# Effects Analysis

# State Water Project Effects on Longfin Smelt

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## Introduction

In response to the Department of Water Resources (DWR) request for a Permit for incidental take of longfin smelt for existing and future operations of the State Water Project (SWP) facilities (Project), we conducted an analysis based on existing data, literature, and particle tracking modeling results. We also present conceptual models for longfin smelt adult migration and spawning, and larva and juvenile dispersal to facilitate understanding of our analytical approach and results. In the sections below, we provide background information, methodologies and approaches used, and discussions and definitions of the terminology and information available.

As part of our analysis, we have consider 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 U.S. Fish and Wildlife Service (FWS) Delta Smelt Biological Opinion of the Operating Criteria and Plan for the Coordinated Operations of the Central Valley Project and State Water Project (OCAP) that the FWS issued on December 16, 2008 (2008 OCAP Biological Opinion) for the Project. In addition, we consider that the Project will comply with all applicable state, federal, and local laws in existence or adopted thereafter of issuance of the Permit as well as SWRCB Water Rights Decision 1485, which have been carried forward to SWRCB Water Rights Decision 1641.

## Project Description

SWP facilities in the Delta include Clifton Court Forebay (CCF), John E. Skinner Fish Facility (Skinner Facility), Harvey O. Banks Pumping Plant (collectively referred to as the Banks Pumping Plant Complex), and the North Bay Aqueduct (NBA) at Barker Slough. Facilities run jointly with the Central Valley Project (CVP) are the Suisun Marsh Salinity Control Gates (SMSCG), Roaring River Distribution System (RRDS), Morrow Island Distribution System (MIDS), Goodyear Slough Outfall, and the South Delta Temporary Barriers Project (TBP). Within this project, there are four rock barriers across south Delta channels (at Middle River near Victoria Canal, Old River near Tracy, Grant Line Canal near Tracy Boulevard Bridge, and the head of Old River near the confluence of Old River and San Joaquin River) which can be installed and removed during spring and fall. This will continue until permanent gates are constructed. Other facilities of the SWP include Oroville Dam which is operated for flood control and water supply and described in general terms below in SWP operations.

The CCF is a 31,000 acre foot reservoir located in the southwestern edge of the Delta, about ten miles northwest of Tracy. The CCF provides storage for off-peak pumping, moderates the effect of the pumps on the fluctuation of flow and stage in adjacent Delta channels, and collects sediment before it enters the California Aqueduct. Diversions from Old River into CCF are regulated by five radial gates whose real-time operations are constrained by a scouring limit (i.e. 12,000 cubic feet per second (cfs)) at the gates and by water level concerns in the south Delta for local agricultural diverters. When a large head differential exists between the outside and the inside of the gates, theoretical inflow can be as high as 15,000 cfs for a very short time. However, existing operating procedures identify a maximum design flow rate of 12,000 cfs, to minimize water velocities in surrounding south Delta channels, to control erosion, and to prevent damage to the facility.

The South Delta Temporary Barriers Project consists of installation of four temporary rock barriers across south Delta channels. The barriers on Middle River, Old River near Tracy, and Grant Line Canal are flow control facilities designed to improve water levels for agricultural diversions. The head of Old River barrier is designed to reduce the number of out-migrating salmon smolts entering Old River. During the fall this barrier is designed to improve flow and dissolved oxygen conditions in the San Joaquin River for the immigration of adult fall-run Chinook salmon.

The SWP is operated to provide flood control and water for agricultural, municipal, industrial, recreational, and environmental purposes. Water from Oroville facilities and surplus Sacramento-San Joaquin flows are captured in the Delta and conveyed to SWP contractors. Water is conserved in Oroville Reservoir and released to serve three Feather River area contractors, two contractors by the NBA, and is delivered to the remaining 24 contractors in the SWP service areas south of the Delta from the Harvey O. Banks Pumping Plant in the south Delta.

Facilities of the SWP are permitted by the California State Water Resources Control Board (SWRCB) to divert surplus water in the Delta and re-divert water that is stored in upstream reservoirs. The Bureau of Reclamation and DWR coordinate the operations of the SWP and CVP to meet water quality, quantity, and operational criteria in the Delta set by the SWRCB. DWR proposes to divert and manipulate flows consistent with applicable law and contractual obligations.

## Longfin smelt Life History

Below are conceptual models for longfin smelt adult migration and spawning, and larva and juvenile dispersal to facilitate understanding of our analytical approach and results. We also discuss and define terminology and information available

### *Conceptual Model of Longfin Smelt Migration and Spawning*

During late fall, as water temperatures drop below 18°C, maturing adults migrate from the lower estuary to the low salinity zone and congregate prior to spawning. As adults ripen, most often from December through February, they make generally short-distance, brief spawning runs into freshwater where spawning takes place over a sand substrate, then return to the low salinity zone. Spawning activity appears to decrease with distance upstream from the low salinity zone, so the location of X2 approximately predicts the geographic location of this upper estuary congregation and influences how far spawning migrations penetrate the Delta.

Mature longfin smelt may migrate directly to the south Delta and be entrained, or high OMR flows may miscue spent adults into swimming toward the pumps rather than to Suisun Bay.

Longfin smelt smaller than our current approximate size for maturity (≥ 80 mm FL) are also found within the Delta upstream of X2 during winter. This represents either occupation of habitat that expanded as Delta temperatures cooled in fall or fish maturing below our approximate size of maturity that are actually part of the spawning run.

### *Conceptual Model of Longfin Smelt Larva and Juvenile Dispersal*

Larval longfin smelt hatch locations are, to some degree, determined by X2 location immediately prior to adult spawning. Larvae hatch farther into the Delta in low outflow as compared to high outflow years, because X2 and X0.5, which approximates the spawning habitat boundary, are located farther into the Delta in low outflow years. Net current direction within hatching channels determines whether larvae are transported downstream toward Suisun Bay or upstream toward the pumps. Once entrained within CCF, longfin smelt larvae may be rapidly transported into aqueducts heading south if export rates are high. Alternatively, wind-driven surface currents and the larvae's proclivity for the surface may cause them to remain within the CCF for a protracted period of time if export rates are low. This latter circumstance can lead to larvae growing to juvenile size (≥20 mm) within the CCF and lead to disjunction between dates of entrainment and salvage. Juvenile longfin smelt will attempt to migrate to avoid water temperatures > 20ºC, leading to increased salvage of already entrained fish. Longfin smelt cannot survive summer temperatures in the CCF.

### *Entrainment*

The entrainment of longfin smelt into CCF represents a direct effect of SWP operations that is not assessed directly. Instead, total entrainment is calculated based upon expansions of estimates of the number of longfin smelt salvaged at the Skinner Facility (e.g., Kimmerer 2008). Brown et al. (1996) provides a description of fish salvage operations. Thus, entrainment estimates are indices because fish salvage is estimated from sub-samples and fish entrainment into the Forebay has not been quantified from direct observations (Table 1). Also, entrained fish may succumb to predation or, in late spring and summer, to lethal 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 (Kimmerer 2008). Moreover, many of the entrained longfin smelt salvaged likely die due to handling, transport, and predation as part of the fish salvage operations (Morinaka 2008).

