Fulfilling a paradoxical mandate: An evaluation of efforts to reduce delta smelt (*Hypomesis transpacificus*) export entrainment loss while simultaneously ensuring the reliability of State and Federal water supplies.

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Running title: Fulfilling a paradoxical mandate

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Abstract:

The Environmental Water Account (EWA) is a cooperative management program with the duel purpose of providing protection to fish in the Delta through environmentally beneficial changes in SWP and CVP water operations, while improving water supply reliability by ensuring water users are fully compensated for these changes. During its first four years of operation, the EWA program used approximately 1.3 billion-m^3 (1.054 million-acre-feet) of water assets, at a total cost of about $139 million in public funding. Between 2001 and 2004 approximately 42% of the available EWA water was used to reduce SWP and CVP Delta exports in the last two weeks of May. This application of EWA water is called the “shoulder-on-VAMP” because it extends the one-month curtailment of Delta exports undertaken as part of an adaptive management experiment, the Vernalis Adaptive Management Plan or VAMP.

Patterns and relationships in young delta smelt salvage and temporally associated environmental variables revealed several results: 1) Abrupt increases in salvage of young delta smelt occurred in the May-June period and were generally dominated by salvage at the SWP. 2) Abrupt increases in SWP salvage of young delta smelt occurred during or immediately after a period of export curtailment. And 3) extreme SWP salvage events generally occurred at times when water temperatures were $\geq$ 20 ºC.

Examination of the available data suggests the shoulder-on-VAMP export curtailments did help to protect young delta smelt from excessive export entrainment. However, greater benefits to delta smelt might accrue by timing the onset and duration of export curtailments coincident with the onset and duration of the spawning period as determined by water temperatures. The limited water available from the EWA means actions must be tactical and capitalize on events associated with key biological processes in order to maximize effectiveness in the long run.

A conceptual model is presented to describe the combination of physical conditions that give rise to extreme salvage events of young delta smelt. The conceptual model is based on the premise that extreme salvage events of young delta smelt are a function of the integrated response of the species to environmental conditions that vary in time and space. The environmental conditions driving extreme salvage events are determined by Delta hydrology, SWP water project operations, and water temperature.

Introduction:

The San Francisco Estuary is often defined by its extremes. It is considered one of the most urbanized estuaries in the world (Conomos 1979, Nichols et al 1986) and one of the most invaded estuaries in the United States, with hundreds of aquatic nonindigenous species established throughout the system (Cohen and Carlton 1995, Dill and Cordone 1997; Kimmerer and Orsi 1996). It also is considered one of the most highly managed estuaries, particularly in relation to freshwater inflow, water circulation, and water quality (Arthur et al. 1996, Jassby and Powell 1994, Kimmerer 2002, CSWRCB 1995). In contrast, the Estuary is considered one of the most valuable natural resources in the western United States (CALFED 2000). In addition to its intrinsic habitat values, the Estuary provides important habitat for numerous native plant and animal species of special concern as well as several species with sport and commercial value (CALFED 2000). The pressure to increase human use and urbanization while conserving and restoring estuarine habitat and natural resources is a pressing and complex challenge to government agencies responsible for balancing these conflicting expectations.

The Sacramento-San Joaquin Delta exemplifies the ongoing challenges facing the San Francisco Estuary. Forming the eastern boundary of the Estuary (Figure 1), the Delta is where major efforts are underway to simultaneously maintain and improve ecosystem services (e.g., reliable and ample water supplies for municipal, industrial, and agricultural use, pollution abatement, or flood control) and ecosystem functions (e.g., provision of high quality habitat for native species, nutrient and carbon cycling, or biomass production). Roe and van Eten (2002) refer to this simultaneous pursuit as the “paradoxical mandate” due to the inherent fundamental conflicts in simultaneously improving conditions for human use (ecosystem services) and improving habitat conditions and processes (ecosystem functions). In this paper, I examine the actions and responses from one example to achieve this paradoxical mandate: maintaining the reliability of springtime water deliveries from the two major Delta export projects (the California State Water Project (SWP) and the Federal Central Valley Project (CVP)), while protecting the threatened delta smelt (*Hypomesis transpacificus*) from excessive export entrainment loss.

The delta smelt has received much interest since it’s listing as a threatened species under the State and Federal endangered species acts in 1993 (USFWS 1993, Sweetnam et al. 1993). This interest has centered on understanding the species ecology and population biology in relation to factors that limit its abundance and distribution (Moyle et al. 1992, Bennett and Moyle 1996, Sweetnam 1999, Bennett submitted, Herbold et al. 1992, Kuivila et al. 2002, USFWS 1995a). Long-term SWP and CVP operations are considered an important factor limiting delta smelt abundance and distribution through direct entrainment loss and through degradation of habitat conditions for rearing delta smelt (Stevens et al. 1990, Sweetnam et al. 1991, 1993, CDWR and USBR 1994, USBR 2004).

In 1995, the U.S. Fish and Wildlife Service issued a biological opinion that evaluated the adverse effects on delta smelt arising from long-term SWP and CVP operations (USFWS 1995b). This opinion relied on various existing agreements and regulations in conjunction with the prescription of several terms and conditions, to form an overall package of reasonable and prudent measures necessary to ensure that long-term SWP and CVP operations were unlikely to jeopardize the continued existence of delta smelt (USFWS 1995b). The incidental take statement contained in the biological opinion (Table 1) provided the principal metrics for estimating if future SWP and CVP operations were resulting in potential, unanticipated jeopardy to the species.

Between 1995 and 2000 delta smelt incidental take levels were exceeded in at least one month, in four out of six years (Table 2). These events led to unanticipated and substantial reductions in SWP and CVP water exports (for example see, Nobriga et al. 2000 and 2001), and suggested long-term water project operations were continuing to jeopardize the species through excessive entrainment losses. By 1999 it was clear that additional efforts were needed to address the challenge of ensuring the reliability of springtime water exports while simultaneously ensuring the protection of delta smelt.

In 2001, the Environmental Water Account (EWA) was initiated in part to address the chronic springtime conflict between SWP and CVP water project exports and the episodes of apparent high delta smelt entrainment losses. The EWA is a cooperative management program with the duel purpose of providing protection to fish in the Delta through environmentally beneficial changes in SWP and CVP water operations, while improving water supply reliability by ensuring water users are fully compensated for these changes (CALFED 2000). During its first four years of operation, the EWA program used approximately 1.3 billion-m^3 (1.054 million-acre-feet) of water assets, at a total cost of about $139 million in public funding (White and Poage 2004, J. White, CDFG, pers. comm.).

