2.2.1.3 Effects of Delta water quality and salinity

In general, Chinook salmon appear capable of migrating upstream under a wide range of temperatures. Bell (1986) reported that salmon and steelhead migrate upstream in water temperatures that range from 3–20ºC (37–68°F). Bell (1986) reports that temperatures ranging between 3–13ºC (37–55°F) are suitable for upstream migration of spring-run Chinook salmon, and 10–19ºC (50–66°F) for upstream migration of fall-run Chinook salmon. In a review of available literature, Marine (1992) reported a water temperature range of 6–14ºC (43–57°F) as optimal for pre-spawning broodstock survival, maturation, and spawning for adult Chinook salmon.

Although growth rates of juvenile Chinook salmon may be high at temperatures approaching 19°C (66°F), cooler temperatures may be required for Chinook to successfully complete the physiological transformation from parr to smolt. Smoltification in juvenile Sacramento River fall-run Chinook was studied by Marine (1997, as cited in Myrick and Cech 2001), who found that juveniles reared under a high temperature regime of 21–24°C (70–75°F) exhibited altered and impaired smoltification patterns relative to those reared at low 55–61°F (13–16°C) and moderate 17–20°C (63–68°F) temperatures. Some alteration and impairment of smoltification was also seen in the juveniles reared at the moderate temperatures. Chronic exposure to high temperatures may also result in greater vulnerability to predation. In this same study by Marine (1997), Sacramento River fall-run Chinook salmon reared at the highest temperatures (21–24°C) 70–75°F) were preyed upon by striped bass more often than those reared at low or moderate temperatures. Consumption rates of piscivorous fish such as Sacramento pikeminnow, striped bass, and largemouth bass increase with temperature, which may compound the effects of high temperature on juvenile and smolt predation mortality. Juvenile growth rates are an important influence on survival because juvenile salmon are gape-limited predators that are themselves subject to gape-limited predation by larger fish. Faster growth thus both increases the range of food items available to them and decreases their vulnerability to predation (Myrick and Cech 2004).

2.2.1.4 Biotic interactions

In addition to mortality resulting from the SWP/CVP export facilities, abundance and survival of salmonids are influenced by an interconnected complex of Delta environmental factors, including food and habitat availability and quality, water quality, and distribution of predators and conditions affecting susceptibility to predation. All of these factors are also affected to some degree by Delta hydrodynamics (Bennett and Moyle 1996).

Adult largemouth bass feed on a variety of prey, including fish, crayfish, and amphibians and are capable of changing foraging behavior based on prey availability, habitat type, experience, and size (Schindler et al. 1997, as cited in Moyle 2002). They may become completely piscivorous by the time they attain lengths of 3–4 inches (Keast 1970, Clady 1974, Kramer and Smith 1962; all as cited in Werner et al. 1977). Their ability to forage on a wide variety of prey under many conditions, and their broad environmental tolerances allow largemouth bass to play the role of a keystone predator in many aquatic environments (Moyle 2002). These fish may cause changes throughout the aquatic ecosystem, primarily through reducing populations of their preferred prey. In the large, low-elevation reaches of the valley floor, native cyprinids do not persist where populations of largemouth bass are present, even with continual colonization from upstream areas (Moyle 2002).

Largemouth bass in the Delta appear to be expanding coincident with an increase in the exotic aquatic weed *Egeria densa*, which provides cover for bass and their prey (Moyle 2002). Predation within the Sacramento and San Joaquin rivers and tributaries during smolt outmigration is expected to be most important during years when smolt production is relatively low because of the short amount of time that smolts are exposed to the predators, and the fact that predator populations are not likely to respond to changes in smolt abundance from year to year.

2.2.1.5 Selection rationale

Chinook salmon are a rather obvious selection as a focal species. Chinook salmon are native to the Delta (Step 1). Winter-run Chinook salmon are listed as endangered, and spring-run Chinook salmon as threatened by the federal and state Endangered Species Acts (Step 2). The two remaining runs (fall-run and late fall-run) have been designated as species of concern by NMFS (Step 3a). All of the salmon runs have high economic value because they support commercial fisheries (Step 3b). Each run also has high public interest value, both as charismatic megafauna that appeal to the broad public and as a target of recreational angling (Step 3). Numerous human activities have reduced the extent and quality of habitats that Chinook salmon used historically (Step 3). All salmon runs in the Sacramento and San Joaquin watersheds have experienced general population declines in the last 35 years (Step 3), which has stimulated numerous restoration and recovery efforts. There is a significant volume of information available for the different runs of Chinook salmon that occur in the Delta because salmon passage and survival has been a primary object of study in the Delta (Step 4). All of these factors combine to produce a high priority ranking for Chinook salmon and to explain their selection as a focal species for this report (Step 5).

2.2.2 Striped bass (*Morone saxatilis*)

2.2.2.1 Species summary and affected life stages

Striped bass are native to the Atlantic Coast of North America that were introduced to California in 1879. Striped bass are a large (> 1 m), long-lived (> 10 years) species. Striped bass is widespread in the San Francisco Estuary watershed as juveniles and adults. Striped bass move regularly from salt to fresh water. They require a large body of water for foraging on fish (usually estuaries or large reservoirs) and large cool rivers for spawning. Striped bass spend most of their life in estuaries. Adult striped bass are distributed mainly in the lower bays and ocean during the summer, and in the Delta during fall and winter. Spawning takes place in the spring (April–June) at which time striped bass swim upstream to spawning grounds. In the Sacramento River, most spawning takes place between RM 77.7 and RM 121.2 (Moyle 2002). After spawning, adults move downstream into the Delta and bays (Blunt 1962).

Female striped bass mature between 4 and 6 years and can spawn every year. In the Delta and Sacramento and San Joaquin rivers, spawning occurs from April to June at temperatures between 14°C and 21°C. Eggs are free-floating and negatively buoyant, and hatch in about two days as they drift downstream, with larvae occurring in shallow and open waters of the lower reaches of the Sacramento-San Joaquin rivers, the Delta, Suisun Bay, Montezuma Slough, and Carquinez Strait. Location of spawning varies based on temperature, flow, and salinity (Turner 1972). In the Yolo Bypass, Harrell and Sommer (2003) observed that flow pulses immediately preceding floodplain inundation triggered upstream movement of striped bass, resulting in successful spawning. During low flow years, spawning occurs within the Delta itself.

Newly hatched striped bass feed off their yolk sac for up to 8 days (Wang 1986), after which they start feeding on zooplankton. Larvae in the Sacramento River migrate into the water column from April to mid-June (Stevens 1966). In the Sacramento River, embryos and larvae are carried into the Delta and Suisun Bay (Moyle 2002). In the San Joaquin River, embryos remain in the same general area where spawning took place, as freshwater outflow is balanced by tidal currents (Moyle 2002). When larval bass from both rivers begin to feed, they are concentrated in the most productive part of the estuary—where freshwater and salt water meet or near X2 (Moyle 2002).

2.2.2.2 Effects of Delta hydrodynamics

Striped bass eggs, larvae, and juveniles are impacted by direct entrainment into CVP and SWP export facilities during the first year of life from April through fall, and sometimes during winter. The impact on eggs and young fish occurs from April to July, with further impacts on larger juveniles through summer and fall. Under current conditions, the population is likely to continue to decline in the absence of a stocking program. In recent years, young striped bass abundance has remained low despite higher-than-average delta outflows and low export rates, both of which were conducive to strong year classes in the past.

2.2.2.3 Effects of Delta water quality and salinity

Striped bass are tolerant of a wide range of environmental conditions, surviving temperatures up to 25°C (77ºF) (and up to 34°C [93ºF] for shorter periods), rapid temperature swings, low oxygen levels between 3–5 mg/L, and high turbidity (Moyle 2002). Hassler (1988), in a summary of environmental tolerance studies, reported that striped bass could tolerate dissolved oxygen concentrations ranging from 3–20 mg/L, and a pH range of 6–10, though the optimum level ranged from 6–12 mg/L and 7–9 respectively. The information compiled by Hassler (1988) suggested juveniles preferred rearing temperatures of 24–26°C (60.8–66.2°F). As striped bass grow, their temperature preference shifts towards cooler water (Hill et al. 1989). Adult striped bass appear to prefer water temperatures ranging from 20–24°C (68–75.2°F) (Emmett et al. 1991, as cited in SWRI 2003).

Typical of an anadromous species, salinity tolerance of striped bass also changes with age (Lal et al. 1977, as cited in Hassler 1988; Hill et al. 1989). Eggs and larvae reportedly thrive at salinities less than 3 psu (Mansueti 1958, Dovel 197l, both as cited in Hill et al. 1989), and can tolerate salinities of 8–9 psu without ill effects (Albrecht 1964, Morgan and Rasin 1973, both as cited in Hill et al. 1989). Adults can apparently tolerate salinities from 0–34 psu or more (Rogers and Westin 1978, as cited in Hassler 1988), with a range of 10–20 psu reported as optimal for larger juveniles (Bogdanov et al. 1967, as cited in Hassler 1988).

Despite striped bass's adaptability to a wide range of environmental conditions, they are at the top of the food chain and have a relatively long lifespan, and, thus are particularly prone to bioaccumulation of toxic substances in their tissues (Moyle 2002). Young et al. (1994) link high levels of toxic material in the livers of striped bass to annual summer die-offs of larger fish. Larval bass are also impacted by pesticides due to their susceptibility and occurrence in pesticide laden water (Moyle 2002). Bailey et al. (1994) presented evidence for mortality of young striped bass due to discharge of agricultural drainage water containing rice herbicides into the Sacramento River, which eventually led to new discharge regulations (USBR 2008). Similarly, Bennett et al. (1995) found about a third of striped bass larvae had liver damage at lethal levels, presumably due to herbicides. Preliminary evidence suggests that contaminants and disease may impair striped bass. Ostrach et al. (2008) found high occurrence and severity of parasitic infections, inflammatory conditions, and muscle degeneration in young striped bass collected in 2005, although levels were lower in 2006. Several biomarkers of contaminant exposure including P450 activity (detoxification enzymes in liver), acetylcholinesterase activity (enzyme activity in brain), and vitellogenin induction (presence of egg yolk protein in blood of males) were also reported from striped bass collected in 2006 (Ostrach et al. 2008).

2.2.2.4 Biotic interactions

Striped bass are pelagic, opportunistic predators, feeding on invertebrates and fishes. They tend to exhibit a roving school foraging strategy (Pickard et al. 1982). Larval and juvenile striped bass feed on invertebrates such as copepods or opossum shrimp. In the San Francisco Bay area, juvenile bass form small schools or feeding groups (Skinner 1962) with specific prey varying with fish size, habitat, and season (Hill et al. 1989).

Striped bass are a top predator in the Delta and are considered major predators on fish (Thomas 1967, as cited in Moyle 2002). Fish become important in the diet of juveniles when they reach a fork length (FL) of 130–350 mm, especially late in the summer when young-of-the-year striped bass and shad become available (Moyle 1976). Striped bass are primarily piscivorous as subadults, when they reach 250–470 mm FL (approximately age 2+). Stevens (1966) found that the importance of fish in the diet of subadult (260–470 mm FL) and adult (>380 mm FL) striped bass in the Sacramento-San Joaquin estuary varied seasonally. Fish were most prevalent in the diet of subadults in fall, and occurred most frequently in the diet of adults in fall and winter. Adult striped bass feed primarily on smaller striped bass, threadfin shad, and juvenile salmonids, as well as pelagic ocean fishes (Moyle 2002). Striped bass can successfully switch to feeding on novel prey (Moyle 2002). Striped bass are considered important predators on juvenile salmon in the Sacramento River (Tucker et al. 1998, Moyle 2002). Average populations of 1.7 million adults during the late 1960s to early 1970s, and 1.25 million adults during 1967-1991 (USFWS 1995), likely exerted considerable predation pressure on outmigrating juvenile salmon (Yoshiyama et al. 1998). The impact of striped bass on delta smelt and Sacramento splittail is not known (Moyle 2002). Delta smelt were occasional prey fish for striped bass in the early 1960s (Turner and Kelley 1966) but went undetected in a recent study of predator stomach contents (Nobriga and Feyrer 2007). Striped bass are likely the primary predator of juvenile and adult delta smelt given their spatial overlap in pelagic habitats (NMFS 2009).

Though striped bass may commonly exhibit a roving school foraging strategy (Pickard et al. 1982), they appear to take advantage of prey that is concentrated at screened diversions or pumps, and may be partially responsible for the decline of some native fishes, including salmon, thicktail chub, and Sacramento perch (Tucker et al. 1998). Striped bass are considered to be a primary cause of juvenile salmon mortality at the state water-export facility in the south Delta (USFWS 1995, as cited in Yoshiyama et al. 1998). Tucker et al. (1998) observed striped bass preying heavily on juvenile Chinook salmon that passed through the diversion facilities at Red Bluff Diversion Dam on the Sacramento River. Juvenile chinook salmon were found by Thomas (1967) to be a major food item in the diet of striped bass in the spring and early summer during smolt outmigration through the Sacramento and San Joaquin rivers and Delta.

