United States Department of the Interior

FISH AND WILDLIFE SERVICE
San Francisco Bay-Delta Fish and Wildlife Office
650 Capitol Mall, 8th Floor
Sacramento, California 95814

August 17, 2012

Technical Staff Comments to the State Water Resources Control Board re: the Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan

The U.S. Fish and Wildlife Service (Service) submits the following written comments in response to the questions posed by the State Water Resources Control Board (Board) for discussion at the low-salinity zone and pelagic fish workshops that support the Comprehensive (Phase 2) Review and Update to the Bay-Delta Plan. The following discussion contains additional scientific and technical information that was not addressed in the 2009 Staff Report or the 2010 Delta Flow Criteria Report. It also provides general background information related to delta smelt and ecosystem changes in the low salinity zone (LSZ). These comments also supplement the Department of Interior's April 25, 2012 comments to the Board regarding the Comprehensive Review and Update of the Bay-Delta Plan. Overall, we make the following key points to supplement our April 25th key points:

- We suggest that the Board model and evaluate a range of flow objectives that could be incorporated in the Water Quality Control Plan (WQCP). Our suggested evaluation should include flow objectives that are likely to improve habitat conditions for delta smelt, longfin smelt, and other native estuarine biota and put the ecosystem on a path toward recovery.

- For adult delta smelt, negative Old and Middle River (OMR) flows contribute to entrainment risk during spawning migrations.

- For age-0 delta smelt OMR flows are a suitable index of the hydrodynamic conditions that *drive* entrainment loss.

- The Service recognizes that multiple factors have contributed to the substantial long-term degradation of the LSZ. Nonetheless, Sacramento-San Joaquin Delta (Delta) outflow remains an extremely important aspect of LSZ habitat suitability for delta smelt, particularly during low flow periods.

Background

The Service uses the Department of Fish and Game's (DFG) Fall Midwater Trawl (FMWT) index as our primary indicator of delta smelt status. The FMWT indices date to 1967. The 1967 index for delta smelt was 414. Since that time, the indices have occasionally reached new record lows reflecting the delta smelt decline that has been reported previously (Moyle et al. 1992;

Bennett 2005; Sommer et al. 2007), but the frequency of occurrence of new record lows increased notably in the last decade. The time series of new lows in the delta smelt FMWT indices is as follows: 1969 index = 315, 1983 index = 132, 1985 index = 110, 1994 index = 102, 2004 index = 74, 2005 index = 26, 2008 index = 23, and 2009 index = 17. The delta smelt is an estuarine-dependent species (Moyle et al. 1992; Bennett 2005). Estuaries are places where marine water meets and mixes with sources of freshwater. Central San Francisco Bay to the Golden Gate Bridge is the seaward boundary of the San Francisco Estuary (Kimmerer 2004). Here, the estuary's waters are highly contiguous with the Pacific Ocean and thus they are typically about the same salinity as the open Pacific coast. The Delta is the landward region of the San Francisco Estuary. Most of the Delta is maintained as a freshwater environment to support water diversions that serve numerous agricultural, industrial, and municipal uses. Ecologically, the estuary extends upstream to the limit of tidal influence in the Sacramento and San Joaquin watersheds. However, the upstream limit of tidal influence depends on the magnitude of river flow and the strength of individual tides. The Board has provided a legal boundary for the Delta. It extends from Chipps Island in the west to the City of Sacramento on the Sacramento River and to Vernalis on the San Joaquin River.

The Service's comments focus on delta smelt and their interactions with Delta flows, including south Delta flows and the LSZ. Therefore, these comments are relevant to both the Board's upcoming Low Salinity Zone and the Pelagic Fishes workshops. The function of the LSZ is extremely important to delta smelt. The LSZ is a constantly moving habitat that frequently transcends the Board's legal boundaries (i.e., the Delta or Suisun Marsh). The LSZ is the primary freshwater-seawater mixing zone in the San Francisco Estuary (Kimmerer 2004). It has been defined differently by different authors, but Kimmerer (2004) reported that the historical chlorophyll maxima in the upper estuary occurred over a salinity range of about 0.5 to 6.0 psu[1], which represents an approximate definition of the LSZ. It is important to note however that a definition of a lower salinity bound near 0.5 psu is not based on fish distributions. It is based on the ability to distinguish oceanic salt from salts in agricultural return water flowing into the Delta based on measurements of specific conductance. Delta smelt are fairly freshwater tolerant fishes (Swanson et al. 2000). They do not recognize 0.5 psu as a boundary, and can sometimes be collected to the limits of tidal excursion and at salinities down to circa 0.1 psu when other water quality attributes like turbidity and temperature are suitable (Feyrer et al. 2007; 2011; Kimmerer et al. 2009). The upper bound of salinity chosen to represent the LSZ has typically been based on collection of the organisms that were the target species of individual studies. Delta smelt are somewhat tolerant of brackish water, but rarely captured at salinities higher than 10 psu. Thus, delta smelt can be considered to complete its life cycle in the LSZ and some fresher water habitats that are *highly contiguous* with the 'official' freshwater boundary salinities that scientists have proposed for the LSZ. The following sections crosswalk the life cycle of delta smelt with Delta flows.

[1] psu is 'practical salinity units' which are equivalent to parts per thousand

Migrating and Spawning Adults (~ December through March)

Adult Entrainment

Adult delta smelt are entrained during spawning migrations (Grimaldo et al. 2009a; Sommer et al. 2011). Their spawning migrations occur during the winter when precipitation increases the freshwater flow and turbidity in the Delta. Salvage of adults has occurred mainly from late December through March (Kimmerer 2008; Grimaldo et al. 2009a). For migrating adults, the risk of entrainment is influenced by flow cues and turbidity in the south Delta.

The Distribution of Spawning Delta Smelt

Delta smelt probably spawn in shallow, sandy habitats (Bennett 2005). This hypothesis is supported by laboratory experiments and by delta smelt's close evolutionary relationship with the marine surf smelt, which spawns in the intertidal habitat of Pacific coast beaches and embayments. Shallow, sandy habitats occur throughout the Delta. Given suitable conditions, delta smelt can spawn successfully throughout the Delta, Suisun Marsh, and as far seaward as the Napa River, but this full range of potential spawning habitats is not available every year (Hobbs et al. 2005; 2007).

Snapshots of adult delta smelt distribution are available via the Spring Kodiak Trawl Survey (SKTS) (www.dfg.ca.gov/delta/; Figure 1). The survey is conducted once per month from January-May and has been occurring since 2002. During the first nine years of the SKTS, most delta smelt have been collected in Montezuma Slough (36%) and the Cache Slough region (32%); 6% have been collected in the Delta at trawl stations numbered 809 and higher, i.e., the San Joaquin River 'half' of the Delta (Figure 2)[2]. Thus, the Service notes that most adult delta smelt have not been collected from locations where they would be expected to have a high risk of entrainment (i.e., stations numbered 809 and higher). However, the Service also notes that adult delta smelt have been collected in the lower San Joaquin River at or upstream of station 809 every year that the SKTS has been conducted and that the ability of the survey to detect delta smelt appears to be dependent on population abundance (Figure 3). Note that both Kimmerer (2008; 2011) and Miller (2011) have assumed the SKTS is essentially 100% efficient for collecting delta smelt. This assumption is mainly for computational simplicity. However, this assumption of 100% gear efficiency is probably not strictly correct because (1) the ability to detect delta smelt in the San Joaquin River is contingent upon overall abundance, and (2) delta smelt are observed in salvage even when they are not observed in south Delta trawls (Figure 4).

2 Percentages calculated from the data shown in Figure 2. The region of the Delta encompassed by trawl stations numbered 809 and higher is considered by the Service to represent a region of elevated risk of entrainment based on Kimmerer and Nobriga (2008).

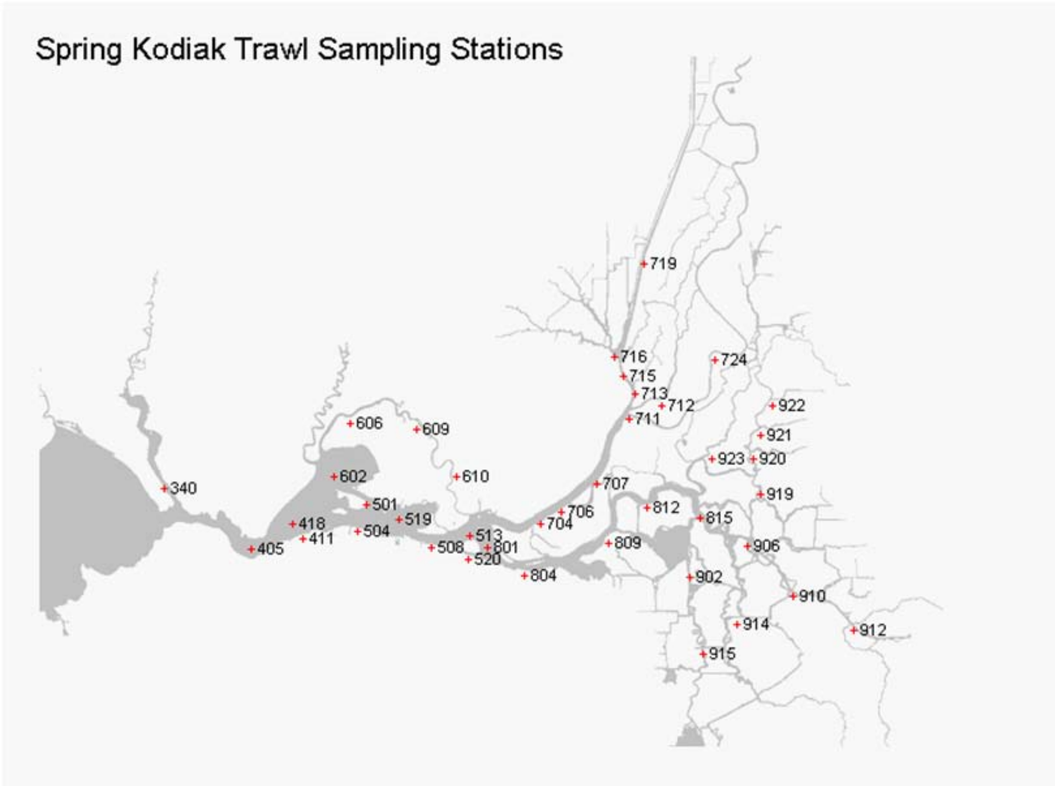

Figure 1. Map of the Department of Fish and Game's Spring Kodiak Trawl Survey sampling stations. Source: http://www.dfg.ca.gov/delta/data/skt/skt_stations.asp; August 30, 2011.