Three fishery management agencies (CA Dept. of Fish and Game, U.S. Fish and Wildlife Service, and NOAA Fisheries) determine the use of EWA water assets. Use of EWA assets has most commonly involved curtailing SWP and CVP water exports from the Delta to reduce the apparent entrainment loss of fish species of concern (e.g., delta smelt or winter-run Chinook salmon; White and Poage 2004). EWA water was used to reduce SWP and CVP Delta exports in the last two weeks of May between 2001 and 2004 (White and Poage 2004, J. White, CDFG, pers. comm.). This application of EWA water is called the “shoulder-on-VAMP” because it extends the one-month curtailment of Delta exports undertaken as part of an adaptive management experiment, the Vernalis Adaptive Management Plan or VAMP (SJRG 2004). The shoulder-on-VAMP export curtailment is thought to reduce direct entrainment loss of young delta smelt, and improve interior Delta hydraulic conditions affording young delta smelt greater opportunity to emigrate from the Delta to rearing areas in Suisun Bay, Suisun Marsh, and the lower Sacramento River (Figure 1, Poage 2004).

This paper attempts to answer two questions of relevance to the challenge of ensuring the reliability of springtime SWP and CVP water deliveries, while simultaneously protecting young delta smelt from excessive export entrainment loss:

1. What effect does the shoulder-on-VAMP export curtailment have on young delta smelt?

2. What is the combination of physical conditions in the Delta (flows, transport, temperature) that give rise to extreme entrainment events of young delta smelt?

Study Area:

The SWP and CVP water export facilities are both located in the South Delta (Figure 1). Although the SWP and CVP are operated for the same general purpose: move freshwater entering the Delta to regions and storage reservoirs south of the Delta, there are important differences in the physical features and resulting operations of each project. Head works of the CVP include: 1) an export canal from Old River, 2) weirs to capture course debris and fish salvage facilities all situated near the export canal entrance, and 3) the pumping plant which lifts water from the export canal into the Delta-Mendota aqueduct (Figure 2). This physical design means the CVP must continually pump at or near the maximum allowed rate (up to a design capacity of ~125 m^3/s) to achieve its contracted water deliveries. In contrast, the SWP head works includes five radial gates, which regulate water diversion from Old River into Clifton Court Forebay, a 37-million-m^3 regulating reservoir (Figure 3). Water is drawn out of Clifton Court through an approach channel, which contains the SWP fish salvage facility and the pumping plant that lifts water into Bethany reservoir, the headwater reservoir for the California aqueduct. Clifton Court Forebay affords SWP operators greater control over factors that affect pumping efficiency (i.e., tidal stage) and salvage efficiency (i.e., water velocity). Clifton Court Forebay also allows temporal separation of water diversions from the Delta and water pumping into the California aqueduct. Separating these two processes allows SWP operators to divert water from the Delta at times of optimal tidal conditions (generally just before or after high tide), and allows operators to run the large pumps at times when power costs are lower (generally at night).

The number of fish collected in fish salvage facilities at the SWP and CVP serves as the only routine quantitative measure of incidental take and fish entrainment in State and Federal water exports. These facilities aim to reduce the loss of fish entrained in water destined for export south of the Delta, through the collection and return of entrained fish. These processes are collectively referred to as "fish salvage" or "salvage."

CVP and SWP water export rates on any given day are reported as the daily average export rate. The export rate at either facility is limited by physical features (e.g., water capacity of the Delta-Mendota canal for the CVP or Clifton Court storage capacity for the SWP) and a variety of regulations designed to minimize degradation of water levels and water quality (CSWRCB 2000) and limit fish entrainment loss (USFWS 1995). For the CVP, daily average export rates are a relatively accurate measure of the export rate at any time throughout the day because the export rate is generally constant over the entire day. This is not the case at the SWP, because diversions out of the Delta into Clifton Court Forebay only occur over a portion of the day ranging from one to 17 hours. So, for example, to achieve a daily average export rate of ~42.5 m^3/s during the shoulder-on-vamp export curtailment, the diversion rate into Clifton Court Forebay might range from 122 m^3/s to 208 m^3/s over a 5-hour period or it might range from 40 m^3/s to 110 m^3/s over an 8-hour period.

Methods and Materials:

<u>Study organism</u>

Analyses in this paper only consider one species, the delta smelt. The delta smelt is endemic to the low-salinity and freshwater regions of the San Francisco Estuary (Moyle 2002, Bennett submitted). This relatively small planktivore is semelparous, reproducing in late winter and spring in the freshwater regions of the Sacramento-San Joaquin Delta and Suisun Bay (Figure 1; Moyle 2002). Fertilized eggs produce adhesive stalks allowing eggs to develop while attached to demersal substrates (Mager et al. 2003). In laboratory studies, Mager et al. (2003) found embryo development and hatching take 260 – 320 hours (at 14.8 – 16 ºC), while larval development including swim bladder inflation and fin differentiation takes 60 – 70 days (at 16 – 17 ºC). Delta smelt larvae are 5-mm in length at hatch and average growth rates in the laboratory are ~ 0.4 mm/day (B. Bridges, UCD, pers. comm.). Larvae and juveniles rear in fresh and brackish water areas of the Estuary (Moyle 2002).

<u>Study Design:</u>

Analyses and results presented in this paper concentrate on an examination of patterns and relationships among long-term data sets of delta smelt salvage at the SWP and CVP and temporally associated environmental variables (i.e., water temperature, water export rates, and Delta river flow). The analyses focus on the period between March 1 and July 1, because this is the time when young delta smelt occur in the central and south Delta and when episodes of high incidental take typically occur (Table 2). This period also includes the time when the shoulder-on-VAMP export curtailment occurred. Data from the March 1 to July 1 timeframe were divided among four periods: 1) the 31-day period prior to the VAMP export curtailment (Pre-VAMP), 2) the 31-day VAMP export curtailment period (VAMP), 3) the 11 to 16-day shoulder-on-VAMP export curtailment period (Shoulder), and 4) the 31-day period after the shoulder-on-VAMP export curtailment (Post-Shoulder). The analyses consider all four years in which the shoulder-on-VAMP export curtailment occurred (2001 – 2004).