The introduction of the overbite clam (see below) in the 1980’s has been associated with large decreases in zooplankton and phytoplankton densities in San Francisco Bay and the western Delta (Carleton et al.1990), which has decreased the amount of food available for larval and juvenile striped bass. The population responses of juvenile striped bass to winter-spring outflows changed after the overbite clam invasion as young striped bass relative abundance stopped responding to outflow altogether (Sommer et al. 2007). In addition to decreased copepod densities, the principal historic copepod food source, *Eurytemora affinis*, for larval and juvenile striped bass has largely been replaced by alien copepod species that may be energetically less desirable (Meng and Orsi 1991 as cited by Moyle 2002).

Within the Delta, adult striped bass feed primarily on threadfin shad and juvenile striped bass. Thus when shortages of alternate prey exist, survival rates of juvenile bass may decrease as they become increasingly important to adult diets, resulting in an unusually high response to decreased productivity in the Delta (Moyle 2002).

2.2.2.5 Selection rationale

Striped bass are a species that currently occur in the Delta and are adapted to the current habitat conditions (Step 1). In addition, conservation and enhancement of striped bass habitat would not likely pose a threat to an existing population (delta smelt) since larval and juvenile life stages of these fish are similar (Step 1). Striped bass have a high economic and public interest value, is a strong interactor with other species, and have experienced population declines (Step 3). There is an abundance of habitat and abundance information for this species (Step 4). This species received a high ranking for selection as a focal species due to it occurring in and being adapted to the Delta (Step 1), has economic and public value (Step 3), and there being a great deal of information available on habitat and abundance, was selected as a focal species (Step 5).

2.2.3 Delta smelt (*Hypomesus transpacificus*)

2.2.3.1 Species summary and affected life stages

Delta smelt are endemic to and resident in the Delta and San Francisco Bay, typically downstream of Isleton on the Sacramento River and downstream of Mossdale on the San Joaquin River, and are seasonally distributed in Suisun Bay (Moyle 2002). Delta smelt abundance and geographic distribution are dependent upon freshwater outflows and the salinity of the Bay and Delta (Herbold et al. 1992).

Delta smelt have an annual, 1-year lifecycle. They typically require low-salinity, shallow open-water habitat in the estuary (Moyle 2002). They are found at 0–18 psu surface salinity (Baxter et al. 1999), although most are caught at salinities < 6.0 psu, with older juveniles and adults being found at the higher end of that gradient (Bennett 2005). Delta smelt feed primarily on planktonic copepods, cladocerans, and amphipods (Baxter et al. (2008). In September or October delta smelt begin a slow upstream migration toward freshwater spawning areas in the upper Delta, a process which may take up to several months (Moyle 2002). Adequate flows and suitable water quality are needed to attract migrating adults in the Sacramento and San Joaquin River channels and their associated tributaries, including Cache and Montezuma sloughs and their tributaries (USFWS 1996, as cited in USFWS 2001). Spawning can occur from late February to July (Wang 1986, Sweetnam and Stevens 1993, both as cited in Moyle 2002), although most spawning takes place from early April to mid-May (Moyle 2002).

Delta smelt spawn in shallow water along edges of rivers and sloughs subject to tidal influence (USFWS 2001). Based upon the occurrence of ripe females and yolk-sac larvae, spawning areas during dry and typical years are found in the north Delta reaches of the Sacramento River (Moyle 2002). The specific geographic area critical to the maintenance of suitable rearing habitat for delta smelt extends eastward from Carquinez Strait, up the Sacramento River to its confluence with Three Mile Slough (at river mile 9), and south along the San Joaquin River including Big Break (USFWS 1996, as cited in USFWS 2001). Ideal rearing habitat conditions are typically shallow water areas most common in Suisun Bay, which provides vital nursery habitat for delta smelt (Bennett 2005). When the mixing zone is located in Suisun Bay, it provides optimal conditions for algal and zooplankton growth, an important food source for delta smelt (Moyle 2002). When freshwater outflow is low, the mixing zone moves further up into the deeper, narrow channels of the Delta and Sacramento River, reducing food availability and total area available to the smelt (Moyle 2002).

2.2.3.2 Effects of Delta hydrodynamics

Larvae and young juveniles are affected by entrainment during the spring and early summer. As delta smelt become adults, they migrate downstream to brackish water areas in the fall and winter and are considered less vulnerable to diversion effects. Pre-spawning adults migrating back into freshwater to spawn in the late winter and early spring become vulnerable to entrainment effects once again.

The quantity and suitability of delta smelt habitat increases with higher outflow (Bennett 2005). When the near-bottom mixing zone is contained within Suisun Bay and when adequate outflow from both the Sacramento and San Joaquin rivers have allowed downstream movement, young delta smelt are dispersed more widely throughout a large expanse of shallow-water and marsh habitat than when the isohaline is upstream in the narrower, deeper Delta sloughs and channels. If smelt use this habitat and their distribution is wider and shifted downstream, subsequent entrainment in the winter will be reduced. Habitat conditions suitable for transport of larvae and juveniles are needed as early as February 1 and as late as August 31, because the spawning season varies from year to year and starts as early as December and extends until July (USFWS 1996, as cited in USFWS 2001). Adequate river flow is necessary to provide this transport to Suisun Bay and to maintain rearing habitat (USFWS 1996, as cited in USFWS 2001).

Spawning adults become vulnerable to entrainment effects during the winter and spring (Kimmerer 2008). Combined particle tracking models and 20 mm survey distributions suggest delta smelt population losses from entrainment at the Banks and Jones pumping plants are directly correlated with X_2 position and might reach an estimated 20–40% when X_2 moves landward of 60 km (37 mi). Maintaining X_2 in a favorable location (i.e., away from Central and South delta) during the spawning period of delta smelt reduces their exposure to the effects of reverse flow in the southern Delta channels (Resources Agency 2007). Larvae and young juveniles typically follow the direction of spring flows downstream into the estuary. Reverse flows have been shown to direct larvae and young juvenile smelt toward the pumps and salvage of adult delta smelt is very low or zero during years when Old and Middle River flows are positive (i.e., away from the export facilities) (Resources Agency 2007). A favorable location for X_2 during this period is defined as seaward of 40 mi (65 km) from the Golden Gate Bridge based on a 14-day running average (Resources Agency 2007).

2.2.3.3 Effects of Delta water quality and salinity

There is a close association between delta smelt abundance and surface salinity of 0–18 psu (psu, or practical salinity units, are roughly equivalent to parts per thousand, or psu), suggesting that their distribution is determined largely by the interaction with salinity conditions as determined by tidal currents, freshwater outflow, and diffusion, rather than by geography (Bennett 2000, Moyle 2002, Bennett 2005). For instance, water clarity and salinity were found to be the most reliable abiotic predictors of delta smelt abundance during the summer and fall (Feyrer et al. 2007, Nobriga et al. 2008). In addition, geographic distribution for particular life stages can vary dramatically between dry and wet years. Thus, in low outflow years, delta smelt occur primarily in the lower Sacramento River, with the area near Decker Island consistently exhibiting greatest catch over time. In years of very high outflow, however, their distribution extends into San Pablo Bay and the Napa River (Bennett 2000).

The abundance of many local estuarine taxa has tended to increase in years when flows into the estuary are high and the X_2 location is pushed seaward (Jassby et al. 1995), implying that over the range of historical experience the quantity or suitability of estuarine habitat increases when outflows are high. Feyrer et al. (2007) reported that fall environmental quality has declined over the long-term in the core range of delta smelt, including Suisun Bay and the Delta. This decline was largely due to changes in salinity in Suisun Bay and the western Delta, and changes in water clarity within the Delta. Baxter et al. (2008) reported the long-term environmental quality declines for delta smelt and striped bass are defined by a lowered probability of occurrence in samples based on changes in specific conductance and Secchi depth.

2.2.3.4 Biotic interactions

Planktonic copepods, cladocerans, amphipods, and, to a lesser extent, insect larvae, are the primary prey items for delta smelt (Moyle 2002). Delta smelt larvae have more specific prey-size requirements for first feeding. In a study conducted in the northern estuary and Delta, Lott (1998) found that smaller size classes of delta smelt tended to consume more nauplii and juvenile copepods, while larger size classes consumed more adult copepods. It appears that food availability after yolk-sac absorption is critical in determining success of delta smelt (Nobriga 1998). However, it is not known if a limited food supply contributes to reduced year-class success and therefore has population-level implications.

The overbite clam (see below) has been associated with large changes in phytoplankton abundance in San Francisco Bay and the western Delta (Carleton et al.1990), causing a decrease in abundance of other species that depend on phytoplankton (zooplankton) for food. Due in part to its efficiency in filtering water, the clarity of Suisun Bay and delta waters has increased. This has affected delta smelt by reducing food supply and increasing its susceptibility to predation.

2.2.3.5 Selection rationale

Early in this project, we determined that delta smelt was likely to be selected as a focal species. This is a native species and as such the conservation and enhancement of existing habitat would not pose a threat to other native species (Step 1). Delta smelt are listed as threatened under both the Federal and state ESAs (Step 2). Delta smelt have relatively narrow habitat requirements (salinity and turbidity range), serve as a prey species, and have suffered a loss of habitat as a result of decreases in water quality and water diversions (Step 3). There is a great deal of information available about this species (Step 4). This species received a high ranking for selection as a focal species due to it being a native species that has attained threatened status under the ESA (Steps 1 and 2), has narrow habitat requirements (Step 3), and has an abundance of information relating to it habitat requirements, population abundance, and threats to its existence (Step 4). All of these factors support its inclusion as a focal species (Step 5).

2.2.4 Sacramento Splittail (*Pogonichthys macrolepidotus*)

2.2.4.1 Species summary and affected life stages

Sacramento splittail are a relatively long-lived cyprinid species found primarily in marshes, turbid sloughs, and slow-moving river reaches. They are endemic to the Sacramento-San Joaquin drainage, including the Delta, Suisun Bay, portions of the Sacramento-San Joaquin estuary (Moyle 2002). San Pablo Bay is currently the downstream-most area where splittail are found (Sommer et al. 2007). Historically, splittail were found in the Sacramento River as far upstream as Redding, in the Feather River to Oroville, and in the American River upstream to Folsom. In the San Joaquin River they were once documented as far upstream as Friant (Rutter 1908). When population levels are low, splittail abundance may be highest in Suisun Marsh and the northern and western Delta, and during years with successful year classes, they may be more evenly distributed throughout the Delta (Sommer et al. 1997, Turner 1966, both as cited in Moyle 2002).

Adult splittail move upstream beginning in late November to late January (Figure 5), to forage in flooded areas along the main rivers, bypasses, and tidal freshwater marsh areas of Montezuma and Suisun sloughs and San Pablo Bay prior to the onset of spawning (Moyle et al. 2000). Feeding in flooded riparian areas prior to spawning may contribute to spawning success and survival of adults after spawning (Moyle et al. 2000).

Spawning occurs from February through June on floodplains inundated by spring high flows, with peak spawning in March and April (Figure 5). Individuals spawn over a protracted period—often as long as several months (Wang 1995, as cited in Moyle 2002). Older fish are believed to begin spawning first (Caywood 1974, as cited in Moyle 2002). Splittail are broadcast spawners with adhesive eggs that attach to submerged vegetation and woody debris, which can make the eggs susceptible to dessication if water levels recede too quickly. Available information indicates that splittail spawn in open areas with moving, turbid water less than 1.5 m (5 ft) deep, amongst dense annual vegetation and where water temperatures are less than about 15° C (59° F) (Moyle et al. 2000). Perhaps the most important spawning habitat in the eastern Delta is the Cosumnes River floodplain, where ripe splittail have been observed in flooded fields with cool temperatures (<15° C [59° F]), turbid water, and submerged terrestrial vegetation (Moyle, Crain, and Whitener, unpublished data, as cited in Moyle et al. 2000).

During extended high flow events in Above Normal and Wet water year types, the Sutter and Yolo bypasses become inundated for extended periods, providing essential habitat for spawning and rearing splittail (Moyle et al. 2000). Sommer et al. (1997) found that the number of days the Yolo bypass was flooded between February and May and the average Delta outflow during the same period were related to the abundance of age-0 splittail from fall mid-water trawl samples. Bypass inundation for a month or more appears to be needed for the development of a strong year-class (Sommer et al. 1997). Stranding of eggs or juveniles in poorly drained floodplains, however, can be a source of mortality.

Survey data indicate that some successful reproduction occurs on a yearly basis, but large numbers of juvenile splittail are produced only when outflow is relatively high. Thus, the majority of adult fish in the population probably result from spawning in wet years (Moyle et al. 2000). Outflow in February–May can explain much of the variability in abundance of juvenile splittail. Not all Wet years result in high splittail recruitment, however, since recruitment success is largely dependent on the availability of flooded spawning habitat. In 1996, for example, most high river flows occurred in December and January, which is prior to the onset of the splittail spawning season (Moyle 2002). Splittail are highly fecund, with the largest individuals potentially producing 100,000 or more eggs, so a small number of large females can produce a large number of young if environmental conditions are favorable (i.e., Delta outflow is high). Fecundity has been found to be highly variable, however, and may be influenced by food supplies in the year prior to spawning (Moyle et al. 2000).