Sum of Catch	Column Labels																					
Row Labels	340	405	411	418	501	504	508	513	519	520	602	606	609	610	704	705	706	707	711	712	713	715
2002	1	3	2	3	1	0	5	13	3	17	8	257	256	76	17		26	3	41	1	8	6
2003	0	0	5	14	8	5	13	12	17	0	21	42	13	24	13		23	54	2	13	39	125
2004	1	0	0	3	6	2	0	8	15	23	7	170	360	1	98		25	15	0	0	4	6
2005	3	0	1	3	18	4	4	2	11	0	1	92	128	10	34		34	4	1	0	6	20
2006	34	2	5	1	8	5	3	3	8	2	1	49	10	4	1		0	1	0	0	0	18
2007	0	0	0	0	0	0	1	8	21	0	1	53	29	3	40		16	3	1	0	1	13
2008	0	1	0	0	4	1	4	3	4	0	1	4	3	0	63	4	19	11	0	0	2	9
2009	0	0	0	0	0	0	1	2	13	0	0	64	34	3	35		99	19	0	0	0	0
2010	0	0	0	1	0	0	2	3	3	0	1	64	37	1	27		11	2	0	0	5	18
Grand Total	39	6	13	25	45	17	33	54	95	42	41	795	870	122	328	4	253	112	45	14	65	215

Row Labels	716	719	724	725	801	804	809	812	815	902	906	910	912	914	915	919	920	921	922	923	Grand Total
2002	23			1	19	22	44	14	5	4	6	0	0	3	2	1	0	2	2	0	895
2003	173			7	8	1	28	4	2	0	3	0	0	1	0	0	0	0	2	9	681
2004	2			1	3	54	80	29	8	2	21	1	0	2	0	2	1	0	1	0	951
2005	51	42	1	0	1	0	2	4	2	2	1	0	0	0	0	0	2	0	0	0	484
2006	9	102	0		1	2	3	0	1	3	0	0	0	1	0	2	1	0	2	0	282
2007	12	187	0		0	3	6	0	0	0	0	0	0	0	0	0	0	0	0	0	398
2008	11	122	0		0	0	1	2	1	0	0	0	0	0	0	0	1	0	0	0	271
2009	3	459	0		0	0	11	0	1	0	0	0	0	0	0	0	0	0	1	0	745
2010	9	116	0		0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	303
Grand Total	293	1028	1	9	32	82	178	53	20	11	31	1	0	7	2	5	5	2	8	9	5010

Figure 2. Cross-tabular summary of adult delta smelt catch by survey station in the Spring Kodiak Trawl Survey, 2002-2010. The catch data were only summarized for surveys that sampled a full array of stations, i.e., no special surveys of only particular regions of the sampling grid. Empty cells show where no sampling occurred at a given station. Stations considered by the Service to potentially be within the typical hydrodynamic influence of the Projects' south Delta water diversions are shaded in light blue. See Figure 1 for locations of SKTS sampling stations.

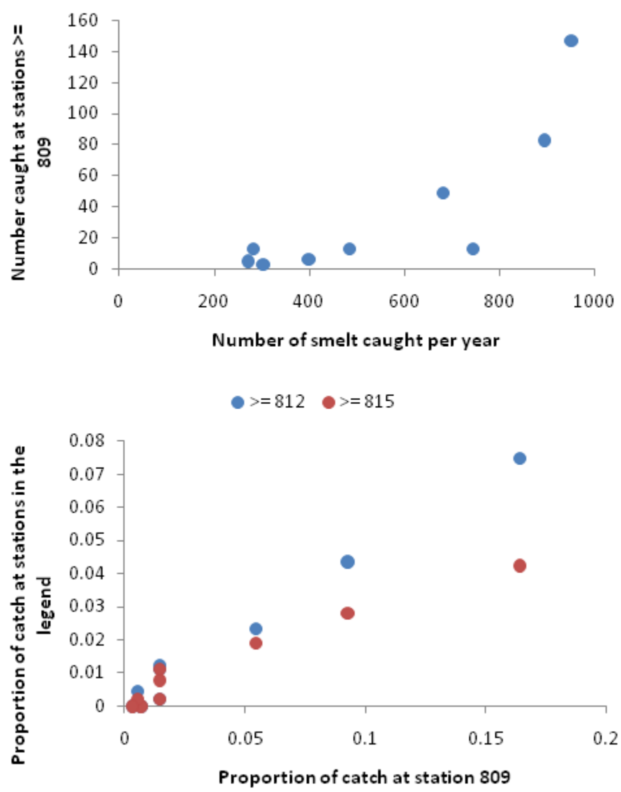

Figure 3. Top Panel: Scatterplot of number of delta smelt caught at all SKTS stations versus the number collected from stations numbered 809 and higher. Bottom panel: Scatterplot of the proportion of total SKTS catch collected from station 809 near Jersey Point on the San Joaquin River and the concurrent proportions collected at the next two stations located upstream, 812 (blue circles) and 815 (red circles). See Figure 1 for locations of sampling stations.

The entrainment of delta smelt into the State Water Project (SWP) and Central Valley Project (CVP) facilities is strongly influenced by Delta flows. Total entrainment is calculated based upon estimates of the number of fish salvaged[3] (Kimmerer 2008). However, these estimates are indices - most entrained fish are not observed (Table 1), so most of the fish are not salvaged and therefore do not survive. Many, if not most, of the delta smelt that do reach the fish facilities likely die due to predation and handling stress (Bennett 2005). Pre-screen loss (PSL) due to entrainment into the SWP and CVP facilities, is an additional cause of mortality for delta smelt. The PSL in Clifton Court Forebay was estimated to be up to 100 percent during recent studies that used captive bred fish (Castillo et al. 2010).

3 See Brown et al. (1996) for a description of fish salvage operations.

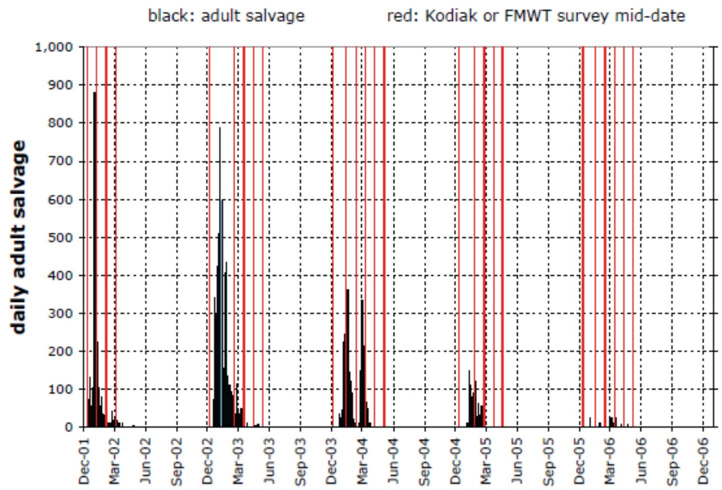

Figure 3 Daily adult salvage and mid-dates for Kodiak and Fall Midwater Trawl (FMWT) surveys

Figure 4. Copy of Figure 3 from Miller (2011). The vertical red lines denote dates of Spring Kodiak Trawl Surveys when very low numbers of delta smelt were collected from stations numbered 809 or higher (Figure 2). The black histogram data show the timing and magnitude of adult delta smelt salvage at the Projects' fish facilities as a continuous time series for December 2001-2006.

Old and Middle Rivers are distributary channels of the San Joaquin River. The export of water from the Delta can cause the tidally filtered, or "net" flows in these channels to move "upstream". This occurs because water removed by SWP's Banks Pumping Plant and CVP's Jones Pumping Plant is back-filled by tidal and river flows. This phenomenon is mathematically depicted as negative flow. Negative OMR flows are often associated with adult delta smelt entrainment (Kimmerer 2008; Grimaldo et al. 2009a), but there is no particular OMR flow that assures entrainment will or will not occur (Figure 5 to 8). The net OMR flows indicate how strongly the tidally averaged flows in these channels are moving toward Banks and Jones. Thus, it is possible the net flows themselves are the mechanism that increases entrainment risk for delta smelt. However, high exports can also lead to the loss of ebb tide flows in Old and Middle Rivers (Gartrell 2010), so altered tidal flows are a second, covarying mechanism that could increase delta smelt's risk of entrainment.

Table 1. Factors affecting delta smelt entrainment and salvage.

	Adults	Larvae < 20 mm	Larvae > 20 mm and juveniles
Predation prior to encountering fish salvage facilities[a]	89.9-100%	unquantified	99.9%[b]
Fish facility efficiency (based on Kimmerer 2008)	Limited data indicate an efficiency of about 13 percent for the CVP facility; SWP efficiency averaged an estimated 50%, but actual efficiency was related to operating conditions (Castillo et al. in review)	~ 0 percent	Likely < 13 percent at any size; << 13 percent at less than 30 mm; estimated at 24% and 30% in two experiments in June 2009 (Castillo et al. in review)
Efficiency of collection screens	~ 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 Handling, trucking and release back into the Delta[c]	Controlled conditions trial (2005): 94% were recovered from the Skinner fish facility; 87% survived for 48 hrs in a holding tank after the experiment Empirical salvage trial (2006): 90% were recovered from the Skinner fish facility; 78% survived for 48 hrs in a holding tank after the experiment	0 percent	Controlled conditions trial (2005): 73% were recovered from the Skinner fish facility; 37% survived for 48 hrs in a holding tank after the experiment Empirical salvage trial (2006): 89% were recovered from the Skinner fish facility; 58% survived for 48 hrs in a holding tank after the experiment

[a]Pre-screen loss (Castillo et al. in review)
[b]Based on one release experiment (Castillo et al. in review)
[c]Unpublished report sent by Jerry Morinaka (CDFG) on July 13, 2011; numbers reported do not include predation at release sites

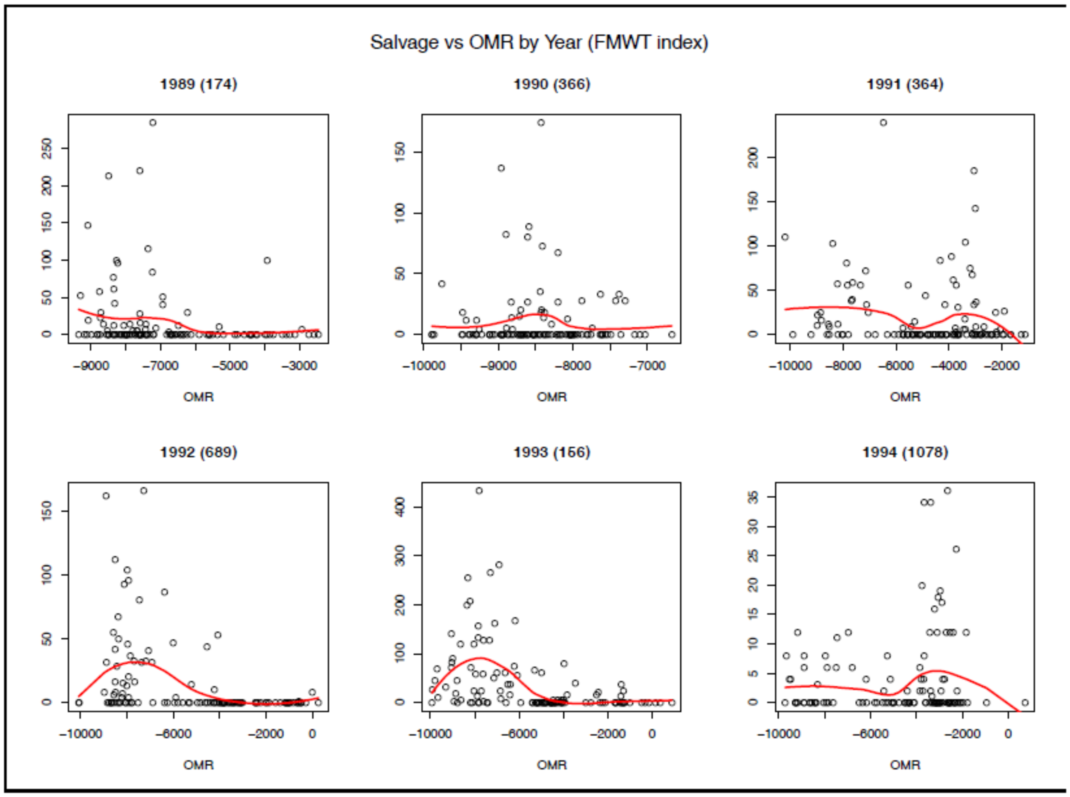

Figure 5.Scatterplots of net daily flow in Old and Middle rivers versus daily delta smelt salvage for the months December-March, 1989-1994 (December data are 1988-1993). The Fall Midwater Trawl (FMWT) abundance index for delta smelt that immediately precedes the salvage data in time is shown at the top of each panel in parentheses. The red lines are splines showing the empirical trend in the data. Source: Ken Newman (Stockton Fish and Wildlife Office)