Patterns and temporal relationships in export rate, Delta river flow, young delta smelt salvage, and water temperature were also examined for two years (1993 and 2000) in which the shoulder-on-VAMP export curtailment did not occur. An approximately three-week export curtailment did occur in 1993, but this was a year of relatively limited export curtailment and relatively high numbers of young delta smelt in the central and south Delta. 2000 was chosen because this was the first year of the VAMP export curtailment (SJRG 2000), and the only year when VAMP and shoulder-on-VAMP export curtailments did not co-occur.

The Environmental Water Account provides water earlier or later in the year to compensate the CVP and SWP for the shoulder-on-VAMP export reductions (White and Poage 2004). Between 2001 and 2004 the annual shoulder-on-VAMP export curtailment represented a substantial use of available EWA water (Table 3). Variations in the amount of EWA water used by the shoulder-on-VAMP export curtailment depended on the duration of the curtailment, and more importantly, on estimates of water export levels that would have occurred in the absence of the curtailment. These estimates depend on the annual delivery commitments of the water projects and the delivery schedule (T. Pettit, CDWR, pers. comm.). The shoulder-on-VAMP export curtailment always ended by May 31st. Overall, the shoulder-on-VAMP export curtailments consumed approximately 42% of all EWA water devoted to fish protection actions between 2001 and 2004.

Fish salvage processes at the SWP and CVP include regular sampling to estimate the number, species, and length of fish collected during the salvage efforts. A multiplier based on the proportion of the pumping interval sampled is used to amplify the number of individual fish collected in a sample to arrive at estimates of “expanded salvage.” For example, if export pumping occurs for 120 minutes and a 10-minute sample is taken during that 120-minute interval, then the expansion multiplier is 120/10 = 12. Generally, a 10-minute sample is collected every two hours of export pumping. These expanded values are summed over the day to yield an estimate of total daily salvage for each fish species collected. Fish length (total length) is measured and recorded by species for a subset of fish collected during each sampling interval. The size of the subset varies depending on the number of individuals collected. These data and associated operational data (e.g., the flow rate of export water, water temperature, and time of day) are managed by the CA Department of Fish and Game. Brown et al. (1996) provides more information about the salvage facilities and the sampling program.

Although enumeration of delta smelt collected at the CVP and SWP fish salvage facilities is the only quantitative estimate of fish entrainment at these diversions, neither facility is able to routinely collect and enumerate delta smelt less than 20 mm total length (Figure 4A) due to physical and process limitations (S. Foss, CDFG, pers. comm.). Annual estimates of delta smelt spawning onset and duration indicate larval delta smelt between 5 and 20 mm are in Delta waters, including water exported from the Delta, in the April – May period of most years (Figure 4B). Thus, the existing salvage operations likely provide an incomplete estimate of young delta smelt entrainment in the SWP and CVP diversions. Although understanding the factors driving extreme entrainment events is a purpose of this paper, the available data only permit investigation of the factors responsible for extreme salvage events. Therefore, the second question posed in this paper is modified to: What is the combination of physical conditions in the Delta (flows, transport, temperature) that give rise to extreme salvage events of young delta smelt?

The CA Department of Water Resources continuously monitors water temperature at several locations in the Delta. For this study, we used average daily water temperature data collected at the SWP Harvey O. Banks pumping plant, because we wanted to examine the relationship between delta smelt salvage levels at the SWP and the water temperatures these fish were exposed to. Water temperature data are available from the California Data Exchange Center http://cdec.water.ca.gov/cgi-progs/selectOMWQ.

Hydrodynamic variables (e.g., water stage and velocity) are continuously monitored at several locations in the Delta by the U.S. Geological Survey (USGS). Analyses in this paper use average daily river flow data in Old River at Bacon Island (Figure 1) as an indication of the timing and magnitude of SWP and CVP operational effects on interior Delta hydraulics. USGS Delta hydrodynamics data are available at http://baydelta.wr.usgs.gov/. Ruhl and Simpson (in prep.) provide details on the instrumentation and methods used to collect and process daily river flow data in the Sacramento-San Joaquin Delta.

Data on SWP and CVP export rates were used to document water project operations. These data are maintained as part of the fish salvage database and are available at http://www.delta.dfg.ca.gov/Data/Salvage/. Export rates are reported as daily average cubic feet per second and export volumes are reported as acre-feet per day. These data were converted to appropriate metric values (cubic meters per second (m^3/s) or cubic meters per day (m^3/d) respectively).

Calculations and statistical comparisons:

Analyses presented in this paper use daily total salvage data collected at the SWP and CVP over the period of interest. Delta smelt salvage data collected prior to 1993 are not considered due to limited confidence in the accuracy of these data (S. Foss, DFG, pers. comm.). Historical data are available at http://www.delta.dfg.ca.gov/Data/Salvage/. A two-sample t-test was used to test for significant differences between the mean daily delta smelt salvage at the two facilities and mean daily delta smelt salvage density at the two facilities. Delta smelt salvage data collected during the May 1 – June 30 period in the years 1994 through 2004 were used in these t-tests because this is the typical period of peak delta smelt salvage. The t-test was used to test the two-tailed hypotheses, H_o: $mean_{swp} = mean_{cvp}$ and H_a: $mean_{swp} \neq mean_{cvp}$.

Calculations were made of hourly diversion rates into Clifton Court Forebay in an attempt to better understand SWP water diversion dynamics and its potential effects on delta smelt entrainment. For the March 1 – July 1 period in the years 2001 – 2004 I used a spreadsheet model developed by staff at the California Department of Water Resources. This spreadsheet calculates hourly inflow through the radial gates and into Clifton Court Forebay based on measured values of water stage inside and outside of the radial gates, and based on the height to which each of the five radial gates is raised. This spreadsheet is available at http://www.iep.ca.gov/dsm2pwt/dsm2pwt.html. The data used to populate the spreadsheet are available at http://iep.water.ca.gov/cgi-bin/dss/dss1.pl?station=CHWST000.

Results from the spreadsheet calculations include hourly inflow rate and hours of gate opening (duration of diversion). These results were divided according to the four periods (Pre-VAMP, VAMP, Shoulder, and Post-Shoulders). Mean inflow rates and mean durations of diversion among the four periods were analyzed for significant differences using a two-factor, fixed effects ANOVA with unequal replication. The factors in the ANOVA model were year, period, and year x period interaction. A Tukey multiple comparison test was used to determine among which means differences existed.