After spawning, adults move into the lower Delta, where they remain until the first autumn rains begin. Although juvenile splittail are known to rear in upstream areas for a year or more (Baxter 1999, as cited in Moyle et al. 2000), most move to the Delta after only a few weeks, often in response to flow pulses (Moyle et al. 2000). The majority of juveniles apparently move downstream into the shallow, more productive Delta from April–August (Meng and Moyle 1995).

Splittail generally mature at 2 years and may live 5–7 years or more (Daniels and Moyle 1983, as cited in Moyle 2002, Sommer et al. 1997). Compared with other North American cyprinids they are relatively long-lived and reach fairly large sizes (Moyle et al. 2000). Mature splittail can exceed 400 mm (15.7 in) standard length (SL), but fish over 300 mm (11.8 in) SL are rare (Moyle et al. 2000). Although the sex ratio of adult fish is reportedly 1:1, the largest and oldest fish tend to be females (Moyle 2002).

2.2.4.2 Effects of Delta hydrodynamics

There is an increase in Sacramento splittail spawning habitat and access to spawning habitat during high flow years where floodplain inundation occurs. The Sutter and Yolo bypasses along the lower Sacramento River appear to provide important splittail spawning areas when inundated (Sommer et al. 1997). At least a month of bypass inundation appears to be needed for the development of a strong year-class (Sommer et al. 1997). Accounts of early fisheries suggested that splittail undertook large seasonal migrations (Walford 1931, as cited in Moyle et al. 2000). Splittail migration now appears closely tied to river outflow. In wet years with increased river flow, adult splittail will still move long distances upstream to spawn, allowing juvenile rearing in upstream habitats. The tidal upper estuary, including Suisun Bay, provides most juvenile rearing habitat, although young-of-the-year may rear over a broader area, including the lower Sacramento River. Because splittail are long-lived, they can conceivably persist through years of unfavorable conditions as long as years with favorable conditions for spawning and rearing occur with enough regularity.

Entrainment of splittail at the SWP and CVP diversions in the Delta are highest in wet years when abundance is high. It does not appear that entrainment results in changes to the splittail population under most conditions (Sommer et al. 1997). Unscreened agricultural diversions in the Delta and Suisun Marsh do not seem to present a significant threat to splittail (Nobriga et al. 2004, as cited in Sommer et al. 2007).

2.2.4.3 Effects of Delta water quality and salinity

Juvenile and adult splittail demonstrate optimal growth at 20°C (68°F), and signs of physiological distress only above 28°C (84.2°F) (Cech and Young 1995, as cited in Winternitz and Wadsworth 1997). Because splittail are adapted for living in brackish waters with fluctuating water quality conditions, they are quite tolerant of high salinities and low dissolved oxygen levels. They are often found in salinities of 10–18 ppt (Moyle 2002), although they appear to prefer lower salinities (Meng and Moyle 1995). Salinity tolerance increases with age, and older adults can tolerate 29 ppt for brief periods (Young and Cech 1996). Young and Cech (1996) found that age-0 splittail were much less tolerant of high salinity levels than older fish, and recommended 16 ppt be used as an approximate salinity requirement for this age class. Splittail can survive very low dissolved oxygen concentrations, 0.6 ppm to 1.2 ppm (mg/l) for young-of-the-year, juveniles, and subadults (Young and Cech 1995, 1996).

Sacramento splittail reproduction could possibly be affected by eating *C. amurensis*, which is a filter-feeder that bioaccumulates toxins such as selenium (P. B. Moyle, pers. comm., 2002). Because they are benthic feeders that consume a lot of detritus, they may be one of the species that is most vulnerable to contaminants (Daniels and Moyle 1983; Feyrer et al. 2003; Moyle et al. 2004); however, very little is known about their potential effects on splittail populations.

2.2.4.4 Biotic interactions

Splittail forage benthically for invertebrates and detrital material (Daniels and Moyle 1983), and were thought to feed extensively on opossum shrimp (*Neomysis mercedis*) (Daniels and Moyle 1983, Moyle et al. 1995, Feyrer et al. 2003). Cladocerans have been documented as important prey of splittail (Stevens 1966). Feyrer and Matern (2000) found that splittail also consume the non-native and invasive clam, *Corbula amurensis*. Terrestrial invertebrate prey may also be important for splittail, especially on flooded areas (Sommer et al. 2004, as cited in Sommer et al. 2007). Larval chironomids may represent a major food source for juvenile splittail (Kurth and Nobriga 2001, as cited in Sommer et al. 2007). Because splittail have a high tolerance for variable environmental conditions and are generally opportunistic feeders, reduced prey abundance is not likely to have major population-level impacts.

The introduction and subsequent spread of *Corbula amurensis* had caused a decline in phytoplankton and invertebrates by the mid-1980s (Jassby et al. 2002; Kimmerer 2002; both as cited in Sommer et al. 2007). Now, Neomysis, once a major food source, is almost absent from the diet of splittail (Feyrer et al. 2003). Splittail populations decreased in Suisun Marsh after the invation of *C. amurensis,* and bivalves and amphipods became much more important in their diet. There is some evidence that fecundity was lower in the 1990s than the 1980s, which could be related to reduction of splittail food resources by *Corbula amurensis* (Feyrer and Baxter 1998).

Inundated areas can provide spawning and foraging habitat and vegetative cover that may aid them in avoiding predation (Sommer et al. 1997), but more recent research suggests that such habitats may not actually function as refuge from piscivorous fish (Sheaves 2001). This same shallow habitat with submerged vegetation is favored by largemouth bass, which become piscivorous at relatively small size and that can easily access floodplains, marsh, and channel edge shallows used by splittail. Red shiners and inland silversides can be extremely abundant in shallow-water habitats and may be important predators of Sacramento splittail eggs and larvae and may compete for food with them in these habitats as well.

2.2.4.5 Selection Rationale

The endemic splittail's dependency on floodplains for spawning makes the species a key indicator for floodplain habitat quality and quantity. It is likely the most floodplain-dependent of the fish species in the Delta (Sommer et al. 2001, as cited in Sommer et al. 2007). The loss of floodplain and other shallow-water spawning habitat is believed to have been a major contributor to their decline in the basin. The importance of the Yolo and Sutter bypasses to the species may now be crucial to its persistence because of this loss of habitat (Step 1).

The USFWS listed Sacramento splittail as a threatened species in February 1999 because of the reduction in its historical range and because of the large population decline during the drought of 1987–1993 (Moyle 2002). Its status was remanded in 2003 because of recent increases in abundance and population stability, but this decision has subsequently been challenged. The U.S. Fish and Wildlife Service has agreed to revisit the splittail's status and make a new 12-month finding on whether listing is warranted by September 30, 2010. (Step 2). Changes to food webs in the Delta, such as the invasion of *Corbula amurensis*, and the increase in largemouth bass populations in the Delta may have important implications for splittail in terms of reproduction and juvenile mortality (Step 3). Because of numerous monitoring and research activities ongoing in the Delta, we have good information on splittail life history and habitat requirements (Step 4). Based on the information above, it seemed as if splittail would be a good choice as a focal species (Step 5).

2.2.5 Overbite clam (*Corbula amurensis*)

2.2.5.1 Species summary and affected life stages

The overbite clam (*Corbula amurensis*) is a suspension-feeding mollusk that is native to Japan, China and Korea in tropical to cold temperate waters. The overbite clam uses subtidal habitats, occasionally abundant on intertidal mudflats, living partly buried in the sediment with its hind third or half exposed above the surface. An efficient feeder, it has been associated with large changes in phytoplankton abundance in San Francisco Bay and the western Delta (Carleton et al.1990), causing a decrease in abundance of other species that depend on phytoplankton for food.

Although overbite clams appear to be able to reproduce year-round, San Francisco North Bay populations typically spawn in Spring and Fall (Carleton et al.1990). In laboratory studies, the larvae spent 17–19 days in the plankton (Nicolini and Penry 2000) and 2–3 cm in length at maturity after a few months. A single female can produce from 45,000 to 220,000 eggs.

2.2.5.2 Effects of Delta hydrodynamics

Because dispersal of the overbite clam is strongly affected by tidal influences, dispersal has generally been from east to west due to the prevailing currents (Nicolini and Penry 2000). The clam may be limited from exclusively freshwater environments as discussed below.

2.2.5.3 Effects of Delta water quality and salinity

The overbite clam has been collected at sites in San Francisco Bay with salinities of 1–33 parts per thousand, though long-term survival is greatest above 5 parts per thousand (). Spawning and fertilization require 5–25 psu and are most successful at 10–15 psu. In San Francisco Bay, the overbite clam has been collected at temperatures ranging from 8°C (46.4ºF) on subtidal bottoms in the winter to 23°C (73.4ºF) on intertidal flats in the summer, which is within the 0–28°C (32–82.4ºF) temperature range suggested by its latitudinal range in Asia (Carleton et al.1990).

2.2.5.4 Biotic interactions

The overbite clam was discovered in Suisun Bay, in the northern part of San Francisco Bay, soon after a major flood in the spring of 1986, and its increase and spread coincided with eastward movement of the high salinity zone during a multi-year dry period that began in mid-1986. The 1986 flood had wiped out the benthic community in the Suisun Bay area, which may have facilitated the overbite clam's establishment. That community— previously dominated by the Atlantic soft-shell clam (*Mya arenaria*), the Atlantic amphipod (*Ampelisca abdita*), the Atlantic polychaete worm (*Streblospio benedict)*, and *Monocorophium acherusicum*, an exotic amphipod whose origin is unknown—did not return. These organisms were presumably excluded by consumption of their food or larvae by the overbite clam.

Werner and Hollibaugh (1993) found that the overbite clam filters bacterioplankton less efficiently than it does phytoplankton, but assimilates both well. They calculated that at typical densities in the northern Bay of over 2,000 clams per square meter, the clam is capable of filtering the entire water column over the channels more than once per day and over the shallows almost 13 times per day. This filtration rate exceeds the phytoplankton's specific growth rate and approaches or exceeds the bacterioplankton's growth rate, and thus could permanently depress the primary productivity and biomass of these organisms. Phytoplankton blooms which had occurred annually in the northern bay in earlier years essentially disappeared after the clam became established.

Sturgeon and diving ducks such as scaup and surf scoter feed heavily on the overbite clam in their diets within northern San Francisco Bay. The foregut of one white sturgeon contained 214 essentially intact overbite clams and 8 isopods and amphipods, making up about ¼ of the volume of food, with the remaining ¾ consisting entirely of pieces of overbite clam shell. The hind gut contained 501 overbite clams and parts of 3 isopods and shrimp, making up 40% of the volume of food, with the remaining 60% consisting of pieces of overbite clam. Unfortunately, the overbite clam accumulates selenium at roughly three times higher concentrations than the clams that had lived in the northern part of San Francisco Bay prior to its introduction. The birds and fish that commonly feed on these clams are thus ingesting selenium at levels that may lead to reproductive damage, including birth defects, impaired hatching, and reduced growth of young life stages.

2.2.5.5 Selection Rationale

The overbite clam was discovered in Suisun Bay, in the northern part of San Francisco Bay in 1986, and its increase and spread coincided with a multi-year dry period that began in mid-1986. The adaptation to the Delta serves to clarify our knowledge of the environmental changes that have conferred a competitive advantage to them (Step 1). Although the species are not listed (Step 2), it is a strong interactor (Step 3e) and has changed the food web structure of the Delta ecosystem, converting portions of the Bay-Delta estuary from a pelagic to a benthic system. We have general knowledge of habitat requirements and life history stages of the overbite clam (Step 4). Primarily due to the large impacts to the Delta food web and ecology since its introduction, the overbite clam received a high ranking for selection as a focal species (Step 5).

3 FLOW ASSESSMENT FOR THE SELECTED FOCAL SPECIES

The simplest approach to ensuring that future flows in the Delta are protective of the public trust resources would be to re-establish the full natural flow regimes of the Sacramento and San Joaquin Rivers and their tributaries while dramatically reducing CVP and SWP export levels in all but flood flow conditions (Lund et al 2007). A key challenge in developing flow regimes to protect Public Trust Resources in the Delta ecosystem is the inherent natural variability in the region's climate and hydrology. It is clear that California's climate produces an exceptionally wide range of hydrological conditions from year to year and active water management cannot readily duplicate the full range of natural variability that brought about the diverse habitats and species that make use of the Delta.

The current understanding of the Delta ecosystem stems from a long history of scientific studies, monitoring, and surveys. Analyses of these data have resulted in numerous correlations between flows or exports and focal species abundance or survival, and development of several models (e.g. X_2-fish relationships). The correlations between the abundance of the focal species selected for this paper and flows or exports are generally focused on simple relationships between one physical factor such as flow, and an index of a species abundance or survival of key life stages. There is little doubt that survival or abundance of fish is related to many factors that affect one or more life stages of each of the species while in the Delta. Regardless, these relationships and models are used as part of the basis for the current management of Delta flows and diversions.

