Effects Analysis

State Water Project Effects on Longfin Smelt and Delta Smelt

March 2020

Prepared by California Department of Fish and Wildlife

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Acronyms and Abbreviations

20mm	20mm Delta Smelt Survey
°C	degrees Celsius
AF	acre-feet
AMP	Adaptive Management Plan
Banks Pumping Plant	Harvey O. Banks Pumping Plant
Bay Study	San Francisco Bay Study
BSPP	Barker Slough Pumping Plant
CCF	Clifton Court Forebay
CDFG	California Department of Fish and Game
CDFW	California Department of Fish and Wildlife
CESA	California Endangered Species Act
cfs	cubic feet per second
CHNSR	spring-run Chinook salmon (*Oncorhynchus tshawytscha*)
CHNWR	winter-run Chinook salmon (*Oncorhynchus tshawytscha*)
cm	centimeter(s)
CVP	Central Valley Project
D-1641	SWRCB Water Rights Decision 1641
DCI	Delta-Mendota Canal/California Aqueduct Intertie
Delta	Sacramento–San Joaquin Delta
DS	Delta smelt (*Hypomesus transpacificus*)
DSM2	Delta Simulation Model 2
DWR	California Department of Water Resources
EIR	Environmental Impact Report
EPA	U.S. Environmental Protection Agency
Estuary	San Francisco Bay Estuary
FEIR	Final Environmental Impact Report
FL	fork-length
FMWT	Fall Midwater Trawl
FR	Federal Register
ft	feett
GYSO	Goodyear Slough Outfall
HORB	Head of Old River Barrier
IEP	Interagency Ecological Program
ITP	Incidental Take Permit
Jones Pumping Plant	C.W Bill Jones Pumping Plant
km	kilometer
LAD	length-at-date
LFS	Longfin smelt (*Spirinchus thaleichthys*)
LSNFH	Livingston Stone National Fish Hatchery
MIDS	Morrow Island Distribution System
min	minute
mm	millimeter(s)
m/s	meter per second

NBA	North Bay Aqueduct
NMFS	National Marine Fisheries Service
NTU	nephelometric turbidity units
OBI	Old River at Bacon Island
OMR	Old and Middle River
ppt	parts per thousand
PTM	Particle Tracking Model
QA/QC	Quality Assurance/ Quality Control
QWEST	Net flow on the San-Joaquin River at Jersey Point
RPA	Reasonable and Prudent Alternative
RRDS	Roaring River Distribution System
salvage facilities	Tracy Fish Collection Facility and John E. Skinner Delta Fish Protective Facility
SAV	submerged aquatic vegetation
SFBS	San Francisco Bay Studies
Skinner Fish Facility	John E. Skinner Delta Fish Protective Facility
SJR	San Joaquin River
SLS	Smelt Larva Survey
SMSCG	Suisun Marsh Salinity Control Gates
SWP	State Water Project
SWRCB	State Water Resources Control Board
TAF	thousand acre-feet
TBP	South Delta Temporary Barrier Project
TL	total length
USFWS	U.S. Fish and Wildlife Service
WOMT	Water Operations Management Team
X2	Distance up the axis of the estuary measured from the Golden Gate where the near-bottom daily average salinity is 2 psu

1. Introduction

In response to the Department of Water Resources (DWR, Permittee) request for authorization for the incidental take of longfin smelt (*Spirinchus thaleichthys*, LFS), Delta smelt (*Hypomesus transpacificus*, DS), winter-run Chinook salmon (*Oncorhynchus tshawytscha*, CHNWR), and spring-run Chinook salmon (*Oncorhynchus tshawytscha*, CHNSR) under the California Endangered Species Act (CESA) for existing and future operations of the State Water Project (SWP; Project), we conducted an analysis based on DWR's Incidental Take Permit (ITP) Application for Long-term Operation of the Project dated December 13, 2019 (ITP Application), DWR's Draft and Final Environmental Impact Report (FEIR), existing data, and literature. In the section below, we provide background information, methodologies and approaches used, and discussions and definitions of the terminology and information available. This document focuses on analyses conducted for LFS and DS.

As part of our analysis, we have considered that Project operations will be consistent with existing water supply contracts, flood control needs, and certain operational criteria and other actions set forth in the FEIR, U.S. Fish and Wildlife Service (USFWS) Biological Opinion for the Reinitiation of Consultation on the Coordinated Operations of the Central Valley Project and State Water Project issued on October 21, 2019 (USFWS 2019 BiOp; USFWS 2019) and the National Marine Fisheries Service (NMFS) Endangered Species Act Section 7 Biological Opinion on Long-term Operation of the Central Valley Project and the State Water Project (NMFS 2019 BiOp; NMFS 2019). In addition, we considered that the Project will comply with all applicable State, federal, and local laws and regulations in existence or adopted thereafter the issuance of the Incidental Take Permit (ITP) as well as State Water Resources Control Board (SWRCB) Water Rights Decision 1641 (D-1641).

At the time DWR submitted its ITP Application to CDFW, DWR had completed CalSim II model runs and runs of hydrologic and biological models that incorporate CalSim II outputs, including Delta Simulation Model 2 (DSM2), that characterized operations described in the Proposed Project of the DEIR. After DWR submitted the ITP Application, DWR conducted additional CalSim II modeling to characterize operations described in Alternative 2b of the Draft EIR. DWR provided preliminary results from the Alternative 2b CalSim II runs to CDFW in January 2020 in separate transmittals. After completing Alternative 2b CalSim II runs, DWR ran hydrologic and biological models that incorporate CalSim II outputs, including DSM2, to support the effects analysis for Refined Alternative 2b within the FEIR and the Project Description and associated Conditions of Approval in the ITP. These additional model results were provided to CDFW in separate transmittals and as administrative drafts of the FEIR in February and March 2020. When analyses conducted by DWR are referenced in this document, they refer to the Refined Alternative 2b model runs included in the FEIR.

Since operations began, the SWP has coordinated operations with the CVP to maintain Delta water quality and a formal coordination agreement has been in place since 1986 to ensure each project retains its portion of the shared water for export and bears its share of the obligation to protect beneficial uses (DWR and USBR 1995, Arthur et al. 1996). Some facilities were developed for joint use, such as San Luis Reservoir, O'Neill Forebay, and more than 100 miles of the California Aqueduct and related pumping facilities (DWR and Reclamation 1995). Such coordination is increasingly necessary over time to achieve multiple, mandatory water quality objectives (e.g., D-1641) while optimizing water supply south of the Delta (Arthur et al. 1996). Water exports from the south Delta SWP and CVP facilities create hydrodynamic conditions that result in fish entrainment into the south Delta and subsequently the export facilities (Brown et al. 1996, Kimmerer 2008, Grimaldo 2009). Using adult DS as an example, a recent analysis of salvage identified hydrodynamics (total exports, OMR flow), water quality (turbidity), and population abundance as the most important factors influencing salvage (Grimaldo et al. 2017a). More specifically, SWP exports, Yolo Bypass flows, and DS abundance best explained adult DS salvage at the SWP across the entrainment season, whereas species abundance, OMR flows, and turbidity best explained adult salvage through the entire entrainment season at the CVP (Grimaldo et al. 2017a). Because salvage at both the SWP and CVP fish facilities were found to be determined either directly by SWP exports or by local hydrodynamic conditions strongly influenced by SWP exports (OMR flow), entrainment risk attributable to SWP is best assessed by evaluating patterns of Covered Species salvage at both the SWP and CVP fish facilities as combined salvage. Currently, combined salvage from both the SWP and CVP fish facilities provides the only means to effectively extrapolate the effects of south Delta SWP export operations on entrainment of fishes into the central and south Delta (Smith 2019).

2. Project Description

DWR will continue to operate the SWP facilities in the Sacramento-San Joaquin Delta (Delta) and Suisun Marsh. The State Water Project (SWP) includes water, power, and conveyance systems, conveying an annual average of 2.9 million acre-feet (AF) of water. The principal facilities of the SWP are Oroville Reservoir and related facilities, and San Luis Dam and related facilities, facilities in the Delta, the Suisun Marsh Salinity Control Gates (SMSCG), the California Aqueduct including its terminal reservoirs and the Delta-Mendota Canal/California Aqueduct Intertie (DCI), and the North and South Bay Aqueducts. Permittee holds contracts with 29 public agencies in northern, central, and southern California for water supplies from the SWP. Water stored in the Oroville facilities, along with water available in the Delta (consistent with applicable regulations) is captured in the Delta and conveyed through several facilities to SWP contractors. The SWP is operated to provide flood control and water for agricultural, municipal, industrial, recreational, and environmental purposes.

The Project includes operations of the Harvey O. Banks Pumping Plant (Banks Pumping Plant), the Clifton Court Forebay (CCF), the John E. Skinner Delta Fish Protective Facility (Skinner Fish Facility), the Barker Slough Pumping Plant (BSPP), the South Delta Temporary Barriers, San Luis Reservoir, the Delta-Mendota Canal/California Aqueduct Intertie, the Georgiana Slough Migratory Barrier, and Suisun Marsh facilities including the Suisun Marsh Salinity Control Gates (SMSCG), Roaring River Distribution System (RRDS), Morrow Island Distribution System (MIDS), and Goodyear Slough Outfall (GYSO).

The Project is located within the following geographic area (Project Area, See Figures 1A and B attached to the ITP):

- Sacramento River from its confluence with the Feather River downstream to the legal Delta boundary at the I Street Bridge in the City of Sacramento;
- Sacramento-San Joaquin Delta (i.e., upstream to Vernalis and downstream to Chipps Island); and
- Suisun Marsh and Bay

Project operations will be in all fish-bearing waterways within the Project Area. The northern edge of the Project Area is located approximately 8.56 km northeast of Knights Landing in Yolo County at approximately 38.785281 latitude, -121.621825 longitude and extends downstream on the Sacramento River to the Delta. To the south and east the Project Area is bounded by the legal boundary of the Delta. To the west the Project Area is bounded by the legal Delta, Suisun Marsh, and Suisun Bay.

3. Covered Species List

The ITP provides Permittee with incidental take authorization for the Project for the following species, referred to collectively as "Covered Species":

1. Longfin smelt, CESA-listed as Threatened
2. Delta smelt, CESA-listed as Endangered
3. Spring-run Chinook salmon, CESA-listed as Threatened[1]
4. Winter-run Chinook salmon, CESA-listed as Endangered

4. Covered Species Life History

4.1. Longfin Smelt Life History

The longfin smelt (*Spirinchus thaleichthys*) in California is a small (to 150 mm TL), presumably semelparous, anadromous member of the "true smelt" family Osmeridae (Moyle 2002). It exhibits a predominantly two-year life history (Moyle 2002) though the potential to spawn at the end of their first and third years of life has been detected (CDFG 2009a). The abundance of LFS has been in decline for decades (Rosenfield and Baxter 2007; Sommer et al. 2007) only interrupted by short periods of high spring outflow and coincident population increases (Thomson et al. 2010). Increasing spring X2 – defined as the distance of the 2 PSU isohaline, measured from the bottom, from the Golden Gate Bridge in kilometers (km) – (i.e., reduced outflow) and to a lesser degree water clarity have had negative effects on LFS abundance over the long-term (Thomson et al. 2010) and changes in its feeding environment subsequent to the introduction of the overbite clam, *Potamocorbula amurensis*, likely led to its initial step decline ca. 1988 (Baxter et al. 2010; Feyrer et al. 2003; Kimmerer 2002a). The cause of its step decline in the early 2000s remains unknown (Mac Nally et al. 2010; Thomson et al. 2010). LFS abundance has since declined to record lows (Hobbs et al. 2017).

<u>Spawning in California</u>: Although individuals have been collected as far south as Monterey Bay, the San Francisco Estuary is home to the southern-most spawning population for the species and the largest

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[1] CDFW's analyses of effects to spring-run Chinook salmon and winter-run Chinook salmon are in a separate document.

spawning population in California (Garwood 2017). Spawning has also been noted in the Eel River and tributaries to Humboldt Bay (Garwood 2017). Within the San Francisco Estuary, LFS appear to spawn at least periodically in Coyote Creek, a tributary to south San Francisco Bay; Petaluma River and Sonoma Creek, tributaries to San Pablo Bay; Napa River, tributary to Carquinez Strait (Lewis et al. 2017; Parker et al. 2017); Green Valley Creek, tributary to Suisun Marsh (CDFG 2009b); and likely throughout eastern Suisun Bay, the central Delta/San Joaquin River to about Turner Cut/Rough and Ready Island and north Delta into the Cache Slough and the Sacramento Deepwater Ship Channel (CDFG 2009a; Moyle 2002), and rarely higher in the Sacramento and San Joaquin rivers (CDFG 2009a).

<u>Spawning</u>: Maturing and immature fish move toward freshwater sources in late fall and winter as water cools and appear to stage in low salinity habitat around X2 with lesser densities detected with distance upstream in freshwater (CDFG 2009b, Hobbs pers. comm. 2019); thus, LFS move farther into the Delta during dry years when X2 is farther upstream in the Delta and this increases their vulnerability to entrainment (CDFG 2009b). In Lake Washington, ripe adults make short (1-2 km), night-time migrations into tributaries to spawn (Dryfoos 1965; Moulton 1970; Moulton 1974), laying small adhesive eggs on sand and, to a lesser degree, gravel substrates (Brocksmith and Sibley 1995; Martz et al. 1996; Moulton 1974). In Coyote Creek, a tributary to south San Francisco Bay, maturing LFS were observed to congregate in low salinity habitats and ripe adults were collected several km upstream (Hobbs pers. comm. 2019), like behaviors observed in Lake Washington tributaries. Spawning is also inferred to occur in some marshes, particularly within Suisun Bay and the western Delta (Grimaldo et al. 2017b). In the San Francisco estuary, spawning occurs primarily from December through March but periodically extends from November through April (CDFG 2009a). Adhesive eggs are not believed to be particularly vulnerable to direct entrainment, although they are known to be captured by drift nets in Lake Washington tributaries at times (Martz et al. 1996), so eggs can be displaced by strong currents. Eggs spawned in brackish water or near the downstream limit of freshwater in the Bay-Delta may be affected by increases in salinity due to declining outflow related to natural runoff and to SWP operations. Those spawned in Bay tributaries could similarly face harsh salinity conditions due to flashy tributary flows or water diversions that lead to salinity encroachment upstream.

<u>Egg, larval and juvenile development</u>: Egg incubation duration is inversely related to water temperature and typically ranges from two to four weeks (CDFW unpublished). Eggs have not been observed in the Bay-Delta. In tributaries to Lake Washington, LFS select predominantly sand and gravel substrates for spawning (Brocksmith and Sibley 1995; Martz et al. 1996) and high flows dislodged some eggs reducing survival (Chigbu 2000; Martz et al. 1996). At hatching, larvae are buoyant and become predominantly surface oriented until they reach >10 mm Total Length (TL), when air bladder development begins and facilitates vertical movement allowing fish to better maintain position or move within the estuary (Bennet et al. 2002). Larvae are initially dispersed by tidal currents and net flows, and thus are susceptible to entrainment when hatched in the central or south Delta (CDFG 2009b).

<u>Temperature</u>: LFS larvae and small juveniles are most commonly found in temperatures of 13-16 ºC (Lewis et al. 2016). They are sensitive to water temperatures of 20ºC and above (95% collected below 21.1 ºC, Jeffries et al. (2016)), and appear to leave the Delta in early summer as water temperatures exceed 20ºC (CDFW unpublished). In small Bay tributaries water temperatures can reach 20ºC and

above in March and larvae and juvenile LFS are seldom observed in these habitats at temperatures above 16 ºC (Lewis et al. 2017). Such early temperature increases limit the length of time Bay tributaries can provide nursery habitat.

Salinity: Over time, as larvae and juveniles develop, they disperse downstream from spawning habitat and into brackish water and eventually marine habitats (Baxter 1999). Both larvae and early juveniles are initially distributed around the location of X2 (Dege and Brown 2004; Parker et al. 2017). As a result, hatch location, net channel currents and the position of X2 influence the risk of entrainment for these early life stages. Early rearing in the low salinity zone, particularly in the 1-4 ppt range has produced the best recruitment (Hobbs et al. 2010) though larvae and small juveniles have been found in salinities of 14 to 18 ppt (Kimmerer et al. 2013; Parker et al. 2017). The volume and surface area of this low-salinity habitat varies with X2 and reaches local maxima when X2 is in Suisun Bay at about 68 km and again when X2 is in San Pablo Bay at about 40 km (Kimmerer et al. 2013).

Food sources: This low salinity habitat, whether in Suisun Bay or San Pablo Bay also contained important LFS food sources, including the calanoid copepod *Eurytemora affinis* and the mysid *Neomysis mercedis* (Kimmerer and Orsi 1996 ; Orsi and Mecum 1996 ; Winder and Jassby 2011). Since their introductions, the calanoid copepod *Pseudiaptomus forbesi* and the mysid *Hyperacanthomysis longirostrus* have also become important food sources (Baxter et al. 2010). Historically, *E. affinis* was abundant and available for much of the year and its abundance was not correlated with flow. After the invasion of the overbite clam (and possibly copepods like *P. forbesi*), *E. affinis* is currently only abundant for a month or two in spring and its abundance is now positively correlated with spring outflow (Hennessy and Burris 2017; Kimmerer 2002a). Recently, Mac Nally et al. (2010) developed strong evidence that low outflow (reported as high levels of X2) significantly reduced calanoid copepod biomass in spring and mysid biomass in summer, both in the low salinity zone. The introduced calanoid copepod, *P. forbesi,* and introduced mysids, primarily (*H. longirostrus*) now provide important LFS diet components from late spring through fall (Baxter et al. 2010). The abundance of *P. forbesi* in the low salinity zone during summer and fall is subsidized from upstream and influenced by freshwater outflow (Durand 2010; Hennessy and Burris 2017; Kimmerer et al. 2018). This food subsidy in Suisun Bay replaces some of the local zooplankton production lost to feeding by the overbite clam, *P. amurensis* (Kimmerer et al. 2018). These authors note that this subsidy decreases as outflow decreases (reported as X2 advancing upstream; see also Mac Nally et al. (2010)) and the *P. forbesi* population shifts east placing it at greater risk of entrainment and loss to south Delta and in-Delta water exports.

Juvenile dispersal: Many juvenile LFS disperse into marine salinities by summer, others rear in intermediate salinities in San Pablo Bay and a successively smaller remnant remains and rears in Suisun Bay during summer and fall (Baxter et al. 2010; Baxter 1999). After the introduction of the overbite clam, *P. amurensis*, LFS exhibited a distribution shift toward higher salinities (Fish et al. 2009). Actions in spring, summer and fall aimed at improving habitat and productivity of Suisun Bay could provide benefits to rearing juvenile LFS and, if successful, may over time increase LFS use of this region.

LFS abundance (i.e., year-class strength) continues to be positively related to freshwater outflow during its winter-spring spawning and early rearing periods (Jassby et al. 1995; Kimmerer 2002b; Rosenfield and Baxter 2007; Sommer et al. 2007; Stevens and Miller 1983; Tamburello et al. 2019; Thomson et al. 2010) and there is strong evidence that adult stock size also influences the outflow abundance relationship (Nobriga and Rosenfield 2016).

4.1.1. Conceptual Models of Entrainment

Below we provide two conceptual models of how LFS behavior and distribution at various life stages influence the risk of entrainment with particular reference to entrainment into the south Delta and into SWP export facilities. We focus on two periods, the late fall through early spring period when immature and mature individuals move upstream and into the upper estuary and Delta to rear and spawn, respectively; and the winter through early summer period when eggs, larvae and young juveniles spawned in or near the Delta hatch, rear and begin their downstream migration. During each period, some portion of the population inhabits the central and south Delta and is at risk of entrainment in south Delta water exports.

4.1.1.1. Mature and Immature Adults (Late Fall and Winter)

Maturing age-1 LFS are rare or not present in the estuary during the late summer and early fall (August and September) just prior to their spawning season and presumably rear in marine waters at this time (Rosenfield and Baxter 2007). As estuarine waters cool in late fall, both maturing and immature individuals re-occupy the upper estuary (i.e., Suisun Bay/Marsh and the Delta; Figure 1). From at least December through March, adults appear to stage in low salinity water to ripen (Figure 2) and potentially make short-distance, nocturnal spawning runs into freshwater for spawning as they do in Lake Washington (Dryfoos 1965; Moulton 1970; Moulton 1974). Some LFS may spawn in brackish water (Grimaldo et al. 2017b), which would position them out of the influence of south Delta export facilities, but potentially within the influence of other Project facilities. Freshwater and turbidity sources for Suisun Bay may attract spawners to regions were they or their progeny are at risk of entrainment in other diversion facilities: for example 1) to Green Valley Creek and Cordelia Slough and the Morrow Island diversion; and 2) Cache Creek and Cache and Lindsey sloughs and the Barker Slough export facility (CDFG 2009b). LFS distribution shifts with X2 location (Figure 2). Species density and perhaps spawner distribution appears to decrease with distance upstream from the low salinity zone (Figure 2). As a result, the location of X2 approximately predicts the location of this congregation and influences how far spawning migrations penetrate the Delta, which in turn increases their risk of entrainment and that of their progeny (CDFG 2009b; Sommer et al. 1997). Individuals remaining and spawning in low salinity regions (e.g., 2-4 ppt) are relatively invulnerable to entrainment as a result of south Delta exports except when X2 is high and Old and Middle River (OMR) flow is more negative than -5000 cfs. The location of X2, the abundance of LFS in the upper estuary (i.e., proximity to facilities), and export rates during the spawning period are believed to have the greatest effects on LFS entrainment as indexed by salvage (CDFG 2009b; Grimaldo et al. 2009; Sommer et al. 1997).

Immature and mature LFS migrate through and spawn in the San Joaquin River to about Turner Cut and the vicinity of Rough and Ready Island (CDFG 2009a). Immature and mature LFS may also migrate directly to the south Delta and are subsequently entrained. Alternately, high OMR flows may mis-cue individuals in the central or south Delta into swimming toward the pumps rather than to Suisun Bay.

As mentioned above, LFS smaller than the current approximate size for maturity (≥ 85 mm FL; i.e., immature or juvenile fish, Figure 1) are found within the Delta upstream of X2 during winter. These individuals are either rearing in habitat that became available as Delta temperatures cooled in fall, or they are mature individuals below the approximate size of maturity that are actually part of the spawning run, or a combination of both.

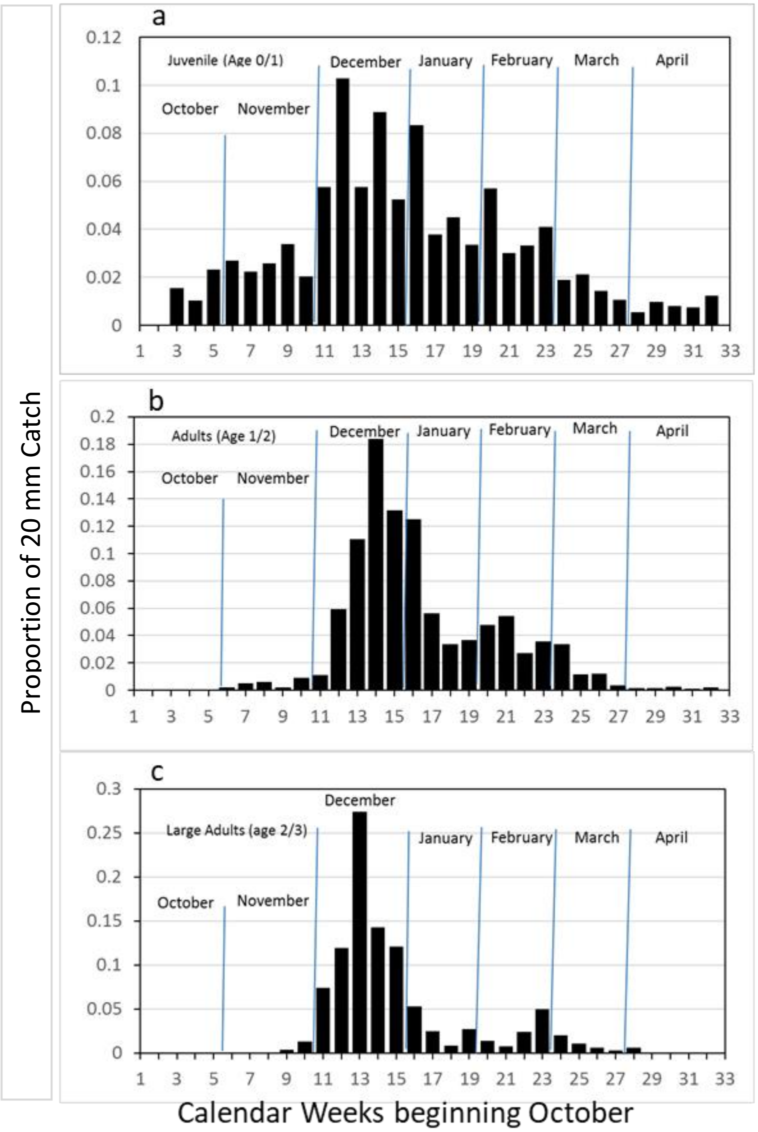

Figure 1: *Timing of LFS catch by age group in the upper San Francisco Estuary based on Chipps Island Trawl data, 1993 – 2017. Graphics depict grand means across years by age group of weekly proportion of total catch per 20-min trawl, months of October through April only. Data depiction begins the 2nd week in October and continues 31 weeks. Graphs depict relative densities within groups for a) juveniles (<85mm FL); b) adults (85 to <120 mm FL); and c) large adults (≥120) based on the weekly proportion of total October to April weekly catch per trawl values.*

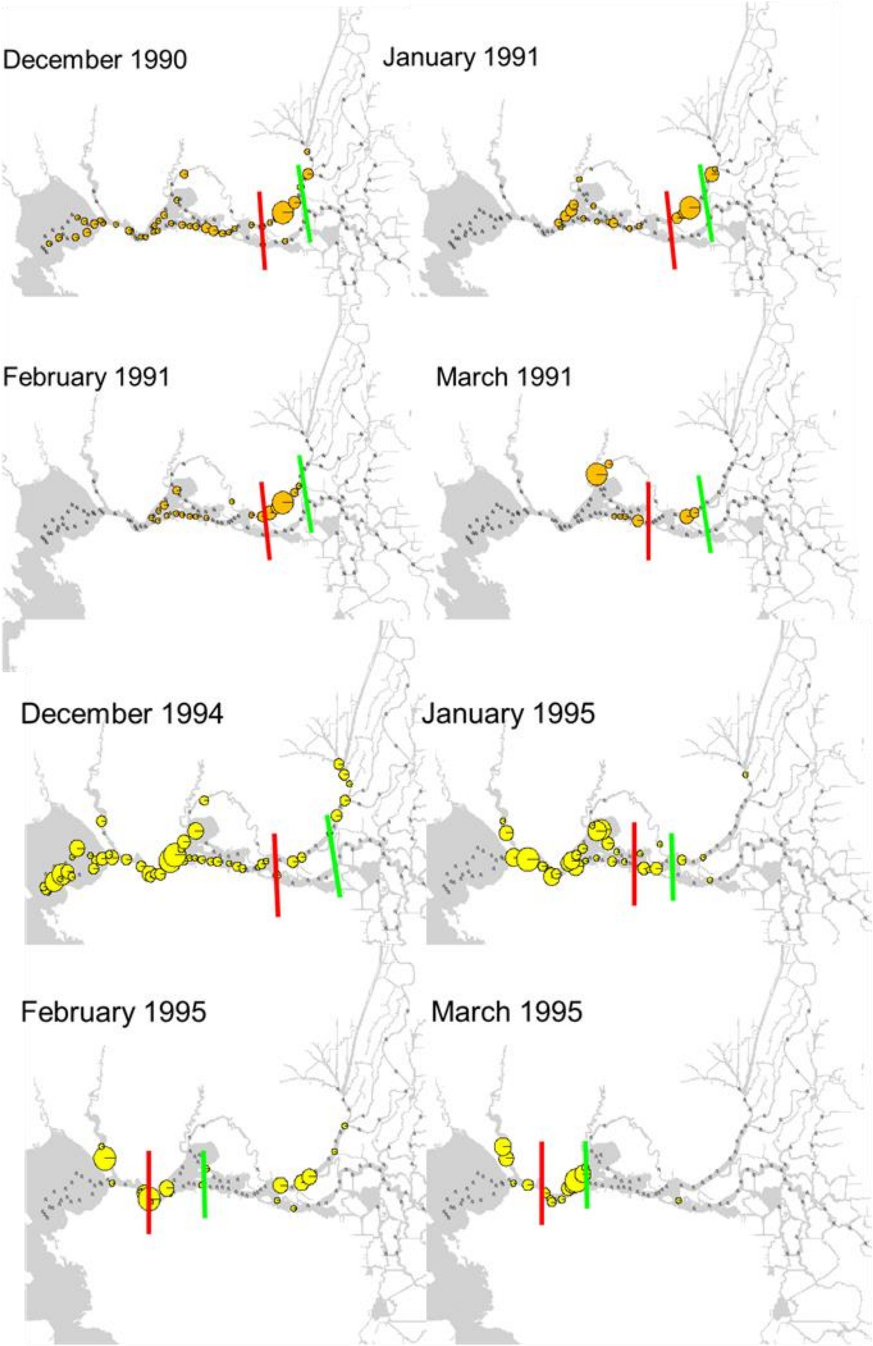

Figure 2: *LFS relative density (catch per tow, all ages; scale varies by year) for December through March in relation to X2 (red line) and X0.5 (green line, freshwater) in a low and high outflow water-year, 1991 and 1995, respectively. X2 values for mean dates of monthly sampling were derived from calculations from Chris Enright (DWR) provided in January 2008. X0.5 positions were determined relative to X2 using the equations: X0.5 =-(X2 position)*(Ln((31-(target salinity))/(515.67*(target salinity)))/-7)-1.5), where 0.5 is the target salinity (Unger 1994) X2 and X0.5 locations were plotted by hand referencing the X2 map in Jassby et al. (1995).*

4.1.1.2. Larvae and Small Juvenile (Spring and Early Summer)

Larval LFS hatch from December through April or May (Baxter 1999; CDFG 2009a). Hatching locations are, to some degree, determined by X2 location immediately prior to adult spawning and directly related to adult LFS spawning migration efforts and site selection. Larvae generally hatch farther into the Delta in low outflow as compared to high outflow years (CDFG 2009b), which results in greater salvage of juveniles in low outflow years as well (CDFG 2009b; Sommer et al. 1997). Larvae hatched or transported into the south Delta, south of Franks Tract, are assumed to be entrained into the south Delta and those drawn into Clifton Court Forebay (CCF) are assumed entrained into the facilities and lost to the system, because fish in this stage are too small to be effectively diverted to the salvage facilities (CDFG 2009b). Larval growth is slow, requiring almost three months to achieve 20 mm TL (c.f., months of first sizable abundance of yolk-sac larvae and 20 mm juveniles, Figure 3; Lewis et al. (2017)). Only juveniles greater than 20 mm are counted in fish salvage operations; larvae are lost to the system without documentation of magnitude, only presence (Morinaka 2013a).

Net current direction within channels where eggs hatch determines whether larvae are predominantly transported downstream toward Suisun Bay or upstream toward the south Delta export facilities (CDFG 2009b). Thus, OMR and QWEST flows interact to determine the fate of larvae hatched near the confluence of Old River and the San Joaquin River (CDFG 2009b). Once entrained within the south Delta, export rates and San Joaquin River and east-side tributary flows determine how rapidly fish are entrained in CCF. Once within CCF, LFS larvae may be rapidly transported into aqueducts heading south if export rates are high. Alternatively, if exports are moderate or low, wind-driven surface currents and surface orientation by larvae may cause them to remain within the CCF for a protracted period of time. While in CCF, predation and loss of fish is assumed to be relatively high (CDFG 2009b). In both the south Delta and CCF, moderate and low export rates can lead to a disjunction between dates of entrainment into the south Delta or CCF, and dates of passage into fish salvage facilities. The time span between entrainment into the south Delta and observation is salvage can be long enough to allow larvae to grow to juvenile size (≥20 mm) within the south Delta or CCF. Juvenile LFS will attempt to avoid water temperatures approaching and exceeding 20ºC (Jefferies et al. 2016; Lewis et al. 2017), by swimming downstream leading to potentially increased CCF entrainment of fish mis-cued by south Delta currents and to increased salvage of fish already entrained in CCF swimming toward the pumps attempting to exit CCF.

4.1.1.3. Spring and Summer Entrainment of Larvae and Small Juvenile Longfin Smelt in Barker Slough Pumping Plant and Suisun Marsh facilities

LFS larvae are also known to hatch in the north Delta near the Barker Slough Export facility, in Suisun Marsh near the Roaring River Diversion and in Green Valley Creek upstream of the Morrow Island Diversion (CDFG 2009a; CDFG 2009b). The Barker Slough and Roaring River facilities are screened, but nonetheless, they may entrain or impinge newly hatched and small LFS larvae. Positive barrier fish screens, consisting of a series of flat, stainless steel, wedge-wire panels with a slot width of 3/32 inch, have been shown to exclude larval fishes smaller than their design criteria of 25 mm or larger (Nobriga et al. 2004). However, it has not been demonstrated that such screens are similarly effective when placed at the upper end of a dead-end slough like Barker Slough. Fish growth and seasonal temperature increases leading to emigration will both reduce and eventually eliminate risk of entrainment and impingement.

RRDS, on the south eastern edge of Suisun Marsh is also within the range of spawning LFS. It too possesses a positive barrier fish screen, but one that boarders a tidal channel rather than at the upper end of a dead-end slough, so its potential to entrain or impinge LFS larvae is much reduced relative to the BSPP.

The MIDS diversion is not screened and has entrained LFS larvae in the past (Enos et al. 2007). Presumably, the freshwater inflows from Green Valley Creek periodically attract LFS spawners and place their larvae at risk of entrainment (CDFG 2009b).

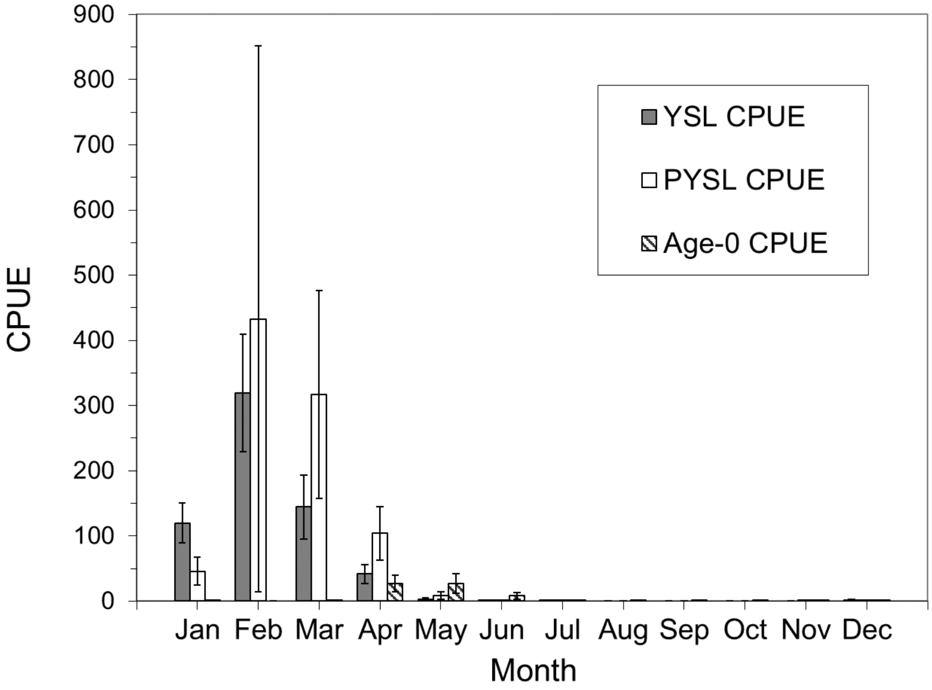

Figure 3: *LFS monthly mean density (±SD) of recently hatched yolk-sac larvae (YSL CPUE), post-yolk sac (PYSL CPUE) larvae and juveniles (Age-0 CPUE) from Bay Study Egg and Larva sampling 1980-1986.*

4.1.1.4. Entrainment into the South Delta

The entrainment of LFS into the south Delta represents indirect effect, because LFS are believed to be exposed to increased mortality, though this has not been quantified (see Grossman (2016)). The south Delta and CCF are considered poor habitats for LFS due to risk of loss at the export facilities, to predation and because both will reach summer temperatures exceeding LFS tolerance (CDFG 2009b; Grossman 2016; Jefferies et al. 2016; Lewis et al. 2017). Entrainment into the south Delta need not lead to entrainment into the export facilities if 1) LFS are either large enough to emigrate and chose the correct direction to exit the Delta or 2) if export rates are sufficiently low to allow time for growth and development of larvae entrained in the south Delta into juvenile stage, which is capable of swimming out of the south Delta. Emigration from the south Delta is presumably cued by increasing spring and summer temperatures.

4.1.1.5. Entrainment into Export Facilities and salvage

Entrainment into CCF represents a direct effect of SWP operations that is not quantified directly. Instead, total entrainment into CCF is calculated based upon expansions of the number of LFS salvaged at the Skinner Salvage Facility to account for fish lost to predation and for fish not effectively diverted from export flows to salvage (Brown et al. 1996; CDFG 2009b; Kimmerer 2008). Thus, entrainment estimates are indices because the number of fish salvaged varies by fish size and swimming ability, and is estimated from sub-samples of individuals diverted from exported water (Brown et al. 1996; CDFG 2009b; Kimmerer 2008). The number of fish entrained in CCF has not been quantified from direct observations (Table 1; Brown et al. 1996).

Table 1: Factors affecting LFS entrainment and salvage at the south Delta export facilities from CDFG (2009b).

Factors	Adults >80 mm	Larvae < 20 mm	Juveniles 20-80 mm
Predation prior to encountering fish salvage facilities	Unquantified, assume similar to other fishes	Unquantified.	Unquantified, assume similar to other fishes
Mortality due to high temperatures in spring	Unquantified, probably small	Unquantified, probably small due to growth to juvenile.	Unquantified, but probably high due to tolerance[1]
Louver efficiency (based on DS results)	Limited data indicate an efficiency of about 27 percent for the CVP facility; about 37 percent for the SWP facility	~ 0 percent	Likely ≤ 30 percent at any size; << 30 percent at less than 30 mm
Collection screens efficiency	~ 100 percent	~ 0 percent	<< 100 percent until at least 30 mm
Identification protocols	Identified from subsamples, then expanded in salvage estimates	Identified from subsamples as present since 2008[2]	Identified from subsamples, then expanded in salvage estimates
Fish survival after fish collection, handling, transport and release back into the Delta based on DS studies)[3]	78 percent for SWP and no information available for CVP	Unquantified	58 percent for SWP and no information available for CVP

[1] Jeffries et al. (2016) [2] Morinaka (2013a) [3] Aasen (2013), Afentoulis et al. (2013), Morinaka (2013b)

Fish entrained into CCF may succumb to predation or, in late spring and summer, to lethal water temperatures prior to entering the salvage facilities. Alternatively, fish, particularly larvae, may not be effectively screened from diverted water and subsequently salvaged (Brown et al. 1996). Fish <20mm in length are considered larval and not counted in salvage even if they are successfully diverted from exported water (Kimmerer 2008). However, in 2008 presence/absence sampling was conducted for DS larvae (Morinaka 2013a) and LFS larvae were identified as present and reported as part of the process. Moreover, like DS, many of the LFS salvaged at the fish facility likely die before release back into the estuary due to stress, injury or predation encountered during fish collection, handling, transport and release operations (Aasen 2013; Afentoulis et al. 2013; Brown et al. 1996; Morinaka 2013b).

The population-level effects of LFS entrainment have not been previously quantified, though a pseudo-population of LFS larvae was modeled and particle tracking used to estimate fractional entrainment during three water year (CDFG 2009b). LFS salvage is highest during low outflow years (Sommer et al. 1997; CDFG 2009b; Figure 4A). As a result, mortality associated with entrainment is highest when the population already faces adverse environmental conditions throughout the upper estuary.

4.1.1.6. Patterns in Salvage

Salvage declined during successive years of low Delta outflow and with decreases in overall abundance (Figure 4A, B). Effects of salvage likely also vary among years with low Delta outflow. LFS has undergone a protracted decline in abundance as a result of changes in hydrology, Delta hydrodynamics and the upper estuary pelagic food web; changes in contaminant loads and possibly also increased predation (Baxter et al. 2008; Baxter et al. 2010; Mac Nally et al. 2010; Sommer et al. 2007; Thomson et al. 2010). Several researchers have identified increased Delta outflow (or reduced X2) during the winter and spring as the largest factor positively affecting LFS abundance (Baxter et al. 2008; Baxter et al. 2010; Jassby et al. 1995; Kimmerer 2002b; Mac Nally et al. 2010; Stevens and Miller 1983). During high outflow years, larvae presumably benefit from increased transport and dispersal downstream, increased food production, reduced predation through increased turbidity, and reduced loss to entrainment due to a westward shift in the boundary of spawning habitat and strong downstream dispersal of larvae (CDFG 1992; CDFG 2009a; Hieb and Baxter 1993; Mac Nally et al. 2010). Conversely, during low outflow years, negative effects of reduced transport and dispersal, reduced turbidity and potentially increased loss of larvae to predation and increased loss at the export facilities result in lower young of the year recruitment. Analyses to disentangle the separate effects of these multiple factors have been initiated (see Mac Nally et al. 2010; Thomson et al. 2010), although additional work is needed.

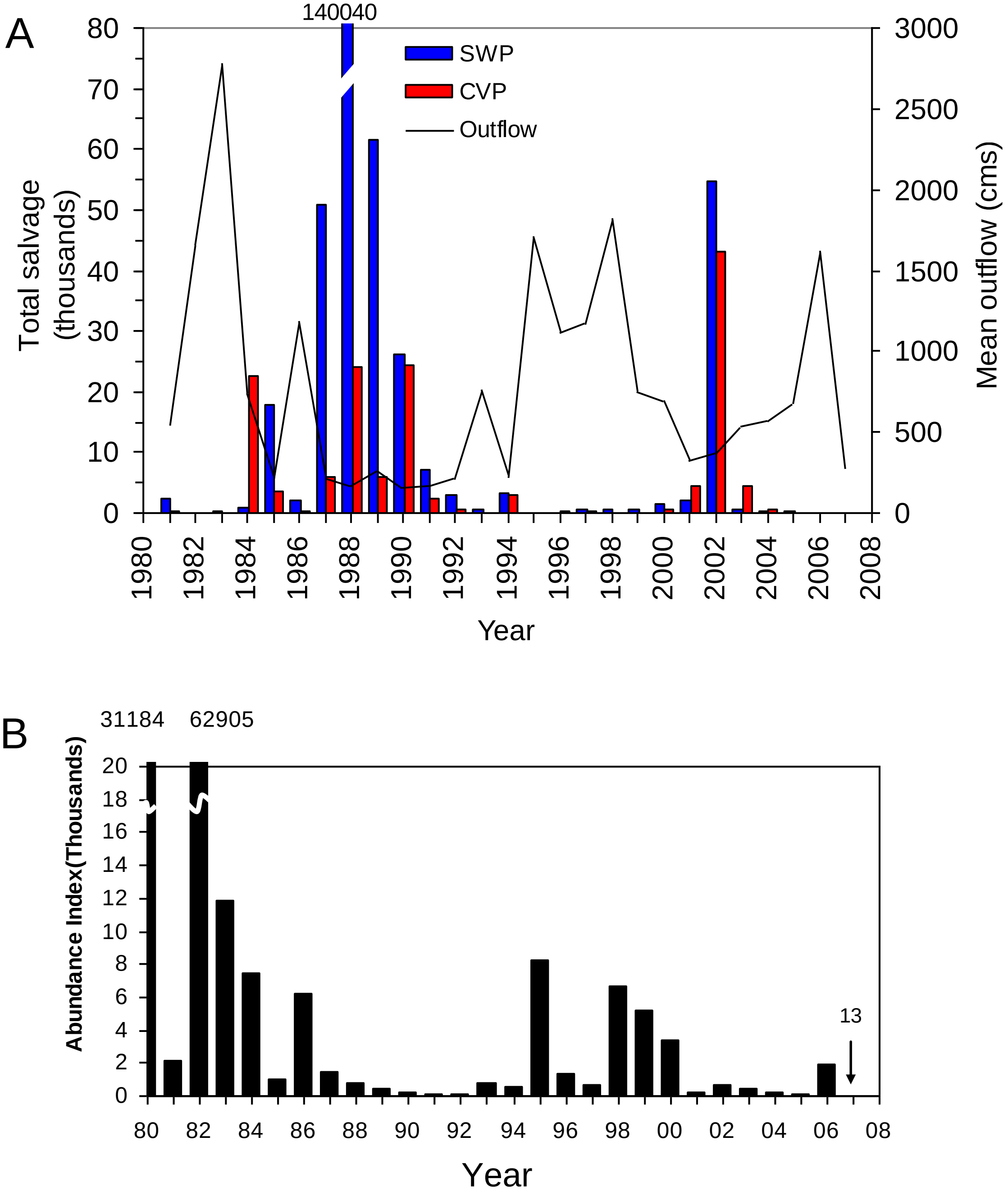

Figure 4: *(A) Sum of annual salvage (Jan-Dec) of longfin smelt (all ages) at the State (SWP) and Federal (CVP) Facilities and mean Jan-Dec outflow (cms), 1981 – 2007. Note that annual salvage data for 2007 is limited to 01/01/2007 -07/31/2007. (B) Fall Midwater Trawl annual longfin smelt abundance indices (all ages combined) for 1980-2007. Longfin smelt salvage declined over successive dry years as abundance declined: compare trends in A and B for 1987-1992.*

4.2. Delta Smelt Life History

The Delta smelt (*Hypomesus transpacificus*) is a small (≤ 120 mm TL), euryhaline, member of the "true smelt" family Osmeridae that is endemic to the upper San Francisco Estuary, primarily Suisun Bay and the Delta (Moyle 2002; Sweetnam 1999). In recent years few adults exceeding 90 mm have been observed (Bennett 2005; Sweetnam 1999). It exhibits a predominantly one-year life history (Moyle 2002) though a few adults survive after spawning (Baxter 1999) and may contribute to subsequent spawning periods (Bennett 2005). In the benign environment of artificial culture, two-year-old fish survive and remain viable for spawning (Lindberg et al. 2013). DS abundance suffered a step decline in the early 1980s followed by an unexplained sharp drop in the early 2000s (Sommer et al. 2007; Thomson et al. 2010) and its abundance has since dropped to record lows (Hobbs et al. 2017). DS abundance does not exhibit a linear relationship with Delta outflow (IEP 2015; Tamburello et al. 2019), as does LFS abundance (Kimmerer 2002; Sommer et al. 2007; Rosenfield and Baxter 2007). Instead, peaks in DS abundance are associated with intermediate levels of outflow, specifically those that position X2 and the low salinity zone (0.5-6.0 psu [practical salinity units], Kimmerer (2004)) in Suisun Bay where habitat quality reaches a local maxima (Feyrer et al. 2007a; Feyrer et al. 2011; Kimmerer et al. 2013). Such an orientation aligns the preferred salinity range of DS with shallow, turbid and potentially cooler water in Suisun Bay.

The DS has undergone a protracted abundance decline influenced by changes in hydrology, Delta hydrodynamics and the upper estuary pelagic food web; changes in contaminant loads and possibly as a result of increased predation (Baxter et al. 2008; Baxter et al. 2010; IEP 2015; Sommer et al. 2007). No single factor has been identified as being largely responsible for the decline of DS (IEP 2015). During high outflow years, larvae presumably benefit from increased transport and dispersal downstream, increased food production, reduced predation through increased turbidity, and reduced loss to entrainment due to a reduced influence of negative flows on DS spawning habitat (IEP 2015). Conversely, during low outflow years, negative effects of reduced transport and dispersal, reduced turbidity and potentially increased loss of larvae to predation and increased loss at the export facilities result in lower young of the year recruitment. Analyses to disentangle the separate effects of these multiple factors have been started (e.g., Mac Nally et al. 2010; Thomson et al. 2010).

Life history contingents and habitats: Through much of its life, a large contingent of the DS population inhabits the low salinity zone (Dege and Brown 2004; Feyrer et al. 2007a; Feyrer et al. 2011; Sommer et al. 2011), whose location is indexed by X2 (Kimmerer 2004). During its juvenile and subadult stages in summer and fall, the distribution of DS in the estuary is strongly related to freshwater outflow and the location of the low salinity zone (Sweetnam 1999; Moyle 2002; Dege and Brown 2004). When the low-salinity zone is positioned in Suisun Bay it overlaps with other important habitat characteristics, principally regions of higher turbidity and potentially lower water temperatures (Feyrer et al. 2007a; Feyrer et al. 2011; IEP 2015; Wagner et al. 2011).

The low-salinity zone is not the only summer/fall habitat for DS. Recent otolith chemistry analyses indicate three predominant life history phenotypes: 1) a freshwater resident contingent (23% of the population; mean across 7 years examined); 2) a brackish water resident contingent (7% of the population); and 3) a migratory contingent (70% of the population) that moves to freshwater to mature and spawn, and subsequent larvae and young rear in freshwater prior to dispersing/migrating to brackish water in the low salinity zone to rear during summer and fall (Bush 2017b; Hobbs et al. 2019b). The freshwater contingent uses tidal freshwater regions in the lower Sacramento River adjacent and directly upstream from Sherman Lake and the north Delta, including Cache Slough/Sacramento Deepwater Ship channel; the latter when summer and fall temperatures allow. Such a migratory schedule, particularly juvenile migration in late summer or fall, may provide food benefits for migrants, specifically improved foraging in freshwater in summer and in brackish water in fall and winter (Hammock et al. 2017). If temperatures approach or exceed about 25ºC in the north Delta, DS have the capacity to move downstream toward cooler water; if temperatures do not approach the apparent 25ºC limit, a contingent of DS may remain in the north Delta through summer and fall (Bush 2017; Hobbs et al. 2019). The ability to maintain a broad summer/fall range reduces the risk of a regional disaster decimating the population. DS have lost use of the lower San Joaquin River during the summer/fall due to clearing water and increased water temperature (Nobriga et al. 2008).

Although DS inhabit pelagic waters, typically away from shore and structure, a recent investigation found that DS proximity to tidal marshes resulted in greater stomach fullness. Tidal marsh habitats provide food benefits in the form of larval fish and zooplankton, particularly during winter, for DS preparing to spawn and recovering from spawning (Hammock et al. 2019).

Staging and Spawning: During the period from December through February, the migratory contingent inhabiting the low salinity zone uses periods of increased turbidity to move upstream into freshwater habitats (Bennett and Burau 2014; Grimaldo et al. 2009; Sommer et al. 2011) where they stage, continue to forage and eventually spawn. If no such period of increased turbidity occurs, this migratory contingent will disperse into freshwater habitats in March or April, just prior to spawning. During this migratory period DS can become vulnerable to entrainment in the south Delta and the export facilities, particularly when OMR flows are strongly negative (Grimaldo et al. 2009).

Spawning appears to be temperature controlled and begins at about 12ºC as early as February and continues into May or June or until water temperatures surpass 18ºC (Baskerville-Bridges et al. 2005; Bennett 2005). Spawning likely takes place in both freshwater and slightly brackish water (Hobbs et al. 2019). Exact spawning locations and substrates are not known. DS release small adhesive eggs that form a stalk to hold the egg above the substrate (Wang 2007) suggesting that spawning takes place on solid substrates, but in areas of deposition. Investigations using wild DS and a selection of natural substrates assorted in experimental tanks found that pebbles were the primary and sand the secondary choice for spawning substrates. DS consistently selected substrates in the highest water velocity treatment available under experimental conditions. In the lab they preferred spawning in the velocity of 8.8 cm/s compared to 1.4 cm/s in the first experiment and 15.4 cm/s compared to 8.7 cm/sec in the second experiment (Lindberg et al. 2019). These authors also found a significant difference in egg retention among substrates exposed to a water velocity of 14.6 cm/s for 3 days. Of the 955 eggs counted for all substrates, 86.4% remained on cobble, 68.9% remained on dead wood, 95.9% on empty tray, 85.3% on pebble, 59.4% on sand and 88.6% on natural vegetation; dead wood and sand experiencing significantly poorer retention than most other substrates (Lindberg et al. 2019). This result led authors to believe that sand might have been selected more in prior experiments, specifically in 15.4 cm/s flows, but some eggs were displaced from trays prior to counts. Within the spawning period female DS can spawn more than one batch of eggs – potentially up to three batches – depending upon the duration of the spawning window (Damon et al. 2016; Nagel et al. 2015).

Egg, larval and juvenile development: Adhesive eggs are not believed to be vulnerable to direct entrainment, although those spawned on sand can be displaced by high water velocities (Lindberg et al. 2019). Those spawned in brackish water may be affected by increases in salinity due to SWP operations or natural outflow fluctuations. Egg incubation duration is inversely related to water temperature and typically takes one to two weeks. Incubation lasts about 11 to 13 days at 14 to 16°C (Mager et al. 2004), and 8 to 10 days at 15 to 17°C (Baskerville-Bridges et al. 2004a; Baskerville-Bridges et al. 2005). At hatching, larvae are positively phototactic and swim up in the water column for the first 4-6 days post-hatch and become vulnerable to transport by tidal and net currents (Baskerville-Bridges et al. 2005, Bennett 2005). Presumably, this surface-oriented period does not last long, because larval DS have not been captured in proportion to their abundance in larva sampling (c.f., relative numbers of larval and juvenile DS and LFS collected in larval fish sampling, Baxter 1999). Swim bladder development occurs between 14 and 20 mm (Bennett 2005) and allows larvae to better maintain vertical distribution and move in the water column using tidal currents to change or maintain their position in the estuary (Bennett et al. 2002). When larvae and small juveniles enter the water column they are initially dispersed by tidal currents and net flows, and thus are susceptible to entrainment. Those in or near the central Delta are at risk of entrainment in the south Delta, and those in the south Delta are at risk of entrainment in the export facilities.

Temperature: DS larvae and post-larvae (60-64 days post-hatch) are the life stages most tolerant of high water temperatures (Komoroske et al. 2014b), allowing time for air bladder and fin development prior to seasonal temperature becoming a threat. Juveniles and adults are successively less temperature tolerant, yet are present during the warmest seasons of the year and thus have the least tolerance for additional warming (Komoroske et al. 2014). Initial temperature tolerance experiments found that small juveniles are sensitive to water temperatures approaching and above 25ºC (Swanson et al. 2000). Although subsequent investigations showed increased temperature tolerance, few juvenile DS have been caught at temperatures exceeding 25ºC in field surveys (Komoroske et al. 2014). With time and development, larvae and later juveniles disperse downstream from spawning habitat (Baxter 1999; Dege and Brown 2004) and away from warmer temperatures. As a result, DS are believed move out of the Delta in early summer before temperatures reach 25ºC.

Salinity: Both larvae and early juveniles are primarily distributed upstream of the location of X2 (Dege and Brown 2004). As a result, the position of X2 influences the risk of entrainment of these life stages. Even though larvae are primarily distributed above X2, post-larvae (60-64 days post-hatch) are tolerant of salinities to full sea water (Komoroske et al. 2014), perhaps providing this life stage some tolerance to survive fluctuations in salinity, then develop and reposition themselves in lower salinity habitat within the estuary. Many juvenile DS disperse into Suisun Bay and the low-salinity zone by summer, while others rear in freshwater habitats as long as temperatures don't reach extremes (Dege and Brown 2004, Bush 2017, Hobbs et al. 2019). Few juvenile and adult DS in the low-salinity zone will venture into more saline water, although DS have occasionally been caught in the wild at 18 ppt (Bennett 2005), and they can physiologically tolerate higher salinities in the laboratory (Komoroske et al. 2014b; Swanson et al. 2000). It appears that DS juveniles and adults can physiologically cope with salinities in the 18 ppt range without change to body condition or survival, but appear not to do so frequently, probably due to other limiting factors (Komoroske et al. 2016). As mentioned earlier, there are potential benefits associated with improved foraging when rearing in freshwater during summer and then migrating to the low-salinity zone in fall and remaining for winter (Hammock et al. 2017).

Food sources: Food quantity and quality are likely important factors in DS population dynamics (Sommer et al. 2007, Baxter et al. 2010, Mac Nally et al. 2010, IEP 2015). However, these factors have been declining since the late 1980s (Kimmerer and Orsi 1996; Orsi and Mecum 1996; Winder and Jassby 2011) potentially leading to smaller adults after the introduction of the overbite clam, *P. amurensis* (Sweetnam 1999). Adult size and thus egg production were important factors in modeled DS population dynamics (Rose et al. 2013a; Rose et al. 2013b).

The location of the low salinity zone has moved eastward in recent decades relative to unimpaired and earlier impaired conditions (Fleenor et al. 2010). Historically, the low salinity zone provided habitat for important food sources to DS, including the calanoid copepod *E. affinis* and the mysid *N. mercedis* (Moyle et al. 1992, Kimmerer and Orsi 1996, Orsi and Mecum 1996, Winder and Jassby 2011). Since their introductions, the copepods *P. forbesi*, *Sinocalanus doerri*, *Acartiella sinensis, Tortanus dextrilobatus, Limnoithona tetraspina* and the mysid *H. longirostrus* have also become important food sources as well and contribute a majority of the DS diet in summer and fall (Moyle et al. 1992; Slater and Baxter 2014). Historically, *E. affinis* was abundant and available for much of the year in the low salinity zone and its abundance was not correlated with flow, but since the invasion of the overbite clam (and possibly copepods like *P. forbesi*), *E. affinis* is only abundant for a month or two in spring and its abundance is now related to outflow (Hennessy and Burris 2017; Kimmerer 2002b). Recently, Mac Nally et al. (2010) developed strong evidence that low outflow (reported as high levels of X2) significantly reduced calanoid copepod biomass in spring and mysid biomass in summer, both in the low salinity zone. The abundance of *P. forbesi* in the low salinity zone during summer and fall is subsidized from upstream and influenced by freshwater outflow (Durand 2010; Kimmerer et al. 2018). This subsidy for Suisun Bay replaces some of the local zooplankton production lost to feeding by the overbite clam, *P. amurensis* (Kimmerer et al. 2018). These authors note that this subsidy decreases as outflow decreases (reported as X2 advancing upstream; see also Mac Nally et al. 2010) and the *P. forbesi* population shifts east placing it at greater risk of entrainment and loss to south Delta and in-Delta water exports. To counteract this loss of productivity, modest flow actions in the north Delta for spring, summer and fall have been proposed and implemented to improve habitat and productivity downstream and into Suisun Bay, if possible, for the benefit of DS (Natural Resources Agency 2016).

4.2.1. Conceptual Models of Entrainment

Below we provide two conceptual models of how DS behavior and distribution at various life stages influence the risk of entrainment with particular reference to entrainment into the south Delta and into

SWP export facilities. We focus on two periods, the early winter through spring period when immature and mature individuals move upstream and into the Delta to stage and spawn; and the late winter through early summer period when eggs, larvae and young juveniles spawned in or near the Delta hatch, rear and begin their downstream movement. During each period, some portion of the population inhabits the central and south Delta and is at risk of entrainment in south Delta water exports.

4.2.1.4. Entrainment of Maturing and Mature Delta Smelt in Winter and Spring

From December through February, the migratory contingent of maturing adult DS inhabiting the low salinity zone keys on periods of increased flow and turbidity called the “first flush” to make pre-spawning movements into tidal freshwater habitats where they stage and mature prior to spawning (Bennett 2005, Sommer et al. 2011, Bennett and Burau 2015). During the first flush, when water exports and tributary inflows are sufficient to draw turbid water into the south Delta, DS have been observed to follow the turbidity, increasing their entrainment (Grimaldo et al. 2009). Moreover, the magnitude of negative OMR flows and increasing X2 significantly interacted to increase adult DS salvage (Grimaldo et al. 2009). In low outflow years when a first flush does not occur, maturing DS will move to tidal freshwater in late February or March when spawning temperatures are approached and achieved (Bennett 2005). In such a scenario, maturing DS may be less likely to move into the clear waters of the south Delta for staging and spawning, reducing their risk of entrainment. Adults that volitionally move into the south Delta to spawn or are drawn into the south Delta and spawn, place their progeny at risk of entrainment in the SWP.

Individuals remaining in low salinity regions to spawn remain relatively invulnerable to entrainment in SWP projects. Similarly, those adults in the vicinity of the BSPP and RRDS are unlikely to be affected based on their ability to avoid screens employing proper approach velocity criteria.

4.2.1.5. Entrainment of Larval and Small Juvenile Delta Smelt during Spring and Summer

Larval DS hatch from March through June (Bennett 2005) but more commonly from early April through early June (Baxter 1999). Hatch locations are largely determined by where they were spawned because eggs are adhesive, though there is some evidence of egg movement when spawned on sand and velocities achieve ≥ 14-15 cm/s (Lindberg et al. 2019). Adhesive eggs are presumed to suffer limited or no entrainment in SWP facilities. DS larvae initially swim to the surface (Baskerville-Bridges et al. 2004; Baskerville-Bridges et al. 2005; Bennett 2005), so the net current direction within hatching channels determines whether larvae are initially transported downstream toward Suisun Bay or upstream toward the pumps. Thus, QWEST and OMR flows interact to determine the fate of larvae hatched in the San Joaquin River channel from Jersey Point upstream to Prisoners Point and possibly beyond (c.f., CDFG (2009b)). Limiting OMR no be more negative than -5000 cfs appears to limit entrainment from the San Joaquin River channel. Larvae hatched or transported into the south Delta, south of Franks Tract, are assumed entrained into the south Delta and those drawn into Clifton Court Forebay (CCF) are assumed to be entrained into CCF and the facilities and lost to the system, because fish in this stage are too small to be effectively diverted to salvage (CDFG 2009b).

Once entrained within the south Delta, export rates and San Joaquin River and east-side tributary flows determine how rapidly fish are entrained in CCF (CDFG 2009b). Because DS larvae appear to spend less time in the water column than LFS larvae, their transport in relation to net flows may be slower than that of LFS larvae, allowing more to grow to 20 mm prior to entrainment in the export facilities, and allowing for more of their entrainment to be recognized in salvage counts. Larval growth is slow, requiring about 70 days to achieve 20 mm TL (Baskerville-Bridges et al. 2004; Baskerville-Bridges et al. 2005; Bennett 2005), and be counted in fish salvage operations. Once within CCF, DS larvae may be rapidly transported into aqueducts heading south if export rates are high. Alternatively, if exports are moderate or low, wind-driven surface currents may cause them to remain within the CCF for a protracted period. In both the south Delta and CCF moderate and low export rates can lead to a gap between dates of entrainment (either south Delta or CCF) and dates of salvage enough to allow larvae to grow to ≥20 mm within the south Delta or CCF. Fish <20 mm TL are typically not counted in salvage, but since 2008 the presence of larval DS (i.e., <20 mm) has been reported on a daily basis (Morinaka 2013a). Nonetheless, most larvae entrained in the CCF are lost to the system without documentation of magnitude.

Juvenile DS are believed capable of actively avoiding water temperatures approaching 25ºC by swimming downstream. Such behavior could lead to increased entrainment of fish into CCF when they are mis-cued by negative currents in the south Delta and to increased salvage of fish already entrained in CCF looking for a way out. The south Delta and CCF are considered poor habitats for DS due to risk of loss at the export facilities, to increased predation in clear water, and early summer temperatures that typically exceed DS tolerance (Castillo et al. 2012; Nobriga et al. 2008; Grimaldo et al. 2009; Komoroske et al. 2014; Grossman 2016; Jeffries et al. 2016).

4.2.1.6. **Spring and Summer Entrainment of Larval and small Juvenile Delta smelt in the Barker Slough Pumping Plant and Suisun Marsh**

The BSPP and RRDS in Suisun Marsh are near potential DS spawning habitat. Even though they are screened, they may entrain or impinge newly hatched and small DS larvae. Positive barrier fish screens similar to those in Barker Slough have been shown to exclude larval fishes smaller than their design criteria indicate (Nobriga et al. 2004). Positive barrier fish screens consist of a series of flat, stainless steel, wedge-wire panels with a slot width of 3/32 inch. This configuration is designed to exclude fish approximately 25 mm or larger from being entrained. However, it has not been demonstrated that they can do so when placed at the back of a dead-end slough like the Barker Slough. Thus, operations of the BSPP have the potential to severely degrade DS spawning success in their vicinity in future years.

RRDS on the south eastern edge of Suisun Marsh is within the spawning range of DS. It also possesses a positive barrier fish screen. However, this screen is not located at the upper end of a dead-end channel and has a lower potential to entrain larvae than the BSPP. The MIDS diversion on the far western side of

Suisun Marsh is arguably outside of the DS range. Enos et al. (2007) collected larval through adult-sized fish at the intake from September 2004 through June 2006 and observed no DS.

4.2.1.7. Entrainment into the South Delta

The entrainment of DS into the south Delta represents an impact of the taking, because individuals in the south Delta are believed to suffer increased mortality in clear water, though this has not been quantified (see Grossman 2016). Entrainment into the south Delta need not lead to further entrainment into the export facilities and mortality. Adult DS are large enough to move out of the south Delta if they chose the correct direction for emigration. If exports rates are sufficiently low to allow time for growth and development from the larval to juvenile life stages, fish would have the ability emigrate volitionally. South Delta emigration is presumably cued by increasing spring and summer temperatures approaching 25ºC.

4.2.1.8. Entrainment into the Export Facilities and Salvage

Entrainment into CCF represents a direct effect of SWP operations that is not quantified directly. Instead, total entrainment into CCF is calculated based upon expansions of estimates of the number of DS observed in salvage at the Skinner Fish Facility (e.g., Kimmerer 2008) and estimates of pre-screen loss during transit through CCF (Castillo et al. 2012). Brown et al. (1996) and the CDFW Salmon Effects Analysis provide a description of fish salvage operations. Fish entrained in CCF may succumb to predation or, in late spring and summer, to lethal water temperatures prior to entering the salvage facilities or they may not be effectively “screened” from diverted water (e.g., Brown et al. 1996). Fish <20mm in length are considered larval and not counted in salvage operations (Brown et al. 1996, Kimmerer 2008) though they are currently noted as present or absent (Morinaka 2013a). Many of the DS salvaged at the fish facility likely die before release back into the estuary due to stress, injury or predation encountered during fish collection, handling, transport and release operations (Aasen 2013; Afentoulis et al. 2013; Brown et al. 1996; Morinaka 2013b).