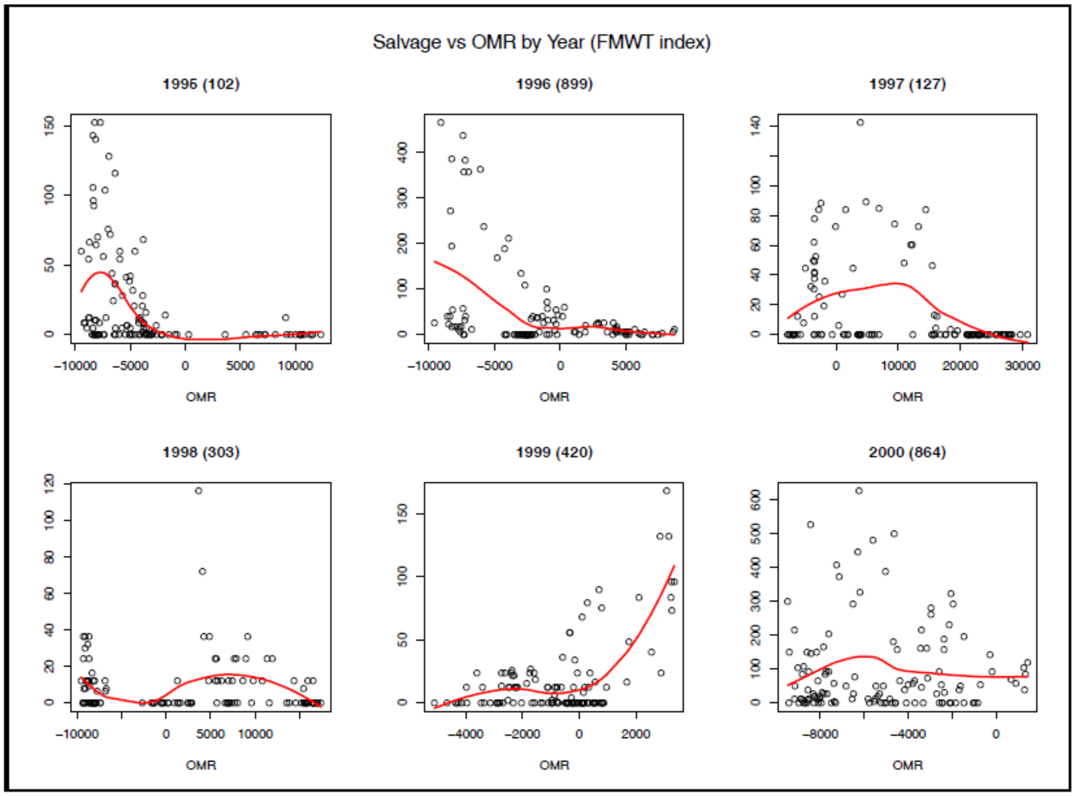

Figure 6. Scatterplots of net daily flow in Old and Middle rivers versus daily delta smelt salvage for the months December-March, 1995-2000 (December data are 1994-1999).The Fall Midwater Trawl (FMWT) abundance index for delta smelt that immediately precedes the salvage data in time is shown at the top of each panel in parentheses. The red lines are splines showing the empirical trend in the data. Source: Ken Newman (Stockton Fish and Wildlife Office)

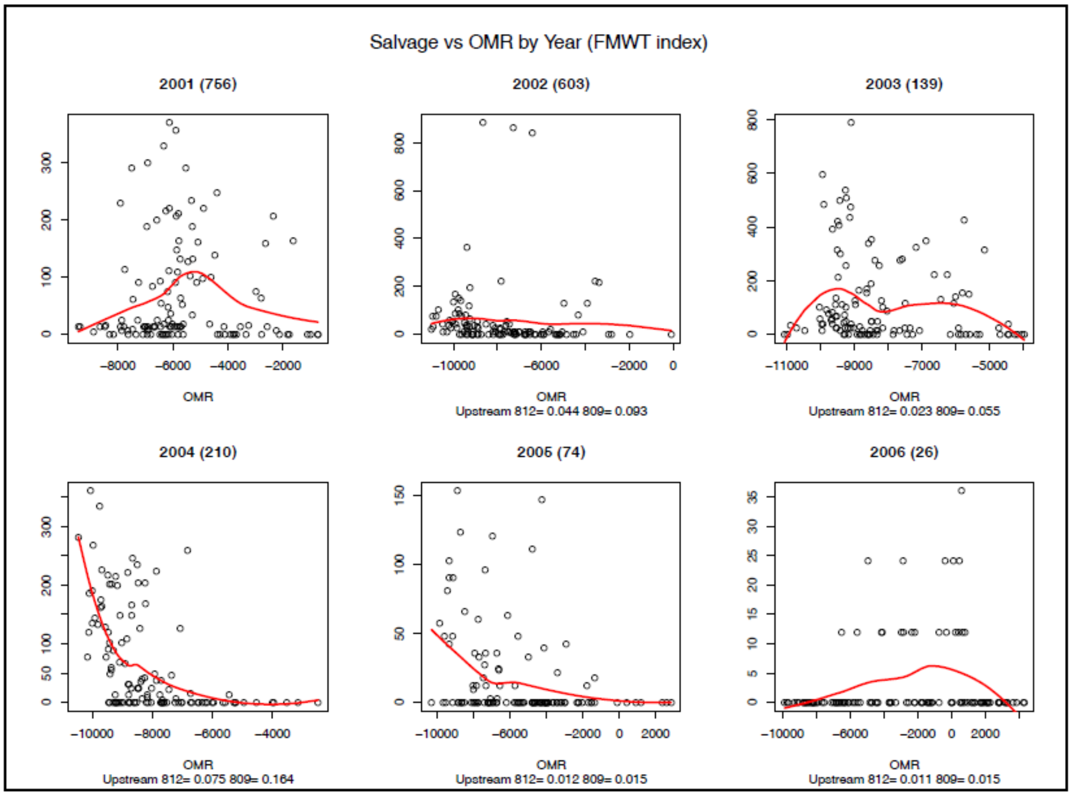

Figure 7. Scatterplots of net daily flow in Old and Middle rivers versus daily delta smelt salvage for the months December-March, 2001-2006 (December data are 2000-2005). The Fall Midwater Trawl (FMWT) abundance index for delta smelt that immediately precedes the salvage data in time is shown at the top of each panel in parentheses. The red lines are splines showing the empirical trend in the data. Source: Ken Newman (Stockton Fish and Wildlife Office)

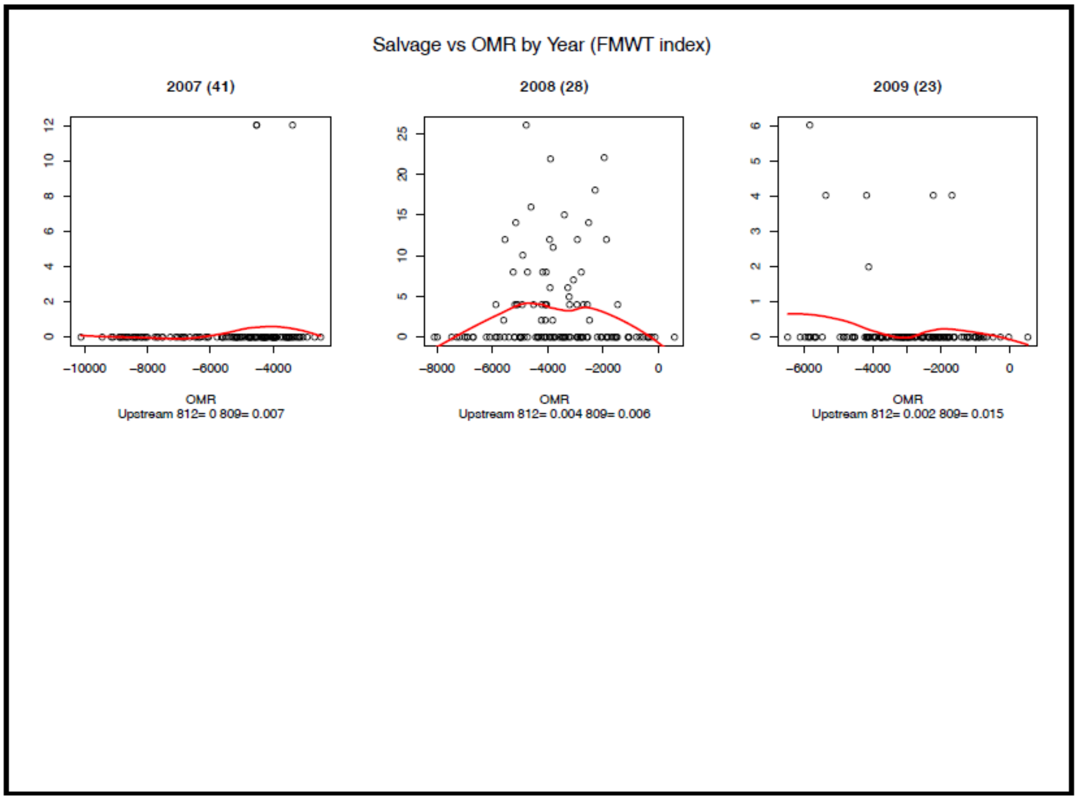

Figure 8. Scatterplots of net daily flow in Old and Middle rivers versus daily delta smelt salvage for the months December-March, 2007-2009 (December data are 2006-2008). The Fall Midwater Trawl (FMWT) abundance index for delta smelt that immediately precedes the salvage data in time is shown at the top of each panel in parentheses. The red lines are splines showing the empirical trend in the data. Source: Ken Newman (Stockton Fish and Wildlife Office)

The empirical shape of the associations between the geographic distribution of the 2 psu salinity isohaline (X2; Jassby et al. 1995), OMR, turbidity and adult delta smelt salvage normalized by the FMWT is shown in Figure 9. Normalized delta smelt salvage is correlated in a nonlinear way with X2. An interpretation of this is that the intermediate river flow or X2 conditions are associated with the highest salvage because flows are high enough to disperse turbidity around the Delta, but not so high that most delta smelt are distributed seaward of the Delta. At higher X2 (lower flows) the south Delta is infrequently turbid enough to attract delta smelt. Figure 9 shows that even when X2 and south Delta turbidity are accounted for, there is still no OMR flow that assures delta smelt entrainment will or will not occur. The predicted relationship is a smooth, accelerating function with increasing normalized salvage as OMR flow becomes more negative.