A linear extrapolation of fish salvage was used to estimate the annual reduction in CVP and SWP salvage of young delta smelt resulting from the shoulder-on-VAMP export curtailment. Specifically, the average density of young delta smelt (number of fish/m^3/d) estimated at each salvage facility during the shoulder-on-VAMP export curtailment period was multiplied by the amount of water that would have been exported if the curtailment had not occurred. The resultant is an estimate of the number of fish that might have been salvaged if the shoulder-on-VAMP export curtailment did not occur. A linear extrapolation of fish salvage at the CVP facilities is considered a reasonable first order approximation of shoulder-on-VAMP export effects, given the relatively constant pumping rates and lack of features (e.g., a forebay) that could result in the retention or accumulation of young delta smelt. There is much great uncertainty associated with a linear extrapolation of fish salvage at the SWP facilities, given the spatial and temporal separation between water diversions and water exports, and the possibility of retention or accumulation of young delta smelt in Clifton Court Forebay. The major assumptions in these calculations are: 1) The density of young delta smelt collected at the salvage facility does not change under different export rates or volumes. And 2) pre-salvage mortality of entrained delta smelt is negligible.

Finally, I investigated the relationship between the distribution of larval delta smelt and freshwater outflow from the Delta. The distribution of larval delta smelt was estimated using monitoring data from the CA Department of Fish and Game 20-mm survey. This survey started in 1995 and is designed primarily to sample young-of-year delta smelt (Dege and Brown, 2004). The survey collects samples throughout the upper San Francisco Estuary (From San Pablo Bay through the Delta, Figure 1) every two weeks in the spring and summer. Dege and Brown (2004) provide more details about the 20-mm survey. Catch of delta smelt during the first four surveys of each year were summed to estimate the proportion of young delta smelt in the southeast Delta just prior to the May-June salvage period. These estimates were compared to estimates of mid-March through mid-May Delta outflow to investigate if any relationship existed between springtime outflow and the resulting distribution of young delta smelt. The 20-mm survey data are available at http://www.delta.dfg.ca.gov/data/20mm/. Estimates of daily Delta outflow are available at http://www.iep.ca.gov/dayflow/index.html.

Results:

Between 1994 and 2004, a majority of young delta smelt was collected at both the SWP and CVP salvage facilities during the months of May and June (Table 2). Closer examination of May – June delta smelt salvage data shows that in most years between 1994 and 2004, young delta smelt salvage and salvage density were higher at the SWP (Figures 5A and 5B). Over the eleven-year period, both mean May-June salvage and mean May-June salvage density differed significantly between the SWP and the CVP ($t_{(2)670} = 9.66 \times 10^{-6}$, $P<0.0001$ and $t_{(2)670} = 4.23 \times 10^{-5}$, $P <0.0001$ respectively). Thus, extreme salvage events of young delta smelt are often driven by salvage events at the SWP during the May-June period. For this reason, subsequent analyses presented in this paper focus on young delta smelt salvage at the SWP.

The examination of patterns and temporal relationships among daily delta smelt salvage and three environmental variables (export rate, interior Delta water flow in Old River, and water temperature) revealed several results. The VAMP and shoulder-on-VAMP export curtailments resulted in substantial changes in interior Delta hydraulics as indicated by changes in the daily average flow in Old River (Figures 6A, 7A, 8A, and 9A). Old River flow was less negative and sometimes slightly positive (i.e., the magnitude of export-mediated reverse flow was reduced) throughout each of the export curtailment events.

The VAMP and shoulder-on-VAMP export curtailments varied somewhat among the four years (Figures 6A, 7A, 8A, and 9A). Overall, export rates were most uniform during the 2001 and 2002 curtailment periods. Export rates were generally lowest in 2001 and 2002, although the shoulder-on-VAMP curtailment period only extended for 11 days in 2001 compared to 16 days in the other years. The level of export curtailment was reduced near the end of the shoulder-on-VAMP action in 2003 and 2004. The export curtailment was reduced in 2003 due to concern that water costs could exceed available EWA assets and the high cost of repayment (White and Poage 2004). The export curtailment was reduced in 2004 after 20-mm survey data indicated young delta smelt were emigrating from the Delta, reducing the concern for excessive entrainment (V. Poage, USFWS, pers. comm.). The shoulder-on-VAMP export curtailment ended on May 31st in each of the four years. Consistency in the ending date was driven primarily by the availability and allocation of EWA assets (V. Poage, USFWS, pers. comm.).

Abrupt increases in SWP salvage of young delta smelt occurred in the May-June period of all years in which the shoulder-on-VAMP export curtailment occurred, although the magnitude and duration of the increase varied among years (Figures 6B, 7B, 8B, and 9B). Extreme SWP salvage of young delta smelt occurred during (2001 and 2002), or immediately after (2003 and 2004) the shoulder-on-VAMP export curtailment. Abrupt increases in CVP salvage of young delta smelt also occurred in the May-June period, although the timing and duration often differed from the SWP events. Appreciable salvage of young delta smelt generally occurred first at the CVP. Extreme SWP salvage events were generally an order of magnitude larger than extreme CVP salvage events in any one year.

Between 2001 and 2004, extreme SWP salvage of young delta smelt occurred when water temperatures inside Clifton Court Forebay were at or increasing above 20 °C (Figures 6C, 7C, 8C, and 9C). In all years except 2002, the highest levels of daily SWP salvage occurred when water temperatures sustained levels ≥ 20 °C for the second time between March 1 and July 1. In 2002, the highest levels of daily SWP salvage occurred when water temperatures were warming to ≥ 20 °C for the first time in the March to July period.

Patterns and relationships in young delta smelt salvage and environmental variables examined for the years 1993 and 2000 were consistent in every respect with observations from 2001 through 2004 (Figures 10 and 11): 1) Abrupt increases in SWP salvage of young delta smelt occurred in the May-June period and immediately after a period of export curtailment. 2) Extreme SWP salvage events of young delta smelt differed from CVP salvage events in timing and duration. 3) Extreme SWP salvage events were at least one order of magnitude larger than peak CVP salvage. And 4) abrupt increases in SWP salvage of young delta smelt generally occurred when water temperatures inside Clifton Court Forebay were at or increasing above 20 °C. The only exception to this was in June 1993 when two, one-day increases in SWP salvage of young delta smelt occurred when daily average water temperatures were ≥ 19 °C.