The population-level effects of DS entrainment have been estimated at 1-50% for adults, though the high value may be biased high (Kimmerer 2008), and these values have been contested (Kimmerer 2011; Miller 2011).

Table 2: *Factors affecting DS entrainment and salvage at the south Delta export facilities.*

Factor	Adults >80 mm	Larvae < 20 mm	Juveniles 20-80 mm
Predation prior to encountering fish salvage facilities	Quantified, but sample size low[1]	Unquantified.	Unquantified, assume similar to other fishes
Mortality due to high temperatures in spring	Unquantified, probably small	Unquantified, probably small due to tolerance[2] & growth to juvenile	Unquantified, potentially high due to tolerance[2]
Louver efficiency (based on DS results)	Limited data indicate an efficiency of about 27 percent for the CVP facility; about 37 percent for the SWP facility[3]	~ 0 percent	Likely ≤ 30 percent at any size; << 30 percent at less than 30 mm
Collection screens efficiency	~ 100 percent	~ 0 percent	< 100 percent until at least 30 mm
Identification protocols	Identified from subsamples, then expanded in salvage estimates	Identified from subsamples as present since 2008[4]	Identified from subsamples, then expanded in salvage estimates
Fish survival after fish collection, handling, transport and release back into the Delta	78 percent for SWP and no information available for CVP[5]	Unquantified	58 percent for SWP and no information available for CVP[5]

[1] Castillo et al. (2012) [2] Komoroske et al. (2014) [3] Morinaka et al. (2008) [4] Morinaka (2013a)

[5] Aasen (2013), Afentoulis et al. (2013), Morinaka (2013a)

5. Take and Impacts of the Taking in Longfin Smelt

5.1. Larval Longfin Smelt

Larval LFS begin hatching as early as December and are present in the Delta into April (CDFG 2009a). The distribution of larvae is to some degree determined by the location of X2 immediately prior to adult spawning (Figure 5; see 5.3 Adult LFS and CDFG 2009b), which affects adult distribution and spawning locations. Larvae hatch from sites selected farther into the Delta in low outflow years than in high outflow years (CDFG 2009b). Similar to the salvage of juveniles slightly later in the spring and summer, entrainment of larvae is likely higher in low outflow years than in high outflow years (CDFG 2009b) (CDFG 2009b). Hatching locations and local hydrology (i.e., net currents driven by inflow and exports (Figure 5) and tidal dispersion facilitate larval LFS movement for many weeks post hatch. Newly hatched larvae appear to be relatively poor swimmers and surface oriented. They are initially incapable of effectively using vertical migration to remain in place or for directed movements and remain relatively incapable until they reach about 10-12 mm FL and develop an air bladder (Bennet et al. 2002). For these reasons, larvae that hatch within the hydrodynamic influence of the SWP and CVP export facilities are considered to be at risk of entrainment, first into the south Delta and subsequently into CCF and the Banks Pumping Plant. Since the SWP began operating in 1968, south Delta exports during the winter and early spring are frequently high enough to cause negative net OMR flows (Figure 5), drawing water into and through the interior Delta towards CCF and Banks Pumping Plant (Figure 6). Pelagic LFS larvae are drawn toward the pumps along with the water until they grow and develop sufficiently to competently vertically migrate. This competent period begins with air bladder development starting at 10-12 mm FL and continues through fin development which completes about 20mm FL (Simonsen 1977). However, even as competent swimmers, larvae and small juveniles must determine which direction leads to the lower estuary, and need to emigrate from the central and south Delta by early summer before water temperatures reach 20-22ºC, creating an increasingly stressful environment (Jeffries et al. 2016).

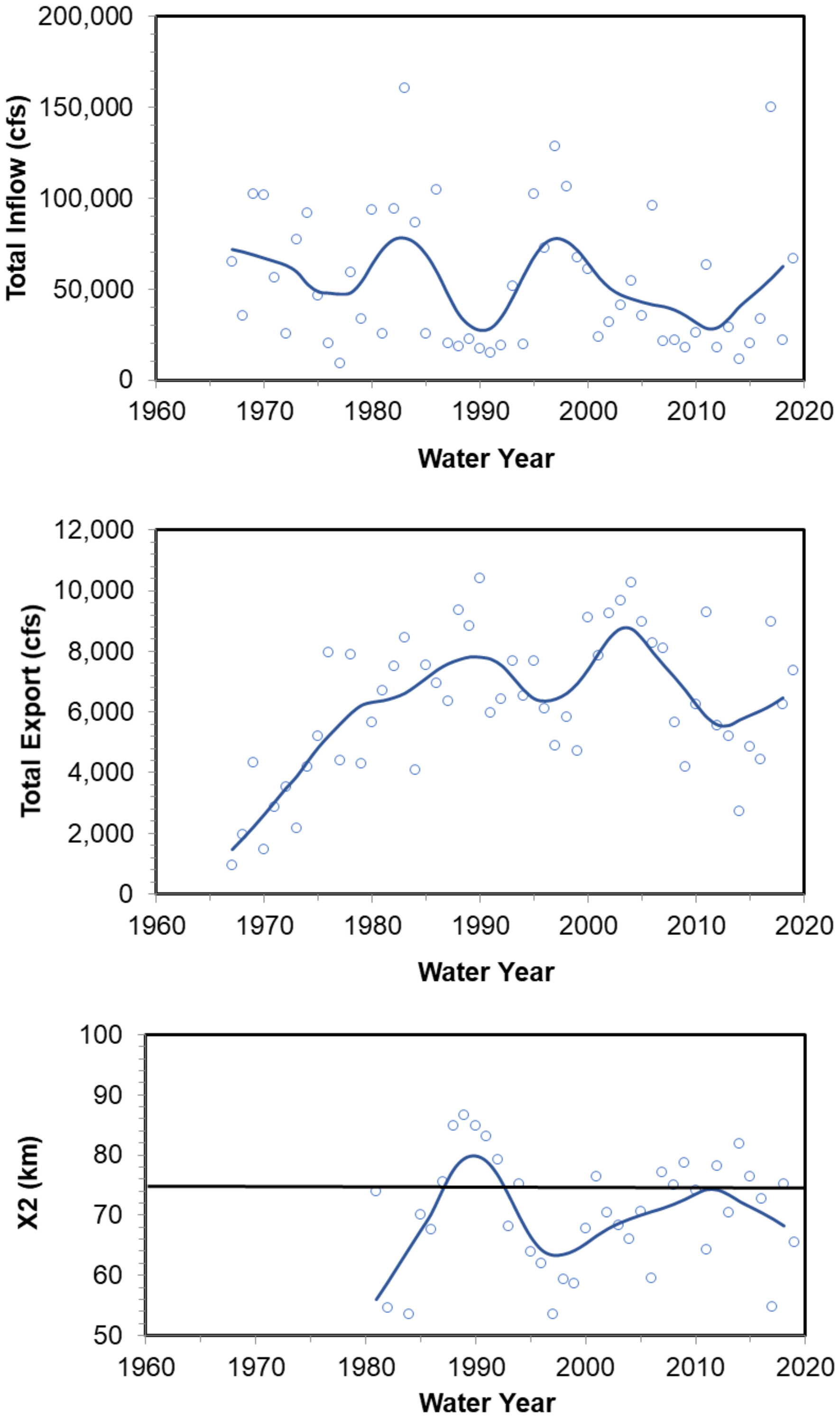

Figure 5: *Mean monthly winter (Dec-Mar) Delta inflow (top), total State Water Project and Central Valley Project exports (middle) and X2 location in km (bottom) for 1967 through 2019 (top and bottom), 1981 through 2019 (middle). Loess smoother line shown but not used in an analysis.*

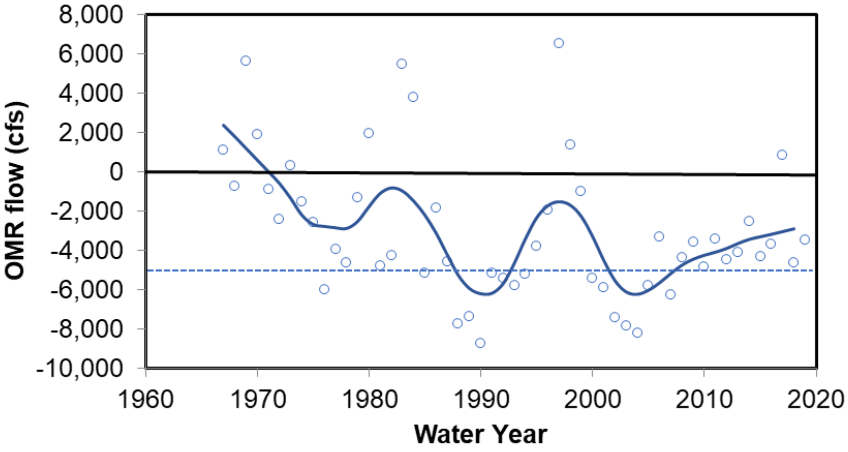

Figure 6: *Mean monthly winter (Dec-Mar) Old and Middle River (OMR) flows for 1967 through 2019. Dashed line at -5000 cfs for reference. Loess smoother line shown but not used in an analysis.*

5.1.1. Banks Pumping Plant and Clifton Court Forebay

Take of LFS larvae in the form of loss to the system or mortality will occur as a result of operations of the SWP south Delta export facilities. The areas where authorized take of LFS is expected to occur include CCF and the Banks Pumping Plant located about 12.9 km northwest of the city of Tracy. Operations of CCF and Banks Pumping Plant will result in take of all life stages of LFS beyond the egg stage, but particularly larvae and early stage juveniles (≥20 mm) (CDFG 2009b). Hatching (5-6 mm larvae) typically begins in December and can last through April, with most larvae transitioning to the more mobile the early post-larval stage (≥ 12mm) within about 30 days and to the early juvenile stage (≥ 20mm) in a little less than 3 months (Table 3). Historically, fish less than 20 mm in length were not identified or counted at either fish salvage facility, but in 2008 larval smelts were identified and reported as present when encountered (Morinaka 2013a). Even though the fish facilities were not designed to salvage larvae, smelt larvae have been regularly detected since the inception of protocols aimed at such detections (Table 4). Presence at the fish facilities of larval LFS is not unexpected given the frequency of newly hatched LFS larvae within the influence of the export pumps (Table 5). These data suggest that LFS regularly select spawning locations within the influence of the export pumps, though the number of larvae detected within the influence of the pumps has declined recently, coincident with declines in overall abundance (CDFW 2020a).

Table 3: *LFS length frequency by calendar month based on Smelt Larva Survey catches, 2009-2019.*

	Calendar Week													
	January					February				March				
Length (mm FL)	1	2	3	4	5	6	7	8	9	10	11	12	13	Grand Total
4					1			4		1				6
5	24	105	36	227	69	306	67	238	22	126	2	9	36	1267
6	105	779	451	1753	552	2365	418	1397	332	1135	5	122	245	9659
7	65	1220	312	2887	628	2863	682	3012	542	1625	7	474	799	15116
8	12	465	90	1399	228	1337	428	2850	387	858	6	403	658	9121
9	1	53	10	189	51	347	86	1509	192	490	8	189	292	3417
10		1	1	45	3	91	23	592	53	352	6	158	84	1409
11				13		30	9	237	11	150	3	98	43	594
12				6	2	23		101	1	120	2	59	30	344
13				3	1	25	1	65	2	82	1	20	15	215
14						11		37		59	1	22	20	150
15						10		10	1	40	2	11	17	91
16						6		8		27		6	15	62
17						1		10	1	18		9	15	54
18								4		8	1	3	4	20
19								4		1		4	6	15
20								3			1	7	5	16
21								1		3		3	2	9
22										1			3	4
23													1	1
24												2		2
26										1				1
30													1	1
77		1												1
Grand Total	207	2624	900	6522	1535	7415	1714	10082	1544	5097	45	1599	2291	41575

Table 4: *Frequency of larval smelt detections by year, facility and species, 2008-2019. Annual initiation of larval sampling at the facilities varied in time, often triggered by presence of one or more spent DS females in Spring Kodiak Trawling or presence of DS larvae in Smelt Larval or 20-mm surveys; thus, detections underrepresent the presence of LFS larvae at the fish salvage facilities.*

	Days Checked		Delta Smelt Larvae		Longfin Smelt larvae		Starting dates for larva presence
Year	SWP	CVP	SWP	CVP	SWP	CVP	determination by facility
2008	138	135	0	10	1	19	SWP and CVP start Feb 2
2009	108	120	12	19	3	10	SWP start March 3, CVP Feb 25
2010	131	89	9	0	0	1	SWP start Feb 20 and CVP 24
2011	99	93	3	0	0	0	SWP and CVP start March 17
2012	136	136	27	42	29	31	SWP and CVP start Feb 16
2013	105	102	14	8	13	17	SWP start March 6 , CVP March 11
2014	122	87	10	5	13	2	SWP start Feb 24, CVP March 13
2015	101	111	1	0	8	5	SWP March 2, CVP Feb24
2016	100	99	0	0	0	1	SWP and CVP start Mar 1
2017	115	122	0	0	0	0	SWP start Feb27, CVP Feb 20
2018	72	82	0	0	2	0	SWP and CVP start Mar 29
2019	91	100	0	0	0	0	SWP and CVP start Mar18

Table 5: *Annual catch frequency of newly-hatched, yolk-sac larval LFS at Smelt Larva Survey stations within the influence of south Delta water export facilities. Record of the presence of a yolk-sac for larvae began in 2011. Such larvae were likely captured in the vicinity of their hatch location, though the presence of a yolk-sac can last for 10 days for LFS larvae.*

		Year									
Sampling Regions	Sampling Station	2011	2012	2013	2014	2015	2016	2017	2018	2019	Grand Total
Sacramento River	704	78	133	119	108	22	10		32	2	504
	705	33	58	55	99	12	1		6	5	269
	706	55	162	145	110	18	15	2	24	12	543
	707	88	188	116	112	26	17		19	1	567
near Barker Slough	716	67	108	95	107	5	4	1	2	1	390
	723	92	118	124	96	3	8		5	2	448
San Joaquin River	809	50	59	102	131	1	17		6	3	369
	812	12	46	12	68	6	7	1	2	1	155
	815	7	12	6	10		3				38
	906	1	5	7							13
	910	1	1								2
	912	1									1
Mokelumne River	919	1	2	13							16
South Delta	901	27	59	62	24	1	5		2		180
	902	3	19	3	1					1	27
	914		3								3
	915	1	7	5	2	1	2				18
	918		4	2	1				1		8
	Grand Total	358	758	647	666	87	77	3	92	25	2713

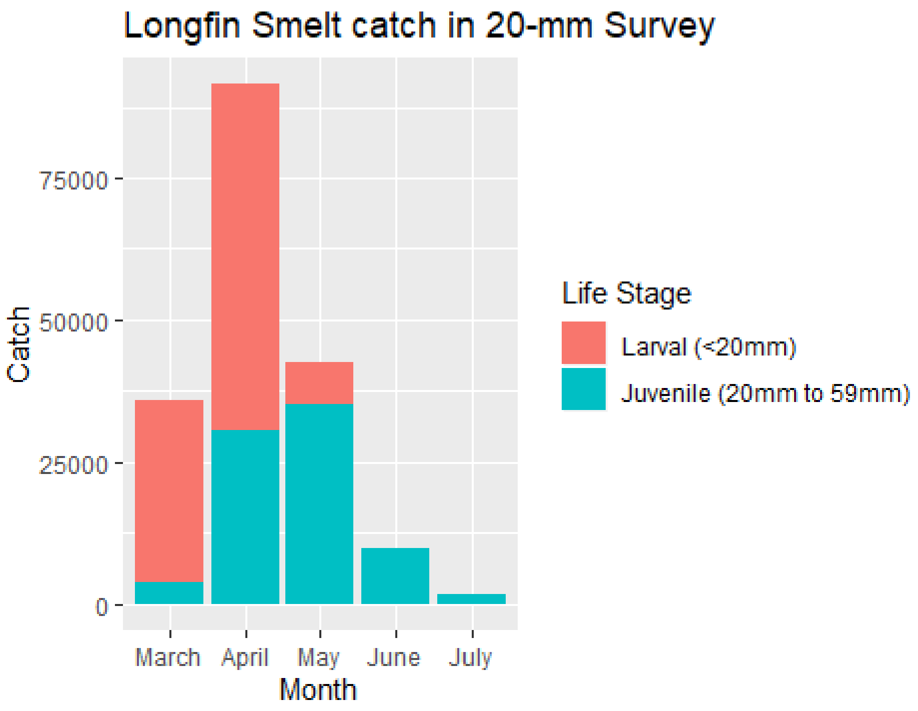

Figure 7: *Total catch per month of LFS from 20 mm survey from 1995 to 2019.*

The absence of quantitative sampling for larvae at the south Delta fish salvage facilities led to the use of particle tracking modeling (PTM) to investigate risk of entrainment under varying hydrological conditions. Previous efforts to model larval entrainment as a result of SWP and CVP exports showed that increasingly negative OMR flows will entrain increasing numbers both neutrally buoyant and surface oriented passive particles which mimic larval fish, and that in certain years, particle entrainment can be high. This is consistent with previous research that demonstrated a negative correlation between salvage of slightly older and larger LFS juveniles (> 20 mm) and OMR flow, indicating that entrainment similarly affected older LFS in a similar manner (Grimaldo et al. 2009). Using PTM CDFG (2009b) showed that during periods of modest outflow and high exports (e.g., 1992, 2002, Figure 12 in CDFG 2009b) entrainment of particles injected into the San Joaquin River commonly reached >50% (Figures 13 and 14 in CDFG 2009b). Even with judicially imposed export restrictions in 2008, PTM results showed modest (>20% of particles) to high (>50% of particles) entrainment in the export facilities of particles injected into the lower San Joaquin River (Figure 15 in CDFG 2009). Thus, even under restrictions imposed by the 2008 USFWS BiOp, LFS hatching in the lower San Joaquin River were at risk of entrainment due to exports under some circumstances (CDFG 2009b). Such risk appears to decline with increasing Delta outflow (CDFG 2009b) but increases substantially when OMR is allowed to flex more negative than -5,000 cfs (Figure 8).

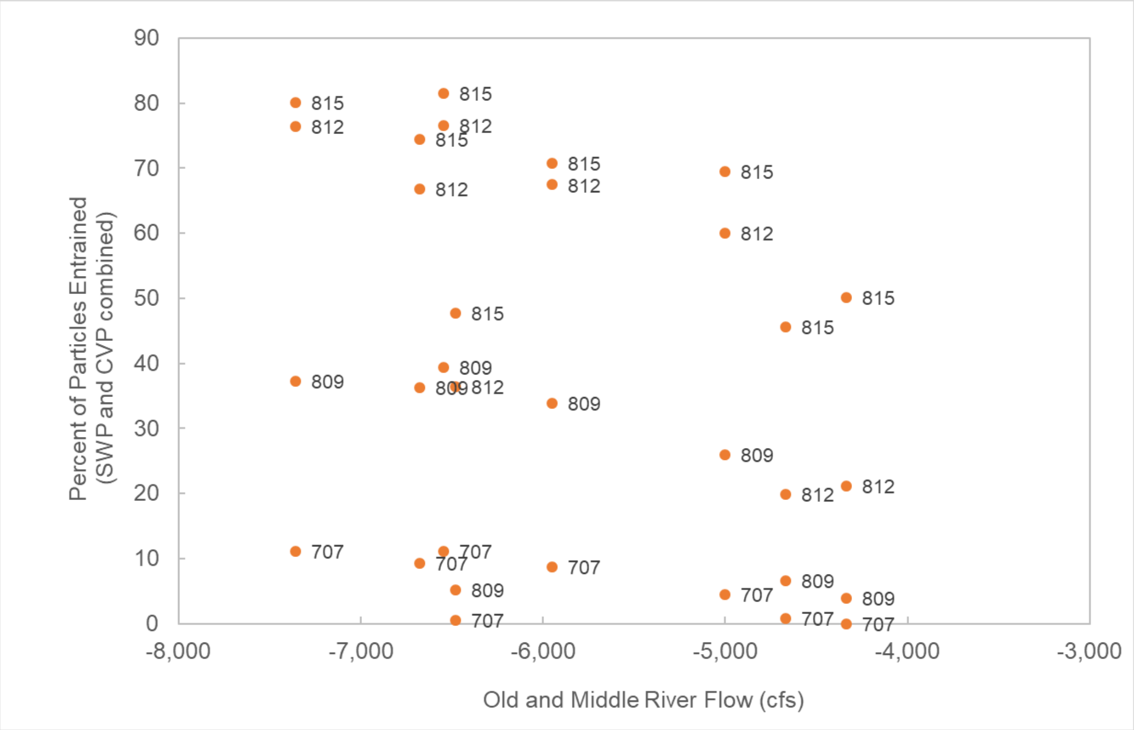

Figure 8: *Percentage of injected particles entrained by the State Water Project and Central Valley Project, combined, plotted against mean Old and Middle River flows (cfs) for the first seven days post injection. Injection points are labeled by fish survey station in proximity to the injection node in the DSM2 map (see Life History and Conceptional Models of Entrainment section).*

During wet periods, the San Joaquin River and eastern Delta tributaries (Mokelumne, Cosumnes, and Calaveras rivers) may provide sufficient flow to maintain a net positive flow in the lower San Joaquin River (i.e., positive QWEST) despite high exports at the SWP and CVP facilities. Such flows would tend to transport pelagic organisms in the main San Joaquin River channel toward Suisun Bay. Even some of those larvae entering or hatching within the northern portion of the south Delta may not be lost. Past PTM results indicate that, during periods of strongly positive QWEST, particles injected at stations 906 and 815 in the mainstem San Joaquin River were drawn into the south Delta via Old River (mostly) or Middle River, then fluxed out again via False River (CDFG 2009b). Presumably, some particles injected in northern Old River and Franks Tract would behave similarly. Under such high outflow conditions, any larvae in the immediate vicinity of CCF will likely remain at great risk of entrainment; however, because of high flows entering the Delta from the south and east satisfy export needs, OMR flows are necessarily less negative (or even positive), and the area to the north influenced by exports is substantially reduced.

Newly hatched LFS present in the south Delta (Table 5) are at high risk of entrainment and those in the San Joaquin River are at moderate risk at all but the lowest export levels (CDFG 2009b; Kimmerer and Nobriga 2008). Larvae entrained into CCF are assumed lost to the population because they cannot volitionally leave CCF once inside, and equally small fish are very inefficiently diverted from export flow and salvaged (Brown et al. 1996). Finally, fish < 20 mm that happen to get salvaged do not likely survive the process of collection, handling, transport and release (Aasen 2013; Afentoulis et al. 2013; Morinaka 2013b).

In addition to direct forms of take identified above, operations of the SWP also result in indirect impacts to LFS larvae through several mechanisms. First, larvae drawn into the south Delta or CCF are vulnerable to increased predation within CCF and the south Delta similar to larger smelts and other fishes (Castillo et al. 2012; Grossman 2016). Second, reduced residence times and direct entrainment of food web resources (Arthur et al. 1996; Hammock et al. 2019; Kimmerer et al. 2019) are believed to reduce feeding opportunities within the south Delta. Third, similar to DS, south Delta habitat suitability has declined for LFS due to increasing water transparency resulting from the combined effects of sediment washout during the extreme outflow of the 1982-1983 El Nino (Jassby 2005) reduced sediment inputs (Wright and Schoellhamer 2004), and expansion of submerged aquatic macrophyte beds (Brown and Michniuk 2007; Nobriga et al. 2008; Nobriga et al. 2005) that may act as filters to settle sediment from the water and reduce or prevent resuspension. At least some of these factors (turbidity and perhaps predation) vary through the year such that habitat suitability appears poor in summer and fall (Feyrer et al. 2007a; Feyrer et al. 2011; Nobriga et al. 2008).

Here, and in other sections of this Effects Analysis, we reference PTM runs conducted to support the 2009 ITP (CDFG 2009b) instead of PTM runs conducted to support the FEIR. Below we note several key differences between the assumptions used for these two PTM runs intended to represent entrainment of larval fishes into CCF, BSPP, and out of the Delta at Chipps Island.

- <u>Number of days simulated using PTM</u>: The CDFG (2009b) PTM runs tracked particle movement and fate for a full 90 days which provides a comprehensive picture of particle fates over the time span required for LFS to reach 20 mm FL after hatching. The FEIR utilized PTM runs that only accounted for particle movement over the span of 30 days (DS) or 45 days (LFS). The FEIR explains that the 30- and 45-day time frames were selected based on the length of time DS and LFS are expected to be neutrally buoyant post-hatch. Current lab studies have indicated that LFS take approximately 90 days to reach a 20 mm FL. Although larval fish swimming ability increases as they mature, it is important to understand particle fates over a much longer time period than 30-, or 45- days, because fish are likely to be heavily reliant on hydrology to position themselves within the water column after 45 days.
- <u>Number of particles at each injection point</u>: CDFG (2009b) runs included 5,000 particles at each injection location while the FEIR included 4,000. As a result, the CDFG (2009b) PTM results had higher resolution when depicting the fate of particles originating from a given injection point due to greater replication of particles at each injection point.
- <u>Number and location of injection points</u>: CDFG (2009b) modeling included only seven injection points that were selected to be adjacent to survey station locations near Project intakes at Barker Slough and CCF. As a result, the estimates of entrainment from these runs provide information specific to real-time management and risk assessments attempting to understand the risk of take at either facility when fish are observed at specific sampling locations identified in the Conditions of Approval. In contrast, the FEIR modeling included 39 injection locations distributed throughout the Delta. This provides a broader sampling of the potential spatial

distribution of spawning DS and LFS and depicts anticipated total entrainment for individuals hatching within the Delta. However, this choice of injection locations is not targeted to the stations specified in Conditions of Approval and closely associated with required salvage thresholds.

As a result of these differences between the approaches used to develop and conduct PTM runs we reference results from CDFG (2009b) here to support our analysis of take and minimization provided by Conditions of Approval required by the ITP.

5.1.2. Barker Slough Pumping Plant

The BSPP is within the range of LFS spawning and early rearing habitat (Table 5) and previous PTM runs have shown strong potential for entrainment as winter wanes into spring and north Delta exports increase (CDFG 2009b). Incidental take of larval LFS in the form of entrainment or impingement resulting in mortality may occur as a result of operations of the BSPP. Although the BSPP possesses a fish screen, it is not designed to be protective of fish < 25 mm, though it may be in actual application (CDFG 2009b; Nobriga et al. 2004). The facility is located at the upper end of a dead-end slough where weakly swimming larvae are drawn toward the screens to be entrained or impinged unless they grow to sufficient size to avoid weak entrainment flows. The configuration of the channel and screens does not allow net or tidal currents to sweep larvae past the screens.

The area where take of larval LFS is expected to occur is approximately 16 km from the mainstem Sacramento River at the upper end of Barker Slough. The BSPP has the capacity to export 175 cfs through a screened diversion. This diversion is operated year-round, except for a brief maintenance period which typically occurs in March. Recent exports tended to be relatively low during winter and spring, when LFS larvae densities are highest in the Delta and increase through the spring (Figure 29 in CDFG 2009b). An analysis of PTM runs showed that entrainment of surface-oriented particles was nonlinearly related to average pumping rate and that the proportion of particles injected at station 716 (in Cache Slough, just north of the Lindsey Slough confluence) and subsequently entrainment ranged from 1.5% to 37% (CDFG 2009b). The proportion of particles entrained tended to increase through the late winter and spring coincident with entrainment in agricultural diversions (Figures 13-15 in CDFG 2009b). Projected export increases at BSPP are expected to lead to 100% entrainment of particles when combined with local agricultural exports, because historical diversions came close to entraining 100% of injected particles (CDFG 2009b). Fortunately, the conditions leading to near 100% entrainment occurred in late spring when LFS hatching was waning (Figure 33 in CDFG 2009b). Nonetheless, substantial entrainment is expected for LFS larvae hatching in the north Delta during April. Thus, increased diversions at BSPP would likely further degrade LFS rearing habitat, particularly in low outflow years when LFS larval distribution is shifted upstream to the vicinity of Station 716.

Incidental take may also occur as a result of maintenance of BSPP facilities and adjoining waterways. Any eggs deposited on or in the immediate vicinity of the concrete apron at the fish screen will be taken during suction dredging conducted for sediment removal if conducted during the December through early April egg incubation period. Moreover, larvae that hatch from eggs deposited in the immediate vicinity of the concrete apron are likely to be entrained or impinged during normal operations due to their planktonic nature and weak swimming ability. Any larvae hatching within the immediate vicinity of the fish screen, or within the embayment immediately in front of the fish screen are assumed to be lost to the population due to entrainment or lethal impingement as a result of BSPP operations. As a result, any additional disturbance caused by clearing the fish screen of debris or vegetation would not result in additional take.

Take and impacts of the taking as a result of aquatic vegetation removal is unknown at this time and will depend upon when the work occurs, and the size and scope of the removal effort. Work in the approximate time frame of July 1 through October 31 should not have a direct impact on LFS because the species does not occupy the region during this period. Chemical and physical methods of vegetation control each represent different modes of take and will need to be assessed independently. Aquatic vegetation removal that occurs when larval LFS are present in the system, mid-December through April, will have a greater impact, particularly if BSPP operations just prior to and during this period are conducive to drawing larvae into Barker Slough or retention of larvae in the affected area.

Indirect impacts related to the operations of Barker Slough include non-lethal impingement/screen contact, increased vulnerability to predation, and entrainment of food web resources.

5.1.3. Suisun Marsh Facilities

Physical facilities in the Suisun Marsh and Bay include the SMSCG, the RRDS, the MIDS and the GYSO. Additional facility details are provided in CDFG (2009b), pg 40-44, and in the FEIR Section 3.1.3.5. Studies required under Condition of Approval 6.1 in CDFG (2009b) were completed prior to the issuance of this ITP.

Suisun Marsh Salinity Control Gates

The SMSCG are located about 3.2 km from the eastern confluence of Montezuma Slough with the Sacramento River near Collinsville (ITP Figures 1A and 1B). SMSCG began operation in October 1988 as Phase II of the Plan of Protection for the Suisun Marsh. The gates span the width of Montezuma Slough and the 3-gate array allows tidal control of the water entering Suisun Marsh, while a boat lock operated independently allows for watercraft passage. Gate operation reduces salinity in the marsh by taking in Sacramento River water during ebb tides and then closing and restricting flow of brackish water from Grizzly Bay into Montezuma Slough. Gate operation reduces salinity just west of the gates to essentially freshwater and acts to create a net movement of water from east to west through Montezuma Slough and parts of Suisun Marsh. Nonetheless, salinity slowly increases farther west within Montezuma Slough. The United States 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. This operational period overlaps the spawning migration and early life stage rearing of LFS. SMSCG operations have recently occurred in the summer and fall to benefit DS by freshening the Marsh and Honker and Grizzly bays. The boat lock portion of the facility is now held partially open during SMSCG operation to allow for continuous salmon passage. Proposed operations include compliance with D-1641 and to improve habitat conditions to benefit DS.

The SMSCG have the potential to cause short-term increases in residence time in the winter and early spring during operation. Potential SMSCG related increases larval residence time in Montezuma Slough could be beneficial or detrimental depending upon circumstances. Increased residence time for water and larvae could allow for coincidental food production and fish development. The former leading to improved foraging and faster development, which in turn could lead to more rapid improvement in salinity tolerance and swimming ability. Conversely, increased residence time could position some larvae near the RRDS intakes just west of the control gates and increase entrainment at the RRDS.

Roaring River Distribution System

The RRDS begins at Montezuma Slough just west of the SMSCG and runs westward through Grizzly Island to Grizzly Bay. Water is diverted from Montezuma Slough on high tides into the RRDS through a bank of eight 1.5 m diameter culverts equipped with fish screens that empty into a 40-acre intake pond raising its water surface elevation above that of adjacent managed wetlands. The pond helps control water levels in the slough running through Grizzly Island to near Grizzly Bay used to deliver water to managed wetlands north and south of the system. The Delta Smelt Resiliency Strategy (Natural Resources Agency 2016) proposes to connect the RRDS to Grizzly Bay using a flap gate so that potentially food-rich water drained from the duck ponds could be discharged into Grizzly Bay.

The RRDS intakes are screened and physically exclude fish greater than 25 mm in length. These screens provide little benefit for avoiding entrainment of recently hatched larval fish. RRDS can result in take of individuals via larvae passaging through the screen and subsequent diversion onto managed wetlands where bird predation or water temperatures would likely be lethal. However, risk of entrainment of larval LFS at RRDS remains unquantified. Moreover, if the RRDS is connected to Grizzly Bay, as proposed, it is possible that larvae could be entrained and not deposited on managed wetlands and instead rearing in the distribution system and eventually released into Grizzly Bay.

Morrow Island Distribution System

The MIDS consists of three 1.2 m culverts without fish screens that divert water from Goodyear Slough through a distribution channel bisecting Morrow Island and discharge into Suisun Slough and Grizzly Bay. It supplies water to managed wetlands to the north and south, and conveys drainage water from the same properties back to the estuary. MIDS is used year-round, but most intensively from September through June. Thus, operations could entrain larval LFS.

Larval entrainment into MIDS is likely if adult LFS spawn nearby, or if larval longfin are transported into an area vulnerable to entrainment into MIDS. Culberson et al. (2004) used DSM2 PTM to show that proximity to the MIDS diversion was the primary factor influencing entrainment risk: Enos et al. (2007) documented LFS larvae, juveniles and adults entrained within MIDS between 2004-2006 . LFS larvae were historically most abundant in Cordelia Slough and Goodyear Slough (Meng and Matern 2001; O'Rear and Moyle 2010), and thus vulnerable to entrainment into MIDS.

Good Year Slough Outfall

The GYSO was constructed in 1979-1980 and connects the upper (south) end of Goodyear Slough to Suisun Bay to improve circulation in the previously dead-end slough. GYSO consists of a channel 21 m wide by 853 m long dredged from the south end of Goodyear Slough to Suisun Bay. The outfall consists of four 1.2 m diameter culverts with flap gates on the Bay side and vertical slide gates on the slough side. When the slide gates are open only trash racks obstruct entry into and out of the system. Fish are believed to be able to enter and leave the system at will.

High rates of diversion from and drainage back into in Goodyear Slough have periodically created extremely low dissolved oxygen concentrations and fish kills even with the system in place (O'Rear and Moyle 2010). Similar to what was described for DS in USFWS (2019), the intakes and outfall of GYSO are unscreened and may entrain larval LFS. Larval fish that enter the system would be able to potentially leave via the intake or the outfall, as GYSO is an open system, given that mortality does not occur during the entrainment process.

5.1.4. Agricultural Barriers

The TBP does not alter total Delta outflow, or the position of X2 (USFWS 2008). However, the TBP causes changes in the hydraulics of the Delta, which may affect smelt, both DS and LFS, in the area. Simulations have shown that placement of the barriers changes south Delta hydrodynamics, increasing central Delta flows toward the export facilities (USBR 2008). In years with substantial numbers of adult LFS moving into the central Delta, increases in negative OMR flow caused by installation of the TBP can increase entrainment. The increased directional flow towards the Banks and Jones increases the vulnerability of fish to entrainment and may result in direct take of the species.

5.2. Longfin Smelt Juveniles

LFS are classified as juveniles at ≥ 20 mm FL (Baxter 1999; Wang 2007). This length typically coincides with complete fin ray development (Simonsen 1977). Air bladder development, which occurs between 10-15 mm, allows larval LFS to more competently use vertical swimming strategies to maintain or change locations in the estuary (Bennet et al. 2002); fin development further improves this competence and may signal readiness for directed migration. This life stage typically occurs within the Delta as early as February (Table 3), but more commonly from March or April through June or later (CDFG 2009b Figure 18). Most LFS larvae have transitioned to the juvenile life stage by May and virtually all by June (Baxter 1999, Figure 7).

The SWP and CVP established a 20 mm minimum length for identification and counting fish in salvage (Brown et al. 1996). When juveniles are present in the central and south Delta, salvage begins in March in most years and lasts through June (CDFG 2009b Figure 18). As Delta water temperatures approach and exceed 20°C, juvenile LFS become stressed (Jeffries et al. 2016) and are believed to move downstream into cooler and more saline habitats where they will continue grow and rear (Baxter 1999; Rosenfield and Baxter 2007). The following discussion will focus on juvenile LFS from the transition into the juvenile life stage (≥20 mm FL) until their emigration downstream in June.

5.2.1. Banks Pumping Plant and Clifton Court Forebay

Like that of adults, salvage of juvenile LFS tends to be higher in low outflow years than in high outflow years (Figure 9). Juvenile salvage at the SWP and CVP fish facilities has been shown to be related to mean X2 position from April through June, the principal salvage period (CDFG 2009b). During low outflow periods, LFS tend to venture farther into the Delta to spawn, placing larvae and subsequent juveniles at greater risk of entrainment. Lack of outflow also limits the influence of net flows on the distribution of larvae and juveniles (Dege and Brown 2004) because transport flows are low. As a result, LFS juveniles remaining within the central and south Delta during spring are vulnerable to entrainment. The combined salvage of juvenile LFS is also significantly and negatively related to mean OMR flows during the April through June period (CDFG 2009b; Grimaldo et al.2009).

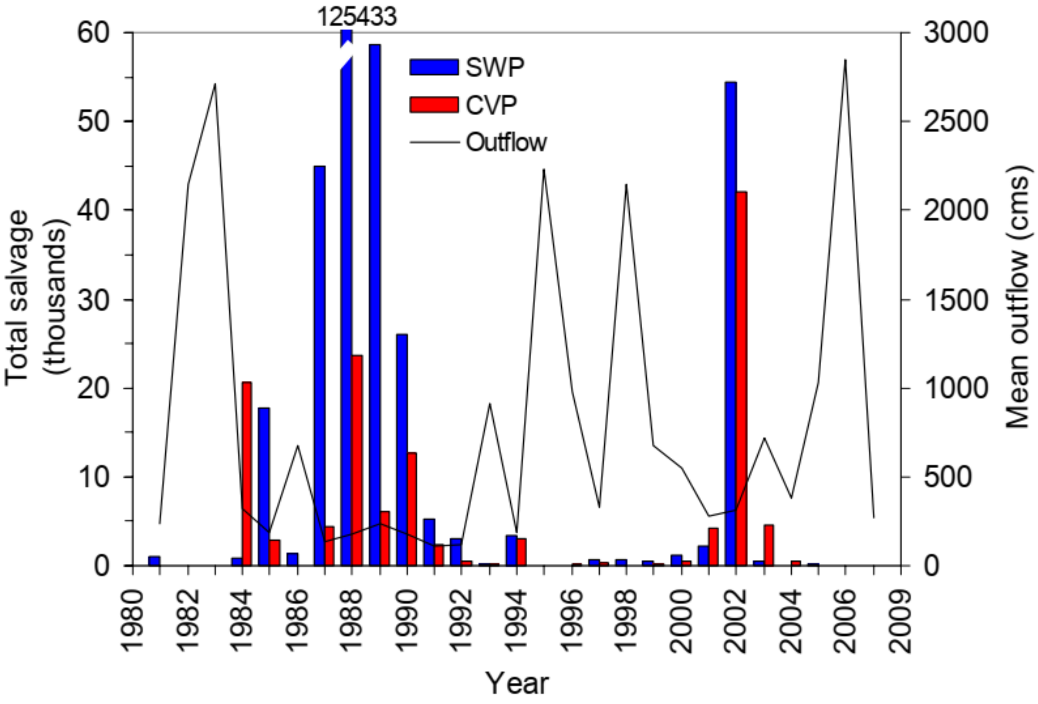

Figure 9: *Total spring (April - June) salvage of LFS at the State Water Project and Central Valley Project from 1981 through 2007 and mean Delta outflow in cubic meters per second for the same period (from CDFG 2009a Figure 19).*

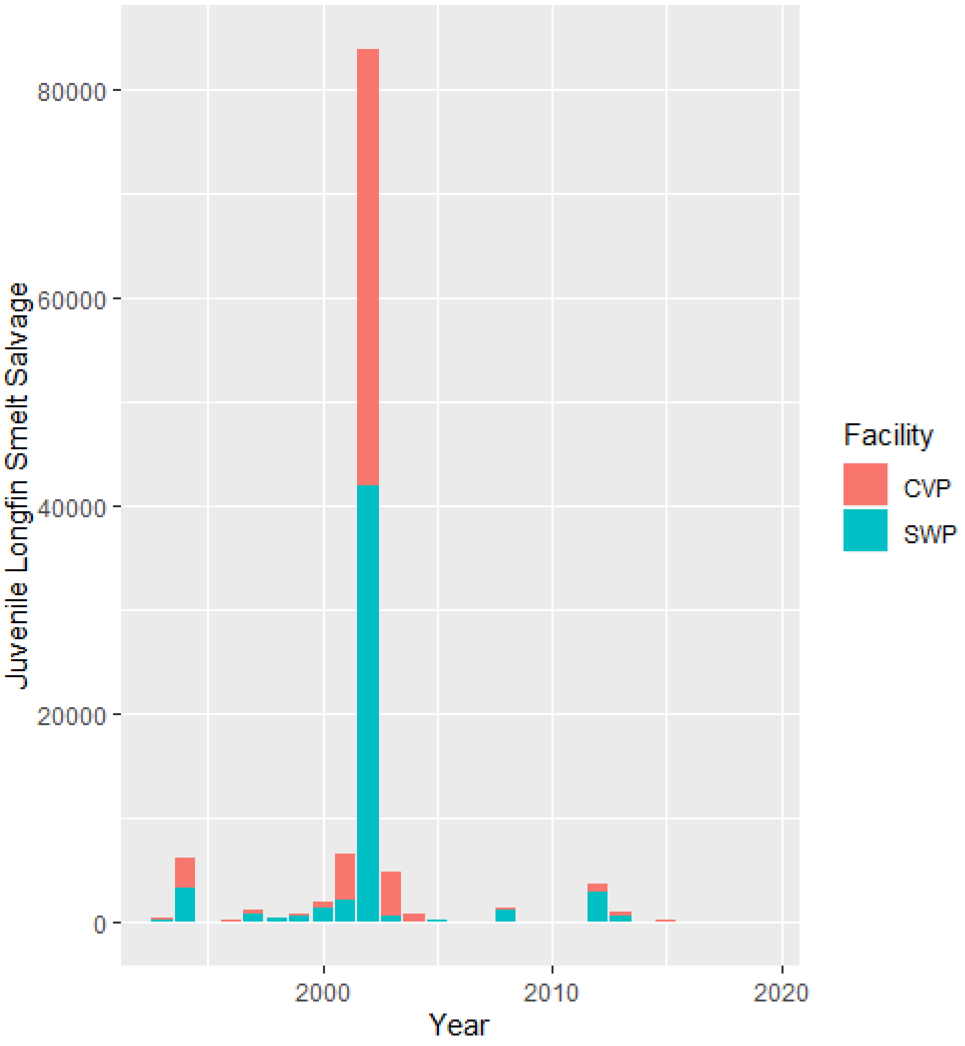

Figure 10: *Total spring salvage of juvenile LFS at the SWP and CVP from 1993 through 2019 for the months of March - June.*

South Delta exports during this period have historically been high (>6,000 cfs) when inflow was sufficiently high to meet D-1641 standards (Figure 11). The 2009 NMFS BiOp established more restrictive export limits based on San Joaquin River inflow for the months of April and May that varied by water year type (combined exports could match San Joaquin River inflow in critical year [1:1 Export to Inflow] up through combined exports no more than four times San Joaquin River flow in a wet year [4:1 Export to Inflow; (NMFS 2009)]. These more restrictive inflow to export standards for the April-May time period (Figure 11) provided additional protection for juvenile LFS remaining in the central and south Delta in the spring and early summer in the form of less negative OMR flows (Figure 12). These export limits scaled to San Joaquin River flows were not carried forward in the NMFS (2019), but are retained in Condition of Approval 8.17 in the ITP , with an off ramp when Delta outflow exceeds 44,500 cfs.

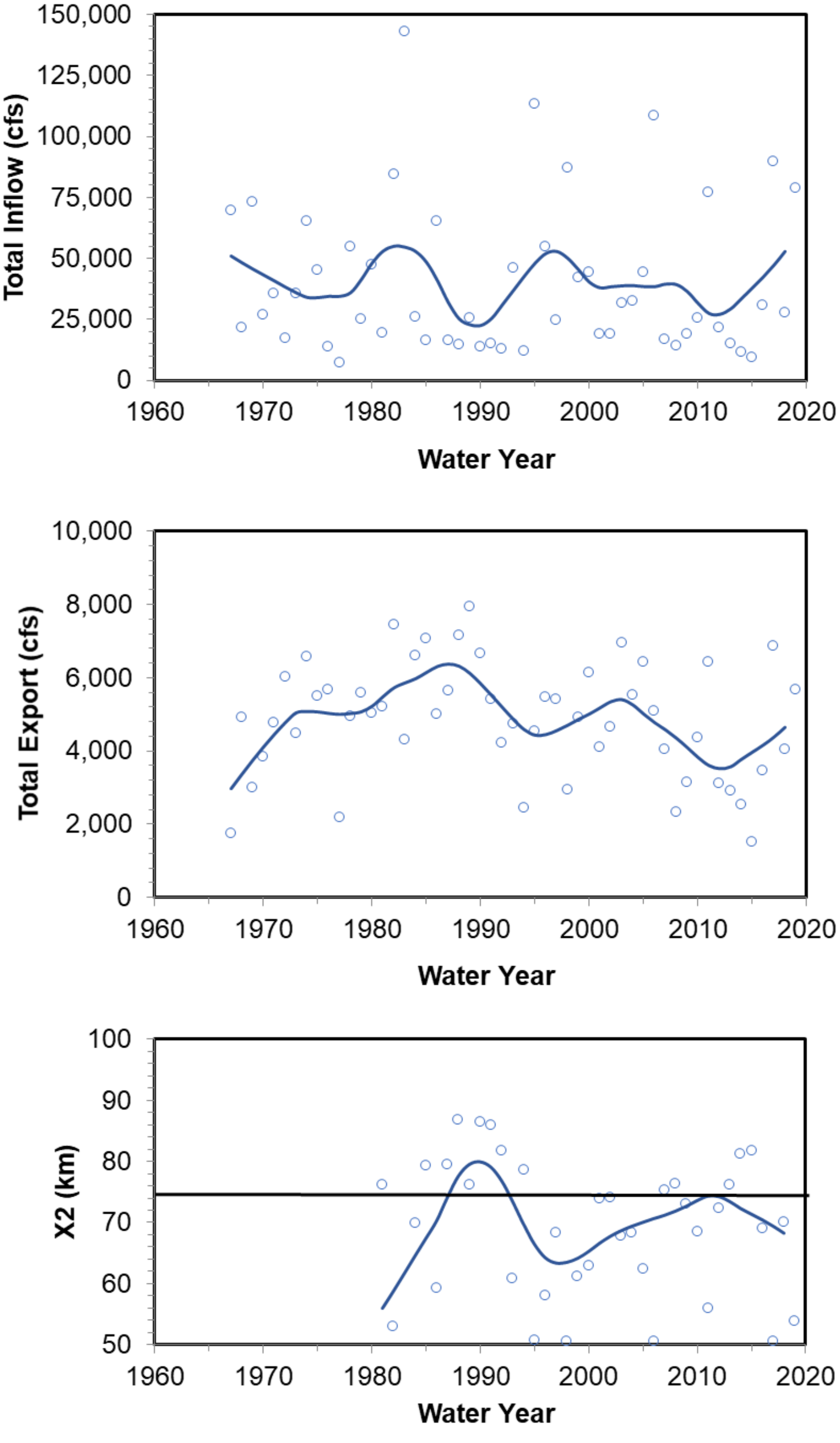

Figure 11: *Mean monthly spring (March - June) Delta inflow (cfs) (top), combined State Water Project and Central Valley Project exports (cfs) (middle) and X2 location (km) (bottom) from 1967 through 2019 (top and bottom) and 1981 through 2019 (middle). A horizontal line at X2 of 75 km (Chipps Island) is included for reference. Loess smoother line shown but not used in an analysis.*

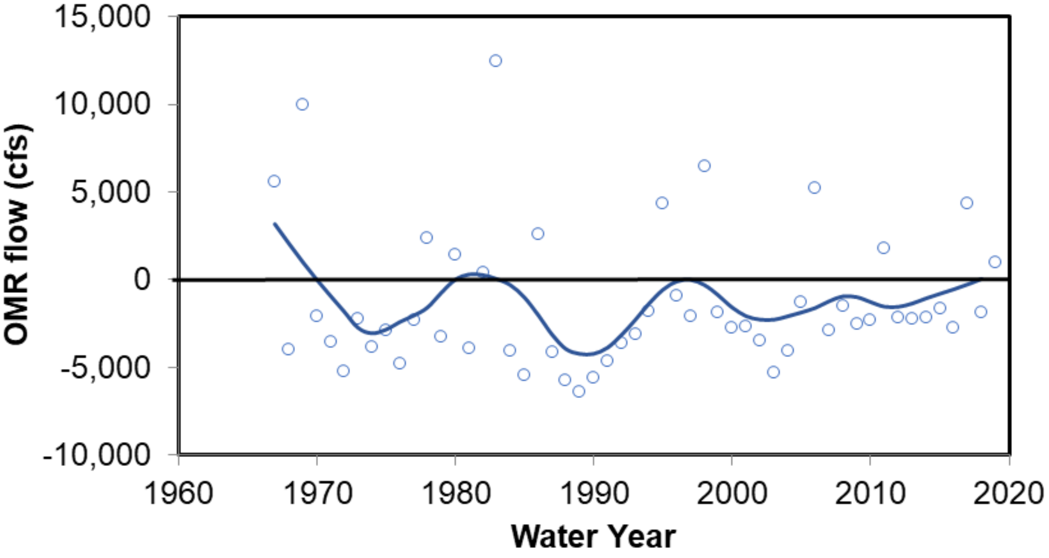

Figure 12: *Mean monthly spring (March - June) Old and Middle River flows (cfs) from 1967 through 2019. Loess smoother line shown but not used in an analysis.*

Most entrainment of young-of-the-year LFS likely occurs during the larval stage and some survive to the juvenile stage and find themselves within the south Delta, CCF, past the louvers and in the SWP water delivery system or deflected by the louvers and salvaged. Young juveniles are not strong swimmers and, like larvae, net negative flows can lead to entrainment into the south Delta (see Section 5.1.1). Once entrained into the south Delta they are believed to rear until increasing water temperatures in spring cue them to emigrate. At this time juveniles try to orient downstream and are possibly miscued by negative OMR flows moving towards the export facilities. During exceptionally wet periods, high flows in the San Joaquin River and from eastern Delta tributaries (Mokelumne, Cosumnes, and Calaveras Rivers) can provide enough flow to generate positive OMR flows despite SWP and CVP exports (Figure 12), and generate transport flows for young juveniles out of the Delta, or at least improve cues for emigrating juveniles. Under these high outflow conditions, any juveniles in the immediate vicinity of CCF are still at risk of entrainment, but risk diminishes with distance from the export facilities. The area influenced by exports is substantially reduced during high San Joaquin River outflow conditions, even when exports are high. In the absence of high flows in the San Joaquin River and east side tributaries juvenile LFS present in the south Delta are at risk of entrainment in all but the lowest export levels (CDFG 2009b; Kimmerer and Nobriga 2008).

Juveniles entrained into CCF are assumed to be lost to the population because they are likely unable to volitionally leave CCF once inside, only a fraction of juveniles entrained into CCF will be observed in salvage due to predation and inefficiencies diverting small fish to salvage (CDFG 2009b; Castillo et al.

2012), and those that are salvaged at the Skinner Fish Facility, like DS juveniles, are unlikely to survive the process of collection, handling, trucking and release during spring (Aasen 2013; Afentoulis et al. 2013; Morinaka 2013b). Moreover, summer water temperatures in CCF exceed the tolerance of juvenile LFS (Jeffries et al. 2016).

In addition to direct take as a result of SWP operations identified above, SWP operations result in indirect impacts to juvenile LFS very similar to those affecting larvae. First, juveniles entrained in the south Delta are believed vulnerable to increased predation similar to other fishes (Grossman 2016). Second, reduced residence times and direct entrainment of food web resources (Arthur et al. 1996; Kimmerer et al. 2019; Hammock et al. 2019) are believed to reduce feeding opportunities within the south Delta. Third, similar to DS, south Delta habitat suitability has declined for LFS due to increasing water transparency resulting from the combined effects of sediment washout during the extreme outflow of the 1982-1983 El Nino (Jassby et al. 2005), reduced sediment inputs (Wright and Schoellhamer 2004), and expansion of submerged aquatic macrophyte beds (Nobriga et al. 2005; Brown and Michniuk 2007; Nobriga et al. 2008) that may act as filters to settle sediment from the water and reduce or prevent resuspension. At least some of these factors (turbidity and perhaps predation) vary throughout the year such that habitat suitability is relatively poor in summer and fall (Nobriga et al. 2008). Fourth, south Delta water temperatures exceed the tolerance of juvenile LFS (Jeffries et al. 2016), so juveniles must emigrate to survive. Finally, strongly negative OMR flows during early summer are likely to either miscue juvenile LFS into migrating in the wrong direction, leading to entrainment in CCF, or to work against migration in the correct direction, possibly exacting a physiological price through added effort needed or by delaying relocation past the onset of stressful or lethal summer temperatures.

5.2.2. Barker Slough Pumping Plant

The BSPP is within the range of LFS spawning and early rearing habitat (Table 5). The facility is located at the upper end of a dead-end slough where weakly swimming juveniles can be drawn toward the screens to be entrained or impinged. The configuration of the screens does not allow tidal or net currents to sweep juveniles past the screens, they must be able to swim away. Previous PTM runs have shown strong potential for entrainment as during spring as north Delta exports increase (CDFG 2009b). Incidental take of juvenile LFS can take the form of: 1) direct entrainment, which can occur for a brief period before fish grow beyond being able to slip through the screen, but entrainment of a healthy juvenile seems unlikely if screens are cleaned and approach velocities are maintained; and 2) impingement and screen contact, which are only likely for small juveniles already compromised by stress or injury.

The BSPP is located approximately 16 km from the mainstem Sacramento River at the end of Barker Slough. The BSPP has the capacity to export 175 cfs through a screened diversion in a terminal side channel of Barker Slough in the North Delta. This diversion is operated year-round, except for a brief maintenance period which typically occurs in March. Authorized exports may be as high as 175 cfs year-round, including the winter and spring when LFS larvae are transitioning to juveniles and rearing for some time in the Delta.

Past PTM runs showed that particle entrainment in BSPP, the North Bay Aqueduct and agricultural diversions typically increased dramatically for April 1 injections at station 716 located in Cache Slough just north of the Lindsey Slough confluence (Figures 13-15 in CDFG 2009a). Moreover, 100% of those particles would be entrained into BSPP and local agricultural diversions when April through June hydrology was modeled even though diversion rates never exceeded 100cfs, which is approximately 57% of maximum capacity (CDFG 2009b). Although juvenile LFS should be competent swimmers, PTM results show that beginning in April BSPP and local agricultural exports create strong negative flows in Cache Slough and adjacent channels that might miscue juveniles into migrating the wrong direction or hinder those attempting to migrate in the correct direction. Such delays might result in additional stress for juveniles attempting to avoid already stressful water temperatures (see Jeffries et al. 2016).

Incidental take may also occur associated if maintenance of BSPP facilities and adjoining waterways must occur when juveniles are present. Juveniles in the immediate vicinity of the concrete apron at the fish screen may be taken during suction dredging conducted for sediment removal. This impact is not believed to be beyond that of normal operations due to the poor habitat located immediately in front of the BSPP. Scheduling such work for summer and fall months when water temperature is ≥ 25ºC would avoid the risk of take altogether. The impact of aquatic vegetation removal is unknown at this time and will depend upon the timing, size and scope of the removal effort. If chemical and physical methods of vegetation control must be used in the presence of LFS (as opposed to the summer and fall months when they are typically absent from the region) each represents a different mode of take. Aquatic vegetation removal that occurs when juvenile LFS are present in the system (April through June) will have a greater impact, particularly if BSPP operations just prior to this period are conducive to entrainment into Barker Slough or retention of juveniles in the affected area.

5.2.3. Suisun Marsh Facilities

Physical facilities in the Suisun Marsh and Bay include the SMSCG, the RRDS, the MIDS and the GYSO. Additional facility details are provided in the ITP Project Description, Section 3.1.3.5 of the FEIR, and in Section 5.1.3 of this Effects Analysis.

Suisun Marsh Salinity Control Gates

As mentioned in Section 5.1.3, operation of the SMSCG typically occurs from October through May to maintain reduced salinity in the Marsh. Thus, it may be in operation during a portion of the juvenile lifestage, April through June. SMSCG operation has the potential to cause short-term increases in residence time in the early spring. If the SMSCG increases juvenile residence time in Montezuma Slough immediately behind the gate structure, this could increase exposure and subsequent entrainment risk at the RRDS, though such risk would be minimal.

Roaring River Distribution System

While the RRDS begins at Montezuma Slough just west of the SMSCG and possesses screened intakes that will physically exclude fish greater than about 25 mm in length. Also, tidal currents, which provide sweeping flows, tend to improve efficiency of such screens for fish < 25 mm and reduce the likelihood of impingement of larger fish (Nobriga et al. 2004). Flood tide currents will be stalled during SMSCG operations (little or no flood tide movement) but ebb tide currents fully present when the gates are open. Thus, risk of entrainment of < 25 mm fish is low and risk of impingement of larger fish is very unlikely.

Morrow Island Distribution System

The MIDS is used year-round but most intensively from September through June. LFS larvae (and subsequently juveniles) were historically most abundant in Cordelia Slough and Goodyear Slough (Meng and Matern 2001; O'Rear and Moyle 2010), and thus vulnerable to entrainment into MIDS. Juvenile LFS have been entrained by the three unscreened 1.2 m intakes that form the MIDS intake. Enos et al. (2007) found juvenile LFS within MIDS during 2004-2006, indicating that entrainment is occurring and can affect juveniles if present. It's unclear whether they can pass successfully through the system.

Good Year Slough Outfall

Similarly to what was described for DS in USFWS (2019), the intakes and outfall of GYSO are unscreened and may entrain juvenile LFS, but just as easily allow their exit presuming that mortality does not occur during transit through the system.

5.2.4. Agricultural Barriers

The TBP does not alter total Delta outflow, or the position of X2 (USFWS 2008). However, the TBP causes changes in the hydraulics of the Delta, which may affect smelt, both DS and LFS, in the area. Simulations have shown that placement of the barriers changes south Delta hydrodynamics, increasing central Delta flows toward the export facilities (USBR 2008). In years with substantial numbers of adult LFS moving into the central Delta, increases in negative OMR flow caused by installation of the TBP can increase entrainment. The increased directional flow towards the Banks Pumping Plant increases the vulnerability of fish to entrainment and may result in direct take of the species.

5.3. Adult Longfin Smelt

Adult LFS migrate into the Delta during the late fall when the water temperature drops below 18 °C to spawn in tidally fresh and low salinity habitat (< 6 psu) (CDFG 2009a; CDFG 2009b; Moyle 2002; Rosenfield 2010). The peak of spawning is generally from December through February, but can range from November through April (CDFG 2009a). Migration into the Delta increases the probability of adult LFS entrainment into the south Delta and the SWP and CVP facilities. Once in the Delta, LFS are vulnerable to take and impacts of the taking at the SWP and CVP export facilities. Here, we describe results from a boosted regression tree analysis of migration timing into the Delta and entrainment into the south Delta and salvage at SWP and CVP. LFS ≥ 60 mm fork length (FL) have been entrained and observed in salvage during the spawning season from 1993-2018 (Figure 13), thus we used 60 mm FL as a threshold to identify the adult migratory life stage in the Chipps Island dataset. However, we note that fish less than 80 mm FL have a low likelihood of reaching sexual maturity in that winter (CDFG 2009a)

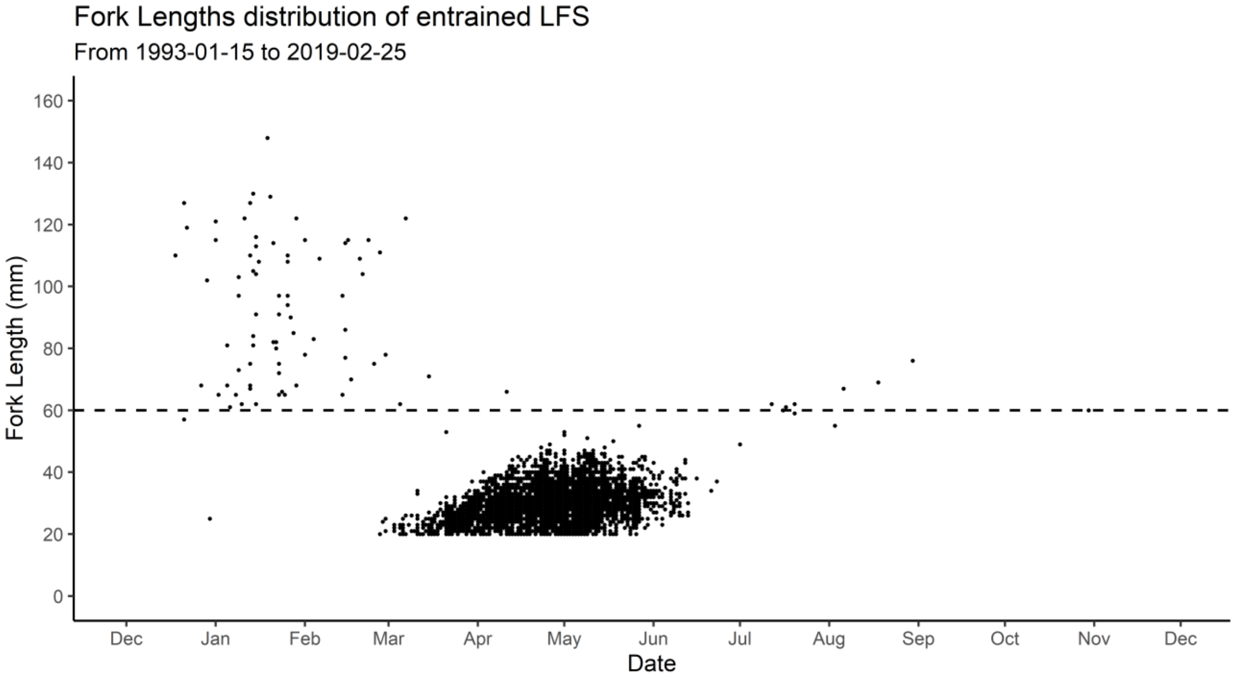

Figure 13: *Fork lengths (mm) of salvaged LFS from 1993-2018*[2] *at both the State Water Project and Central Valley Project south Delta facilities. Fish caught during the spawning period, December through February of each year, are predominantly larger than 60 mm FL.*

To determine the timing of annual adult LFS migration into the Delta we used daily catch data from the Chipps Island Trawl (IEP et al. 2019). Chipps Island is located at the western entrance to the legal Delta, thus we assumed LFS catch at this location served as an appropriate indicator of LFS migration. The Chipps Island Trawl generally samples three days a week, year-round except in December and January when sampling increases to seven days a week with ten 20-minute trawls each day providing near-daily temporal resolution for estimating the timing of LFS migration into the Delta. We examined mean CPUE per day and size distributions of LFS caught in the Chipps Island Trawl dataset from 1993-2017 (see Appendix A for additional description of methods and results). Individuals ≥ 60 mm FL were caught throughout the spawning period but the majority occurred from December through the end of February (Figure 14A). This timing is consistent with our conceptual model of the timing of LFS spawning migration (CDFG 2009a). Fish arriving at Chipps Island in November were generally small, with larger fish arriving in December (Figure 14B-C). Interestingly there appeared to be two modes to the occurrence of larger fish, the first in December and the second in the late-February through March period. We identified the start of the migration period at Chipps Island as the day of the year (1- 365) when 5% of the cumulative catch of LFS was surpassed during the October-February period in each year (Figure 15). In some years, (e.g. 1996) the 5% threshold was surpassed well (>30-days) before catch

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[2] Fork length measurements were not collected for every LFS observed in salvage prior to 2009 (CDFW 2020b).

rapidly increased, while in other years (e.g. 2002 & 2011) the threshold was passed shortly before or on the date when large numbers arrived at Chipps Island. Nevertheless, the 5% threshold provided a conservative estimate to describe the onset of migration season.

We used machine learning models, such as a boosted regression tree, to examine how covariates influence the timing of spawning and migration through data collected at or near Chipps Island. Covariates included: X2 position, water temperature, Secchi depth and day of the year. Day of the year was the most important variable in the model indicating that the spawning migration to Chipps Island is a seasonal phenomenon, consistently beginning in December regardless of environmental conditions. However, the precise timing of the spawning migration did vary, occurring earlier when temperature was < 12.0°C, the seven-day rolling average Secchi depth at Chipps Island was < 0.6 m, and X2 was < 79 km (Figure 16) (also see Appendix A).