For purposes of the focal species identified in this report, we have employed a three-tier structure related to physical and biological functions in an aim to identify the volume, quality, and timing of water necessary for the Delta ecosystem:

1. **Seasonal Flow** – Expressed as volume or flow rate to be applied at a particular location and timing (e.g., diurnal, monthly, seasonal) and under particular water year types.
2. **Proximate function** – rationale for what the flow is intended to accomplish physically (e.g., floodplain inundation, flow direction, velocity, salinity characteristics, dissolved oxygen).
3. **Ultimate function** – linkages to public trust resources that we are trying to protect or enhance. For example, changes in habitat availability (e.g., changes in inundation timing or duration in the Yolo Bypass, floodplain inundation), or other benefits to individual focal species (e.g., spawning attraction flows for Chinook salmon, smolt outmigration flows, reduction or elimination of entrainment).

Recognizing the complexity of current water operations in the Delta, we have attempted to address flows that meet these ecological functions in the absence of export operations. In the sections below, we focus upon two primary functions related to maintenance of the Delta ecosystem. First, while we recognize that normal variations in water year type historically produced large seasonal variations in the westward and eastward position of the X_2 boundary, we focus upon on maintaining variation as a necessary ecological function to maintain the Delta ecosystem under its current physical configuration. Second, we address the need to provide seasonally inundated floodplains within the lower reaches of the Sacramento River, San Joaquin River, and eastside tributaries.

It should be noted that we specifically do not include such flows as needed to overcome structural impediments related to current operations such as: 1) flows necessary to overcome identified hydrodynamic issues such as entrainment (Section 1.3.3 and 1.3.4), 2) additional flows necessary for broader ecosystem needs such as flow volumes necessary to maintain a more gradual flood-stage recession for riparian recruitment, and 3) any additional flows necessary for the protection of species endemic to San Francisco Bay.

3.1 Fall Delta Inflows (Sacramento River Basin)

Under D-1641, the current minimum instream flow requirements for the lower Sacramento River at Rio Vista range from 3,000–4,500 cfs for the months September through November of each year. The corresponding water volume over the fall month ranges from 9.0–13.5% of the total annual unimpaired runoff in Dry years and 4.8–7.2% of unimpaired runoff in Wet years for the Sacramento River basin, respectively (Source: CDEC website). Although these levels would potentially need to be increased to provide appropriate Delta outflows below (Section 3.3) at current CVP and SWP export levels, maintenance of these minimum flow standards is necessary to provide attraction flows for Chinook salmon.

3.1.1 Proximate function

Increased flows in fall from the Sacramento River tributaries improve the homing fidelity of returning Chinook salmon spawners. The prevailing conceptual model regarding fall attraction flows is olfactory cues guide the homing of returning spawners (Harden Jones 1968, Quinn et al. 1989, Quinn 1990).

3.1.2 Ultimate function

Because adult Pacific salmon rely on olfactory cues to guide their upriver migration to their natal stream (Quinn 1990), attraction flows may increase homing fidelity, and tributary spawner returns. At a population scale, improved tributary returns will serve to increase the genetic diversity among tributary populations, and thereby increase the overall viability of Central Valley Fall-run and Late-Fall-run Chinook salmon (Lindley et al.2007).

3.2 Fall Delta Inflows (San Joaquin River Basin and East-side Tributaries)

Under the 1995 Bay/Delta Water Quality Control Plan there are no minimum instream flow requirements for the San Joaquin River at Vernalis for the fall months (September and November) other than fall pulse flow requirements ranging from 1,455–2,000 cfs during October (SWRCB 1999). Based upon investigations for the San Joaquin River dissolved oxygen TMDL, minimum instream flows at the Stockton Deepwater Ship Channel should be maintained in excess of 1,800 cfs during September and October of each year, with flows during November corresponding to current minimum Federal Energy Regulatory Commission (FERC) spawning flow requirements from the Stanislaus, Tuolumne, Merced and upper San Joaquin rivers. In addition, spawning attraction flows in excess of 3,500 cfs at Vernalis should be provided for 10–14 days during October using coordinated releases from the San Joaquin River and tributaries. For the remainder of the fall, Delta inflows would be determined by the minimum instream flow requirements of the San Joaquin River basin and east side tributaries. Upstream flow levels would likely be increased to meet the Delta outflows below (Section 3.3).

3.2.1 Proximate function

Low dissolved oxygen (DO) in the lower San Joaquin River has been found to impede upstream salmon migration (NMFS 2009, p.74). Studies by Hallock (1970) indicate that low dissolved oxygen at Stockton delay upmigration and straying rates. D-1641 states that DO levels below 5.0 mg/l create an oxygen block, impeding upstream salmon migration (SWRCB 2000, p.73). The Decision documents that the 1995 Bay-Delta Plan contains a DO objective of 6 mg/l from September through November in the lower San Joaquin River between Stockton and Turner Cut for the explicit purpose of protecting fall-run chinook salmon, and that the Central Valley RWQCB Basin Plan contains a DO objective for the entire Delta region of 5 mg/l for the entire year. It also notes that the objective for the lower San Joaquin River is typically not met in the late summer and fall months.

D-1641 does not impose a water right action to meet DO objectives (SWRCB 2000, p.95), and specifically states that “[t]here is no evidence in the record showing what flow is necessary to achieve the DO objectives in the absence of a barrier [at the head of Old River]” (SWRCB 2000, p.74). However, it does state that the most beneficial effects of the head-of-Old-River barrier occur when its installation eliminates net negative flows on the San Joaquin River (SWRCB 2000, p.74). This can be reasonably interpreted as acknowledging an ecological purpose for net non-negative flows in the reach of the San Joaquin River between the head of Old River and Turner Cut for at least the period September through November. The current San Joaquin River Dissolved Oxygen TMDL studies indicate that increased base flows during early fall of each year will reduce water residence time within this reach (Lee and Jones-Lee 2003) and allow upstream passage, even in the absence of aeration systems currently undergoing evaluations at the Stockton Deepwater Ship Channel.

In addition to improvements in dissolved oxygen conditions for upstream passage of Fall-run Chinook salmon, increased flows in fall from the San Joaquin River improve the homing fidelity of San Joaquin River basin fish due to improved olfactory homing (Harden Jones 1968, Quinn et al. 1989, Quinn 1990). Based upon a review of studies by Hallock (1970) by Mesick (2001), during October in 1965 and 1967, only 15% of acoustic tagged fish migrated into the Sacramento and Mokelumne rivers when Vernalis flows ranged between 2,000 and 4,000 cfs and the proportion of Vernalis flows exported at Tracy ranged between 45% and 120%. In contrast, during the same period in 1964, 54% of the tagged fish (35) strayed into the Sacramento and Mokelumne rivers in 1964, with 71% of the tagged fish (52) straying in 1966 when Vernalis flow ranged between 700 and 1,500 cfs and the proportion of Vernalis flows exported at Tracy ranged between 150% and 250%. Although adult salmon stray at rates of 2–15% under a range of natural conditions (Mesick 2001), it is clear that increased flows support homing fidelity of returning spawners. An important aspect of attraction flows is that the physical source of the water is at least as important as the volume or rate of flow. This is particularly relevant for San Joaquin basin fish, because it is not unusual for the entire volume of the San Joaquin River inflow to be drawn into the South Delta export facilities of the SWP and CVP at all times of year outside of the April 15–May 15 VAMP period (Section 1.5.2). Even in the absence of exports, it is necessary for the scent of the San Joaquin basin watershed to enter the Bay in order for adult salmonids to find their way back to their natal river (NMFS 2009, p.407).

3.2.2 Ultimate function

As stated above (Section 3.1.1), because adult Pacific salmon rely on olfactory cues to guide their upriver migration to their natal stream, increased attraction flows may increase homing fidelity, and tributary spawner returns. At a population scale, improved tributary returns will serve to increase the genetic diversity among tributary populations, and thereby increase the overall viability of Central Valley Fall-run Chinook salmon (Lindley et al. 2007).

3.3 Fall Delta Outflows

Variable Delta outflows of 7,500, 11,500, and 17,500 cfs as computed by the Net Delta Outflow Index (NDOI) are necessary during September through November of Below Normal, Normal, and Wet water years, respectively to place X_2 at approximately 80 km (50 mi), 75 km (47 mi), and 70 km (43 mi) from the Golden Gate Bridge during below Normal, Above Normal, and Wet water years, respectively (Table 1-2). In addition, a mean daily Delta outflow of 4,800 cfs during Critically Dry and Dry years will ensure suitable delta smelt habitat in the western Delta. Flows could be gradually reduced in the late fall as adult delta smelt gradually migrate further east into the Delta prior to beginning their winter spawning migration.

3.3.1 Proximate function

Increase the westward extent of fresh water into Suisun and San Francisco bays to more closely approximate historical conditions. Increase the availability of food resources for adult Delta smelt, striped bass, and other estuarine and pelagic species. Provision of 11,500, and 17,500 cfs in Normal and Wet water year flows would help allow pelagic fish access to low salinity habitat in the shallow shoals of Grizzly and Honker bays (Figure 1), which would increase the amount of suitable habitat (Feyrer et al.2009). A mean daily Delta outflow of 4,800 cfs during Critically Dry and Dry years would result in an eastward movement of the X_2 zone toward 85 km (53 mi) from the Golden Gate Bridge, similar to what would likely occur under unimpaired flows. This would place the eastward extent of X_2 in the vicinity of the Sacramento/San Joaquin river confluence.

3.3.2 Ultimate function

There is broad consensus that many Delta species are drawn to certain salinity and mixing conditions at certain stages in their life-cycles, and will flourish only when these conditions coincide with other habitat characteristics (e.g., increased primary and secondary productivity) which today are found only in specific regions of the Delta (e.g., Suisun Bay)(Kimmerer et al 2008). However, it should be noted it really does matter that X_2 remains within a relatively fixed position for extended periods of time. For example, there might be little or no value in maintaining the average position of X_2 in the middle of Suisun Bay if the actual, instantaneous position is further inland or out in the San Francisco Bay most of the time.

During the fall, juvenile and sub-adult delta smelt occupy suitable habitat in which to grow and prepare for the upcoming upstream spawning migration. Abundance indices for longfin and Delta smelt were greater in the period between the mid-1960’s and early 1980’s (Sommer et al. 2007, Nobriga et al. 2008). X_2 location during the mid-1960’s to early 1980’s averaged between 65 and 80 km from the Golden Gate Bridge (Jassby et al. 1995). The abundance of numerous taxa increases in years when flows into the estuary are high and the 2 psu isohaline is pushed seaward (Jassby et al. 1995), implying that the quantity or suitability of estuarine habitat increases when outflows are high (Baxter et al. 2007). Delta smelt fall habitat quality does not increase appreciably until X_2 is <80 km (Feyrer 2009). In the low salinity zone studies, delta smelt were 8 times more abundant in northern Suisun Bay and adjoining shallows in Honker Bay and Grizzly Bay (65 to 75 km) than in the deeper shipping channel to the south (Bennett et al. 2002). The amount of suitable habitat available for delta smelt, measured as hectares of surface area, is negatively related to X_2 (USFWS 2008). The average X_2 during fall has exhibited a long-term increasing trend (movement further upstream), which has resulted in a corresponding reduction the amount and location of suitable habitat (Feyrer et al. 2007, 2008 *as cited in* USFWS 2008).

Increasing fall Delta outflow could result in more available habitat in Suisun Bay and reduce the eastward distribution for the overbite clam due to increased westward extent of fresh water. Suitable habitat for delta smelt during fall has been defined as relatively turbid water (Secchi depths < 1.0 m) with a salinity of approximately 0.6–3.0 psu (Feyrer et al. 2007). Due in part to the overbite clam's efficiency in filtering water, the clarity of Suisun Bay and delta waters has increased. This has affected delta smelt by reducing food supply and increasing its susceptibility to predation.

Much like delta smelt, Age-0 striped bass environmental quality can be effectively described by Secchi depth and specific conductance (Feyrer et al. 2007) and this species has experienced similar declines in habitat availability. Filtering of water by the overbite clam has reduced the environmental quality for young striped bass and as such food availability.

3.4 Winter Delta Inflows (Sacramento River Basin)

Current Delta inflow requirements under D-1641 at Rio Vista range from 3,500–4,500 cfs during December (Table 1-4). Although extension of these flow requirements into January and February would more closely approximate the unimpaired hydrograph for the Sacramento Basin, because extensive floodplain inundation in the Yolo Bypass during wetter years is driven largely by inflow from the Sacramento River Fremont Weir (Sommer et al. 2001a,b, JSA 2001), additional winter pulse flows during Normal and Wet water year types would re-establish this ecosystem function.