The population-level effects of longfin smelt entrainment have not been previously quantified. Longfin smelt salvage is highest during low outflow years (Sommer et al.

Table 1. Factors affecting longfin smelt entrainment and salvage.

| | 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, |
| Louver efficiency (based on delta smelt 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 | Not identified | Identified from subsamples, then expanded in salvage estimates |
| Fish survival after fish collection, handling, transport and release back into the Delta based on delta smelt studies) | 78 percent for SWP and no information available for CVP | Unquantified | 58 percent for SWP and no information available for CVP |

1997, Figure 1A), so mortality associated with entrainment is highest when the population already faces adverse environmental conditions throughout the upper estuary.

Salvage during successive years of low outflow declined along with abundance (Figure 1A, B), so effects of salvage likely vary even across low outflow years. The longfin smelt 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 predator numbers may also be involved (Sommer et al. 2007, Baxter et. al. 2008). Current thinking identifies increased delta outflow during the winter and spring as the largest factor positively affecting longfin smelt abundance (Baxter et al. 2008). 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

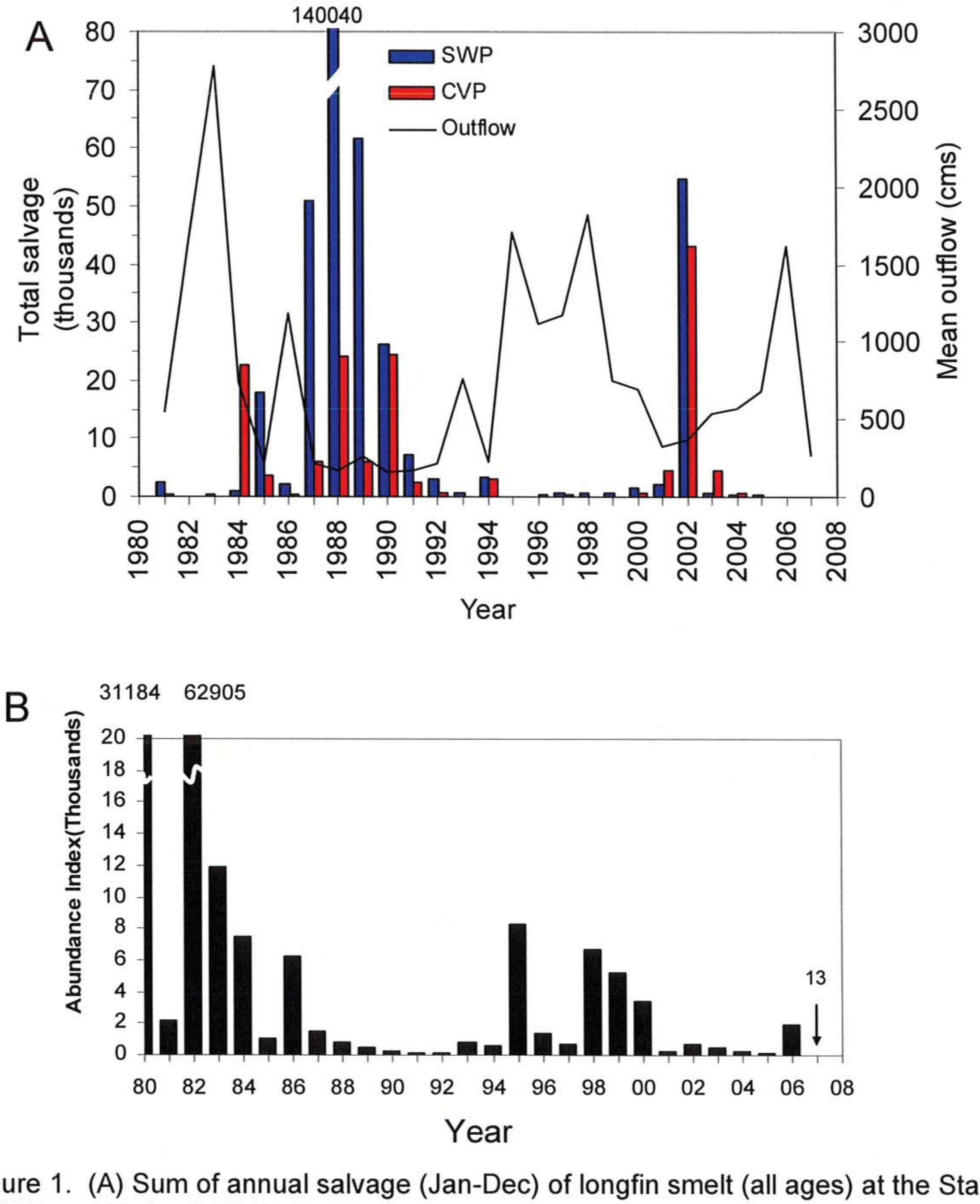


Figure 1. (A) Sum of annual salvage (Jan-Dec) of longfin smelt (all ages) at the State (SWP) and Federal (CVP) Facilities and mean Jan-Dec outflow (cms), 1981 – 2007. Note that annual salvage data for 2007 is limited to 01/01/2007 -07/31/2007. (B) Fall Midwater Trawl annual longfin smelt abundance indices (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.

the boundary of spawning habitat and strong downstream transport of larvae (CDFG 1992, Hieb and Baxter 1993, CDFG 2009a). 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 separate effects of these multiple factors have not been done.

Installation and operation of south Delta barriers might have affected longfin smelt entrainment historically, but is unlikely to in the future given the Delta Smelt Biological Opinion (USFWS 2008). The Head of Old River Barrier (HORB) -- which influences where San Joaquin River flows enter into the south Delta, through the Old River or more northward channels -- was typically installed in April or May (http://www.iep.ca.gov/dsm2pwt/Bay-Delta_barriers_activ.txt) causing export flows to be satisfied from the north, potentially entraining longfin smelt. Currently, the spring HORB cannot be installed until the Service determines that delta smelt entrainment is no longer a concern (USFWS 2008), which could push back installation until July. The presence of delta smelt juveniles and the BO will eliminate negative effects of the HORB for longfin smelt. By June all longfin smelt adults have left the Delta, all eggs have hatched and the last of the current year's fish are emigrating from the Delta. For these reasons, installation and operation of the south Delta barriers are not expected to affect longfin smelt and were not specifically analyzed.

## Methods

Our assessment approach was two-fold. We investigated a suite of hydrological variables for their influence on combined salvage of SWP and CVP to determine which had significant effects. Second, we summarized SWP salvage and estimated losses, then where possible, attempted to place loss in the context of longfin smelt population size. Two annual periods were important for our analyses. The first from the late 1960s through present covered the period during which the SWP was operational and was used wherever data were complete for the period to examine trends over time or plot relationships. The second time period, from 1993 to present, was used in instances when improved identification and measurement frequency of salvage data were needed. Seasonally, two periods were used most often to assess overall effects: December through March was used for winter effects on adult and juvenile salvage and April through June for spring effects on juvenile salvage. Hydrologic variables were similarly summarized for the December through March and April through June periods.