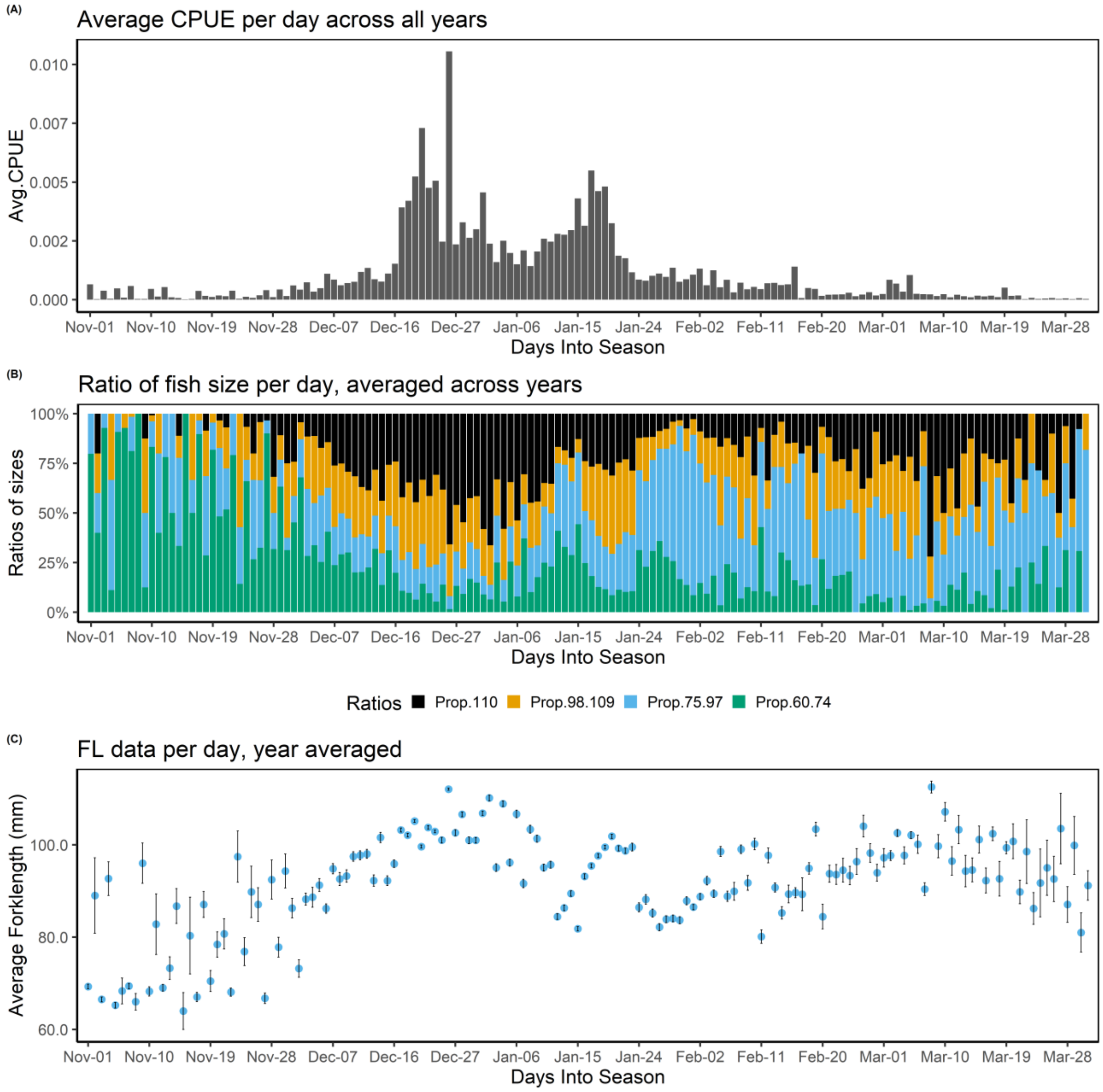


Figure 14: *LFS caught in the Chipps Island Trawl from 1993-2017: (A) the average catch per unit effort (CPUE) of LFS ≥ 60 mm within the November through March period; (B) the average proportion of each age class, 60-74 mm is age-0, 75-97mm is age-1, 98-109 mm is age-2, and 110 mm and greater is age-3; (C) the average fork length per day, with standard error bars.*

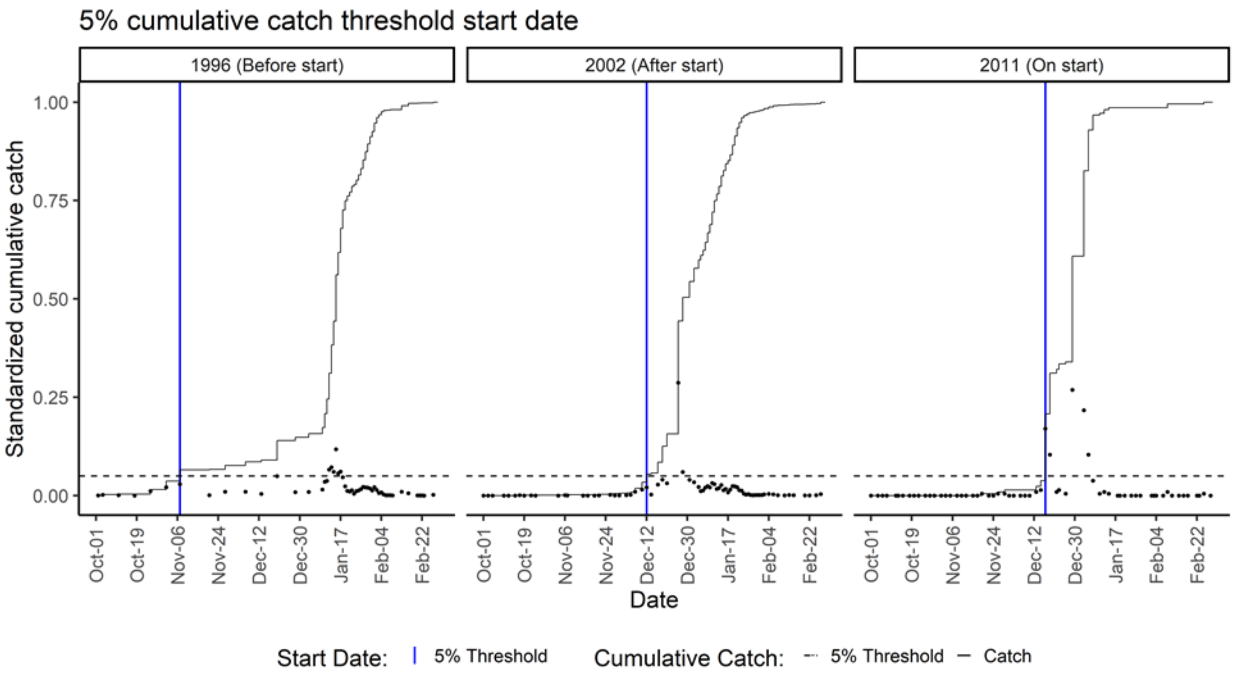


Figure 15: *Cumulative catch standardized to 1 across the October-February period for water years 1996, 2002, and 2011. The 5% cumulative catch threshold was used to predict onset of migration and is shown as the horizontal dashed line. Water years 1996 and 2002 represent the most extreme years during which the 5% cumulative catch threshold failed to predict the start of the modal period. Water year 1996 was the earliest and WY 2002 the latest, while WY 2011 is an example of a year when the 5% accurately predicts the start of the modal period. The blue vertical line shows the date when 5% of catch was observed.*

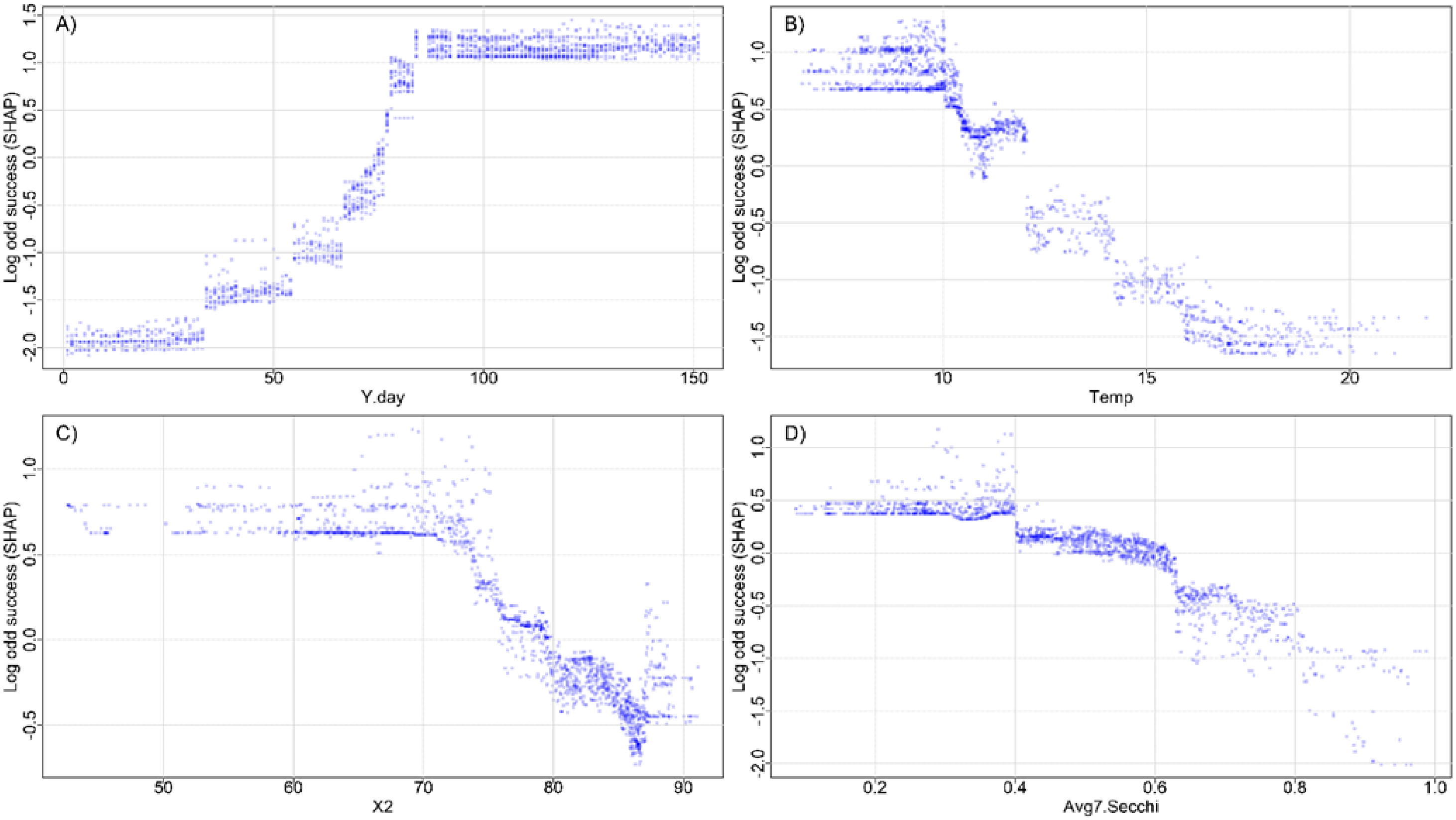


Figure 16: *Contribution plots of the top four variables predicting pre- and post-migration state at Chipps Island: A) season day, B) water temperature (°C), C) X2 (km), and D) seven-day running average Secchi depth (m). SHAP values indicate log odd success chance, with positive values contributing to a positive-state prediction (post-migration state) and vice versa. The model generally predicts post-migration state when season day (Y.day) is > 73, water temperature (Temp) is < 12°C, X2 is < 79 km, and seven-day running average Secchi depth < 0.6 m.*

This analysis illustrates the importance of two assumptions regarding adult LFS spawning behavior. The first being that LFS are known to undergo short, rapid, nocturnal upstream spawning migrations in other sytems, such as Lake Washington (Dryfoos 1965; Moulton 1970; Moulton 1974). If this behavior is reflective of adult LFS within the San Francisco Estuary, then this analysis demonstrates the ability for the Chipps Island Trawl to provide an early indication of spawning in the central and south Delta. Once migration has begun, it is anticipated that adult LFS may enter the central and south Delta to spawn within several days of being detected at Chipps Island.

The second important assumption is that LFS spawning is imminent upon migration. DS are known to disperse into spawning areas in the winter but will not spawn until temperatures increase in the spring (IEP 2015). In contrast, LFS are assumed to spawn soon after migration. This is often evidenced by larval detections in the central and south Delta within the first survey of the SLS in early January (Table 3). Combined, these assumptions in conjunction with findings from this analysis of Chipps island data, implies that spawning is occurring in the central and south Delta as early as December.

5.3.1. Banks Pumping Plant and Clifton Court Forebay

Operations of the SWP can lead to direct take of adult LFS that are in the Delta by entraining individuals into the SWP and CVP export facilities. Historically, LFS used the lower reaches of the San Joaquin River in areas with suitable hydrodynamic and water quality conditions as spawning habitat (Merz et al. 2013; Rosenfield 2010). However, changes in larval catches in the CDFW smelt larva survey (SLS) indicate that LFS abundance has declined in this habitat over time. Despite this decline in the central and south Delta, adult LFS continue to occur in the southern Delta, and likely enter that habitat either voluntarily during spawning migrations, involuntarily due to hydrodynamics, or both (CDFG 2009b). Take of adult LFS at the SWP and CVP south Delta facilities is evident from individuals ≥ 60 mm observed in salvage generally from December (rarely November) to as late as April (Figure 13).

Relative to other pelagic fishes in the Delta, salvage of adult LFS has generally been low, however; during the Pelagic Organism Decline (Sommer et al. 2007) adult LFS salvage was relatively high (Figure 17). Since 2008 salvage of adult LFS has been extremely low, either due to population decline or Old-Middle River flow management implemented under the 2008 BiOP (Smith 2019).

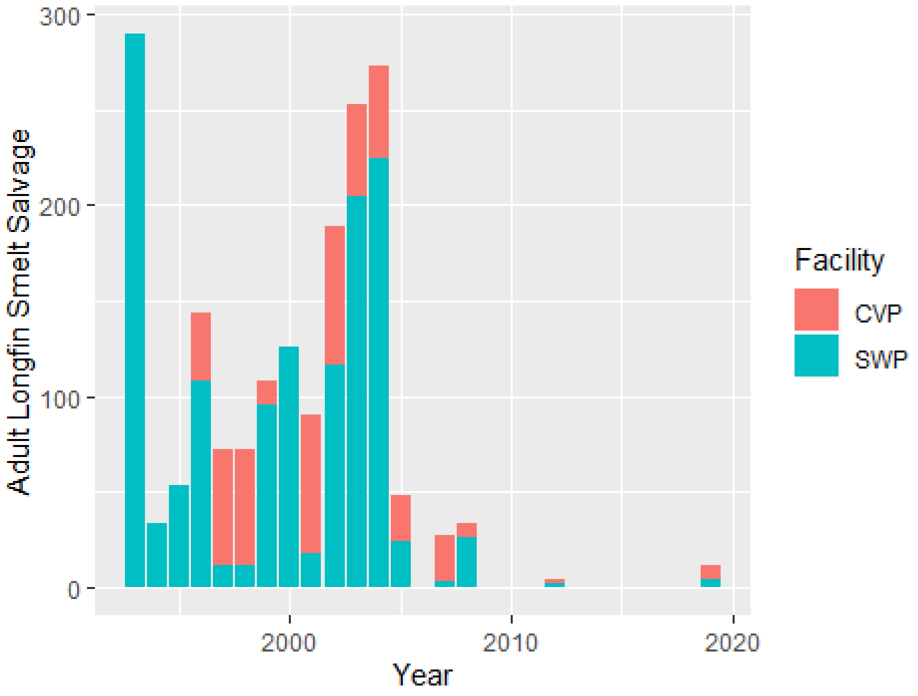


Figure 17: *Barplot of adult LFS salvage from 1993 through 2019. Bars represent total expanded salvage for the CVP and SWP by water year for the months of December – February.*

Grimaldo et al. (2009) found a significant correlation between negative OMR flow and juvenile LFS salvage at SWP and CVP but found no significant patterns among several abiotic covariates for adults. This may be due to the behavior of adult fish during the spawning period. Adult LFS stage in brackish waters downstream of spawning grounds prior to nocturnal migrations into fresher water to spawn (Hobbs et al. 2019a). This migration behavior can lead to entrainment particularly during dry winters when X2 is near the confluence. The winter distribution of adult LFS in the upper estuary is associated with the location of X2 and adult LFS salvage is greatest in years of high Fall Midwater Trawl Index and high Dec-Mar X2 position , however, the biotic and abiotic factors that influence adult entrainment into the SWP and CVP remain uncertain.

For the purposes of this Effects Analysis, we used machine learning models determine if the timing of the spawning migration, as indexed by catch at Chipps Island, could be used to better understand adult LFS salvage at the SWP and CVP (see Appendix B). Using expanded salvage numbers for adult LFS from December through February for the years 1993 to 2019, salvage was greater when fish had recently migrated past Chipps Island (<36-days) and south Delta export rates are high (>11,000 cfs)(Figure 18). More generally, salvage increased with fish proximity to the CVP and SWP and the magnitude of negative OMR flows caused by the export facilities (Appendix B, Figure 5). These are additive effects, where fish closer to the facilities during times of high exports and highly negative OMR will lead to higher salvage than under conditions where only one factor is at play. Individuals salvaged directly at the export facilities are expected to be killed and lost to the population due to direct mortality or screen impingements. Although fish can be successfully recovered and returned to the Delta after take occurs at the salvage facility, (Morinaka 2013b), it is unlikely that a substantial portion of the population is returned to contribute to subsequent generations.

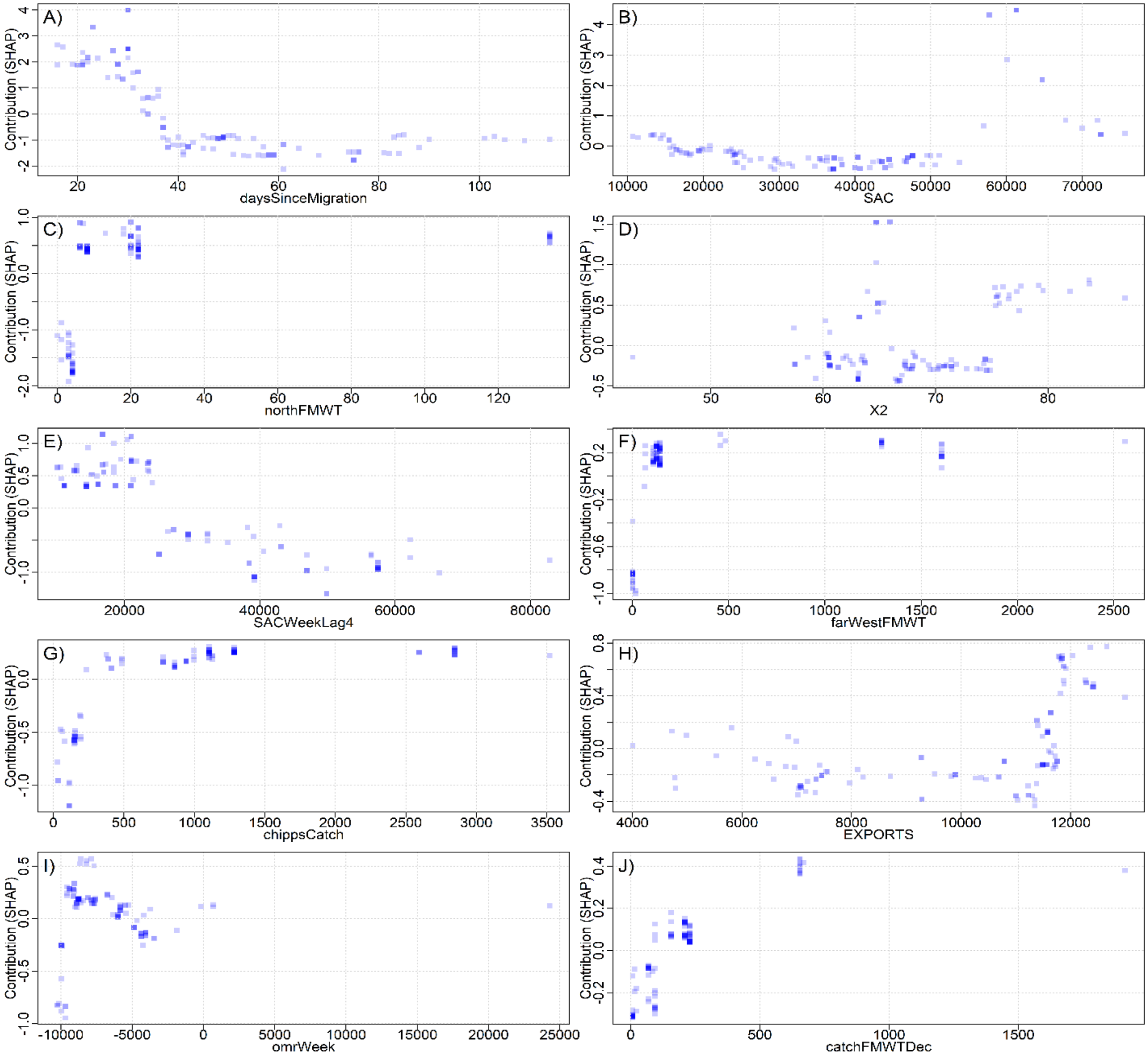


Figure 18: *Contribution plots of the variables used to inform expanded LFS salvage at the facility from 1993-2019. Order of importance is from left to right and top to bottom. daysSinceMigration (A) is the most important variable in the model and shows that increased entrainment is expected within the first 36 days after LFS have entered the Delta, closer in proximity to the export facilities. Higher exports results in higher entrainment of LFS, especially under high flow conditions. Variables are defined as: A) daysSinceMigration is the number of days since the onset of LFS migration as determined by 5% cumulative catch per water year at Chipps Island; B) SAC is Sacramento R. outflow (cfs); C) northFMWT is the total catch in the FMWT for stations 706-797; D) X2 is the position of the 2 psu isohaline from the Golden Gate Bridge; E) SACWeekLag4 is weekly average Sacramento R. outflow (cfs) from four weeks prior; F) farWestFMWT is the total catch in the FMWT for stations 302-418; G) chippsCatch is monthly LFS catch by the Chipps Island Trawl; H) EXPORTS is total daily export from the CVP and SWP from Dayflow; I) omrWeek is weekly average OMR flow; and J) catchFMWTDec is total LFS catch from all FMWT stations for the month of December each year.*

Individuals entrained into CCF are considered taken as it is not likely that adult LFS can swim out of CCF voluntarily. Unfortunately, the total number of LFS entrained into CCF are not directly quantified. Instead entrainment into CCF is calculated based upon expansions of observed LFS salvaged at the Skinner Fish Facility (Brown et al. 1996; CDFG 2009b; Kimmerer 2008). Fish which are entrained into south Delta, but not observed in salvage are approximated in estimates of loss (ERP 2014; Kimmerer 2008), which accounts for both direct, and indirect sources of mortality as it relates to SWP and CVP operations. However, a LFS-specific loss equation has not been developed. Studies of DS salvage efficiency show that take is substantially higher than observed through expanded salvage at the facility because the louver efficiency of the SWP facility is only about 37% for fish > 80 mm FL (Table 1), meaning that fish may not be diverted into salvage facilities. Indirect forms of take and related impacts include mortality due to predation while in CCF or nearby areas, or by succumbing to unfavorable environmental conditions. These factors have also not been directly quantified within CCF, however; CCF is known to harbor large populations of piscivorous fishes, and predation is expected to be high. The CCF Aquatic Weed Control Program can also result in fish mortality due to the effects of contaminants on adult LFS, although the extent of this effect on the population has yet to be quantified.

Impacts of the taking extend beyond the direct entrainment and observation of fish in salvage, to those individuals that are lost ("killed") as an indirect result of SWP operations. This can occur when adult LFS voluntarily or involuntarily move into the central and south Delta. Several mechanisms can cause this loss prior to entrainment into the SWP facilities. First, LFS can be entrained from their intended spawning or rearing destinations into the south Delta by negative OMR flows resulting from operations of the SWP. Once in the south Delta, individuals face unfavorable abiotic conditions, such as reduced turbidity, exposure to contaminants (eg. selenium), warm water temperatures and reverse flows.

In addition to abiotic stressors, adult LFS are also exposed to biotic stressors, such as increased predation risk. Turbidity is generally lower in the southern Delta than elsewhere, attributed to lower inflow and increased presence of both floating and submerged aquatic vegetation (FAV and SAV respectively) (Nobriga et al. 2008). Increased water clarity poses increased predation risk to LFS, for which there is evidence of an overall negative effect on population abundance (Thomson et al. 2010). Predator density is higher in the south Delta due to increased presence of invasive species, specifically black basses (*Micropterus spp.*), which Young et al. (2018) found were the most abundant species in habitats sampled in the south Delta. Conrad et al. (2016) established that juvenile black bass density was positively correlated with the biomass density of *Egeria densa*, an invasive submerged aquatic vegetation (SAV) which has recently invaded the Delta. In particular, SAV density and distribution within the south Delta has increased over time (Santos et al. 2016). The interaction between increased predator presence and clearer water will likely increase predation risk for adult LFS in the area, however, no studies have been conducted to quantify this effect.

Additionally, contaminant levels in fish have been demonstrated to be higher in the south Delta and lower San Joaquin River systems (Davis et al. 2000) relative to other regions of the Delta and Sacramento River watershed. Higher contaminant levels can lead to fish death or stunted growth and bodily functions (Hammock et al. 2015).

The progeny of fish that successfully spawn in the south Delta can be taken once eggs are laid or hatched. Adhesive eggs that are deposited by spawning individuals are not believed to be vulnerable to direct entrainment, but those spawned in brackish water may be affected by changes in salinity due to export operations. Impacts of the taking on eggs and larval LFS as a result of SWP exports has yet to be quantified, but it is likely that a substantial portion of the population is taken based on estimates of DS take (Kimmerer 2008). LFS eggs and larvae may be exposed to predation by Mississippi silverside (Moyle 2002), although this has only been studied for DS (Schreier et al. 2016). Entrainment of eggs and larvae is largely unquantified for individuals smaller than 20 mm FL. However, presence of larval LFS in recent larval samples from the SWP and CVP fish facilities indicates that entrainment of young larvae likely occurs. The southern Delta may have historically been used by spawning LFS, however in recent years, LFS presence in the south Delta is consistently rare (Rosenfield 2010). The population has continued to decline despite protections afforded by the 2008 USFWS BiOp, 2009 NMFS BiOp, and 2009 ITP.

5.3.2. Barker Slough Pumping Plant

The BSPP is made up of 10 pump bays that are individually screened with a positive barrier fish screen consisting of a series of flat, stainless-steel, wedge-wire panels with a slot width of 2.4 mm. This configuration is designed to exclude and prevent the entrainment of fish measuring approximately 25 mm or larger. The bays tied to the two smaller units have an approach velocity of about 0.2 foot per second (ft/sec). The larger units were designed for a 0.5 ft/sec approach velocity, but actual approach velocity is about 0.44 ft/sec. Direct take of LFS occurs when individuals are impinged on the screens or passes through them. However, due to the presence of the fish screen and appropriate approach velocities, direct take of adult LFS is expected to be low.

Although take of adult LFS is expected to be low due to the fish exclusion screens, individuals may be entrained into the area during periods of high water diversion. Adults entrained into the area may spawn nearby. Habitat within the zone of influence of the BSPP is considered to be low quality for larval LFS, as fish less than 25 mm are expected to be killed by impingement onto the fish screen or by passing through it.

5.3.3. Suisun Marsh Facilities

Physical facilities in the Suisun Marsh and Bay include the SMSCG, the RRDS, the MIDS and the GYSO. Additional facility details are provided in the ITP Project Description, Section 3.1.3.5 of the FEIR, and in Section 5.1.3 of this Effects Analysis.

Suisun Marsh Salinity Control Gates

The SMSCG have the potential to cause short-term delays in migrating adult LFS in the late fall and early winter. If the SMSCG increases adult LFS residence time in Montezuma Slough, entrainment at the RRDS could increase, resulting in increased take.

Roaring River Distribution System

The RRDS intakes are screened (2.4 mm opening) and physically exclude fish greater than 30 mm in length from being entrained. RRDS is only expected to take adult LFS if individuals are impinged onto the screens. It is not known whether this occurs, but it is assumed that it is unlikely due to the size and swimming strength of adult LFS.

Morrow Island Distribution System

Individual adult LFS could be entrained by the three unscreened 122 centimeter intakes that form the MIDS diversion. Enos et al. (2007) sampled entrained adult LFS at MIDS from 2004 to 2006, indicating that entrainment has occurred in the past, but it is unclear as to what the magnitude and frequency of these entrainment events are. Based on the data collected in this study, take of adult LFS at MIDS is expected to be low.

Good Year Slough Outfall

The intakes and outfall of GYSO are unscreened and may entrain adult LFS, similar to DS (USFWS 2019). However, fish that enter the system are unlikely to die during the entrainment process and would be able to leave via the intake or the outfall, as GYSO is an open system. Fish could experience indirect effects of entrainment into GSY, such as increased exposure to predators or contaminants. Data from the UC Davis Suisun Marsh Study has documented some presence of adult LFS in the area during the winter, indicating that adult LFS may infrequently spawn in GYS.

5.3.4. Agricultural Barriers

The South Delta Temporary Barrier Project (TBP) does not alter total Delta outflow, or the position of X2 (USFWS 2008). However, the TBP causes changes in the hydraulics of the Delta, which may affect both DS and LFS in the area. Simulations have shown that placement of the barriers changes south Delta hydrodynamics, increasing central Delta flows toward the export facilities (USBR 2008). In years with substantial numbers of adult LFS moving into the central Delta, increases in negative OMR flow caused by installation of the TBP can increase entrainment. The increased directional flow towards the Banks and Jones Pumping Plants increases the vulnerability of fish to entrainment and may result in direct take of the species.

5.4. Food Resources

Food resources contribute to directly to rearing habitat quality for all fishes in the Delta and upper estuary (Baxter et al. 2010). As described in section 4.1 and as described for DS in Section 4.2, food resources for LFS have changed over time (Baxter et al. 2010). Important prey items for LFS rearing in the low salinity include species such as the calanoid copepod *E. affinis* and the mysid *N. mercedis,* both of which declined considerably since the introduction of the overbite clam, *P. amurensis* (Kimmerer and Orsi 1996, Orsi and Mecum 1996, Winder and Jassby 2011). However, since their introductions, the calanoid copepod *P. forbesi* and the mysid *H. longirostrus* have also become important food sources (Baxter et al. 2010). Because some of these food resources, such as *P. forbesi*, are known to be susceptible to entrainment (USFWS 2008), are influenced by hydrology (Kimmerer et al. 2018; Kimmerer et al. 2019) and temporally overlap with DS, the analysis of Project operations on food web resources described in Section 7.6 of the ITP application is also applicable here.

5.5. Spring Outflow

The abundance of LFS exhibits one of the strongest correlations with freshwater flow among a variety of taxa that occur in the San Francisco Estuary, however; the underlying mechanisms for this relationship have not yet been resolved. The trend in LFS abundance and freshwater flow was first described by Stevens and Miller (1983) using the CDFW Fall Midwater Trawl (FMWT) and monthly total inflow to the Delta. In this study, the authors explored using flows during different months (individually and in combination) to determine the best correlation between abundance and flow. They found the mean flow period from December - August explained the greatest variance in abundance (Table 6). The authors concluded “the mechanism for the flow-abundance trend was the result of improved survival due to greater quality or quantity of nursery habitat, wider dispersal of young and reduced density dependent mortality.” Since this first analysis describing the flow/abundance relationship for LFS, numerous publications have found similar strong effects of freshwater flow on their abundance using additional years of FMWT, additional surveys that document catch abundance of LFS and additional metrics of flow (Maunder et al. 2015; Nobriga and Rosenfield 2016; Rosenfield and Baxter 2007; Stevens and Miller 1983; Tamburello et al. 2019; Thomson et al. 2010).

In response to an EPA workshop to develop strategies for protecting estuarine populations in the San Francisco Bay-Delta, Jassby et al. (1995) developed the salinity scalar indicator (X2), which is the geographic location up the axis of the estuary to the near-bottom 2-psu isohaline. The authors hypothesized that the X2 indicator could be used to index the estuarine community response to freshwater flow. The X2 indicator was initially developed largely because in-Delta consumption of water is not readily quantified, thus flows that influence Suisun Bay are not adequately tracked by flows into the Delta or by net Delta outflow (net Delta outflow is calculated utilizing static estimates of within Delta consumption and tidally averaged flows past Chipps Island). LFS abundance (arithmetic scale) exhibited a strongly negative trend with X2 (see Table 1 in Jassby et al. 1995). While Jassby et al. (1995) did not discuss the potential mechanism for the LFS trend, they did demonstrate a strong positive linear declining trend with chlorophyll-a and *Neomysis mercedes* abundance (an important prey), thus a food component to survival may be implicated with this work.

Kimmerer (2002b) updated the relationship between LFS abundance and X2 using data up to 1999. Kimmerer (2002b) used generalized additive model-GLM with a categorical factor for the pre-clam and post-clam years (1987), X2, and an interaction term to determine if the relationship between X2 and abundance had changed following the invasion of *P. amurensis*. The abundance index of LFS continued to have a strong relationship to X2, but also had a significant time period interaction for the post-clam invasion signifying a decline in abundance between the two time periods that was attributed to the effect of clam grazing on the food web in the low-salinity zone.

Rosenfield and Baxter (2007) expanded upon the flow/abundance trend by including the CDFW San Francisco Bay Study's (hereinafter SFBS) otter trawl and midwater trawl catches. The authors recalculated FMWT indices using two age classes based on age-length-month tables developed in Baxter (1999). The paper references the Jassby (1995) paper for the use of a flow metric, but it was not clear whether this was "Total Inflow", and what specific time period was used for outflow. This paper also combined years among three time points, pre-drought (1967-1987 FMWT or 1980-1986-SFBS), drought (1987-1992), and post-drought (1993-2004). They used an ANCOVA with the categorical year variable as the main effect and outflow as the covariate to test whether LFS abundance has declined over time, rather than testing the significance of the flow effect. Outflow had a strong effect on abundance in the FMWT age-1 and age-2 indices and the two SFBS indices (see Table 6).

As part of an National Center for Ecological Analysis and Synthesis (NCEAS) working group, two publications (Mac Nally et al. 2010; Thomson et al. 2010) used more advanced statistical tools to assess population trends for survey data and incorporate a suite of covariates that have been attributed to species decline in the estuary. Thomson et al. (2010) developed a Bayesian hierarchical changepoint model that utilized catch data from the FMWT rather than abundance indices. Thus, it should be noted that the Thompson et al (2010) results pertain to a density metric rather than an expanded abundance estimate. The models were constructed to test for distinct changes (change points) in mean catch over the study years and used covariates to determine how covariates could explain the change points identified. The covariate selection model identified water clarity and spring X2 as the strongest variables, both having negative effects on annual mean catch with an R^2 of 0.88 (Table 6). The authors point out that the effect of water clarity after accounting for the effect of spring X2 was weak. Importantly, the covariate conditioned change point models identified step-changes in abundance in 1989-1991 and 2004 that could not be explained by water clarity or spring X2. The first decline period has been attributed to a decrease in food availability following the introduction of the "overbite" clam *P. amurensis* (Kimmerer 2002b), while the explanation for the decline in 2004, known as the "Pelagic Organism Decline" has yet to be determined. In a second publication from this NCEAS effort, Mac Nally et al. (2010) used a multivariate autoregressive modeling approach and included additional covariates identified by experts to be important drivers of fish abundance in the SFE. These models included covariates for prey availability and predator abundances as well as abiotic factors from Thompson et al. (2010). This approach found strong support for the spring X2 and abundance of LFS, but also identified potential links between flow and prey abundance for LFS, suggesting the mechanism underlying the fall abundance to flow relationship may be driven by increased food and feeding which would promote rapid growth and survival in the early life stages which experience the greatest mortality.

Additional analysis by Tamburello et al. (2019) updated the "Kimmerer regression" approach with data up to 2014, finding similar results as all previous analysis; outflow or X2 is the strongest driver of age-0 LFS abundance. Importantly, the authors point out the change in prediction error (Fig 5D and Fig 6 in

Tamburello et al. 2019) showing the prediction error for LFS abundance based on X2 is increasing, and is now approximately 20%, which is much greater than simulated median differences in Appendix F of the ITP Application. Overall, numerous peer-reviewed publications covering a span of 36-years have all demonstrated a strong positive LFS population response to increasing flow in the winter-spring months.

Table 6: *Comparison of literature cited that addressed hypotheses pertaining to the relationship between Delta outflow and LFS abundance, generally.*

Publication	LFS abundance metric	Flow metric	Years analyzed	Statistical analysis	Conclusion
Stevens and Miller (1983)	FMWT Index (log)	total inflow (all months m^3/s), mean Dec-Aug	1967-1978	Linear Regression/correlation	Survival controlled by spring and early summer flows
Jassby et al. (1995)	FMWT Index (log Aug/Sep-Mar)	X2 (mean Jan-Jun, log)	1968-73,1975-78,1980-1982,1984-1991	Generalized Additive Model, cubic spline	Authors do not specifically discuss LFS.
Kimmerer (2002b)	FMWT (log)	X2 (mean Jan-Jun, log)	1968-73,1975-78,1980-1982,1984-2000	General Linear Regression with a categorical year term for pre-clam (1968-1986) and post clam (1987-2000)	Strongest effect was X2. Abundance exhibited 4-fold decline after 1987
Rosenfield and Baxter (2007)	FMWT and Bay Study age 1 and 2 (all Sep-Dec recalculated indices, $\log_e$).	Outflow (Jan-Jun) per Jassby et al. 1995)	1976-75, 1980-2004 (FMWT), 1980-1988, 1994-2004 (SFBS)	ANCOVA, with three time periods (predrought prior to 1986, drought 1987-1994 and post drought 1985-2004	Longfin declined during the drought and fall abundance is strongly related to outflow
Sommer et al. 2007	FMWT Index (log)	Outflow (Jan-Jun m^3/s,log)	1967-2006	Linear regression with categorical year for pre-clam (1968-1986) and post clam (1987-2000)	Despite a magnitude change in the response, LFS exhibits strong relationship with outflow
Kimmerer 2009	FMWT, Bay Study mid water trawl, Bay Study Otter Trawl Indicies (log)	X2 (mean Jan-Jun, log)	1968-1973,1975-1978,1980-1982,1984-2007(FMWT), 1980-2007, (SFBS)	General Linear Regression with a categorical year term for pre-clam (1968-1986) and post clam (1987-2000)	All three of the abundance metrics have a strong, negative X2 relationship
Thomson et al. (2010)	FMWT-catch-per-trawl (log)	spring X2	1967-2007	Hierarchial Bayesian Changepoint	Spring X2 and water clarity associated with longfin abundance. Spring X2 more important.

Publication	LFS abundance metric	Flow metric	Years analyzed	Statistical analysis	Conclusion
Mac Nally et al. (2010)	FMWT- catch-per-trawl (log)	spring X2 (mean Mar-May)	1967-2007	Bayesian Multivariate Autoregressive Models	Spring X2 had strong negative effect on LFS and calanoid copepods suggesting a food web link associated with flow-abundance pattern
Appendix F_ITP Application	FMWT Index (log)	X2 (mean Jan-Jun)	1967-2014	General Linear Regression with a categorical year term for pre-clam (1968-1986) and post clam (1987-2014)	Spring X2 strong negative effect on LFS abundance and significant changes between eras. Considerable overlap in predictions for PP and PP-Spring and existing conditions
Tamburello et al. (2019)	FMWT, Bay Study mid water trawl, Bay Study Otter Trawl Indices (log)	X2 (mean Jan-Jun, log)	1967-2014	General Linear Regression with a categorical year term for pre-clam (1968-1986) and post clam (1987-2014)	Spring X2 continues to have a negative effect on LFS abundance, but this relationship is getting more variable

Discussion of Delta Outflow- LFS Abundance Analyses in the 2019 ITP Application - Effect of Project operations on LFS abundance based on Nobriga and Rosenfield (2016):

To determine the effect of the Project with (Alternative 2B model run in FEIR) and without (Proposed Project model run in FEIR, PP) Condition of Approval 8.17 as a minimization measure, DWR provided results of a model simulation predicting FMWT abundance given reductions in Net Delta Outflow using the Ricker stock-recruit model (model 2abc) described in Nobriga and Rosenfield (2016) (hereafter NR 2016).

The 2019 ITP Application briefly mentions alternative LFS flow-abundance models published by Maunder et al. (2015) but states "the flow terms included in their best model (Maunder et al. 2015) are not affected by the proposed project: Sacramento River October-July unimpaired runoff and Napa River runoff", and chose to use the NR 2016 model instead for their effects analysis. The Maunder et al. (2015) publication compared simple log-linear models including the NR 2016 model, along with additional stock-recruit models (Beverton-Holt) and a Bayesian state-space model. Maunder et al (2015) found that the Bayesian state-space model outperformed all other models explored in the publication, thus the RN 2016 may not be the best modeling approach available. Furthermore, a Bayesian state-space model is currently being employed by the USFWS for modeling the life cycle of DS. A similar modelling structure may be warranted, but unfortunately, the early life stages of LFS are not adequately sampled to facilitate a full life cycle model like the under development for DS at this time. Future development of a LFS life cycle model will be a focus of the LFS Science Program as described in the ITP (Condition of Approval 7.6.3).

Here we note several concerns regarding the NR 2016 model that preclude its use as a simulation tool for assessing effects of Project operations with and without Condition of Approval 8.17 (Alternative 2B vs Proposed Project FEIR model runs) on LFS abundance as compared to existing conditions.

1. The Ricker function is an inaccurate representation of longfin smelt population dynamics

The NR 2016 publication tested only a subset of models for describing LFS population dynamics based on conceptual models from the Pelagic Organism Decline (Sommer et al. 2007) and the DRERIP model (Rosenfield 2010). All models tested in NR 2016 began with an assumption that accounting for adult stock abundance was necessary for understanding recruitment to the age-0 life stage, and that recruitment to age-0 was density dependent with a functional form described by the Ricker model.

The Ricker model describes the number of recruits entering a population as an exponentially decreasing function of the number of adult spawning fish with strong density dependence at high spawning stock abundance (Figure 19) (Ricker 1954). The strength of the density dependence in the Ricker model is due to a variety of mechanisms including cannibalism, disease, nest site superimposition, density dependent growth, and size-selective predation (Ricker 1975). None of these mechanisms have been documented to occur in LFS.

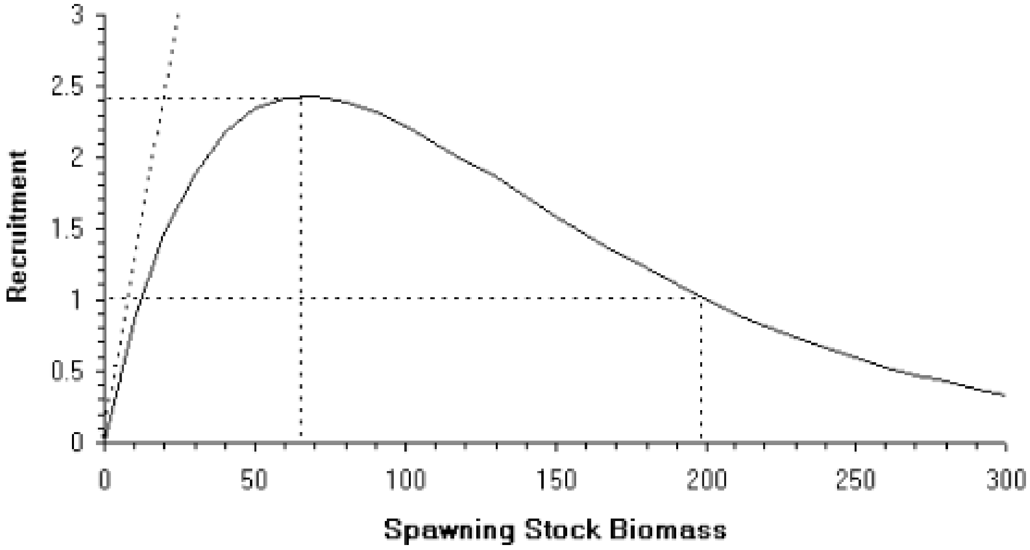


Figure 19: *Ricker stock-recruitment curve (source http://www.fao.org/3/w7219e05.htm, Accessed 3/10/2020)*

Because the original NR 2016 publication was done solely to assess different conceptual models of population dynamics, the appropriateness of applying the Ricker function to predict LFS recruitment was not central to testing their hypotheses, and they did not explore other density dependent stock recruit models. They also did not test whether a density dependent term was necessary for predicting LFS recruitment when flow was included as a covariate in models. To demonstrate the ability of the Ricker function to predict LFS recruitment we fit the Ricker function to the data provided in NR 2016 (Figure 20). The Ricker model, either with or without density-dependence provides a poor fit to the data (Figure 20A). There were three years of anomalously high LFS recruitment (1980, 1982 and 1995), thus we removed these years and re-ran the models (Figure 20B), but the density dependent models were still a poor fit to the actual data. Simulated outcomes provided in the ITP Application are thus not accurate reflections of LFS population dynamics.

To further demonstrate the lack of statistical relationship between stock and recruits we plot recruits (log age-0) to stock using log age-1 (Figure 21A), log age-2 (Figure 21B) and log age-1+2 (Figure 21C) as alternative approaches to adult stock. The log abundance of stock has a very weak, but positive effect on recruits (Figure 21A-C). Meanwhile the relationship between recruits and flow is strong (Figure 21D), as has been observed in numerous publications (Jassby et al. 1995; Maunder et al. 2015; Nobriga and Rosenfield 2016; Rosenfield and Baxter 2007; Stevens and Miller 1983; Tamburello et al. 2019; Thomson et al. 2010).

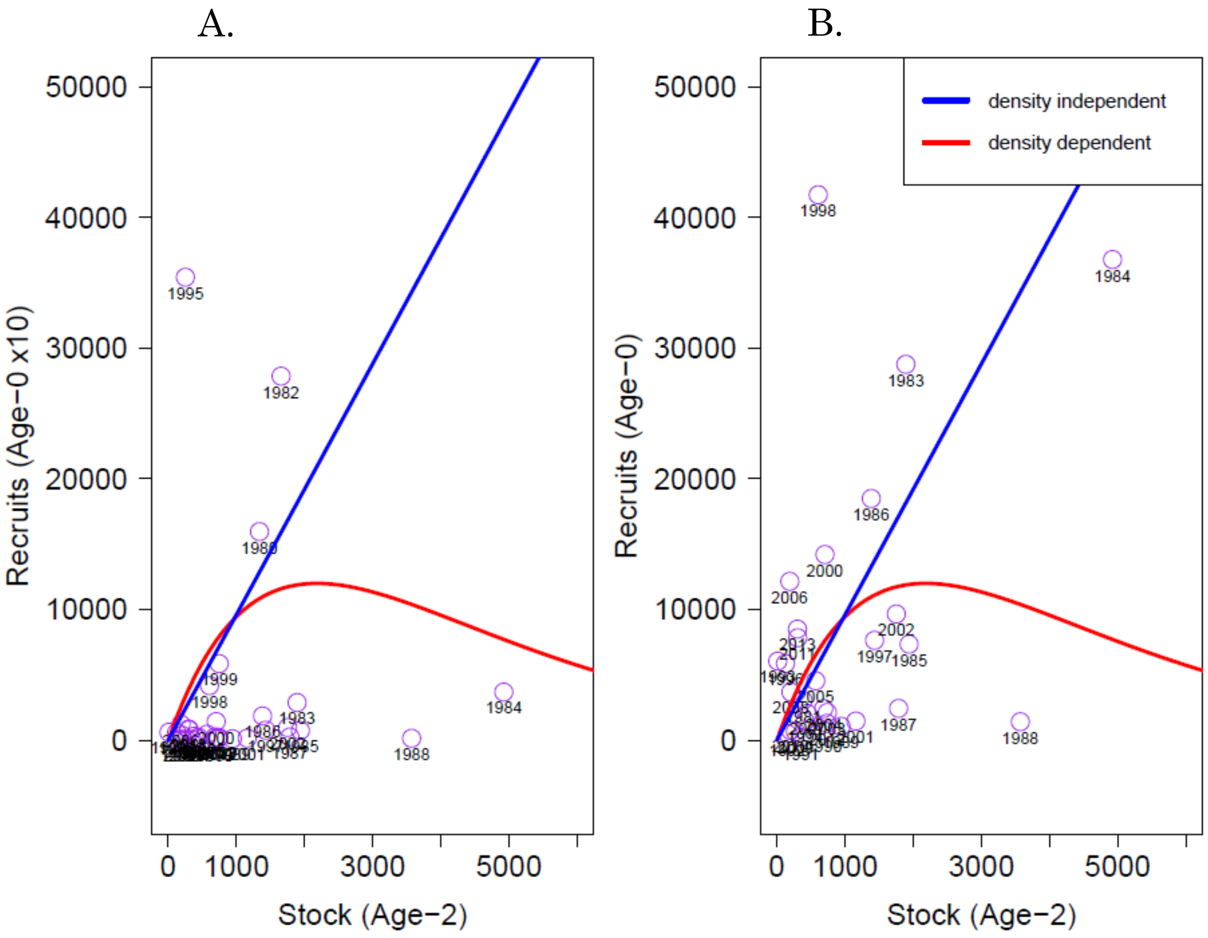


Figure 20: *Stock-recruit plot using Bay Study Age-0 abundance index as recruits and Age-2 index for stock. Red line depicts the fit of the Ricker model with density dependence and blue line depicts the fit without density dependence. (A) all data included and (B) with three anomalous years removed.*

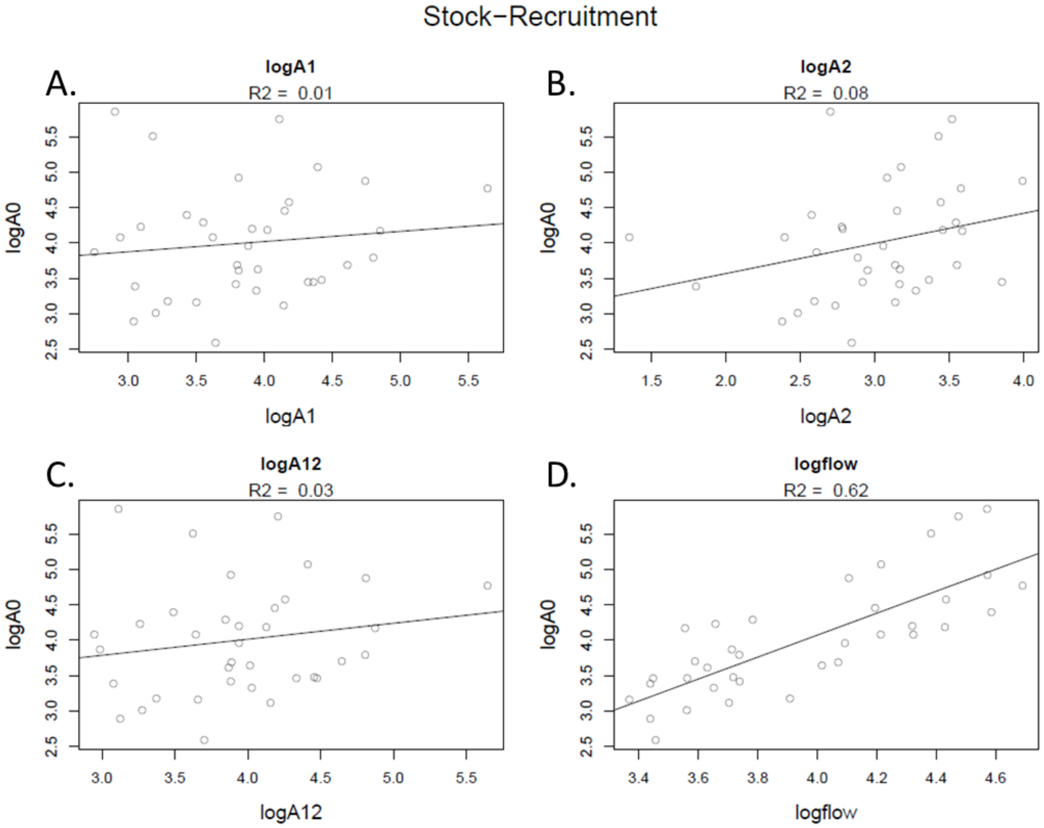


Figure 21: *Stock recruit plots for LFS indices from the San Francisco Bay Study. Y-axis is log of Age-0. (A) log of Age-1, (B) log Age-2, (C) log of Age-1 and Age-2, (D) Age0/Age2 or recruits per stock.*

2. The coefficients were estimated using log ratios and were not directly derived from model fitting.

The authors of NR 2016 did not fit the Ricker model to data to determine coefficients, rather they used log ratios of abundance indices (age-0/age-2) for “a” (density independent term) and for “b” (the density dependent term) they found values that reflected empirical relative abundance maxima given estimates of a. This assured the density dependence term was the maximum possible during the time-series investigated (0.00077), rather than simply estimating these parameters directly using the Ricker model function. Nobriga and Rosenfield acknowledge that this likely led to consistent under-predicted recruitment compared to observed FMWT patterns (Figure 6 in NR 2016).

3. Abundance indices were inappropriately combined

Another unexplored aspect of NR 2016 was their approach to combining abundance indices by gear type in the San Francisco Bay Study (here after SFBS). The SFBS uses both a midwater trawl and an otter trawl and produces separate age specific abundance indices. Nobriga and Rosenfield combined these indices by averaging them, including zeros for years when no index was calculated (1994 age-0, 1995-1996 Age-2). This would result in lower indices for the years when no index was reported and have an unknown influence on parameter estimates in the Ricker model. In addition, the averaging of the two gear specific indices is inappropriate as they represent different scales of abundance. The otter trawl index is based on catch per area swept while the midwater trawl is based on catch per volume sampled, thus the two indices represent very different scales of abundance.

4. The NR 2016 model doesn't predict the FMWT.

The 2019 ITP Application used model 2abc to simulate the effect of PP and Alternative 2b scenarios on the LFS FMWT index by subtracting from NDOI in Dayflow. The model simulates a time series of predictions for FMWT index with starting year in 1956 at a FMWT value of 798. However, the coefficients in the Ricker model are estimated using the data from the Bay Study and it is assumed the Bay Study index is suitably correlated to the FMWT index. The correlation between FMWT and Bay Study age-0 is poor (Figure 22), thus model predictions obtained using this approach would add additional variability in model simulations.

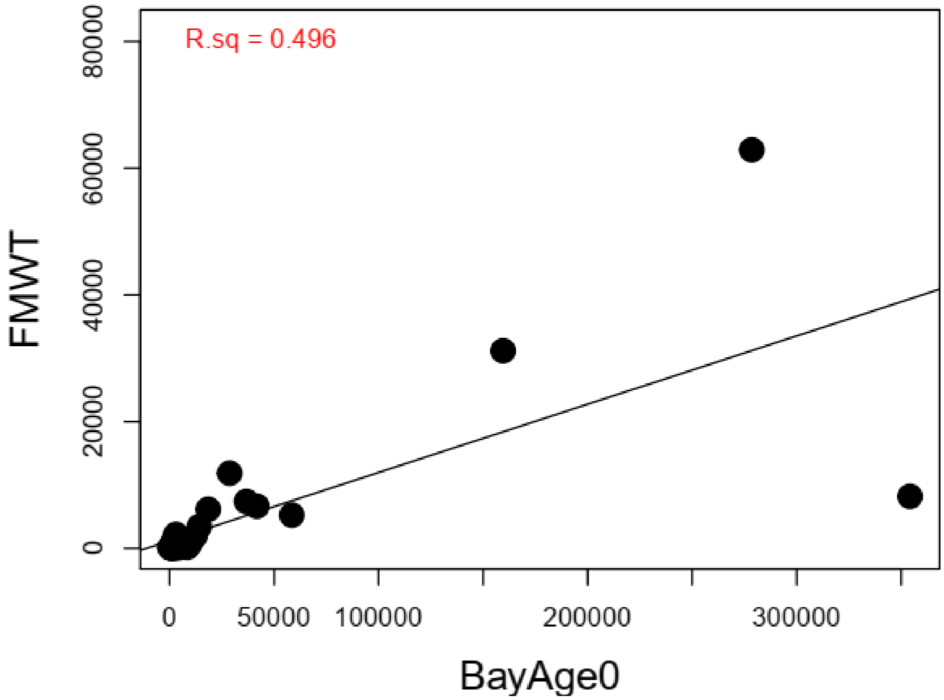
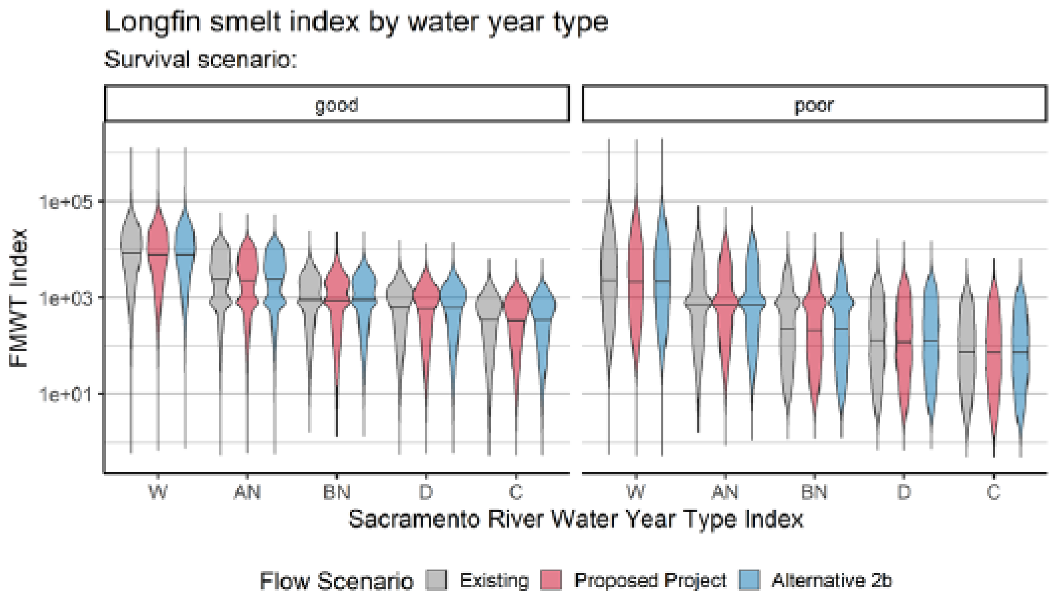


Figure 22: *Correlation between Bay Study Age-0 abundance index and the FMWT abundance index.*

5. Modelled variance was maximized to obscure predicted effects of the Proposed Project and Project Alternatives

The simulations presented in the ITP application compare predictions of the FMWT index given alterations of historic NDOI due to the PP and Alternative 2b scenarios relative to the existing conditions. The ITP Application analysis conducted 1,000 simulations, with each simulation drawing coefficients for the Ricker function using confidence intervals of each coefficient (α,β). As a result, each simulation has some level of variance associated with error in model coefficients. Given the extremely poor fit of the Ricker function to the data, this component of variance likely results in highly inflated prediction error. The simulations were also run across a period of precipitous decline in LFS abundance which further accentuates prediction variance. Model outputs were then summarized by water year type and plotted using a "violin" plot which serves to maximize simulated variance, obscuring differences between the existing conditions and the PP and Alternative 2b modeling runs (Figure 23).

The 2019 ITP application and FEIR claim that the PP and Alternative 2b scenarios will have a negligible effect on LFS age-0 abundance when comparing predicted median FMWT index between the two scenarios. The median of simulated predictions is consistently smaller than the mean difference, thus the choice of median over the mean difference serves to minimize effects of the PP and Alternative 2b scenarios when compared to existing conditions. To further obscure the small difference between scenarios, the median differences were divided by the mean confidence interval as an indicator of the signal to noise ratio of the models. This approach is similar to using prediction intervals rather than confidence intervals, the difference being that prediction intervals will include the unexplained variance of the model into the prediction. Overall, these choices are not necessarily statistically inappropriate but have the consistent effect of downplaying the effect of PP and Alternative 2b scenarios on LFS abundance estimates as compared to existing conditions.



Note: Median is indicated by the horizontal line.

Figure 4-55. Violin Plots of Predicted Longfin Smelt Fall Midwater Trawl Index by Water Year Type for Existing Conditions, Proposed Project, and Proposed Project Including Additional Spring Delta Outflow (Labeled as 'Alternative 2b').

Figure 23: *Violin plot from Figure 4-55 in the 2019 ITP application.*

However, given the extremely poor fit of the data to the Ricker model and the additional problems with averaging indices that have an unknown influence on parameter estimates in the model, we prefer to rely on the "Kimmerer regression" approach provided in Appendix E of the FEIR as it is also consistent with the scientific literature's consistent conclusions about the effects of Delta outflow to LFS abundance.

Effect of Project operations on LFS abundance based on X2-Longfin Smelt Abundance Index Relationship

The 2019 ITP Application and FEIR included an additional analysis of expected changes in LFS abundance under PP, Alternative 2b and existing conditions scenarios described in Appendix E of the FEIR. This analysis is an update to the "Kimmerer regression" which modeled the log FMWT index for LFS as a function of mean X2 from January to June and different eras including the pre-clam (1967-1986) and post-clam (1987-2002) periods, assuming profound changes in the food web have caused the decline in LFS after the introduction of *P. amurensis* (Kimmerer et al. 2009). This analysis also included a post-POD era (2003-2014) as LFS abundance appeared to experience another step change in abundance (Thompson et al. 2010). Results from these models clearly demonstrated the strong effect of Delta outflow on LFS abundance as represented by spring-X2, a result similar to prior modelling efforts, but also identified the importance of eras as a factor influencing LFS abundance, the post-POD era experience greater than 10-fold decline from the pre-clam era (Appendix E of FEIR).

To assess the potential effect of the PP and Alternative 2b scenarios, two sets of analyses were undertaken in the FEIR, to account for different methods of X2 calculation. The first set of analyses used the X2 outputs from CalSim modeling (see FEIR Appendix C). For consistency with the ITP Application analysis, the second set of analyses was based on X2 estimated from CalSim-modeled Delta outflow and the previous month's X2, using a starting value of X2 = 80 km to initiate the calculations. Estimated effects were similar to those produced by the RN 2016 model analysis provided in Appendix E of the FEIR, thus we prefer the use of this model due to its lack of additional statistical problems noted above. Both models predict declines in abundance for LFS under Alt 2B, from 0-4% assuming different survival levels in the RN 2016 model or 1-12% using the updated Kimmerer model. Regardless of the issues with either model, the inherent signal to noise ratios (simulated variability), all model simulations demonstrated a reduction in the FMWT index for LFS under the PP and Alternative 2b as compared to existing conditions. Although, that reduction in the FMWT index was lesser in the Alternative 2b scenario as compared to the PP scenario.

6. Minimization of Take and Impacts of the Taking on Longfin Smelt

Section 4.1 describes the life history and ecology of LFS in the Delta, Suisun Marsh and Suisun Bay. Following the description of LFS life history and ecology, Section 5 describes the overlap between Project operations and LFS life history, explaining the ways in which Project operations result in take and impacts of the taking of LFS. This section builds upon the preceeding sections and explains how Conditions of Approval in the ITP are expected to minimize the take and impacts of the taking of LFS due to the Project.

6.1. Real-time Operations Management – Smelt Monitoring Team

The Smelt Monitoring Team will be composed of technical experts from CDFW, USFWS, DWR, SWRCB, and USBR. The team will compile and interpret the latest near real-time information regarding LFS, which can include catch patterns, developmental stage, distribution, salvage, current and projected operations, water conditions, and modelling results. During weekly meetings, the team will evaluate available information, discuss whether a protective action is warranted, and submit a recommendation on what protective actions should be taken. Additional meetings will be convened as appropriate or if required by any of the Conditions of Approval listed in the ITP. Collaborative real time risk assessment will minimize take of the larval, juvenile and adult life stages of LFS by informing and assessing minimization measures.

6.2. OMR Flexibility During Delta Excess Conditions

As described in the ITP Project Description, Permittee may increase exports to capture excess flows in the Delta (hereafter referred to as "OMR Flex") during the OMR Management period of January 1 through June 30[3]. Condition of Approval 8.7 describes specific hydrologic and species-specific restrictions limiting initiation of OMR Flex and imposing off ramps from OMR Flex operations. During OMR Flex operations, Condition of Approval 8.7 requires Permittee to maintain an OMR flow no more negative than -6,250 cfs on a 5-day average.

Permittee will continue to monitor fish in real-time and operate in accordance with additional real-time OMR restrictions described in Conditions of Approval 8.3.1, 8.3.3, 8.4.1, 8.4.2, 8.5.1, 8.5.2, 8.6.1, 8.6.2, 8.6.3, and 8.6.4, which include Conditions that trigger the onset of OMR Management (Integrated Early Winter Pulse Protection, Adult Longfin Smelt Entrainment Protection and Salmonid Presence) as well as

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[3] OMR Management may start earlier than January 1 if an Integrated Early Winter Pulse Protection action occurs during December (see Condition of Approval 8.3.1) or Adult Longfin Smelt Entrainment Protections (see Condition of Approval 8.3.3) are initiated after December 1. OMR Management may end earlier in June if specific off-ramps occur (see Condition of Approval 8.8).

other species protection measures such as Turbidity Bridge Avoidance, larval and juvenile DS and LFS protections, salmonid single-year loss thresholds, and salmonid daily loss thresholds.

The first four requirements for OMR Flex require elevated flows in the Sacramento River or San Joaquin River basins. Positive values of QWEST represent a net positive flow at Jersey Point, indicating a positive inflow westward to the Delta. Negative values of QWEST indicate greater potential for fish entrainment at the export facilities due to lower inflow into the Delta (R. Baxter pers. comm.). During wet periods, the San Joaquin River and eastern Delta tributaries (Mokelumne, Cosumnes, and Calaveras rivers) may provide sufficient flow to maintain a net positive flow in the lower San Joaquin River (i.e., positive QWEST) despite high exports at the SWP and CVP facilities. Such flows would tend to transport pelagic organisms in the main San Joaquin River channel toward Suisun Bay. By restricting OMR Flex only when there are elevated flows in the Delta, Condition of Approval 8.7 minimizes the risk of LFS of all lifestages to entrainment into the SWP export facilities and south Delta.

Additionally, per Condition of Approval 8.7, if during OMR Flex, any of the last four biological requirements are no longer being met, Permittee must off-ramp OMR Flex to provide protections to listed species by reducing exports to achieve an average OMR Index no more negative than -5,000 cfs on a 14-day average, unless further reduction in exports is required by a specific Condition of Approval. Off-ramp of OMR Flex operations, again driven by analyses and recommendations of the Salmon and Smelt Monitoring Teams, is essential to reducing take of listed smelt when real-time data indicate fish are present in the zone of entrainment and when salvage/loss data indicates fish are being entrained at the facilities.

Together, these eight requirements will minimize entrainment of LFS by only limiting OMR Flex operations to times when there is positive Delta inflow from both the Sacramento River and the San Joaquin River basins, there are no controlling Conditions of Approval[4], and the risk of entrainment is low based on risk assessments conducted by the Smelt Monitoring Team.