Full Model

```
*** Generalized Additive Model ***

Call: gam(formula = Sal.pfmwt ~ s(O.M.flow) + s(CCFNTU) + s(X2),
family = gaussian,
               data = biop, na.action = na.omit, control = list(epsilon =
0.001,
               bf.epsilon = 0.001, maxit = 50, bf.maxit = 10, trace = F))
Deviance Residuals:
      Min        1Q      Median       3Q       Max
 -0.6108443 -0.1510043 -0.05404843 0.0677257 4.971304

(Dispersion Parameter for Gaussian family taken to be 0.1261855 )

   Null Deviance: 355.2256 on 2060 degrees of freedom

Residual Deviance: 258.4277 on 2047.999 degrees of freedom

Number of Local Scoring Iterations: 1

DF for Terms and F-values for Nonparametric Effects

          Df Npar Df  Npar F        Pr(F)
(Intercept)  1
s(O.M.flow)  1      3 22.77489 1.698641e-014
  s(CCFNTU)  1      3 31.86953 0.000000e+000
      s(X2)  1      3 29.17776 0.000000e+000
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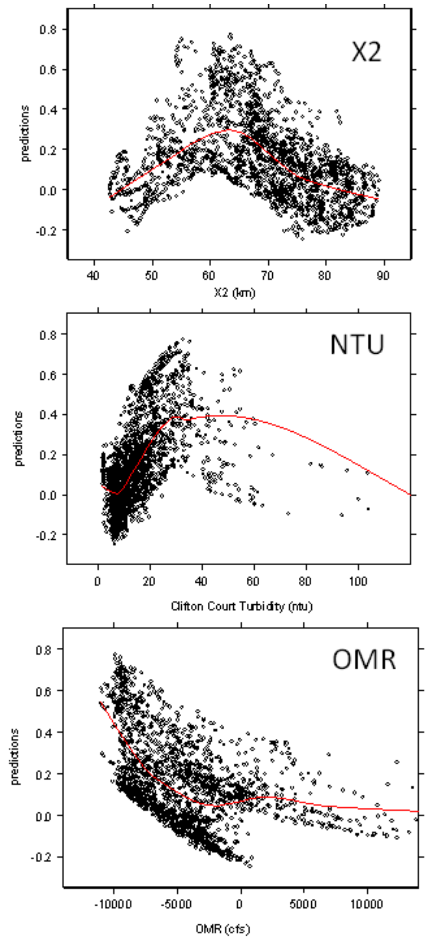

Figure 9. S-Plus output of a generalized additive model (GAM) testing for effects of X2, turbidity at Clifton Court Forebay (Nephelometric Turbidity Units; NTU), and net flow in Old and Middle rivers (OMR) on adult delta smelt salvage normalized by the preceding Fall Midwater Trawl abundance index. The text on the left shows the model code, the model fit is 1-(residual deviance/ null deviance). Thus, the model explains 1-(258/355) = 0.273 of the variation in normalized salvage. The column Pr(F) shows the probability of no trend in the data – these P-values are all much less than a standard 0.05 threshold due to the non-random trends in the data but also due somewhat to the very large sample size (> 2000 data points). The model predictions are shown in the panels on the right. The scatter in each panel is due to the interacting effects of the other two variables. The red lines are splines showing the empirical trends in the predictions. Source: Lenny Grimaldo (Reclamation Bay-Delta Office).

The entrainment risk of larval delta smelt has been estimated quantitatively with particle tracking models (PTMs), in particular, the Department of Water Resources' (DWR) DSM-2 PTM (Kimmerer and Nobriga 2008; Kimmerer 2008). The entrainment risk for adult delta smelt actively migrating into the lower San Joaquin River cannot be quantitatively summarized with current PTMs[4]. Even without a vetted quantitative modeling tool, PTM data provide the best available indication of the hydrodynamic influence on adult delta smelt entrainment risk given

4 DSM-2's particle tracking model can generate upstream particle movements when the particles are given simple tidal surfing behavior (Sommer et al. 2011). A PTM that may more accurately characterize delta smelt spawning migrations is being developed by RMA.

two conditions: (1) turbid water is present in Old and Middle rivers, and (2) adult delta smelt migrate into the San Joaquin River. This is likely true because the particle tracking modeling shows the extent of the Projects' hydrodynamic influence on the Delta and how that influence changes as river flows and exports vary (Kimmerer and Nobriga 2008).

Miller (2011) assumed that because migrating delta smelt actively swim, they would not be vulnerable to OMR flows and therefore scaling delta smelt loss to OMR flows would result in loss estimates that were persistently biased high. Kimmerer (2011) disagreed, noting that there were not automatically any environmental cues that would signal migrating delta smelt to stop swimming toward the pumps. The Service agrees with Kimmerer (2011) that Miller (2011) was confounding bias with statistical uncertainty. Bias occurs when an estimate is always too high or too low, whereas statistical uncertainty is variation around an estimate that is sometimes too high and sometimes too low.

Migrating delta smelt are actively swimming, likely using a combination of their own swimming behaviors and tidal currents to move upstream against the net Delta outflow (e.g., Sommer et al. 2011). If they encounter an adverse environmental cue in the south Delta, such as water that is not sufficiently turbid, they might adjust their behavior and stop short of being entrained. However, if they do not perceive such a cue, they may keep migrating and move south down Old and Middle rivers *faster or slower* than the net flow. Note that the occurrence of a spawning migration itself demonstrates that delta smelt can move faster than (and against) the net flow in the estuary. Thus, the link between adult delta smelt entrainment and OMR flows is more an issue of statistical uncertainty (sometimes their southward flux is slower than OMR flow and sometimes it is faster) than bias (always slower or higher).

OMR flows between -2000 and -5000 cfs minimize the Projects' hydrodynamic influence in the San Joaquin River (mainstem). Extending that hydrodynamic influence to the mainstem of the San Joaquin River decreases the likelihood that delta smelt can reproduce successfully in the expanses of shallow sandy habitats that occur from downstream of the City of Stockton to the City of Antioch.

The flow cues that contribute to adult delta smelt entrainment have increased over time. Winter exports first exceeded 400 thousand acre-feet (TAF)/month in March of 1972 (Figure 10). Since that time, monthly winter exports have seldom been less than that. Winter exports first exceeded 600 TAF/month in January 1978 and 700 TAF in January 1993. The frequency that monthly winter exports has exceeded 600-700 TAF has generally increased, though they were well below this level during the very wet middle of the 1990s and during the past few years, likely due to a combination of drought and export restrictions for fishery protection. Monthly winter exports have not dropped below 200 TAF since March of 1997.

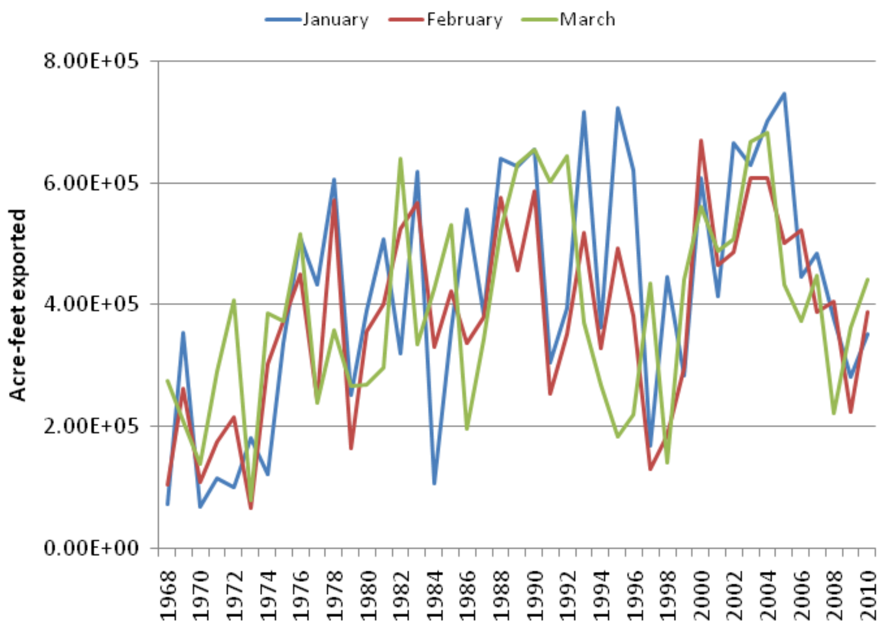

Figure 10. Time series of winter exports (CVP and SWP combined), 1968-2010. Source: DAYFLOW database

The population-level effects of winter exports via delta smelt entrainment vary; delta smelt entrainment can best be characterized as having a sporadically significant influence on population dynamics. Kimmerer (2008) estimated that annual entrainment of the adult delta smelt population ranged from approximately four percent to 50 percent per year from 2002-2006. He revised these estimates downward slightly (Kimmerer 2011) following a rebuttal by Miller (2011) (Table 2). Major population declines during the early 1980s (Moyle et al. 1992) and early 2000s (Sommer et al. 2007) were both associated with hydrodynamic conditions that increased delta smelt proportional entrainment losses. However, currently published analyses of long-term associations between delta smelt salvage and subsequent abundance do not support the hypothesis that entrainment is driving population dynamics year in and year out (Bennett 2005; Manly and Chotkowski 2006; Kimmerer 2008; Maunder and Deriso 2011).