### Adult Migration, Juvenile Distribution (~December though March)

We investigated entrainment of longfin smelt juveniles and adults by plotting annual salvage separately for juveniles and adults and for SWP and CVP. We also estimated total loss due to entrainment for juvenile and adult longfin smelt for both projects. We used available fish length data to classify the life stage of salvaged longfin smelt (20-79 mm for juvenile and ≥80 for adults). If length information was not available, we classified life stage based on seasonal patterns of salvage. We found salvage of different longfin smelt life stages highly seasonal so most of our analyses focused upon these identified seasonal periods: December through March for adults and March through June for juveniles; when length data were not available fish were classified based on this seasonal distinction also.

The distribution of adult and juvenile longfin smelt during winter and early spring is hypothesized to influence entrainment. Based on our conceptual model, we plotted relative catch from the Fall Midwater Trawl December through March surveys (when available) and overlaid the approximate average monthly locations of X2 and X0.5, the latter representing the freshwater boundary. X2 was derived from DayFlow and X0.5 was calculated from the X2 value as: X0.5 = -(X2 position) *(Ln((31-(target salinity))/(515.67* (target salinity)))/-7)-1.5), where 0.5 ppt is the target salinity (see Appendix A).

We used combined SWP and CVP salvage to examine the hydrological and environmental factors influencing salvage and SWP salvage alone to assess effects on longfin smelt. Similar to Grimaldo et al. (accepted), we used OMR flows rather than daily export because the former reflect the net daily draw of water toward the pumps and negate the need to account for periods when Clifton Court gates were open or closed. Old and Middle River flows from 1993 to 2007 were measured daily using acoustical velocity meters (installed by the United States Geological Survey, USGS) located near Bacon Island (Arthur et al. 1996). OMR flows from 1967 through 1992 were calculated from flows measured in other south Delta channels by Lenny Grimaldo. Total inflow, combined SWP and CVP exports and X2 location data were derived from DayFlow (http://www.iep.ca.gov/dayflow/index.html).

Entrainment and loss estimates were calculated with an equation routinely used to calculate juvenile Chinook salmon entrainment loss from reported salvage estimates. Estimator constants for pre-screen loss, screening efficiency, and handle and trucking losses were obtained from experiments using delta smelt and other fish species as proxies for longfin smelt (see Appendix B).

### Larva Entrainment SWP (~January through April)

Current Banks (SWP) and Jones (CVP) fish salvage protocols excuse the identification of fishes <20mm long, so no salvage information exists to assess larvae entrainment (longfin smelt are classified as larvae until 20 mm long). Instead we used particle tracking modeling (PTM) to assess potential entrainment at and effects of State Water Project facilities. PTM model runs were accomplished by the California Department of Water Resources (CDWR) using Delta Simulation Model 11 (DSM2). Model daily results were transferred to CDFG for processing, summarization and analyses.

Limited computing and processing time sharply constrained the number of model runs possible, so we selected three years for hydrology, seven injection locations within the Delta and seven injection dates to capture as much variation as possible to assess the various risks to entrainment and factors influencing those risks. Each PTM year, date, location combination was run separately with surface oriented and neutrally buoyant particles to contrast the entrainment risk of each "behavior". Surface oriented PTM runs best emulate the behavior of longfin smelt larvae.

The observed pattern of increased longfin smelt salvage during low outflow years, and concern for entrainment of larvae lead to the use of 1992, 2002 and 2008 hydrology (all low outflow years) as the basis for the PTM runs: 1992 low outflow with modest flow increase in mid-February, modest to high exports; 2002, one short early flow spike followed by low outflow and extremely high juvenile spring summer salvage; 2008 low outflow with three small flow spikes Jan, Feb and Mar and exports constrained by Wanger restrictions. Typically, PTM runs used neutrally buoyant particles (e.g., Kimmerer 2008), but longfin smelt larvae are initially oriented toward the surface (CDFG 1992, Bennett et al. 2002), so our PTM runs were conducted with both surface oriented and neutrally buoyant particle "behaviors" for both comparison and to evaluate whether surface orientation enhanced entrainment.

We chose 7 injection locations (Figure 2) to depict: 1) a range of potential for entrainment spread across putative spawning regions in the Sacramento and San Joaquin river channels, 2) to assess impacts of State Water Project facilities (e.g., NBA, Montezuma Sl, the south Delta export pumps), and 3) to correspond to limited larvae sampling data. No south Delta locations were selected because particles injected within south Delta channels were destined to be entrained in the export pumps, unless export rates were exceedingly low (Kimmerer and Nobriga 2008).

To cover the principal hatch period of longfin smelt, January through March (Baxter 1999), we selected injection dates of January 1 and15, February 1 and 15, March 1 and 15, and April 1. For each year, date, location, and behavior, 5000 particles were injected continuously over 24 hrs and their fates assessed daily for 90 days. This 90 day time period should cover the larval period of longfin smelt, which is about the same length (Hobbs pers comm. 2008).

For each injection permutation, particle flux (cumulative percent passage) was quantified daily at the SWP, the CVP, in agricultural diversions (AG diversions), at the North Bay Aqueduct, in Montezuma Slough and those passing Chipps Island to assess relative losses to exports. In addition, flux was measured daily at Three Mile Slough, each of the injection stations, Morrow Island and Roaring River in Suisun Marsh, and at channel entrances to the south Delta at False River near Fisherman's Cut, Old River and Middle River near Columbia Cut.

For each injection location, date and behavior, we estimated an average Delta residence time as the mean time in days needed for ≥50% of the particles to resolve their fate: that is pass Chipps Island or into Montezuma Slough or become entrained in one of the aforementioned export facilities. Similar calculations were made for the Sacramento River channel and the San Joaquin River channel by combining the respective stations.