6.3. Adult Longfin Smelt

Adult LFS are most vulnerable to entrainment when they migrate upstream for spawning. The location of X2 approximately predicts the geographic location of migrating LFS and influences how far adults migrate into the Delta (CDFG 2009b). Entrainment may occur if mature LFS migrate directly into the entrainment area, or if negative OMR flows miscue spent adults causing them to swim deeper into the south Delta rather than downstream to Suisun Bay (CDFG 2009b). The following Conditions of Approval will avoid and minimize take of adult LFS by reducing the magnitude of reverse OMR flow when adults are at risk of entrainment based on monitoring or other pertinent factors.

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[4] Controlling Conditions of Approval include 8.3.1, 8.3.3, 8.4.1, 8.4.2, 8.5.1, 8.5.2, 8.6.1, 8.6.2, 8.6.3, and 8.6.4. These conditions includes all Conditions of Approval from 8.3-8.6 with the exception of Conditions of Approval 8.3.2 (Salmonid Presence), 8.4.3 (High Flow Off-ramp for Longfin Smelt OMR Restrictions), 8.6.5 (Funding for CHNSR Hatchery Surrogates), and 8.6.6 (Evaluate Proactive Salmon Entrainment Minimization During Real-time Operations).

6.3.1. Banks Pumping Plant and Clifton Court Forebay

The primary management mechanism to minimize direct take of adult LFS at the SWP is export reduction via OMR flow requirements in years where adult LFS are observed in salvage or as determined through risk assessments conducted by the Smelt Monitoring Team.

*Condition of Approval 8.3.1 - **Integrated Early Winter Pulse Protection***

The Integrated Early Winter Pulse Protection, as described in the ITP, will provide some minimization of take of adult LFS into the south Delta. As Discussed in Section 5.3, older LFS consistently migrate into the Delta from December through February of each year. When triggered, this Condition of Approval will limit OMR flows to no more negative than -2000 cfs for 14 consecutive days; this in turn will minimize entrainment of adult LFS as the magnitude of entrainment is negatively correlated with OMR flows (Grimaldo et al. 2009) as discussed in Section 5.3.1. The immediate onset of OMR management after an Integrated Early Winter Pulse Protection will also minimize take of LFS by limiting OMR to no more negative than -5000 cfs. The earlier in the season that an Integrated Early Winter Pulse Protection is initiated, the greater the benefit for LFS.

Condition of Approval 8.3.2 - Salmonid Presence

If Conditions of Approval 8.3.1 or 8.3.3 have not been initiated, this action will limit exports to achieve a 14-day average OMR Index of no more negative than -5,000 cfs after January 1 through the end of the OMR management season beginning when the Salmon Monitoring Team determines that 5% of CHNWR or CHNSR have entered the Delta, except during periods of OMR Flex. From November through April, migrating LFS can enter the Delta to spawn (Section 4.1.1.1 and Section 5.3 of this Effects Analysis, and CDFG 2009b). As discussed in Section 5.3.1, the magnitude of OMR is negatively correlated with smelt salvage at the SWP (CDFG 2009b; Grimaldo et al. 2009). Therefore, when this Condition of Approval controls Project operations it will reduce entrainment risk to adult LFS migrating into the Delta or adults present in the Delta.

Condition of Approval 8.4.1 - Adult LFS Entrainment Protection

Condition of Approval 8.4.1 restricts SWP exports to achieve an OMR no more negative than -5000 cfs in response to an adult LFS cumulative combined expanded salvage greater than the immediately previous FMWT index divided by 10. This Condition may trigger between December 1 to February 28 each year.

This same cumulative salvage trigger approach was carried over from the 2009 ITP. However, the 2009 salvage threshold is no longer appropriately protective for the species given substantial declines in LFS abundance (see Section 4.1 of this Effects Analysis). When the threshold in the 2009 ITP was first developed, the LFS population abundance was substantially higher than in the years following 2009, with a mean FMWT index of 1,743 from 1998-2008 compared to a mean index of 111 from 2009-2019. The probability of detecting individuals in the salvage process is not likely to decrease linearly with decreasing abundance, especially when abundance is below certain threshold, because the salvage process is a coarse subsampling of the total take of fish by the facility (Kimmerer 2008; Smith 2019).

Table 7: *Salvage threshold requirement of Condition of Approval 5.1 of the 2009 LFS ITP. Condition of Approval 5.1 was not triggered by observed salvage of adult LFS at the facilities.*

Water Year	Expanded Salvage	Previous FMWT	Salvage/FMWT Ratio	Triggered
2011	4	191	0.02	no
2012	8	477	0.03	no
2013	4	61	0.26	no
2014	4	164	0.12	no
2015	0	16	0.00	no
2016	0	4	0.00	no
2017	0	7	0.00	no
2018	0	141	0.00	no
2019	12	52	0.62	no

The 2009 ITP approach to minimize take of adult LFS in the 2009 ITP was updated to include the ability to initiate export restrictions and OMR limits to minimize take of LFS in response to a cumulative salvage threshold or advice provided by the Smelt Monitoring Team. Condition of Approval 8.3.3 may control operations between December 1 and February 28th each year.

LFS consistently begin migrating into the Delta by the beginning of December of each year, with migration peaking in the middle of December (see Section 5.3 of this Effects Analysis and Appendix A). An OMR limit of -5000 cfs was chosen because the magnitude of OMR flow is negatively correlated with adult LFS entrainment (CDFG 2009b; Grimaldo et al. 2009). Additionally, an OMR limit of -5000 cfs has been postulated to limit the zone of influence of the export facilities enough to allow LFS and DS to access potential spawning habitat in the main channels of the San Joaquin River (USFWS 2008). However, because LFS entrainment does still occur at -5000 cfs (Grimaldo et al. 2009), the Smelt Monitoring Team may recommend further restricting exports and limiting OMR flow to minimize the zone of entrainment and risk of take of LFS. This Condition of Approval off ramps before March 1st because the LFS spawning season generally ends by late February.

Condition of Approval 8.5.1 – Turbidity Bridge Avoidance

Condition of Approval 8.5.1 requires management of exports in order to maintain daily average turbidity at Bacon Island (OBI) less than 12 NTU. If turbidity cannot be maintained at less than 12 NTU after 5 days Permittee shall manage exports to achieve an OMR no more negative than -2,000 cfs until the daily average turbidity at Bacon Island drops below 12 NTU. However, if 5 consecutive days of -2,000 cfs OMR flows do not reduce daily average turbidity at Bacon Island below 12 NTU, the Smelt Monitoring Team may convene to assess the risk of entrainment of DS and provide a recommendation to WOMT regarding changes in operations that could be conducted to minimize the risk of entrainment of DS.

OMR flow is an indicator of the influence of export pumping at the export facilities on hydrodynamics in the south Delta. The management of OMR flow, in combination with other environmental variables, can minimize or avoid entrainment of fish in the south Delta and salvage facilities. Condition of Approval 8.5.1 has the potential to benefit adult LFS from February (potentially January) until April 1 if the turbidity criteria cannot be maintained and OMR flows are temporarily (until turbidity criteria are met) restricted to no more negative than -2,000 cfs. As discussed in Section 5.3 of this Effects Analysis, the magnitude of adult LFS salvage is negatively correlated to OMR flows. An increase in OMR flow will provide increased protection to adult LFS against entrainment into the south Delta. This Action will afford more protection for LFS the earlier it starts in the season.

Conditions of Approval 7.4, 7.4.1, 7.4.2 and 8.15 – Skinner Fish Salvage Facility Operations and Staff

Duties of the CDFW staff at the Skinner Fish Facility include, but are not limited to: receive daily salvage data from the fish facilities, conduct QA/QC on salvage data, train salvage facility staff, oversee salvage facility operations, work with DWR to develop a revised Salvage Facility Protocol, and engage in real-time decision making to determine whether reduced count times are appropriate. The salvage process at the Skinner Fish Facility generates one of the largest data sources characterizing entrainment and take of DS with a high amount of sampling effort. The duties performed by these staff will ensure proper identification of state and federally listed smelt species at the Skinner Fish Facility, which allows for an accurate calculation of loss which will trigger subsequent protections. These staff will also maintain consistency in operating to the established protocols to ensure generation of a robust dataset with QA/QCed data. This salvage data will be used in OMR Management to curtail exports during periods of high entrainment risk as identified by increased salvage. Together, these Conditions of Approval will serve to minimize take by facilitating implementation of Conditions of Approval that rely upon salvage data.

Conditions of Approval 7.6.1, 7.6.2 and 7.6.3 in combination with Condition of Approval 8.16 and the AMP – New Monitoring and Adaptive Management

Together, Conditions of Approval 7.6.1, 7.6.2 and 7.6.3, and 8.16 will support new monitoring and science to improve understanding of LFS entrainment risk as a result of Project operations and LFS ecology. These Conditions of Approval will contribute to our existing knowledge of LFS by requiring additional monitoring and science focused on improved understanding of LFS ecology and Project impacts:

- New larval monitoring to quantify entrainment risk and entrainment of larval DS and LFS into CCF

- Development of a mathematical LFS life cycle model
- New monitoring throughout the distribution of LFS in the Bay-Delta that addresses high priority topics
- Complete the LFS life cycle in captivity at the FFCL
- Characterize LFS spawning substrate and the distribution of spawning substrate in the Delta
- Improve understanding of adult and juvenile migration behavior

When implemented, this suite of monitoring and science will better inform understanding of take as a result of Project operations and methods to proactively minimize take. New science and monitoring will be synthesized and evaluated as a part of the AMP as described in Condition of Approval 8.16 and Attachment 2 to the ITP. Review and synthesis as a part of the AMP may result in recommendations regarding operational components of the ITP, and consequently Permittee may request an amendment of the ITP based on new information and science.

6.4. Larval Longfin Smelt

Larval LFS are most vulnerable to entrainment if hatching occurs within the zone of influence of pumping operations, and if conditions facilitate larval transport toward the central Delta and Banks Pumping Plant. LFS behave as passive particles until the development of an air bladder at 10-12 mm total length. Thus, larvae and young juveniles are likely dispersed via tidal currents and net flows. Managing negative OMR flows when larval LFS are within the hydrologic influence of the Banks Pumping Plant will minimize the amount of larval fish entrained into CCF.

6.4.1. Banks Pumping Plant and Clifton Court Forebay

The OMR flow criteria limit entrainment of larval LFS into CCF and the south Delta and increase the likelihood that LFS hatching in the lower San Joaquin River can successfully out-migrate. The rational for using OMR flow criteria is based on the Conditions of Approval included in the 2009 ITP (CDFG (2009b). Additionally, recent research has shown that OMR management has lowered adult and post larval entrainment mortality for DS (Smith 2019). OMR criteria described in this ITP are intended primarily to restrict operations and minimize the deleterious effects of changes in south Delta flows during Project operations, (i.e., reduce the magnitude of reverse flows in Old and Middle Rivers). Operating to maintain OMR within a range of target flow levels, from -1,250 cfs to -5,000cfs, minimizes direct take of larval LFS by applying an appropriate level of protection based on informed advice from the Smelt Monitoring Team. This advice will incorporate all relevant and available information including distribution data from field collections, abiotic factors such as water temperature, turbidity and forecasted hydrology as well as population trends and knowledge of LFS life history.

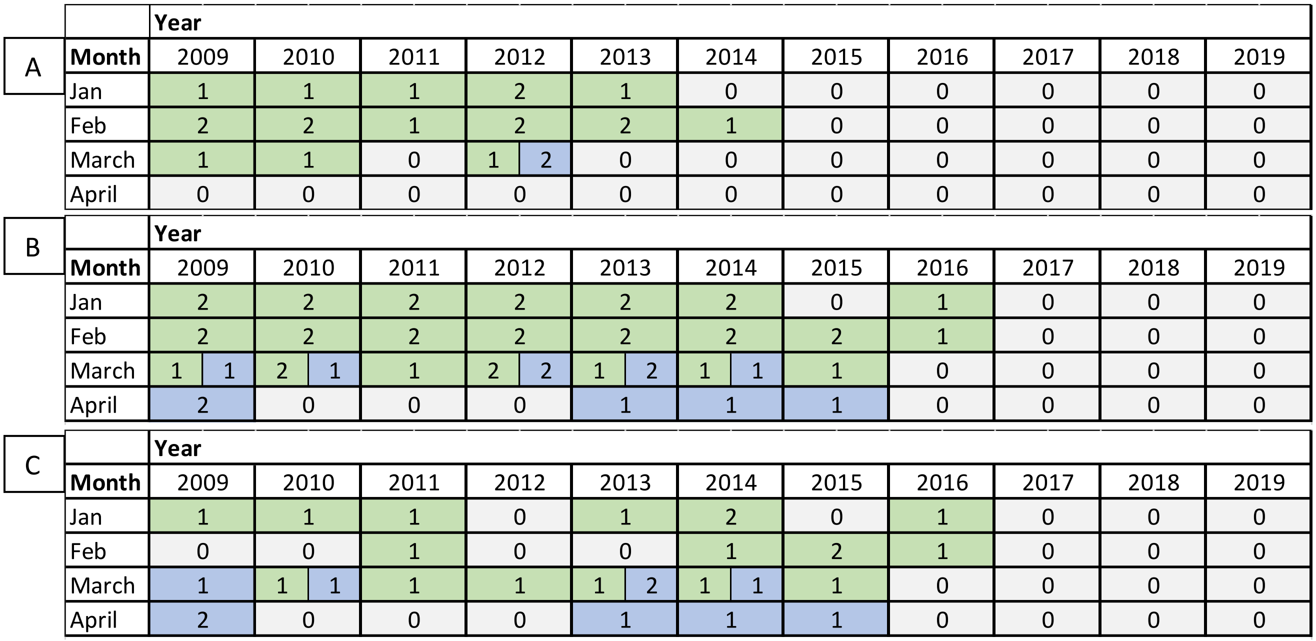
Condition of Approval 7.6.1 – Longfin Smelt December Larval Surveys

Beginning on November 1st of each water year, Condition of Approval 7.6.1 will provide CDFW staff on the Smelt Monitoring Team the ability to schedule at least one modified SLS survey for the period of December 1st through January 31st based on adult LFS detections in the Chipps Island Trawl. As discussed in Section 5.3 and Appendix A of this Effects Analysis, adult LFS catch at Chipps Island is an indicator of LFS migration into the Delta in the winter. Because it is assumed that spawning migrations are quick, a modified SLS survey in the month of December can provide CDFW staff on the Smelt Monitoring Team information related to larval LFS entrainment risk earlier in the season. CDFW staff on the Smelt Monitoring Team may make a recommendation to restrict operations and operate to an OMR flow target based on this information (see Section 6.1 above).

Conditions of Approval 8.4.2 – Larval and Juvenile Longfin Smelt Entrainment Protection

The same larval and juvenile LFS distribution and density approach was carried over from the 2009 ITP. However, the 2009 density and distribution thresholds are no longer appropriately protective for the species given substantial declines in LFS abundance (see Section 4.1 of this Effects Analysis). Condition of Approval 8.4.2 will minimize take as a result of entrainment of larval and juvenile LFS life stages into CCF and the south Delta by reducing the magnitude of reverse OMR flow when they are known to be present. These Conditions of Approval will control operations when larval recruitment in the interior Delta exceeds distribution or density criteria within the south Delta, or when hydrologic conditions are conducive to increased LFS entrainment risk into the region. Data collected by the SLS can provide some indication of entrainment risk when LFS larval abundances are high enough to be detected in the southern Delta. As a result, this condition will minimize take and impacts of the taking when newly hatched LFS could be vulnerable to entrainment within the region.

Table 8: *Comparison of larval and juvenile density criteria from CDFG (2009b) and those in Condition of Approval 8.4.2. Green cells indicate when SLS data (LFS larva) would meet the criteria, blue cells indicate when 20 mm (LFS juveniles) would meet the criteria. The number within the cell represents the number of times the criteria was met for each table. (A) represents criteria from CDFG 2009b, (B) represents criteria in Condition of Approval 8.4.2. and (C) represents the increase between (A) and (B).*



A

	Year										
Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan	1	1	1	2	1	0	0	0	0	0	0
Feb	2	2	1	2	2	1	0	0	0	0	0
March	1	1	0	1 2	0	0	0	0	0	0	0
April	0	0	0	0	0	0	0	0	0	0	0

B

	Year										
Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan	2	2	2	2	2	2	0	1	0	0	0
Feb	2	2	2	2	2	2	2	1	0	0	0
March	1 1	2 1	1	2 2	1 2	1 1	1	0	0	0	0
April	2	0	0	0	1	1	1	0	0	0	0

C

	Year										
Month	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019
Jan	1	1	1	0	1	2	0	1	0	0	0
Feb	0	0	1	0	0	1	2	1	0	0	0
March	1	1 1	1	1	1 2	1 1	1	0	0	0	0
April	2	0	0	0	1	1	1	0	0	0	0

6.4.2. Barker Slough Pumping Plant

BSPP is operated year-round, including times when LFS larvae may be present and susceptible to entrainment. The diversion is located in or near LFS spawning habitat in the north Delta. Per screening criteria required by CDFW, each of the ten BSPP bays is individually screened with a positive barrier fish screen consisting of a series of flat, stainless steel, wedge-wire panels with a slot width of 3/32 inch. This configuration is designed to exclude fish approximately 25 mm or larger from being entrained. The bays tied to the two smaller units have an approach velocity of about 0.2 ft/s. The larger units were designed for a 0.5 ft/s approach velocity, but actual approach velocity is about 0.44 ft/s.

Condition of Approval 8.12 – Barker Slough Pumping Plant Longfin and Delta Smelt Protection

By design, the BSPP fish screens are considered sufficiently protective for older juvenile LFS (FL ≥ 25mm), however, operational restrictions are needed to protect younger LFS juveniles and larvae. Although positive barrier fish screens similar to those in Barker Slough have been shown to exclude larval fishes smaller than their design criteria (Nobriga et al. 2004), their effectiveness has not been evaluated when placed at the back of a dead-end slough like the Barker Slough screens. Export restrictions for BSPP during dry and critical years will minimize take of larval and young juvenile LFS by curtailing exports when they are known or expected to be present based on detection in sampling or pertinent abiotic and biotic factors. LFS are exposed to greater risk of entrainment at Barker Slough during dry and critical years due to their proximity to low salinity habitat at multiple life stages. LFS stage in low salinity habitat prior making brief runs into fresh or brackish water to spawn. They utilize the Cache Slough region for spawning more in low outflow years (CDFG 2009b) and the resulting young of year are distributed further upstream when X2 is upstream (Dege & Brown 2004). The fate of newly emerged larvae is strongly influenced by hydrology, putting those that hatch near the BSPP at high risk of entrainment.

6.5. Juvenile Longfin Smelt

Juvenile LFS are most vulnerable to entrainment if hatched larvae are retained in the south and central Delta long enough to grow (CDFG 2009b). As temperatures increase, juveniles will attempt to migrate downstream to avoid lethal temperatures. Increased entrainment may occur if high OMR flows miscue these fish into swimming deeper into the south Delta rather than to Suisun Bay (CDFG 2009b).

6.5.1. Banks Pumping Plant and Clifton Court Forebay

OMR flow criteria limit the magnitude of reverse flows in the Old and Middle Rivers to minimize entrainment of larval and DS into CCF and the south Delta and increase the likelihood that LFS hatching in the lower San Joaquin River can successfully out migrate (CDFW 2009b). OMR flow criteria required by Conditions of Approval in this ITP are intended to restrict exports and reduce the magnitude of reverse flows in Old and Middle Rivers. Operating OMR to a range of target flow levels, from -1,250 cfs to -5,000cfs, minimizes direct take of larval LFS by applying an appropriate level of protection based on informed advice from the Smelt Monitoring Team. This advice will incorporate all relevant and available information including distribution data from field collections, abiotic factors such as water temperature, turbidity and forecasted hydrology as well as population trends and knowledge of life history.

Condition of Approval 8.4.2 - Larval and Juvenile Longfin Smelt Entrainment Protection

The larval and juvenile LFS distribution and density thresholds will minimize loss as a result of entrainment of these life stages into CCF and the south Delta by reducing the magnitude of reverse OMR flows when individuals are known to be present. This Condition of Approval will only control operations when larval recruitment in the interior Delta results in conditions such that SLS surveys detect larvae or juveniles at a subset of the south and central Delta stations, or when hydrologic conditions are conducive to increased entrainment risk into the region as determined by the Smelt Monitoring Team. When the thresholds included in Condition of Approval 8.4.2 were compared to historical SLS and 20 mm survey data, they were met more often by data collected by the 20-mm survey (Table 8), which occurs later in the season, indicating that the protections are more likely to go into effect when a higher proportion of newly recruited LFS are in the juvenile stage and vulnerable to entrainment.

6.6. Spring Outflow

Given the concerns we discussed above in Section 5.5 regarding the NR 2016 analysis, we rely upon the "Kimmerer regression" approach provided in Appendix E of the FEIR to describe take of LFS as a result of the relationship between Project operations and Delta outflow. However, we acknowledge the uncertainty in these predictions given the inherent noise (variability) in the LFS abundance-flow relationship since the POD. Providing additional spring outflow through Condition of Approval 8.17 (and as modeled under the Alternative 2b scenario) reduces potential impacts on LFS as compared to the PP scenario which does not include Condition of Approval 8.17. A large body of research and peer-reviewed publications indicate increased spring outflow will result in a higher LFS abundance index and, conversely, that decreased spring outflow will result in a lower LFS abundance index. Because SWP exports have the effect of reducing outflow, including during the spring, Condition of Approval 8.17 is a key measure to minimize the Project's impacts to LFS in the form of population abundance reductions. Additionally, the relationship between LFS abundance and spring outflow will be evaluated through the Longfin Smelt Science Program and the Adaptive Management Program in conjunction with a new LFS life cycle model to measure the benefits of spring flow on LFS growth, condition and health metrics that can be associated with greater survival probability.

6.7. End of OMR Management: Salmon and Smelt Temperature Off-ramps

The discussion in Section 8.5 of this Effects Analysis discusses how Condition of Approval 8.8 ensures minimization of juvenile LFS entrainment into the SWP export facilities and south Delta until they exit the Delta due to increasing water temperatures.

6.8. Additional Measures

Additional measures are those which are intended to avoid and minimize take and impacts of the taking to a covered species other than LFS but may provide ancillary protections to LFS when implemented. The following describes these additional measures and how they provide additional avoidance and minimization for LFS.

Condition of Approval 8.6.1 – Winter-run Single-Year Loss Threshold

This Condition of Approval will limit exports to maintain a 14-day average OMR Index of no more negative than -3,500 or -2,500 cfs for at least 14 days. Exports will be restricted once annual loss of natural or hatchery CHNWR exceeds 50% or 75% of their respective calculated annual loss threshold and ends when OMR management ends, or when agreed upon by WOMT based on risk assessment advice from the Salmon Monitoring Team. From November through April, migrating LFS can enter the Delta to spawn ; similarly, adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts both species at risk of entrainment at the Project south Delta export facility. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species

(CDFG 2009b; Grimaldo et al. 2009; USFWS 2008). Therefore, when this Condition of Approval controls operations of the Project it will reduce entrainment risk to both adult LFS and adult DS migrating into the Delta or adults present in the Delta. This action provides greater minimization for LFS and DS when it controls Project operations earlier in each species migration and spawning period and provides less minimization later in each species migration period.

Condition of Approval 8.6.2 - Early-season Natural Winter-run Salmon Discrete Daily Loss Threshold

This Condition of Approval will limit exports to achieve an average OMR Index of no more negative than -5000 cfs for five consecutive days. Exports will be restricted for five consecutive days once daily loss of natural-origin Chinook salmon identified as CHNWR based on LAD exceeds daily loss thresholds from November 1 through December 31. From November through April, migrating LFS can enter the Delta to spawn ; similarly, adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts both species at risk of entrainment into the SWP south Delta export facility. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species (CDFG 2009b; Grimaldo et al. 2009; USFWS 2008). Therefore, this action will reduce entrainment risk to both migrating LFS and adult DS migrating into or are present in the Delta when it controls Project operations.

Condition of Approval 8.6.3 – Mid and Late-season Winter-run Chinook Salmon Daily Loss Threshold

This Condition of Approval will limit exports to achieve an average OMR Index of no more negative than -3,500 cfs for five consecutive days. Exports will be restricted for five consecutive days once daily loss of natural-origin Chinook salmon identified as CHNWR based on LAD exceeds the daily loss threshold for that month from January 1 through May 31. From November through April, migrating LFS can enter the Delta to spawn; similarly, adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts both species at risk of entrainment at the SWP south Delta export facilities. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species (CDFG 2009b; Grimaldo et al. 2009; USFWS 2008; USFWS 2009). Therefore, this action will reduce entrainment risk to both adult LFS and adult DS migrating into or present in the Delta when controlling Project operations.

Conditions of Approval 8.6.4 and 8.6.5 - Daily Spring-run Chinook Salmon Hatchery Surrogate Loss Threshold and Funding for Spring-run Hatchery Surrogates

These Conditions of Approval will limit exports to achieve an average OMR Index of no more negative than -3,500 cfs for five consecutive days. Exports will be restricted for five consecutive days once cumulative loss of any spring-run surrogate release groups exceeds 0.25%, effective from February 1 through June 30. From November through April, migrating LFS can enter the Delta to spawn ; similarly, adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts both species at risk of entrainment at the SWP. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species (CDFG 2009b; Grimaldo et al. 2009; USFWS 2008). Therefore, this action will reduce entrainment risk to both adult LFS and adult DS migrating into or present in the Delta when controlling Project operations.

7. Take and Impacts of the Taking on Delta Smelt

7.1. Larval Delta smelt

Larval DS typically begin hatching as early as March and are present in the Delta through June (Figure 24, Table 9). The distribution of larvae is assumed to be a function of hatching location and local hydrology which facilitates their movement immediately post-hatch. Newly hatched larvae are surface oriented for a short period after hatching and then likely bottom-oriented when not feeding (Baskerville-Bridges et al. 2004b; Bennett 2005). They are likely inefficient at using a vertical-migration retention strategy until they develop an air bladder (Bennet et al. 2002) which occurs between 14 and 20 mm (Bennett 2005). During this time, larval DS remain susceptible to transport from tidal flows or net flows from inflows and exports (Figure 25). For these reasons, larvae that hatch within or near the hydrodynamic influence of the SWP and CVP export facilities are at risk of entrainment into both facilities. Since the SWP began operating in 1968, south Delta exports during the spring tend to be high enough to cause net flows in Old and Middle rivers to be negative, drawing water through the interior Delta towards the SWP and CVP export facilities (Figure 26). Historically, larvae (i.e., fish less than 20 mm in length) were not identified or counted at either fish salvage facility, but in 2008 larval smelt were identified and reported as present when encountered (Morinaka 2013a). Even though the fish facilities were not designed to salvage larvae, smelt larvae have been regularly detected since the inception of protocols aimed at such detections (see Table 4 in Section 5.1).

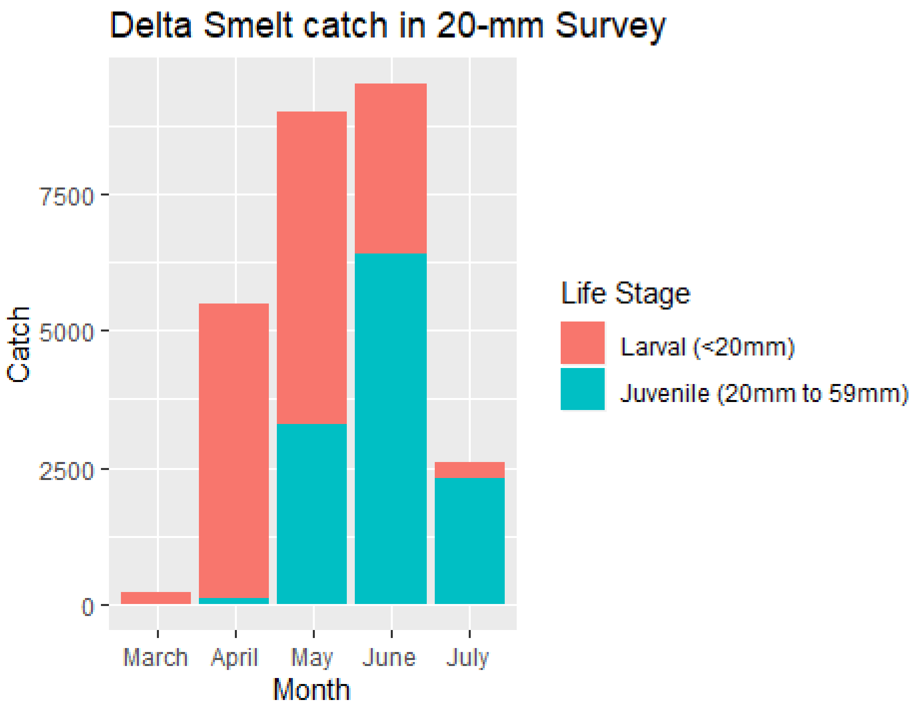


Figure 24: *Total catch per month of DS from the 20-mm Survey, 1995-2019.*

Table 9: *Catch of DS larvae by length (mm) and month of capture in the Smelt Larva Survey, 2009-2019. No larvae larger than 11 mm have been detected by the Smelt Larva Survey.*

		Month		
Length	January	February	March	Grand Total
5	0	0	90	90
6	0	0	238	238
7	0	0	88	88
8	0	0	10	10
9	0	0	2	2
10	0	0	2	2
11	0	0	1	1
Grand Total	0	0	431	431

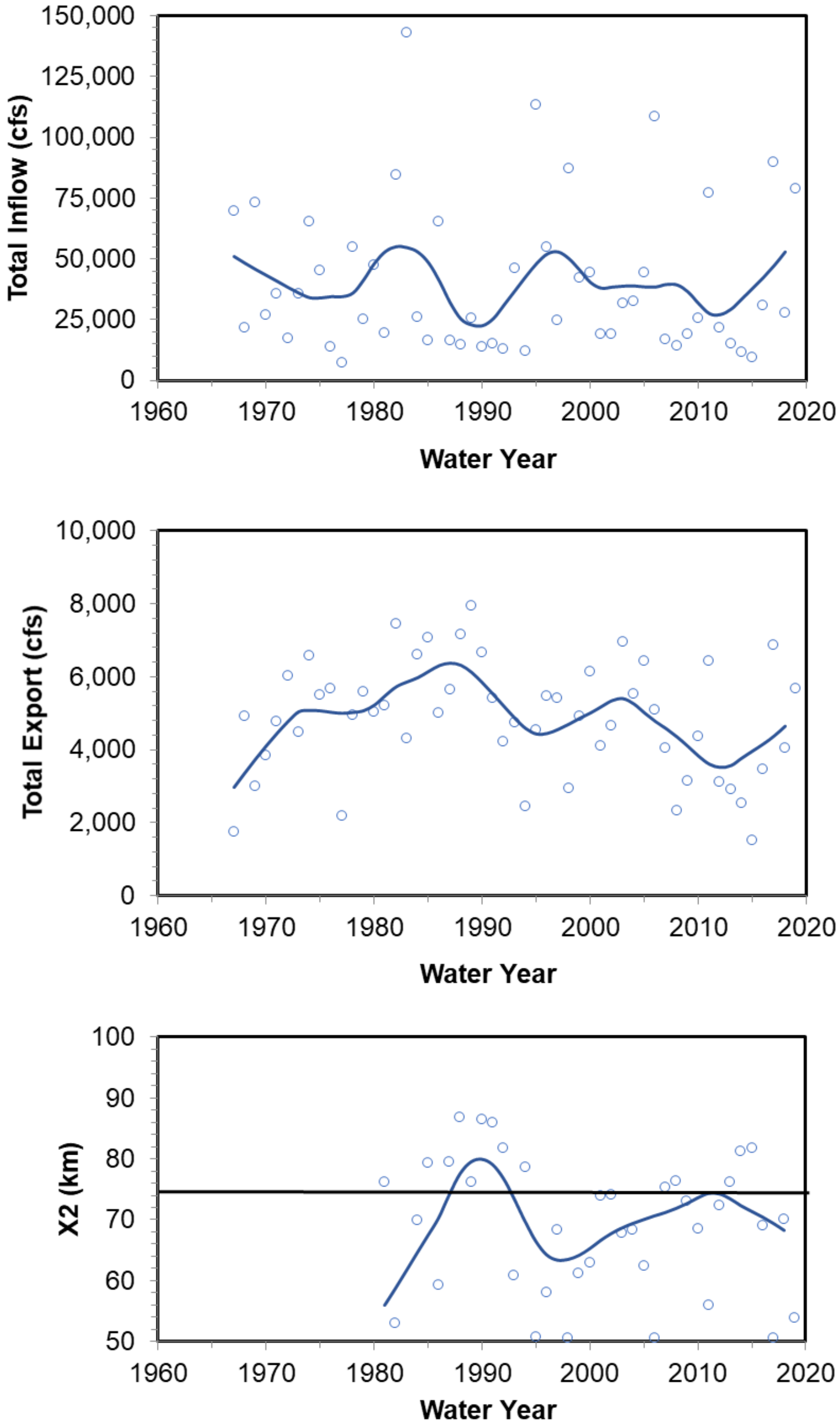


Figure 25: *Mean monthly spring (March - June) Delta inflow (top), total State Water Project and Central Valley Project exports (middle) and X2 location in km (bottom) from 1967 through 2019 (top and bottom) and 1981 through 2019 (middle). Loess smoother line shown but not used in an analysis*

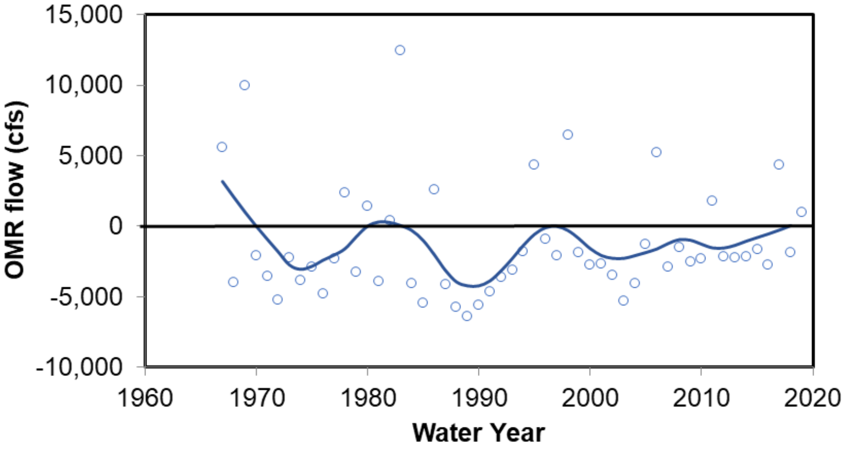


Figure 26: *Mean monthly spring (March - June) Old and Middle River (OMR) flows from 1967 through 2019. Dashed line at -5000 cfs included for reference. Loess smoother line shown but not used in an analysis*

7.1.1. Banks Pumping Plant and Clifton Court Forebay

Take of DS larvae in the form of mortality will occur as a result of operations of the SWP south Delta export facilities. The areas where authorized take of DS is expected to occur include CCF and Banks Pumping Plant located about 12.9 km northwest of the city of Tracy. Operations of the CCF and Banks Pumping Plant will result in take of all life stages of DS except eggs. Hatching typically begins in March and can last through June, with most larvae transitioning to the juvenile stage (≥ 17 mm) by July (Figure 24, Table 9). Small larvae (5-9 mm) in the wild appear to spend minimal time in the water column and are poorly represented in fish survey sampling (Figure 24, Table 9). For this reason, DS larvae may be slower to transport toward the export pumps than LFS larvae or DS juveniles. Recently hatched DS larvae are rarely detected in the south Delta, but are more common in the San Joaquin River channel, where they are still at risk of entrainment (Table 10 in Section 5.1.1). Since both the CVP and SWP fish salvage facilities implemented sampling for larval smelt presence beginning in 2008, DS larvae were annually detected in salvage at one or both facilities up until 2015, even with export restrictions promulgated by the 2008 and 2009 BiOps; zero detections have occurred since 2015 (see Table 4 in Section 5.1). Similar to LFS larvae, DS larvae likely benefit from increased outflow during the larval period, which can transport them toward Suisun Bay, reducing entrainment in the south Delta (see discussion below and in Section 5.1).

Table 10: *Frequency of newly hatched DS yolk-sac larvae collected by survey station and year in the Delta by the Smelt Larva Survey, 2011-2019 (i.e., years when yolk-sac presence was noted). No yolk-sac larvae were collected in Suisun Marsh. All in-Delta yolk-sac larvae were collected in March surveys (last surveys of the year), though presence of 9-11 mm larvae in March indicates some hatching in February. No larvae were collected from the stations shown below in 2017.*

				Year						
Sampling Regions	Sampling Station	2011	2012	2013	2014	2015	2016	2018	2019	Grand Total
	703		11					3		14
	704		13	4			1			18
Sacramento River	705		4	20	1					25
	706		15		1		3	1		20
	707		13	2	1				1	17
	716		20	9	1	1				31
near Barker Slough	723	2	9	19	4					34
	801		9	2	1			1		13
	804		2							2
	809		6		1			1		8
San Joaquin River	812		7	8						15
	815		4	1						5
	906		2				1			3
Mokelumne River	919		2							2
	901		2							2
South Delta	902			1						1
	Grand Total	2	119	66	10	1	5	6	1	210

As mentioned above, salvage data for DS < 20 mm is sparse because 20 mm is the threshold for identification and enumeration at the SWP and CVP fish facilities. This absence of quantitative sampling led to use of PTM to investigate the risks of entrainment under varying hydrological conditions. Previous efforts to model larval entrainment as a result of SWP export operations using PTM showed that negative OMR flows will entrain both neutrally buoyant, and surface-oriented particles which mimic different larval fish species, and that in certain years, particle entrainment can be high (>50% of particles injected) (CDFG 2009b; Kimmerer and Nobriga 2008). Both Grimaldo et al. (2009) and Smith (2019) demonstrated that intra-annual salvage of older and slightly larger DS juveniles (> 20 mm) was best explained by the magnitude of negative OMR flow, turbidity and 20-mm Survey abundance. Essentially, juvenile DS salvage increases with more negative OMR, higher turbidities in the south Delta, and juvenile abundance is high.

During wet periods, the San Joaquin River and eastern Delta tributaries (Mokelumne, Cosumnes, and Calaveras Rivers) may provide enough flow to generate positive OMR flows despite SWP and CVP exports (cf. data for 2011, 2017 and 2019 in Figure 25 and Figure 26). Such conditions of positive OMR flows would tend to transport larval DS downstream out of the northern portion of south Delta, the central Delta and toward Suisun Bay reducing or eliminating their risk of entrainment. Such conditions also result in strong, net positive flows in the lower San Joaquin River (i.e., positive QWEST), which also tends to transport pelagic organisms in the main stem San Joaquin River channel toward Suisun Bay (CDFG 2009b). Under such high outflow conditions, any larvae in the immediate vicinity of CCF will likely remain at great risk of entrainment. However, because of high flows entering the Delta from the south and east satisfy export needs, OMR flows are necessarily less negative from the north (e.g., mean monthly March-June total exports and OMR: 2011 exports = 6,430 cfs, OMR = +1,804; 2017 exports = 6,881, OMR = + 4,304; 2019 exports = 5,680, OMR = +953; Figure 25 and Figure 26) and the area influenced by exports is substantially reduced, which can be inferred by the varying effect on OMR. Thus, DS that are not in the immediate vicinity of CCF under these very high outflow and positive OMR conditions are at a reduced risk of entrainment.

Newly hatched DS present in the south Delta (Table 10) are at high risk of entrainment at all but the lowest export levels (Kimmerer and Nobriga 2008). Larvae entrained into CCF are assumed lost to the population because they cannot volitionally leave CCF once inside, and equally small fish are very inefficiently diverted from exported flow and salvaged (Brown et al. 1996). Finally, fish < 20 mm that happen to get salvaged are not likely to survive the process of collection, handling, transport and release (Aasen 2013; Afentoulis et al. 2013; Bennett 2005; Morinaka 2013b).

In addition to direct forms of take identified above, operations of the SWP also result in indirect impacts to DS larvae. These impacts include increased vulnerability to predation within CCF and the south Delta similar to larger DS and other fishes (Castillo et al. 2012; Grossman 2016)(Castillo et al. 2012, Grossman 2016); reduced residence times and direct entrainment of food web resources (Arthur et al. 1996; Hammock et al. 2019; Kimmerer et al. 2019) are believed to reduce feeding opportunities within the south Delta; and habitat suitability of the south Delta has declined for DS, at least later in the summer (Nobriga et al. 2008 and see citations and discussion in Section 5.1).

7.1.2. Barker Slough Pumping Plant

The BSPP is within the range of DS spawning and early rearing habitat (Table 10) and previous PTM runs have shown strong potential for entrainment as winter wanes into spring and north Delta exports increase (CDFG 2009b). Incidental take of larval DS in the form of entrainment and impingement resulting in mortality may occur as a result of operations of the BSPP. Although the BSPP possesses a fish screen, it is not designed to be protective of fish < 25 mm though it may be in actual application (Nobriga et al. 2004; CDFG 2009b). The facility is located at the upper end of a dead-end slough where weakly swimming larvae can be drawn toward the screens to be entrained or impinged unless they grow to sufficient size to avoid weak entrainment flows. The configuration of the channel and screens does not allow net or tidal currents to sweep larvae past the screens, reducing entrainment.

The area where take of larval DS is expected to occur is approximately 16 km from the mainstem Sacramento River at the upper end of Barker Slough. The BSPP has the capacity to export 175 cfs through a screened diversion. This diversion is operated year-round, except for a brief maintenance period which typically occurs in March. Recently, exports tended to be relatively low during winter and early spring, though they increase through spring (CDFG 2009b, Figure 29) when DS larvae densities are increasing in the Delta (Figure 24). A review of PTM run results showed that entrainment of surface-oriented particles was nonlinearly related to average pumping rate and that the proportion of particles injected at station 716 (located in Cache Slough just north of the Lindsey Slough confluence) and subsequently entrained ranged from 1.5% to 37% (CDFG 2009b). The proportion of particles entrained increased through the spring coincident with particle entrainment in agricultural diversions (CDFG 2009b, Figures 13-15). Projected export increases at BSPP are expected to lead to 100% entrainment of the particles injected at Station 716 when combined with agricultural exports, because historical diversions at lower export rates came close to entraining 100% of injected particles (CDFG 2009b). Thus, substantial entrainment is expected for DS larvae hatching in the north Delta during April and May, resulting in further degradation of DS rearing habitat in Barker Slough, Lindsay Slough and its vicinity in the north Delta.

Incidental take may also occur as a result of maintenance of BSPP facilities and adjoining waterways. Any eggs deposited on or in the immediate vicinity of the concrete apron at the fish screen will be taken during suction dredging conducted for sediment removal if conducted during the late February through May egg incubation period. Moreover, larvae that hatch from eggs deposited in the immediate vicinity of the concrete apron are likely to be entrained or impinged during normal operations due to the planktonic nature of DS larvae and their weak swimming ability. Any larvae hatching within the immediate vicinity of the fish screen, or within the embayment immediately in front of the fish screen are assumed to be lost to the population due to entrainment or lethal impingement as a result of exports at the BSPP. As a result, any additional disturbance caused by clearing the fish screen of debris or vegetation would not result in additional take.

Take and impacts of the taking as a result of aquatic vegetation removal are unknown at this time and will depend upon when the work occurs and the size and scope of the removal effort. Work in the approximate time frame of July 1 through October 31 will have a reduced impact on DS because the species should be fully mobile and able to avoid effected areas. Chemical and physical methods of vegetation control are both expected to result in direct mortality and take, if larvae are present (March through June). Moreover, negative effects might increase if BSPP exports increase just prior to this period and draw more larvae into Barker Slough or retain more larvae in the affected area.

7.1.3. Suisun Marsh Facilities

Physical facilities in the Suisun Marsh and Bay include the SMSCG, the RRDS, the MIDS and the GYSO. Additional facility details are provided in the ITP Project Description, Section 3.1.3.5 of the FEIR, and in Section 5.1.3 of this Effects Analysis.

Suisun Marsh Salinity Control Gates

A description of the location, composition and effects of operation of the SMSCG is provided in Section 5.1.3. The SMSCG have the potential to cause short-term increases in residence time in the winter and early spring during operation. Potential increases in larval residence time in Montezuma Slough could be beneficial or detrimental depending upon circumstances. Increased residence time for water and larvae could allow for coincidental food production and improved foraging and fish development. Faster development, in turn, could lead to more rapid improvement in salinity tolerance and swimming ability.

Conversely, increased residence time could position some larvae near the RRDS intakes just west of the control gates and increase entrainment into the RRDS.

Roaring River Distribution System

The RRDS begins at Montezuma Slough just west of the SMSCG and runs westward through Grizzly Island to Grizzly Bay. Water is diverted from Montezuma Slough on high tides into the RRDS through a bank of eight 1.5 m diameter culverts equipped with fish screens that empty into a 40-acre intake pond raising its water surface elevation above that of adjacent managed wetlands. The pond helps control water levels in the slough running through Grizzly Island to near Grizzly Bay used to deliver water to managed wetlands north and south of the system.

The RRDS intakes are screened and physically exclude fish > 25 mm in length. These screens provide some benefit for avoiding entrainment of larval fish: similar screens showed benefit to fish <25 mm (Nobriga et al. 2004). RRDS can result in take of individuals via passage through the screen and subsequent diversion onto managed wetlands where bird predation or water temperatures would likely be lethal. However, risk of entrainment of larval DS at RRDS remains unquantified.

Morrow Island Distribution System

The MIDS consists of three 1.2 m culverts without fish screens that divert water from Goodyear Slough through a distribution channel bisecting Morrow Island and discharge into Suisun Slough and Grizzly Bay. MIDS is used year-round, but most intensively from September through June. Thus, operations could entrain larval DS. Enos et al. (2007) documented adult DS within MIDS between 2004-2006. Presence of DS larvae in Cordelia Slough (Meng and Matern 2001) suggest that adults remained nearby spawned and that larvae reared in the area. Culberson et al. (2004) used the PTM DSM2 to show that proximity to the MIDS diversion was the primary factor influencing entrainment risk and that risk of entrainment was very low for particles injected outside the immediate vicinity. Thus, risk of entrainment of larvae is high in Goodyear Slough and only somewhat less so in Cordelia Slough.

Good Year Slough Outfall

The GYSO, constructed in 1979-1980, connects the upper (south) end of Goodyear Slough to Suisun Bay to improve circulation in the previously dead-end slough. It’s run year-round. The outfall consists of four 1.2 m diameter culverts with flap gates on the Bay side and vertical slide gates on the slough side. When the slide gates are open only trash racks obstruct entry into and out of the system. Fish are believed to be able to enter and leave the system at will.

High rates of diversion from and drainage back into in Goodyear Slough have periodically created extremely low dissolved oxygen concentrations and fish kills even with the GYSO system in place (O’Rear and Moyle 2010). Similar to what was described in USFWS (2019), the intakes and outfall of GYSO are unscreened and may entrain larval DS. Larval fish that enter the system would be able to potentially leave via the intake or the outfall, as GYSO is an open system, assuming that mortality does not occur during the entrainment process or within the system.

7.1.4. Agricultural Barriers

Similar to what is described for in USFWS (2019), the TBP has occurred almost annually since 1991. A major component of the TBP, the Head of Old River Barrier (HORB) is a temporary structure installed seasonally between September 15 and November 30 at the divergence of Old River from the San Joaquin River but is not included in the Project. The HORB and other south Delta barriers do not alter total Delta outflow, or the position of X2 (USFWS 2008). However, the TBP causes changes in the hydraulics of the Delta, which may affect DS in spring. These increased channel flows can increase risk of entrainment for particles injected in the east and central Delta by up to about 10 percent (Kimmerer and Nobriga 2008)Reclamation 2008). In years with substantial numbers of larval DS in the central Delta, increases in negative OMR flow caused by installation of the SDTBs can increase entrainment. Installation of barriers in fall does not affect DS because it does not use the central and south Delta as habitat during the September 15 to November 30 installation period (see Nobriga et al. 2008).

7.2. Juvenile Delta Smelt

For the purposes of this Effects Analysis, juvenile DS are defined as those > 19 mm FL as this length typically coincides with the full development of the fins and air bladder (Mager et al. 2004). At this stage, juvenile DS are fully competent to use vertical migration to maintain or change their position in the estuary (Bennett et al. 2002, Bennett 2005). This life stage typically occurs within the Delta as early as April and almost all have transitioned to the juvenile stage by July (Figure 24). Juveniles ≥ 20 mm begin to appear in salvage by mid-April in most years and continue into July (Figure 27). As Delta water temperatures approach and exceed 25°C, juvenile DS will generally move downstream into low salinity habitats where they will continue to grow and rear until they return to the Delta as adults (Baxter 1999; Bush 2017b; Dege and Brown 2004; Hobbs et al. 2019a). Due to high temperatures and other factors, the central and south Delta no longer provide habitat for juvenile DS in the late summer and fall (Nobriga et al. 2008). For this reason, the following analysis will focus on the April through July period when most larval DS have transformed to juveniles and a short rearing period occurs before their emigration from the central and south Delta to downstream habitats.

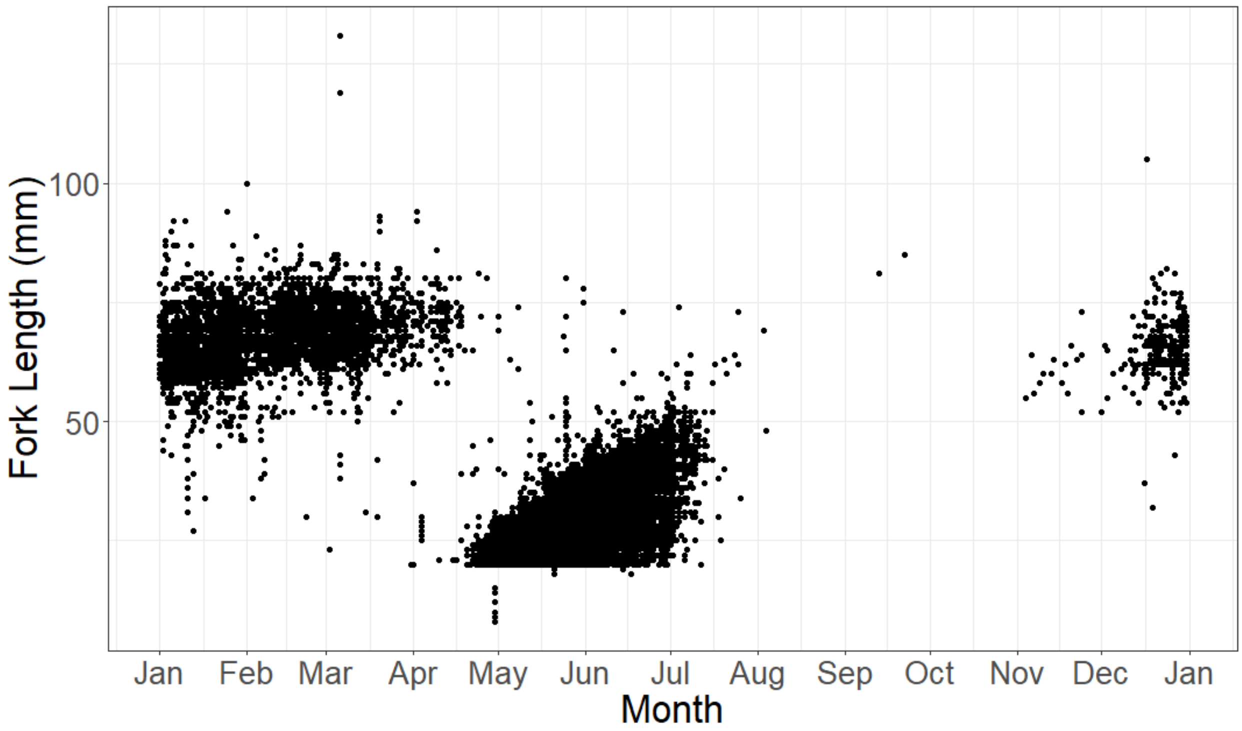


Figure 27*: Scatterplot of salvaged DS by fork length and calendar day for the years 1993 - 2018.*

7.2.1. Banks Pumping Plant and Clifton Court Forebay

Take of DS juveniles in the form of direct mortality or loss to the system will occur as a result of operations of the south Delta export facilities. The areas where authorized take of DS is expected to occur include CCF and Banks Pumping Plant located about 13 km northwest of the city of Tracy. Operations of the CCF and Banks Pumping Plant will result in take of juveniles. Entrainment of juvenile DS (> 19 mm FL) may begin as early as March, however, fish are not identified nor enumerated in salvage counts until they are ≥ 20 mm FL. Salvage data shows that fish > 20 mm are observed from mid-April through July in most years (Figure 27).

During March through June, inflow and exports typically decline from winter levels, while X2 shifts higher in the system (Figure 5 and Figure 6). The inflow and exports varied from 2,000 – 8,000 cfs and inflow was typically less than 25,000 cfs after 2011, but has increased in the past 4 years; the X2 trend was inverse (Figure 25). OMR flows are frequently negative during this time period, over the past 20 years, but after 2008 tended to be less negative than in previous years of low outflow (Figure 26). Nonetheless, continued negative spring OMR flows draw water and potentially juvenile DS through the interior Delta towards the SWP and CVP pumping plants (Figure 26). Entrainment of early stage juvenile DS is likely similar to that of larvae described previously. Efforts to model larval entrainment resulting from SWP operations showed that negative OMR flows will entrain particles, and in certain years particle entrainment can be high (>50% of particles injected as some sites) (CDFG 2009b; Kimmerer and

Nobriga 2008). Hydrologic effects on larvae after hatching further influence their distribution and influence the initial distribution of juveniles. However, these early stage juveniles may have improved buoyancy and swimming capabilities compared to younger larvae (Bennet et al. 2002) and are likely to be slightly more resistant to entrainment by negative OMR.

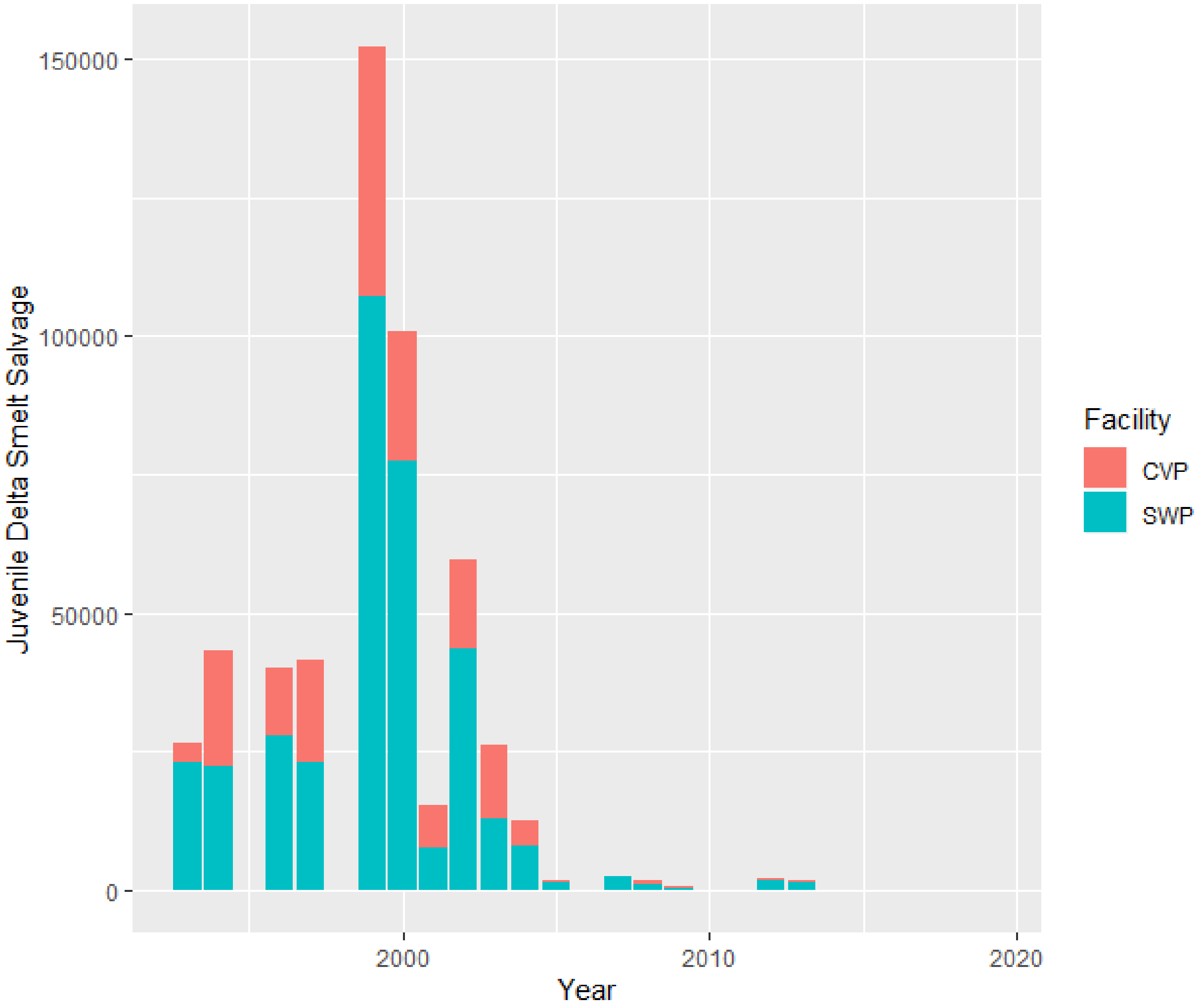


Figure 28: *Barplot of expanded juvenile DS salvage at the SWP and CVP from 1993-2019.*

Salvage of juvenile DS at an intra-annual scale was best explained by negative OMR flows, turbidity and abundance in the 20-mm Survey (Grimaldo et al. 2009). During wet periods, the San Joaquin River and flows coming from eastern Delta tributaries (Mokelumne, Cosumnes, and Calaveras Rivers) may provide enough flow to generate positive OMR flows despite SWP and CVP exports (cf. data for 2011, 2017 and 2019 in Figure 25 and Figure 26). Such conditions of positive OMR flows would tend to transport juvenile DS downstream out of the northern portion of south Delta, the central Delta and toward Suisun Bay, reducing or eliminating their risk of entrainment. Under such high outflow conditions, any juveniles in the immediate vicinity of CCF would still remain at risk of entrainment. However, the area influenced by exports would be substantially reduced (i.e., locations where OMR flows are measured show net positive currents: Figure 26, years 2011, 2017 and 2019), even when exports continue at a high level

(Figure 25 for years 2011,2017 and 2019). As a result, in the absence of high flows from the south and east, juvenile DS present in the south Delta are at high risk of entrainment in all but the lowest export levels (Kimmerer and Nobriga 2008).

Juveniles entrained into CCF are assumed to be lost to the population because they are unlikely or unable to volitionally leave CCF once inside. CCF is considered poor habitat for DS due to risk of loss at the export facilities (even adults are not salvaged at 100%, Smith 2019), to increased predation in clear water, and increaasing temperatures exceeding DS tolerance (Castillo et al. 2012; Komoroske et al. 2014b; Nobriga et al. 2008; Swanson et al. 2000) Moreover, of the juvenile DS salvaged, most will die during the capture, handling, transport and release process (Aasen 2013; Afentoulis et al. 2013; Morinaka 2013b).

In addition to direct take as a result of entrainment into CCF identified above, operations of the SWP also result in indirect impacts to DS juveniles. These impacts include entrainment of juvenile DS into, or retention within, unfavorable south Delta habitats (see Nobriga et al. 2008), entrainment of food web resources (Jassby and Powell 1994; Jassby and Cloern 2000), increased vulnerability to predation within the south Delta (Grossman 2016), reduced turbidity leading to impaired feeding opportunities (less of a problem for juveniles than larvae, (Baskerville-Bridges et al. 2005) and potential migratory delays if negative OMR flows transport fish the wrong direction, impede migration in the right direction, or mis-cue them as to the correct direction of downstream.

The central and south Delta no longer provide summer and fall habitat for DS (Feyrer et al. 2007a; Feyrer et al. 2011; Nobriga et al. 2008) and a contingent of DS has developed a migratory life history that includes a downstream migration away from spawning grounds. The magnitude and direction of OMR and QWEST flows potentially impact the ability of juveniles to successfully emigrate through physical and behavioral mechanisms. Specifically, OMR and QWEST may impact the fate of juveniles through two mechanisms. The first being that more energy is needed for juveniles DS to migrate out of the south Delta and central Delta, past Jersey Point, when OMR and QWEST flows are negative. Secondly, negative OMR and QWEST flows may also interfere with the ability of juvenile DS to orient and choose the correct route when initiating their migration out of the Delta. If juvenile DS instinctively follow net flow during migration, substantially negative OMR and QWEST will cause them to move toward the export facilities. Such miscuing could result in increased retention in the south or central Delta and increased mortality via mechanisms previously described, including entrainment in SWP and CVP facilities.

7.2.2. Barker Slough Pumping Plant

Unlike the south Delta, a contingent of juvenile DS often inhabits the north Delta, including the sloughs, throughout the summer and fall (Bush 2017, Hobbs et al. 2019). Thus, juvenile DS remain in the vicinity of the BSPP and incidental take of juveniles in the form of entrainment, impingement, or screen contact mortality may occur as a result of its operations. The BSPP is located approximately 16 km from the mainstem Sacramento River at the upper end of Barker Slough. The BSPP has the capacity to export 175 cfs through ten screened pump bays located at the terminal end of Barker Slough. Positive barrier fish screens like those in Barker Slough have been shown to exclude larval fishes smaller than their design criteria where sweeping velocities can assist fish in avoiding entrainment (Nobriga et al. 2004). However, such sweeping flows are not likely to be present at the BSPP, which is located at the upper end of a terminal slough; thus, juvenile DS < 25 mm will need to swim to avoid exposure to the screen and it has not been demonstrated that such positive barrier fish screens are as efficient at limiting entrainment of DS < 25 mm. Although juvenile DS > 25mm are not expected to be entrained they are susceptible to impingement on the screens.

The BSPP operates year-round, except for a brief maintenance period which typically occurs in March. Authorized exports may be as high as 175 cfs year-round, including the spring and early summer, when vulnerable DS larvae and small juveniles are present and may be in the vicinity. PTM results showed that entrainment of surface-oriented particles was nonlinearly related to average pumping rate and that the proportion of particles injected at station 716, in Cache Slough located just above the confluence with Lindsey Slough, ranged from 1.5% to 37% (CDFG 2009b). The same analysis showed that 100% of those particles would be entrained into the BSPP and local agricultural diversions when April through June hydrology was modeled even though diversion rates never exceeded 100cfs, approximately 57% of maximum capacity (CDFG 2009b). Behavior of particles may be somewhat representative of juvenile DS < 25 mm, but older juvenile DS (> 25 mm) are presumed to be competent swimmers and will be much less likely to be drawn into BSPP screens than particles.

In addition to increased diversions, maintenance operations at the BSPP might severely degrade local habitat quality if conducted in late spring and early summer when juvenile DS are present. Incidental take may also occur as a result of maintenance of BSPP facilities and adjoining waterways. Juveniles in the immediate vicinity of the concrete apron in front of the fish screen may be taken during suction dredging conducted for sediment removal, though surface oriented juveniles might be avoided by priming and clearing the dredge with the intake close to the bottom (USAERDC 2013). The impact of aquatic vegetation removal is unknown at this time and will depend upon the size and scope of the removal effort and when it is conducted. Chemical and physical methods of vegetation control each represent different modes of take and will need to be assessed independently. Aquatic vegetation removal that occurs when small juvenile DS are present in the vicinity (April through June) will have a greater impact than for older, more mobile fish. Such impacts might be exacerbated by increased BSPP pumping just prior to vegetation removal efforts, if the pumping draws more juvenile DS closer to the pumps. Indirect impacts related to the operations of the BSPP are the same as those described for DS larvae (Section 7.1.2).

7.2.3. Suisun Marsh Facilities

Physical facilities in the Suisun Marsh and Bay include the SMSCG, the RRDS, the MIDS and the GYSO. Additional facility details are provided in the ITP Project Description, Section 3.1.3.5 of the FEIR, and in Section 5.1.3 of this Effects Analysis.

Suisun Marsh Salinity Control Gates

The SMSCG, when operated, have the potential to cause short-term increases in residence time in the winter and early spring. Gate operation increases juvenile residence time in Montezuma Slough in the vicinity west of the gates, leading to exposure and subsequent increased entrainment risk at the RRDS.

Roaring River Distribution System

The RRDS intakes are screened and physically exclude fish greater than about 25 mm in length. Similar screens provide some benefit for avoiding entrainment of fish < 25 mm (Nobriga et al. 2004). Opening intakes of the RRDS can result in take of individuals via passage through a screen or being impinged upon it, though operation to achieve correct approach velocities likely results in low entrainment and impingement of juvenile DS.

Morrow Island Distribution System

Juvenile DS could be entrained by the three unscreened 1.2 m intakes that form the MIDS intake. MIDS is used year-round, but most intensively from September through June, including when juvenile DS are present. Meng and Matern (2001) found DS larvae commonly in nearby Cordelia Slough suggesting that some juveniles subsequently reared in the vicinity. Enos et al. (2007) found adult DS within MIDS during 2004-2006, indicating that entrainment is occurring and can affect juveniles if present.

Good Year Slough Outfall

Similar to what was described in USFWS (2019), the intakes and outfall of GYSO are unscreened and may entrain juvenile DS. Fish that enter the system would potentially be able to leave via the intake or the outfall, assuming that mortality does not occur while in the system. High rates of diversion from and drainage back into in Goodyear Slough have periodically created extremely low dissolved oxygen concentrations and fish kills even with the GYSO system in place (O’Rear and Moyle 2010).