The Fremont Weir is a passive facility that begins to spill when the Sacramento River Flow at Verona reaches 55,000 to 56,000 cfs (JSA 2001, USGS 2003). Feyrer et al. (2006) indicate that a flow of 3,500 cfs above this level (59,500 cfs total) is required to begin inundating floodplains in the Yolo Bypass. Although Sommer et al. (2001b) suggested that the Yolo Bypass is fully inundated around 74,205 cfs, the NMFS (2009b) draft recovery plan for the Sacramento Winter-run Chinook, Central Valley Spring-run Chinook, and Central Valley Steelhead ESUs calls for an annual Spring flow of 8,000 cfs (approximately 64,000 cfs at Verona) above the initial spill level "to fully activate the Yolo Bypass floodplain." At least one managed pulse flow event of 64,000 cfs at Verona lasting at least 14 days should be provided during Below Normal water year types, 21 days during Above Normal water year types, and 28 days during Wet water year types. A series of pulse flows exceeding 64,000 cfs, instead of single extended high flow event at 64,000 cfs, could also be used to achieve the desired target of continuous days of inundated floodplain. The goal for combined winter and spring floodplain activation flows (described in section 3.7 below) is to maintain inundated seasonal floodplain habitat conditions in much of the Yolo Bypass during January through April for a minimum of 21 consecutive days in Below Normal water year types, 35 days in Above Normal water year types, and 49 days in Wet water year types. For the purposes of this assessment, we have allocated inflows for floodplain inundation to February and March for winter and spring, respectively.

3.4.1 Proximate function

Increase the frequency and duration of extensive floodplain inundation in the north Delta (primarily in the Yolo Bypass and Cache Slough Complex). Moyle et al. (2007) concluded that, based on studies in the Yolo Bypass and Cosumnes River floodplains, extensive early season flooding (January-April) is important in managing Central Valley floodplains to provide benefits for native fish species. Junk et al. (1989) suggested that annual flooding of terrestrial habitats drives the existence, productivity, and interactions of the major biota in river-floodplain systems and the predictable duration (i.e., hydroperiod) allows biota to efficiently use the resources available in the aquatic/terrestrial transition zone For example, multiple, short-lived flood pulses followed by long draining periods may produce more phytoplankton than the simpler hydrograph of the Yolo Bypass (Mueller-Solger 2003).

3.4.2 Ultimate function

Research suggests that rearing juvenile Chinook salmon, as well as a number of native resident species such as Sacramento splittail, would benefit from optimizing the frequency, duration, and timing of seasonal inundation of the Yolo Bypass floodplain habitat (Sommer et al. 1997, 2001a, 2004). In addition, increased phytoplankton, zooplankton, and other organic material transported from the Yolo Bypass floodplain to Cache Slough, the lower Sacramento River, the western Delta, and Suisun Bay is expected to increase the food supply for delta smelt, striped bass and other pelagic species.

There is also evidence that substantial numbers of delta smelt utilize freshwater sloughs in areas adjacent to wetlands and seasonal floodplains in the northern Delta for part of their life cycle, especially spawning and early larval stages. Seasonally inundated floodplains upstream of the Delta generate high levels of high quality plankton biomass that is exported to adjacent channels and downstream areas that are occupied by delta smelt (Schemel et al. 2003, and Sommer et al. 2004, as cited in CDWR and CDFG 2007). This leads to the conclusion that an increase of productive seasonal floodplains would likely increase appropriate prey organisms for delta smelt larvae, as well as for other pelagic species. Daniels and Moyle (1983) found that year-class success in splittail was positively correlated with Delta outflow, and Caywood (1974) found that a successful year class was associated with winter-runoff sufficiently high to flood the peripheral areas of the Delta.

3.5 Winter Delta Inflows (San Joaquin River Basin and East-side Tributaries)

Although D-1641 does not establish minimum winter flows at Vernalis before February (710–3,420 cfs as shown in Table 1-5), minimum flows at Vernalis and the eastside tributaries should be coordinated to maintain net seaward flows at Jersey Point for the benefit of Chinook salmon. USFWS (2001) recommended flows at Jersey Point, of 1,000 cfs in critical and dry years, 2,000 cfs in Below and Above Normal years, and 3,000 cfs in Wet years. In addition, for the benefit of rearing Chinook salmon and other native fishes, floodplain activation flows of 14,800 cfs in the lower San Joaquin River should be provided for a minimum of 14 days during Above Normal water year types and 21 days during Wet water year types. A series of pulse flows instead of single extended high flow event at 14,800 cfs might also be used to achieve the desired target of continuous days of inundated floodplain. In addition, the current, natural high flow regime that routinely inundates the floodplain within the lower Cosumnes River system should be maintained (i.e., if any water supply developments affecting flows on the Cosumnes River are proposed in the future they should not interfere with current levels of floodplain functioning). The goal for combined winter and spring inflows is to maintain inundated seasonal floodplain habitat conditions (or the potential for such conditions in sites where floodplain restoration actions may be undertaken in the future) in the lower San Joaquin and east-side tributary zone during January through April for a minimum of 21 consecutive days in Above Normal water year types and 35 days in Wet water year types. For the purposes of this assessment, we have allocated these inflows for floodplain inundation to February and March.

3.5.1 Proximate function

In addition to providing net seaward flows for the benefit of outmigrating juvenile salmon, the proximate benefit of winter Delta inflows is maintain or enhance the frequency and duration of ecologically beneficial floodplain inundation in the lower San Joaquin River and east-side tributaries, and maintain the potential for achieving increased floodplain functioning in the future if floodplain restoration is undertaken in this portion of the Delta. A pilot study of the Ecosystem Flow Model developed during the Sacramento and San Joaquin Rivers Comprehensive Study conducted in a 13-mile (21 km) reach on the lower San Joaquin River, downstream of the Stanislaus River confluence, indicated that there is a "natural terrace" inside of the levee on one side of the river that would be inundated and provide floodplain habitat beneficial to native fishes at flows of 14,800 cfs in winter and spring (SCBR and USACE 2002).

3.5.2 Ultimate function

As stated above, Moyle et al. (2007) conclude that extensive early season flooding (January–April) is important in managing the Cosumnes River and other Central Valley floodplains to provide benefits for native fish species. Comparison between the Yolo Bypass and the Cosumnes River shows that the more natural Cosumnes system has higher production of high-quality food sources for native fish. The more natural hydrograph of the Cosumnes appears to be a principal cause of this difference, and therefore the key components of the current hydrograph should be maintained.

3.6 Winter Delta Outflows

During December through February, continuation of the Fall Delta Outflow objectives of 7,500, 11,500, and 17,500 cfs (NDOI) in Below Normal, Above Normal, and Wet water year types, respectively would place X_2 at approximately 80 km (50 mi), 75 km (47 mi), and 70 km (43 mi) from the Golden Gate Bridge during these water year types (Table 1-2). During Wet water year types, flows of 26,800 cfs (NDOI) would maintain X_2 location in Suisun Bay near 65 km (40 mi) from the Golden Gate Bridge based upon Resources Agency (2007).

3.6.1 Proximate function

The proximate function of the winter Delta outflows is to increase the westward extent of fresh water into Suisun and San Francisco bays to more closely approximate historical conditions. This would place the eastward extent of X_2 in the vicinity of the Sacramento/San Joaquin river confluence, approximately 85 km (53 mi) from the Golden Gate Bridge. This will serve to increase the availability of food resources to larval fish species in late winter as well as improve access to low salinity habitat in the shallows of Grizzly and Honker bays (Feyrer et al.2009).

3.6.2 Ultimate function

Winter flows are typically relatively high, X_2 location is generally in Suisun Bay, and pelagic fish (delta smelt and striped bass) have begun upstream migrations to spawning grounds. Therefore, Delta outflows are designed to limit eastward distribution and density of overbite clam. Although the overbite clam is less sensitive to salinities above 1 psu (Section 1.6.2.1), low salinity may inhibit spawning and subsequent adult recruitment, thereby reducing grazing pressures on phytoplankton and the pelagic food web. Improvements in food resources to the western Delta will serve to increase populations of Delta smelt, striped bass, and other pelagic species that are currently in decline (Section 1.6.5).

3.7 Spring Delta Inflows (Sacramento River Basin)

Although there are no Delta inflow requirements currently established under D-1641 (Table 1-4), establishing base flows of at least 10,000 cfs in the Sacramento River in spring would improve transport of eggs and larval striped bass and other young anadromous fish and to reduce egg settling and mortality at low flows (USFWS 2001). In addition, as described above under Winter Delta Inflows (Section 3.4), for the benefit of rearing Chinook salmon and other native fishes, floodplain activation flows should be provided to inundate floodplains within the Yolo Bypass under Below Normal and wetter water year types. Floodplain activation could be achieved with at least one managed pulse flow event of 64,000 cfs at Verona lasting at least 7 days during Below Normal water year types and 14 days during Above Normal water year types, and 21 days during Wet water year types. A series of pulse flows exceeding 64,000 cfs, instead of a single extended high flow event at 64,000 cfs, could also be used to achieve the desired target of continuous days of inundated floodplain. The goal for winter (described in section 3.4 above) and spring floodplain activation flows is to maintain inundated seasonal floodplain habitat conditions in much of the Yolo Bypass during January through April for a minimum of 21 consecutive days in Below Normal water year types, 35 days in Above Normal water year types, and 49 days in Wet water year types. For the purposes of this assessment, we have allocated the Delta inflows for floodplain inundation to February and March.

3.7.1 Proximate function

For the benefit of outmigrating salmon, delta smelt and striped bass, the proximate function of the Delta inflows is to maintain net transport of passively swimming fishes (juvenile salmonids, larval delta smelt, and striped bass) and nutrients towards Suisun and San Francisco bays (USFWS 2008). The mechanisms by which Chinook salmon smolts find their way from the Sacramento River through the Delta and out to the ocean are not so well understood. However, it is well known from tagging experiments that the paths smolts take through the Delta are affected by internal flows, and that survival differs greatly among paths (Brandes and McClain 2001).

3.7.2 Ultimate function

Sacramento River fall-run Chinook move into the lower Sacramento River and Yolo Bypass in February and March (Moyle 2002), and are known to have substantially higher growth and survival rearing in the Yolo Bypass than in the mainstem Sacramento River (Sommer et al. 2001a). It should be noted that early season inundation (March) should favor native fish species with lower temperature tolerances, while limiting many non-native fish species using floodplains which generally use floodplains later in the season when conditions are warmer (Brown and Ford 2002). In addition to improved rearing conditions due to floodplain inundation, reductions in in-river and Delta travel times associated with higher base flows will reduce predator exposure and improve subsequent returns of Chinook salmon as well as other native fish species.

3.8 Spring Delta Inflows (San Joaquin River Basin and East-side Tributaries)

Although USFWS (1995) previously recommended spring Delta inflows ranging from 4,050 cfs to 15,750 cfs at Vernalis based upon of regression models of Chinook salmon smolt survival. The current D-1641 flow minimums range from 3,110 cfs to 8,620 cfs (Table 1-5), depending upon water year type, have never been fully implemented. In addition to baseline flows, for the benefit of rearing Chinook salmon and other native fishes, floodplain activation flows should be provided of 14,800 cfs in the lower San Joaquin River for a minimum of 7 days in Above Normal water year types and 14 days during Wet water year types. A series of pulse flows instead of a single extended high flow event at 14,800 cfs might also be used to achieve the desired target of continuous days of inundated floodplain. In addition, current floodplain activation flows within the lower Cosumnes River system should be maintained (i.e., if any water supply developments affecting flows on the Cosumnes River are proposed in the future they should not interfere with current levels of floodplain functioning) . The goal for combined winter and spring floodplain activation flows is to maintain inundated seasonal floodplain habitat conditions (or the potential for such conditions in sites where floodplain restoration actions may be undertaken in the future) in the lower San Joaquin and east-side tributary zone during January through April for a minimum of 21 consecutive days in Above Normal water year types and 35 days in Wet water year types. For the purposes of this assessment, we have allocated the Delta inflows for floodplain inundation to February and March.

3.8.1 Proximate function

In addition to benefits of improved salmonid rearing downstream of tributary spawning grounds, the proximate function of the recommended flows is to maintain net positive (seaward) flows in the lower San Joaquin River past Stockton, as well as the Old and Middle Rivers past Bacon Island. Delta inflows are intended to maintain net transport of passively swimming fishes (juvenile salmonids, larval delta smelt and striped bass) and nutrients towards Suisun and San Francisco bays (USFWS 2008). For example, delta smelt hatch dates back-calculated from otoliths (ear bones) indicate most fish surviving to summer-fall were hatched during the April 15 to May 15 VAMP period when San Joaquin River flow is typically augmented, export pumping is relatively low and Old and Middle River flows are from south to north (Resources Agency 2007). Another proximate function of spring Delta inflows is to maintain or enhance the frequency and duration of ecologically beneficial floodplain inundation in the lower San Joaquin River and east-side tributaries, and maintain the potential for achieving increased floodplain functioning in the future if floodplain restoration is undertaken in this portion of the Delta. A pilot study of the Ecosystem Flow Model developed during the Sacramento and San Joaquin Rivers Comprehensive Study conducted in a 13-mile (21 km) reach on the lower San Joaquin River, downstream of the Stanislaus River confluence, indicated that there is a “natural terrace” or berm inside of the levee on one side of the river that would be inundated and provide floodplain habitat beneficial to native fishes at flows of 14,800 cfs in winter and spring (SCBR and USACE 2002).