Linear extrapolations suggest the shoulders-on-VAMP export curtailment reduced CVP and SWP salvage of young delta smelt in each year between 2001 and 2004 (Table 4). The estimated amount of salvage reduction varied among years due to both differences in salvage density and the estimated increase in exports that would have occurred in the absence of the shoulder-on-VAMP curtailment. Over the four year period, the linear extrapolations suggest young delta smelt salvage would have more than doubled at the CVP and more than tripled at the SWP, due mainly to increased salvage estimates for 2002.

Calculations of average hourly diversion rates into Clifton Court Forebay show large deviations from the generally reported daily average values. During the VAMP and Shoulder-on-VAMP export curtailment periods, the total combined (CVP + SWP) export rate was targeted to average ~43 m^3/s over a 24-hour period. In most years, the CVP and SWP operate to achieve an equal export rate meaning the SWP export rate averages ~21.5 m^3/s over a 24-hour period during curtailment events. However, calculated values for the SWP during the export curtailment periods show average diversion rates ranged from ~79 m^3/s over a seven-hour period in 2001 to ~212 m^3/s over a five-hour period in 2003 (Figures 12A and 12B). During periods when export curtailments are not in effect, the SWP can routinely divert water at a maximum average rate of ~189 m^3/s over a 24-hour period. However, calculated values during the pre-VAMP and post-shoulder period show average SWP diversion rates ranged from ~149 m^3/s over a five-hour period in 2001 to ~267 m^3/s over a 15-hour period in 2003. Overall, calculations of estimated diversion rates into Clifton Court Forebay suggest very high diversion rates are common and hourly diversion rates can deviate substantially from 24-hour averages.

The magnitude of the average diversion rate into Clifton Court Forebay did decline during the VAMP and shoulder-on-VAMP export curtailment periods, although the differences among years and across periods were inconsistent (Figure 12A). ANOVA tests for calculated diversion rates found significant differences among years ($F_{3,3296}$ = 41.5; P < 0.000), among periods ($F_{3,3296}$ = 125.5; P < 0.000), with a significant interaction of years and periods ($F_{9,3296}$ = 18.9; P < 0.000). Tukey multiple comparisons tests of main effects found the Pre-VAMP and shoulder-on-VAMP diversion rates differed from all other periods. Diversion rates during the VAMP and post-shoulder periods were not significantly different. 2001 and 2003 diversion rates across the four periods differed from all other years. Diversion rates in 2001 were lower on average due to additional export reductions in April extending into the first five day of VAMP, and due to an SWP pumping outage throughout much of June due to a failure of the aqueduct lining. Diversion rates in 2003 were higher on average due to higher exports levels during the shoulder-on-VAMP and post-shoulder periods. The interaction of years and periods was significant due to differences among the four years in the average diversion rates across periods.

The average duration of diversion into Clifton Court Forebay also declined during the VAMP and shoulder-on-VAMP export curtailment periods (Figure 12B). ANOVA results for calculated durations of diversion found significant differences among years ($F_{3,386} = 16.4$; $P < 0.000$), among periods ($F_{3,386} = 158.4$; $P < 0.000$), and significant interaction of years and periods ($F_{9,386} = 12.8$; $P < 0.000$). Tukey multiple comparison tests found the VAMP and shoulder-on-VAMP periods (fewer hours open) differed from the pre-VAMP and post-shoulder periods (more hours open). Duration of gate opening in 2003 differed from all other years, driven by longer periods of gate openings in the pre-vamp and post-shoulder periods. The interaction of years and periods was significant due to differences among the four years in the average diversion duration across periods.

Examination of the data for the individual variables (i.e., water stage, height of gate opening, and duration of gate opening) suggest SWP project operators first consider the duration of gate opening to reduce total inflow and secondarily consider rate of inflow which may be limited by the extent to which the individual gates are open and the differential in water stage across the gates. Thus, both the magnitude and duration of the diversion event into Clifton Court Forebay must be considered when examining entrainment dynamics at the SWP.

Between 2001 and 2004 the SWP diverted water into Clifton Court Forebay almost every day between March 1 and July 1 (Figure 12C). The only exception was in 2001, when repairs to the aqueduct lining necessitated a complete shutdown of the pumps removing water from the Forebay during much of June. Daily diversions into Clifton Court Forebay and daily pumping out of the Forebay represent normal SWP operations whether export curtailments occur or not.

The proportion of young delta smelt in the southeast Delta during spring ranged from zero to 57% between 1995 and 2004 (Figure 13). The results show some proportion of young delta smelt occurred in the southeast delta when average daily Delta outflow was < 1,500 m^3/s during the mid-March to mid-May period. The proportion of delta smelt in the southeast Delta ranged from 10% to 57% in the years when combined (CVP + SWP) salvage exceeded the authorized incidental take level (Table 2), and these values generally bracketed the proportions of young delta smelt estimated to occur in the southeast delta in 2001 through 2004.

Discussion:

This paper examines a common set of water management actions taken to fulfill the paradoxical mandate of ensuring the reliability of springtime SWP and CVP water deliveries, while simultaneously protecting young delta smelt from excessive export entrainment loss. The EWA was able to fully compensate for all SWP and CVP export curtailments during spring 2001 – 2004 (White and Poage 2004, J. White, CDFG, pers. comm.), so the mandate of ensuring the reliability of springtime SWP and CVP water deliveries was fully met. The remainder of this discussion focuses on answering the two questions that relate to the second part of the paradoxical mandate: simultaneously protecting young delta smelt from excessive export entrainment.

1. What affect does the shoulder-on-VAMP export curtailment have on young delta smelt?

At a qualitative level, it seems reasonable to conclude the shoulder-on-VAMP export curtailments did help to protect young delta smelt from excessive export entrainment. Reducing the amount of water diverted from the Delta during the time young delta smelt are present in the Delta should generally result in concurrent reductions in fish entrainment. Linear extrapolations suggest young delta smelt salvage was reduced substantially at both the CVP and SWP during the two-week shoulder-on-VAMP export curtailment undertaken in 2001 through 2004. However, the utility of these numbers is severely limited by the untested assumptions underlying the linear extrapolations of salvage, the absence of variability estimates, and at the SWP, the spatial and temporal separation between water diversions into the Forebay and export pumping out of the Forebay.