7.2.4. Agricultural Barriers

The TBP has been implemented almost annually since 1991. The TBP does not alter total Delta outflow or the position of X2, but does cause changes in the hydraulics of the Delta, which may affect juvenile DS. A major component of the TBP, the Head of Old River Barrier (HORB) is a temporary structure previously installed seasonally between September 15 and November 15 at the divergence of Old River from the San Joaquin River and blocks San Joaquin River flow from entering Old River. Installation and operation of the HORB is not included in the Project. Juvenile DS may be present in the central or south Delta during April and May. The installation of the south Delta barriers do not alter total Delta outflow or the position of X2 (USFWS 2008), but they do alter flows in south Delta channels. The barriers block flow into Old River while increasing flow toward the SWP and CVP from Turner and Columbia cuts. These increased channel flows can increase the predicted entrainment risk for particles injected in the east and central Delta by up to about 10 percent (Kimmerer and Nobriga 2008). In years with substantial numbers of juvenile DS in the central Delta, increases in negative OMR flow caused by the TPB can increase entrainment and direct take of the species.

7.3. Adult Delta Smelt

Each year, adult DS initiate dispersal into fresh water habitat during December through March in preparation to spawn in fresh and low-salinity water (Bush 2017b; Moyle 2002). This movement generally coincides with high outflow and a spike in turbidity conditions associated with winter storms, known as “first flush” events (Bennett and Burau 2014; Sommer et al. 2011). The specific flow and/or turbidity thresholds which would define a first flush event have not been formally described, however the concept is that the first substantial winter storm will produce a freshet of turbid water that would cue adult DS to disperse upstream. In low outflow years when first flush conditions do not occur, adult DS will eventually disperse into spawning habitat by late February or March when water temperatures are warm enough to initiate spawning (Bennett 2005). During this upstream dispersal, adult DS are at risk of entrainment into export facilities (Grimaldo et al. 2009; IEP 2015). After this initial dispersal, additional regional movement is not likely (Polansky et al. 2018). The fish are presumed to hold and wait for favorable water temperatures to begin spawning (Bennett 2005; Grimaldo et al. 2009; Sommer et al. 2011).

7.3.1. Banks Pumping Plant and Clifton Court Forebay

Operations of the SWP will lead to take of adult DS that are in the Delta through direct entrainment of individuals into CCF and the export facilities. Here, the process of entrainment is defined as the geographic redistribution of individuals via hydrodynamic advection as a result of pumping. For adult fish dispersing into freshwater, suitable spawning habitat occurs in the primary channels of both the Sacramento and San Joaquin rivers (USFWS 2019). Although south Delta habitat quality for DS has declined over time (Nobriga et al. 2008), individuals continue to occur in the southern Delta due to either volitional movement into the area, or through entrainment due to hydrodynamics, or both (Kimmerer 2008). Direct take of adult DS by the SWP and CVP facilities is evident from adults observed in historical salvage data, generally occurring from December to March (Grimaldo et al. 2009; IEP 2015).

Involuntary movement into the south Delta is caused by an interaction between reverse flows in Old and Middle rivers (negative OMR in cfs) due in part to SWP operations and the proximity of adult DS to the SWP export facility. Studies have shown that there is a significant negative correlation between OMR flow, X2 position and adult DS salvage at both the SWP and CVP fish facilities (Grimaldo et al. 2009).

While no single prescribed OMR flow rate or duration may guarantee avoidance of DS entrainment, greater reverse flows in Old and Middle rivers are generally associated with higher numbers of fish entrained. Importantly, high winter exports and reverse OMR flows have been linked to population level declines in DS (Thomson et al. 2010). This was particularly evident during the Pelagic Organism Decline when total entrainment of adult DS at the SWP and CVP hit record levels while winter exports and reverse OMR flows were also all-time highs (Smith 2019 (Smith 2019)). Entrainment of adult DS at the SWP and CVP may account for 4-50% of the adult population in a given year (Kimmerer 2008); this loss of adults to the population affects recruitment into the next generation. Using an individual-based model, Kimmerer and Rose (2018) showed that eliminating entrainment mortality altogether results in an increase of the annual finite population growth rate. Furthermore, a 26-year simulation with a mean 10 % annual loss of due to entrainment resulted in a 10-fold reduction in the total DS population size (Kimmerer 2011). Collectively, these studies demonstrate the potential for winter exports to have a population level effect on DS.

Take of individuals occurs when they are entrained into CCF. Individuals entrained at the export facilities are expected to be lost to the population. Although fish can survive handling during salvage and trucking back to the Delta (Morinaka 2013b), it is unlikely that a substantial portion of the DS (USFWS 2019) population is returned to contribute to subsequent generations. Unfortunately, the abundance of fish entrained into CCF can only be indirectly calculated using fish facility salvage data and assumptions associated with pre-screen loss processes (Kimmerer 2008; 2011; Smith 2019). Components of pre-screen loss in CCF include: survival of individuals in the forebay, the sampling efficiency of the behavioral louver system, and the sampling efficiency of the subsampling and observation process (Smith 2019). Mark-and-recapture studies of adult DS released at the entrance of CCF have shown low percent recaptured (0-5%) and high pre-screen loss rates (90-100%) (Castillo et al. 2012). Comparison of loss estimates that account for pre-screen loss (Smith 2019) to expanded salvage of DS from December through March of 1993-2016 shows a 600-2,200% difference in the estimated number of fish entrained at the facilities (Table 11).

Take of individuals may also occur as a result of the CCF Aquatic Weed Control Program, which can result in fish mortality due to contaminant effects. However, the extent of this effect on the population has yet to be quantified.

Table 11: *Comparison of observed expanded salvage and estimated total entrainment from Smith (2019)*

Water Year	Observed Expanded Salvage	Estimated Total Entrainment	Increase (%)
1994	447	4719	1056
1995	2608	24499	939
1996	5634	49294	875
1997	1828	11069	606
1998	1027	6342	618
1999	2074	12793	617
2000	11493	142488	1240
2001	7991	97853	1225
2002	6865	54559	795
2003	14305	116495	814
2004	8120	119356	1470
2005	2016	24292	1205
2006	324	3320	1025
2007	36	221	614
2008	350	3495	999
2009	24	521	2171
2010	92	676	735
2011	48	459	956
2012	197	2168	1101
2013	260	2792	1074
2015	68	759	1116
2016	12	119	992

Impacts of the taking extend beyond the direct observation of fish counted in salvage to those individuals that are lost from the population (“killed”) as an indirect result of SWP operations. This indirect effect of taking occurs primarily as a result of entrainment into the central and south Delta during their dispersal period due to reverse OMR flows. Historically, the southern Delta was used as spawning and rearing habitat for young, however; this region of the Delta has become less suitable to DS over time (Nobriga et al. 2008). Habitat degradation in the central and south Delta can be attributed to SWP operations. Long-term changes to turbidity in the Delta has been attributed to the spread of freshwater submerged aquatic vegetation (SAV), whereby the spread of SAV was facilitated by diversion of river water at SWP and the resulting freshening of the Delta for export (Nobriga et al. 2008; Schoellhamer et al. 2016). The expansive meadows of SAV in the central and south Delta trap suspended sediments reducing turbidity (Hestir et al. 2016). Concomitant with the spread of SAV has been the proliferation of non-native piscivorous fishes which can prey upon adult DS when entrained into the central and south Delta (Conrad et al. 2016; Ferrari et al. 2014; Lehman et al. 2019; Young et al. 2018). The interaction between increased predator presence and clearer water dramatically increases predation risk for DS and there is evidence for a significant negative effect of predation on population abundance (Maunder and Deriso 2011; Miller et al. 2012; Thomson et al. 2010). Adult DS suffer both direct (consumption) and indirect (injuries) mortality from largemouth bass in lab studies (Davis et al. 2019b). Therefore, adult DS which are entrained into the southern Delta likely have a lower survival rate.

Contaminant levels are also potentially higher in the south Delta due to a combination of increased proximity to nutrient sources, lower rate of inflow, higher residence time and overall smaller volume of water (Fong et al. 2016; Lehman et al. 2017). Several recent studies identified contaminants as significant stressors to DS. Ambient water exposures to cultured DS have demonstrated altered gene expression for immune response, development and significantly greater levels of apoptosis and necrosis (Connon et al. 2009; Hasenbein et al. 2013b; Jeffries et al. 2015). In field studies higher contaminant levels have been associated with histological lesions, stunted growth and overall poor health (Hammock et al. 2015). Reduced Delta outflow as a result of SWP export operations indirectly increases contaminant levels in the Delta by reducing the dilution effect of rivers flows, increasing the risk to DS.

Additional impacts on the species occurs as water export generally reduces Delta outflow in the fall (Hutton et al. 2019; Hutton et al. 2017a; Hutton et al. 2017b) which reduces the amount of available low-salinity rearing habitat for DS (Hobbs et al. 2007). The centroid of the distribution of subadult DS is locate near X2 and moves with X2 as it retreats in the summer-fall, until the start of the spawning migration in December (Sommer et al. 2011). This upstream movement of X2 is associated with reduced habitat suitability (Bever et al. 2016; Feyrer et al. 2007a; 2011), which appears to be an important habitat attribute for describing recruitment to the next generation, although the mechanism for this relationship has yet to be determined (Bever et al. 2016; Feyrer et al. 2007a; 2011).

The progeny of fish that successfully spawn in the south Delta are subject to increased mortality and entrainment risk. USFWS (2019) concludes that expanded adult distribution initially affects the distribution of the next generation because the eggs are adhesive and believed not to be very mobile (Mager et al. 2004). Adhesive eggs that are deposited by spawning adults are not believed to be vulnerable to direct entrainment, but larvae that hatch in the southern Delta face increased entrainment risk due to their proximity to the south Delta export facilities (Kimmerer and Nobriga 2008). Furthermore eggs deposited downstream in Montezuma Slough and the confluence region may be affected by changes in salinity due to SWP export operations in the spring (Hutton et al. 2019; Hutton et al. 2017b). Subsequently, DS eggs and larvae are also vulnerable to predation by Mississippi silverside and other nonnative fishes within the Delta, thus any level of exports that may increase the residence time of larvae may increase predation risk (Baerwald et al. 2012; Schreier et al. 2016). Presence and absence data at the SWP export facilities indicate that entrainment of larval DS at the facilities do occur, however; this is not currently quantified. Prior attempts to estimate larval DS entrainment suggests rates of 0-25% of the population (Kimmerer 2008), however, there is concern that this estimate may be biased high (Miller 2011). Although the southern Delta may have historically been favorable for spawning DS, presence in the modern southern Delta is consistently rare (Nobriga et al. 2008), and likely attributed to the factors mentioned above. The population has continued to decline despite protections afforded by the 2008 USFWS BiOp and 2009 NMFS BiOp.

7.3.2. Barker Slough Pumping Plant

The BSPP is made up of 10 pump bays that are individually screened with a positive barrier fish screen consisting of a series of flat, stainless-steel, wedge-wire panels with a slot width of 2.4 mm. This configuration is designed to exclude and prevent the entrainment of fish measuring approximately 30 mm or larger. The bays tied to the two smaller units have an approach velocity of about 0.2 foot per second (ft/sec). The larger units were designed for a 0.5 ft/sec approach velocity, but actual approach velocity is about 0.44 ft/sec. Due to the presence of the fish screen and appropriate approach velocities, direct take of adult DS is expected to be low.

Although entrainment of adult DS is expected to be low due to the fish screens at the facility, individuals may be entrained into the area during periods of high water diversion. Adults entrained into the area may also spawn in the area. Habitat within the zone of influence of the BSPP is of low quality for larval DS as fish less than 25 mm can be entrained by the facility. DS less than 25 mm are expected to be killed if they are impinged on the fish screens or pass through the screens and into the pumping plant.

7.3.3. Suisun Marsh Facilities

Physical facilities in the Suisun Marsh and Bay include the SMSCG, the RRDS, the MIDS and the GYSO. Additional facility details are provided in the ITP Project Description, Section 3.1.3.5 of the FEIR, and in Section 5.1.3 of this Effects Analysis.

Suisun Marsh Salinity Control Gates

Under current operations DS could be entrained into Montezuma Slough when the SMSCG is opened and then closed, especially during the late summer and fall when the gates are most likely to be used (USFWS 2019). The degree to which movement of DS around the low salinity zone is constrained by opening and closing the SMSCG and whether this harms DS is unknown. Striped bass may aggregate near the SMSCG, which could elevate predation rates. Additionally, DS may experience an increased risk of entrainment into the managed duck club marshes where they would be unlikely to survive (Culberson et al. 2004; USFWS 2008). However, a recent study found that the body condition of DS collected from Montezuma Slough/Suisun Marsh was better than Suisun Bay and the confluence region (Hammock et al. 2015). The freshening of Montezuma Slough through gate operations during the summer and fall is likely to provide additional low salinity habitat for DS to forage, spawn and rear.

Roaring River Distribution System

As described in USFWS (2019), The RRDS intakes are screened 2.4 mm and physically exclude fish greater than 30 mm in length from being entrained. RRDS operations are only likely to result in take if individuals are impinged onto the screens. It is not known whether this occurs. We consider higher entrainment or impingement mortality to be unlikely because the RRDS intakes are positioned in a part of Montezuma Slough where the channel is about 90-110 m wide and DS would need to be within a meter of the fish screens to have any vulnerability to variation in approach velocities through the screens. The information that we have available indicates that DS generally avoid in-water structures and would therefore have little tendency to be near the RRDS intakes, particularly given the substantial width of the adjacent channel.

Morrow Island Distribution System

As described in USFWS (2019), individual DS could be entrained by the three unscreened 122 cm intakes that form the MIDS intake. Enos et al. (2007) noted that this would generally only occur in wet years, per Hobbs et al. (2006). (Enos et al. 2007) did not collect any DS during sampling of the MIDS intake in 2004-2006, although they did capture adult DS with purse seines during sampling in the adjacent Goodyear Slough. It is expected that mortality is likely to occur when individual DS enter the intakes.

Good Year Slough Outfall Gates

The intakes and outfall of GYSO are unscreened and may entrain adult DS. However, fish that enter the system are unlikely to die during the entrainment process and would be able to leave via the intake or the outfall, as GYSO is an open system.

7.3.4. Agricultural Barriers

The TBP does not alter total Delta outflow, or the position of X2 USFWS (2008). However, the TBP causes changes in the hydraulics of the Delta, which may affect DS. In most instances, net flow is directed towards the Banks and Jones pumps and local agricultural diversions. Simulations have shown that placement of the barriers changes south Delta hydrodynamics, increasing central Delta flows toward the export facilities (USBR 2008). In years with substantial numbers of adult DS moving into the central Delta, increases in negative OMR flow caused by installation of the TBP can increase entrainment. The directional flow towards the Banks and Jones pumping plants increases the vulnerability of fish to entrainment and may result in direct take of the species.

7.4. Summer Habitat

The IEP-MAST (2015) conceptual model describes DS habitat during the June through September period, focusing on factors which affect the probability of transitioning from juvenile to subadult lifestages during this time. Specifically, this conceptual model hypothesizes that the quality of habitat is driven by specific habitat attributes including water temperature, predation risk, toxicity from harmful algal blooms, and food availability and quality.

As discussed in the IEP-MAST (2015), water temperature is known to affect the survival of juvenile and subadult DS through the summer. Komoroske et al. (2014a) found that while juveniles can withstand higher water temperatures, they also exhibit the lowest warming tolerance relative to other life stages. During the summer months, juveniles are exposed to water temperatures closer to their Critical Thermal Maximum (CTM) and Maximum Chronic Lethal Temperature (CLT) and studies have documented juveniles exposed to temperatures above their CTM in the wild (Nobriga et al. 2008). These results indicate that small differences in temperature (± 1^{o}C) during summer conditions can have substantial impacts on DS survival. In addition, recent findings demonstrate that DS may experience sub-lethal impacts when in water temperatures slightly lower than 25-28^{o}C. In laboratory conditions, DS exhibited potentially deleterious behavioral responses when exposed to persistent elevated temperatures between 20-22^{o}C (Davis et al. 2019a), indicating that sublethal effects can begin to occur before water temperatures reach 25^{o}C.

Findings from a retrospective analysis of historic water temperature data (1975-2012) show that the coolest average and maximum temperatures occurred in Suisun Bay and San Pablo Bay during the July to August period (average 19-21^{o}C, maximum 24^{o}C) while the western Delta was slightly warmer (average 21-23 °C, maximum 25 °C) (IEP-MAST 2015). These regional differences in water temperature are also supported by Wagner et al. (2011). Together these analyses indicate that the western portions of Suisun Marsh and Suisun Bay will generally provide the coolest water temperatures relative to other upstream regions during the summer and early fall.

Turbidity is also an important DS habitat attribute during the summer (IEP-MAST 2015), and has been associated with observations of juvenile and subadult DS in survey data (Nobriga et al. 2008; Sommer and Mejia 2013). Increased turbidity has been hypothesized to increase survival (Hasenbein et al. 2016) and reduce DS predation risk (Ferrari et al. 2014; IEP-MAST 2015). Studies have shown that turbidity is generally higher in Suisun Bay and Marsh (Durand 2014; Nobriga et al. 2008) relative to upstream regions because of dynamic variables, such as wind (Rhul and Schoellhamer 2004), interact with static variables, such as the high levels of baythmetric complexity and increased erodible sediment supply found in the Suisun Region (Brown et al. 2014).

Salinity is also an important DS habitat attribute during the summer. Komoroske et al. (2014a) found that DS mortality in the laboratory was greatest at high salinities (34 ppt) with little difference between 2 ppt and 18 ppt treatments. However, field studies have demonstrated that DS are mostly observed in low salinity conditions during the summer (Nobriga et al. 2008) indicating that while individuals may tolerate more saline habitats, their preference appears to be for areas where salinity is < 6 psu. This is further supported by the findings of Hasenbein et al. (2013a) that showed DS experienced increased osmoregulatory stress at salinities greater than 12 ppt, whereas optimal performance occurred at low salinities (0-6 ppt) and low turbidity (< 120 NTU).

In the wild, low salinity zone habitat for DS is defined as areas with salinities ≥ 0.5 psu but ≤ 6 psu. The low salinity zone is corelated and indexed by the variable X2 (Jassby et al. 1995). Overall, the centroid of the distribution of juvenile DS is understood to occur within the low salinity zone (Dege and Brown 2004), although a subset of the population occupies fresh water regions of the Sacramento Deep Water Ship Channel. Recent otolith analyses indicate that the majority of the DS population typically occupies habitats with salinities > 0.5 psu during the summer-fall period of most years (Bush 2017a). Because of this, the location of low salinity zone within the Bay-Delta during the summer period is important as it determines whether DS will have access to relatively cooler waters with higher turbidities. This section describes the relationship between SWP operations and the location of the low salinity zone during the summer by analyzing changes to Delta outflow over time.

Summer hydrology

The summer season in California is characterized by little to no precipitation within the upper watersheds. As a result, Delta hydrology is primarily driven by antecedent snowpack and other storage accumulated during the winter and spring months. For the purposes of this Effects Analysis, we focused our discussion on the months of June - August because they represent the portion of the year when we expect ambient air and water temperatures to be highest and imposing stress on juvenile DS.

To better understand both the historic variability in Delta hydrology over time during the summer, we examined Delta outflow and SWP exports using data from Dayflow (*www.data.ca.gov/dataset/dayflow*) with two questions in mind:

1) How has Delta outflow changed in the summer and fall months? Does this relationship differ among water year types?
2) How has the proportion of total Delta outflow exported by the SWP changed during summer and fall months? Does this relationship differ among water year types?

We also utilized X2 data from Dayflow, however data was only available beginning in 1997. Estimates of X2 before 1997 were calculated using the X2 formula in Dayflow with historical salinity and outflow data. We used a 10,000 cfs outflow as a reference point in our analysis since most summer outflows are expected to be relatively low from July through August. These data were then compared across years going back to 1967. These years were selected because they both represent the current FMWT abundance record of DS (1967 – present) and capture the start of the SWP south Delta operations (1968).

During the summer period, Delta outflows less than 10,000 cfs are associated with a relatively wide distribution of X2, ranging from approximately 95 km to 75 km (Figure 29). Delta outflows between ~5,000 - 15,000 cfs are associated with X2 at 75 km and outflows of ~10,000-50,000 are associated with

X2 at 65 km, although this level of outflow is rare in the summer and only likely to occur early in wet years.

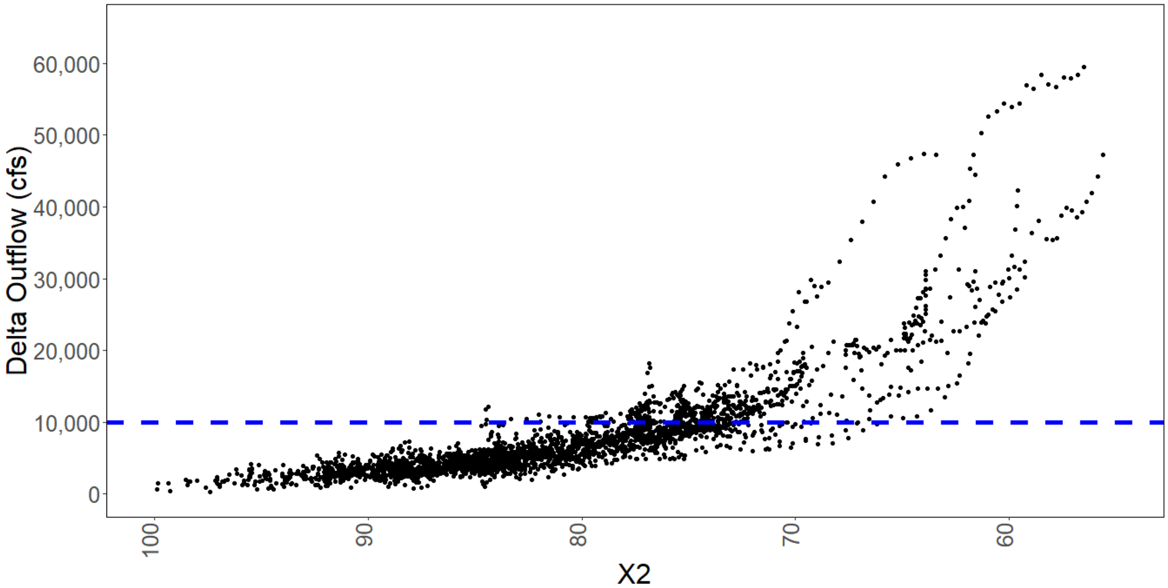


Figure 29: *Scatterplot of daily average Delta outflow versus X2 location for the months of June through August for years 1967 through 2014. X2 values prior to 1997 were reconstructed using a combination of Dayflow and historic data. Blue dashed line represents 10,000 cfs outflow.*

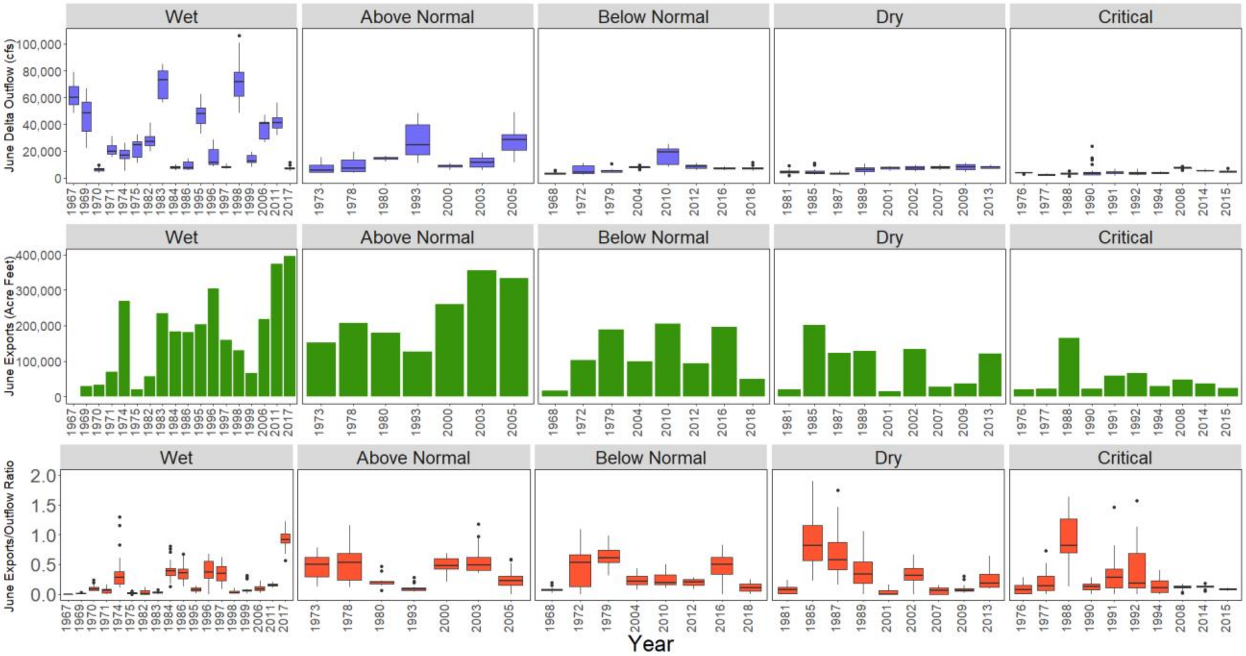


Figure 30: *Boxplots of Delta outflow (top row) and Exports/Outflow Ratio (bottom row) for the month of June, differentiated by water year type. Solid black lines within the boxplots represent median values. Bar plots of total volumes of water exported for the month of June, differentiated by water year type (middle row).*

June hydrology for wet years illustrates a relatively high amount of variability in Delta hydrology year to year (Figure 30) with flows being less than 10,000 cfs in some years and as high as 80,000 to 100,000 cfs in others. It should be noted that above normal year types haven't occurred in since 2009 and may look substantially different under regulatory requirements in place after 2009. In below normal (n=8), dry (n=9), and critical (n=9) years, outflows are generally less than 10,000 cfs with slight increases in recent years. The export to outflow ratio (E-O) varies among water year types but is generally 0.5 or slightly less.

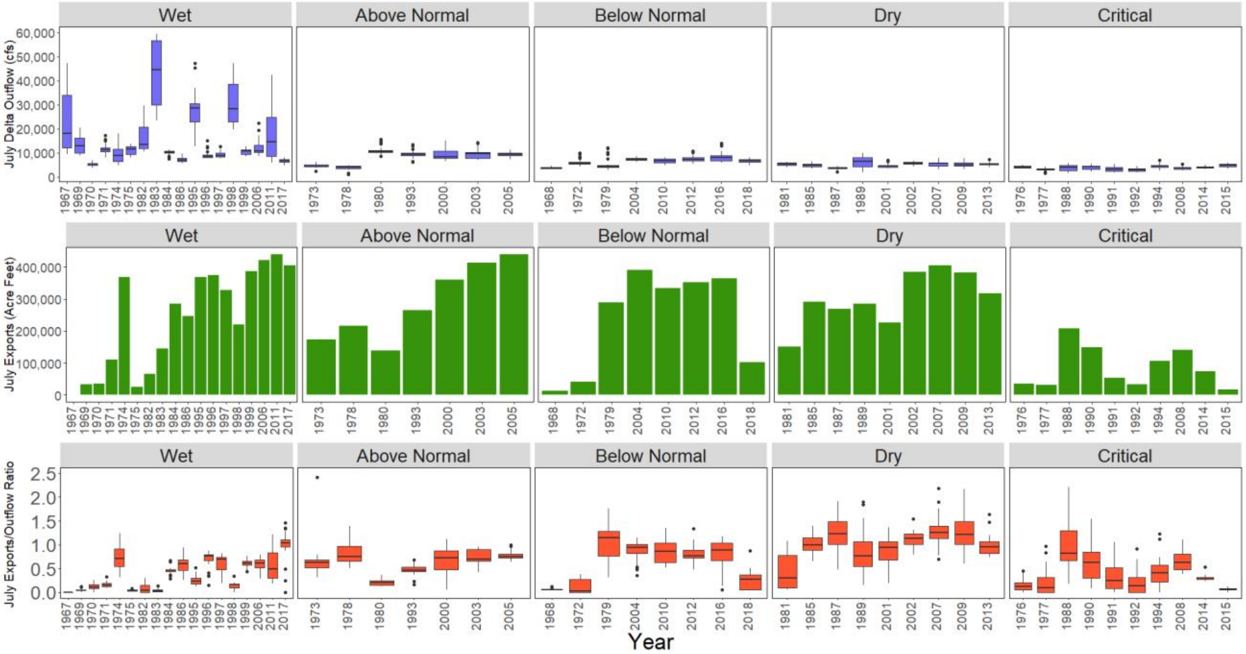


Figure 31: *Boxplots of Delta outflow (top row) and Exports/Outflow Ratio (bottom row) for the month of July, differentiated by water year type. Solid black lines within the boxplots represent median values. Bar plots of total volumes of water exported for the month of July, differentiated by water year type (middle row).*

Similar to June, July hydrology for wet years illustrates a relatively high amount of variability in Delta outflow year to year (Figure 31), with median flows at approximately 10,000 cfs in 13 of the 18 wet years and flows ranging between 20,000 and 45,000 cfs in the remaining years. Median outflows are less than 10,000 cfs in all other water year types with drier year types nearer 5,000 cfs. The E-O ratio varies in wet year types from 0 to almost 1 in recent years. Above normal E-O for the month of July is generally constant, with most median values between a ratio of 0.5 to 1.0. Below normal and dry years vary, with most years around a ratio of 1.0. E-O is highest in dry years with median ratios close to 1.0 and ratios as high as 2.0 in some years.

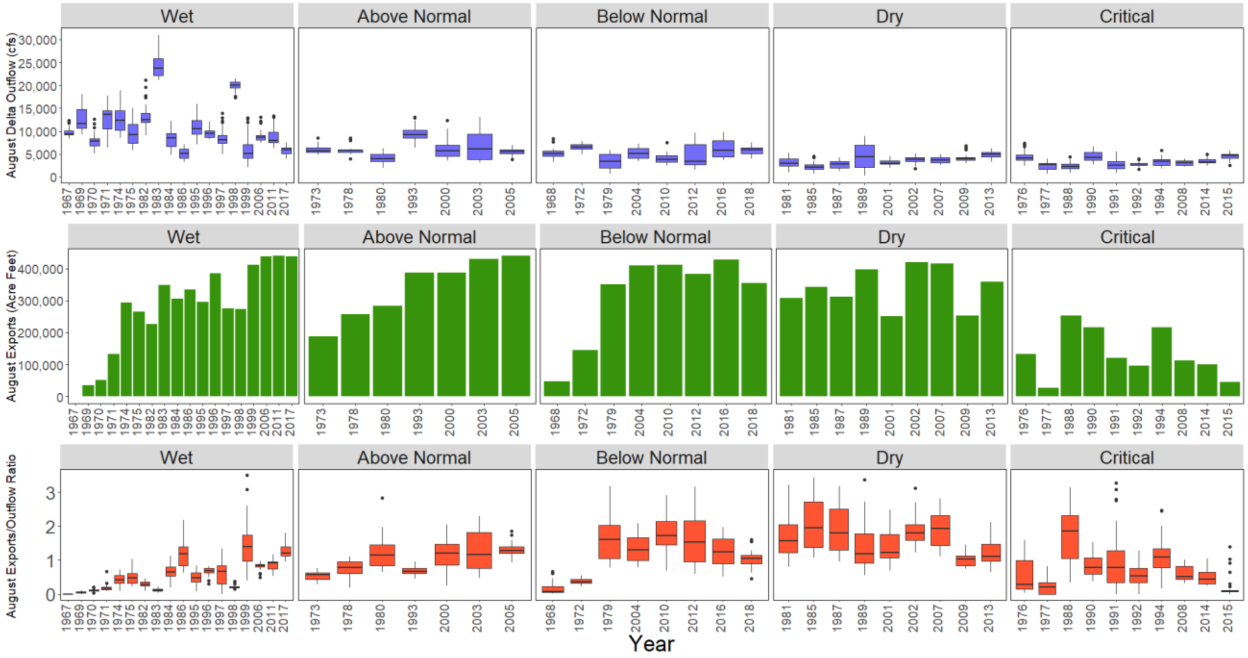


Figure 32: *Boxplots of Delta outflow (top) and Exports/Outflow Ratio (bottom) for the month of August, differentiated by water year type. Solid black lines within the boxplots represent median values. Bar plots of total volumes of water exported for the month of August, differentiated by water year type (middle row).*

Median outflows in August of wet years were generally between 10,000 cfs and 15,000 cfs early in the historic record, with 1983 being an exception (Figure 32). In recent wet years median outflows have been between 5,000 and 10,000 cfs. Outflows for all other water year types (above normal, below normal, dry, and critically dry) are similar with median flows generally at or near 5,000 cfs, with drier year types (dry and critically dry) having median flows at or less than 5,000 cfs in most years. Similar to both June and July, SWP exports have increased over time in all water year types except critical years for the month of August. However, total exports for in the month of August are generally greater than June and July. E-O is generally greater than 1.0. Three of the 18 years examined have median ratios above 1.0 and daily ratios as high as 2.0 (1999). In above normal and below normal water year types median ratios in most years are above 1.0. Although the E-O in dry and critically dry years was near 2.0, it is closer to 1.0 in recent years. The E-O in critically dry years has reduced over time, with median ratios as high as 1.5 (1988) and decreasing to less than 0.5 in recent years (2015).

Based on Dayflow data, summer (June – August) Delta outflow appears to be highly managed and changes in SWP exports have the potential to modify summer low-salinity zone habitat for DS. DS low salinity zone habitat would benefit substantially from the deployment of the Additonal 100 TAF or Spring Outflow blocks of water when available (Conditions of Approval 8.18 and 8.19) in addition to the required SMSCG operations during the summers of above normal, below normal and dry water years.

7.5. Fall Habitat

Several peer-reviewed publications have linked the location of X2 to the amount of suitable abiotic habitat for DS during the fall (September – December) (Bever et al. 2016; Feyrer et al. 2011; IEP-MAST 2015). The IEP-MAST (2015) conceptual model describes the same abiotic habitat attributes in the summer and fall as drivers of the transition probability from subadults to adults, but also includes toxicity related to contaminants and the size and location of the low salinity zone, therefore, much of the discussion in Section 7.4 of this Effects Analysis is also applicable here.

During this time period, the distribution of the subadult DS population is associated with the location of low salinity zone, as indexed by X2 (Sommer et al. 2011). Because this habitat attribute is affected by outflow, we will apply concepts from the Fall Low-Salinity Conceptual Model described in Brown et al. (2014) to qualitatively assess how the SWP operations have affected the location of the low salinity zone through highly managed outflows.

The fall period is similar to the summer in that it is generally a season with little to no precipitation occurring within the upper watershed, and the variability in Delta outflow likely results from variation in antecedent snowpack and storage releases from the winter and spring of that year. We focused this section on the months of September and October, as these are critical periods in the fall for DS. This section considers both the historical variability in Delta hydrology over time and the ratio of exports to outflow during September and October. To better understand both the historic variability in Delta hydrology over time during September and October, we examined Delta outflow and SWP exports using data from Dayflow, similar to the summer habitat analysis described above.

As observed in the summer months, a wide range of Delta outflows are associated with a given X2 value during the months of September and October (Figure 33). In the fall, Delta outflows less than 10,000 cfs are associated with a relatively wide distribution of X2, ranging from approximately 95 km to 75 km. Substantially more Delta outflow is needed (approx. 35,000 cfs total outflow) to move X2 from 75 km to 65 km, although this level of outflow only occurs very rarely during the fall.

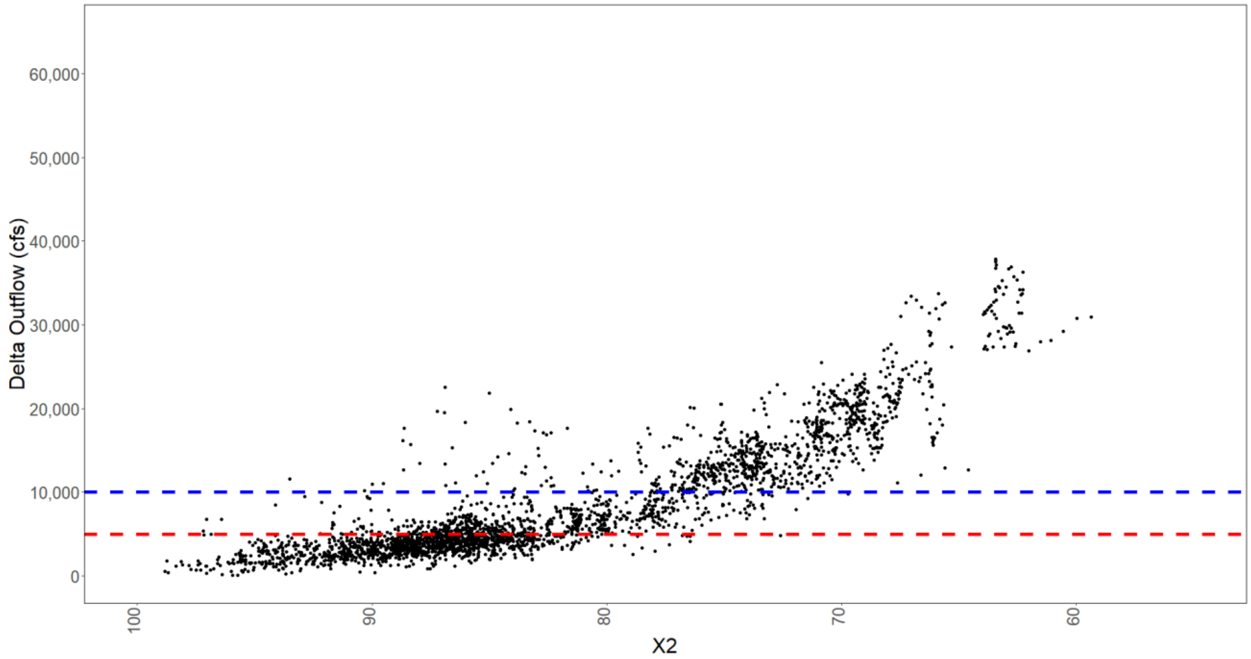


Figure 33: *Scatterplot of daily average Delta outflow versus X2 location for the months of September and October for years 1967 through 2014. X2 values prior to 1997 were reconstructed using a combination of Dayflow and historic data. Blue dashed line represents 10,000 cfs, red dashed line represents 5,000 cfs.*

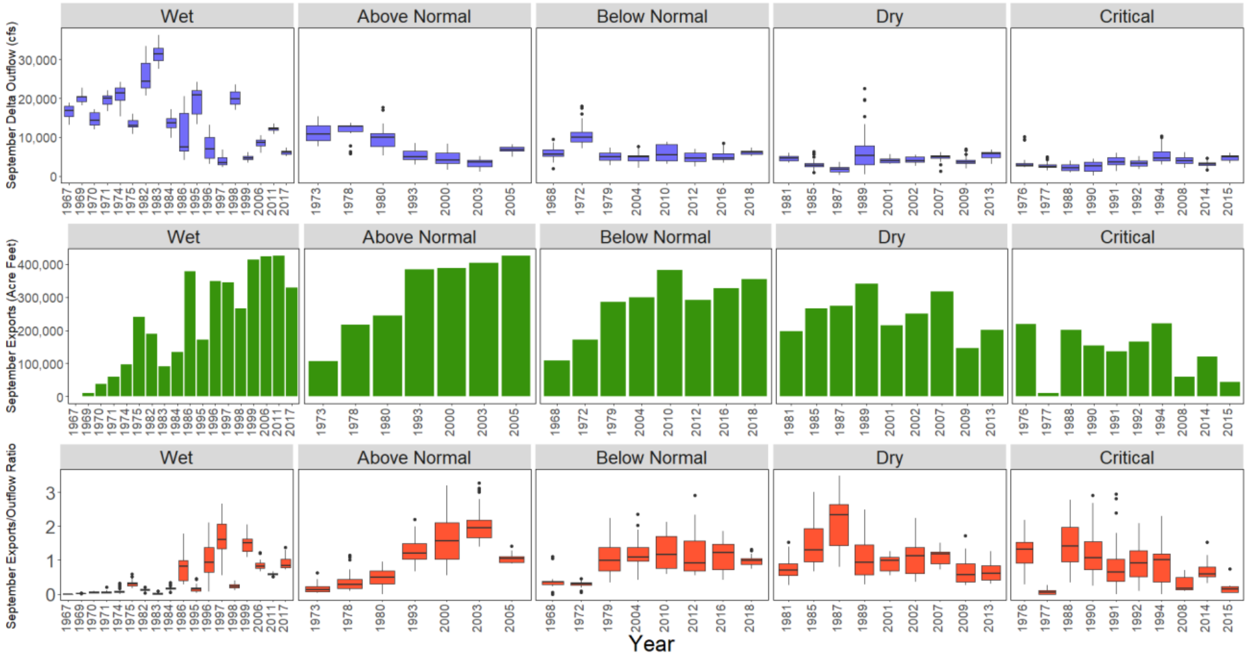


Figure 34: *Boxplots of Delta outflow (top) and Exports/Outflow Ratio (bottom) for the month of September, differentiated by water year type. Solid black lines within the boxplots represent median values. Bar plots of total volumes of water exported for the month of September, differentiated by water year type (middle row).*

We observed some variability in Delta hydrology among wet years during September (Figure 34), with median flows greater than 20,000 cfs in 7 of the 18 years. However, wet year median outflows in three of the four recent wet years were less than 10,000 cfs (1999, 2006, 2011 and 2017). September median Delta outflows in above normal years were approximately 5,000 - 10,000 cfs. It should be noted that above normal year types haven't occurred in recent years and may look substantively different under regulatory conditions in place since 2009. Below normal, dry, and critically dry year Delta outflow was generally constrained to less than 5,000 cfs with slight increases observed in recent years. SWP exports for the month of September have generally increased over time in all but dry and critically dry years, when exports have been generally constant through time. The ratio of exports to outflow in September of wet years in recent years was approximately 1.0, with a maximum of ~1.5 in 1997. In above normal and below normal years, the median E-O exceed 1.0 in most years. In all other years (dry and critically dry), the ratio varied between 1.0 and close to zero.

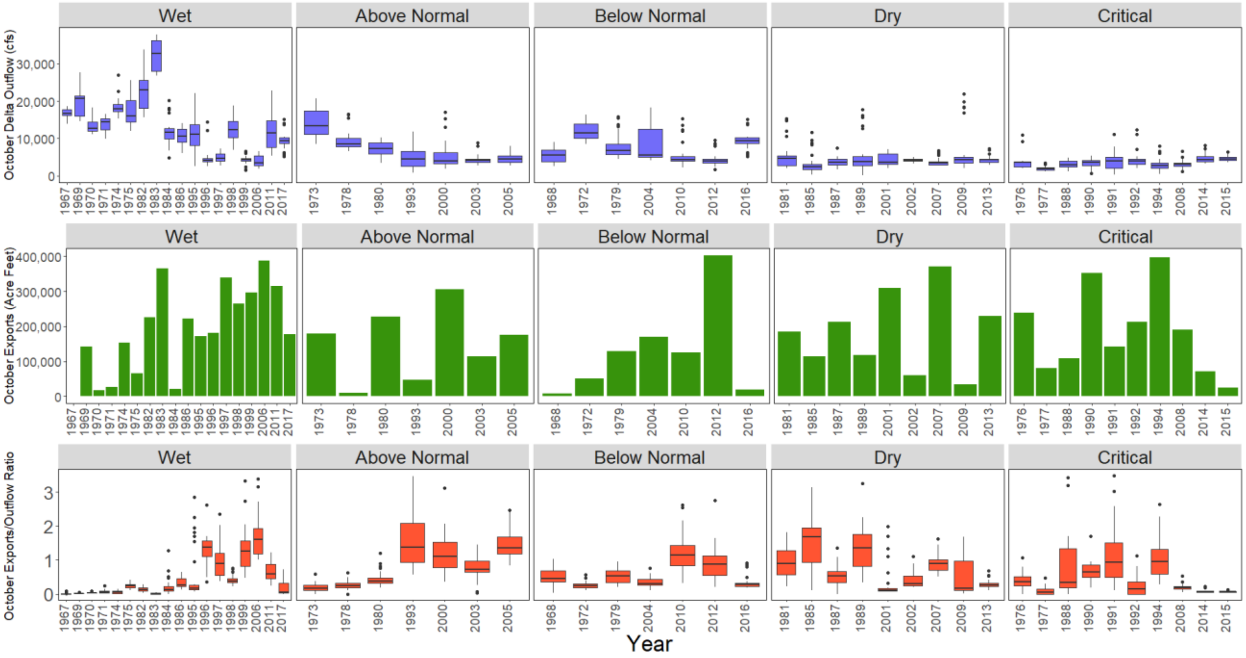


Figure 35: *Boxplots of Delta outflow (top) and Exports/Outflow Ratio (bottom) for the month of October, differentiated by water year type*[5]*. Solid black lines within the boxplots represent median values. Bar plots of total volumes of water exported for the month of October, differentiated by water year type (middle row).*

October hydrology in wet years is very similar to the month of September (Figure 35), however median flows were generally lower with median outflows of less than 10,000 cfs in three of the last four recent wet years. In above normal years median flows ranged from 10,000 to 5,000 cfs. In below normal, dry, and critically dry year's outflows are generally constrained to less than 5,000 cfs with slight increases in recent years. The E-O in recent wet years is approximately 1.0, with 2006 being the highest ratio for the month of October. In above normal and below normal years, the median E-O exceeds 1.0 in most above

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[5] The month of October is included with the previous year's water year type to keep consistency within the analysis

normal years, while below normal ratios are much more variable. In dry and critically dry years the E-O ratio has varied substantially between 1.0 and almost zero.

Based on this examination of Dayflow data, fall hydrology (September – October) appears to be highly managed with SWP daily export rates often matching or exceeding the corresponding outflow for the same time period. Observed fall outflows resemble a constant, stable, low flow period where DS habitat is consistently outside of Suisun and mostly within the confluence of the Sacramento and San Joaquin rivers, or upstream. This has the effect of reducing the extent and quality of available DS habitat. Therefore, maintaining outflow to achieve an X2 of 80 km or less in September and October of wet and above normal water years will contribute to maintaining DS low salinity zone habitat in areas where water temperatures are likley to be cooler and bathymetric complexity is higher in addition to maintaing a greater total extent of habitat.

7.6. Food Resources

As described in Section 4.2 of this Effects Analysis, DS prey items have changed over time, and the availability of some food types, particularly in Suisun Bay, is influenced by hydrology (e.g., Kimmerer et al. 2018, 2019). A hydrodynamically facilitated food subsidy from the Delta to Suisun Bay can be important in summer and fall when fish are rearing in the low salinity zone and growing rapidly (Bennett 2005). As previously mentioned, the IEP-MAST (2015) conceptual model describes food availability as an important habitat attribute that can affect the probability of successful DS transitions between life stages. Although prey availability is influenced by hydrology the exact magnitude of changes in outflow (via increased inflows or reduced exports) leading to optimal advection of zooplankton from the central Delta remains unknown. In Section 4.4.7.4 and Appendix E of the FEIR, this uncertainty is demonstrated when trying to predict *E. affinis* density based on Delta outflow (as indexed by X2) during the spring (Kimmerer 2002b). The analysis show that there is appreciable uncertainty in the predictions of *E. affinis* density as a function of X2: 95% prediction intervals spanned 1-2 orders of magnitude (Figure 36). Nonetheless, increased outflows are still expected to improve relative food availability even though the magnitude of change is uncertain.

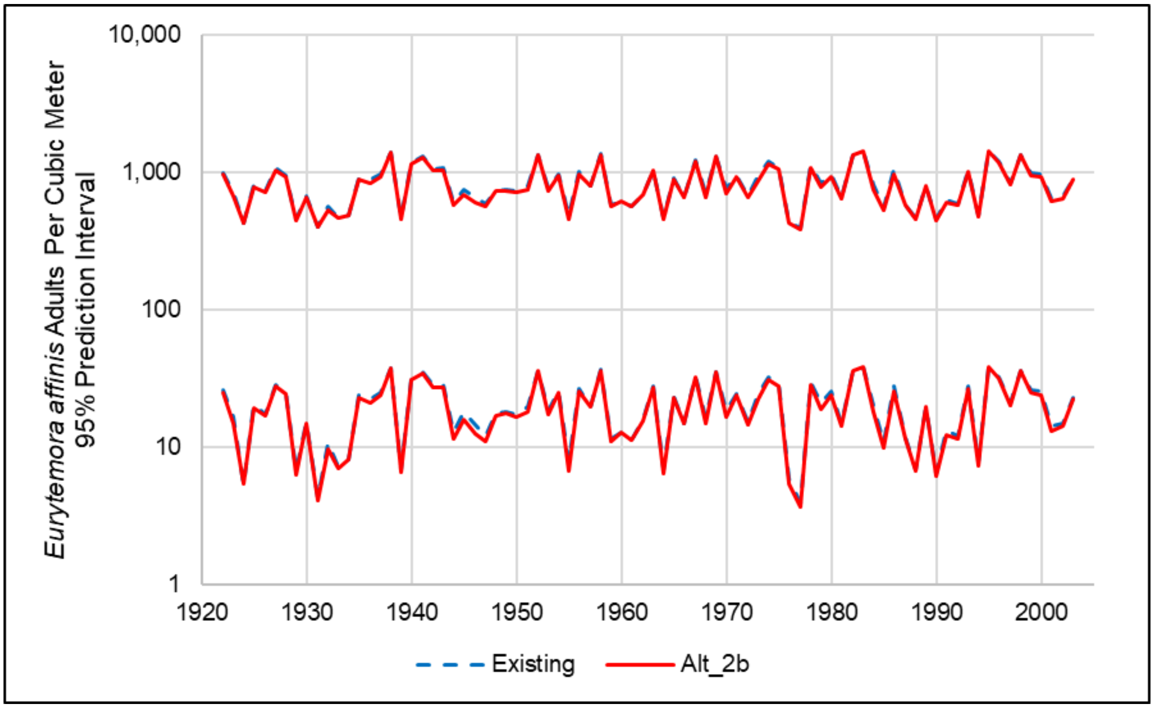

Figure 36: Eurytemora affinis density in the low salinity zone 95% prediction interval, for the 1922-2003 modeled period. Figure *5.3-21 was copied from Section 5.3.9 in the FEIR.*

Current high summer and fall export levels entrain considerable proportions of Delta food web products (USFWS 2008; Kimmerer et al. 2019), limiting what is available for distribution downstream. This is also evident from high particle entrainment observed in PTM simulations using typical inflow and export levels (Kimmerer and Nobriga 2008; CDFG 2009b). In particular, the San Joaquin River appears to harbor high densities of *P. forbesi* that can, with modest outflow, be advected to Suisun Bay, supplementing food in that region (Kimmerer et al. 2019). Conceptually, SWP south Delta exports can affect the direction food resources in the central Delta/lower San Joaquin River are transported (CDFG 2009b, Kimmerer and Nobriga 2008). Highly negative (more negative than -5000) OMR and similarly negative QWEST strongly favor south Delta entrainment (Kimmerer and Nobriga 2008, CDFG 2009b). Reduction in exports at the same inflow levels allowing for a substantially positive QWEST (i.e., as great or greater than the absolute value of OMR at the time) could provide a food subsidy to the low salinity zone (Kimmerer et al. 2018) where most DS rear.

South Delta exports entrain *P. forbesi* (USFWS 2008; Kimmerer et al. 2019), removing organisms that would otherwise support the food webs of the Delta and perhaps Suisun Bay. The positive correlation between July–September Delta outflow and *P. forbesi* density in the low salinity zone provides support for the food subsidy theory (Kimmerer et al. 2018). Alternative 2b and Existing Conditions scenarios in the FEIR show that July to September Delta outflow is generally expected to be similar between the scenarios, except for differences attributable to the changes in X2 criteria beginning in September and continuing in October. In these months Existing Conditions and Alternative 2B scenarios differ by ~2,000-cfs at ~5% to 30% exceedance levels: outflow is ~10,500–11,500 cfs for the Existing Conditions scenario, and ~8,500–9,500 cfs for the Alternative 2b scenario (Figure 37). Such differences, amounting to 50 cumecs (the unit used by Kimmerer et al. 2018), would be predicted to result in reduced *P. forbesi* density subsidy to Suisun Bay.

The importance of the lower San Joaquin River spatial subsidy of *P. forbesi* to the low-salinity zone was also investigated in Section 5.3.9 of the FEIR. The FEIR used CalSim data to analyze of *P. forbesi* to entrainment by the south Delta export facilities using modeled flows in the lower San Joaquin River (QWEST) as an indicator of downstream *P. forbesi* subsidy potential from the lower San Joaquin River to the low-salinity zone. Because QWEST is calculated from CVP and SWP exports, San Joaquin River Flow, and flow from the Cosumnes and Mokelumne Rivers, it provides an indication of net San Joaquin river flow closer to the confluence of the Sacramento and San Joaquin Rivers (Jersey Point). This analysis was based on the assumption that net positive QWEST provides an indicator of *P. forbesi* subsidy potential from the lower San Joaquin River to the low salinity zone. Results suggest that the potential for subsidy of *P. forbesi* to the low-salinity zone may be similar under Alternative 2b and Existing Conditions scenarios in July and August, which have a similar percentage of positive QWEST (Figure 38 and Figure 39) In September the percentage of years with positive QWEST was somewhat greater (nearly 20%) under Alternative 2b compared to the Existing Conditions scenario (~10%) (Figure 40). Uncertainty exists regarding the benefits to DS of such subsidies. For example, the food subsidy might not persist long enough to benefit DS, given the high rate of grazing in the low-salinity zone (Kayfetz and Kimmerer 2017; Kimmerer et al. 2019). Furthermore, a portion of the DS population would not be present to benefit: an appreciable portion of DS population often rears upstream of the low-salinity zone, i.e., an average of 23% (range 2% to 47%) during the 2005–2014 period (Bush 2017). Nonetheless, QWEST is generally expected to be negative under both the Alternative 2b and Existing Conditions scenarios, indicating potential downstream subsidy of *P. forbesi* would be very limited regardless of scenario.

Based on the discussion of summer and fall outflows in Sections 7.4 and 7.5 of this Effects Analysis, and the analysis presented here, Project exports during the summer and fall period reduce food availability to DS rearing in the low salinity zone. Actions which are directed at improving summer and fall flows will minimize these impacts during these periods.

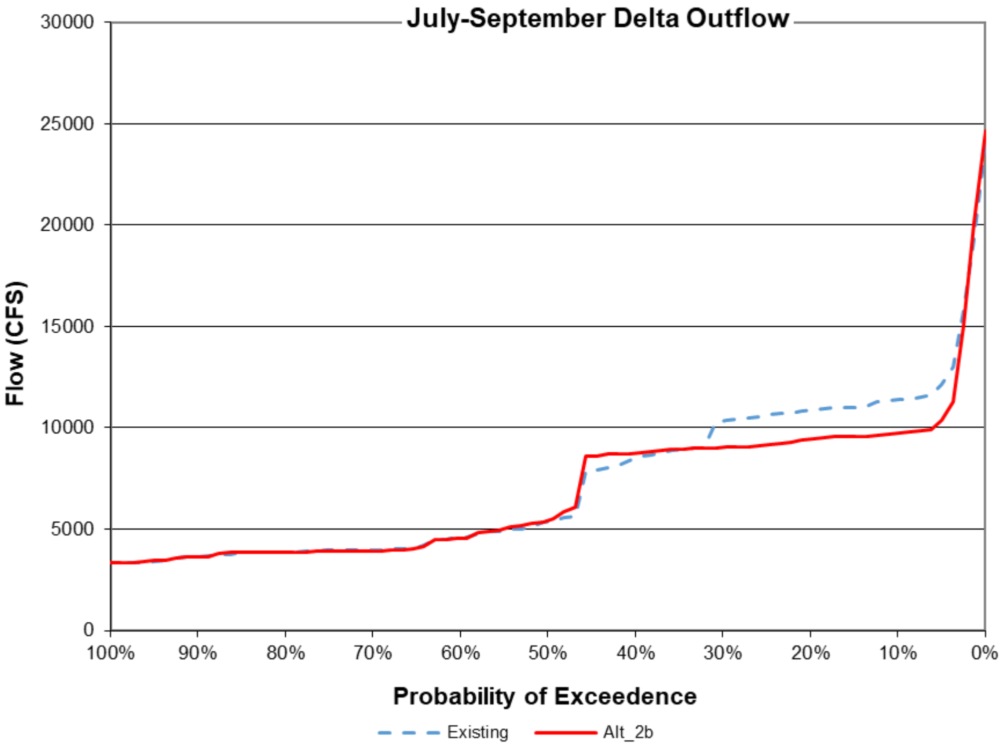

Figure 37: *Mean modeled Delta outflow July – September. Figure 5.3-24 copied from Section 5.3.9 in the FEIR.*

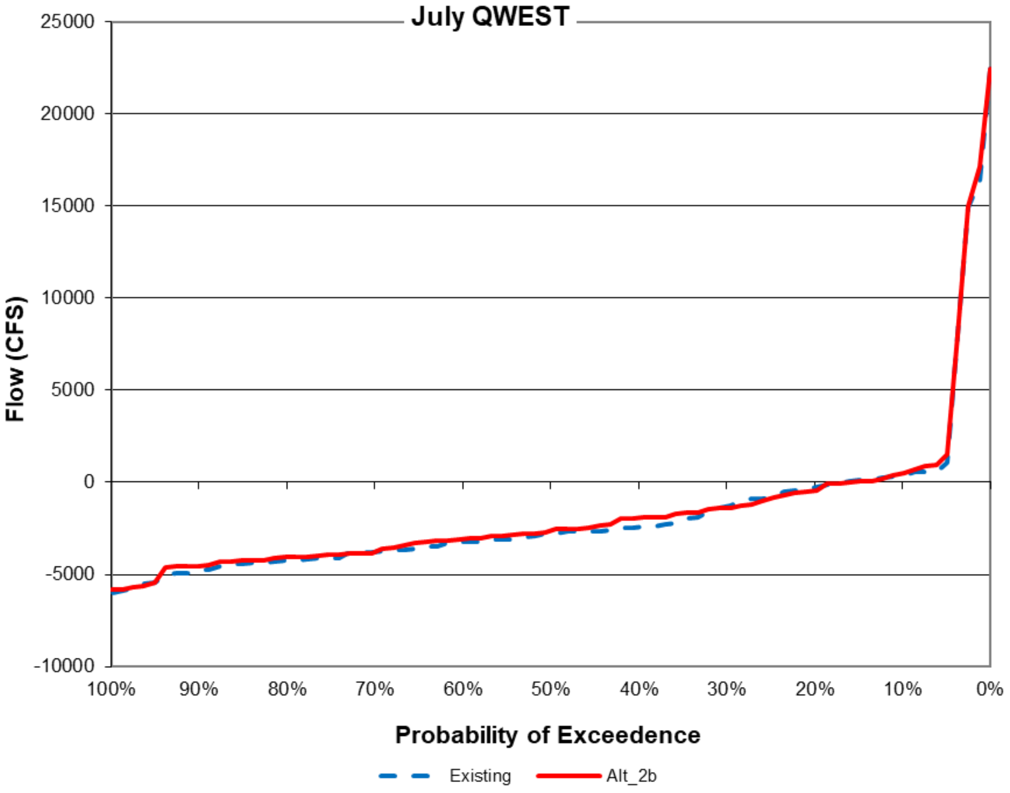

Figure 38: *Mean modeled QWEST flow, July. Figure 5.3-25 copied from Section 5.3.9 in the FEIR*

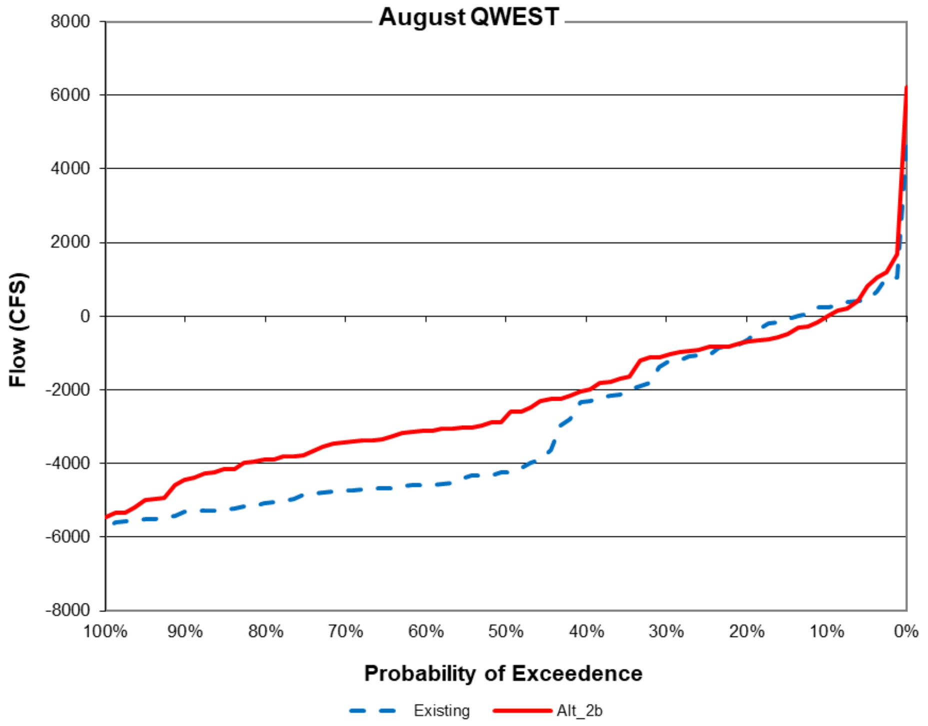

Figure 39: *Mean modeled QWEST flow, August. Figure 5.3-26 copied from Section 5.3.9 in the FEIR.*

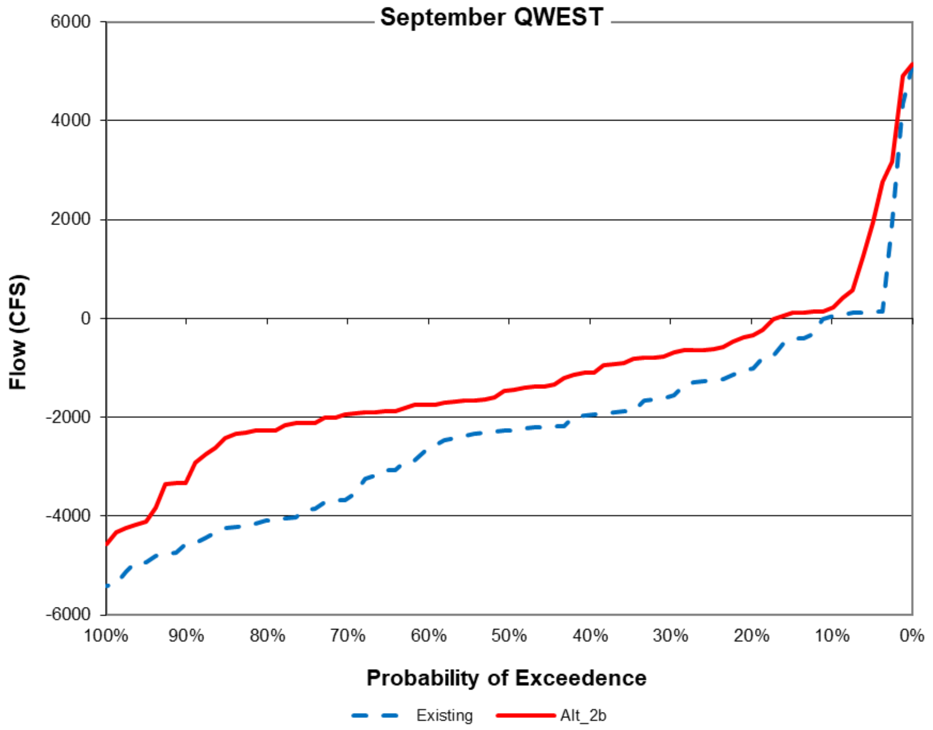

Figure 40: *Mean modeled QWEST flow, September. Figure 5.3-27 copied from Section 5.3.9 in the FEIR.*

8. Minimization of Take and Impacts of the Taking on Delta Smelt

Section 4.2 describes the life history and ecology of DS in the Delta, Suisun Marsh and Suisun Bay. Following the description of DS life history and ecology, Section 7 describes the overlap between Project operations and DS life histories, explaining the ways in which Project operations result in take and impacts of the taking of DS. This section builds upon the preceeding sections and explains how Conditions of Approval in the ITP are expected to minimize the take and impacts of the taking of DS due to the Project.

8.1. Real-time Operations Management – Smelt Monitoring Team

The Smelt Monitoring Team will be composed of technical experts from CDFW, USFWS, DWR, and USBR. The team will compile and interpret the latest near real-time information regarding LFS, which can include catch patterns, developmental stage, distribution, salvage, current and projected operations, water conditions, and modelling results. During weekly meetings, the team will evaluate available information, agree whether a protective action is warranted, and submit a recommendation on what protective actions should be taken. Additional meetings will be convened as appropriate or if required by any of the minimization or mitigation measures listed in this permit. Collaborative real time risk assessment will minimize take of the larval, juvenile and adult life stages of DS by informing and assessing minimization measures.

8.2. OMR Flexibility During Delta Excess Conditions

As described in the ITP Project Description, Permittee may increase exports to capture excess flows in the Delta (hereafter referred to as "OMR Flex") during the OMR Management period of January 1 through June 30[6]. Condition of Approval 8.7 describes specific hydrologic and species-specific restrictions limiting initiation of OMR Flex and imposing off ramps from OMR Flex operations. During OMR Flex operations, Condition of Approval 8.7 requires Permittee to maintain an OMR flow no more negative than -6,250 cfs on a 5-day average.

Permittee will continue to monitor fish in real-time and operate in accordance with additional real-time OMR restrictions described in Conditions of Approval 8.3.1, 8.3.3, 8.4.1, 8.4.2, 8.5.1, 8.5.2, 8.6.1, 8.6.2, 8.6.3, and 8.6.4, which include Conditions that trigger the onset of OMR Management (Integrated Early Winter Pulse Protection, Adult Longfin Smelt Entrainment Protection and Salmonid Presence) as well as other species protection measures such as Turbidity Bridge Avoidance, larval and juvenile DS and LFS protections, salmonid single-year loss thresholds, and salmonid daily loss thresholds.

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[6] OMR Management may start earlier than January 1 if an Integrated Early Winter Pulse Protection action occurs during December (see Condition of Approval 8.3.1) or Adult Longfin Smelt Entrainment Protections (see Condition of Approval 8.3.3) are initiated after December 1. OMR Management may end earlier in June if specific off-ramps occur (see Condition of Approval 8.8).