3.8.2 Ultimate function

Improved growth rates as well as reduced travel times through the Delta will improve outmigration survival, adult recruitment, and subsequent returns of Chinook salmon spawners to the San Joaquin River tributaries. In addition, westward transport of larval fish and food supplies will improve subsequent rearing conditions and adult recruitment of delta smelt and striped bass.

As stated above, Moyle et al. (2007) conclude that extensive early season flooding (January–April) is important in managing the Cosumnes River and other Central Valley floodplains to provide benefits for native fish species. Early Spring inundation (March-April) should favor native fish species with lower temperature tolerances, while limiting many non-native fish species using floodplains which generally use floodplains later in the spring when conditions are warmer (Brown and Ford 2002). Comparison between the Yolo Bypass and the Cosumnes River shows that the more natural Cosumnes system has higher production of high-quality food sources for native fish. The more natural hydrograph of the Cosumnes appears to be a principal cause of this difference, and therefore the key components of the current hydrograph should be maintained.

3.9 Spring Delta Outflows

Provide a daily mean Delta outflow from March through May ranging from 17,500 cfs and 26,800 cfs (NDOI) in Critically Dry to Wet year types.

3.9.1 Proximate function

The proximate function of the Delta outflows is to maintain the westward extent of freshwater flows to locate the X_2 boundary 65 km (40 mi) and 70 km (43 mi) from the Golden Gate Bridge for all water years. These flows would allow larval and juvenile pelagic fish access to the low salinity habitat in the shallow shoals of Grizzly and Honker bays, which would increase the amount of suitable habitat (Feyrer et al.2009). These flows could increase the nursery area, shallow water habitat, and food abundance, as well as reducing intraspecific competition. The Dry and Critically Dry year flows would result in an eastward movement of the X_2 zone toward 70–75 km (43–47 mi), similar to what would likely occur under natural unimpaired flow conditions. This would place the eastward extent of Dry and Critically Dry year X_2 between Honker Bay and Chipps Island.

3.9.2 Ultimate function

Several lines of evidence indicate that maintaining low salinity habitat in Suisun Bay during spring can be beneficial for delta smelt (Bennett et al. 2005). Herbold (1994) found a significant relationship between the number of spring days X_2 was located in Suisun Bay and adult delta smelt abundance. Post-larvae were on average larger and had higher feeding success in the north shoal area than in the Ship channel (Hobbs et al. 2004). The longitudinal position of X_2 during spring and/or early summer, which varies as a function of freshwater flow into the estuary, has been correlated with abundance or survival indices of numerous estuarine taxa (Jassby et al. 1995).

Bennett et al. (2008) stated "This action assumes that maintaining the low salinity zone in Suisun Bay during spring will benefit delta smelt (see Kimmerer 2002b, 2004). Although there is no statistical relationship justifying its usefulness (Kimmerer 2002b, Figure 20,), the X_2 standard remains a worthwhile management action, because the abundance of delta smelt is elevated only in years when the low salinity zone is located in Suisun Bay, and, from an ecosystem perspective, the abundances of a variety of organisms are enhanced with X_2 in Suisun Bay (Jassby et al. 1995, Kimmerer 2002b, 2004)."

Restoration of delta smelt to sustainable population size could require maintenance of the mixing zone in Suisun Bay and maintenance of a net seaward flow in the lower SJR during the period when delta smelt larvae are present (Moyle 1992). Maintaining X_2 in a favorable location during the spawning period of delta smelt reduces their exposure to the effects of reverse flow in the southern Delta channels (Resources Agency 2007). If X_2 is in a less favorable location and delta smelt spawn within the Central and southern Delta, then avoiding upstream flow in Old and Middle Rivers once they have begun spawning will reduce entrainment losses of the smelt larvae. A favorable location for X_2 during this period is defined as seaward of 65 km based on a 14-day running average (Resources Agency 2007).

Delta outflow affects the distribution of striped bass larvae. When X_2 is in Suisun Bay, striped bass larvae density is greatest in Suisun Bay; when X_2 is in the Delta, larvae density is greatest in the Delta. Striped bass survival from egg size to 1.52 in (39 mm) long and from 0.36–1.52 in (9–39 mm) TL is higher at higher outflows (i.e., when X_2 is farther downstream) (CDFG 1992 and San Francisco Estuary Project 1993 as cited in USFWS 2001). High outflow may benefit larval striped bass by:

- increasing the nursery area and reducing intraspecific competition,
- increasing shallow habitat area and food abundance,
- diluting toxic materials, and
- increasing turbidity and reducing predation.

Higher outflows could reduce salinity in the east delta region thus limiting overbite clam distribution and/or density (Section 1.6.2.1).

3.10 Summer Delta Inflows (Sacramento River Basin)

Currently, D-1641 does not establish minimum summer inflows to the Delta (Table 1-4) and Delta inflows will be determined by Delta outflows below (Section 3.12).

3.10.1 Proximate function

As discussed in Section 3.12 below, the proximate function of Delta inflows is to increase Delta outflows, thereby increasing the westward extent of fresh water into Suisun and San Francisco bays to more closely approximate historical conditions.

3.10.2 Ultimate function

As discussed in Section 3.12 below, improvements in Delta outflows will lead to increases in delta smelt, striped bass and other pelagic species.

3.11 Summer Delta Inflows (San Joaquin River Basin and East-side Tributaries)

Currently, D-1641 does not establish minimum summer inflows to the Delta (Table 1-5) and Delta inflows will be determined by Delta outflows below (Section 3.12).

3.11.1 Proximate function

As discussed in Section 3.12 below, the proximate function of Delta inflows is to increase Delta outflows, thereby increasing the westward extent of fresh water into Suisun and San Francisco bays to more closely approximate historical conditions. In addition to potential improvements in

DO conditions at the Stockton Ship Channel (Section 3.2.1), water with a higher level of primary productivity could be moved further into the delta for use by pelagic organisms with positive Old and Middle River Flows (USFWS 2008).

3.11.2 Ultimate function

As discussed in Section 3.12 below, improvements in Delta outflows will lead to increases in delta smelt, striped bass and other pelagic species.

3.12 Summer Delta Outflows

Mean daily Delta outflows of 7,500, 11,500, and 17,500 cfs (NDOI) should be maintained during the summer (June, July, August) period of Below Normal, Normal, and Wet water years, respectively. In addition, a mean daily Delta outflow of 4,800 cfs should be maintained during Dry and Critically Dry years.

3.12.1 Proximate function

The proximate function of the Delta outflows is to increase the westward extent of fresh water into Suisun and San Francisco bays to more closely approximate historical conditions. In addition, the flows could serve to increase the availability of food resources for adult Delta smelt, striped bass, and other estuarine and pelagic species. The Delta outflows would place X_2 at approximately 80 km, 75 km and 70 km from the Golden Gate Bridge during Below Normal, Normal, and Wet water years, respectively (Table 1-2). This would provide improved pelagic fish habitat conditions and survival.

The Dry and Critically Dry year Delta outflows in summer would result in an eastward movement of the X_2 zone toward 85 km from the Golden Gate Bridge, similar to what occur naturally. This would place the eastward extent of X_2 in the vicinity of the Sacramento/San Joaquin river confluence.

3.12.2 Ultimate function

As stated above, although the causal bases for the observed correlations between X_2 and the Delta ecosystem are not well characterized, there is broad consensus that many Delta species are drawn to certain salinity and mixing conditions at certain stages in their life-cycles, and will flourish only when these conditions coincide with other habitat characteristics (e.g., increased primary and secondary productivity) which today are found only in specific regions of the Delta (e.g., Suisun Bay). Improvements in Delta outflows will lead to increases in delta smelt, striped bass and other pelagic species.

The longitudinal position of X_2 during spring and/or early summer, which varies as a function of freshwater flow into the estuary, has been correlated with abundance or survival indices of numerous estuarine taxa (Jassby et al. 1995). Delta smelt in northern Suisun Bay (X_2 at 65 to 70 km) adjacent to shoal habitats have higher feeding success (Hobbs 2004). Nobriga et al. (2008) reported that Delta smelt relative abundance in the Suisun region varied in association with specific conductance, which is a function of river inflow variation. This is consistent with previous findings for larvae during spring–early summer (Dege et al. 2004) and juveniles and pre-spawning adults during fall (Feyrer et al. 2007).

Bennett et al.’s (2008) results (using 2005 trawl survey data) suggest that selective mortality and poor delta smelt body condition were intensified by extreme environmental conditions, elevating mortality during late-summer and contributing to poor year-class success. Bennett et al. (2008) further suggested that this provides a comprehensive explanation for patterns implying elevated summer mortality (or, a juvenile life history bottleneck) for delta smelt (Bennett 2005), as well as recent evidence for a long-term decline in suitable summertime habitat (Nobriga et al. 2008).

4 SYNTHESIS

The Delta is host to a highly complex and diverse biota dependent on riverine inflows and delta outflow that vary with season and water year type. Native fish species are well-adapted to the seasonal and annual flow fluctuations characteristic of the region, including multi-year periods of flooding and drought, while many non-native species have evolved with the more stable flow conditions and altered flow patterns found under current conditions (Moyle 2002). For these and other reasons, several species native to the Delta are threatened or endangered, and populations of many non-native species are flourishing. The south Delta is also the point at which water is conveyed from the relatively wet portions of the Great Valley ecoregion (Miles and Goudey 1997) in northern California to the drier climates within the San Joaquin Valley and southern California. As such, tremendous pressure is placed on the Delta to meet competing needs, very few of which have been satisfactorily met.

Development of the suggested Delta outflows involved reviewing existing scientific and regulatory documents, assessing habitat needs for different life history stages of the focal species, understanding the habitat relationships of the focal species populations, as well as evaluating current habitat conditions in relation to those that occurred historically. The synthesis of this information led to the development of inflow and outflow recommendations by season and water year type.

For this particular analysis, Delta outflows were developed without regard for the diversion and export needs of the state. The recommendations for delta outflows developed for this document were focused on maintaining or improving delta conditions for four focal fish species: Chinook salmon, striped bass, delta smelt, and Sacramento splittail, as well as to reduce habitat quantity or quality for the invasive overbite clam that has flourished under the low and steady Delta outflows during recent decades. In large part, the final flow recommendations for Delta outflow are driven by two primary factors: (1) the need for seasonally inundated floodplain habitat in the lower reaches of the Sacramento and San Joaquin River systems, and (2) the need to locate the ETM and X_2 salinity zone in the shallower portions of the Delta, both within and to the west of Suisun Bay, depending upon water year type.

4.1 Fall Flows

Fall flows discussed above were based primarily on Delta outflows needed to maintain X_2 in the productive shallow-water habitats in Suisun Bay. Mean daily Delta outflows in the fall should range from 4,800–17,500 cfs (286–1,041 TAF) in each month, depending on water year type as computed by the Net Delta Outflow Index during September, October, and November. In some months and water years, depending on water year type and month, the projected monthly outflows are higher than the unimpaired (280–1,803 TAF) and/or current flow ranges (255–1,370 TAF). Thus, some modification of upstream reservoir release schedules may be required to meet these flows.

Although not as large as the Delta outflow requirements required to provide suitable habitat within Suisun Bay, secondary objectives for Fall outflows from the Delta were to provide attraction flows for upstream-migrating salmonids and to maintain adequate dissolved oxygen concentrations for Fall-run Chinook salmon within the lower San Joaquin River system. Without consideration of irrigation and export water needs, the Sacramento and San Joaquin River and tributary inflows, based primarily upon fishery flow needs determined in under the FERC and

SWRCB processes for the individual rivers, would necessarily have to be increased to meet the increased outflow demands for X_2.

4.2 Winter Flows

Winter flows discussed above were primarily designed to provide upstream migration passage for salmonids and striped bass during December and January, as well as to inundate floodplains such as the Yolo Bypass during February for the benefit of rearing juvenile salmonids and other floodplain associated species. Mean daily Delta outflows in the winter should range from 7,500–26,800 cfs in each month, depending on water year type as computed by the Net Delta Outflow Index during December, January, and February. However, with the provision of floodplain activation flows of variable duration by water year type, total Delta outflow volumes correspond to 461–4,212 TAF over the winter months. In some months and water years, depending on water year type and month, the combined monthly outflows are higher than the current flows (783–6,196 TAF), but below the unimpaired flow ranges (1,004–6,952 TAF) in all water year types.

A primary objective for the Delta outflows was to provide enough Delta outflow to maintain X_2 westward of 65 km (40 mi) from the Golden Gate Bridge, with variations to allow eastward excursion of X_2 as far as 80 km (50 mi) in drier water year types to limit the proliferation of the overbite clam. Winter Delta outflows to maintain the X_2 recommendations correspond to mean daily outflows of about 7,500 to 26,800 cfs (461 to 1,648 TAF per month). In addition, because extensive floodplain inundation in the Yolo Bypass during wetter years is driven largely by inflow from the Sacramento River Fremont Weir (Sommer et al. 2001a,b, JSA 2001), the total outflow volumes include additional winter pulse flows be supplied during Normal and Wet Water year types.