Table 2. Estimates of the proportion of the adult delta smelt population entrained at Banks and Jones pumping plants.

Year	Kimmerer (2008) estimate	Kimmerer (2011) correction
1995	18	14
1996	3	2

1997	3	2
1998	1	0.76
1999	3	2
2000	5	4
2001	5	4
2002	16	12
2003	22	17
2004	19	14
2005	9	7
2006	3	2

Fig. 8. Estimates of the adult abundance with and without adult entrainment (top panels) and the ratio of adult abundance without adult entrainment to that with adult entrainment (bottom panels, *y* axis limited to show details) from the lowest AIC_c model (left panels) with Ricker survival from juveniles to adults and a Beverton–Holt stock–recruitment relationship and the alterative model (the model that has the fewest covariates and the AIC is less than two AIC units greater than the lowest AIC model) (right panels).

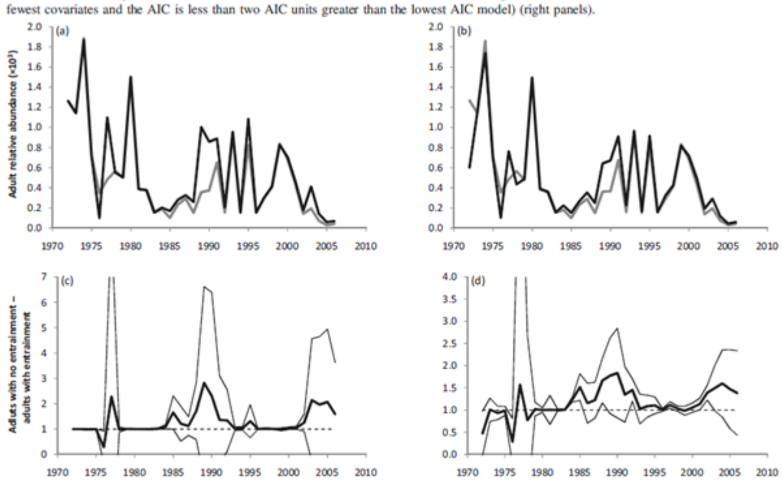

Figure 11. Copy of Figure 8 from Maunder and Deriso (2011). The top panels show predicted time series of delta smelt abundance based on two variations of life cycle models developed by the authors; black lines are predicted abundance without adult entrainment, gray lines are predicted abundance with adult entrainment.

The bottom panels depict the same data as relative deviations. "AIC_c" in the authors' caption refers to the Akaike Information Criterion, an indicator of the relative fit of alternative statistical models.

The evidence for a negative effect of adult entrainment on delta smelt population dynamics is supported by Maunder and Deriso's (2011) Figure 8, reproduced here as Figure 11 and Kimmerer's (2011) Figure 3, reproduced here as Figure 12. In the Maunder and Deriso simulations, adult entrainment had the sporadically significant effect mentioned above. Entrainment did not drive the delta smelt decline in their simulations, but it sometimes exacerbated it (Figure 11). Kimmerer developed a simulation model which showed that, given delta smelt's present-day, essentially density-independent population dynamics, an average entrainment loss of 10% would cause a 10-fold reduction in abundance and it would probably not be discernable using correlation-based statistics (Figure 12). In conclusion, the scientific evidence available to the Service is inconclusive about the *long-term* population-level importance of adult entrainment. However, there is new evidence based on model simulations that in years with comparatively negative OMR flows, adult entrainment can cause the population to decline (Kimmerer 2011; Maunder and Deriso 2011).

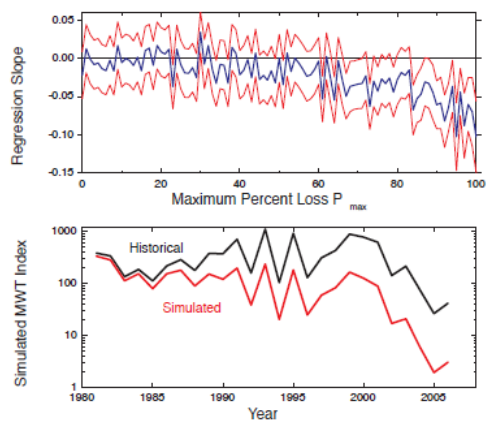

Figure 3 Results of simulation of ability to detect export loss through regression analysis. Upper panel: individual simulation results giving the slope (thick blue line) and 95% confidence limits (thin red lines) for regressions of the stock-recruit index on southward OMR flow. Lower panel: trajectory of the fall midwater trawl index (upper line) and the same index with a 20% P_{max} value imposed for the entire time series (mean P_L ~10%). This is for illustration only (see text), and does not imply anything about the cause of the decline in delta smelt.

Figure 12. Copy of Figure 3 from Kimmerer (2011). In the author's caption, P_{max} refers to a maximum proportion of the delta smelt population assumed to be entrained by the Projects and P_L refers to an average proportional entrainment loss of 10% of the population. The bottom panel shows how much this level of entrainment loss would cause the delta smelt population to decline in the absence of density-dependence. Note (1) the log-scale on the y-axis of the bottom panel; (2) the author made the case, similar to the Service, that compensatory density-dependence is unlikely to be an important regulator of delta smelt population growth rate due to its very low abundance. The top panel shows that a standard regression analysis searching for an entrainment effect on delta smelt abundance would be unlikely to find one unless the entrainment loss was exceptionally high (> 60% of the entire population).

Adult entrainment and south Delta turbidity

Adult delta smelt are strongly associated with turbid water (Feyrer et al. 2007; 2010; Miller 2011; Figure 13). Thus, if turbid water is present in the south Delta then delta smelt are more likely to inhabit that water and be more vulnerable to entrainment. Miller (2011) noted that south Delta waterways often are less turbid than regions to the north and west, a conclusion which had been reported several times in prior studies, albeit for different times of year (Nobriga et al. 2005; Feyrer et al. 2007; Nobriga et al. 2008).

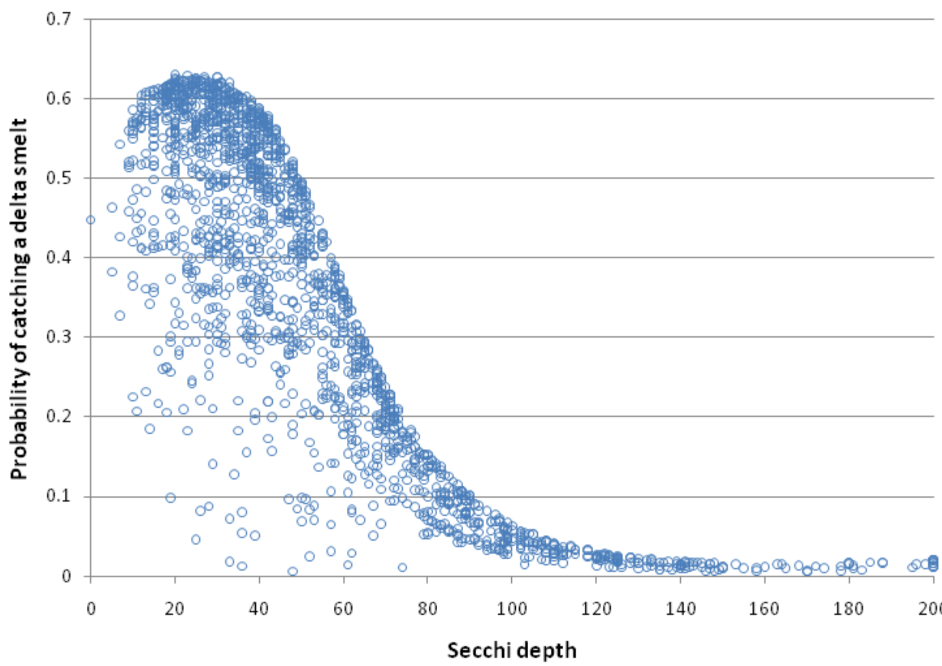

Figure 13. Scatterplot showing the predicted probability of capturing a delta smelt in the Spring Kodiak Trawl Survey relative to water transparency measured as Secchi disk depth in cm. The predictions are based on a binomial generalized additive model as was previously done by Feyrer et al. (2007) for the Fall Midwater Trawl and Nobriga et al. (2008) for the Summer Townet Survey. The scatter shows the variation in predictions caused by the interaction of two other variables (specific conductance and water temperature). In other words, probability of capture can be low in turbid water if salinity or temperature are too high, but probability of capture will never be high where turbidity is low, regardless of the other variables.

Despite the generality that the water in the south Delta is often comparatively clear, turbid conditions can occur there – particularly during winter storms (Grimaldo et al. 2009a). The longest running turbidity sensor in the south Delta is at the intakes of Clifton Court Forebay (CCF). The data from this sensor were used by Deriso (2011) to develop an OMR flow + turbidity model to predict adult delta smelt entrainment events. Figure 14 shows the trend in CCF turbidity for the winter (December-March, 1988-2009). This time period is coincident with the time period of our adult delta smelt salvage analysis, presented below, which was done to expand on that of Deriso (2011). The turbidity at CCF declined during the 1987-1992 drought, then increased to a peak in 1997. The turbidity declined after 1997, but generally remained elevated relative to 1987-1996 levels, during 1998-2006. Turbidity was low in 2007 and 2009, but was fairly high again in 2008. Thus, there has not been a long-term unidirectional trend in turbidity at CCF during the winter. This indicates that comparably turbid conditions can be expected to keep occurring into the future. This contrasts with the south Delta regionally, which has been shown to have trended toward higher water transparency in the summer-fall (Feyrer et al. 2007; Nobriga et al. 2008). The trends in south Delta water transparency for the spring have not been reported in the literature, but they are presented in the larval-juvenile entrainment section of these comments.