The first four requirements for OMR Flex require elevated flows in the Sacramento River or San Joaquin River basins. Positive values of QWEST represent a net positive flow at Jersey Point, indicating a positive inflow westward to the Delta. Negative values of QWEST indicate greater potential for fish entrainment at the export facilities due to lower inflow into the Delta (R. Baxter pers. comm.). During wet periods, the San Joaquin River and eastern Delta tributaries (Mokelumne, Cosumnes, and Calaveras rivers) may provide sufficient flow to maintain a net positive flow in the lower San Joaquin River (i.e., positive QWEST) despite high exports at the SWP and CVP facilities. Such flows would tend to transport pelagic organisms in the main San Joaquin River channel toward Suisun Bay. By restricting OMR Flex only when there are elevated flows in the Delta, Condition of Approval 8.7 minimizes the risk of entrainment of all lifestages of DS into the SWP export facilities and south Delta.

Additionally, per Condition of Approval 8.7, if during OMR Flex, any of the last four biological requirements are no longer being met, Permittee must off-ramp OMR Flex to provide protections to listed species by reducing exports to achieve an average OMR Index no more negative than -5,000 cfs on a 14-day average, unless further reduction in exports is required by a specific Condition of Approval. Off-ramp of OMR Flex operations, again driven by analyses and recommendations of the Salmon and Smelt Monitoring Teams, is essential to reducing take of listed smelt when real-time data indicate fish are present in the zone of entrainment and when salvage/loss data indicates fish are being entrained at the facilities.

Together, these eight requirements will minimize entrainment of DS by only limiting OMR Flex operations to times when there is positive Delta inflow from both the Sacramento River and the San Joaquin River basins, there are no controlling Conditions of Approval[7], and the risk of entrainment is low based on risk assessments conducted by the Smelt Monitoring Team.

8.3. Adult Delta Smelt

Adult DS are most vulnerable to entrainment into the SWP facilities when they disperse into the central and south Delta for spawning. DS are strongly associated with turbid water (Feyrer et al. 2007b; Feyrer et al. 2011; Grimaldo et al. 2009; Sommer and Mejia 2013) and turbidity may serve as a cue for migratory DS movements (Bennett and Burau 2014). Historically, higher adult DS salvage coincided with high turbidity associated with first flush events (Grimaldo et al. 2009). The risk of entrainment for DS that move into the central and south Delta is currently highest when net Delta outflow is at intermediate levels (~20,000 to 75,000 CFS) and OMR flow is more negative than negative 5,000 CFS (USFWS 2008). Managing the magnitude of negative OMR flows in combination with regional increases in turbidity can avoid and minimize take of adult DS at the SWP export facilities.

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[7] Controlling Conditions of Approval include 8.3.1, 8.3.3, 8.4.1, 8.4.2, 8.5.1, 8.5.2, 8.6.1, 8.6.2, 8.6.3, and 8.6.4. These conditions includes all Conditions of Approval from 8.3-8.6 with the exception of Conditions of Approval 8.3.2 (Salmonid Presence), 8.4.3 (High Flow Off-ramp for Longfin Smelt OMR Restrictions), 8.6.5 (Funding for CHNSR Hatchery Surrogates), and 8.6.6 (Evaluate Proactive Salmon Entrainment Minimization During Real-time Operations).

8.3.1. Banks Pumping Plant and Clifton Court Forebay

The primary management mechanism to minimize direct take of adult DS at the SWP is through export reduction via OMR flow requirements when conditions in the south Delta pose increased risk to DS, or as determined through risk assessments conducted by the Smelt Monitoring Team. The following Conditions of Approval describe how take of adult DS will be minimized through export restrictions and OMR flow requirements.

Condition of Approval 8.3.1 - Integrated Early Winter Pulse Protection

The Integrated Early Winter Pulse Protection, as described in the ITP, is intended to minimize adult DS entrainment into Old and Middle rivers during the population-scale migration into freshwater spawning habitat in the winter period. This Condition will limit exports to achieve a 14-day average OMR Index of no more negative than -2000 cfs for 14 days during the December 1 through January 31 time period. Integrated Early Winter Pulse Protection conditions are defined as:

1. Running 3-day average of daily flows at Freeport > 25,000 cfs **and**
2. Running 3-day average of daily turbidity at Freeport ≥ 50 NTU; **or**
3. When warranted by real-time monitoring.

This Condition can only be implemented once each water year and is not required if a spent DS female has been found previously in any survey. After 14 days of OMR no more negative than -2,000 cfs, OMR management begins, and OMR flows are limited to no more negative than -5000 cfs until the end of OMR management (Condition of Approval 8.8). The Turbidity Bridge Avoidance Action (Condition of Approval 8.5.1) can be initiated immediately after the Integrated Early Winter Pulse Protection is finished.

The population-scale migration of DS is believed to occur in response to inflowing freshwater and turbidity (Grimaldo et al. 2009; Sommer et al. 2011). Thereafter, fish make local movements with little evidence for further population-scale migration (Polansky et al. 2018). During the population-scale dispersal, the average travel time of adult DS from Chipps Island to the facilities is generally assumed to be between 10-30 days (Sommer et al. 2011). Conceptually, Condition of Approval 8.3.1 protects migrating DS from entrainment by limiting the zone of influence of the south Delta export facilities to allow fish safe passage to spawning grounds, after which the fish are holding and are less vulnerable to export activities (USFWS 2008).

For purposes of this Effects Analysis, we analyzed the timing of Integrated Early Winter Pulse Protection events in the recent historical record to assess the effectiveness of Condition of Approval 8.3.1 in minimizing take of DS. Using an analysis of recent historical hydrology and salvage we assessed whether the action was initiated between 10-30 days before the start of the first DS entrainment events at the export facilities. Analysis of data from 2010 to 2019 in the ITP Application showed that these conditions occurred in December or January in eight of the ten years, with no action in 2014 and 2018 (Figure 41). This Condition was implemented in five out of the eight years (2010, 2011, 2013, 2015, 2019 vs 2012, 2016, 2017). With the exception of 2019, pulse protection would have been implemented within 9 to 29 days before the start of the first DS entrainment event (Figure 41), consistent with the DS migration rate estimated in Sommer et al. (2011). For water year 2019, this value was 45 days but is likely confounded by the lack of DS entrainment due to the historically low population abundance. The first DS entrainment events in 2012 appear to be independent of flow and turbidity at the Freeport gauge (Figure 42). This analysis indicates that the timing of the Integrated Early Winter Pulse Protection will be effective in minimizing take of DS because it would frequently be implemented within 10 to 30 days of the presence of adult DS in salvage, and by limiting negative OMR flows would reduce the entrainment of these adults into CCF and subsequent salvage.

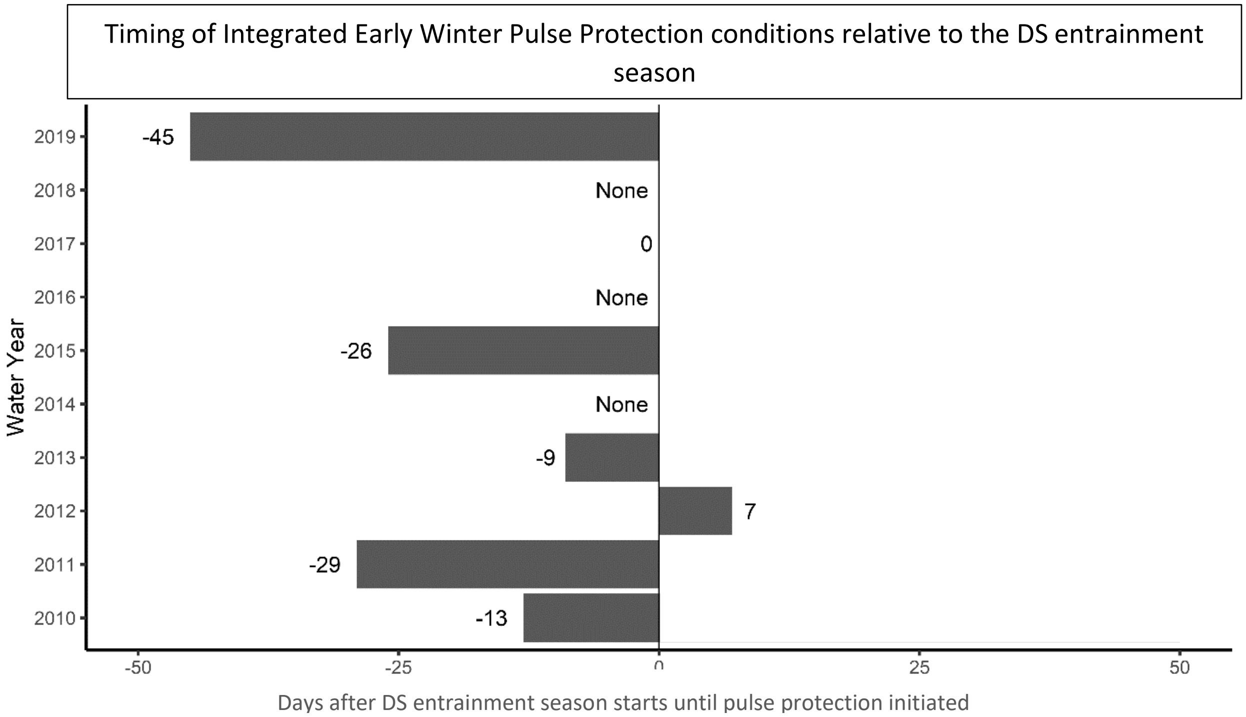

Figure 41: *Difference in date between the first integrated early winter pulse event and the first DS entrainment of the season. A negative value on the X-axis indicates that pulse protection would have occurred before the start of the entrainment season. An integrated early winter pulse protection did not trigger in 2018. 2016, and 2014. A singular entrainment event occurred in the beginning of December of water year 2010 and was removed.*

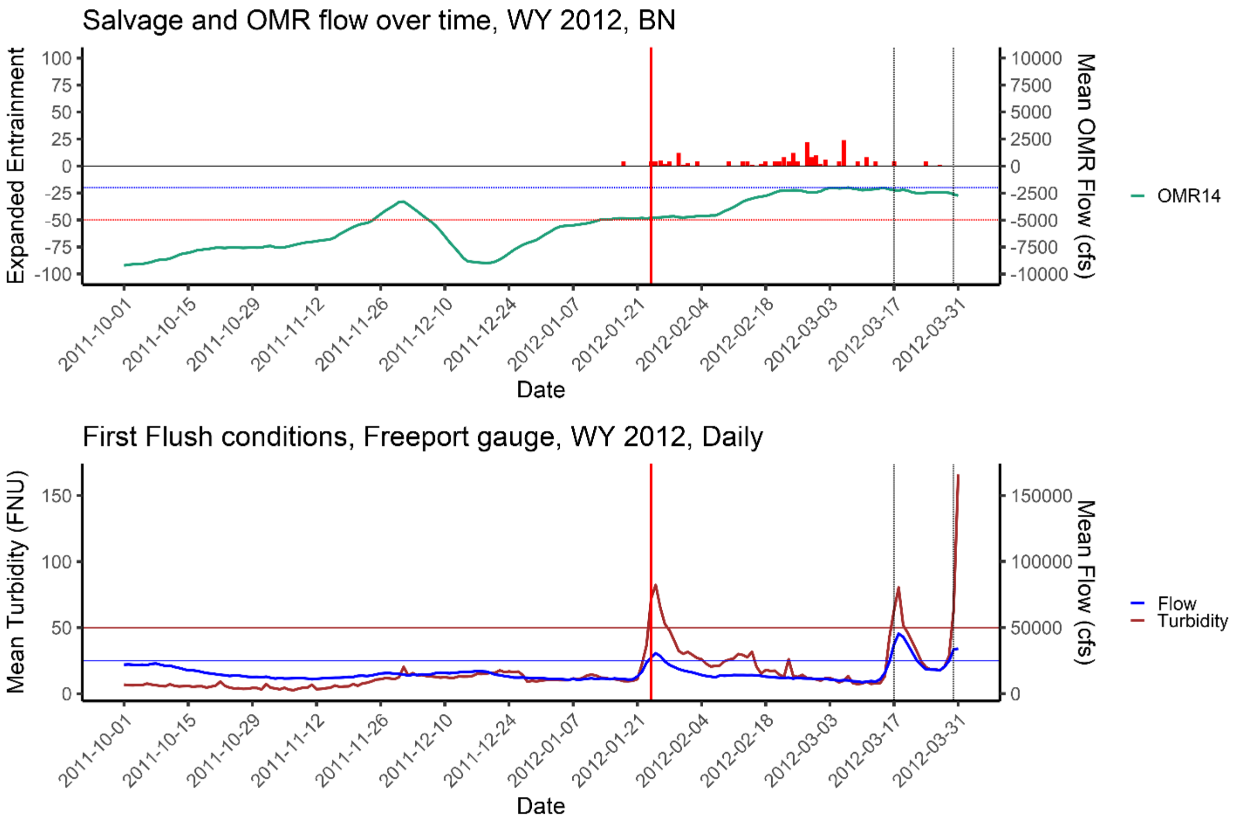

Figure 42: *Date of salvage events of DS (top graph) and Freeport mean daily flow (cfs) and turbidity (cfs) (bottom graph). The horizontal red and blue lines highlight the 50 NTU and 25,000 cfs thresholds, respectively. The solid red vertical line in each graph represents the first integrated early winter pulse event of the season; the dashed vertical lines are subsequent pulse events.*

Condition of Approval 8.3.2 - Salmonid presence

This action will limit exports to achieve a 14-day average OMR Index of no more negative than -5,000 cfs after January 1 when the Salmon Monitoring Team determines that 5% of CHNWR or CHNSR have entered the Delta through the end of the OMR management season, except during periods of OMR Flex. Adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts DS at risk of entrainment at the SWP. After DS spawn and eggs hatch larvae and juveniles are present in the Delta and vulnerable to entrainment as a result of Project operations. DS larvae and juveniles are expected to be present in the Delta from March to June each year. It is well documented that the magnitude of OMR is negatively correlated with entrainment (Grimaldo et al. 2009; USFWS 2008). Therefore, when this Condition of Approval controls Project operations it will reduce entrainment risk to adult DS migrating into the Delta or adults present in the Delta.

Condition of Approval 8.4.1 - Adult LFS Entrainment Protection

Condition of Approval 8.4.1 restricts SWP exports to achieve an OMR Index no more negative than -5000 cfs in response to an adult LFS cumulative combined expanded salvage greater than the immediately previous FMWT index divided by 10. This Condition may trigger between December 1 to February 28 each year. Similarly to what is described above for Condition of Approval 8.3.2, when this Condition of Approval controls Project operations it will reduce entrainment risk to adult DS migrating into the Delta or adults present in the Delta.

Condition of Approval 8.5.1 - Turbidity Bridge Avoidance

Condition of Approval 8.5.1 requires management of exports in order to maintain daily average turbidity at Bacon Island (OBI) less than 12 NTU. If turbidity cannot be maintained at less than 12 NTU after 5 days Permittee shall manage exports to achieve and OMR no more negative than -2,000 cfs until the daily average turbidity at Bacon Island drops below 12 NTU. However, if 5 consecutive days of -2,000 cfs OMR flows do not reduce daily average turbidity at Bacon Island below 12 NTU, the Smelt Monitoring Team may convene to assess the risk of entrainment of DS and provide a recommendation to WOMT regarding changes in operations that could be conducted to minimize the risk of entrainment of DS.

OMR flow is a surrogate indicator of the influence of export pumping at the export facilities on hydrodynamics in the south Delta. The management of OMR flow, in combination with other environmental variables, can minimize or avoid entrainment of fish in the south Delta and salvage facilities. Condition of Approval 8.5.1 has the potential to benefit adult DS from February (potentially January) until April 1 if the turbidity criteria cannot be maintained and OMR flows are temporarily (until turbidity criteria are met) restricted to no more negative than -2,000 cfs.

As discussed in Section 4.2.1.4 of this Effects Analysis, DS population-scale dispersal cues on high turbidity and flow events associated with winter storms. Since entrainment of DS into the south Delta generally occurs when turbidity is high, limiting exports to avoid pulling turbidity into the area is assumed to decrease entrainment of DS into the south Delta. However, our understanding of the degree to which this Action minimizes take of DS cannot be quantified. Qualitatively, this Action is likely to minimize take of DS by limiting export to achieve OMR targets no more negative than -5000 cfs. The potential to limit export to achieve OMR no more negative than -2000 cfs for 5 consecutive days will offer greater protection and minimization against DS entrainment.

Conditions of Approval 7.4, 7.4.1, 7.4.2 and 8.15 - Skinner Fish Salvage Facility operations and staff

Duties of the CDFW staff at the Skinner Fish Facility include, but are not limited to: receive daily salvage data from the fish facilities, conduct QA/QC on salvage data, train salvage facility staff, oversee salvage facility operations, work with DWR to develop a revised Salvage Facility Protocol, and engage in real-time decision making to determine whether reduced count times are appropriate. The salvage process at the Skinner Fish Facility generates one of the largest data sources characterizing entrainment and take of DS with a high amount of sampling effort. The duties performed by these staff will ensure proper identification of state and federally listed osmerids at the Skinner Fish Facility, which allows for an accurate calculation of loss which will trigger subsequent protections. These staff will also maintain consistency in operating to the established protocols to ensure generation of a robust dataset with QA/QCed data. This salvage data will be used in OMR Management to curtail exports during periods of high entrainment risk as identified by increased salvage. Together, these Conditions of Approval will serve to minimize take by facilitating implementation of Conditions of Approval that rely upon salvage data.

Conditions of Approval 7.6.2 and 7.6.4 in combination with Condition of Approval 8.16 and the AMP
Together, Conditions of Approval 7.6.2, 7.6.4, and 8.16 will support new monitoring and science to improve understanding of DS entrainment risk as a result of Project operations and DS ecology. These Conditions of Approval will contribute to our existing knowledge of DS by requiring additional monitoring and science focused on improved understanding of DS ecology and Project impacts:

- New larval monitoring to quantify entrainment risk and entrainment of larval DS and LFS into CCF.
- New science and monitoring to:
    - Better characterize DS summer-fall habitat and the effects of habitat on DS survival.
    - Understand habitat benefits associated with implementation of the Summer-Fall Action and deployment of the Additional 100 TAF each year

When implemented, this suite of monitoring and science will better inform understanding of take and related impacts of the taking as a result of Project operations and methods to proactively minimize take and related impacts. New science and monitoring will be synthesized and evaluated as a part of the AMP as described in Condition of Approval 8.16 and Attachment 2 to the ITP. Review and synthesis as a part of the AMP may result in recommendations regarding operational components of the ITP, and consequently Permittee may request an amendment of the ITP based on new information and science.

8.4. Larval and Juvenile Delta Smelt

Young DS are most vulnerable to entrainment when they hatch within the zone of influence of export facilities. Newly hatched DS behave as passive particles, typically occurring near the surface, until they develop an air bladder at 15-16 mm total length (Wang 2007, Bennet 2002). Thus, larvae are likely dispersed via tidal currents and net flows. Managing OMR flow when larval DS are within the zone of influence of export facilities will minimize the amount of larval fish entrained into the southern Delta and SWP export facilities. Similarly, salvage of juvenile DS (≥ 20 mm) has been shown to be directly influenced by OMR (Grimaldo et al. 2009), indicating that OMR management can serve to also minimize entrainment of juvenile DS.

8.4.1. Banks Pumping Plant and Clifton Court Forebay

Condition of Approval 8.5.1 – Larval and Juvenile Delta Smelt Protection

OMR flow criteria chiefly serve to constrain the magnitude of reverse flows in the Old and Middle rivers, limit entrainment of larval and DS into CCF and the south Delta, and increase the likelihood that DS hatching in the lower San Joaquin River can successfully out migrate. Recent research has shown that OMR management has lowered adult and post larval entrainment mortality (Smith 2019). OMR criteria described in the ITP are designed primarily to restrict operations and minimize the deleterious effects of changes in south Delta flows as a result of Project operations, (i.e., they would reduce the magnitude of reverse flows in Old and Middle Rivers). Condition of Approval 8.5.1 requires OMR to be established within a range of target flow levels, from -1,250 cfs to -5,000 cfs, and minimizes direct take of larval and juvenile DS by applying an appropriate level of protection based on informed advice from the Smelt Monitoring Group. This advice will incorporate all relevant and available information including distribution data from field collections, abiotic factors such as water temperature, turbidity and forecasted hydrology as well as population trends and knowledge of life history.

As discussed in Sections 4.2.1.8 of this Effects Analysis, salvage of all life stages of DS has become increasingly rare as the population declines. Any single salvage event potentially represents take of a large portion of individuals present in the south Delta. Salvage has become difficult to predict and now appears to be sporadic and random. Juvenile salvage thresholds in Condition of Approval 8.5.2 are intended to provide OMR flows that minimize subsequent entrainment when a salvage event occurs while simultaneously initiating discussion to determine what additional actions, if any, are needed to prevent minimize take. The juvenile salvage threshold is scaled to relative abundance, as indexed by FMWT, to provide greater protections when the population abundance is low. A second level of export restrictions and associated minimization is required if juvenile salvage continues following the initiation of OMR restrictions initiated by the prior salvage event.

8.4.2. Barker Slough Pumping Plant

BSPP is operated year-round, including times when DS larvae may be present and susceptible to entrainment. The diversion is located in or near DS spawning habitat in the north Delta. Per screening criteria required by CDFW, each of the ten BSPP bays is individually screened with a positive barrier fish screen consisting of a series of flat, stainless steel, wedge-wire panels with a slot width of 3/32 inch. This configuration is designed to exclude fish approximately 25 mm or larger from being entrained. The bays tied to the two smaller units have an approach velocity of about 0.2 44 ft/s. The larger units were designed for a 0.5 ft/s approach velocity, but actual approach velocity is about 0.44 ft/s.

Condition of Approval 8.12 – Barker Slough Pumping Plant Longfin and Delta Smelt Protection

By design, the BSPP fish screens are considered sufficiently protective for older juvenile DS (FL ≥ 25mm), however, operational guidelines are needed to protect younger DS juveniles and larvae. Although positive barrier fish screens similar to those in Barker Slough have been shown to exclude larval fishes smaller than their design criteria (Nobriga et al. 2004), their effectiveness has not been evaluated when placed at the back of a dead-end slough like the Barker Slough screens. Export restrictions for BSPP during dry and critical years will minimize take of larval and young juvenile DS by curtailing exports when they are known or expected to be present based on detection at a nearby sampling station or pertinent abiotic and biotic factors.

8.5. End of OMR Management: Salmon and Smelt Temperature Off-ramps

The following analysis evaluates entrainment minimization achieved from Condition of Approval 8.8. as a result of the smelt-specific temperature off-ramps from OMR Management, which must be met for OMR Management to off-ramp prior to June 30.

To evaluate the effectiveness of the species-specific OMR Management temperature off-ramps in reducing entrainment, this analysis included a review of DS and LFS temperature tolerance and their historical presence in the south Delta in June, historical review of estimates of CHNWR and CHNSR exit from the Delta, historical entrainment of CHNWR and CHNSR, evaluation of when the specified temperature stations would have historically off-ramped OMR, and historic temperature variability across the interior Delta. To evaluate the protectiveness of CCF as an OMR Management temperature off-ramp for DS and LFS, scientific literature was reviewed in addition to salvage data, to determine both the presence in the south Delta during June as well as thermal tolerances of both species.

Temperature Station Off-Ramp

Daily mean temperature data for the month of June in water years 2010-2019 was obtained from CDEC for the three OMR Management temperature off-ramp stations: Mossdale, Prisoner's Point, and CCF. Data from each station was filtered to only include the specific day in June of each water year in which OMR Management was off ramped at that station based on the temperature criteria.

Temperature Variability Across the Delta

Using CDEC, thirteen temperature stations were selected to represent the southern, central, and northern regions of the interior Delta. These stations included: MSD, CLC, BDT, MHO, OH4, SJG, OBI, TRN, HLT, ORQ, BET, PRI, and BLP (Table 12 and Figure 43).

Table 12: *Temperature stations in the interior Delta listed south to north by location*

Temperature Station (south to north)	Location
MSD	San Joaquin River at Mossdale Bridge
CLC	Clifton Court Forebay
BDT	San Joaquin River at Brandt Bridge
MHO	Middle River near Howard Road Bridge
OH4	Old River at Highway 4
SJG	San Joaquin River at Garwood Bridge
OBI	Old River at Bacon Island
TRN	Turner Cut near Holt
HLT	Middle River near Holt
ORQ	Old River at Quimbly Island Near Bethel Island
BET	Bethel Island
PRI	San Joaquin River at Prisoner's Point near Termino
BLP	Blind Point

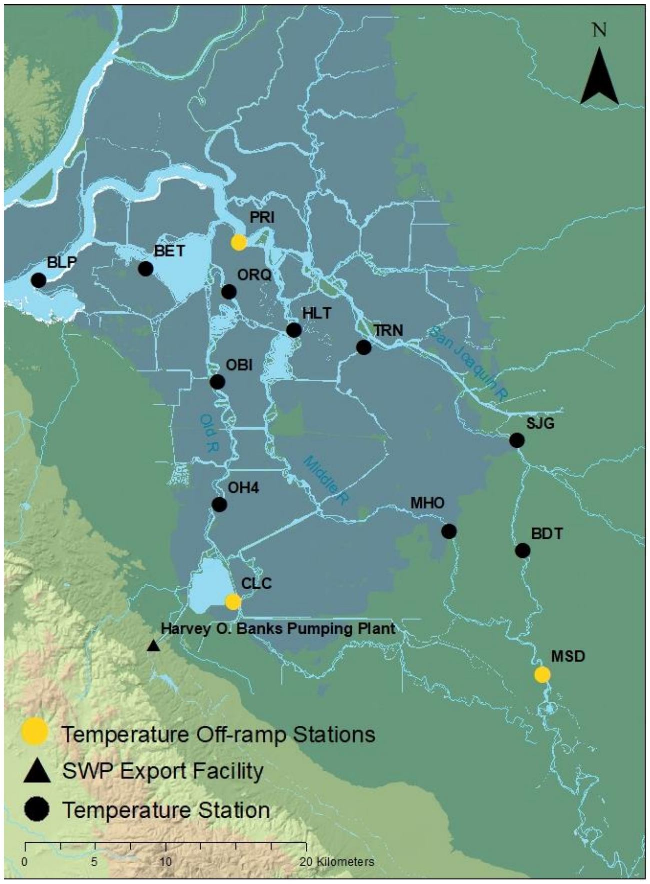

Figure 43: *Map of the interior Delta showing the locations of the thirteen temperature stations. Temperature stations that off-ramp OMR Management as described in Condition of Approval 8.8 are indicated with a yellow dot.*

The temperature stations specific to OMR Management are MSD, CLC, and PRI. Daily mean temperature data for the month of June was downloaded from CDEC for each station for water years 2010 to 2019. Temperature data for all stations was filtered to only include dates with daily mean temperatures of 22.2°C or greater in June to determine the dates in which the temperature off-ramps were met. The date of the seventh non-consecutive day of temperatures exceeding 22.2°F (Mossdale and Prisoner's Point) and date of the third consecutive day of temperatures exceeding 25°C (CCF) were identified as the "off-ramp" dates for salmonids and smelt, respectively, for years 2010-2019. The June temperature dataset was visually analyzed by plotting individual box plots for each station within each year.

Results and Discussion

Larval and juvenile DS are generally found inhabiting water temperatures below 25°C (Nobriga et al. 2008; Sommer and Meija 2013). This upper thermal limit of 25°C is consistent with physiological studies of larval and juvenile DS in the lab (Swanson et al. 2000; Komoroske et al. 2014). This is further supported by historic salvage data which indicates that while juvenile salvage has occurred in July in the past, it was uncommon and appeared sparse compared to juvenile salvage data prior to July (see Figure 27 in Section 7.2 of this Effects Analysis). Therefore, it is expected that DS move out of the south Delta once temperatures approach this limit. As such, when south Delta temperatures reach a daily average of 25°C for three consecutive days at CCF, it is expected that DS are no longer within the entrainment zone of the SWP. Thus, the OMR Management off-ramp temperature station at Clifton Court Forebay effectively minimizes take of DS.

For larval and juvenile LFS, thermal stress occurs at water temperatures of 20°C and above (Jeffries et al. 2016). Most LFS will begin moving out of the Delta in the early summer as water temperatures approach their thermal limit. Salvage data indicates that juvenile LFS have generally left the south Delta by June in most years. While salvage would occasionally occur, it was generally sparse (see Figure 13 in Section 5.3 of this Effects Analysis). By the end of June, most LFS should be emigrating downstream toward more saline habitats, with some rearing in intermediate salinities in San Pablo Bay, while a successively smaller, remnant group of fish rears in Suisun Bay during the summer (Baxter 1999). Therefore, when south Delta temperatures reach a daily average of 25°C for three consecutive days at CCF, it is expected that LFS are no longer within the entrainment zone of the SWP. Thus, the OMR Management off-ramp temperature station at Clifton Court Forebay effectively minimizes take of LFS.

Temperature Station Off-Ramp

Table 13 provides a summary of the dates in June during each water year (2010-2019) in which the OMR Management species-specific temperature off-ramps established in Condition of Approval 8.8 would have occurred.

Table 13: *OMR temperature off-ramps occurring in June during water years 2010-2019 for each temperature station. The blue and green highlights indicate which temperature station would have off-ramped OMR Management for salmonids and smelt, respectively, prior to June 30. The asterisk (*) indicates years in which OMR Management ended on June 30 because a temperature off-ramp did not occur.*

Water Year	Clifton Court Forebay Prisoner's Point (25°C for 3 consecutive days)	Mossdale (22.2°C for 7 consecutive days)	Prisoner's Point (22.2°C for 7 consecutive days)
2010	June 30*	June 30*	June 30
2011	June 30*	June 30*	June 30*
2012	June 30*	June 15	June 30*
2013	June 30*	June 7	June 30*
2014	June 10	June 7	June 10
2015	June 14	June 7	June 13
2016	June 7	June 7	June 5
2017	June 25	June 30*	June 22
2018	June 14	June 24	June 25
2019	June 30*	June 30*	June 30*

For smelt, the CCF temperature station would have off-ramped OMR Management in 5 of the 10 years. For the other 5 years, the OMR Management end date of June 30 would have off-ramped OMR Management for smelt prior to temperatures exceeding 25°C for 3 consecutive days at CCF. As discussed above, few smelt, if any, are expected to be in the Delta past June or when water temperatures meet or exceed 25^{o}C in the south Delta, therefore the off-ramp sufficiently provides entrainment protections for both smelt species if present in June.

Temperature Variability Across the Delta

As shown in Figure 44, most water years (2012-2016 and 2018) show a decreasing trend in water temperature from the southern Delta near CCF to Prisoner's Point on the San Joaquin River. However, in wetter water years (2011, 2017, and 2019), the trend reverses and shows water temperatures increasing from CCF to Prisoner's Point. This may be due to relatively low residence time on the San Joaquin River under higher flows, which would indicate that regional temperature stratification within the southern Delta is likely influenced by the magnitude of San Joaquin River inflow. Water temperatures across the Delta were relatively uniform in 2010.

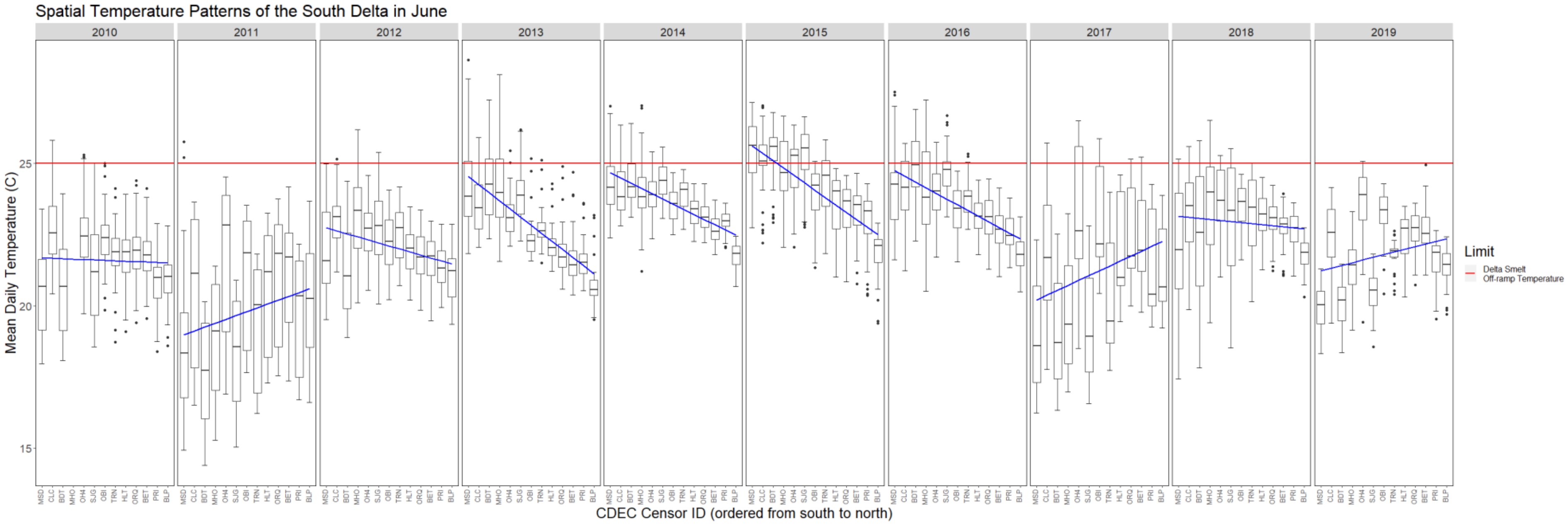

Figure 44: *Box plots showing mean daily temperature trends in the month of June for each water year from 2010 through 2019. Temperature stations are listed on the x-axis in order from south (MSD; Mossdale) to north (BLP; Blind Point). The blue trendlines indicate the direction of temperature change across the interior Delta as represented by the temperature stations. The salmonid OMR Management temperature offramp of 22.2°C is represented by a solid red line. The smelt OMR Management temperature off-ramp of 25°C is represented by a dashed red line.*

The smelt and salmonid OMR Management off-ramp temperature stations at CCF and MSD are located in the southern portion of the interior Delta and are assumed to be representative of conditions for fish throughout the southern Delta. As described above, the smelt temperature station at CCF provides entrainment protection to smelt as both DS and LFS are not expected to present in the interior Delta as water temperatures increase in June. Similarly, CHNWR are also not expected to be present in the interior Delta in June, while CHNSR may still be emigrating during this time. The salmonid OMR Management off-ramp temperature station PRI is located along the edge of the zone of entrainment and near the junctions of the San Joaquin River, Middle River, and Mokelumne River. Its location is significant because salmonids entrained through Georgiana Slough and the DCC pass through this area during their juvenile emigration. PRI is also located in the central Delta, which has different temperature patterns compared to the southern region in most years. To best represent thermal conditions experienced by salmonids across the Delta it is important to equally represent temperatures from the San Joaquin River and south towards CLC for the OMR Management temperature off-ramp. As shown in Figure 44 above, even in drier water years (2013-2015), temperatures near PRI are still below the temperature off-ramp for salmonids.

8.6. Summer Operation of the Suisun Marsh Salinity Control Gates

Salinity in Suisun Marsh is typically managed through operation of the SMSCG. 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. DWR has typically operated the SMSCG from October through May, and the gates remain open from June through September. In 2018, DWR implemented a pilot study to understand how salinity changes within the marsh based on tidal gate operations during the summer (DWR 2018). In 2018 this “re-operation” of the SMSCG was proposed as a tool for managing the size and extent of DS habitat within the Marsh and surrounding areas during times of the year where preferred habitat is limited and often constrained to the confluence (see discussion under Section 7.4, above).

Previous UnTrim models suggested that operation of the SMSCG during August of 2018 would produce salinity conditions within the marsh and parts of Grizzly Bay lower than what was expected to occur under normal operations (Figure 45). However, our analysis of empirical water quality data from August of 2018 was unable to conclude whether salinities changed in Grizzly Bay as predicted by modeling due to a lack of fine scale sampling stations in the margins of Grizzly Bay (Figure 47). Salinities in the marsh were reduced as predicted by the model and this likely provided some additional low salinity conditions in the marsh through the first week of September after the action ended. It is possible that the changes in salinity occurred away from the nearest CDEC stations in Grizzly Bay (Figure 46) and would therefore present a finding of no change.

To support the ITP application and the FEIR, DWR conducted an additional analysis of salinity conditions within Suisun Marsh and surrounding areas for August 2012 and 2017 based on tidal operations of the SMSCG using a different 3D hydrodynamic model, SCHISM (ITP application Appendix C). According to the

SCHISM outputs presented within the application and supporting information, SMSCG tidal operation would not improve water quality over an appreciable acreage in Grizzly Bay during the operation period, and appeared to rotate the salinity field in a way that slightly reduces low salinity zone habitat, as shown in (Figure 49). However, appreciable changes in salinity would occur within Suisun Marsh. SCHISM modeling was also used to simulate gate operations for August of 2009, a dry year, and produced similar results to the analysis of 2012[8] (Figure 50).

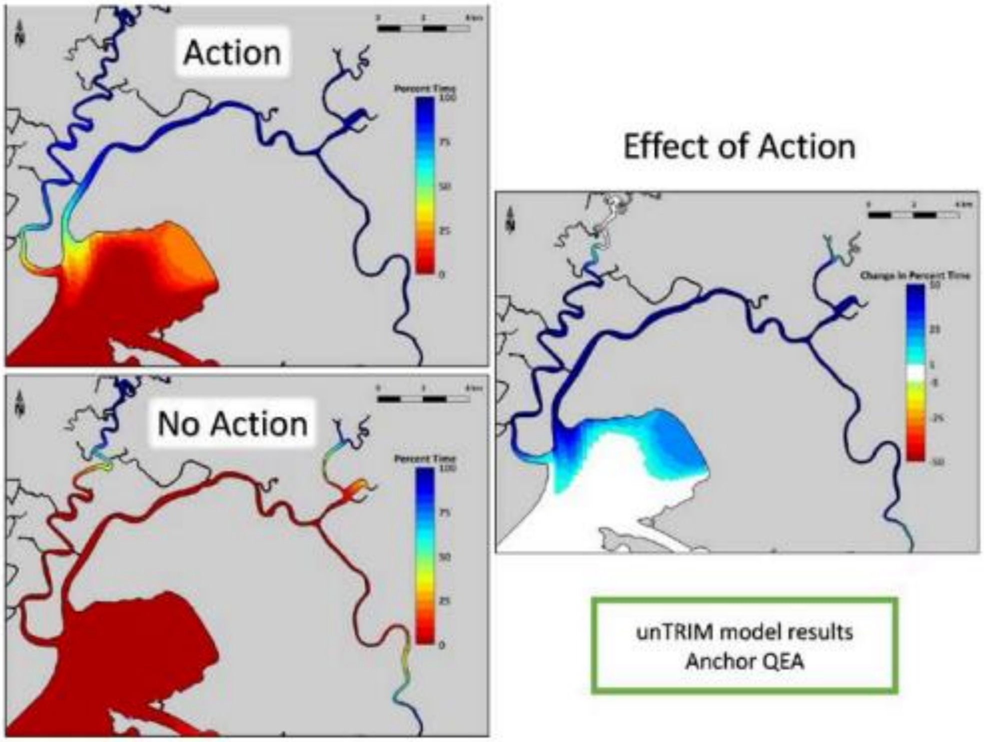

Figure 45: *UnTrim modeling of average August 2018 habitat conditions in the Suisun Region with and without the SMSCG Action (left panels) and their net effect (right panel). The graph is summarized based on the percentage of time that habitat was <6 psu [Figure 14 from (DWR 2019)].*

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[8] Additional SCHISM modeling results were transmitted to CDFW to support the ITP Application in January and February 2020 to depict changes in DS habitat expected as a result of SMSCG operations during the summer of a dry year.

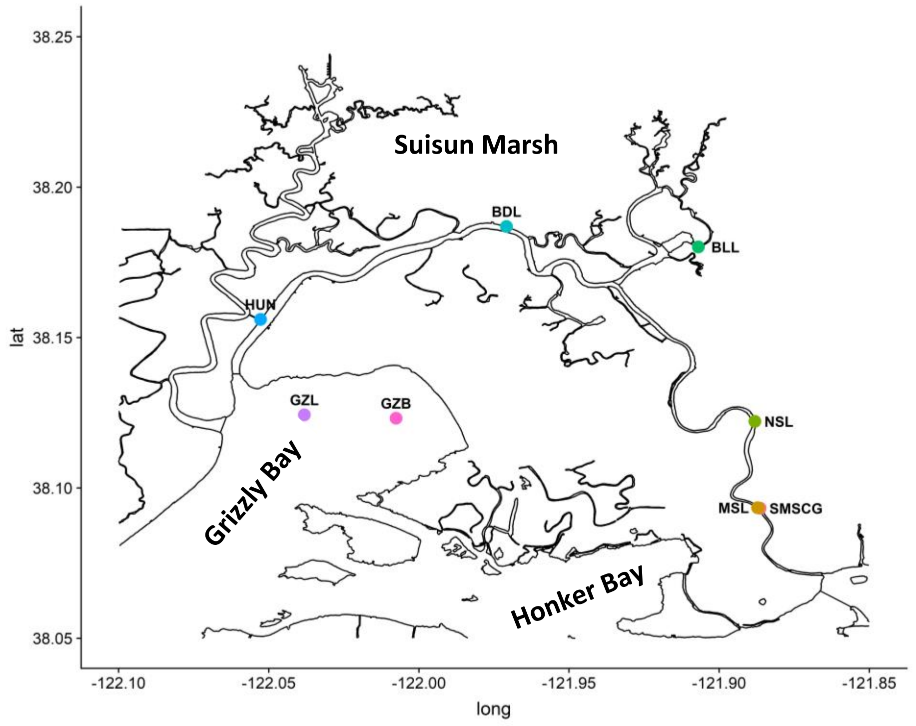

Figure 46: *Map of CDEC water quality stations within Suisun Marsh and Grizzly Bay. All seven stations and the SMSCG are plotted on the map with their respective abbreviations. The SMSCG and MSL are the most upstream locations while GZB is the most downstream location.*

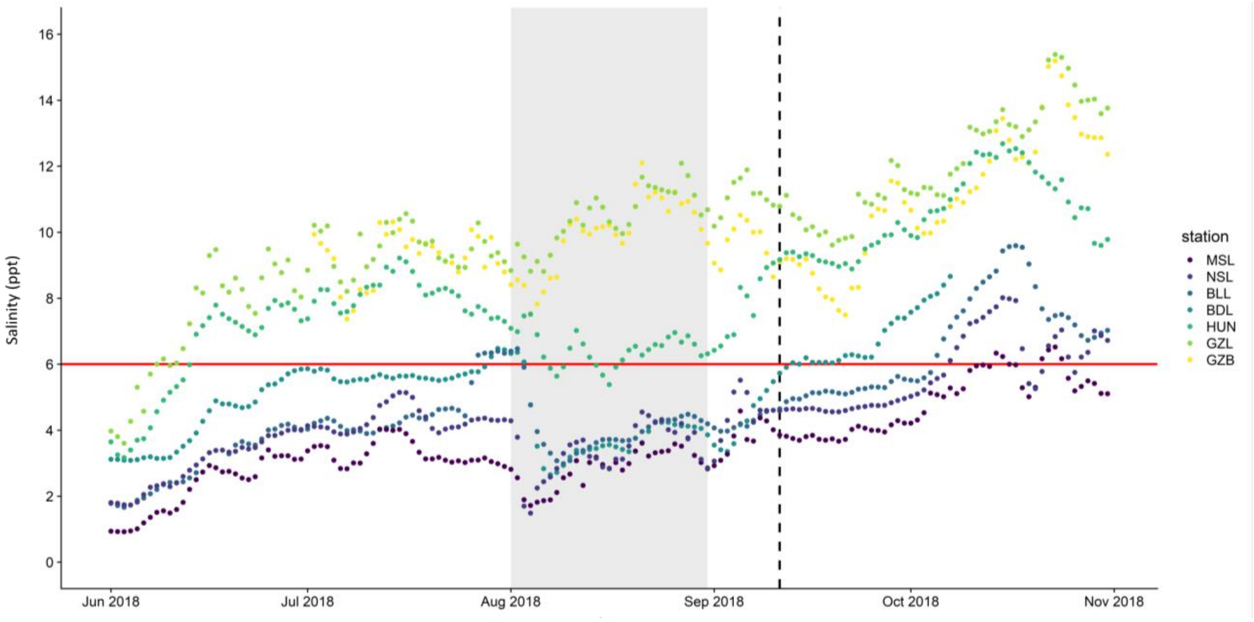

Figure 47: *Salinity over time per station during the pilot SMSCG study in August 2018. Daily average salinity (ppt) plotted on the y-axis. The shaded box represents the period of SMSCG operation; a horizontal red line represents 6 ppt; and a vertical dashed line represents September 11, the date after which salinities appear to return to pre-operation levels.*

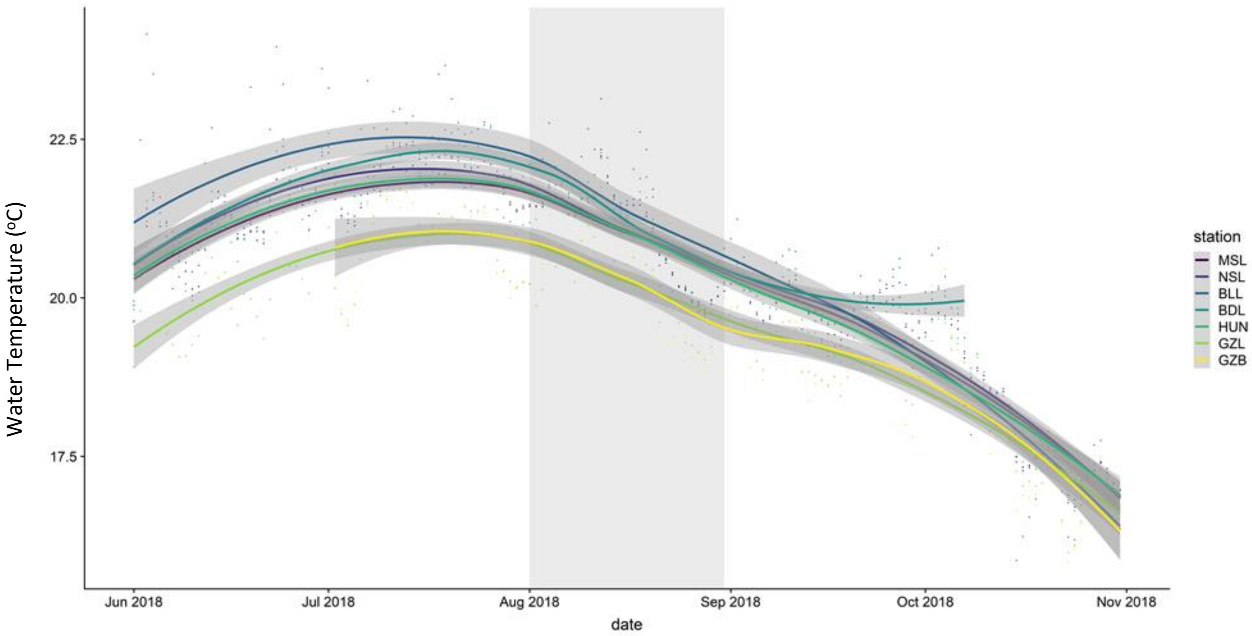

Figure 48: *Temperature at seven stations within Suisun Marsh and Grizzly Bay through the summer and fall of 2018. The lines are LOESS smoothers of water temperature to depict data trends. The shaded box represents the period of SMSCG operation.*

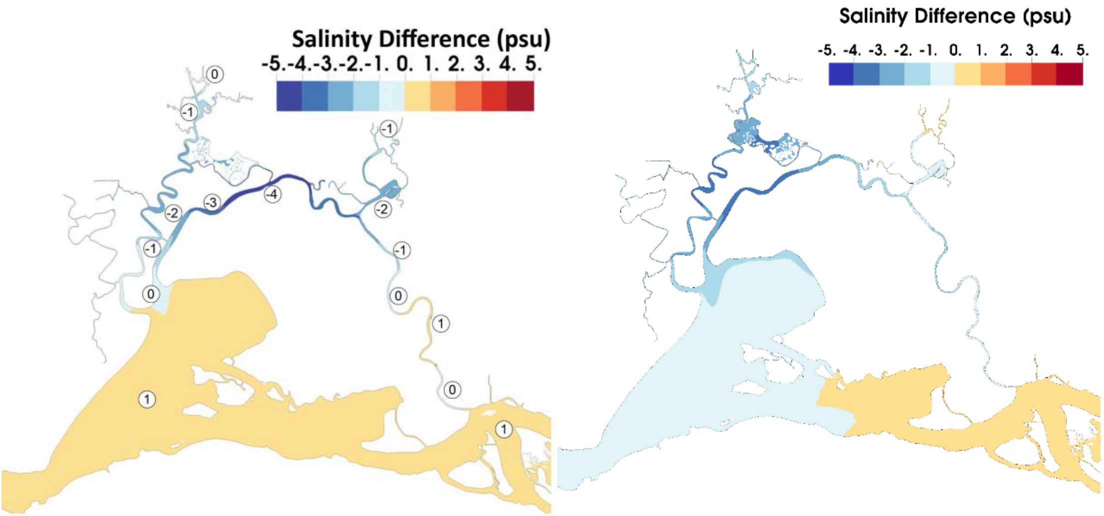

Figure 49: *Modeled change in salinity over two-week intervals in the Suisun Marsh region induced by operating the SMSCG tidally starting August 14, 2012 (left) and salinity change induced by the 60 day continuous SMSCG operation in 2009, averaged over Aug 1,2009 to Aug 14, 2009 (right).*

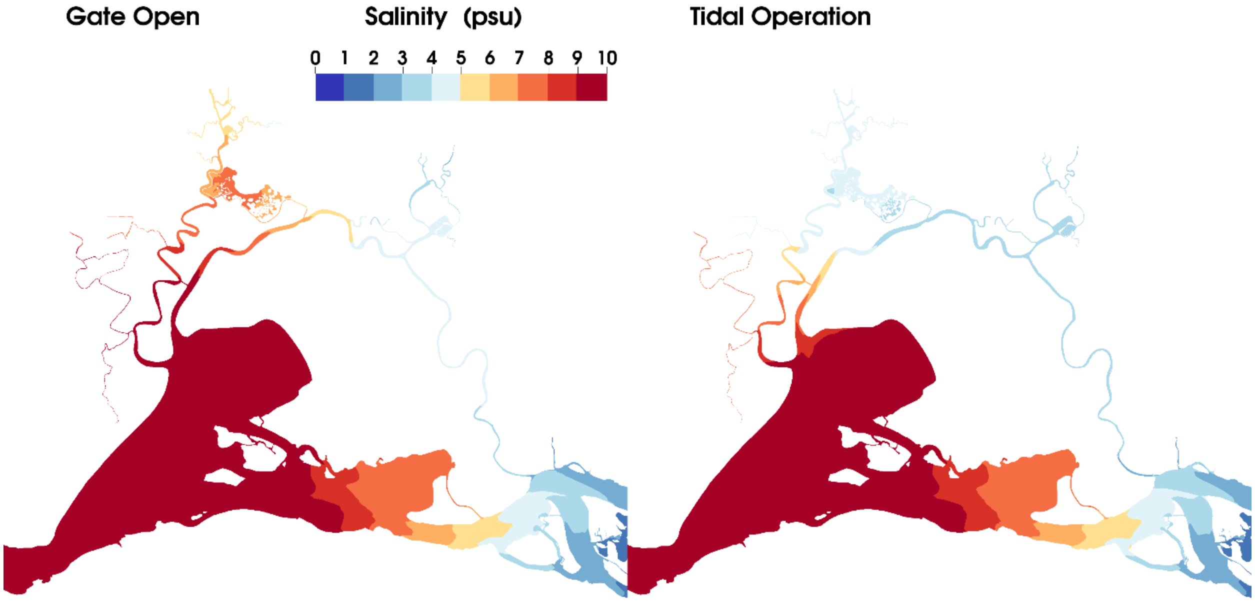

Figure 50: *SCHISM results for SMCG operations in a dry year (2009). Depth averaged salinity, averaged from Aug 1,2009 to Aug 14 2009 is shown.*

Based on both the results of the 2018 pilot study and in combination with model results presented in the 2019 ITP application and supplemental information, the SMSCG tidal operation appears to reliably freshen Suisun Marsh but the extent of the effect within Grizzly Bay remains unclear. Additionally, variation in model outputs between years suggests that salinity conditions in Grizzly Bay may require further study to determine the extent of low salinity habitat produced through summer operations of the SMSCG. The importance of understanding the changes in salinity within Grizzly Bay is apparent when considering water temperatures during the SMSCG pilot study, where temperatures in Grizzly Bay were consistently 1-2°C cooler than areas of Suisun Marsh through most of the summer and fall (Figure 48), and consequently would have provided more favorable habitat to DS should salinity have been reduced. This uncertainty will be addressed and resolved by Condition of Approval 9.1.3.3 which requires new monitoring stations in and near Grizzly Bay to better understand changes in DS habitat as a result of SMSCG operations. Increased monitoring in Grizzly Bay will aid in minimizing impacts to DS by determining the extent of low salinity habitat within the area as a result of gate operations, in addition to the observed changes in salinity within Suisun Marsh. If suitable salinities occur in northern Grizzly Bay during the summers of below normal and dry years than DS may have access to potential thermal refuge during peak summertime temperatures.

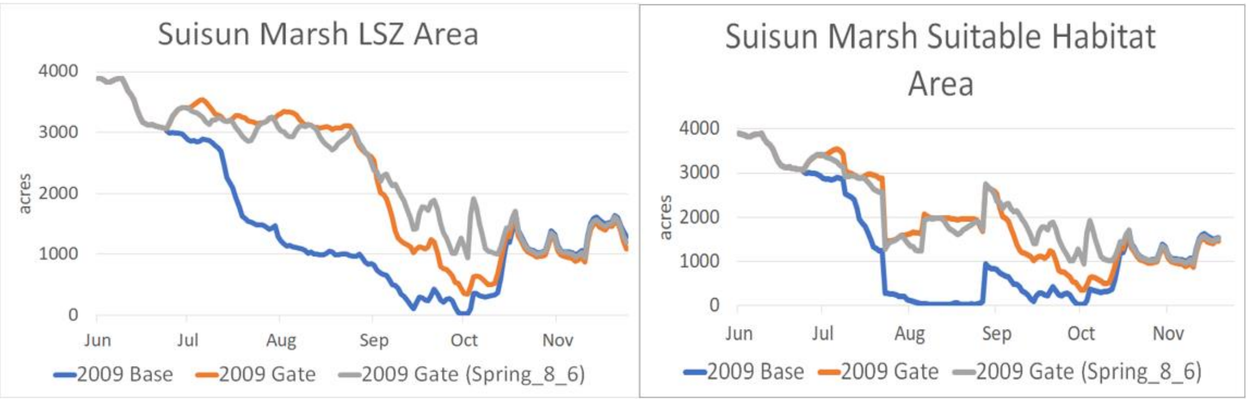

Figure 51: *Suisun Marsh low salinity zone and 3-factor suitable habitat area based on turbidity, water temperature, and salinity.*

In addition to the anticipated benefits from operating SMSCG for a 60-day period in the summer, the action is also expected to produce some low salinity conditions in the fall of BN and D years as an ancillary effect of operating the SMSCG in the summer (Figure 51). Salinities at Belden's Landing remained low, around 4 ppt, for 1-2 weeks following the end of SMSCG operations associated with the test pilot in August 2018. This additional habitat will diminish in size over time as salinity returns to baseline conditions or until SMSCG operations resume in October. However, incremental increases in DS habitat will provide some amount of additional minimization in the fall of BN and D years.

Improvements in DS summer habitat through SMSCG operations are required as mitigation for impacts to DS and described in Conditions of Approval 9.1.3, 9.1.3.1, 9.1.3.2, and 9.1.3.3.

8.7. Fall X2

Ongoing scientific research has demonstrated that changes in abiotic conditions encountered by rearing DS in the fall have significant overall effects on population size. From September through December, sub-adult DS distribution and survival responds to changes in abiotic conditions in the low salinity portion of the estuary. USFWS (2008) defined suitable habitat for DS during this time period as "the abiotic and biotic components of habitat that allow DS to survive and grow to adulthood". Biotic components of habitat include suitable amounts of food resources and sufficiently low predation pressure; abiotic components of habitat include the physical characteristics of water quality parameters, especially salinity and turbidity. As described above, many of these abiotic and biotic components of fall habitat for DS are typically enhanced when the low salinity zone extends into Suisun Bay and Marsh. Condition of Approval 9.1.3.1 will provide low salinity habitat in parts of Grizzly Bay and Honker Bay and most of Suisun Marsh by requiring an X2 of 80 km on a 30-day average for the months of September and October in wet and above normal water years. This Condition of Approval will provide DS access to parts of Suisun Bay and Marsh where regional water temperatures are lower (Figure 48), turbidities are higher, and survival is improved.

UnTrim modeling of DS low salinity zone habitat distribution in the vicinity of the Sacramento-San Joaquin confluence through Suisun Bay during the fall indicates that an X2 of 80 km would be the minimum location in which portions of Grizzly Bay are still within the extent of the low salinity zone

(Figure 52) Similar models have estimated the surface area of the low salinity zone based on X2 locations. These models show that a X2 of 80 km produces approximately 1,340 hectares more low salinity habitat than a X2 of 81 km, representing a 25% increase (Table 2-1 in Brown et al. 2014). Whereas shifting X2 to locations upstream of 81 km results in smaller, incremental changes, indicating that the low salinity zone is constrained to the confluence with little variation in surface area when upstream of 80 km. Estimates of the distribution of DS suitable habitat based on methods developed in Feyrer et al. (2011) also show an increase in suitable habitat index when X2 is held at 80 km as compared to 81 km (Table 3-1 in Brown et al. 2014).

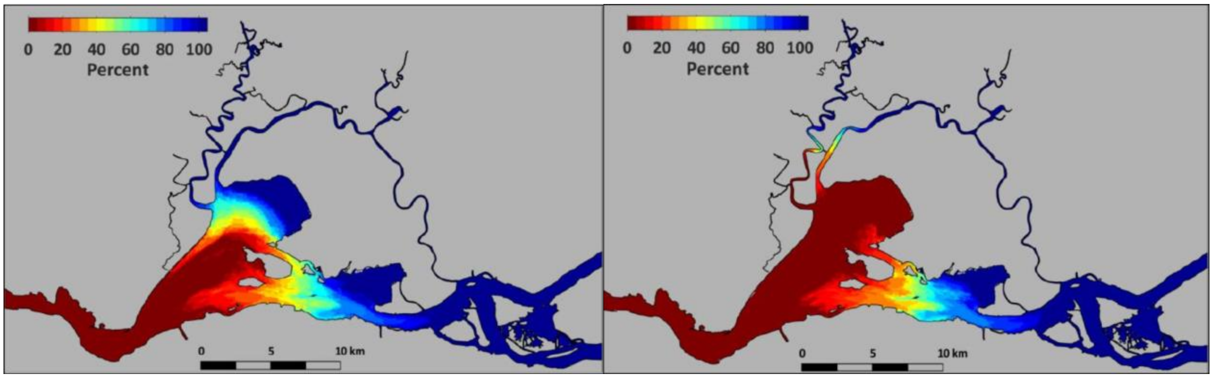

Figure 52: *UnTrim model depictions of the percent time that salinity < 6 psu for X2 locations of 80 km (left) and 81 km (right).[From Figure 6 and Figure 7 in USBR (2017)].*

As a result of the requirement to maintain X2 at 80 km or less on a 30-day average in Condition of Approval 9.1.3.1 during the months of September and October, DS will have improved access to parts of Suisun Bay and most of Suisun Marsh in the fall of wet and above normal years. This will mitigate the effects of Project operations on the DS population by providing suitable abiotic conditions in the Suisun region where DS survival and growth is improved.

Findings from (Miller et al. 2012; Rose et al. 2013a; Rose et al. 2013b) have demonstrated that increased prey density for rearing DS may also have significant beneficial effects on population size during this time. As discussed in Section 7.6 of this Effects Analysis, by shifting the geographical location of low salinity zone habitat through increases in outflow, DS will also have improved food availability, either through access to more productive wetlands in Suisun Marsh (Brown et al. 2016) or by subsidizing food resources into the area from freshwater regions upstream (Jassby and Powell 1994; Kimmerer 2002b; Kimmerer et al. 2018). Finally, other stressors on DS are expected to be reduced when X2 is held at 80 km or less, such as reduced exposure to contaminants due to dilution well as a reductions in microcystis abundance by decreasing residence time (Lehman et al. 2017).

8.8. Additional Water for use in the Summer and Fall

In addition to use of the SMSCG during the summer months of above normal, below normal and dry years and a requirement to maintain X2 at or below 80 km on a 30-day average during September and October of wet and above normal years, Conditions of Approval 8.18 and 8.19 will provide two blocks of water (Additional 100 TAF and Spring Outflow Block) to be used to augment Delta outflow during the spring, summer and fall. As described above, increases in summer and fall outflows will improve food resources, survival, growth, and potential access to thermal refuge during peak summertime water temperatures while also reducing exposure to contaminants. When available, these blocks of water will be implemented through a structured decision making and associated planning process each year to determine how to best use the water to improve conditions for DS in the summer and fall months.

Permittee will provide the Additional 100 TAF of Delta outflow during wet and above-normal years to supplement Delta outflow, or allow CDFW to defer the 100 TAF until the following year to be redeployed during the spring-summer-fall time period (Condition of Approval 8.19). The ITP indicates that CDFW is likely to defer the Additional 100 TAF in above normal or wet years and redeploy it to the following year to improve DS survival during this critical portion of their life history. If deferred, CDFW would prioritize use of the block of water to operate the SMSCG in the summers of dry years or to supplement spring-summer outflow in below normal years. Operations during the spring, summer and fall time period each year will be described in the Delta Outflow Operations Plan and reporting afterwards will be provided to CDFW in the Delta Outflow Operations Report (Condition of Approval 8.20). Condition of Approval 8.18 also requires Permittee to provide up to 150 TAF for use in the spring-fall time period if CDFW approves an increase in exports during April and May above what would otherwise be allowed by operating according to Condition of Approval 8.17. This Spring Outflow Block of water will be accounted for in the Spring Outflow Block Report each August and used in the following year to supplement Delta outflow as described in the CDFW-approved Delta Outflow Operations Plan (8.20).

The ITP requires DWR to work collaboratively with CDFW and the Delta Coordination Group as a part of the AMP to begin to fill this gap in knowledge. The Delta Coordination Group will conduct studies during deployment of the Additional 100 TAF block of water when it is deployed during the summer-fall time period or deferred and redeployed to the following water year (Condition of Approval 7.6.4). The benefits associated with the 100 TAF block of water would be evaluated in conjunction with new monitoring in Grizzly Bay to better quantify changes in salinity associated with SMSCG operations. This new science will also evaluate components of the Delta Smelt Resiliency Strategy by studying outflow effects on DS habitat.

Each year, the Delta Coordination Group will convene to develop a Summer-Fall Action Plan that describes how SMSCG will be operated to maximize the number of days when Belden's Landing is at or below 4 ppt and enhance DS habitat (Condition of Approval 9.1.3.1). When the additional 100 TAF block of water is available during the summer of wet, above normal, or below normal years, the Delta Coordination Group will plan deployment or deferral of this water to maximize benefits to DS habitat. When this water is available for redeployment in dry years, the group would plan its deployment to enable SMSCG operations to enhance DS habitat between June and October. In addition to existing data and monitoring efforts, the Summer-Fall Action Plan will be informed by: 1) structured decision making process, 2) learning from implementation of prior year plans, 3) new monitoring stations in or near Grizzly Bay, and 4) new science focused on improving understanding of DS summer-fall habitat and survival during this critical life history stage. Because this action will be informed by results from prior year implementation it will be closely aligned with the AMP, which is designed to evaluate new science conducted over the next ten years.

Additional water in the form of increased Delta outflow will minimize Project impacts discussed in Sections 7.4, 7.5, and 7.6 of this Effects Analysis by enhancing summer and fall habitat for DS. When applied, these additional amounts of water and associated operational criteria would be expected to further improve low salinity conditions within the Suisun region by enhancing an existing action, such as the summer use of the SMSCG or fall X2 (Condition of Approval 9.1.3.1), or by applying the water in ways that may promote habitat connectivity and increased habitat suitability during the summer and fall of years where no action is expected to occur, such as the summer of wet and above normal years, or the fall of below normal and dry years.

8.9. Additional Measures

This section describes Conditions of Approval that are intended to avoid and minimize take and related impacts of the taking to a Covered Species other than DS but may provide ancillary protections to DS when implemented.

Condition of Approval 8.6.1 – Winter-run Chinook Single-Year Loss Threshold

This Condition of Approval will limit exports to maintain a 14-day average OMR Index of no more negative than -3,500 or -2,500 cfs for at least 14 days. Exports will be restricted once annual loss of natural or hatchery CHNWR exceeds 50% or 75% of their respective calculated annual loss threshold and ends when OMR management ends or when agreed upon by WOMT based on risk assessment advice from the Salmon Monitoring Team. From November through April, migrating LFS can enter the Delta to spawn ; similarly, adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts both species at risk of entrainment at the Project south Delta export facility. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species. Therefore, when this Condition of Approval controls operations of the Project it will reduce entrainment risk to adult DS migrating into the Delta or adults present in the Delta. This action provides greater minimization for LFS and DS when it controls Project operations earlier in each species migration and spawning period and provides less minimization later in each species migration period.

Condition of Approval 8.6.2 - Early-season Natural Winter-run Salmon Discrete Daily Loss Threshold

This Condition of Approval will limit exports to achieve an average OMR Index of no more negative than -5000 cfs for five consecutive days. Exports will be restricted for five consecutive days once daily loss of natural-origin Chinook salmon identified as CHNWR based on LAD exceeds daily loss thresholds from November 1 through December 31. Adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts DS at risk of entrainment into the SWP south Delta export facility. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species

(Grimaldo et al. 2009; USFWS 2009). Therefore, this action will reduce entrainment risk to migrating adult DS migrating into or are present in the Delta when it controls Project operations.