A secondary goal for the winter delta outflows is to provide 64,000 cfs to maintain inundated seasonal floodplain habitat in much of the Yolo Bypass for a minimum of 14 consecutive days in February in Below Normal water years, 21 days in Above Normal water years, and 28 days in Wet water years. In the lower San Joaquin River, the corresponding floodplain activation flows would require 14,800 cfs pulse flow events lasting 14 and 21 days in Above Normal and Wet water year types, respectively. These floodplain activation flows will promote natural seasonal connections between the channel and its floodplain, allowing access to the floodplain for spawning by native fish such as Sacramento splittail, as well as nutrient and invertebrate input into the aquatic food web of the Delta.

4.3 Spring Flows

Spring flows discussed above were primarily based on delta outflows needed to maintain X_2 in locations that are beneficial to delta open-water fish populations as well as the provision of floodplain inundation in the Yolo Bypass during March. Mean daily Delta outflows in the spring should range from 17,500–26,800 cfs in each month, depending on water year type as computed by the Net Delta Outflow Index during March, April, and May. With the provision of floodplain activation to the Yolo Bypass and lower San Joaquin River, total Delta outflow volumes correspond to 1,041–3,390 TAF over the spring months, depending upon water year type. In some months and water years, depending on water year type and month, the projected monthly outflows are higher than the current flows (453–5,380 TAF), but below the unimpaired flow ranges (2,104–6,337 TAF) in all water year types.

As discussed above, a primary objective for the Delta outflows was to provide enough Delta outflow to maintain X_2 westward of 65 km (40 mi) from the Golden Gate Bridge, with variations to allow eastward excursion of X_2 as far as 70 km (43 mi) in drier water year types to limit the proliferation of the overbite clam. Spring Delta outflows to maintain the X_2 recommendations correspond to mean daily outflows of about 7,500 to 26,800 cfs (461 to 1,648 TAF per month).

A secondary goal for the spring Delta outflows is to provide 64,000 cfs in the Sacramento River at Verona to maintain inundated seasonal floodplain habitat in much of the Yolo Bypass for a minimum of 7 consecutive days in March of Below Normal water years, 14 days in Above Normal water years, and 21 days in Wet water years. In the lower San Joaquin River, the corresponding floodplain activation flows would require 14,800 cfs pulse flow events in March of 7 and 14 day duration in Above Normal and Wet water year types, respectively. In both the Yolo Bypass and lower San Joaquin River the optimal benefit of floodplain inundation flows would occur if early Spring flows were coordinated with flows in late Winter and timed to provide prolonged periods of favorable floodplain habitat by extending February floodplain inundation events into March. These floodplain activation flows will promote natural seasonal connections between the channel and its floodplain, allowing access to the floodplain for spawning by native fish such as splittail, as well as nutrient and invertebrate input to the Delta.

4.4 Summer Flows

Summer flows discussed above were based primarily on Delta outflows needed to maintain X_2 in the productive shallow-water habitats in Suisun Bay. Mean daily Delta outflows in the summer should range from 4,800–17,500 cfs (286–1,041 TAF) in each month, depending on water year type as computed by the Net Delta Outflow Index during June, July, and August. In some months and drier water year types, depending on month, the projected outflows are higher than the unimpaired (269–4,051 TAF) and/or current flow ranges (205–1,779 TAF). Thus, some modification of upstream reservoir release schedules may be required to meet the projected Delta outflows.

4.5 Caveats and Complexity

We have focused exclusively on identifying ecologically beneficial flows under the current physical configuration of the Delta, but have done so without regard to competing water supply demands (i.e., exports and diversions). Although we have attempted to address aquatic habitat needs of focal species in the Delta without consideration of the current operations of the Delta export facilities, much of the available information provided in this report has been developed in the context of current operations.

It must be noted that the hydrodynamic conditions currently affecting fish in the Delta are the result of complex interactions between exports and other factors. For example, while the *possibility* of net reverse flows only exists because of export operations, the actual *occurrence* of such flows also depends upon inflows and barrier operations.

California's climate produces an exceptionally wide range of hydrological conditions from year to year. It is very unlikely that any factor affects fish in the same way every year or that the interactions among factors stay the same from year to year. Thus, the primary source of fish mortality in one year may be irrelevant in other years: temperature stress on winter-run salmon is much less likely in years of high Sierra snowfall, entrainment of delta smelt in the south Delta is unlikely in years when the bulk of the population is in Suisun Bay, bird predation on salmon in the Delta is probably minimal in low flow years. Even within an individual year many factors can affect the final adult population (Bennett and Moyle 1995).

Thus, we generally have reviewed scientific findings from the Delta to identify whether various environmental factors related to flow are ever important and, if so, we describe the times and the conditions under which each factor is most likely to be important. In addition, since current scientific understanding indicates that *seasonal and annual variations in flows are important* for maintaining a dynamic and diverse Delta ecosystem, our assessment incorporates the desire for variations in flow by specifying beneficial flows by *season* and by *water year type*.

Our Delta outflow projections were developed based on the life histories, habitat requirements, and available knowledge about relationships of habitat and life history needs to Delta inflows and outflows for the five focal species. These focal species were selected to represent a range of aquatic species found in the Delta, and it was intended that provision of the flows for the five focal species would also address primary needs of many other desirable species and the habitats upon which they depend. However, due to limitations in the number of focal species that could be directly addressed using this approach, there are undoubtedly other ecosystem functions not addressed in this document which could require additional magnitude or altered timing of delta inflows and outflows relative to the assessment we have presented. For example, managing spring flows to mimic key components of the natural snowmelt hydrograph to support riparian vegetation establishment and development in some portions of the Delta during Above Normal and Wet water year types would be beneficial to many native species of plants and animals. Flow objectives might also be developed to address issues and potential ecological benefits related to sediment transport, water quality, water circulation in San Francisco Bay, food web support, and the habitat needs of a broader array of native flora and fauna (including more species dependant on wetland and riparian habitats).

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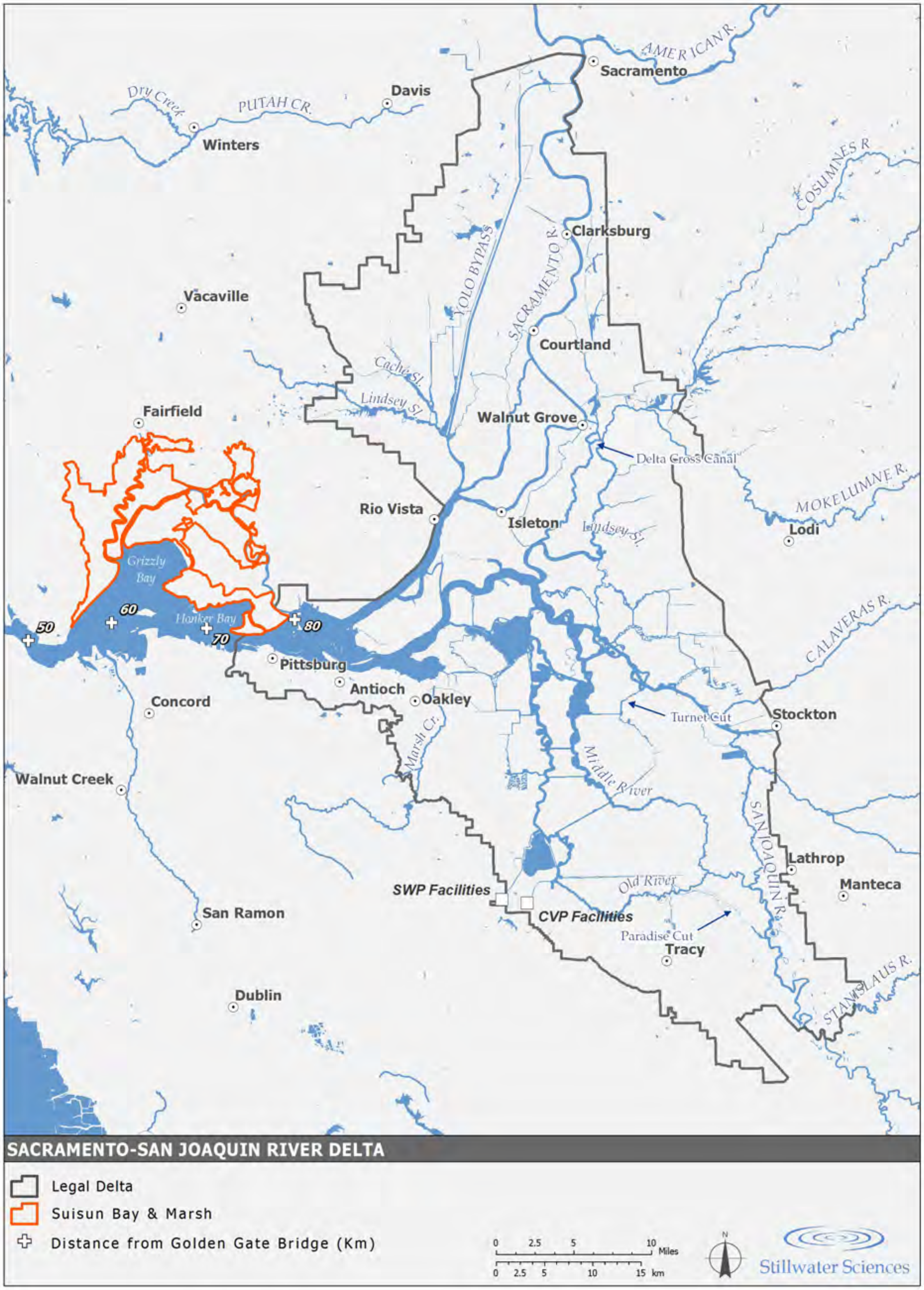
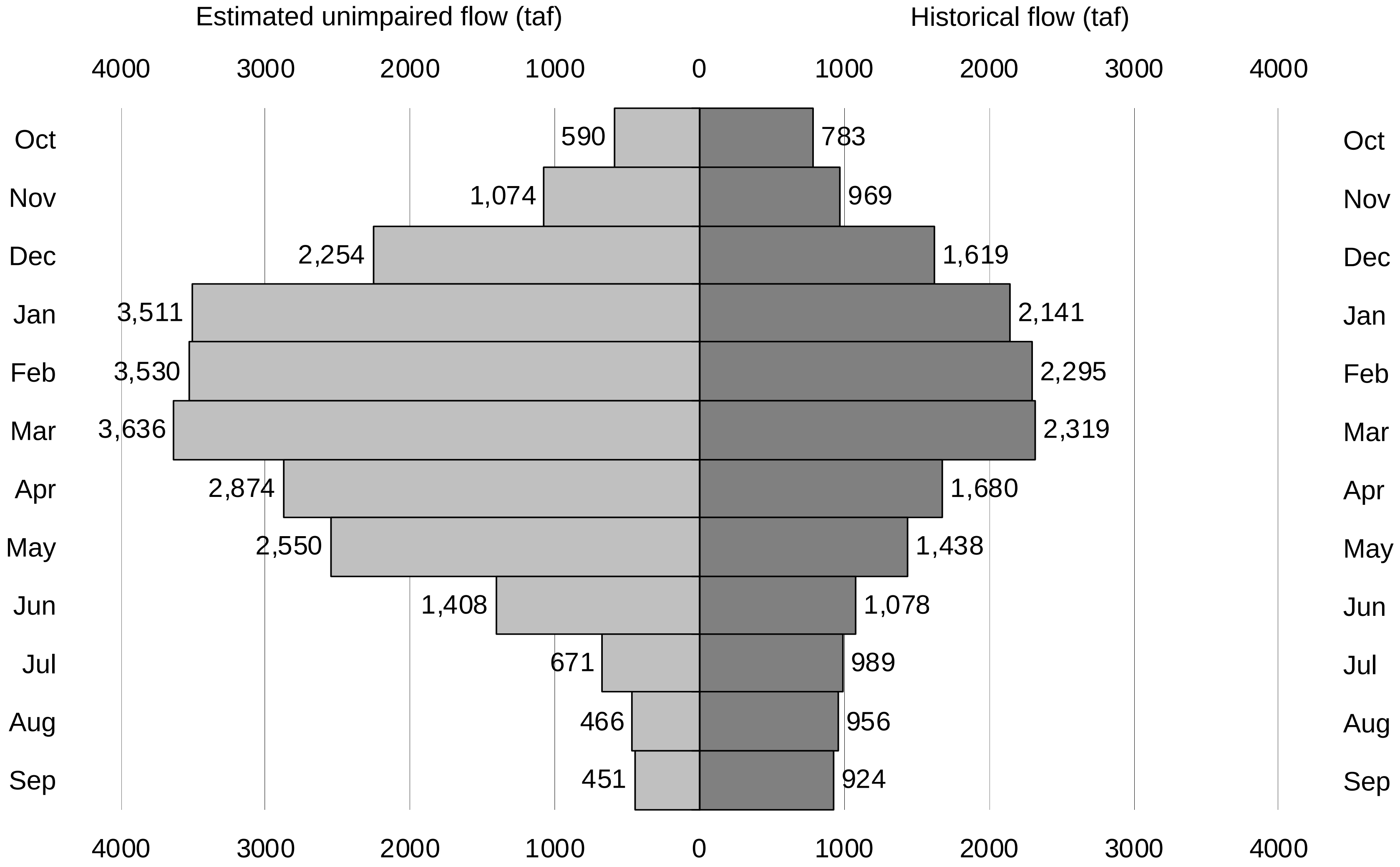
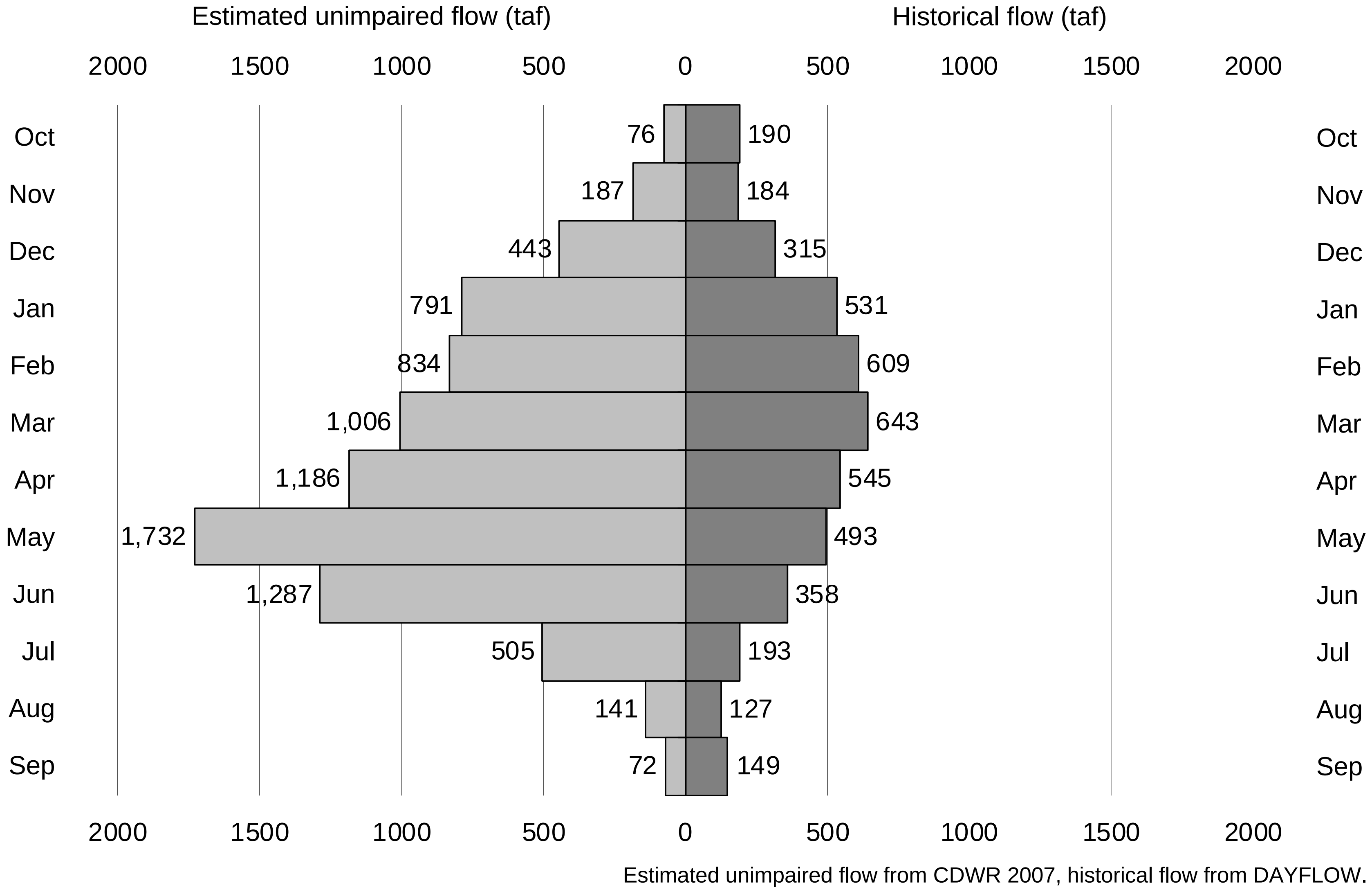