Maximizing the benefit of export reductions on young delta smelt requires explicit consideration of the temporal relationship between biological processes and water project operation schedules. Specifically, greater benefits to delta smelt might accrue by timing the onset and duration of export curtailments coincident with the onset and duration of the spawning period. Bennett (submitted) examines the important role water temperature has in the timing and duration of delta smelt spawning. Water temperature is easily monitored, and these monitoring data could be used as an indicator for the onset of delta smelt spawning and the timing of export curtailments. Reducing exports early in the spawning period could be more beneficial to young delta smelt by minimizing the adverse affects of SWP and CVP diversions on south Delta hydraulics at a time when developing larvae are most vulnerable to hydrodynamic influences.

In the past, after the fact evaluations of measures to protect delta smelt from excessive entrainment generally compare the actual salvage levels to the USFWS authorized incidental take levels (i.e., Table 2 vs. Table 1; see for example Poage 2004, or Nobriga et al. 2001). If salvage levels stay below the authorized incidental take levels then it is generally concluded that excessive export entrainment loss was avoided. The major drawback of this evaluation —besides not knowing the quantitative relationship between entrainment and salvage— is that events in any one-year are compared only to average historical salvage. Such comparisons are of limited value for an annual species that is susceptible to large fluctuations in abundance among years and life stages (Bennett, submitted). More recent efforts have focused on the development and use of evaluation criteria to determine if a shoulder-on-VAMP export curtailment should occur in any given year (Poage 2004). These criteria include: 1) the index of adult abundance in the previous year, 2) the relative abundance of young delta smelt in the south Delta, 3) delta smelt salvage levels, 4) hydrologic conditions, and 5) length of spawning period estimated from Delta water temperatures. Yet, with the exception of salvage levels, none of these criteria are routinely used to assess the effectiveness of measures specifically designed to protect delta smelt.

It will be difficult to conduct more sophisticated assessments of protective measures until several underlying knowledge limitations are addressed. Key limitations include: 1) the inability of the SWP and CVP facilities to quantify the salvage of young delta smelt < 20 mm, 2) the unknown quantitative relationship between fish salvage and fish entrainment, and 3) limited use of an existing particle tracking model to understand how SWP and CVP operations might affect young delta smelt distribution. The particle tracking model uses inputs of physical conditions derived from a hydrodynamic simulation model of the Delta to track the movement and re-distribution of individual particles. Factors such as freshwater inflow, tidal conditions, and SWP and CVP export levels can be modified to compare how particle distribution changes under different hydraulic conditions.

2. What is the combination of physical conditions in the Delta (flows, transport, temperature) that give rise to extreme salvage events of young delta smelt?

Since its listing in 1993, Delta hydrology and the effects of SWP and CVP exports on interior Delta hydraulics have figured prominently in several conceptual models used to describe the physical conditions that result in extreme salvage events of delta smelt (USFWS 1995a and 1995b, Herbold et al. 1992). Most recently, Dege and Brown (2004) investigated how Delta outflow affects young delta smelt distribution. They found the distribution of young delta smelt relative to a fixed geographic point (i.e., the Golden Gate Bridge) differed significantly among outflow conditions: the distribution shifted upstream under low outflow conditions and downstream under high outflow conditions. Once in the Delta, the alteration of interior Delta hydraulics by SWP and CVP operations is thought to inhibit the ability of delta smelt to emigrate from the Delta resulting in direct entrainment losses as well as an increased potential for indirect losses due to increased localized predation, food limitation, increased exposure to small agricultural water diversion facilities, or increased exposure to pollutants. This conceptual model provides much of the basis for the shoulder-on-VAMP export curtailment (Poage 2004).

Recent results in the literature combined with results in this paper can be used to refine and augment the conceptual model for describing the combination of physical conditions that give rise to extreme salvage events of young delta smelt. The results of Dege and Brown (2004) and results presented in this paper (Figure 13) support the role of Delta hydrology in affecting delta smelt distribution. The fact that extreme salvage events of young delta smelt are typically determined by SWP salvage suggests SWP water operations have a prominent role. Further, we must also consider the role of water temperature and the biological processes that are tied to changes in water temperature (Bennett, submitted).

The conceptual model described here is based on the premise that extreme salvage events of young delta smelt are a function of the integrated response of the species to environmental conditions that vary in time and space (Figure 14). Delta outflow during the spring is the initial environmental factor important to determining if an extreme salvage event could occur. Delta outflow has a relatively broad spatial affect influencing conditions in the Delta and upper Estuary and a temporal affect spanning weeks to months. Adult immigration and dispersal to spawning areas is thought to occur largely in response to Delta outflow conditions. The data (Figure 13) suggest springtime Delta outflow operates like a switch: the switch is on for adults to move into the Delta to spawn when average daily mid-March to mid-May Delta outflow is < 1,500 m^3/s. The switch is off when average daily mid-March to mid-May Delta outflow is > 1,500 m^3/s with adults seeking suitable spawning areas downstream of the Delta. The distribution of spawning adults in response to Delta outflow is thought to be a primary determinant in the initial distribution of delta smelt larvae.

Water temperature in the spawning area is the second environmental factor important to determining if an extreme salvage event could occur. Bennett (submitted) used water temperature data to estimate the delta smelt spawning period. His research shows the onset and duration of the spawning period varies among years and is strongly influenced by large-scale climate events (i.e., el niño or la niña events). Thus, water temperature also has a relatively broad spatial affect influencing conditions throughout the Estuary, but the temporal affect on delta smelt spawning is on the order of weeks.

It is the timing of delta smelt spawning and rearing in relation to changes in water export conditions that is key to determining how interior delta hydraulics affect initial larval distribution and subsequent entrainment. If spawning in the Delta occurs relatively early (March and April) then a relatively smaller proportion of the larval rearing period will occur under low export conditions afforded by the VAMP (mid-April to mid-May) and shoulder-on-VAMP (mid-May to June) export curtailments. If spawning occurs relatively late (April and May) then a relatively greater proportion of the larval rearing period will occur during the period of export curtailments.