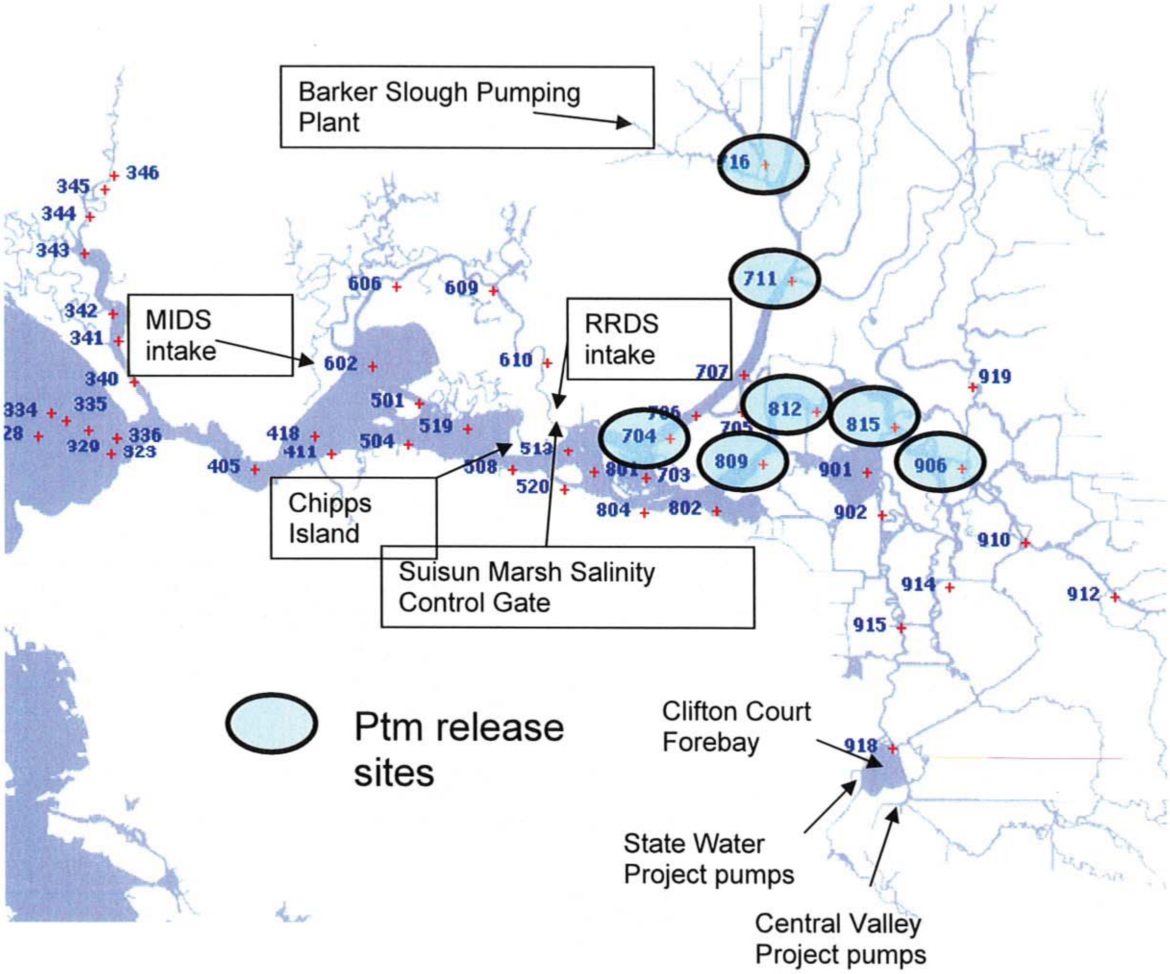


Figure 2. State Water Project facility locations and particle injection locations for 1992, 2002 and 2008 particle tracking model (PTM) runs for surface oriented and neutrally buoyant particles.

Finally, we estimated water export facility impact on larvae by scaling PTM results based on temporal and geographic estimates of relative larva hatch times and locations, the relative volumes of the Sacramento and San Joaquin river channels where most spawning was believed to take place, and another scaling factor to compensate for the higher number of injection sites, thus particles, in the San Joaquin River (4) as compared to the Sacramento River (3). The combined, scaled, 90th-day-particle-fate data for all injection locations and dates were used to calculate annual percent entrainment at the SWP, CVP, NBA, Ag Diversions separately for surface oriented and neutrally buoyant particles. Details are provided in following paragraphs.

Our estimates of temporal presence and spatial distribution of longfin smelt larvae in the Delta were constrained because of historically limited seasonal sampling and lack of

Osmerid identification in early sampling. Historically, egg and larvae sampling within the Delta did not often start prior to April with the onset of striped bass spawning and identification of Osmerids did not commence until the 1990s when delta smelt became a species of concern. The San Francisco Bay Study (Bay Study) provided the only year-round sampling data for longfin smelt larvae to assess monthly hatch timing. This study distinguished recently hatched, yolk-sac larvae from older, post-yolk-sac larvae for all samples. However, the survey only sampled as far upstream as Sherman Lake in the Sacramento River and Antioch on the San Joaquin River, so spring presence may have been slightly underestimated because larvae remained in the Delta upstream of sampling locations. Osmerid identification was attempted by the Bay Study from the start of the survey in 1980 and identifications confirmed in the early 1990s. Seasonal hatching (monthly) was estimated by yolk-sac larva monthly average catch per 1000 $m^3$ filtered by the plankton net. Bay Study surveys were usually completed during the first two weeks of each month. To develop seasonal scaling factors for weighting the twice monthly injections of particles, we used monthly densities for first-of-the-month injections and interpolated between monthly densities to estimate mid-month densities. First of the month and mid-month densities were directly used to scale PTM 90-day results: 1 Jan = 120, 15 Jan = 220, 1 Feb = 320, 15 Feb = 232, 1 Mar = 144, 15 Mar = 93, 1 Apr = 42.

Geographic estimates of larva hatch locations were based on in-Delta larva sampling conducted by CDFG for 1991-1994 and 2005. Three of four years during 1991 through 1994 were low outflow years in which larvae were not expected to be rapidly dispersed downstream. In 2005, outflow was relatively high, so larvae were probably rapidly dispersed. We also assumed that the total catch at a given station represented total "hatch at that station", and the relative contributions of stations representing the injection locations were derived from summing all the catches from 1991-1994 and normalizing by dividing all station total catches by the total catch at station 906, the station with the lowest catch; the station quotients were used as geographic hatch density scalars for all the PTM 90 day results. The first series of geographic hatch density scalars based on 1991-1994 larva densities were: 906 = 1, 815 = 4, 812 = 8, 809 = 28; 716 = 12, 711 = 21, 706 = 48. In a separate analysis, 2005 densities were also used as scalars: 906 = 1, 815 = 2, 812 = 3, 809 = 5; 716 = 7, 711 = 4, 706 = 37.

The scaled densities represented their locations, but not necessarily the channels in which they were located. We used historical channel volume estimates for the Sacramento and San Joaquin rivers derived by Ken Devore (CDFG GIS) to scale for channel volume. Although these estimates did not include the upper stations in each channel, they both extended below the lower stations and were believed approximately representative of the two channel volumes, and their absolute values were not important, only their relative value. The Sacramento River channel volume was divided by the San Joaquin River volume resulting in a quotient of 1.8, which was used to scale Sacramento River injection location data. Also, the number of injection locations within each river channel influenced the number of particles possible to entrain. To compensate for only 3 injection locations in the Sacramento River channel, all Sacramento River particle injection location results were scaled up by 1.33.

We assessed SWP effects on an annual basis and determined the annual fates of injected particles separately for surface oriented and neutrally buoyant particles by the following process. For each injection date and injection location we took the 90th day, final results (in percent) for flux to final fate locations (Chipps Island, Montezuma Slough, North Bay Aqueduct, Agricultural diversions, SWP and CVP, where particle fates were resolved) and multiplied by 1) 5000 (the original number of particles), 2) the seasonal scaling factor, and 3) the geographic scaling factor which contained the product of station and channel scaling. These products were then summed for each final fate location and for all final fate locations. Lastly, we calculated annual particle fates by dividing the summed results from each final fate location by the grand sum for all final fate locations and multiplying by 100, producing a result in percentage lost at each final fate location. This same process was run twice using a different geographic scaling factor each time. The first scaling factor based on 1991-1994 larva sampling results represents our "best estimate" for relative hatch distribution in low outflow years. The second scaling factor, based on 2005 larva sampling data, represents the entrainment effects resulting when hatching densities were not highly favoring the Sacramento River.