Figure 1. Sacramento-San Joaquin River Delta.



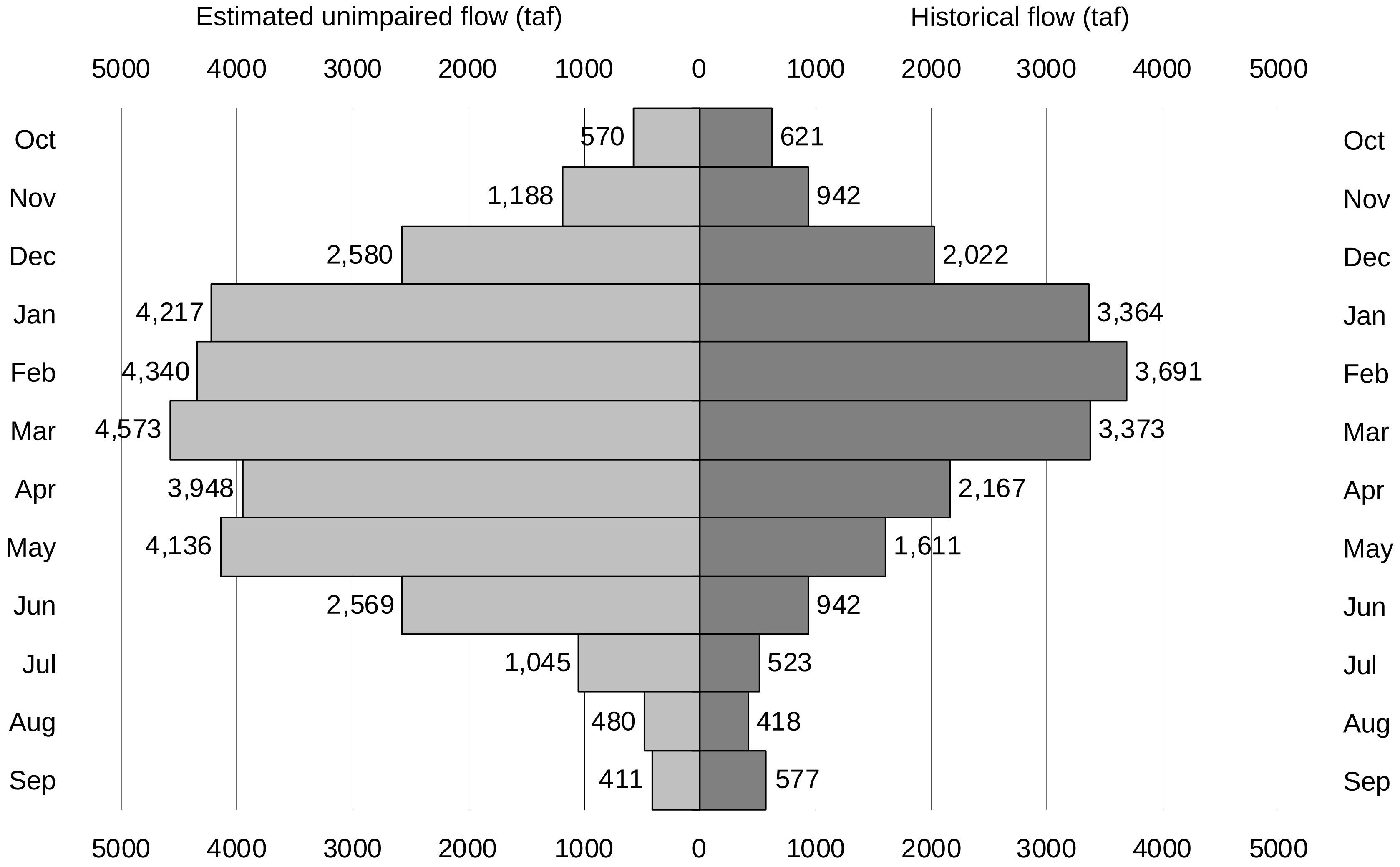
Estimated unimpaired flow from CDWR 2007, historical flow from DAYFLOW.

Figure 2. Sacramento Valley mean monthly inflow, 1955–2003.



Estimated unimpaired flow from CDWR 2007, historical flow from DAYFLOW.

Figure 3. San Joaquin Valley and East-side streams mean monthly inflow, 1955–2003.



Estimated unimpaired flow from CDWR 2007, historical flow from DAYFLOW.

Figure 4. Delta mean monthly outflow, 1955–2003.

Life Stage of Focus Fish Species	Fall			Winter			Spring			Summer			Notes/References
	(Sep-Nov)			(Dec-Feb)			(Mar-May)			(Jun-Aug)			
Chinook Salmon (Central Valley spring-run)													Fisher 1994; C. Harvey, pers. comm., as cited in Moyle et al. 1995; Colleen Harvey, CDFG, pers. comm., 2002; Hill and Webber 1999; Marcotte 1984; Moyle et al. 1995; Rutter 1908; Sacramento River Winter-Run Chinook Salmon Recovery Team 1997; Vogel 1987a and b, as cited in Moyle et al. 1995; Ward and McReynolds 2001; Yoshiyama et al. 1996
Adult upstream migration			░	░	░	░	▓	▓	▓	░	░		
Spawning & egg incubation	Spawning/Incubation Occurs Upstream of Delta												
Larval/fry/ juvenile rearing	░	░	░	░	░	░	░	░	░	░	░	░	
Smolt outmigration		░	▓	▓	░	░	░	░	░	░			
Adult habitat	No adult Chinook residency within the Delta												
Chinook Salmon (Central Valley fall run)													Williams 2006
Adult upstream migration	▓	░	░						░	░	░	▓	
Spawning & egg incubation	Spawning/Incubation Occurs Upstream of Delta												
Larval/fry/ juvenile rearing				░	░	░	░	░	░	░			
Smolt outmigration			░	░	░	░	░	░	░	░	░		
Adult habitat	No adult Chinook residency within the Delta												
Chinook Salmon (Central Valley late fall run)													Kjelson et al. 1982; Yoshiyama et al. 1998
Adult upstream migration	░	░	▓	░	░	░	░						
Spawning & egg incubation	Spawning/Incubation Occurs Upstream of Delta												
Larval/fry/ juvenile rearing							░	░	░				
Smolt outmigration	░	░	░	░	░	░	░	░	░	░	░	░	
Adult habitat	No adult Chinook residency within the Delta												
Chinook Salmon (Sacramento River winter run)													Hallock and Fisher 1985, as cited in Sacramento River Winter-Run Chinook Salmon Recovery Team 1997; Sacramento River Winter-Run Chinook Salmon Recovery Team 1997; Vogel and Marine 1991; Yoshiyama et al. 1998
Adult upstream migration			░	░	░	▓	░	░	░	░			
Spawning & egg incubation	Spawning/Incubation Occurs Upstream of Delta												
Larval/fry/ juvenile rearing	░	░	░	░	░	░	░	▓	▓	░	░	░	
Smolt outmigration	░	░	░	░	░	░	░	░					
Adult habitat	No adult Chinook residency within the Delta												
Striped Bass													Baxter et al. 2008; Moyle 2002
Adult upstream migration						░	▓	▓	▓	▓	░		
Spawning & egg incubation							░	▓	▓	▓	░		
Larval/fry/ juvenile rearing	░	░	░	░	░	░	░	▓	▓	▓	▓	░	
Adult habitat	░	░	▓	▓	▓	▓	░	░	░	░	░	░	
Delta Smelt													Moyle 2002; Sweetnam and Stevens 1993, as cited in Moyle 2002; USFWS 1996, as cited in USFWS 2001; Wang 1986, as cited in Moyle 2002
Adult upstream migration				░	░	░	░	░	░	░		░	
Spawning & egg incubation						░	░	▓	▓	░	░		
Larval/fry/ juvenile rearing	░	░	░				░	░	░	░	░	░	
Adult habitat	░	░	░	░	░	░	░	░	░	░	░	░	
Sacramento Splittail													Turner 1966, as cited in Moyle 2002; Meng et al. 1994, as cited in Moyle 2002; Meng and Moyle 1995; Sommer et al. 1997, as cited in Moyle 2002; Baxter 1999, as cited in Moyle et al. 2000; Moyle et al. 2000
Adult upstream migration			░	░	░								
Spawning & egg incubation						░	▒	▒	░	░			
Larval/fry/ juvenile rearing						░	░	▒	▒	▒	▒	░	
Adult habitat	░	░	░	░	░	░	░	░	░	░	░	░	
Overbite Clam													Carleton et al 1990; Nicolini and Penry 2000
Spawning and fertilization	▓	▓	▓	░	░	░	▓	▓	▓	░	░	░	
Eggs/oocytes	▓	▓	▓	▓	░	░	▓	▓	▓	▓	░	░	
Larvae	░	░	░	░	░	░	░	░	░	░	░	░	
Adults (male and female)	░	░	░	░	░	░	░	░	░	░	░	░	

Figure 5. Life history timing of selected focal fish species.