We cannot presently determine how the temporal relationship between delta smelt spawning and rearing, and changes in water export conditions ultimately affects fish salvage or entrainment loss. It may be that extreme salvage events at the SWP are driven by the accumulation of young delta smelt (< 20 mm) in Clifton Court Forebay. Accumulation of young delta smelt in the Forebay could occur through several mechanisms: 1) the accumulation of fish entrained in diversions into the Forebay, 2) through the successful spawning of adults in the Forebay, or 3) a combination of the two. For this hypothesis to be true, young delta smelt in the Forebay must be able to accumulate at rates greater than the rates of mortality due to predation or removal by export pumping. Although the data needed to test this hypothesis do not exist, several pieces of information suggest this hypothesis is plausible. First, calculations of water diversion velocities into Clifton Court Forebay show diversion rates remain high even during periods of export curtailment. Although the diversion period is reduced during export curtailments, there is little doubt these rates of diversion are sufficient to entrain young delta smelt into Clifton Court Forebay throughout the VAMP and shoulder-on-VAMP export curtailment period. Meanwhile, export pumping out of Clifton Court Forebay is reduced during the curtailment period, so there is a reduction in the hydraulic forces that remove young delta smelt from the Forebay. Second, the SWP and CVP salvage patterns between March 1 and July 1 in 2001 through 2004 often show appreciable salvage of young delta smelt occurs first at the CVP. This delay in salvage at the SWP may be an indication of the continuing accumulation of young delta smelt in the Forebay without appreciable loss due to export pumping removal.

Water temperature changes through the larval rearing period are thought to be the third and final environmental factor important to determining if an extreme salvage event could occur. Extreme SWP salvage events of young delta smelt consistently occur when water temperatures inside Clifton Court Forebay are $\geq$ 20 ºC, while SWP exports may be either high or low. I suggest warming water temperatures motivate young delta smelt residing in Clifton Court Forebay to seek out other locations with cooler waters. It is during periods of active movement that young delta smelt become most susceptible to salvage at the SWP facilities. Increasing water temperatures would affect young delta smelt occurring throughout the Delta, but the temporal effect is on the order of days.

Clearly, additional research is needed to test and verify the cause-effect relationships between environmental variables (Delta inflow, SWP and CVP export operations, and water temperature) and the responses of delta smelt. Critical information needs include:

- Verify calculated estimates of inflow rates into Clifton Court Forebay with *in-situ* measurements.
- Quantitatively estimate SWP and CVP entrainment of young delta smelt with field sampling.
- Determine the quantitative relationship between SWP and CVP entrainment and salvage of young delta smelt.

- Verify if young delta smelt do accumulate in Clifton Court Forebay and the sources of any accumulation (entrainment, spawning, or both).
- Conduct experiments to estimate the magnitude of delta smelt mortality in Clifton Court Forebay.
- Begin rigorous use of an existing particle-tracking model to develop a better understanding of how entrainment risk might change under different SWP and CVP water project operations.
- Conduct mesocosm studies to understand how young delta smelt respond to changes in hydraulics and water temperature.

Government agencies will continue to take actions using EWA water assets to achieve the paradoxical mandate of ensuring the reliability of springtime SWP and CVP water deliveries, while simultaneously protecting young delta smelt from excessive export entrainment loss. Results presented here indicate the shoulder-on-VAMP actions have achieved some measure of success in satisfying this mandate. Yet the actions to date seem to be predicated more on the availability and amount of water assets and less on delta smelt ecology. The results of this study suggest actions focused on protecting young delta smelt might provide more benefit if the timing and duration of the export curtailment are more closely aligned with the spawning period. Springtime water temperatures appear to be an effective indicator of the delta smelt spawning period and may also be important in triggering emigration. Timing export curtailment events around key water temperatures may help to maximize the protective benefits of these events. The limited water available from the EWA means actions must be tactical and capitalize on events associated with key biological processes in order to maximize effectiveness in the long run.

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Table 1. Combined (SWP + CVP) authorized incidental take of delta smelt for each month by water year type (USFWS 1995b). Values are averages of the upper quartile of delta smelt collected at SWP and CVP salvage facilities from 1980 to 1992. Water year (WY) types (above normal or below normal) are based on hydrologic forecasts that predict with 90% confidence the total inflow to the Delta between October 1 and September 30. Methods for estimating the number of delta-smelt collected at the salvage facilities are described in the methods and materials section of this paper.

Months	Above Normal WY	Below Normal WY
January	5,397	13,354
February	7,188	10,910
March	6,979	5,368
April	2,378	12,345
May	9,769	55,227
June	10,709	47,245
July	9,617	35,550
August	4,818	25,889
September	1,329	1,978
October	11,990	6,440
November	3,330	2,001
December	733	8,052

Table 2. Combined (CVP + SWP) monthly (March – July) collections of delta smelt at the two salvage facilities from 1995 through 2004. (AN): above normal water year. (BN): below normal water year, as described in Table 1. Values in bold type exceed the monthly incidental take levels authorized by USFWS (see Table 1).

Year	March	April	May	June	July
1995(AN)	16	24	0	0	0
1996(AN)	155	111	**30,399**	9,465	148
1997(AN)	1,730	1,159	**32,828**	7,876	228
1998(AN)	592	48	4	66	124
1999(AN)	564	410	**58,929**	**73,368**	**19,822**
2000(AN)	2,746	1,746	**49,401**	**49,124**	1,513
2001(BN)	3,748	519	13,134	2,325	6
2002(BN)	225	372	47,361	11,926	24
2003(BN)	483	492	16,216	9,580	12
2004(BN)	2,267	276	5,239	6,416	18

Table 3. Total amount of water available in the Environmental Water Account (EWA) annually for all actions taken to protect fish (EWA Fish Actions), and amounts of EWA water applied annually to the VAMP export curtailment (VAMP Actions) and Shoulder-on-VAMP export curtailment (Shoulder Actions). All values are millions of m^3. Values in parentheses are percentages of EWA fish action water consumed by an individual action.

Year	EWA Fish Actions	VAMP Actions	Shoulder Actions
2001	357.7	53.04 (15)	18.50 (5)
2002	360.2	55.51 (15)	162.8 (45)
2003	429.3	39.47 (9)	240.5 (56)
2004	153.0	24.67 (16)	128.3 (84)
4-year Total	*1,300.2*	*172.69 (13)*	*550.2 (42)*

Table 4. Actual and estimated young delta smelt salvage at the CVP and SWP during the shoulder-on-VAMP export curtailment period in 2001 – 2004. Actual salvage is the sum of reported daily values during the curtailment period. Mean salvage density (fish/m^3/d) is the mean of daily salvage densities derived from reported values of daily salvage and daily exports during the curtailment period. Estimated export (m^3) is the estimated amount of water (T. Pettit, CDWR, pers. comm.) that would have been exported by the CVP or SWP over the shoulder-on-VAMP period if the export curtailment did not occur. Estimated salvage for each year is a linear extrapolation: (mean salvage density)*(estimated exports). Salvage difference: (estimated salvage) – (actual salvage).