## Results

### Adult Migration, Juvenile Distribution (~December though March)

Winter conditions have become less favorable over time for longfin smelt. Winter Delta inflow has declined slightly since the 1970s, while combined winter exports (Dec-Mar) have climbed rapidly (Figure 3A, B). Inflow and exports influenced the location of X2. Average X2 position during winter moved into the Delta (>75) during the 1987-1992 drought and again in 2001 and 2007 (Figure 3C). Such an upstream shift may have caused more longfin smelt to spawn within or near the influence of the pumps. In addition, OMR flows have become more negative (Figure 4). More negative OMR flows could lead to additional entrainment of longfin smelt adults, older juveniles and subsequent larvae.

The winter distribution of longfin smelt (juveniles and adults combined) in the upper estuary appeared to be associated with the geographic position of the low salinity zone as indicated by the location of X2 (Appendix A) and X2 was periodically located within the Delta (X2>75) during winter (Figure 3C). As freshwater outflow increased from December 1994 though March 1995, the location of X2 and the apparent congregation location of longfin smelt moved lower in the estuary (Figure 5). The opposite occurred in water year 1997 as X2 moved back upstream after outflow declined beginning in February (Figure 6). Presumably, as X2 moves closer to the Delta, adult and juvenile longfin smelt become more vulnerable to entrainment (see next section).

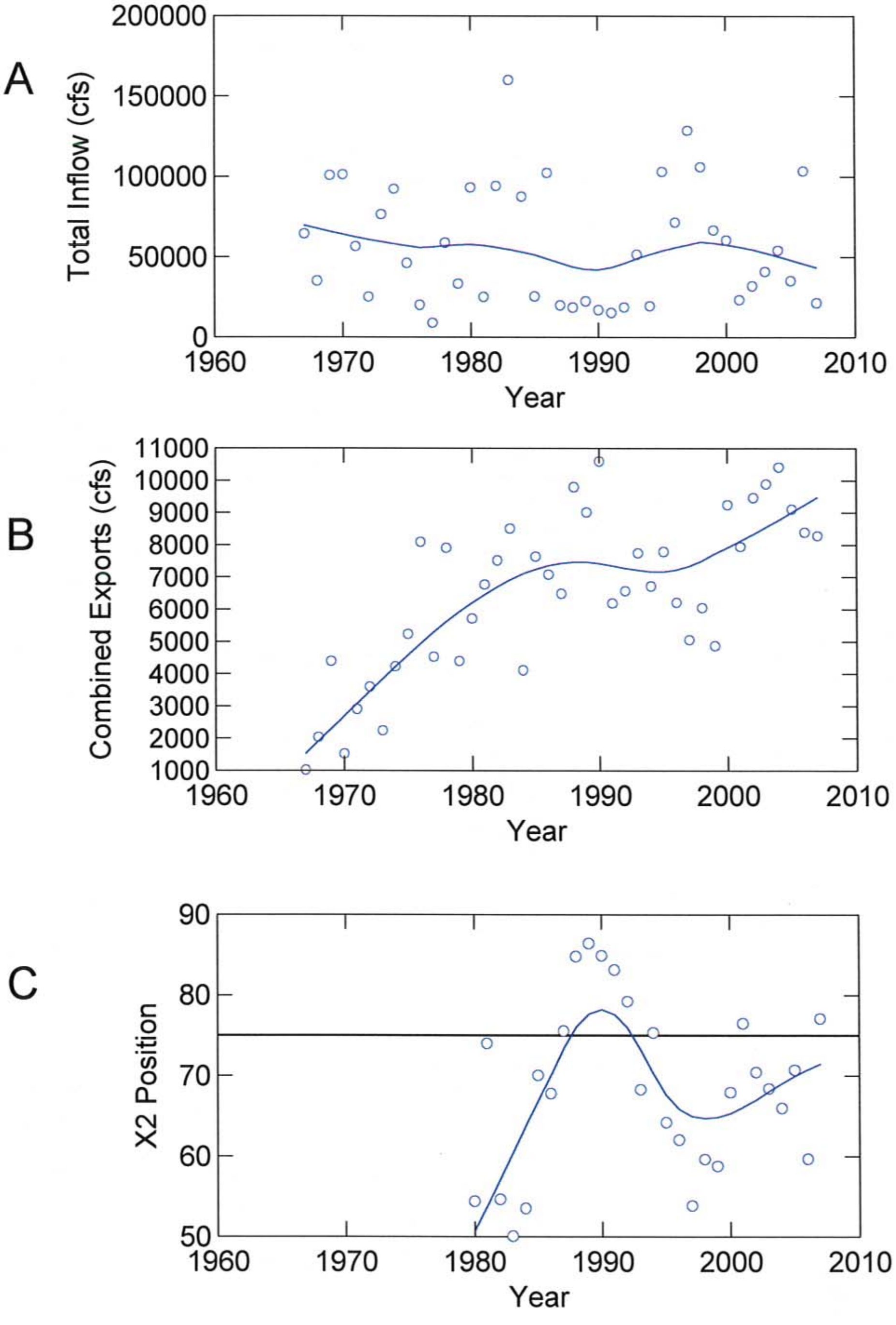


Figure 3. Trends in average winter (Dec-Mar) total delta inflow (A), combined SWP/CVP exports (B), and X2 position (C), 1967-2007, except for (C), which is 1980-2007. A LOWESS line was plotted through points to show general trend. The horizontal line at 75 km in (C) represents the location of Chipps Island.

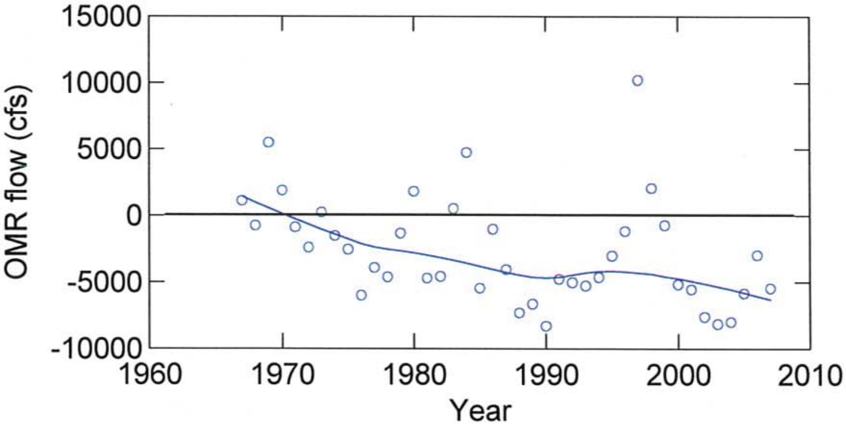


Figure 4. Trend in average winter (Dec-Mar) Old and Middle River (combined) flows, 1967-2007, based on estimated (1967-1992) and measured (1993-2007) flows. See text for data sources. A LOWESS line was plotted through points to show general trend.