Condition of Approval 8.6.3 – Mid and Late-season Natural Winter-run Chinook Salmon Daily Loss Threshold

This Condition of Approval will limit exports to achieve an average OMR Index of no more negative than -3,500 cfs for five consecutive days. Exports will be restricted for five consecutive days once daily loss of natural-origin Chinook salmon identified as CHNWR based on LAD exceeds monthly calculated daily loss thresholds from January 1 through May 31. Adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts DS at risk of entrainment at the SWP south Delta export facilities. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species (Grimaldo et al. 2009; USFWS 2009). Therefore, this action will reduce entrainment risk to adult DS migrating into or present in the Delta when controlling Project operations.

Conditions of Approval 8.6.4 and 8.6.5 - Daily Spring-run Chinook Salmon Hatchery Surrogate Loss Threshold and Funding for Spring-run Hatchery Surrogates

These Conditions of Approval will limit exports to achieve an average OMR Index of no more negative than -3,500 cfs for five consecutive days. Exports will be restricted for five consecutive days once cumulative loss of any spring-run surrogate release groups exceeds 0.25%, effective from February 1 through June 30. Adult DS can migrate into the Delta from December through May (IEP 2015). This movement puts DS at risk of entrainment at the SWP. It is well documented that the magnitude of OMR is negatively correlated with entrainment of both species (Grimaldo et al. 2009; USFWS 2009). Therefore, this action will reduce entrainment risk to adult DS migrating into or present in the Delta when controlling Project operations.

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James Hobbs (Environmental Program Manager, California Dept of Fish and Wildlife) in-person discussion on December 17, 2019 in Stockton, CA.

Randy Baxter (Senior Environmental Scientist, California Department of Fish and Wildlife) in-person discussion on February 6, 2020 in West Sacramento, CA.

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APPENDIX A

Of the

State Water Project Effects Analysis on Longfin Smelt and Delta Smelt

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Prepared by California Department of Fish and Wildlife

Understanding and Predicting the Onset of Adult Longfin Smelt Migration into the Delta

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Background

Longfin smelt (LFS) have historically been documented migrating into the Sacramento-San Joaquin Delta (Delta) during the late fall every year to spawn in freshwater habitat (Rosenfield 2010). Due to the location of Chipps Island at the entrance of the Delta, winter sampling programs at Chipps Island by the United States Fish and Wildlife Services (USFWS) can provide insights into LFS migration in the Delta. This appendix analyzes adult LFS migration to address three questions:

1. How does the Chipps Island Trawl dataset capture seasonal migration of adult LFS into the Delta?
2. What abiotic variables affect the timing of the seasonal migration of adult LFS into the Delta?
3. How accurate is a model with these abiotic variables in predicting the seasonal migration of LFS across years?

The first question was addressed by summarizing historical trawl data, while the second and third questions were addressed by modeling historical trawl data as classification problem.

Methods

Question 1: How does the Chipps Island Trawl dataset capture seasonal migration of adult LFS into the Delta?

Determination of qualifying fork length limit and migration months
The Incidental Take Permit issued by the California Department of Fish and Wildlife (CDFW) for ongoing operations of the State Water Project in 2009 (2009 LFS ITP) and associated effects analysis classified LFS ≥ 80 mm fork length (FL) as adults based on observations of sexual maturation in individuals of that size. However, analysis of salvage data from 1993-2018 indicated that fish as small as 60 mm FL are salvaged and lost to the population during the same migration period as ≥ 80 mm FL fish (see Figure 13 in Section 5.3 of the Effects Analysis). As such, we used 60 mm FL as a threshold to identify the adult migratory life stage in the Chipps Island dataset. However, we note that fish less than 80 mm FL have a low likelihood of reaching sexual maturity in that winter (CDFG 2009).

To capture the LFS migration period, Chipps Island Trawl data from November through March of each water year was included in analyses (CDFG 2009). Data was further constrained to water years 1994-2018, the duration of the winter sampling program of the Chipps Island Trawl. Due to logistics during holidays resulting in no or little sampling data for December 24, December 25, and January 1, these dates were removed. All sampling on February 29 were reclassified as February 28 to account for leap years. Finally, it was assumed that all applicable LFS caught at Chipps Island during this period were individuals migrating into, and not out of, the Delta.

Biotic variables construction

Catch data at Chipps Island was summarized to understand if the initiation of seasonal migration of adult LFS into the Delta can be detected in the dataset. Catch per unit effort (CPUE) was calculated as (catch)/(water volume trawled (m^3)) and summed per sampling day. To account for subsampling protocols and missing FL measurements, the FL distribution of sampled fish was expanded to the total number of fish caught, per sampling day. Expanded FL was classified as four different age classes determined through otolith analysis: age 0 (60-74 mm FL), age 1 (75-97 mm FL), age 2 (99-109 mm FL), and age 3 (≥ 110 mm) (Hobbs, unpublished). To account for erroneous entries in volume towed per pull, values were standardized against tow duration, (water volume trawled)/(tow duration), and outliers were removed using a conservative Tukey's outlier test, 3.0*interquartile range criteria (IQR) (Wilcoxon-Mann-Whitney test, p = 0.9752).

CPUE, FL, and age class were averaged per day of year (DOY) across all water years to visualize temporal movement at Chipps Island. Although averaging CPUE per DOY buffered against increased sampling in December and January, a parallel analysis of average CPUE restricted data to contain only sampling on Monday, Weds, and Friday in all months as another way to standardize sampling effort.

Water quality variables construction

Based on the current LFS conceptual model (see Sections 4.1 and 5.3 in the Effects Analysis), temperature (°C) and Secchi depth (m) are correlated to LFS migration at Chipps Island. Temperature and Secchi depth measured during sampling were averaged across all tows per DOY across all water years. Visual inspection of the data and the use of box plots determined that Secchi depth greater than three meters and temperature less than 5°C or greater than 25°C were erroneous entries. A total of five days were removed. Although other physical parameters may be correlated with migrating LFS at Chipps Island, only temperature and Secchi depth spanned all years of interest. Physical data from all trawling efforts, regardless of species caught, were used.

Three water flow variables of interest from Dayflow (from https://data.cnra.ca.gov/dataset/dayflow) were similarly analyzed for seasonality: OUT (cfs), QWEST (cfs), and X2 (km). QOUT is an index of estimated Net Delta Outflow and is a summation of river inflows, precipitation, various exports and diversions; QWEST is the net flow at Jersey Point; and X2 represents the position of the 2 parts per thousand (ppt) salinity isohaline in km. In Dayflow, X2 values are only available from water year 1997-2016. Therefore, values before water year 1997 were predicted using an autoregressive lag model, $X2(t) = 10.16 + 0.945*X2_{t-1} – 1.487*\log(OUT(t))$, where t = current day; for days when OUT was negative, a constant of 50 cfs was used for calculation instead (Mueller-Solger 2012). Dayflow data used spanned water years 1994-2016.

Persistence of seasonal migration

Due to the drastic decline of LFS after the pelagic organism decline (POD), the Chipps Island Trawl dataset was separated into pre- and post-POD time periods. Thomson et al. (2010) determined that the POD changepoint for LFS occurred in year 2004. All previously described analyses were redone for the water year subsets pre-POD (1994-2004) and post-POD (2005-2018).

Similarly, average CPUE was analyzed per water year type to understand the persistence of seasonality across water year types.

Questions 2 and 3: What abiotic variables affect the timing of the seasonal migration of adult LFS into the Delta? How accurate is a model with these abiotic variables in predicting the seasonal migration of LFS across years?

Data construction

Response variable

To describe LFS migration periods, the timing of Chipps Island Trawl catch data was transformed into a binary classification of pre- and post-migration state. Raw catch was first normalized by the total number of adult LFS caught during each water year. The normalized data was then converted into accumulated catch per water year. Plots of normalized accumulated catch numbers against sampling date were visually inspected for each water year to determine that 5% accumulated catch generally predicted the onset of adult LFS migration into the Delta. Accordingly, sample dates < 5% cumulative catch were classified as pre-migration and sample dates ≥ 5% cumulative catch as post-migration. There was class imbalance in the dataset, with a ratio of negative to positive class of 0.3429. Data from October through February of each water year was used. Data in October contains relevant information for pre-migration conditions while February is the end of the peak LFS spawning season (Moyle 2002). For water year 1994, data from October was not collected by the survey and is missing from the analysis.

Predictor variables

All previously mentioned water quality variables were considered: temperature and Secchi depth (Temp and Secchi) from the Chipps Island Trawl dataset and QOUT (OUT), QWEST (QWEST), and X2 (X2) from Dayflow database. A correlation threshold of 0.70 was used to select among highly correlated predictor variables, of which only the variable with the highest correlation to the response variable was kept (Dormann et al. 2013).

Seven missing and fifteen outlying values in the Temp variable were imputed by averaging the two-neighboring data points. Two erroneous entries in the Secchi depth dataset were removed entirely from analysis. To reduce the amount of noise in the Secchi depth data, three- and seven-day rolling averages of Secchi depth were calculated. Based on higher correlation with the response variable, the rolling average of the previous seven days was chosen for modeling (Avg7.Secchi). Due to high correlation between OUT and QWEST, QWEST was removed from the analysis because it was less correlated with the response variable (Figure 1). Despite high correlation between X2 and Avg7.Secchi (> 0.70), both variables were kept in the model as both are understood to be important to the current conceptual model of LFS migration (Section 5.1, CDFW Smelt Effects Analysis) and were relevant to the analysis.

To account for stock and recruitment effects, two population indices derived from the FMWT LFS Index (Stock, Partial.FMWT) were included. The LFS FMWT index is calculated from total catch at samples sites scattered throughout the Delta from September through December of every year (from http://www.dfg.ca.gov/delta/projects.asp?ProjectID=FMWT). “Stock” was defined to be the FMWT LFS index with a two-year lag due to the life history of the species. “Partial.FMWT” was defined to be the summation of the FMWT index from September to November of the immediate year.

Catch month was included as a non-ordinal factor (Month) to represent the influence of seasonal factors independent of the other variables analyzed, including day length. Because time of year is ordinal in predicting LFS catch, season day (Y.day) was also included, derived from DOY with October 1 being 1. Despite high correlation between Y.day and Temp, both were kept in the model as both are understood to be important to the current conceptual model of LFS migration (see Sections 4.1 and 5.3 in the CDF Smelt Effects Analysis) and were relevant to the analysis (Figure 1).

Two variables were included to address catch efficiency: 1) a non-ordinal factor to address net size changes on 10-07-1997 and 11-01-2001 (Net); and 2) a binary factor to address the POD in 2004.

All variables were merged by sample date of the Chipps Island Trawl dataset and included dates with zero LFS catch. Analysis spanned water year 1994-2016, due to the availability of winter sampling at Chipps and most recent Dayflow data. To improve model accuracy and to satisfy requirements of algorithms used, all numeric variables were scaled and centered, and all categorical variables were made numeric using one-hot encoding (Harris and Harris 2010).

Models

Ecological relationships are complex and multivariate in nature. They are governed by variables of differing types and distributions which interact and can be highly collineated (Dormann et al. 2013; Michaelsen et al. 1987). The LFS migration described by the Chipps Island Trawl dataset is no exception (Figure 1). To address these sources of complexity in the dataset, pre- and post-migration periods were modeled using machine learning algorithms. These algorithms are entirely data driven and can model complex, collineated, interacting, and nonlinear relationships without having to satisfy assumptions associated with traditional parametric models (Povak et al. 2013). Two classes of machine learning algorithms were considered: penalized and tree-based algorithms.

Penalized or regularized algorithms leverage substantial bias to reduce model variance and to shrink the magnitude of the regression coefficients. In linear regression models, the coefficients of correlated variables can be poorly determined and exhibit high variance, e.g. a large positive coefficient for one variable may be negated by a similarly large negative coefficient of a correlated variable (Hastie et al. 2009). The shrinkage process associated with penalized algorithms alleviates this problem by reducing overfitting that can arise from collineated variables and may inform variable selection (Goeman 2010). Three penalized regression algorithms of interest were the ridge, lasso, and elastic net (net) algorithms.

The ridge algorithm minimizes a penalized residual sum of squares of each coefficient, i.e., L_2 norm, shrinking all coefficients towards but not exactly to zero and to each other. The lasso algorithm minimizes a penalized sum of absolute residual of each coefficient, i.e., L_1 norm, shrinking all coefficients towards and possibly to exactly zero. The ability of the lasso to shrink coefficients to zero allows for sparse solutions and can directly inform variable selection, an advantage over the ridge. The elastic net algorithm is a hybrid approach, minimizing both L_1 and L_2 norms (Hastie et al. 2009). No one algorithm is superior under all circumstances. Although the ridge regression is generally preferable when minimizing prediction error, it tends to penalize the largest coefficients most by design and does not offer a sparse solution (Hastie et al. 2009). The lasso regression offers a sparse solution, but it cannot distinguish between highly correlated variables and simply picks one over the others (Zou and Hastie 2005) and is most accurate when the true model is itself sparse. The elastic net regression is a hybrid and may act as ridge or lasso when the former or latter is closest to the true model (Hastie et al. 2009).

Tree-based algorithms successively partition the data into discrete groupings and attempt to fit simple models to each grouping. At each binary split, a predictor and splitting value is chosen to achieve the best fit to the data; this process is done iteratively for all values of the predictor and for all predictors individually until a stopping criteria is met (Hastie et al. 2009; Povak et al. 2013). Two tree-based algorithms of interest were the Random Forest (RF) and XGBoost (XGB) models (Breiman 2001; Chen and Guestrin 2016).

The RF is a bagging algorithm of many de-correlated and complex trees and is applicable to both regression and classification problems. Each tree is generated on a bootstrapped sample with replacement from the training dataset and grown to the largest extent possible without pruning (Breiman 2001). Once all trees are grown, each tree then casts a vote on a class based on the input vectors and the majority decides the prediction of the model.

The XGB model is also suitable to use for regression and binary classification problems. It is a boosting algorithm based on an ensemble of additive, simple trees (Chen and Guestrin, 2016). After the initial naïve tree is grown, successive trees are built based on the residuals of the preceding tree in a process called additive training. Errors arising from a tree are assigned higher weight values that the next tree attempts to address. A specific objective function and a corresponding evaluation metric is specified and optimized during model construction. K-fold cross validation is used to determine both the optimal number of iterations to run to avoid overfitting the data and to tune various hyperparameters (Chen and Guestrin, 2016).

Both tree-based algorithms were considered in the analysis. Advantages of the RF include high predictive accuracy, internal cross-validation, high resilience to overfitting, resilience to multicollinearity, and being able to handle a large amount of data and variables (Breiman 2001). The XGBoost, method "xgbTree", offers the same benefits with potentially greater performance; a well-tuned XGBoost algorithm offers competitive performance comparable to much more complex ensemble and stacking methods (Chen and Guestrin 2016). Both algorithms automatically account for variable interactions with greater tree depth allowing for higher order interactions and variable selection (Hastie et al. 2009). To aid model interpretability, global relative variable importance is provided for both algorithms as "variable importance", a metric quantifying the improvement across the entire ensemble a variable offers to model prediction (Hastie et al. 2009). Local variable importance is also provided as partial dependence effects (for RF) or SHapley Additive exPlanations (SHAP, for XGB) values. These local importance metrics are calculated at each datum for each variable by comparing model prediction with and without the variable and accounting for the average effects of other variables on that prediction (Hastie et al. 2009; Lundberg and Lee 2017).

In addition to the machine learning algorithms, a logistic regression model was trained. This model served only as a baseline model that the machine learning algorithms should outperform.

Model construction

Candidate algorithms

The performance of traditional logistic regression, penalized logistic regression, and machine learning techniques were compared to characterize variable importance influencing LFS migration at Chipps Island. Multiple algorithms were assessed because each is known to perform well for some, but not all problems, and it is seldom known in advance which procedure will perform best for the dataset of interest (Hastie et al. 2009). Specifically, we tested the logistic regression, lasso, ridge, net, RF, and XGB algorithms.

Evaluation metrics

Models were trained to optimize accuracy (misclassification rate) and AUC (area under the receiver operating characteristic curve (ROC)). Accuracy is defined as the misclassification rate of model predictions compared to the observed, with a higher value indicating greater performance. The AUC metric is defined as the area under the ROC curve. The ROC curve summarizes the tradeoff between true positive rate (sensitivity) and the false positive rate (1 - specificity) across different decision thresholds (Safari et al. 2016). In turn, the AUC metric summarizes the overall performance of the ROC curve independent of the decision threshold chosen, with a higher score indicating greater average performance (Bradley 1997). By optimizing AUC, sensitivity and specificity are prioritized equally (Safari et al. 2016), as is appropriate for the exploratory nature of this report.

Model training

Evaluating model performance using data that the model was trained on can lead to an optimistic evaluation of model success (Arlot and Celisse 2010; Hastie et al. 2009). One method to better gauge the performance of a model is to predict onto data not trained to the model, i.e., unseen test data. A common technique used in machine learning is the "hold out" method, in which a certain percentage of the dataset is chosen as training data and the rest as testing data. This data split must be truly random to ensure independence, i.e., no data leakage, between the two sets. The "hold out" method is a special case of cross-validation (CV) where there is only one fold, i.e., one split of the dataset into one training and one validation set (Arlot and Celisse 2010). Due to limited and dependent nature of the data, the hold out method was not considered for this analysis.

Instead of evaluating performance using the "hold out" method, we used a more exhaustive cross validation approach, the "*hv*-block" method. In this approach, a block of data, *v*, is removed from the dataset to serve as the validation set; concurrently, two blocks of data, *h*, are removed from both sides of the *v*-block to maintain independence between the training and validation sets. The *hv*-block approach is asymptotically optimal, providing consistent cross-validatory model selection for dependent data (Racine 2000). As such, an entire season was assigned as the *v*-block to be dropped and tested, while periods preceding and following the season were treated as the *h*-blocks to prevent data leakage. This led to a CV with each season acting as a fold, i.e., 23 folds composed of 23 different training and test datasets. This approach addresses the limited and dependent nature of the Chipps Island Trawl data by: allowing all data to be used in model training while guarding against overfitting particular years by allowing all data to also be used in model testing; and ensuring autocorrelated data are grouped together across the training and testing sets to maintain independence across seasons.

Model hyperparameter tuning

The RF, lasso, ridge, net, and XGB models were subjected to hyperparameter tuning to maximize model performance. Hyperparameters are specific to each algorithm and control various aspects of model fit. Tuning was done using a grid search approach for each hyperparameter to maximize the evaluation metrics.

The RF model has only one tunable variable *m*, the number of variables to be randomly tested at each terminal node of each tree. A grid search was performed for *m* values 1 through 10.

The lasso and ridge models have one tunable variable each, the L1 (lasso) or L2 (ridge) penalty parameters. A grid search was performed for values ranging from 0.0001 to 0.1 in steps of 0.0005. The net model has two tunable variables, both the L1 and L2 penalty parameters; a grid search was done with values determined by tuneLength = 50 in *caret* R package.

The XGB model has several tunable variables: 1) *nrounds*, the number of trees to be built, 2) *eta*, the learning rate between successive trees; 3) *max_depth*, the maximum depth of each decision tree; 4) *min_child_weight*, the minimum Hessian requirement for a new leaf partition; 5) *gamma*, the minimum loss requirement for a new leaf partition; 6) *subsample*, the percentage of rows used to train each boosting iteration; and 7) *colsample_by_tree*, the percentage of columns used to train each boosting iteration. Tuning of the XGB models was done stepwise (see Table 1 for order and values).

Once all hyperparameters were determined for their respective models, final models were trained with tuned values using all available data.

Model evaluation

The best performing model was defined as the model with the highest mean cross-validated accuracy metric. Although models were also trained and optimized on the AUC metric, AUC scores were abnormally high and less distinguishable between models; as such, the sensitivity and specificity scores of each models were used as secondary metrics to verify the ranking based on the accuracy metric.

Variable importance

Global variable importance was considered for the model with the highest cross-validated accuracy metric. Due to the exploratory nature of this analysis, variable importance of the second and third most accurate models were also assessed for confluence with the top performing model. These models were the net, lasso, and XGB models. Variable importance in the lasso and net models is determined by the shrinkage term causing unused variables to have a coefficient of zero. Variables with non-zero coefficients were considered significant. However, the intentional bias that the model introduces into its shrinkage algorithm means that actual importance rank order cannot be determined for these models (Goeman 2010).

Global variable importance in the XGB model is determined by how often a variable is selected to optimize each split in each decision tree. All variables are evaluated by the model internally and rank order, determined by the average improvement in accuracy brought by a variable to the model, is provided and standardized to a scale of 1. A clustering algorithm attempts to distinguish variable importance groupings for greater interpretability.

Local variable importance is also provided by the XGB model and is informed by each individual data point SHAP (SHapley Additive exPlanation) values. SHAP values combine Shapley values, values used in cooperative game theory to determine player contribution to a goal, with additive predictor variables importance measures, i.e. interaction effects between all variables (Lundberg and Lee 2017). SHAP values in a classification problem represent log odd success rate, i.e., a positive SHAP value indicates a positive contribution to predicting the positive state and a negative SHAP value a negative contribution to predicting the positive state. The summation of SHAP values across all predictor variables per datum determines the actual likelihood of post-migration state at that datum; this process is unique to each datum and accounts for interactions between all predictors.

Simplified XGB models

Variable importance as determined by the full lasso, net, and XGB models were used to build simplified XGB models. Although the XGB algorithm inherently offers feature selection, a more parsimonious model can isolate and improve understanding of the most relevant variables correlated to LFS migration at Chipps Island if accuracy is maintained or improved. Non-zero variables in the lasso and net models were considered in one model. Since the full XGB model ranked X2 above Avg7.Secchi, a second simplified model was built to include the non-zero variables from the penalized models and X2. These simplified XGB models used the tuned hyperparameters of the full XGB model, except for *nrounds* which used a grid of 1000-5500 at intervals of 250, and *max_depth* which used a grid of 1-6 at intervals of 1 to account for changes in the number of predictors.

Model prediction

By construction of the response variable, the first occurrence of a positive class in each water year represented the start date of the migration period for each model. A comparison of these predicted values to the migration onset date estimated by the 5% cumulative catch criteria was calculated as difference in days. Since the difference in days can only be biased high due to inconsistent sampling frequencies across the time period, the difference in absolute row position in the data frame was also provided. Both metrics were only used to improve interpretability of model performance and were not used for model selection or tuning.

To further evaluate the predictive abilities of the top performing models, water year 2017 was isolated as a hold-out year to serve as testing data completely unseen by any models. This year was chosen as it is the most up to date year available and can serve as a measure of how applicable the developed models are to the current environment.

Software

All analyses were performed in R Cran Statistical Software (version 3.6.2; R Core Team 2019). Data manipulation and visualization utilized the ‘tidyverse’ (version 1.3.0; Wickham et al. 2019). The logistic, lasso, ridge, and net regressions were performed using the ‘glmnet’ package (version 3.0-2; Friedman et al. 2010); the random forest regression was performed using the ‘randomForest’ package (version 4.6-14; Liaw and Wiener 2002); and the xgboost regression was performed using the ‘xgboost’ package (version 0.90.0.2; Chen and Guestrin 2016). Model construction was done using the ‘caret’ package (version 6.0-85; Kuhn 2020).

Results

Question 1: How does the Chipps Island Trawl dataset capture seasonal migration of adult LFS into the Delta?

Seasonal migration of adult LFS – biological

Average CPUE per day across all years indicated that catch of adult LFS begins increasing in early December, then follows a bimodal distribution peaking at the end of December and the middle of January, and ends by March (Figure 2a). Change in the ratio of age classes within a season showed an influx of age class two and three fish beginning in December, peaking at the end of December, and dwindling by the start of February (Figure 2b). Similarly, examination of changes in FL per day across all years shows that an average FL of age one and two fish typically begins at the start of December and ends in early February (Figure 2c). This seasonality persists after standardizing catch to only Mondays, Wednesdays, and Fridays, before and after POD (Figure 4), and in all water year types (Figure 6).

Seasonal migration of adult LFS – physical

Average temperature plotted per day across all years shows consistent patterns of seasonal change at Chipps Island, decreasing below 12°C on December 2nd, reaching the minimum by late December through January, and increasing beyond 12°C at the beginning of March (Figure 3b). Average Secchi depth per day across all years also shows consistent patterns of seasonal change at Chipps Island, decreasing below 0.58 m at the beginning of December and stabilizing at a minimum around the beginning of January (Figure 3c).

Questions 2 and 3: What abiotic variables affect the timing of the seasonal migration of adult LFS into the Delta? How accurate is a model with these abiotic variables in predicting the seasonal migration of LFS across years?

Model performance

The net, lasso, full XGB models trained to maximize the accuracy metric performed best. The overall CV mean accuracy metrics of these three models were 0.9327 (± 0.0606), 0.9310 (± 0.0585), and 0.9262 (± 0.0651), respectively (Table 2). Model performance was less clear between the models based on the AUC metric, with which all models scored > 0.9950 (Table 2). When broken down to sensitivity and specificity, the XGB model scored above 0.9 in both metrics, while the LR, lasso, ridge, and net models scores were more skewed towards sensitivity (Table 2; Table 3). It is noted that the SD's of all metrics overlap with one another (Table 2). However, this overlap does not signify overlap in performance across the different models; instead, it signifies the overlap in performance of each model between the folds or water years, i.e. a better performing model will perform better on average across each fold than a poorer performing model. Based on the accuracy metric, the lasso, net, and XGB models were selected as the top performing models for variable importance analysis.

Variable importance

The lasso and net models yielded similar results, keeping Y.day, Temp, and Avg7.Secchi while shrinking all other variables to 0 (Table 4). The specific importance ranking of these variables cannot be interpreted from the coefficients due to the design of these algorithms (Goeman, 2010). The full XGB ranked Y.day as the most important variable, followed by Temp, X2, and Avg7.Secchi, and the rest of the variables. Y.day and Temp were clustered together as the most important variables, while the rest of the variables were clustered together (Figure 8).

For local variable importance in the full XGB model, an analysis of where the LOESS regression of the SHAP values of the top four ranked variables crossed zero showed that migration is more likely when Y.day > 75.37, Temp < 12.01°C, X2 < 78.46 km, and Avg7.Secchi < 0.58 m (Figure 10; Table 5). These points are approximated and should not be interpreted as discrete distinctions between pre- and post-migration states.

Simplified XGB models

The simplified XGB model built on the three non-zero variables from the lasso and net models, Y.day, Temp, and Avg7.Secchi, had a CV mean accuracy of 0.9305 (± 0.0552). The simplified XGB model that also included X2 in addition to Y.day, Temp, and Avg7.Secchi had a CV mean accuracy of 0.9325 (± 0.0503) (Table 3). This simplified four variable XGB model was determined to be the best performing across all models. The simplified three variable XGB model built from variables selected by the lasso and net models will not be discussed further.

Global variable importance of the four variables XGB model ranked Y.day > Temp > X2 > Avg7.Secchi. The ranking order of the top four variables was consistent between the full and simplified XGB models (Figure 9). Local variable importance of the four variable XGB model was also similar to the full XGB model (Figure 11; Table 5).

Predicting the onset of adult LFS migration

The earliest and latest predicted LFS migration season start dates for the lasso, net, full XGB model (XGB.full), and simplified XGB model were 11-24-2000 and 12-17-2008, 11-16-2000 and 12-18-2006, 11-

28-1994 and 12-20-1995, and 11-09-2011 and 12-20-1995, respectively. The lasso model had a range of -18 days (too early) to 37 days (too late); the net model had a range of -18 to 37 days, the full XGB model had a range of -26 to 43 days; and the simplified XGB model had a range of -15 to 43 days. It must be noted that these differences in days are, and can only be, biased high; this is due to periods of infrequent (less than daily) sampling by the survey. When these differences are measured as data rows, which are less affected by sampling frequency, they are tighter, ranging overall between -13 to 13 (Table 6).

Each model predicted similarly when tested using the holdout water year 2017 with a predicted day difference of -2 days and -1 row (Table 6).

Discussion

Question 1: How does the Chipps Island Trawl dataset capture seasonal migration of adult LFS into the Delta?

Adult LFS migrating into the Delta are susceptible to take and impacts of the taking as a result of exports at the Banks Pumping Plant and operations of the SWP (CDFG 2009). Take and impacts of the taking can be minimized by understanding when LFS individuals migrate into the Delta and informing risk assessments conducted in real-time to assess the need for OMR management.

Seasonality of catch in the Chipps Island Trawl

LFS enter the Delta in the late fall/early winter in search of freshwater habitat to spawn every year. This report showed that this seasonal migratory event is captured in the Chipps Island Trawl survey. Seasonality can be seen in the average distribution of CPUE, FL, age class proportions, temperature, and Secchi depth per DOY across all water years (Figure 2; Figure 3). More specifically, LFS appear to migrate into the Delta from December through February of each year, with peak migration in December and January. The increase in LFS CPUE at the beginning of December stems primarily from an increase in the proportion of larger sized fish, with an average FL equivalent to an age 2-3 fish (Figure 2b); this supports the hypothesis that these migrating individuals are mostly spawning fish entering into the Delta to spawn. This is further supported by the seasonality of favorable spawning conditions at Chipps Island and in the Delta where current conceptual models assume LFS spawn during this period, temperature ≤ 12°C and Secchi depth < 0.6 m (see Sections 4.1 and 5.3 in the CDFW Smelt Effects Analysis). Spawning has been hypothesized to occur quickly after migration and, if so, the seasonality of catch at Chipps Island is confluent with previous observations of peak LFS spawning during December-March within the Delta (CDFG 2009).

We also observed seasonal variation in Delta outflow indices and X2 position (Figures 7b-d). There were no clear relationships between outflow metrics, QOUT and QWEST, and average CPUE at the beginning of the LFS migration period. For the latter part of the migration period, high pulse flow during the beginning of January does precede the second peak of LFS CPUE at Chipps Island, however, this specific relationship was not explored as a part of this modeling exercise. Seasonal X2 conditions show that, on average, X2 is approximately 82.5 km at the beginning of December and is approximately 77.22 km on December 17 when the average first spike of adult LFS catch occurs. These X2 values coincides with the general location of Chipps Island and, in general, spawning LFS generally tracks X2 positions (CDFG 2009).

Persistence of seasonality of catch at Chipps Island

Seasonality of LFS catch at Chipps Island persisted across water year types and the POD but with varying distribution patterns. In wet and pre-POD years, LFS catch at Chipps Island followed a bimodal distribution, while in the drier years and post-POD years, catch followed a unimodal distribution (Figures 4, 6). This bimodal distribution in wet years is likely due to a longer spawning window during wet, cool years, as has been documented for Delta smelt (Damon et al. 2016), while in drier years a shorter spawning window may limit the number of late migrating individuals. These differing distributions may be due to the drastic decrease in the LFS population after POD, an increased frequency of drier water year types in the recent historic record, or a combination of the two. A truncated migration season with the start of the season remaining the same is intuitive; a decrease in the population would not affect when favorable spawning conditions would occur in the Delta to signal the start of the migration period, but would instead affect the number of individuals available to undergo the migration and, thus, when and how the migration period ends.

Questions 2 and 3: What abiotic variables affect the timing of the seasonal migration of adult LFS into the Delta? How accurate is a model with these abiotic variables in predicting the seasonal migration of LFS across years?

Algorithm selection

The simplified four variable XGB model was chosen as the best performing model. This decision was supported by several findings: 1) the model returned the highest accuracy; 2) accuracy standard deviation was lowest; and 3) sensitivity and specificity were both above 0.90. Stated more plainly, this model was most accurate in predicting migration states across the entire dataset, most consistently accurate across each water year, and balanced true positive and negative detection rates the best. However, it should be noted that the variable importance and prediction results from the lasso, net, and full XGB model are confluent with the findings in the chosen top performing model, the simplified XGB model (Figure 8; Figure 9; Table 4; Figures 12; Figure 13; Table 7).

Global variable importance

Adult LFS catch at Chipps Island was modeled as a classification problem of pre- and post- migration state for each water year, 1994-2017, to understand the potential abiotic variables influencing LFS migration into the Delta. The simplified XGB model selected for both Y.day and Temp, ranking them as the first and second most important variables. This is despite very high correlation, 0.79, between the two variables. Since the boosting process tends to not refocus on a link between a variable and the response once established (Hastie et al. 2009), this retention is possibly due to unique information described by each variable. Season day contains information on daylight hours that temperature at Chipps Island captures less clearly, i.e. daylight duration is determined by DOY but is only correlated with water temperature. Additionally, water temperature at Chipps Island may not accurately reflect ocean water temperature that could cue adult LFS to begin migrating into the estuary. On the other hand, if daylight hours experienced by migrating LFS between the ocean and Chipps Island at the same latitude is similar, season day can serve as a more accurate predictor of migration informed by diel variation in light conditions. It was previously observed that LFS respond to diel variation through vertical migration within a day (Bennet et al. 2002). It is possible that a combination of both day of year and water temperature determines migration timing, where daylight hours initiate migration from the ocean into the San Francisco Estuary, but more regional conditions, e.g. temperature, determine when the fish migrate into the Delta itself. The inclusion of both highly correlated variables was also supported by the lasso and net models, which are biased heavily against such collineated variables (Goeman 2010).

The simplified XGB model also retained X2 and 7-days running average Secchi depth as important variables, despite high correlation between the two variables, 0.72. For mature LFS, spawning movement generally follows the movement X2 (CDFG 2009). Since the location of hatching LFS is primarily determined by where they are spawned, the location of X2 also influences larval and juvenile distribution. The centroid of the distributions of larval and juvenile LFS also follow the movement X2 (Dege and Brown 2004). For Delta smelt turbidity is a key predictor of migration as it provides both protection from predators and increased feed efficiency (IEP-MAST 2015). These same mechanisms may be true for LFS as Secchi depth has been linked to increased LFS abundance across multiple life stages (Baxter et al. 2010; Kimmerer et al. 2009). The high correlation between the two variables is due to peaks in turbidity commonly observed at X2 (Jassby et al. 1995). Although the inclusion of both variables in the XGB model may describe the same mechanism(s), their inclusion supports the idea that the both variables together better describe these underlying mechanism(s) than including one variable individually.

Local variable importance

Analysis of the SHAP values of the top four variables in the simplified XGB model showed thresholds similar to exploratory analyses of averages per day across all water years (Figure 2; Figure 11). The identified thresholds are immediately after contributions become positive and are expected to occur earlier in the season than predictions in the exploratory averaging analyses. Due to the binary construction of the response variable, positive SHAP values of the four most important variables will generally plateau as the chance of post migration conditions approaches 100% later into each water year.

The SHAP plots are similar between the simplified and full XGB models, with a slight difference in X2. The general similarity between the plots across the two models is expected as these four variables are highly important compared to the rest of the variables (Figure 8; Figure 9). In the X2 plot of the simplified model, there is an inflection point around 87 km. Since this was not observed in the full XGB model, this implies that the relationship between X2 and migration state at Chipps Island is degraded past this point as other mechanisms become more important and interact with X2. This would also explain the inclusion of both X2 and Secchi depth in the simplified model despite their high correlation; if X2 and Secchi depth describe similar mechanisms, having both in the model allows for a finer representation of those mechanisms.

Predicting the onset of migration

All start date predictions from the simplified four variable XGB model can be categorized into two categories: 1) earlier than the actual start date and 2) later than the actual start date. Since this model approximates the true model and the 5% cumulative threshold approximates the true start of the migration period, only these two categories apply, i.e., the observed migration start dates should not be viewed as the true LFS migration start dates. Therefore, it is more useful to discuss why the model predicts too early or too late compared to the specified 5% start date instead of the actual start date predictions themselves.

For the following discussion, it should be noted that the difference as measured in days may be biased high, depicting less accuracy in results than is warranted. For example, in water year 1996, the full and simplified XGB models predicted 43 days too late while the lasso and net models predicted 36 days too late; when looking at the row positions of these predictions, this is only a difference of one row in the dataset. Therefore, predictions within the interval may result in large perceived differences due to low sampling rate, if these models were ran iteratively to produce a prediction interval.

Predictions earlier than the specified start date

For water years in which the models predict migration initiation too early, fish are not caught in the Chipps Island Trawl despite physical conditions being favorable for migration. Generally, this shortcoming can be attributed to the lack of additional relevant predictor variables in the model, a suboptimal representation of the included predictor variables, inherent biases associated with the modeling algorithm, and inherent variance associated with the data itself.

The lack of additional relevant predictor variables is illustrated best in water year 2016 where the simplified XGB, lasso, and net models all predicted 18 days too early, while the full XGB model only predicted two days early. In this case, including additional variables led to a more accurate prediction.

The suboptimal representation of the predictor variables can be seen when comparing the SHAP plots between the full and simplified XGB model. Under the assumption that the composite nature of X2 is a proxy for mechanism(s) responsible for the onset of LFS migration, how well X2 represents those mechanism(s) is dependent on how the variable is defined. In the simplified XGB model, the relationship between X2 and migration onset breaks down for values greater than 87 km. Since this is not observed in the full XGB model, it indicates that the construction of X2 used in this report requires interactions with additional variables to serve as a better proxy for mechanism(s) related to onset of LFS migration.

Inherent biases in the algorithm can be seen in water year 2012 in which both the simplified XGB models (three and four variable variants) predict 26 days too early while the lasso, net, and full XGB models predict 0 days. The models approach the data differently when constrained to the same predictor variables.

Inherent variance associated with the Chipps Island Trawl data likely stems from catch efficiency and sampling frequency that is not accounted for in the model or abiotic data. No trawl is 100% efficient and will miss fish even when fish are present. Low sampling rates lead to the same complication, where fish are not observed despite being present. In contrast, sampling physical variables is simpler and more accurate. As a result, it is possible to observe spawning migration conditions even when fish are not observed in the trawl.

Predictions later than the specified start date

For water years in which the models predict a much later start date than the defined date, an underlying cause is that the defined 5% cumulative catch start date occurred too early in the season, in October or November. An example is water year 1999 in which the observed start date was 10-27. This is an abnormal timing for adult LFS to show up at Chipps Island to initiate spawning migration and is inconsistent with our current conceptual model of the species life history (CDFG 2009). In late October of water year 1999 temperature was 16.8°C, average seven days Secchi depth was 0.295 m, and X2 was 73.83 km. Although Secchi depth and X2 were favorable for migration initiation conditions, season day and temperature were not. Because these two variables are weighted the most important in the simplified XGB model, it is not surprising that the model did not predict an early season start date for this water year. This disconnect between temperature, X2, Secchi depth and Chipps Island Trawl catch data is consistent across all water years when the models predict a start date that is later than the actual 5% cumulative catch date.

An early 5% cumulative catch start date could also occur if immature fish not part of the true adult LFS migration are included in the dataset. Both immature age 0 and 1 fish are occasionally found inland of

Chipps Island during certain years, possibly due to the expansion of habitat use in response to favorable conditions (Baxter 1999). The inclusion of these individuals in early October or November would bias the 5% start date earlier than the spike in catch associated with adult spawning migration initiation. Since early detection of immature fish in the Chipps Island Trawl occurred in only 7 out of the 23 years analyzed, while the peak in adult abundance in the data occurred every year, these early immature fish are underrepresented in the dataset. As a result, the model trained itself primarily on data associated with the migration peak of adults that occurs every year and, thus, would appear to predict late in the few years when immature individuals are observed in October and November.

It is also likely that the inherent variability in Chipps Island Trawl data, the lack of relevant predictor variable, suboptimal representation of predictor variables used, and inherent biases in the algorithms described in the previous section could also result in predictions that are earlier than the start date as discussed here. Additional predictor variables, greater refinement of the included variables, greater refinement of the model construction, and more frequent sampling data may further improve the ability of the models to accurately predict the initiation of LFS spawning migration.

Conclusion

The onset of LFS migration into the Delta is important because the proximity of individuals to the State Water Project and Central Valley Projects is positively correlated to entrainment risk (Grimaldo et al. 2009). This appendix attempted to answer three questions:

1. How does the Chipps Island Trawl dataset capture seasonal migration of adult LFS into the Delta?
2. What abiotic variables affect the timing of the seasonal migration of adult LFS into the Delta?
3. How accurate is a model with these abiotic variables in predicting the seasonal migration of LFS across years?

Question 1: *How does the Chipps Island Trawl dataset capture seasonal migration of adult LFS into the Delta?*

The Chipps Island Trawl dataset was found to capture seasonal migration of adult LFS into the Delta. Seasonality can be seen in the average distribution of CPUE, FL, age class proportions, temperature, and Secchi depth per DOY across all water years. Average seasonal CPUE from water years 1994-2018 exhibit a bimodal distribution beginning in December of every year (Figure 2a). This increase in CPUE is associated with an influx of age two and three sized fish (Figure 2b-c). This migration period also coincides with favorable spawning conditions including low water temperature and high turbidity (Figure 3). This seasonality persists across water year types and the POD event (Figures 4-6).

Question 2: What abiotic variables affect the timing of the seasonal migration of adult LFS into the Delta?

Machine learning algorithms were employed in a classification framework to model pre- and post-migration state using Chipps Island Trawl data. The top performing model was an XGBoost model with a mean CV accuracy metric of 0.9329. Four physical variables were deemed important: season day (Y.day), water temperature (Temp, °C), X2 (km), and Secchi depth (Avg7.Secchi, m). This finding is shared by other high performing models, specifically the lasso, net and the full XGB model. Analysis of SHAP values of these variables are similar to the findings in Question 1 (Figure 11).

Question 3: How accurate is a model with these abiotic variables in predicting the seasonal migration of LFS across years?

Performance evaluation of the simplified XGBoost model indicates that onset of LFS migration is predictable and accurate. When used to predict on hold-out year 2017, the model predicted two days early and one data row before the observed 5% start date (Table 7; Table 8).

Although this model, built using primarily four variables, is too simplistic to capture all potential variation in the onset of LFS migration into the Delta every year perfectly, it does accurately predict the general onset of adult LFS migration in most water years. This implies that season day, water temperature, X2, and Secchi depth at Chipps Island are correlated with the timing of the adult LFS migration at Chipps Island into the Delta and should be considered to minimize entrainment of LFS as a result of operations of the State Water Project.

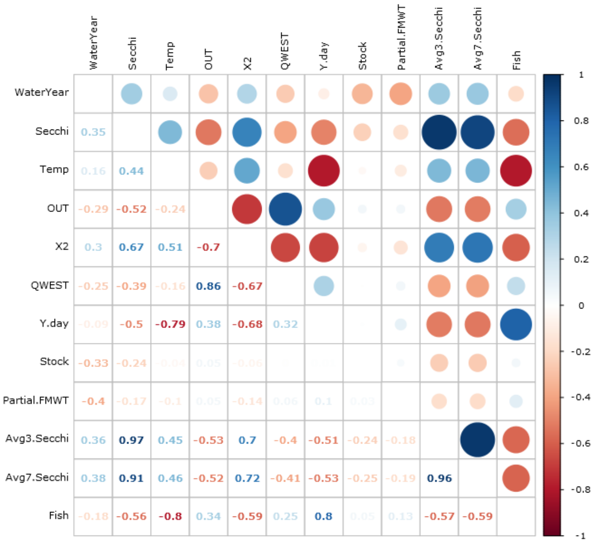


Figure 1: Correlation matrix of all numerical variables. 'Fish' represents the response variable. A general threshold of 0.7 informed preliminary variable selection. Despite a high correlation between water temperature (Temp) and season day (Y.day), both variables were not dropped from the preliminary variable selection, as both were pertinent to the analysis.

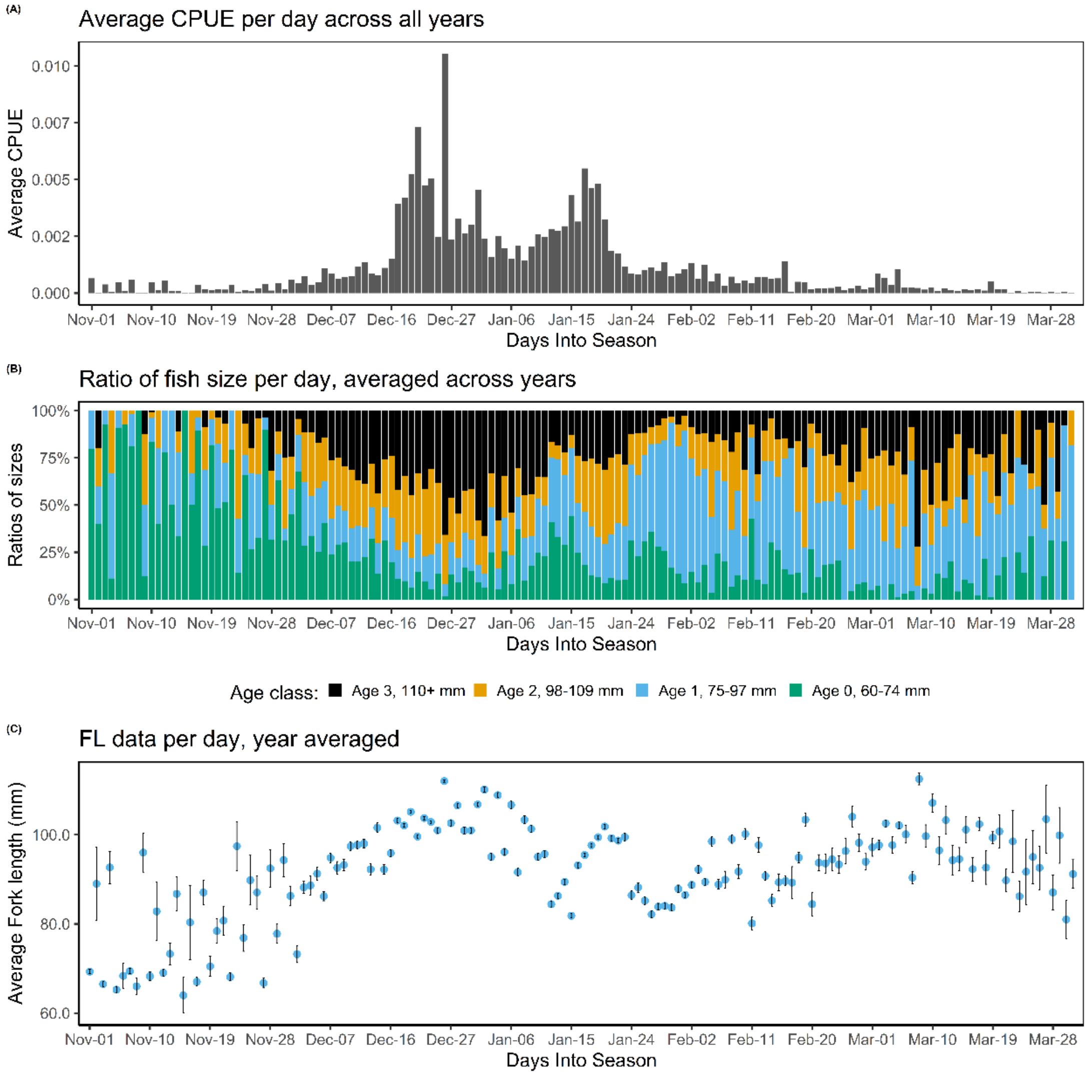
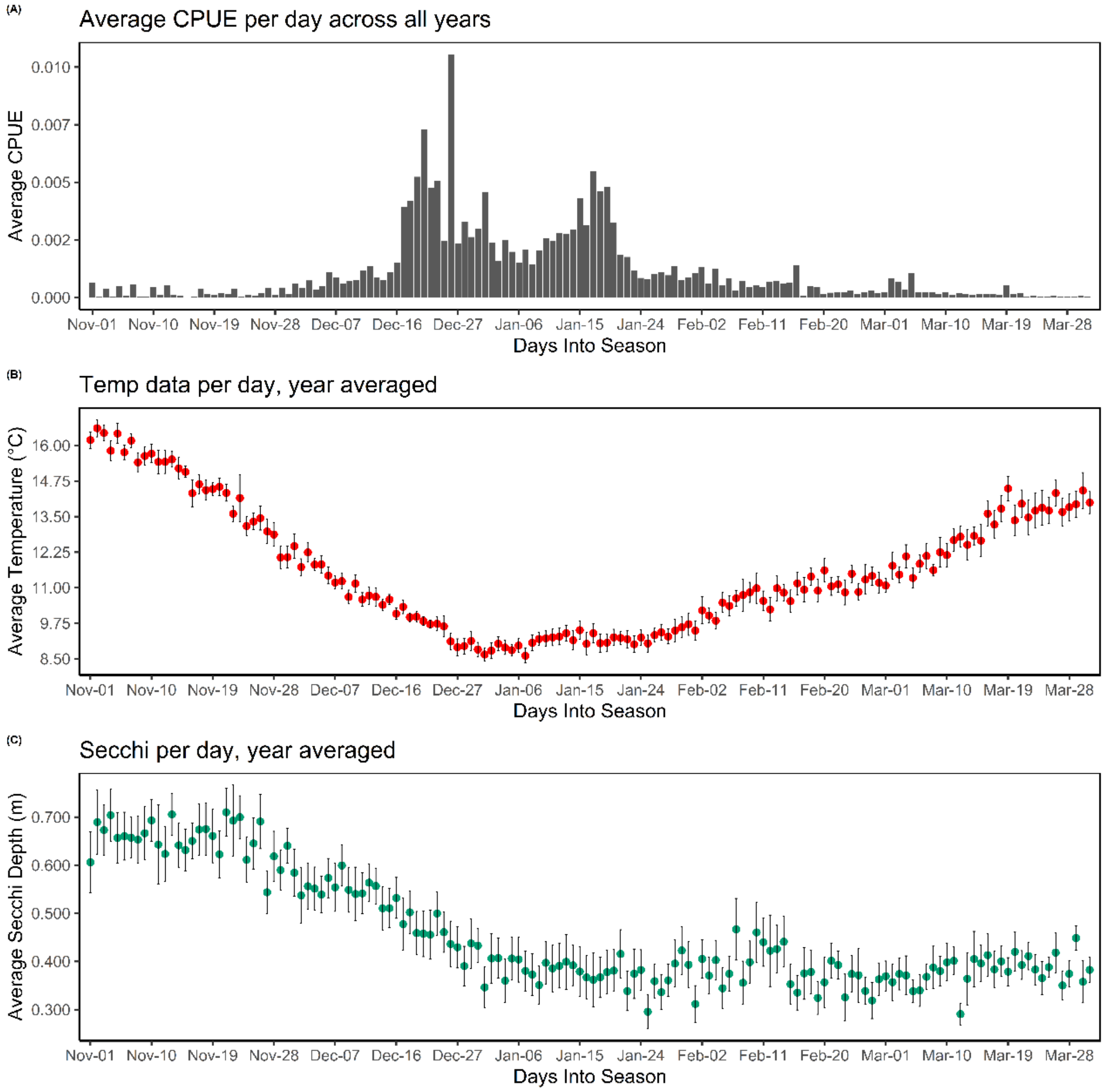


Figure 2: Average analysis of catch data at Chipps Island. Trends over time are shown for (A) average CPUE per day across all water years, (B) average age class distribution per day across all water years, and (C) average fork length per day across all water years. Generally, LFS migration occurs from December through March. Peak migration appears to occur from mid-December through January. This peak migration period corresponds with presence of older, larger fish (age 1-3, average FL between 81-112 mm). Age class are defined as age 0 (60-74 mm FL), age 1 (75-97 mm FL), age 2 (99-109 mm FL), and age 3 (≥ 110 mm) (Hobbs, unpublished).



(A) Average CPUE per day across all years

(B) Temp data per day, year averaged

(C) Secchi per day, year averaged

Figure 3: Average daily CPUE at Chipps Island (A), temperature (B) and Secchi depth (C) data across all years. Peak LFS catch at Chipps Island corresponds with low water temperature and higher turbidity in the area.

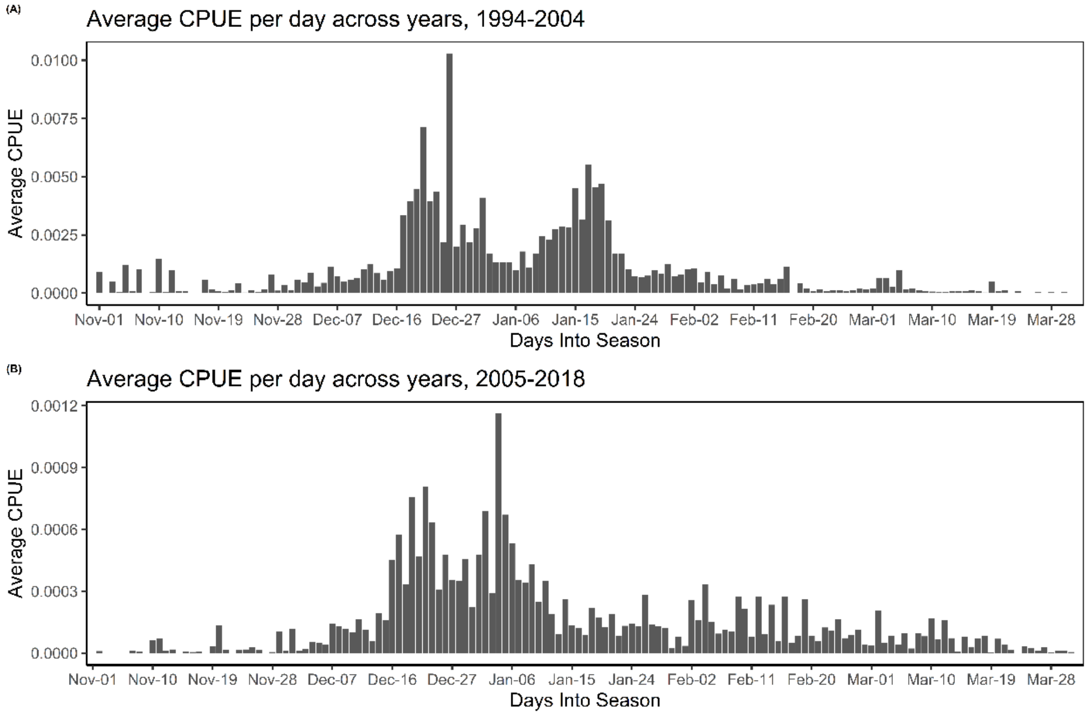


Figure 4: Daily average CPUE across all water years in the pre- and post-POD years. Seasonality in the pre-POD era (A) shows a clearer bimodal distribution than post-POD (B), which shows a more unimodal distribution.

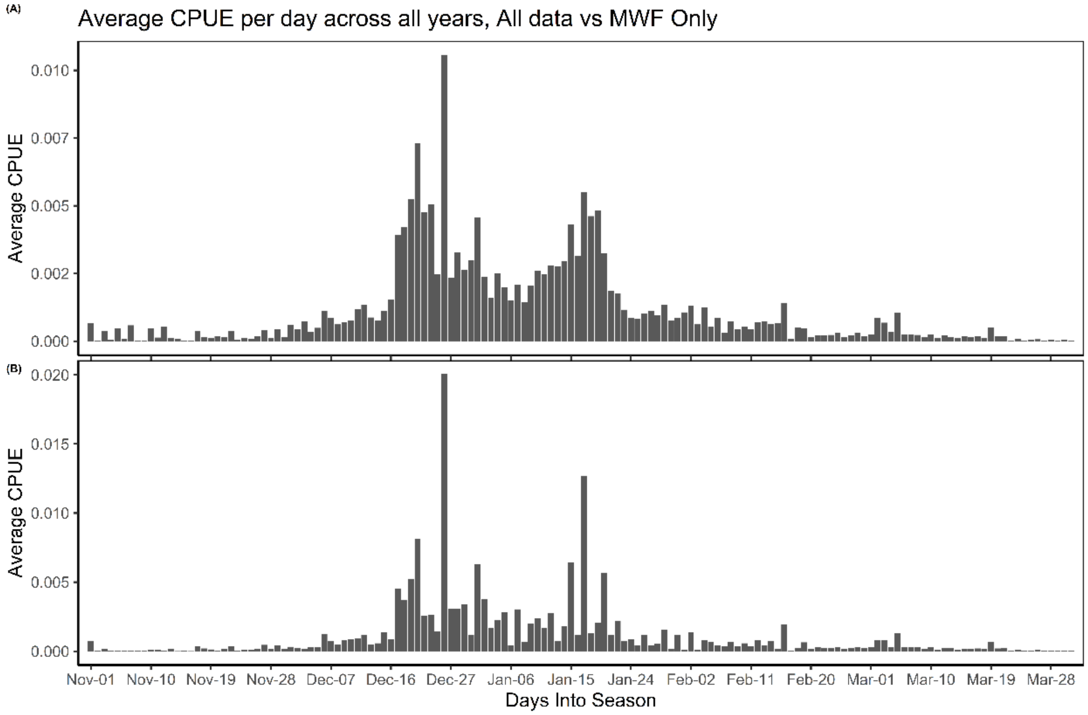


Figure 5: Daily average CPUE across all water years (A) and daily average CPUE restricted to a standardized sampling frequency of Monday, Wednesday, and Friday across all months (B).

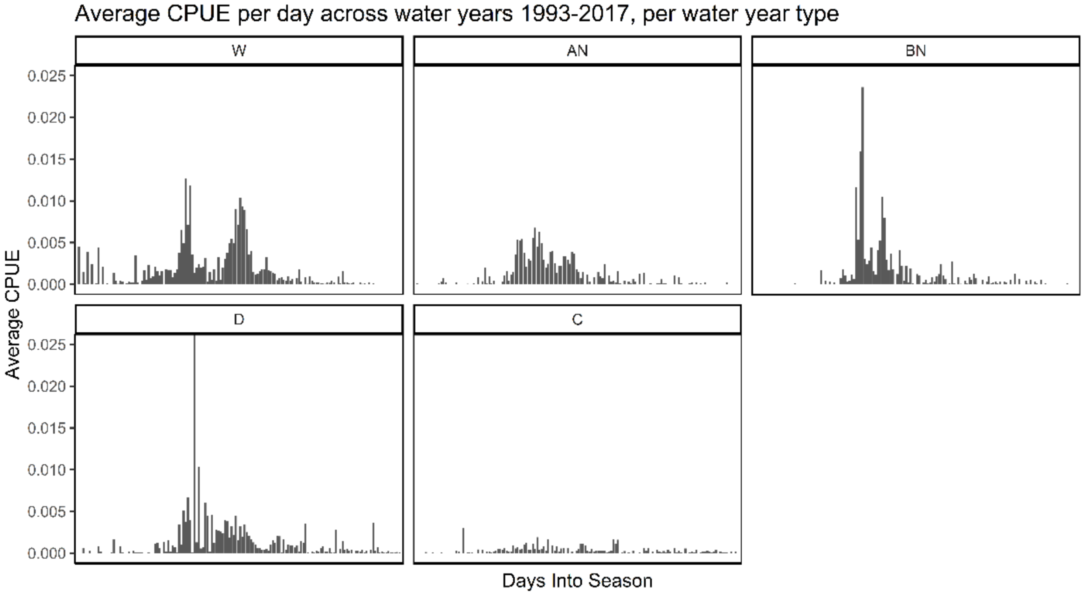
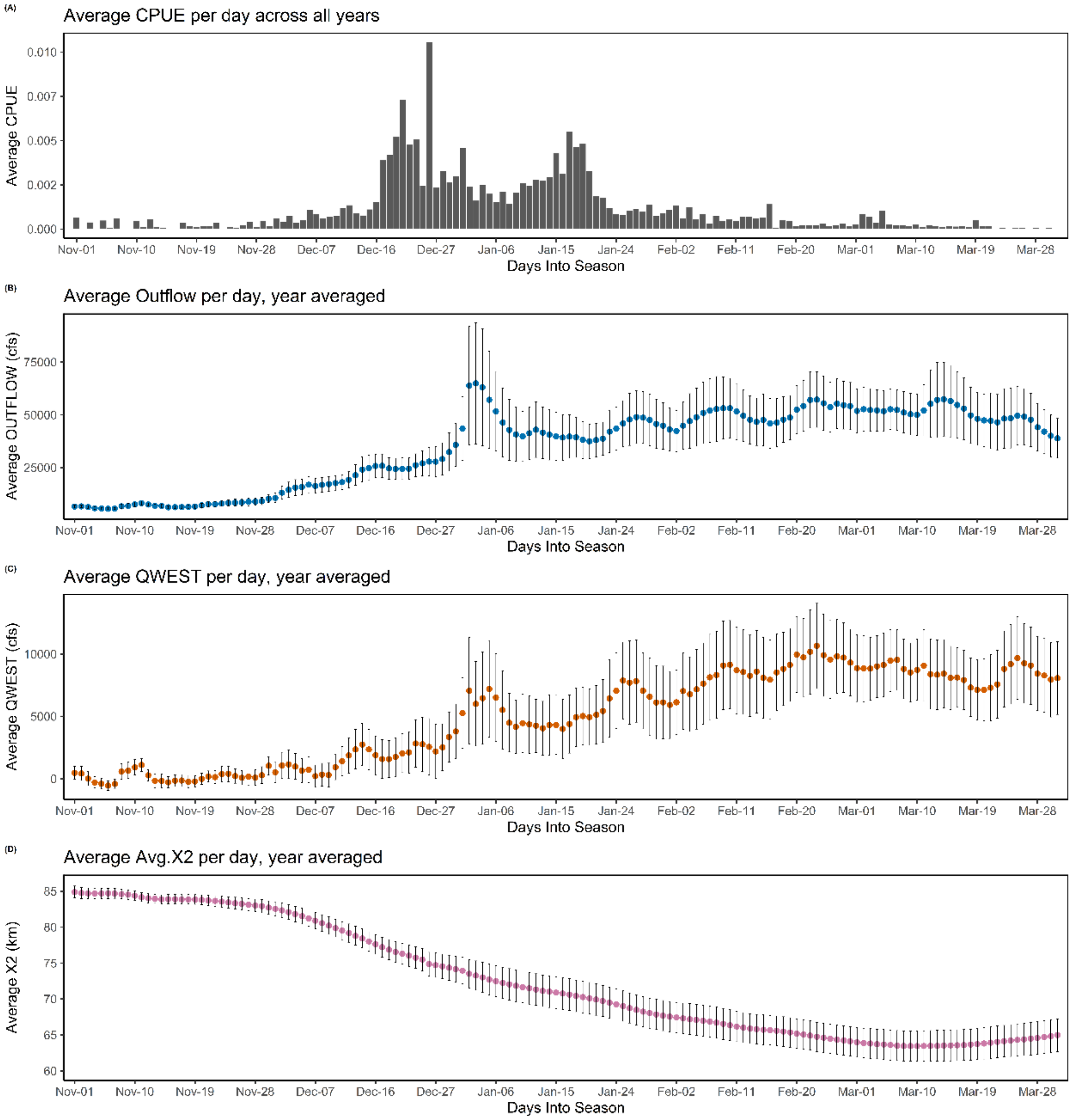


Figure 6: Daily average CPUE by water year type, wet (W), above normal (AN), below normal (BN), dry (D), and critical (C). Seasonal patterns of abundance persist across water year types except that in critical water years migration is more evenly distributed across the season. Note that there is a single day in the dry water year (D) panel that extends beyond the 0.025 CPUE axis, extending up to 0.056.



(A) Average CPUE per day across all years

(B) Average Outflow per day, year averaged

(C) Average QWEST per day, year averaged

(D) Average Avg.X2 per day, year averaged

Figure 7: Daily average CPUE (A) and Dayflow variables, QOUT (B), QWEST (C) and X2 (D).

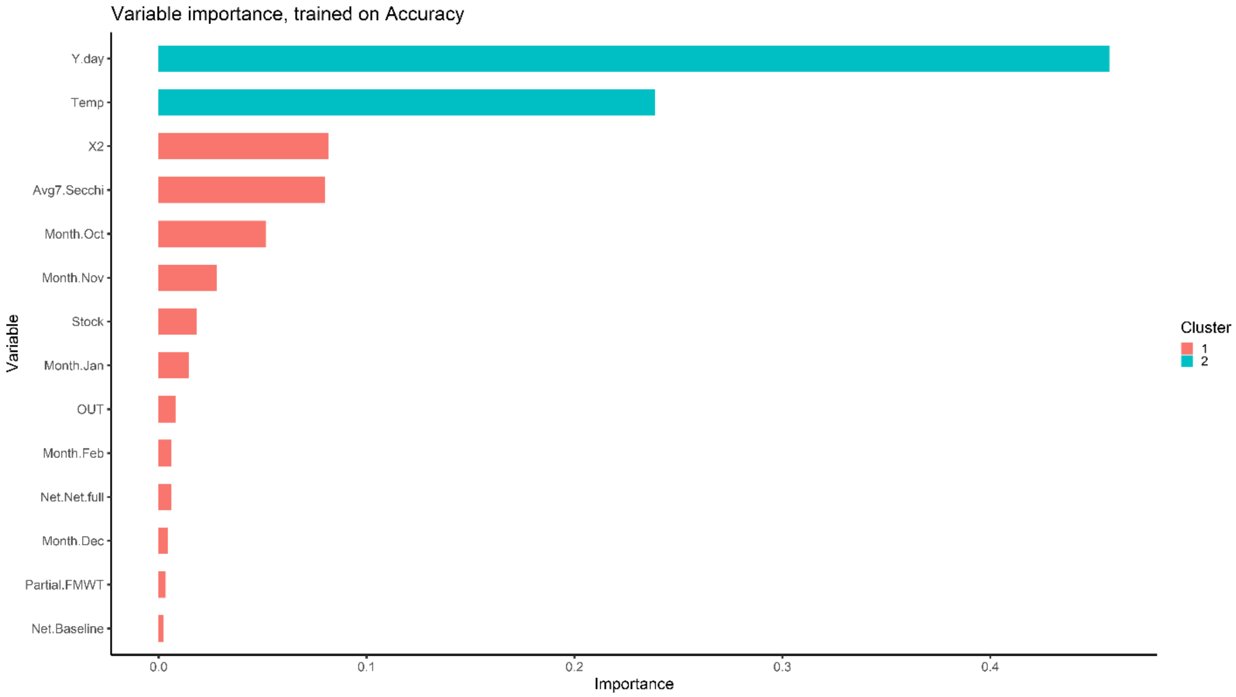


Figure 8. Variable importance plots of the full XGB model trained to maximize accuracy. The number of clusters is optimized from 1-10 by minimizing mean within-cluster distance and maximizing between-cluster distance. It was determined that the optimal number of clusters to separate the importance matrix was two. Cluster one is shown in teal and cluster two is shown in orange.