Year	**Actual Salvage**	**Mean Salvage Density**	**Estimated Export**	**Estimated Salvage**	**Salvage Difference**
		CVP			
2001	2,208	0.93×10^{-4}	48,772,086	4,536	2,328
2002	6,144	1.80×10^{-4}	119,921,349	21,586	15,442
2003	7,896	1.06×10^{-4}	111,387,638	11,807	3,911
2004	2,724	0.57×10^{-4}	120,707,799	6,880	4,156
4-Yr. Total	*18,972*	--	--	*44,809*	*25,837*
		SWP			
2001	5,613	5.94×10^{-4}	28,842,184	17,132	11,519
2002	33,899	9.94×10^{-4}	103,313,097	102,693	68,794
2003	4,506	$1.08 \text{ X } 10^{-4}$	261,025,546	28,191	23,685
2004	2,257	0.75×10^{-4}	83,835,037	6,288	4,031
4-Yr. Total	*46,275*	--	--	*154,304*	*108,029*

Figure Legends:

Figure 1. Location and geographic components of the San Francisco Estuary, California, USA. The Sacramento-San Joaquin Delta includes all of the shaded area to the east of Suisun Bay. The USGS Old River flow monitoring station is located approximately at the arrow label for Old River.

Figure 2. Aerial photograph of the head-works of the Central Valley Project Delta water export facilities (CVP). See Figure one for the general location of the CVP. The export pumps are outside of this photograph.

Figure 3. Aerial photograph of the head-works of the California State Water Project Delta water export facilities (SWP). See Figure one for the general location of the SWP.

Figure 4A. Length of young delta smelt collected at the SWP and CVP fish salvage facilities from 1995 through 2003. Reported lengths are total length measurements from a subset of fish collected during each sampling event. Dates range from March 15th (3/15) to July 30th .

Figure 4B. Estimated delta smelt spawning period (onset and duration) in the Delta between 1970 and 2002. Results from Bennett (submitted).

Figure 5A. Daily number of delta smelt collected at the SWP and CVP salvage facilities in May and June from 1994 through 2004.

Figure 5B. Daily salvage density (fish/10,000 m^3) of delta smelt at the SWP and CVP facilities in May and June from 1994 through 2004.

Figure 6A. Daily export rate at the SWP and CVP Delta export facilities and Daily average flow in Old River between March and July 2001. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 6C.

Figure 6B. Daily number of delta smelt collected at the SWP and CVP salvage facilities between March and July 2001. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 6C.

Figure 6C. Daily average water temperature at the SWP Harvey O. Banks pumping plant between March and July 2001. The pumping plant receives water from Clifton Court Forebay and these data are used to indicate water temperatures in the Forebay. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days.

Figure 7A. Daily export rate at the SWP and CVP Delta export facilities and Daily average flow in Old River between March and July 2002. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 7C.

Figure 7B. Daily number of delta smelt collected at the SWP and CVP salvage facilities between March and July 2002. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 7C.

Figure 7C. Daily average water temperature at the SWP Harvey O. Banks pumping plant between March and July 2003. The pumping plant receives water from Clifton Court Forebay and these data are used to indicate water temperatures in the Forebay. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days.

Figure 8A. Daily export rate at the SWP and CVP Delta export facilities and Daily average flow in Old River between March and July 2003. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 8C.

Figure 8B. Daily number of delta smelt collected at the SWP and CVP salvage facilities between March and July 2001. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 8C.

Figure 8C. Daily average water temperature at the SWP Harvey O. Banks pumping plant between March and July 2003. The pumping plant receives water from Clifton Court Forebay and these data are used to indicate water temperatures in the Forebay. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days.

Figure 9A. Daily export rate at the SWP and CVP Delta export facilities and Daily average flow in Old River between March and July 2004. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 9C.

Figure 9B. Daily number of delta smelt collected at the SWP and CVP salvage facilities between March and July 2004. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 9C.

Figure 9C. Daily average water temperature at the SWP Harvey O. Banks pumping plant between March and July 2004. The pumping plant receives water from Clifton Court Forebay and these data are used to indicate water temperatures in the Forebay. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days.

Figure 10A. Daily export rate at the SWP and CVP Delta export facilities and Daily average flow in Old River between March and July 1993. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 10C.

Figure 10B. Daily number of delta smelt collected at the SWP and CVP salvage facilities between March and July 1993. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 10C.

Figure 10C. Daily average water temperature at the SWP Harvey O. Banks pumping plant between March and July 1993. The pumping plant receives water from Clifton Court Forebay and these data are used to indicate water temperatures in the Forebay. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days.

Figure 11A. Daily export rate at the SWP and CVP Delta export facilities and Daily average flow in Old River between March and July 2000. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 11C.

Figure 11B. Daily number of delta smelt collected at the SWP and CVP salvage facilities between March and July 2000. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days as listed in figure 6C.

Figure 11C. Daily average water temperature at the SWP Harvey O. Banks pumping plant between March and July 2000. The pumping plant receives water from Clifton Court Forebay and these data are used to indicate water temperatures in the Forebay. Daily values are presented for four periods described in the Methods and Materials Section. The x-axis values are Julian days.

Figure 12A. Mean ± S.D. calculated inflow rates into Clifton Court Forebay at times of diversion during four periods between March and July 2001 – 2004. Methods and variables for calculating inflow rates are provided in the methods. Periods are listed under Figure 12C and described in the Methods and Materials section.

Figure 12B. Mean ± S.D. calculated hours of inflow into Clifton Court Forebay at times of diversion during four periods between March and July 2001 – 2004. Periods are listed under Figure 12C and described in the Methods and Materials section.

Figure 12C. Percentage of days the Clifton Court Forebay diversion gates were opened during four periods between March and July 2001 – 2004. Periods are described in the Methods and Materials section.

Figure 13. Percentage of young delta smelt estimated to occur in the Southeast Delta after the first four 20-mm surveys versus mean daily Delta outflow from mid-March to mid-May. The area within the circle on the inset diagram generally indicates the Southeast Delta. Year labels are provided for each data point and bold labels indicate years when the authorized incidental take level for delta smelt was exceeded (see Table 2).

Figure 14. Conceptual diagram listing the regions, events, key conditions, and timeframe of events thought important to the processes leading to extreme salvage events of young delta smelt at the SWP. Text listed in the right-hand boxes provide brief descriptions of the steps in the overall scenario thought to result in an extreme salvage event.