## Adult and Juvenile Entrainment SWP and Combined SWP, CVP (~December though March)

Adult (≥80 mm) and juvenile (age-1fish <80mm) longfin smelt have been salvaged in the SWP Skinner Fish Protective Facility as early in the water year as December (rarely November) and as late as March for adults and May for the previous year's juveniles, now designated age 1 (Figure 7). In years with salvage, both age groups were salvaged coincidentally in a series of 1-6 day pulses spread throughout the December through March spawning season. Peak salvage generally occurred in January for adults and varied from December through March for age-1 juveniles.

Winter salvage varied inversely with Delta outflow and has generally declined over time for both salvage facilities (Figure 8A). During the early portion of the 1987-1992 drought, SWP winter salvage exceeded 500 longfin smelt annually from 1987 through 1991 except for 1990, then declined with declining longfin smelt abundance (c.f., Figures 1B and 8A). Since that time SWP winter salvage only exceeded 200 longfin smelt in 2003 and 2004.

We hypothesized that the location of X2 affected winter salvage. That is as X2 moves upstream into the western Delta, the locations of congregation and spawning move eastward also. As this eastern movement continues, progressively more longfin smelt move to within the export pump zone of influence as they enter the Delta and lower rivers to spawn.

Winter combined SWP and CVP salvage was a significant positive function of X2 position and previous Fall Midwater Trawl abundance ($r^2 = 0.395$, 24 df, $p < 0.05$; Figure

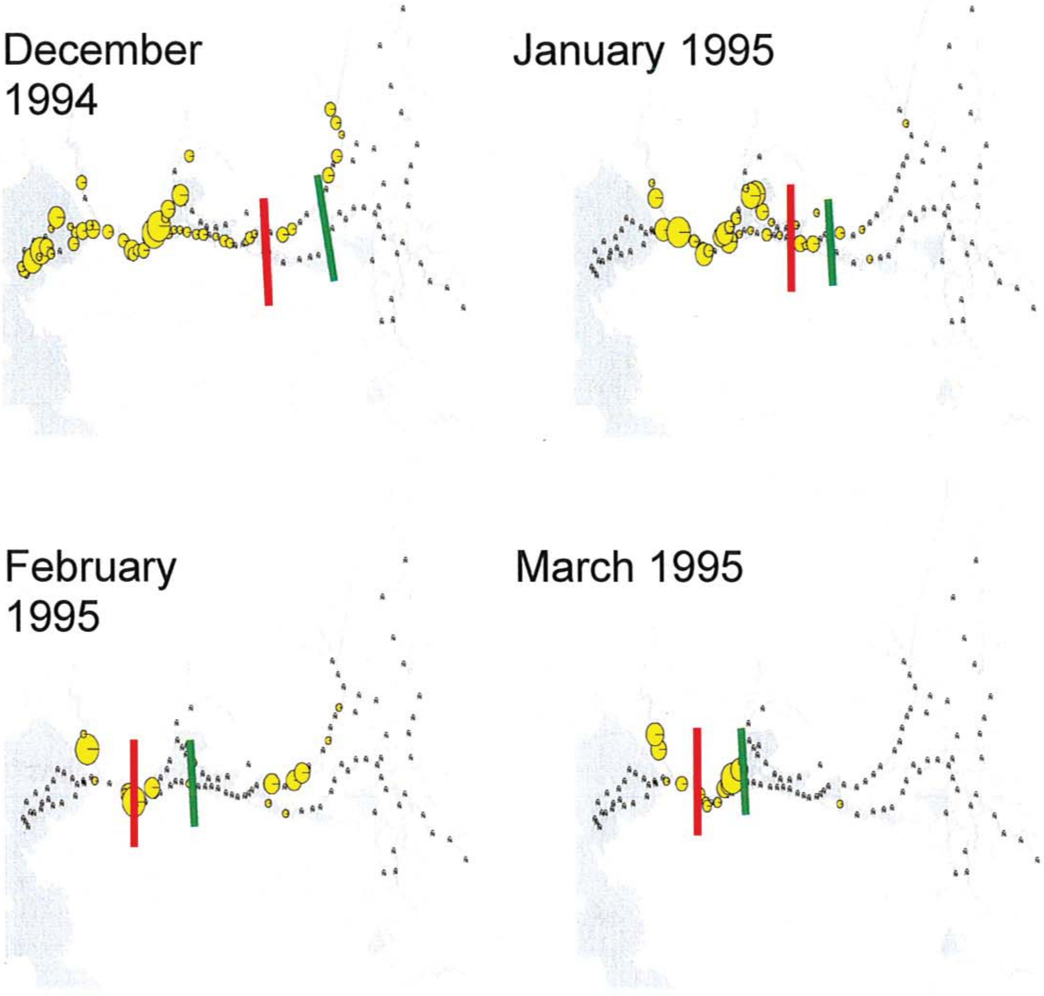
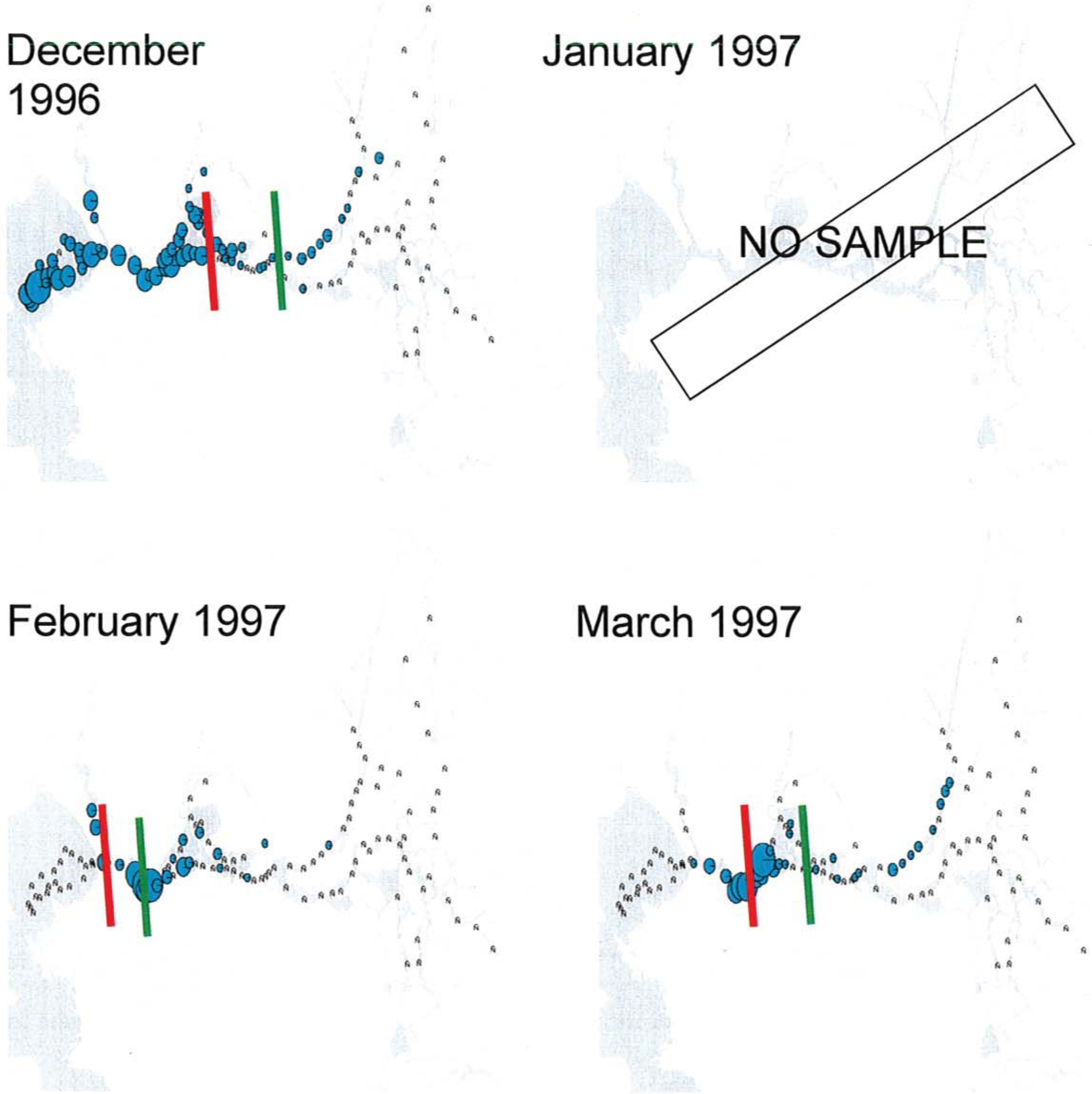