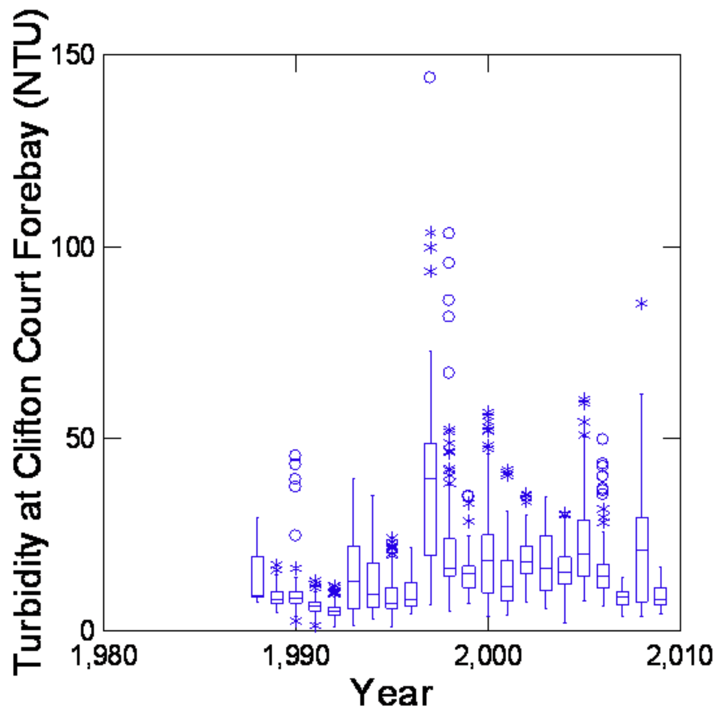

Figure 14. Time series of turbidity measurements at Clifton Court Forebay for the months of December-March (beginning December 1988 and ending March 2009). NTU = nephelometric turbidity units. The box plots are as follows: rectangular box = interquartile range of observations; horizontal line in the box = median; vertical lines = 95% confidence intervals; open circles and asterisks = individual data points the Systat software program determined were "outliers".

Deriso (2011) proposed a statistical model to guide Project operations during winter. The model was developed to predict the combinations of OMR flow and CCF turbidity that resulted in large delta smelt salvage events. The model was developed using daily OMR flow and an average turbidity for the three days prior to the OMR flow estimate (Figure 15). The model predicts the median adult delta smelt salvage normalized to the prior FMWT abundance index.

The Service compiled a dataset based on historical salvage normalized to the prior FMWT, OMR flow and CCF turbidity and explored it using several alternative time scales. The purpose of this analysis was to determine how consistent turbidity and OMR thresholds like those proposed by Deriso (2011) were across time scales.

- daily – mimics Deriso's analysis
- 7-day – a typical management time scale, e.g., the Water Operations Management Team meets weekly to review fishery and operations data
- 14-day – the OMR flow averaging period used in the Service's December 2008 OCAP Biological Opinion
- 24-day – the estimated average migration time for delta smelt to migrate from Chipps Island to Banks (Sommer et al. 2011)
- 30 or 31-day – another time scale included in some previous OMR-salvage relationships including those submitted by DWR during the 2008 consultations with the Service and National Marine Fisheries Service (NMFS)

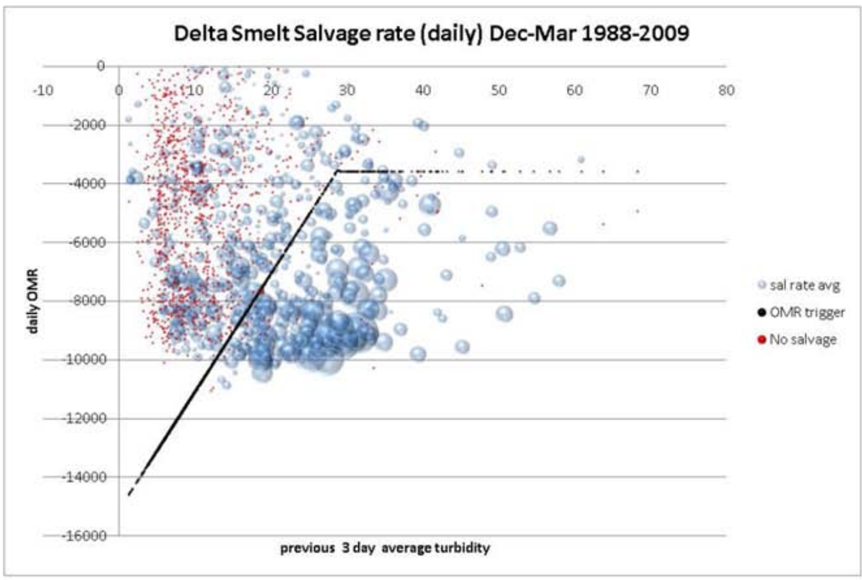

Figure 15. Copy of Figure 3 from Deriso (2011; January 28, 2011 Declaration in support of Plaintiffs' request for injunctive relief in the delta smelt consolidated cases; court document # 772). Bubble plot of average turbidity (NTU at Clifton Court Forebay) for three days prior to a daily net flow in Old and Middle rivers (OMR). The blue data points are sized to reflect the co-occurring adult delta smelt salvage normalized to the Fall Midwater Trawl abundance index immediately preceding fall. Red data = no salvage on that day. The black line is a prediction line generated by the author and proposed as a guide to developing Project operating rules based on combinations of turbidity and OMR. December-March data for December 1988 through March 2009.

Deriso's model showed the general trend in the data is for the highest normalized salvage to occur at combinations of high turbidity and highly negative OMR flows (Figure 15). This trend is generally maintained across each time scale the Service analyzed (Table 3). Other general trends the Service found when analyzing the data over increasingly long time scales, were that the longer the averaging period for the data, (1) the higher the turbidity needed to be to affect the OMR flow that would envelope the data points reflecting more than 5% of the historical maximum normalized salvage, and (2) the more negative the OMR flow could be after the turbidity threshold had changed that would keep normalized salvage lower than 5% of its historical maximum at that time scale (Table 3). The starting point OMR flow or “low turbidity” OMR flow threshold varied inconsistently across averaging periods, but was always between negative 5200 cfs and negative 3000 cfs.

Table 3. Summary information of the combinations of turbidity and OMR flow that corresponded with normalized salvage of at least 5.1% of the historical maximum normalized salvage when OMR flow was less than -1000 cfs.

Time step (days)	Starting OMR (cfs)		Turbidity threshold (NTU)		Alternative OMR
1	-3000	Until	13	Then	-1900
7	-5200	Until	23	Then	-1900
14	-3300	Until	25	Then	-2500
24	-4600	Until	29	Then	-3600
28-31	-4200	Until	No threshold	Then	-4200

The Service also calculated the daily residual mean square (RMS) tide height at Antioch for December-March, of water years 1989-2009. This variable indexes whether the tides are causing a net ‘filling’ or ‘draining’ of the Delta. We generated annual time series plots of (1) turbidity at CCF, or (2) adult delta smelt salvaged normalized to the prior FMWT versus RMS tide height. No consistent influence of this tidal variable was evident on either turbidity or salvage. Thus, the Service does not recommend adding this variable into potential OMR flow rules.

The year to year variability in the OMR-salvage relationships (Figure 5 to Figure 8) is evidence that delta smelt spawning migrations and the distribution changes that result from those migrations also influence their risk of entrainment. The Service recognizes that the upstream migration path of some individuals leads them into Old and Middle rivers regardless of south Delta exports because adult delta smelt salvage has occurred at all OMR flows less than 0 cfs and has even occasionally occurred when OMR was positive.

Larvae (~ March-June)

Delta smelt are “larvae” from the time they hatch and enter the estuary’s planktonic community until they reach lengths of 23-25 mm (Mager et al. 2004). However, we term age-0[5] delta smelt as “larvae” during the period they are vulnerable to SWP and CVP water diversions even though many individuals are morphologically “juveniles” by the end of May. This is done only for organizational convenience. The period of entrainment vulnerability extends from larval emergence through the end of June or the first week of July each year (Kimmerer 2008).