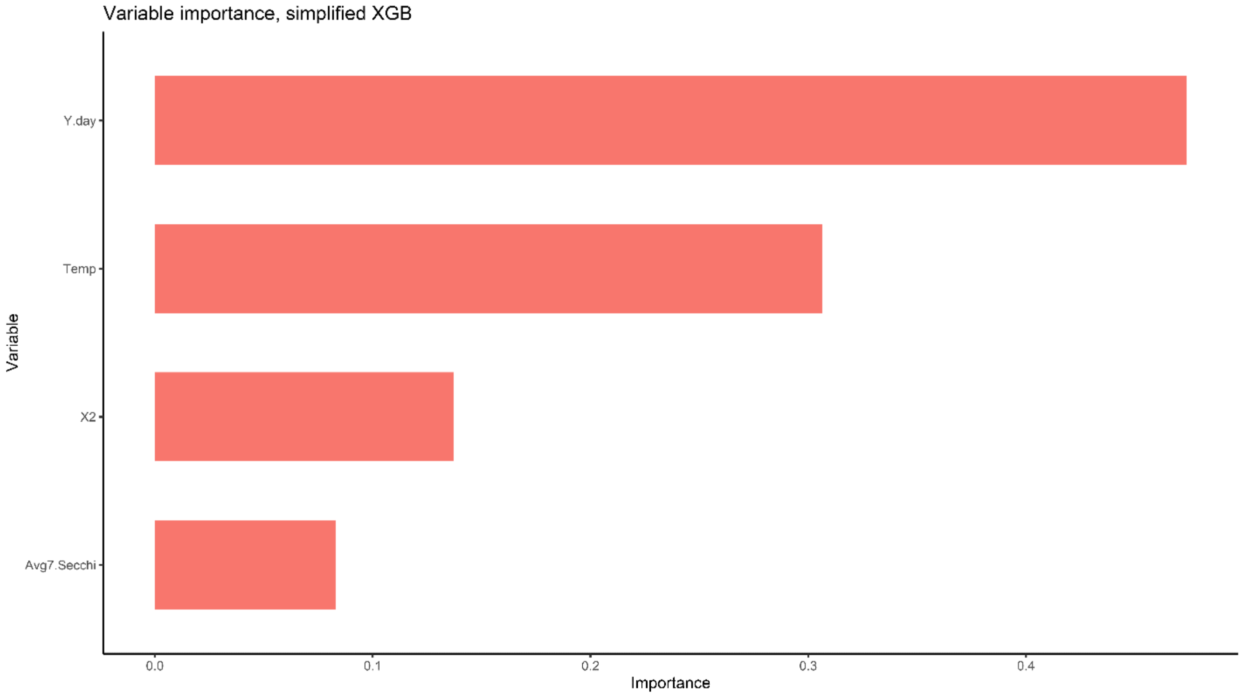


Figure 9. Variable importance for the simplified model based on the top four variables of the full XGB model. This model returned a higher cross-validated accuracy performance than the full XGB model. Variable positions are the same as the full model.

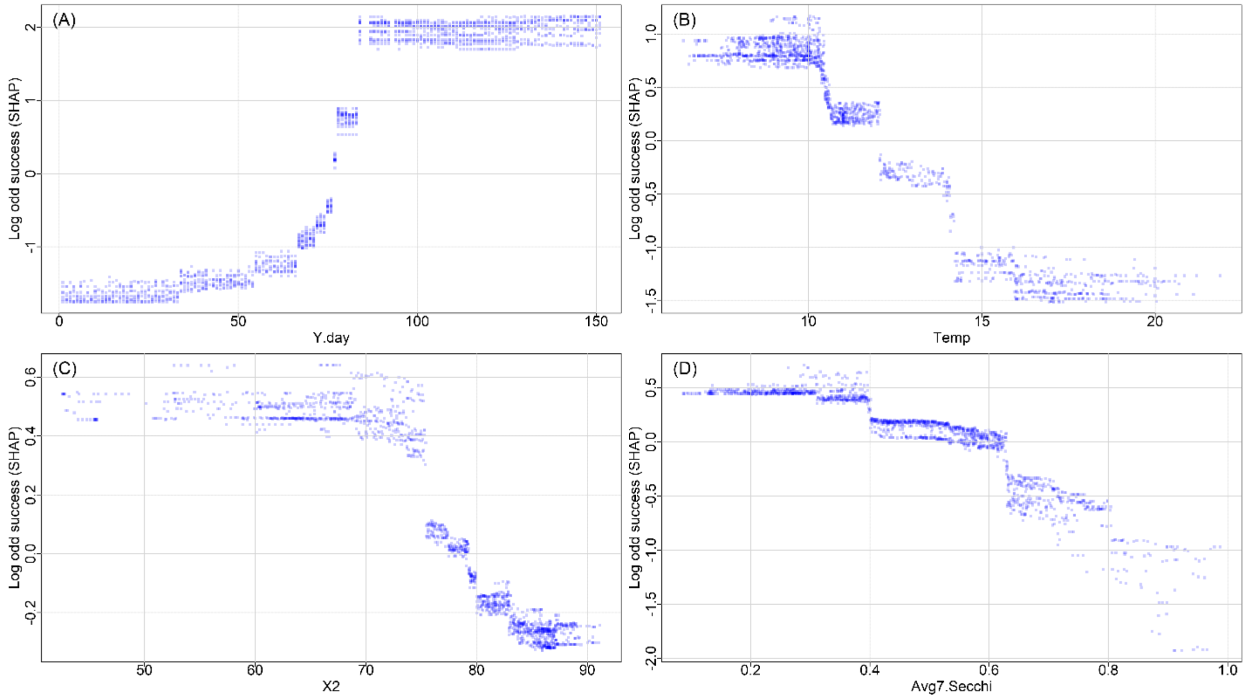


Figure 10. Variable contribution plots for the top four variables in the XGB.full model, Y.day (A), Temp (B), X2 (C), Avg7.Secchi (D). The order of importance flows from top to bottom and left to right. Importance is depicted as SHAP values, or the log odd success percent contribution to predicting a positive class, i.e. post-migration state. SHAP values are displayed as blue points. "Y.day" is season day, with October 1 being 1 and February 28 as 151 A; "Temp" is water temperature (°C); "X2" is the position of the 2 ppt isohaline (km); and "Avg7.Secchi" is the seven days running average of Secchi depth (m).

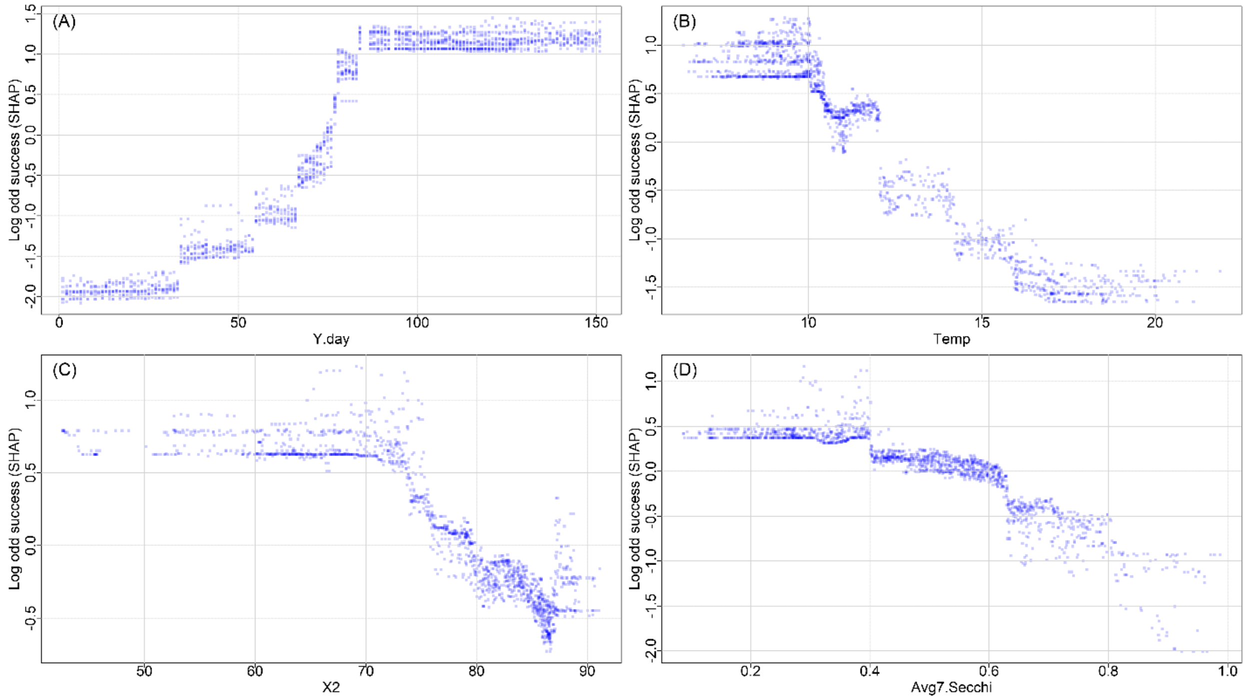


Figure 11: The contribution plots output of the simplified XGB model. The distribution of each variable is similar to the full XGB model (Figure 9).

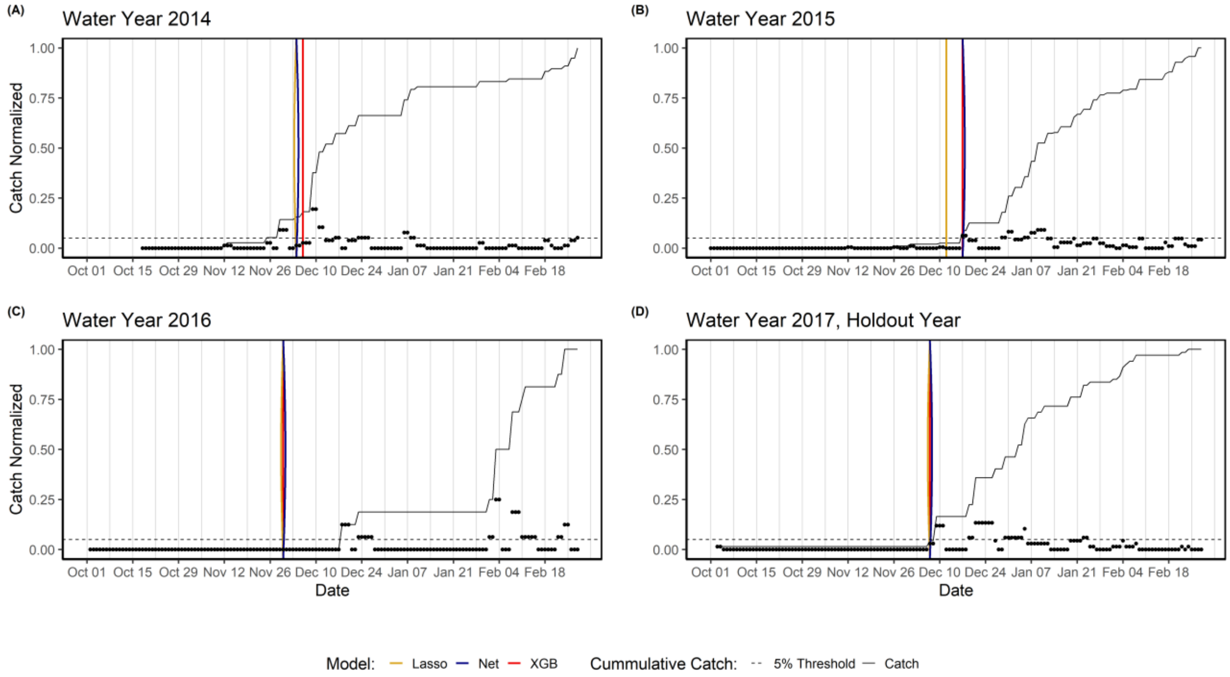


Figure 12. Model predictions of LFS migration onset by the Lasso, Net, and simplified four variable XGB models for water years 2014-2017. The black solid line represents cumulative LFS catch across the season, and the dashed line represents the 5% cumulative threshold; the cross between these two lines indicates theoretical migration onset. The vertical colored lines represent date predictions per model; when two or more models predicted the same start date, the lines were slightly curved for ease of interpretation. All three models predict similar start dates across these years.

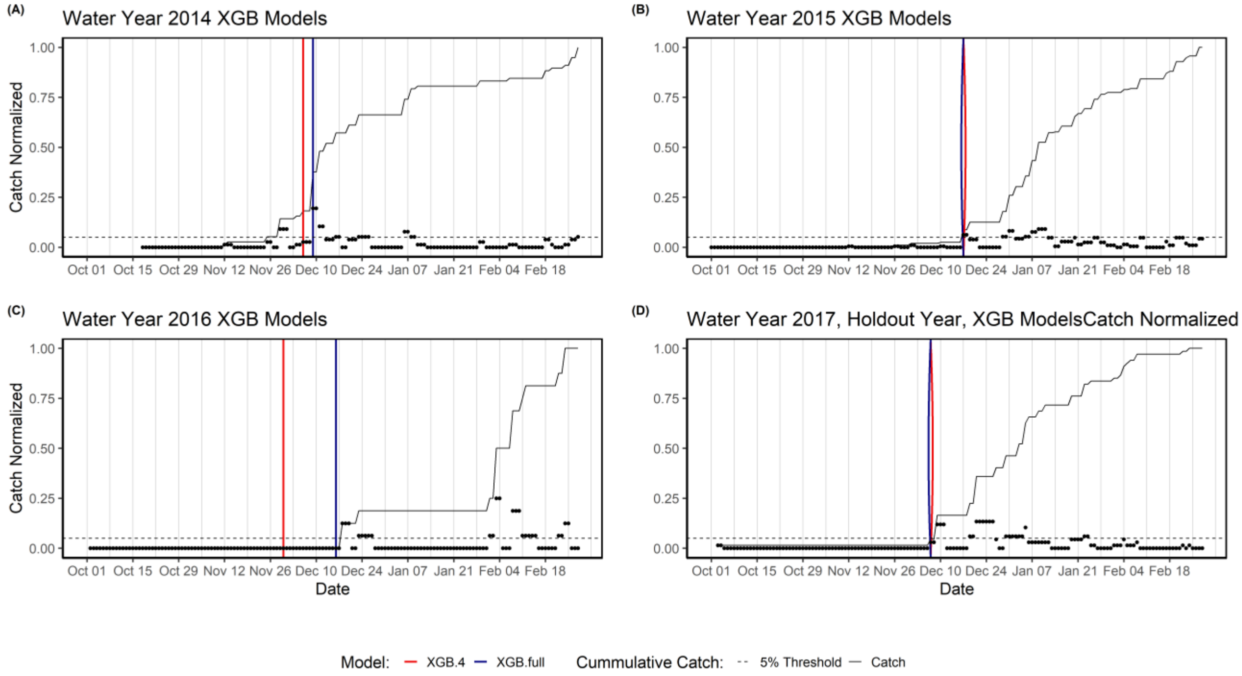


Figure 13. Model predictions of LFS migration onset by the simplified and full XGB models for water years 2014-2017. Both models predict similar start dates across these years except for 2016, where the full model is more accurate.

Table 1. Tuning values and order of the algorithm parameters that were subjected to the tuning process. A stepwise tune was to reduce the number of possible iterations of tuning combinations. The value of each parameter leading to the most accurate model was set static in subsequent tuning steps.

Hyperparameter	**Order**	**Values**
Initial eta	1	0.03, 0.1, 0.3
Max_depth	1	2, 3, 4, 5, 6, 7, 8
Gamma	2	0.1, 0.2, 0.3, 0.4, 0.5
Subsample	3	0.5, 0.6, 0.7, 0.8, 0.9, 1
Colsample_by_tree	3	0.5, 0.6, 0.7, 0.8, 0.9, 1
Final eta	4	0.0003, 0.001, 0.003, 0.01, 0.03, 0.05
Nrounds	4	25 to 5025, by 250

Table 2. Model mean misclassification accuracy, AUC, sensitivity, and specificity for all tested models across all years. Cross-validated standard deviation is provided for each metric and describes model performance across each year and is not meant for comparison between models. The table is sorted based on highest accuracy.

Model	**Accuracy**	**Accuracy_SD**	**AUC**	**AUC_SD**	**Sensitivity**	**Sensitivity_SD**	**Specificity**	**Spec_SD**
XGB_simplified_4	0.9329	0.0513	0.9968	0.0067	0.9464	0.0793	0.9261	0.0986
Net	0.9327	0.0606	1.0000	0.0002	0.9398	0.0899	0.8927	0.1507
Lasso	0.9310	0.0585	1.0000	0.0002	0.9398	0.0899	0.8932	0.1513
XGB_simplified_3	0.9305	0.0552	0.9977	0.0045	0.9518	0.0779	0.9036	0.1280
XGB_full	0.9262	0.0651	0.9971	0.0067	0.9407	0.0947	0.9169	0.1164
Ridge	0.9236	0.0566	0.9995	0.0018	0.9680	0.0663	0.8706	0.1423
RF	0.9226	0.0616	0.9966	0.0077	0.9452	0.0841	0.8948	0.1365
LR	0.8966	0.1008	0.9980	0.0057	0.9301	0.1168	0.8670	0.2056

Table 3. Confusion matrix values of all models tested. A true value occurs when the predicted value matches the observed value. A false value occurs when the predicted value does not match the observed value. Specifically, a false positive occurs when a model predicts a positive class for an observed negative class entry, and a false negative occurs when a model predicts a negative class for an observed positive class entry. All values are reported in percentages and represent the average confusion matrix across all years/resamples. The table is ordered based on average accuracy performance, outlined in Table 2.

Models	**True Positive**	**True Negative**	**False Positives**	**False Negative**
XGB_simplified_4_acc	62.18	31.43	2.86	3.53
XGB_simplified_4_auc	61.88	31.30	2.98	3.84
Net_acc	63.09	30.39	3.90	2.62
Net_auc	61.21	30.15	4.14	4.51
Lasso_acc	62.91	30.45	3.84	2.80
Lasso_auc	61.21	30.15	4.14	4.51
XGB_simplified_3_acc	62.18	31.06	3.23	3.53
XGB_simplified_3_auc	62.24	30.33	3.96	3.47
XGB_full_acc	61.51	31.36	2.92	4.20
XGB_full_auc	61.45	31.06	3.23	4.26
Ridge_acc	63.58	28.87	5.42	2.13
Ridge_auc	63.58	28.87	5.42	2.13
RF_acc	61.63	30.76	3.53	4.08
RF_auc	61.69	29.78	4.51	4.02
LR_acc	60.11	29.17	5.12	5.60
LR_auc	60.11	29.17	5.12	5.60

Table 4. Final variables selected by the lasso and net models. Although the coefficient magnitudes are ordered, this does not represent variable importance.

Feature	Lasso	Net
Y.day	2.267	1.743
Avg7.Secchi	1.200	1.025
Temp	1.110	1.184
OUT	0.000	0.000
X2	0.000	0.000
Stock	0.000	0.000
Partial.FMWT	0.000	0.000
Month.Jan	0.000	0.000
Month.Feb	0.000	0.000
Month.Oct	0.000	0.000
Month.Nov	0.000	0.000
Month.Dec	0.000	0.000
Net.Baseline	0.000	0.000
Net.Net.full	0.000	0.000
Net.Net.int	0.000	0.000
POD.Post.Pod	0.000	0.000
POD.Pre.POD	0.000	0.000

Table 5. Calculated position of a LOESS regression x-intercept for each of the top four variables in both full and simplified XGB models. These values are not predictive values and are only meant to aid interpretation of the model. The values across both models are stable despite the inclusion of additional variables and interactions in the full model.

Variable	XGB.Full.Model	XGB.4.Model
Y.day	75.37	73.04
Temp	12.01	11.82
X2	78.46	78.60
Avg7.Secchi	0.58	0.57

Table 6. Differences between predicted migration start date as determined during the cross-validation and actual migration start dates of the top performing models. The full XGB model is provided as a comparison of stability to the simplified XGB model. “Start.Date” represents the cross of the cumulative catch threshold at 5%, the actual start dates that the models were trained on. “Day diff” represents the difference in days between predicted and actual; “Row diff” represents the difference in dataset rows between predicted and actual as a secondary metric less biased by sampling frequency.

		Lasso		**Net**		**XGB.Full**		**XGB.4**	
WY	**Start.Date**	**Day diff**	**Row diff**	**Day diff**	**Row diff**	**Day diff**	**Row diff**	**Day diff**	**Row diff**
1994	1993-11-22	15 days	8	15 days	8	20 days	13	16 days	9
1995	1994-11-30	-2 days	-1	-2 days	-1	-2 days	-1	2 days	1
1996	1995-11-07	36 days	4	36 days	4	43 days	5	43 days	5
1997	1996-12-07	-4 days	-4	-4 days	-4	-4 days	-4	-4 days	-4
1998	1997-12-06	-3 days	-3	-3 days	-3	-3 days	-3	-3 days	-3
1999	1998-10-27	31 days	10	31 days	10	36 days	13	14 days	4
2000	1999-12-14	-15 days	-11	-15 days	-11	-15 days	-11	-10 days	-7
2001	2000-11-03	21 days	5	13 days	3	33 days	8	33 days	8
2002	2001-12-12	-12 days	-5	-12 days	-5	-9 days	-4	-9 days	-4
2003	2002-12-06	-1 days	-1	-1 days	-1	-1 days	-1	5 days	5
2004	2003-12-16	-13 days	-11	-13 days	-11	-2 days	-2	-15 days	-12
2005	2004-12-16	-17 days	-13	-17 days	-13	-13 days	-11	-13 days	-11
2006	2005-12-07	1 days	1	0 days	0	4 days	4	3 days	3
2007	2006-12-23	-5 days	-5	-5 days	-5	-7 days	-7	-7 days	-7
2008	2007-12-01	0 days	0	0 days	0	10 days	7	5 days	2
2009	2008-11-10	37 days	12	37 days	12	37 days	12	37 days	12
2010	2009-12-11	-4 days	-2	-4 days	-2	-2 days	-1	-4 days	-2
2011	2010-12-17	-14 days	-6	-14 days	-6	-11 days	-5	-11 days	-5
2012	2011-12-05	0 days	0	0 days	0	0 days	0	-26 days	-4
2013	2012-12-14	-7 days	-2	-4 days	-1	-7 days	-2	-7 days	-2
2014	2013-11-25	9 days	4	9 days	4	14 days	6	11 days	5
2015	2014-12-17	-5 days	-1	0 days	0	0 days	0	0 days	0
2016	2015-12-18	-18 days	-8	-18 days	-8	-2 days	-1	-18 days	-8
Hold out year									
2017	2016-12-09	2 days	1	2 days	1	2 days	1	2 days	1
Sum across all years									
		272 days	118	255 days	113	277 days	122	298 days	124

Table 7. Prediction dates of the top performing models, the lasso, net, full XGB, and simplified XGB optimized on the accuracy metric.

Starting Date Predictions

WY	Start Date	Lasso	Net	XGB.Full	XGB.4
1994	1993-11-22	1993-12-07	1993-12-07	1993-12-12	1993-12-08
1995	1994-11-30	1994-11-28	1994-11-28	1994-11-28	1994-12-02
1996	1995-11-07	1995-12-13	1995-12-13	1995-12-20	1995-12-20
1997	1996-12-07	1996-12-03	1996-12-03	1996-12-03	1996-12-03
1998	1997-12-06	1997-12-03	1997-12-03	1997-12-03	1997-12-03
1999	1998-10-27	1998-11-27	1998-11-27	1998-12-02	1998-11-10
2000	1999-12-14	1999-11-29	1999-11-29	1999-11-29	1999-12-04
2001	2000-11-03	2000-11-24	2000-11-16	2000-12-06	2000-12-06
2002	2001-12-12	2001-11-30	2001-11-30	2001-12-03	2001-12-03
2003	2002-12-06	2002-12-05	2002-12-05	2002-12-05	2002-12-11
2004	2003-12-16	2003-12-03	2003-12-03	2003-12-14	2003-12-01
2005	2004-12-16	2004-11-29	2004-11-29	2004-12-03	2004-12-03
2006	2005-12-07	2005-12-08	2005-12-07	2005-12-11	2005-12-10
2007	2006-12-23	2006-12-18	2006-12-18	2006-12-16	2006-12-16
2008	2007-12-01	2007-12-01	2007-12-01	2007-12-11	2007-12-06
2009	2008-11-10	2008-12-17	2008-12-17	2008-12-17	2008-12-17
2010	2009-12-11	2009-12-07	2009-12-07	2009-12-09	2009-12-07
2011	2010-12-17	2010-12-03	2010-12-03	2010-12-06	2010-12-06
2012	2011-12-05	2011-12-05	2011-12-05	2011-12-05	2011-11-09
2013	2012-12-14	2012-12-07	2012-12-10	2012-12-07	2012-12-07
2014	2013-11-25	2013-12-04	2013-12-04	2013-12-09	2013-12-06
2015	2014-12-17	2014-12-12	2014-12-17	2014-12-17	2014-12-17
2016	2015-12-18	2015-11-30	2015-11-30	2015-12-16	2015-11-30
Hold out year					
2017	2016-12-09	2016-12-07	2016-12-07	2016-12-07	2016-12-07

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APPENDIX B

Of the

State Water Project Effects Analysis on Longfin Smelt and Delta Smelt

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Prepared by California Department of Fish and Wildlife

Variables That Influence Adult Longfin Smelt Salvage

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March 2020

Background

Operations of the State Water Project (SWP) and Central Valley Project (CVP) overlap with the period when adult longfin smelt (LFS) migrate into the Delta, from November through April every year (CDFG 2009a). Historically, LFS have been entrained into the SWP and CVP facilities at a rate that increases with proximity to the two facilities and increasingly negative OMR flows (Grimaldo et al. 2009). This appendix describes analyses used to characterize potential variables associated with increases or decreases in adult LFS salvage when salvage events occur.

Data

The model was constructed using six datasets: 1) salvage of adult LFS at both the SWP and CVP facilities; 2) Fall Midwater Trawl (FMWT); 3) Chipps Island Trawl; 4) Old and Middle Rivers (OMR) tidally filtered flows from USGS gauges; 5) Sacramento River stage at Rio Vista Bridge (RVB); and 6) Dayflow. A binary variable was included to attempt to account for the Pelagic Organism Decline (POD) change point in 2004 for LFS (Thomson et al. 2010). The data range for all dataset was constrained to water year 1997-2019based on X2 data availability in the Dayflow dataset.

Salvage dataset

Data was extracted from the salvage Access database obtained from CDFW Region 3's FTP website (*ftp://ftp.wildlife.ca.gov/salvage/*) to include the variables: SampleDate, SampleTime, SampleMethod, StudyRowID, MinutesPumpig, SampleTimeLength, WaterTemperature, BuildingCode, OrganismCode, Count, Forklength, and LengthFrequency. The data ranged from 1993-01-15 to 2019-02-25 and was filtered to include only LFS catch, OrganismCode value 25, from non-special studies, StudyRow IDs' "0000" and "9999". Each count was expanded to account for pre-screen loss (Castillo et al. 2012). For entries with StudyRow ID = "0000", the expansion equation was: $Count * (\frac{MinutesPumping}{SampleTimeLength})$; for entries with StudyRow ID = "9999", the expansion equation was 1. Duplicated count entries caused by fork length entries were accounted for. LFS salvaged from December through February were assumed to be adults.

Fall Midwater Trawl dataset

Data was obtained from the CDFW Region 3's FTP website (*ftp://ftp.wildlife.ca.gov/TownetFallMidwaterTrawl/*). Stations were categorized into four regions, "North", "Far West", "West", and "South", based on the USFWS's Delta Smelt Life Cycle Model nomenclature (version "FMWT_67_15"; Table 2 here). LFS catch was summed per region and year.

Chipps Island Trawl dataset

Data was obtained from the USFWS Delta Juvenile Fish Monitoring Program's website (*https://www.fws.gov/lodi/juvenile_fish_monitoring_program/jfmp_index.htm*). Cumulative catch of LFS was calculated per month from October through February each year. Cumulative catch was also standardized to one per year and the date associated with the 5% cumulative catch was chosen as the starting date of each migration season (see Appendix A for a more detailed explanation).

Old and Middle Rivers dataset

Tidally filtered flows were extracted from the USGS National Water Information System website (*https://nwis.waterdata.usgs.gov/nwis/*) for Old River station (1131340) and Middle River station (11312676). Missing entries from both stations were extrapolated using a linear regression of each station to one another (Adj $R^2 = 0.97$). OMR flow was calculated as the summation of flow at both stations. Weekly average OMR flows was included in the analysis; this variable was also lagged two and four weeks and included as additional variables in the analysis.

Sacramento River stage dataset

River stage data was obtained from DWR CDEC website (*http://cdec.water.ca.gov/index.html*). Weekly average river stage was added to the dataset; this variable was also lagged two and four weeks and included as additional variables in the analysis.

Dayflow dataset

Data from Dayflow was obtained via the California Open Data Portal website (*https://data.ca.gov/dataset/dayflow*). Sacramento River flow (SAC), San Joaquin River flow past Jersey Point (WEST), San Joaquin River flow (SJR), estimated net Delta outflow at Chipps Island (OUT), X2 position (X2), and total Delta exports (EXPORTS) were included. Various running averages were calculated and included for these variables. Weekly average SAC and OUT were added to the dataset; these variables were also lagged two and four weeks and included as additional variables in the analysis.

Model Construction

All datasets were combined with the salvage dataset by date, month, or year of the corresponding salvage event, e.g., a monthly variable was combined with the month that a salvage event occurred in. The model was built on the XGBoost machine learning algorithm and the associated workflow was described in Appendix A of the CDFW Smelt Effects Analysis. Only data after water year 1997 was considered constrained by the availability of Dayflow X2 data. Due to the sparseness of salvage data for adult LFS and the narrow objective of this analysis, only dates with actual salvage were modeled.

All variables were subjected to a model selection process to increase model interpretability (see Table 3). This selection process was guided by the variable importance ranking from the XGBoost model and a correlation threshold of 0.70 (Dormann et al. 2013). SHAP plots were used to interpret local variable importance (see Appendix A of the Effects Analysis for more details).

Model fit

Due to a limited number of datapoints, the model was trained on the entire dataset and subjected to a three-repeats, 10-folds cross validation (CV) design. All models were evaluated on minimizing root mean squared error (RMSE). R^2 calculated from Pearson's correlation was considered as a secondary metric to compare across models but was not used for model optimization.

Results

Model selection

Three clusters were identified in the variable importance matrix from the XGB model containing all relevant variables (Figure 4, Step 1 in Table 3; refer to Appendix A for more details on variable importance). Variables in clusters two and three were selected forward due to their high importance values. The higher ranked variables in the lowest cluster (cluster 1) were also selected: SAC5, omrWeek, SAC14, catchFMWTDec, and X2. farWestFMWTDec was not selected since it was highly correlated with catchFMWTDec (correlation of 0.906), which was already selected. “EXPORTS” was selected in the model to provide a finer resolution of the “omrWeek” variable (Step 2 in Table 3). A final model was chosen after dropping “SAC5” and “SAC14” due to high correlation (> 0.70) with the second most important variable, “SAC” (Step 3 in Table 3).

Model performance

The best performing applicable model contained ten predictor variables with an average CV RMSE of 4.380 (± 1.629) and R^2 of 0.490 (± 0.2198) (Table 1). This represented a 33.90% and 7.693% improvement in average CV RMSE compared to a baseline model using only the average of the response variable to predict (RMSE = 5.865) and to a linear regression model utilizing the same ten predictor variables (RMSE = 4.717 ± 1.651), respectively (Table 1). There was an increase of 21.13% in R^2 when compared to the linear regression model. Correlation coefficients between variables included in the preferred model were all below 0.70 (Figure 3). The highest importance variable, defined as the variable responsible for the greatest increase in accuracy of the model, was the difference in number of days between salvage event and the start of the migration period from Chipps Island in that season (Figure 1). Contribution SHAP plots predicted greater salvage when 1) salvage occurs earlier in the migration season as indexed at Chipps Island, 2) catch of LFS in the estuary is high (“north” and “farWest” FMWT stations, all FMWT stations in December, and at Chipps Island), 3) X2 is at 65 km and above 75 km, 4) daily Sacramento River flow is greater than 50,000 cfs, and 5) water exports are high. Conversely, reduced salvage is predicted when 1) salvage occurs later in the migration season, 2) the average Sacramento River flow from four weeks prior is high, and 3) less fish are caught in the FMWT and Chipps Island Trawl. LFS salvage events were predicted to be greater when mean OMR values are more negative than -5000 cfs and predicted to be lower when mean OMR values are more positive than -5000 cfs, with potentially outlying points at very negative and positive values due to a lack of data (Figure 1).

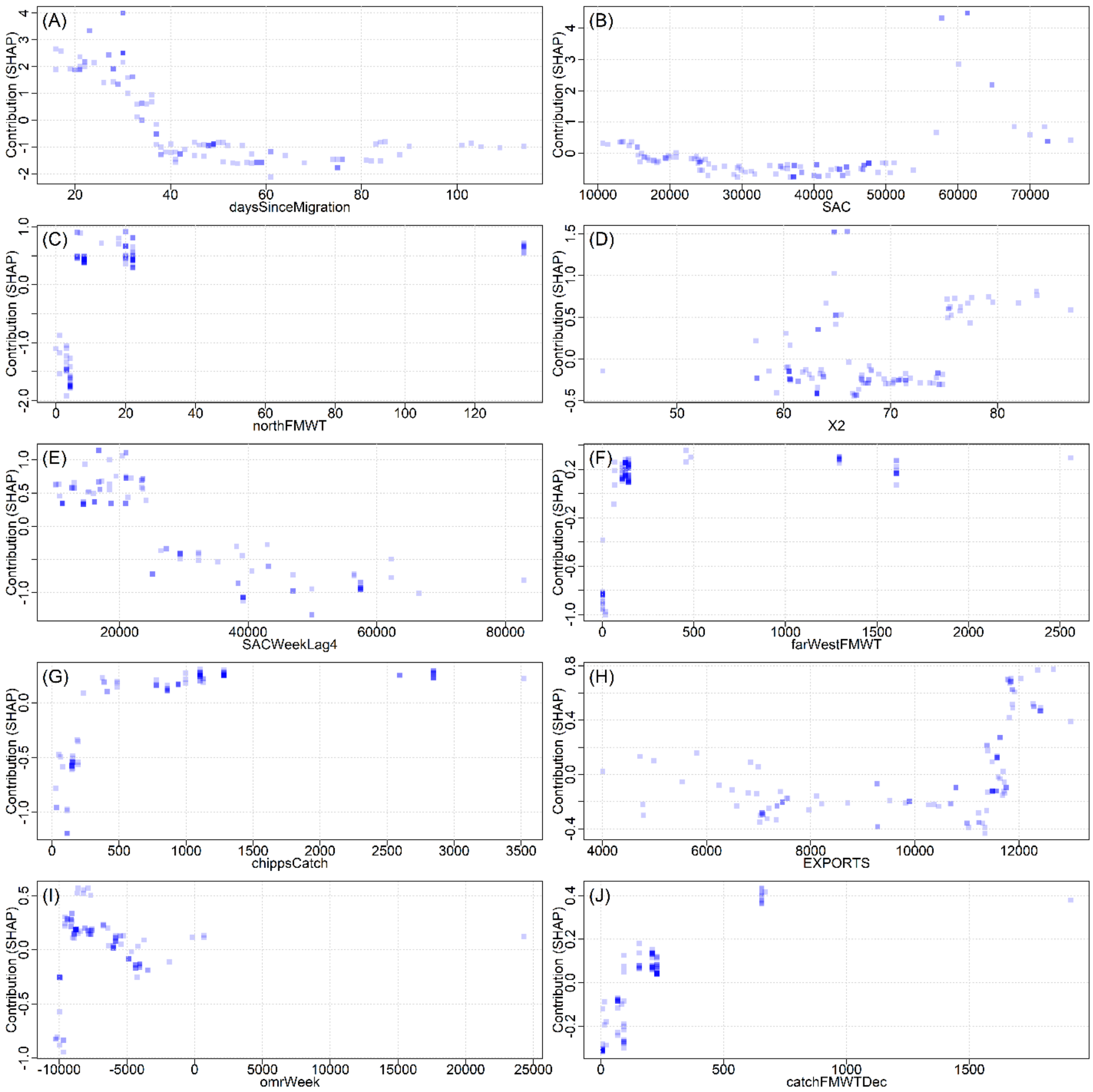


Figure 1. Contribution plots of the variables used to inform expanded LFS salvage at the facility from 1993-2019. Order of importance is from left to right and top to bottom. daysSinceMigration is the most important variable in the model and shows that increased salvage is expected within the first 36 days after LFS have entered the Delta, closer in proximity to the export facilities. Higher exports result in higher salvage of LFS, especially under high flow conditions. Variables are defined as: (A) daysSinceMigration is the number of days since the onset of LFS migration as determined by 5% cumulative catch per water year at Chipps Island; (B) SAC is Sacramento R. outflow (cfs); (C) northFMWT is the total catch in the FMWT for stations 706-797; (D) X2 is the position of the 2 psu isohaline from the Golden Gate Bridge; (E) SACWeekLag4 is weekly average Sacramento R. outflow (cfs) from four weeks prior; (F) farWestFMWT is the total catch in the FMWT for stations 302-418; (G) chippsCatch is monthly LFS catch by the Chipps Island Trawl; (H) EXPORTS is total daily exports from the CVP and SWP from Dayflow; (I) omrWeek is weekly average OMR flow; and (J) catchFMWTDec is total LFS catch from all FMWT stations for the month of December each year.

The overall best performing model contained only one variable with an RMSE of 3.157 and R^2 of 0.732. This model contained only the salvage expansion number. This model was included for demonstration purposes only and was an attempt to better understand the quality of the data.

Table 1. Model steps with the associated evaluation metrics for the preferred model. Model selection was based on minimizing RMSE. R^2 is provided as an aid to interpret model fit but was not used for optimization. Standard deviations are provided for both metrics and are measured across the cross-validation scheme, 10 folds and 3 repeats. Exploratory models are for comparison purposes only. "Count multiplier" is a single variable model while "All Variable" adds in the remaining variables initially considered; both models were constructed on the same training dataset as the preferred model. "Mean response" is predicting every datapoint with the mean expanded count across the entire dataset. R^2 cannot be calculated for this because the predicted value has a variance of zero.

Models	RMSE	R^2	RMSE SD	R^2 SD
Step 0	4.626672	0.4283821	1.655479	0.1834205
Step 1	4.420288	0.5156021	1.708238	0.2426933
Step 2	4.439062	0.5078828	1.665310	0.2394480
Final_Tuned	4.379861	0.4896038	1.629023	0.2197515
Exploratory models				
Count Multiplier	3.157311	0.7324010	1.019376	0.1953650
All variables	3.312426	0.7247030	1.401461	0.1603468
Linear Model	4.716817	0.3861535	1.651460	0.1670112
Mean response	5.864621	NA	NA	NA

Discussion

This analysis was conducted to better understand the underlying mechanisms associated with the magnitude of LFS salvage at the SWP and CVP facilities during the fall and winter periods. Because we excluded dates without LFS salvage events, interpretations of model results should be limited to understanding changes in salvage, when salvage occurs. The ten variables in the preferred model described two general components of LFS salvage: 1) spatial proximity to the export facilities; and 2) hydrologic conditions and water export operations.

Spatial distribution

Six of ten variables in the preferred model related the spatial distribution of the LFS population and to increase or decreases in salvage of fish at the export facilities. Predicted salvage is highest following the start of the peak catch season of LFS at Chipps Island (daysSinceMigration). Adult LFS migrate into low salinity and freshwater habitat to spawn (Rosenfield 2010) and, potentially, within the zone of influence of the export facilities. LFS spawning migration is believed to occur quickly (Dryfoos 1965; Moulton 1974) and higher salvage intuitively should occur early in the season, when the influx of LFS into the Delta is highest.

The quickness of the LFS migration movement was further captured in the farWestFMWT, and chippsCatch, northFMWT variables. These three variables represent a west to east distribution across the estuary, from the Carquinez Strait, to Chipps Island, and into the Sacramento River. Despite the substantial distances between these three variables, the contribution curves of all three exhibit the same shape, increasing in magnitude of salvage with increasing number of LFS by each survey. This is also illustrated in the SHAP plot for the catchFMWTDec variable. Despite the large spatial extent of this variable, encompassing all FMWT stations, it exhibits the same relationship as the three more location specific variables. Altogether, the daysSinceMigration, farWestFMWT, chippsCatch, northFWMT, and catchFMWTDec variables indicate that migrating adult LFS are susceptible to salvage due to how quickly they move through the system.

The last variable explaining the relationship between spatial distribution of LFS and increases in salvage was X2. The X2 SHAP plot predicted increased salvage when X2 was near 65 km and when X2 was beyond 75 km. The distribution of staging and spawning adult LFS has been linked to the location and movement of X2 (CDFG 2009b). An increase in salvage when X2 is at 65 km may be the result of the congregation and staging of adult LFS around Suisun Bay prior to and during the migration period into the Delta. Staging specifically in Suisun Bay may provide fish with increased protection due to the generally higher turbidity in the area (IEP-MAST 2015). Under this scenario, the signal when X2 is at 65 km is similar to the “daysSinceMigration” variable, describing conditions preceding the imminent LFS migration into the Delta. An increase in salvage when X2 is greater than 75 km has a more straightforward explanation, in that fish are staging and migrating closer to the zone of entrainment. Since fish staging are staging farther inland when X2 is at 75 km, average SHAP values should be higher than values at lower X2 values (Figure 1).

Hydrologic conditions and export operations

The remaining four variables, SAC, SACWeekLag4, EXPORTS, and omrWeek, related the magnitude of LFS salvage events to hydrologic conditions and export operations. The predicted magnitude of salvage is greater at higher daily Sacramento River flow. Although this relationship could be explained if LFS behaviorally responded to outflow to initiate migration, similar to the Delta smelt response to first flush conditions, other variables are more important in determining migration timing, i.e., day of year and temperature (refer to Appendix A). An alternative explanation would be that LFS salvage increases in response high Sacramento River flow because of an associated increase in water exports in response to wetter hydrological conditions in the Sacramento River (Figure 2). The model predicted that the magnitude of LFS salvage events increased when total Delta exports increased (Figure 1). Increased exports in response to increased Sacramento River flow causes the zone of influence of the export facilities to expand downstream if the corresponding increase in the San Joaquin River is low, leading to greater entrainment of fish migrating within the Delta into the south Delta. The relationship between increased exports in response to wetter hydrology when it is isolated to the Sacramento River compared to when it is Delta wide requires further analysis.

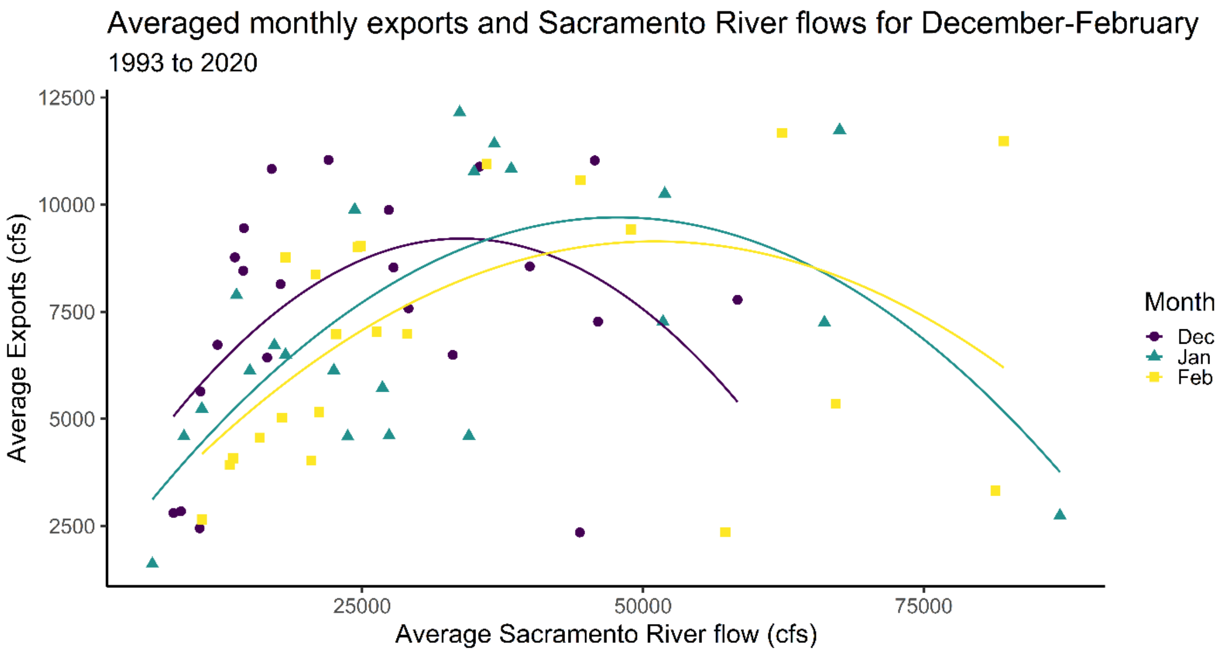


Figure 2. Average monthly exports and average Sacramento River flow for December, January, and February from 1993-2020. Generally, exports increased with increasing Sacramento River flow up until Sacramento River flows exceeded 30,000 cfs (December) or 50,000 cfs (January and February). The data was not constrained to periods with LFS salvage to better depict the relationship between the two variables. Data was taken from Dayflow. The trendlines are a second polynomial fit to each month and are for illustration purposes only.

The contribution plot for the variable describing the average weekly Sacramento River flow from four-weeks prior predicted lower salvage when outflow conditions four weeks prior was high (Figure 1). The inclusion of this weekly lagged variable was motivated by the idea that daily Sacramento River flow should not have an immediate effect on the movement of adult LFS in the Delta. Although the SHAP values indicate an effect of this variable on the magnitude of salvage, the mechanisms associated with this relationship are not easily explained and additional analysis is required to better understand this finding.

The contribution plot for weekly average OMR predicted greater magnitude of salvage events at OMR values more negative than -5000 cfs and reduced magnitude of salvage events at OMR values more positive than -5000 cfs. This threshold is consistent with OMR restrictions required to minimize entrainment of Delta smelt included in USFWS (2008) and the 2020 ITP. It is unknown from this analysis if this threshold is effective in minimizing the magnitude of LFS salvage events, of if these results are an artifact or post-POD era abundance, or the combination of low population abundance post-POD and the prevalence of -5000 cfs in post-2008 Biological Opinion era.

There are several data points at highly negative OMR values that contribute to lowering the predicted magnitude of LFS salvage. These contribution values are not intuitive and are not easily reconciled with the rest of the model. One explanation for these anomalies is that there is also a lack of salvage data at such highly negative values and caution is warranted when interpreting these values.

Data quality

The process of expanding LFS salvage count to account for subsampling introduces noise into the data which may potentially influence the ability to model salvage data accurately using hydrologic and spatial distribution data. In order to better understand the effect of increased noise as a result of expanding salvage counts, a model was trained on the same dataset as the preferred model with only the count multiplier as the predictor variable. This resulted in the highest performing model with an average CV RMSE of 3.157 (±1.019) and R^2 of 0.732 (± 0.1954). Adding the hydrological and spatial distribution variables to this base model results in a poorer fitting model, RMSE of 3.315 (± 0.1603) and R^2 of 0.722 (± 0.1603) (Table 1). Together these results indicate that the subsampling process introduces noise into the salvage dataset that is not attributable to the hydrologic and spatial distribution variables assessed in this analysis. However, in practice it is not feasible to sample continuously and some amount of subsampling is required based on staffing and operational constraints.

Conclusion

This analysis describes variables that influence take of LFS from December to February of each year, narrowly defined as the expanded number of LFS observed at the salvage facilities when salvage occurs. The magnitude of salvage is predicted to increase soon after LFS begin migrating into the Delta and in response to LFS distribution in close proximity to the export facilities. This migration occurs quickly, as the fish enter San Pablo Bay, past Chipps Island, and into the Delta. Higher export levels during this migration resulted in increased magnitude of salvage. High outflow may dampen the magnitude of increases in salvage associated with increased exports by constraining the zone of influence; however, this is only likely when high flow is system-wide and not simply isolated to the Sacramento River. Limiting average weekly OMR to be more positive than -5000 cfs appears to also dampen the magnitude of salvage compared to weekly OMR more negative than -5000 cfs; however, this analysis cannot identify the underlying mechanisms for this threshold.

Effects of the Project on LFS

Take of LFS is expected to continue as a result of Project operations. The model described in this Appendix is capable of informing management actions to minimize take of LFS, but has some limitations. Model results were only able to explain about half of the variance in the salvage dataset. Additionally, the model only analyzed changes in the magnitude of salvage events, when they occurred, and did not assess the potential to use hydrologic or operational variables as a tool to avoid salvage of LFS. As a result, risk assessments that evaluate hydrologic and operational factors to understand the risk of LFS salvage should weigh the limitations associated with this model. Despite these limitations, the model shows that take of LFS could be minimized, but not avoided, using two possible approaches: 1) export curtailments shortly after the start of the LFS migration period as indicated by the Chipps Island Trawl from December-February of each year; or 2) export curtailments when Delta outflow is driven almost entirely by increases in Sacramento River flows, without increases in east side tributary and San Joaquin River flows. Because the model only explained about half of the variance and the salvage dataset and days with zero LFS salvage were not included in the model, conclusions should not be interpreted as capable of preventing salvage of LFS by the SWP, but only as capable of minimizing salvage when salvage occurs.

Table 2. Region assignment for FMWT stations based on the USFWS Delta Smelt Life Cycle Model

Far West	West	North	South
302	413	72	809
309	419	73	810
310	501	706	811
311	502	707	812
315	503	708	813
320	504	709	814
321	505	710	815
322	506	711	901
323	507	712	902
324	508	713	903
325	509	715	904
326	510	716	905
327	511	717	906
328	512	719	907
329	513	721	908
330	514	723	909
331	515	724	910
332	516	735	911
333	517	736	912
334	518	794	913
335	519	795	914
336	601	796	915
337	602	797	916
338	603	NA	917
339	604	NA	918
340	605	NA	919
341	606	NA	920
401	607	NA	921
402	608	NA	922
403	701	NA	923
404	702	NA	924
405	703	NA	925
406	704	NA	NA
407	705	NA	NA
408	801	NA	NA
409	802	NA	NA
410	803	NA	NA
411	804	NA	NA
412	805	NA	NA

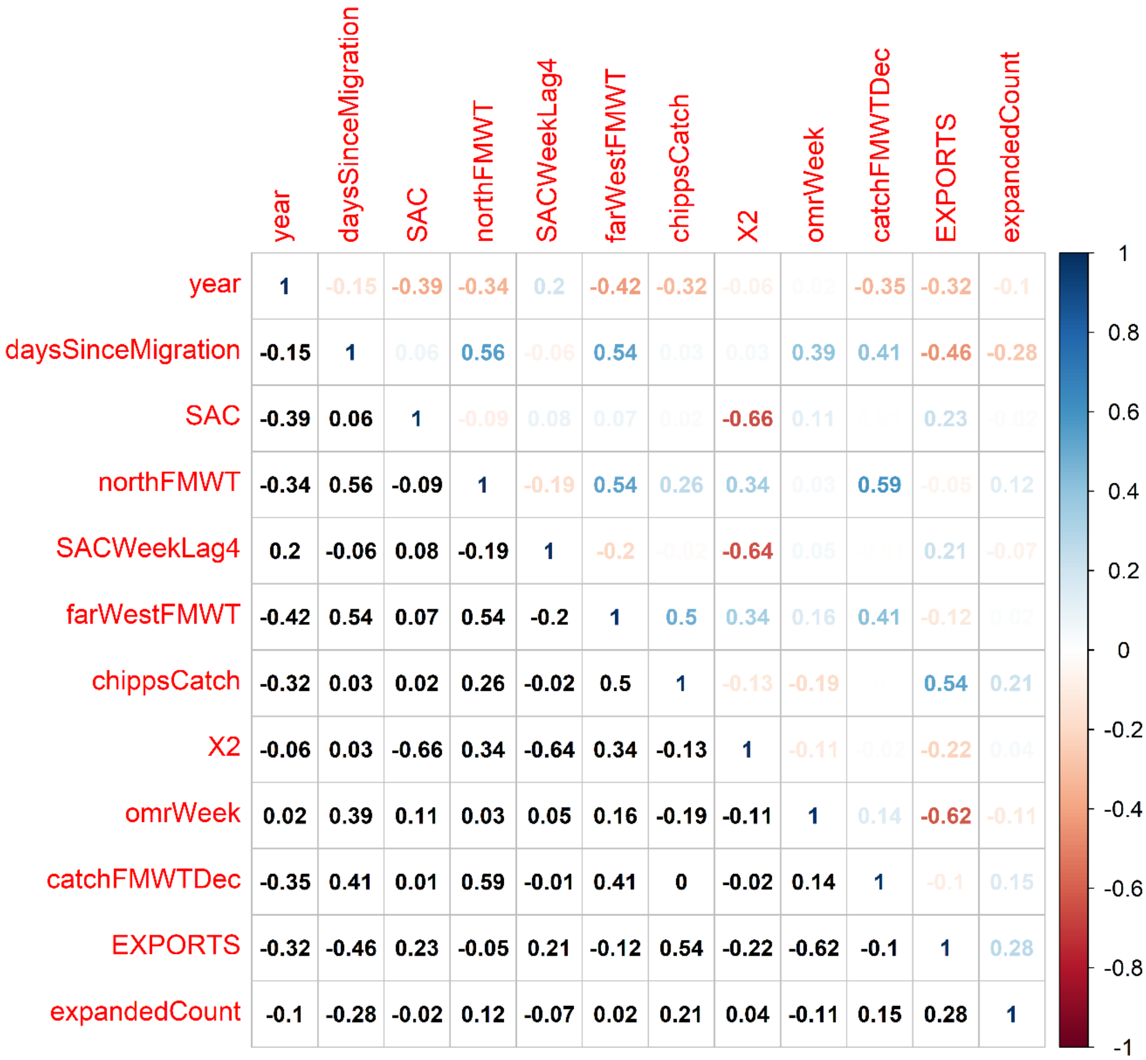
414	806	NA	NA
415	807	NA	NA
416	808	NA	NA
417	NA	NA	NA
418	NA	NA	NA

Table 3. Variable selection table: the variable, followed by a short description, the hypothesized linear relationship to the response variable, and the selection step at which it was dropped (Removed). Variables labeled “final” were part of the final model; the variable labeled “exploratory” was not included in the selection process and was only used for comparative purposes.

Variable	Description	Removed
southFMWT	Total LFS catch, per region	step 0, data quality
southFMWTDec	Total LFS catch, per region during Dec	step 0, data quality
omrFlowExtrap	Extrapolated OMR flows (cfs)	step 0, missing data
omrFlow5Extrap	5-days rolling average omrFlowExtrap	step 0, missing data
omrFlow14Extrap	14-days rolling average omrFlowExtrap	step 0, missing data
omrWeekLag2	Weekly averaged omrWeek, 2 weeks prior	step 0, missing data
omrWeekLag4	Weekly averaged omrWeek, 4 weeks prior	step 0, missing data
RVB_RSWeekLag4	Weekly averaged RVB_RS, 4 weeks prior	step 0, missing data
Step 1		
POD	Binary 1 or 2, at 2004	step 1
month	Month	step 1
sampleHour	Sampling hour	step 1
WEST	QWEST flows (cfs)	step 1
SJR	San Joaquin River flows (cfs)	step 1
OUT	Total Delta outflow (cfs)	step 1
WEST3	3-days rolling average WEST	step 1
WEST5	5-days rolling average WEST	step 1
WEST7	7-days rolling average WEST	step 1
WEST14	14-days rolling average WEST	step 1
SJR5	5-days rolling average SJR	step 1
SJR14	14-days rolling average SJR	step 1
OUT5	5-days rolling average OUT	step 1
OUT14	14-days rolling average OUT	step 1
X2.5	5-days rolling average X2	step 1
X2.14	14-days rolling average X2	step 1
EXP5	5-days rolling average EXPORTS	step 1

Table 3. Variable selection table: the variable, followed by a short description, the hypothesized linear relationship to the response variable, and the selection step at which it was dropped (Removed). Variables labeled “final” were part of the final model; the variable labeled “exploratory” was not included in the selection process and was only used for comparative purposes.

Variable	Description	Removed
EXP14	14-days rolling average EXPORTS	step 1
RVB_RS	Sacramento R. stage at Rio Vista	step 1
SACWeek	Weekly averaged SAC	step 1
OUTWeek	Weekly averaged OUT	step 1
RVB_RSWeek	Weekly averaged RVB_RS	step 1
SACWeekLag2	Weekly averaged SAC, 2 weeks prior	step 1
OUTWeekLag2	Weekly averaged OUT, 2 weeks prior	step 1
OUTWeekLag4	Weekly averaged OUT, 4 weeks prior	step 1
RVB_RSWeekLag2	Weekly averaged RVB_RS, 2 weeks prior	step 1
westFMWT	Total LFS catch, per region	step 1
catchFMWT	Total LFS catch in FMWT, season	step 1
farWestFMWTDec	Total LFS catch, per region during Dec	step 1
northFMWTDec	Total LFS catch, per region during Dec	step 1
westFMWTDec	Total LFS catch, per region during Dec	step 1
waterYearMonth	December as month 1, Feburary as month 3	step 1
Step 2		
SAC5	5-days rolling average SAC	step 2, correlation >
SAC14	14-days rolling average SAC	step 2, correlation >
Final model		
SAC	Sacramento R. flows (cfs)	final
X2	2 ppt isohaline position (km)	final
EXPORTS	Total Delta exports (cfs)	final
omrWeek	Weekly averaged omrFlowExtrap	final
SACWeekLag4	Weekly averaged SAC, 4 weeks prior	final
farWestFMWT	Total LFS catch, per region	final
northFMWT	Total LFS catch, per region	final
catchFMWTDec	Total LFS catch in FMWT during Dec	final
chippsCatch	Total LFS catch in Chipps Island Trawl, season	final
daysSinceMigration	Days since start of LFS migration at Chipps Island	final
Exploratory		
countMultiplier	Count expansion multiplier	exploratory



	year	daysSinceMigration	SAC	northFMWT	SACWeekLag4	farWestFMWT	chippsCatch	X2	omrWeek	catchFMWTDec	EXPORTS	expandedCount
year	1	-0.15	-0.39	-0.34	0.2	-0.42	-0.32	-0.06	0.02	-0.35	-0.32	-0.1
daysSinceMigration	-0.15	1	0.06	0.56	-0.06	0.54	0.03	0.03	0.39	0.41	-0.46	-0.28
SAC	-0.39	0.06	1	-0.09	0.08	0.07	0.02	-0.66	0.11	0.01	0.23	-0.02
northFMWT	-0.34	0.56	-0.09	1	-0.19	0.54	0.26	0.34	0.03	0.59	-0.05	0.12
SACWeekLag4	0.2	-0.06	0.08	-0.19	1	-0.2	-0.02	-0.64	0.05	-0.01	0.21	-0.07
farWestFMWT	-0.42	0.54	0.07	0.54	-0.2	1	0.5	0.34	0.16	0.41	-0.12	0.02
chippsCatch	-0.32	0.03	0.02	0.26	-0.02	0.5	1	-0.13	-0.19	0	0.54	0.21
X2	-0.06	0.03	-0.66	0.34	-0.64	0.34	-0.13	1	-0.11	-0.02	-0.22	0.04
omrWeek	0.02	0.39	0.11	0.03	0.05	0.16	-0.19	-0.11	1	0.14	-0.62	-0.11
catchFMWTDec	-0.35	0.41	0.01	0.59	-0.01	0.41	0	-0.02	0.14	1	-0.1	0.15
EXPORTS	-0.32	-0.46	0.23	-0.05	0.21	-0.12	0.54	-0.22	-0.62	-0.1	1	0.28
expandedCount	-0.1	-0.28	-0.02	0.12	-0.07	0.02	0.21	0.04	-0.11	0.15	0.28	1

Figure 3. Correlation matrix of the predictor and response variables included in the final model. All values were < 0.70, the threshold used to inform the model selection process.

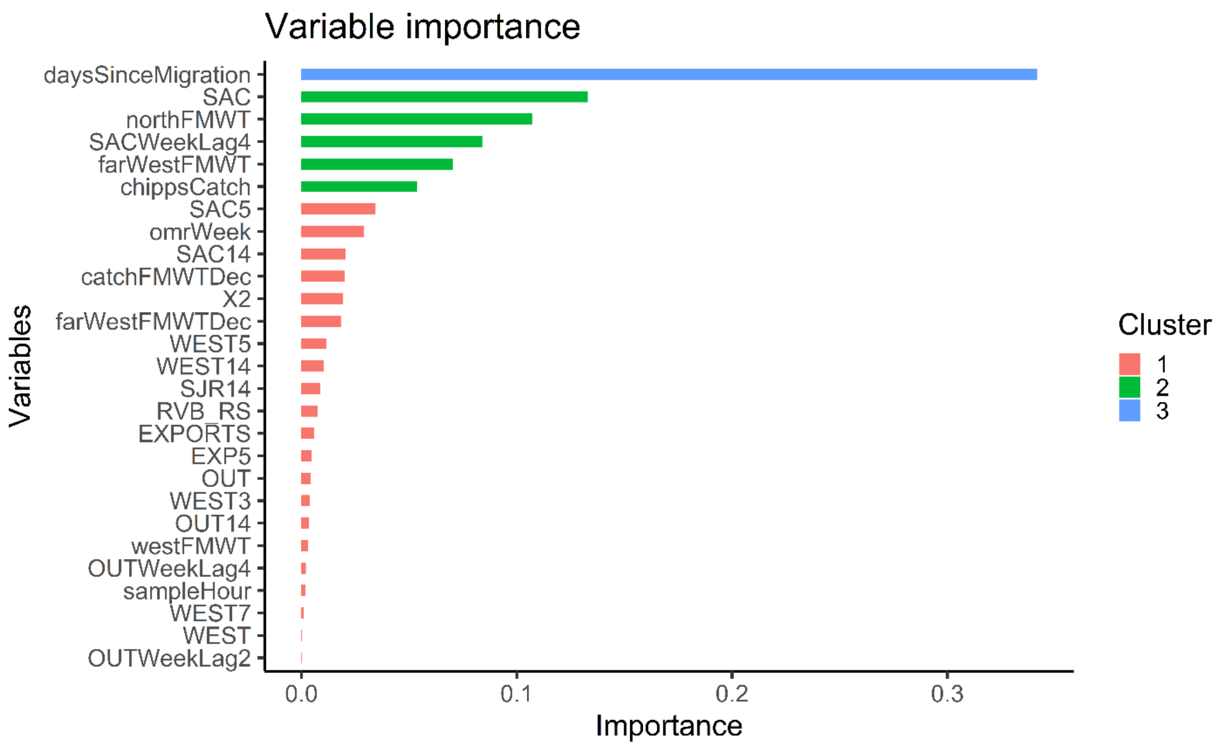


Figure 4. The variable importance plot of the full XGB model, after step 0 as outlined in Table 3. Variable importance is determined by the average improvement in error (RMSE) associated with including a variable in the model. This evaluation metric is accounts for the entire structure of the tree, i.e. the influences of other variables in the model. Clusters of variables are shown to help visualize the data based on clustering analysis.

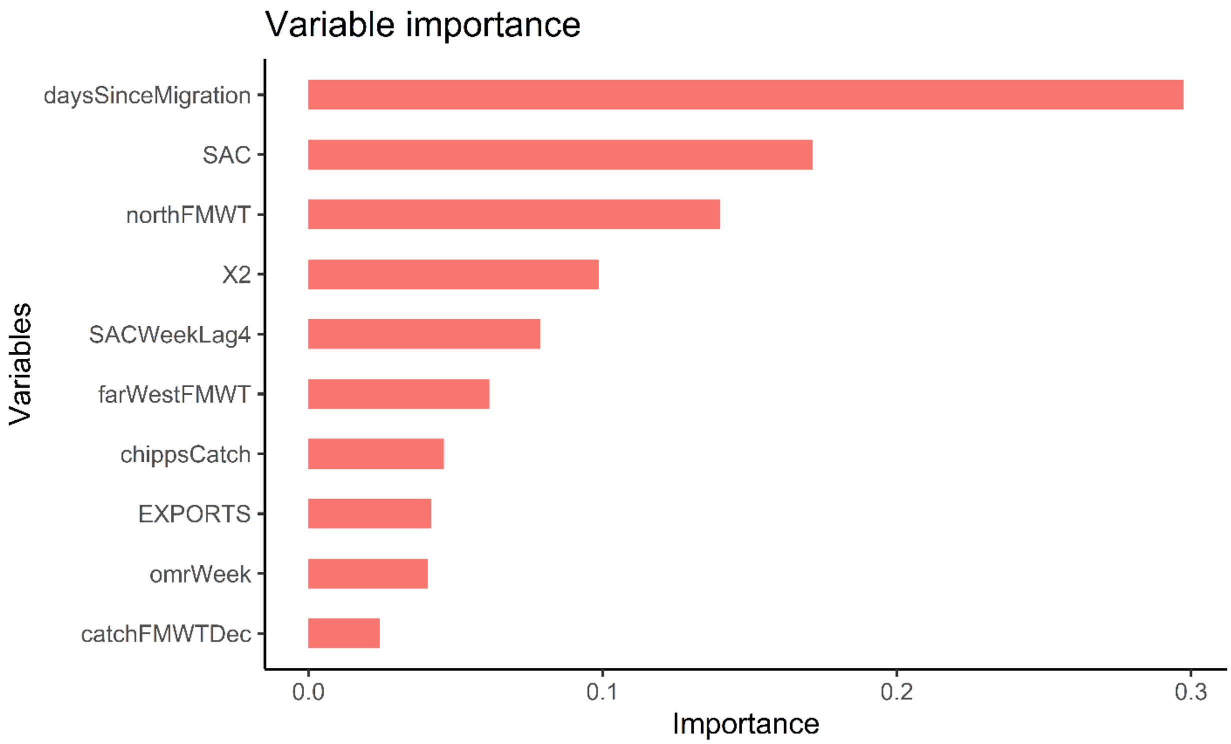


Figure 5. Variable importance plot for the reduced and final preferred model.

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