Figure 5. Winter longfin smelt catch in Fall Midwater Trawl sampling, December 1994 through March 1995. Relative catch per trawl is plotted in relation to average monthly position of X2 (red line) and X0.5 (green line, representing the freshwater boundary). Longfin smelt shifted downstream with X2. See also Appendix A.



December 1996

January 1997

February 1997

March 1997

Figure 6. Winter longfin smelt catch in Fall Midwater Trawl sampling, December 1996 through March 1997. Relative catch per trawl is plotted in relation to average monthly position of X2 (red line) and X0.5 (green line, representing the freshwater boundary). Longfin smelt shifted downstream with X2. See also Appendix A.

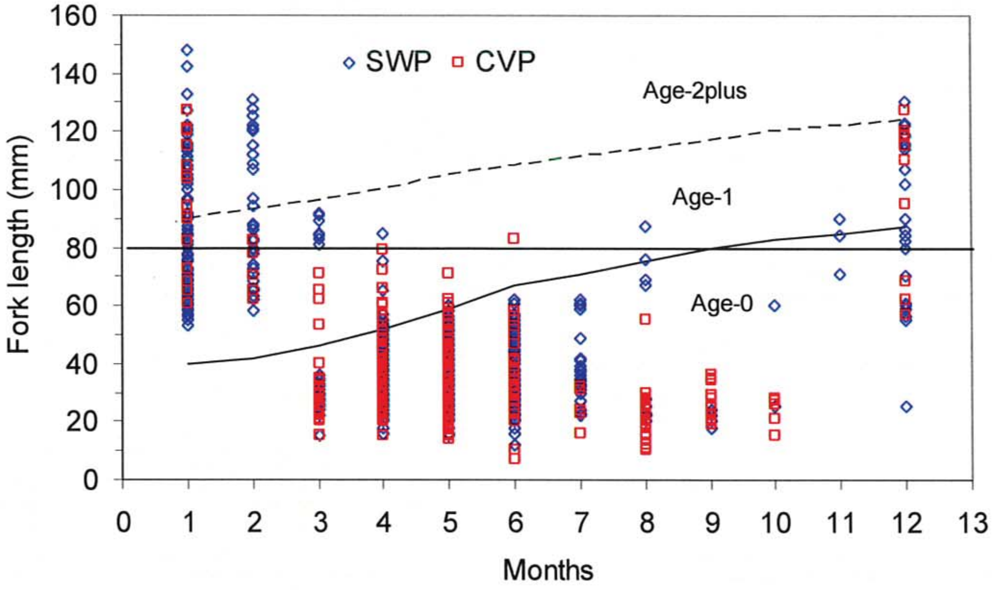


Figure 7. Length frequency of longfin smelt salvaged and measured at the State Water Project (blue diamonds) and Central Valley Project (red squares) by month for 1981-2007. Up-sloping lines represent the lengths of age class separation after Baxter 1999. The horizontal line represents the approximate size of maturity, such that lengths above represent mature fish and those below, immature fish. Fish < 20mm long are generally not identified or recorded at either salvage facility; this includes all longfin smelt larvae.

9). That is, as winter X2 position moved upstream toward and into the Delta, the ratio of total savage divided by the previous Fall Midwater Trawl index (to account for abundance) increased. The winter salvage in water years 1984 and 1985 was zero (exceptional for low outflow years), creating the two low points on Figure 9 and weakening the relationship.

Examining factors affecting longfin smelt winter salvage, Grimaldo et al. (accepted) used General Linear Modeling techniques to examine a suite of physical and biological factors: combined OMR flows, X2 position, water temperature, turbidity, zooplankton abundance and Fall Midwater Trawl, Summer Townet and 20mm Survey abundance indices. They found the best models explaining inter-annual winter salvage trends included combined Old and Middle River flows. Plotting winter combined salvage on average OMR flows (December through March) results in a broad scatter of points depicting rapidly increasing salvage at OMR values approaching and more negative than negative 5000 cfs (Figure 10A). Longfin smelt abundance also influenced salvage, such that salvage during years with positive or weakly negative OMR flows was generally driven by high numbers of longfin smelt present (Figure 10B).