Delta smelt can hatch into pelagic larvae from February-June, but peak hatching usually occurs in April. The distribution of delta smelt larvae initially follows that of the spawners because larvae

5 The term ‘age-0’ refers to fish that are less than a year old. It is synonymous with terms like ‘young-of-the-year’ and ‘larval-juvenile’.

emerge near where they were spawned. Thus, larvae are distributed more widely during high outflow periods because the spawning range extends further west when Delta outflows are high (Hobbs et al. 2007). The survival of delta smelt larvae is probably driven mainly by the interaction of their bioenergetic environment[6] and entrainment, but only mortality rates associated with the latter have been estimated (Kimmerer 2008).

The distribution of larval delta smelt

Delta smelt larvae are generally open-water and planktonic, but they can and do swim (Bennett et al. 2002; Baskerville-Bridges et al. 2004; Mager et al. 2004). They also generally manage to maintain positions within favorable habitats (Bennett et al. 2002; Hobbs et al. 2006). The distribution of age-0 delta smelt collected in the Department of Fish and Game's 20-mm Survey has been analyzed relative to concurrent water quality conditions using the generalized additive modeling framework described by Feyrer et al. (2007) (Figure 16). The analysis shows that larvae tend to be distributed in fresher water than juveniles. This is consistent with the findings of Dege and Brown (2004). These authors noted that delta smelt larvae (< 20 mm) were centered 5-20 km upstream of X2; delta smelt > 20 mm were distributed closer to X2 and later stage juveniles are likewise centered very near X2 (Sweetnam 1999; Nobriga et al. 2008; Sommer et al. 2011). Delta smelt larvae are less sensitive to water transparency than juveniles. Miller (2011) showed that the influence of water transparency on proportional catch increases as the larvae grow larger. Thus, as the larvae transition to the juvenile stage, they tend to occupy more brackish water and limit their distribution more strongly to the most turbid waters available. The distribution of larvae relative to water temperature is similar to juveniles, with a peak probability of capture near 20°C. There is also a tendency for larval capture probabilities to be highest where prey densities are highest.

It has recently been documented that substantial numbers of delta smelt spawn in Liberty Island and the immediately adjacent region including the Sacramento Deep Water Shipping Channel (http://www.dfg.ca.gov/delta/data/skt/DisplayMaps.asp). Subsequent catches of larvae in this region have also been high at times (http://www.dfg.ca.gov/delta/data/20mm/CPUE_map.asp) and have comprised an increasing proportion of total larval catch over time (Kimmerer 2011). The permanent flooding of Liberty Island in the latter 1990s changed north Delta hydrodynamics (Lehman et al. 2010a) and opened up a large area of shallow and turbid open-water habitat that is used by spawning delta smelt and their progeny (Figure 17). Turbidity is the most likely explanation for a shift in delta smelt distribution to the north (Feyrer et al. 2007; Miller 2011; Kimmerer 2011). Water transparency, an index of turbidity (Shoup and Wahl 2009[7]), is lower in the north Delta than the south Delta (Figure 18). Further, water transparency has trended upward in the south, but not in the north.

6 The bioenergetic environment refers to the interaction of food quality/quantity and water temperature. The interaction occurs because delta smelt, like most fishes, require higher amounts of food to maintain any given growth rate at higher temperatures.

7 These authors provided a statistical translation between Secchi disk depth (water transparency in cm) and turbidity: $NTU = 1761 \cdot (\text{Secchi depth}^{-1.514})$; $r^2 = 0.99$.

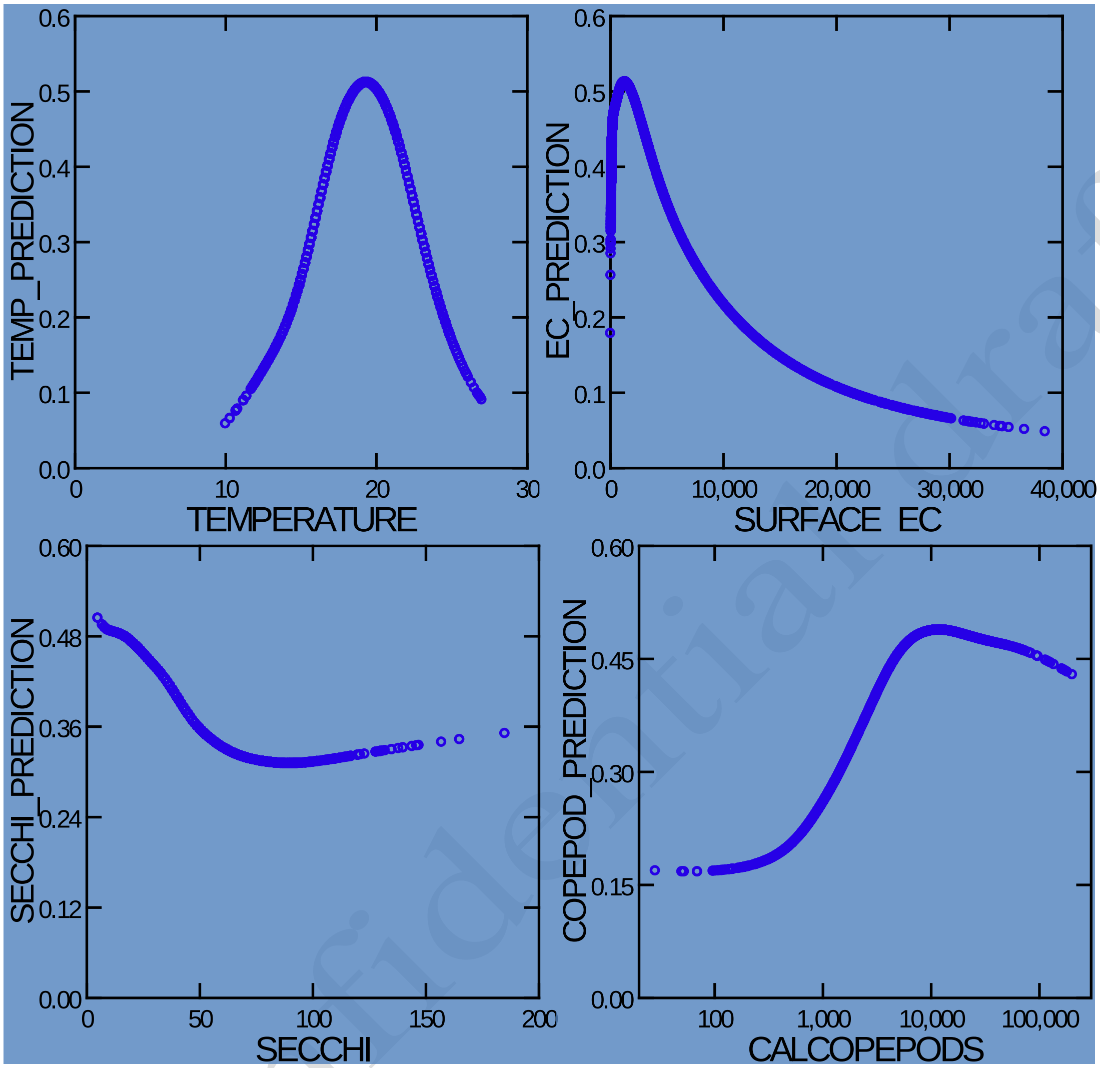

Figure 16. Larval delta smelt capture probabilities based on binomial generalized additive modeling of the 20-mm Survey data. Capture probabilities are shown for individual predicted responses to water temperature in C⁰, specific conductance at the water surface in µS/cm, water transparency as cm Secchi disk depth, and an index of prey density, average number of calanoid copepods per cubic meter sampled.

The south Delta is also warmer than the north Delta (Figure 19). However, the median difference has tended to be only about 1⁰C in any given year, with most of that difference occurring in June-July. In contrast to Secchi depth, the 20-mm Survey data does not show evidence of a time trend in water temperature in either region.

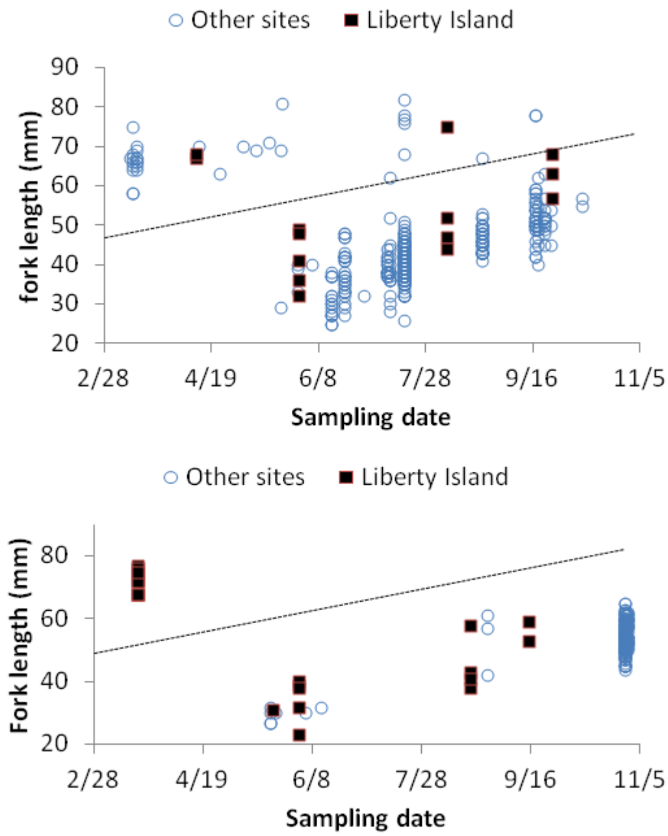

Figure 17. Scatterplots showing the sizes of delta smelt collected in beach seine sampling during 2001 (top graph) and 2003 (bottom graph) (see Nobriga et al. 2005 for details). The dashed lines separate delta smelt year classes; older fish occur above the lines. Thus, the data above the line in the top graph are year class 2000 and below the line they are the age-0 fish born in 2001. Similarly in the bottom plot, fish above the line are year class 2002 and below the line they are the age-0 fish born in 2003. Note that all four cohorts were collected in Liberty Island. Catches were much lower in 2003 than 2001 consistent with previous descriptions of the "Pelagic Organism Decline" (Sommer et al. 2007).

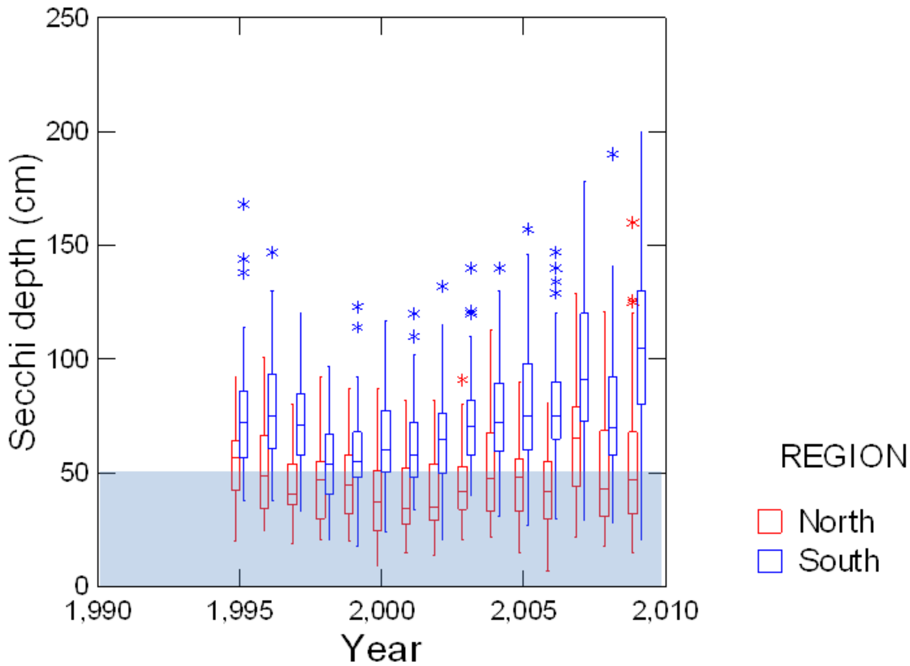

Figure 18. Box plot time series of Secchi disk depth measurements in the California Department of Fish and Game's 20-mm Survey, 1995-2009. The red boxes are for 'north' Delta stations, which are the stations numbered from 704-799 in the 20-mm Survey (http://www.dfg.ca.gov/delta/data/20mm/stations.asp). The blue boxes are for 'south' Delta stations, which are the stations numbered 809-919 in the 20-mm Survey (Figure 1). The box plots are as follows: rectangular box = interquartile range of observations; horizontal line in the box = median; vertical lines = 95% confidence intervals; asterisks = individual data points the Systat software program determined were "outliers". The blue shaded box denotes the region of Secchi disk depths ≤ 50 cm. This is an approximate level of Secchi disk depth below which delta smelt capture probability is somewhat higher based on analysis of the 20-mm Survey data set (see Figure 16).