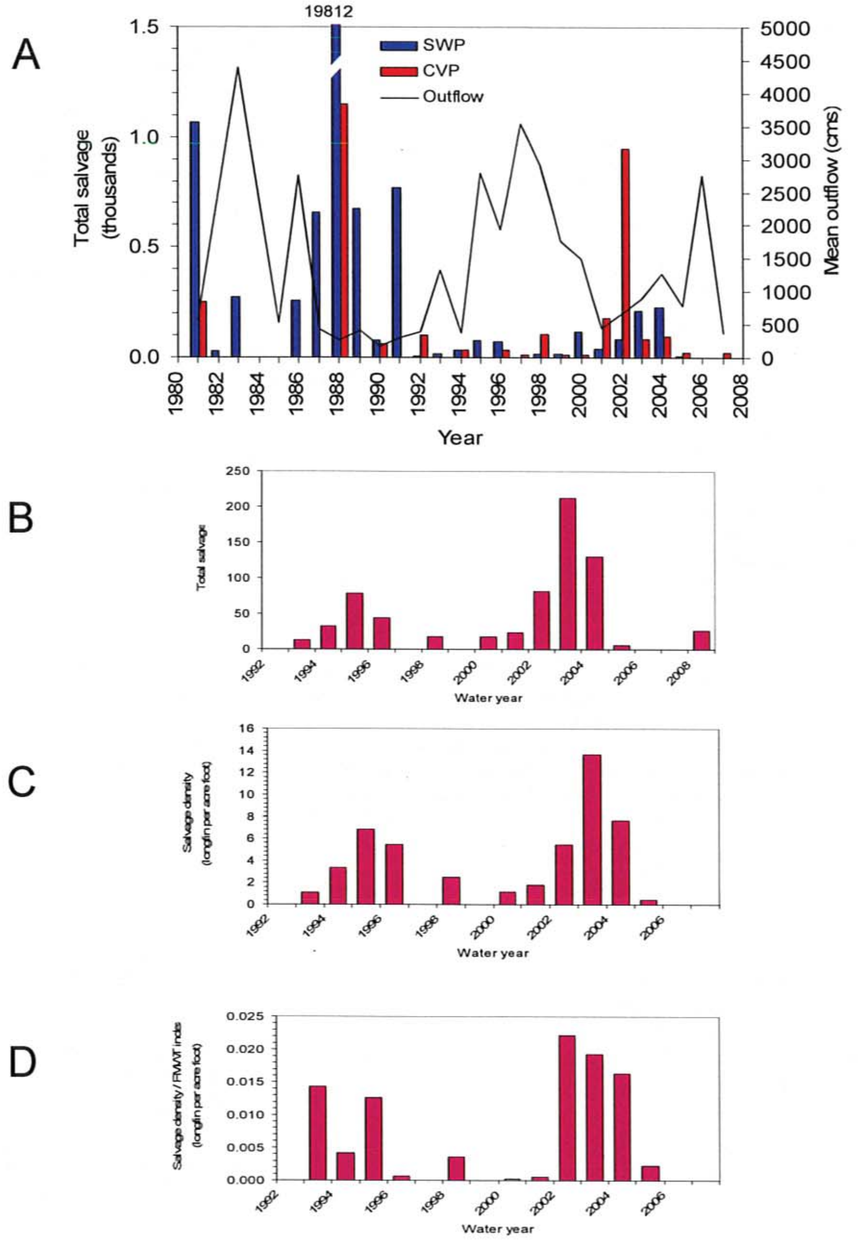


Figure 8. (A) Total winter (Dec-Mar) salvage of longfin smelt (**all ages**) at the State Water Project and Central Valley Project for 1981 through 2007 and mean Delta outflow in cubic meters per second for the same period. (B) SWP **adult** salvage, (C) adult salvage per acre ft exported and (D) adult salvage per acre ft divided by previous FMWT abundance index.

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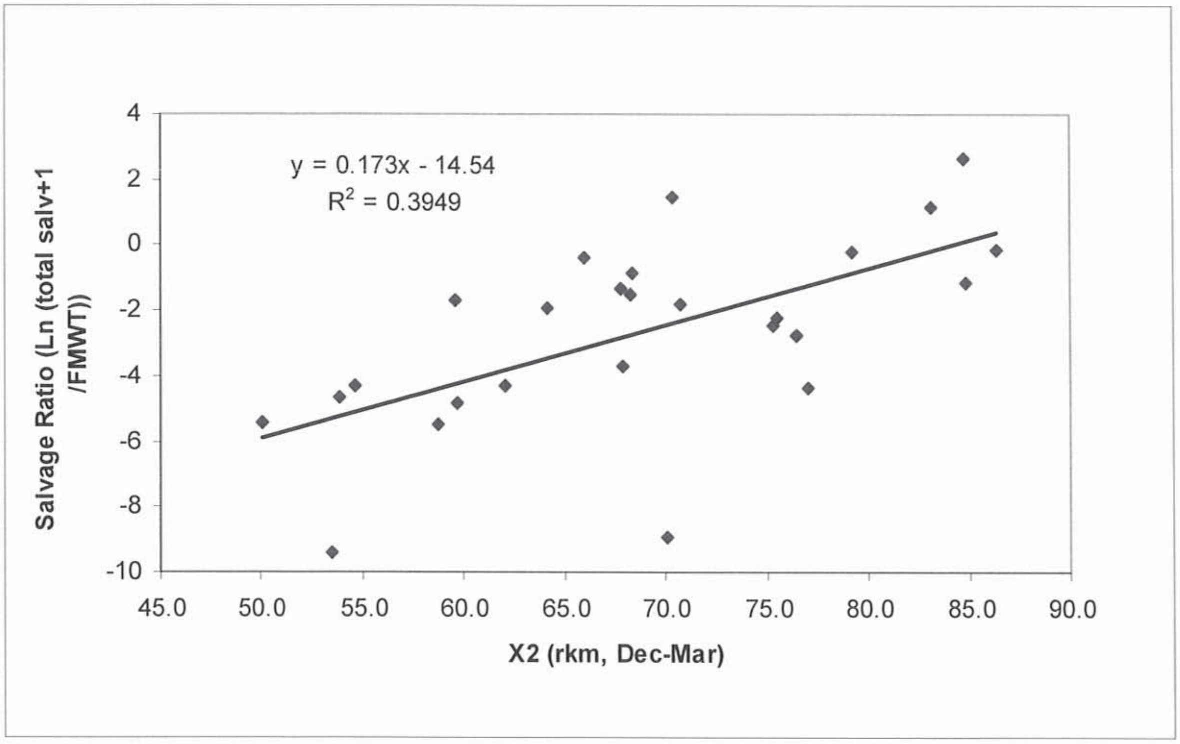

Figure 9. Total salvage of longfin smelt (December through March SWP+CVP) divided by the previous Fall Midwater Trawl longfin smelt index (all ages combined) as a function of X2 position during the same December through March period, 1982-2007. Relationship is significant, $r^2 = 0.395$, 24 df, $p < 0.05$.

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Loss at the Export Pumps. Salvage is an index of longfin smelt entrainment and related to the loss at the export facilities. Entrainment in this case is defined as the number of fish drawn into each facility along with water being pumped (i.e., into Clifton Court Forebay for the SWP and past the trash racks for the CVP). Fish entrained suffer mortality from predation within each facility and are lost to the system if they pass through the louvers designed to behaviorally direct fishes from the soon to be exported water and into fish salvage facilities. Fishes successfully salvaged -- directed into the salvage facilities by the louvers AND survive the process of collection, handing, transport and release -- are subtracted from those estimated to be entrained to calculate loss. Fujimura (2009, Appendix B) calculated estimates of longfin smelt juvenile and adult losses using salvage as a starting point.

Annual losses of adults occurred almost exclusively from December through March and varied substantially from year to year during the 1993-2008 period examined (Table 2). No longfin smelt adults were lost in the SWP in just over 30 percent of the years – mainly those with relatively high winter outflow. Adult loss peaked at an estimated 3,429 in 2003 (Table 2), when winter OMR was most negative (Figure 4).