The freshwater flows that enter the Delta as inflow and pass through it as outflow influence habitat volume for delta smelt during the spring (Kimmerer et al. 2009). They also influence proportional entrainment of the larval delta smelt population (Kimmerer and Nobriga 2008). The combined CVP and SWP water systems began diverting water year-around from the Delta in 1968. Thus, the following analysis considers historical flow conditions based on summaries of the DAYFLOW database for the period 1968-2010. Delta inflows vary among years due largely to interannual differences in precipitation[8] (Kimmerer 2004; Figure 20). Inflows are thus highly correlated among months in the springtime, but typically decline with each successive month as snowmelt and runoff recede. The Projects can have considerable control over Delta inflows during spring, though they tend to have greater control over inflows by early summer (e.g., June) than in the winter and spring.

8 However, the Service reiterates its April 25, 2012 comment that spring inflows and outflows have changed considerably over the longer term due to the cumulative development of freshwater supplies in California.

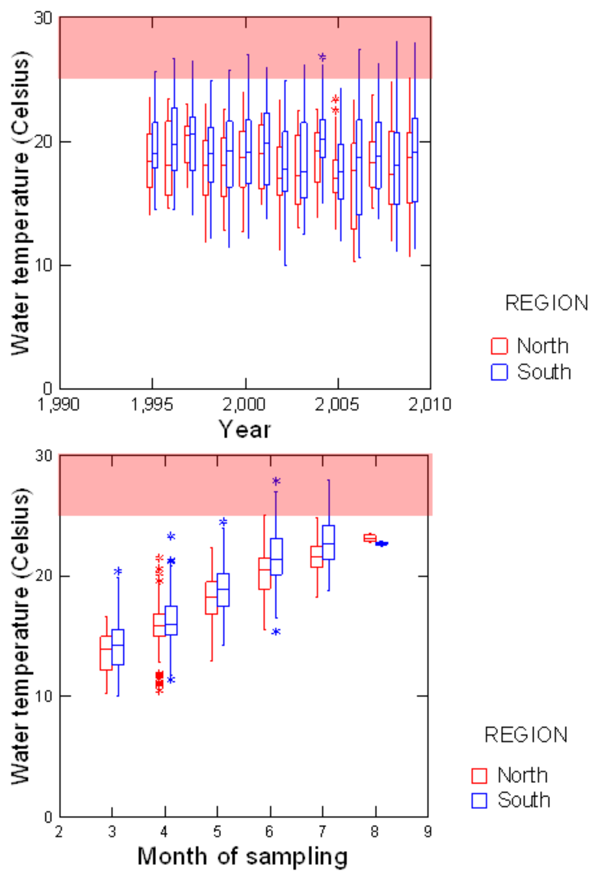

Figure 19. Box plot time series of water temperature measurements in the California Department of Fish and Game's 20-mm Survey, 1995-2009. The red boxes are for 'north' Delta stations, which are the stations numbered from 704-799 in the 20-mm Survey (http://www.dfg.ca.gov/delta/data/20mm/stations.asp). The blue boxes are for 'south' Delta stations, which are the stations numbered 809-919 in the 20-mm Survey. The box plots are as follows: rectangular box = interquartile range of observations; horizontal line in the box = median; vertical lines = 95% confidence intervals; asterisks = individual data points the Systat software program determined were "outliers". The shaded red box in each panel denotes water temperatures ≥ 25ºC. This is an approximate upper lethal water temperature limit for young delta smelt (Swanson et al. 2000).

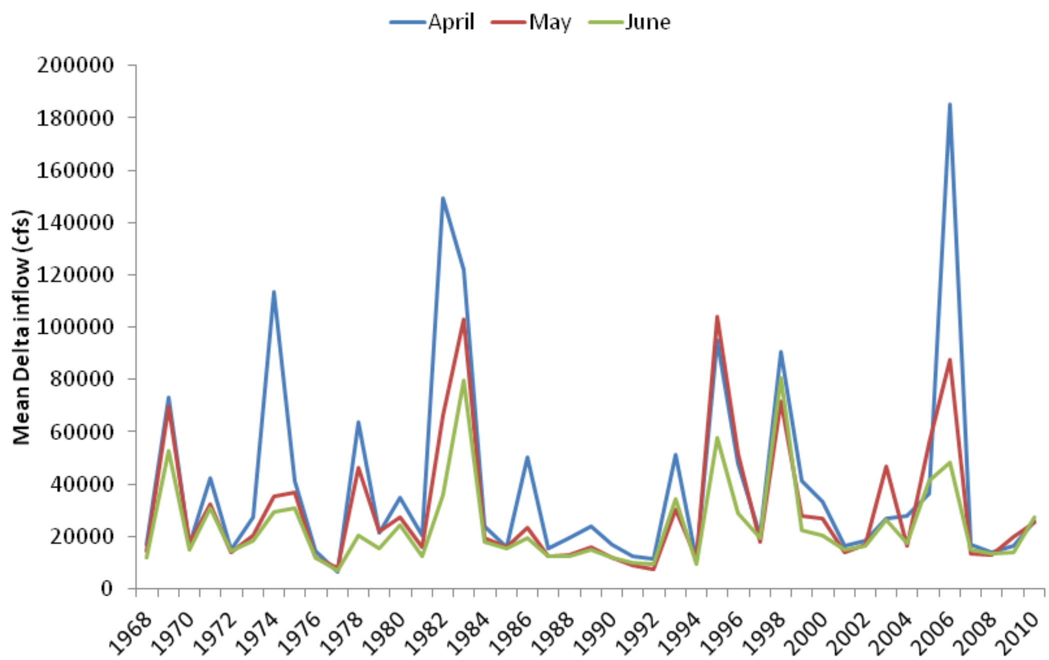

Figure 20. Time series of total Delta inflow for April-June, 1968-2010. Source: DAYFLOW database

April-May exports underwent a step-decline starting in the early 1990s (Figure 21). This was initially due to several years of successive drought but the lower export levels have continued because the Board implemented the X2 standard and the Vernalis Adaptive Management Plan (VAMP) experiment. Project exports frequently exceeded 300 TAF during April-May 1968-1988, but they have only infrequently exceeded that threshold since. Project exports are higher in June, sometimes exceeding 400 TAF per month, but there is no evidence of a long-term trend, except that they first exceeded 600 TAF in 2003. Overall, Project exports are usually lower during April-June than other times of year. The trends in the E:I ratio for the spring months mirror the export trend; step-declines in April-May and no trend in June (Figure 22). The State of California's X2 standard has also shifted the upstream limit of X2 further to the west during April-June (Figure 23).

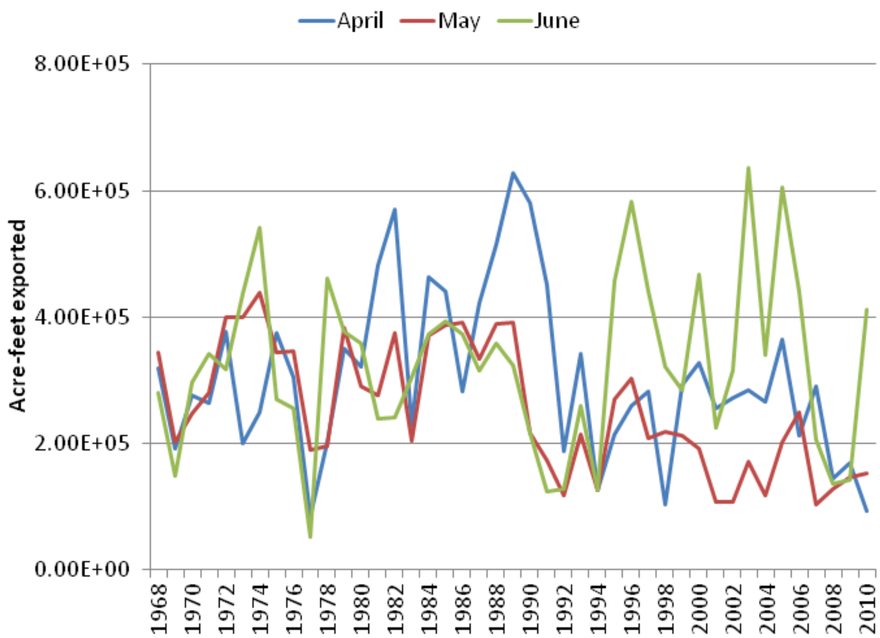

Figure 21. Time series of monthly SWP and CVP exports for April-June, 1968-2010. Source: DAYFLOW database

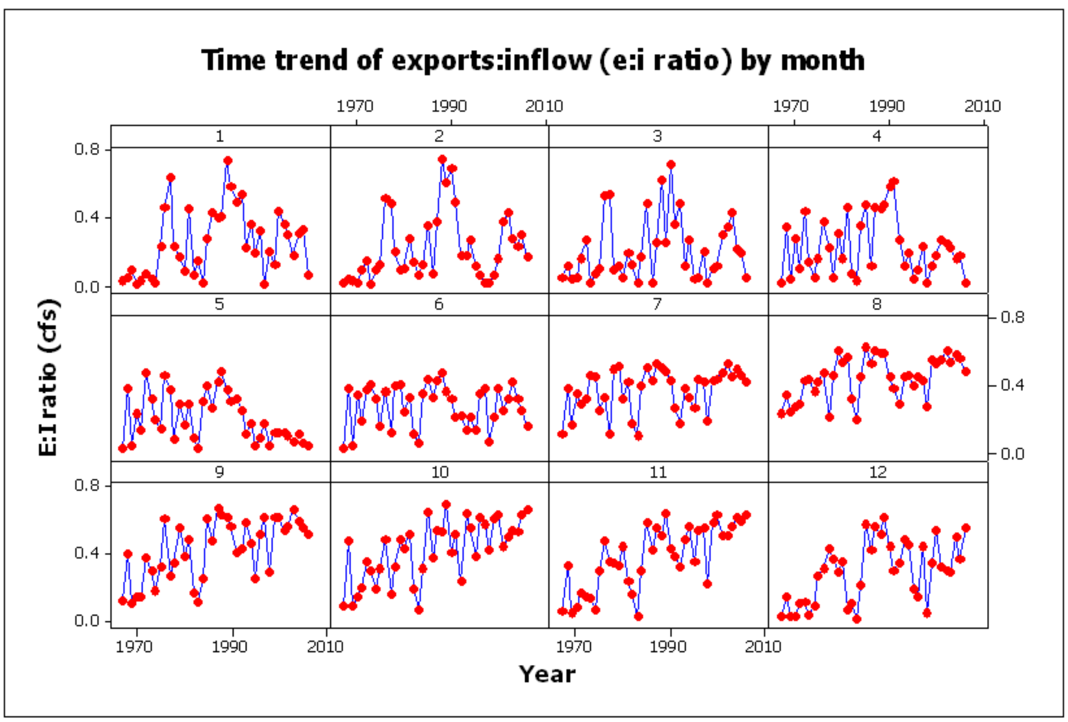

Figure 22. Time series of the monthly mean Export to Inflow ratio, January-December, 1968-2006. Source: DAYFLOW database

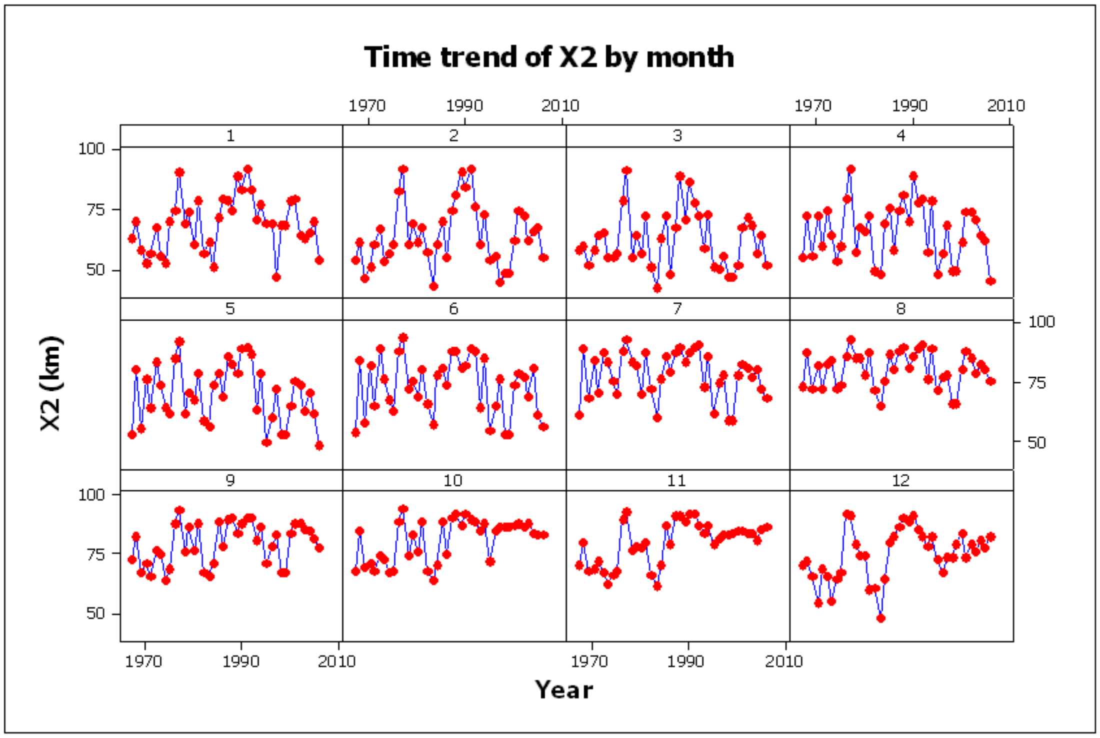

Figure 23. Time series of X2 January-December, 1967-2008. Source: DAYFLOW database

Conceptual background for south Delta entrainment risk

Most age-0 delta smelt *entrainment* at Banks and Jones happens during the true larval stage and is not observed and counted (Kimmerer 2008). The *salvage* of age-0 delta smelt reflects the tail end of the entrainment of age-0 cohorts that started before the fish were large enough to be observed in the fish salvage facilities. Delta smelt are not counted in fish salvage until they reach a minimum length of 20 mm. Age-0 delta smelt are not salvaged efficiently (Table 1). Kimmerer (2008) showed that delta smelt salvage was inefficient, even by delta smelt standards, until the fish were 30 mm long (by which time they are morphologically juveniles; Mager et al. 2004). They typically reach 20-30 mm in May and June. Thus, April is typically the month of highest Project entrainment of age-0 delta smelt, while May-June are the months of highest salvage (Kimmerer 2008).

Previously, the Service (2008) translated Kimmerer's (2008) data-intensive age-0 delta smelt entrainment estimates into a multiple linear regression equation using multi-month averages of X2 and OMR flow as predictor variables. This allowed the Service to hind cast and forecast proportional entrainment (Figure 24). The regression was a quantitative representation of the following conceptual model: (1) the geographic distribution of the population is strongly associated with Delta outflow (or its surrogate, X2; Dege and Brown 2004). Thus, Delta outflow determines how much of the age-0 delta smelt population rears in the Delta during the spring and early summer where it is potentially vulnerable to entrainment, and (2) OMR flow reflects the hydrodynamic influence of the water projects' diversions on the southern half of the Delta and thus the degree of entrainment risk for fishes in that region (Kimmerer 2008; Grimaldo et al. 2009a; Figure 25). The long-term declines in April-May exports and E:I ratio, and April-June X2 location are all indications that the proportional entrainment of age-0 delta smelt has declined. In addition, proportional entrainment may be continuing to decline due to a general shift in delta smelt spawning distribution toward the north Delta (Miller 2011; Kimmerer 2011).

This conceptual model remains valid. The Service notes that Kimmerer's (2008) estimates have recently been criticized on numerous grounds (Miller 2011). However, the Service believes most of Miller's criticisms are unfounded, incorrectly cast, or beyond the scope of currently available data sets to address (Kimmerer 2011). The Service recognizes that the shift in delta smelt distribution toward the north affects the accuracy of the translation of hydrodynamic conditions into specific predictions of proportional entrainment (Miller 2011; Kimmerer 2011).

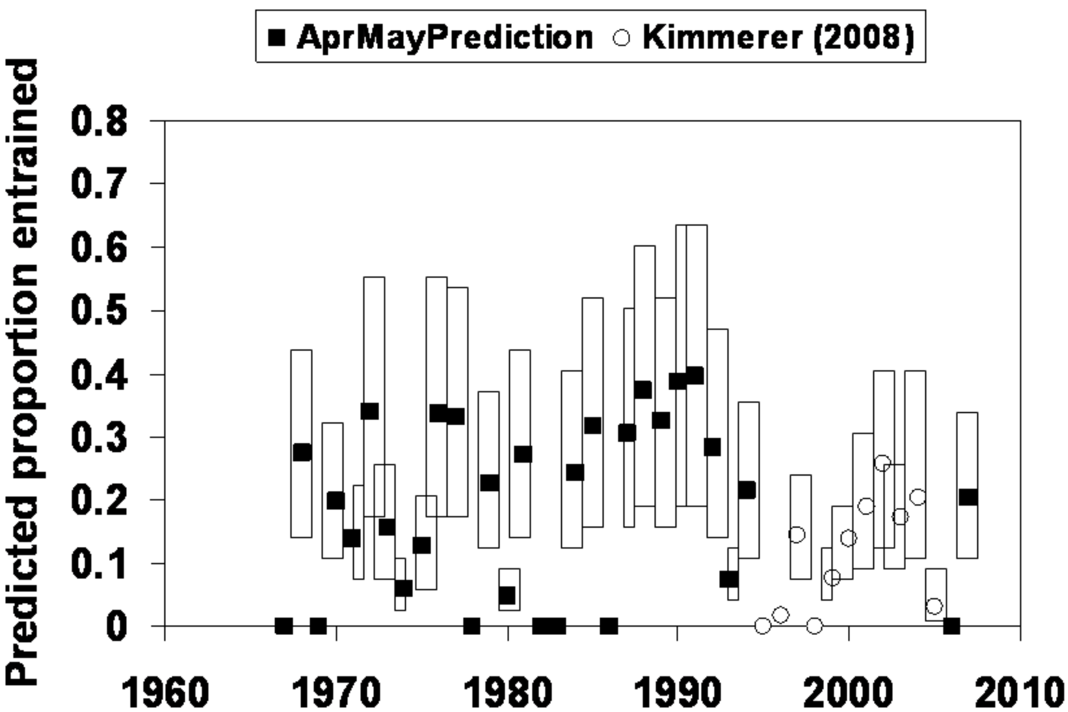

Figure 24. Copy of Figure E-16 from Service (2008). Time series of estimated proportion of the age-0 delta smelt population entrained at Banks and Jones. Open symbols are the empirical estimates made by Kimmerer (2008). Solid symbols were estimated using the linear regression equation developed by the Service (2008). The rectangles depict the approximate 95% confidence intervals on the estimates.

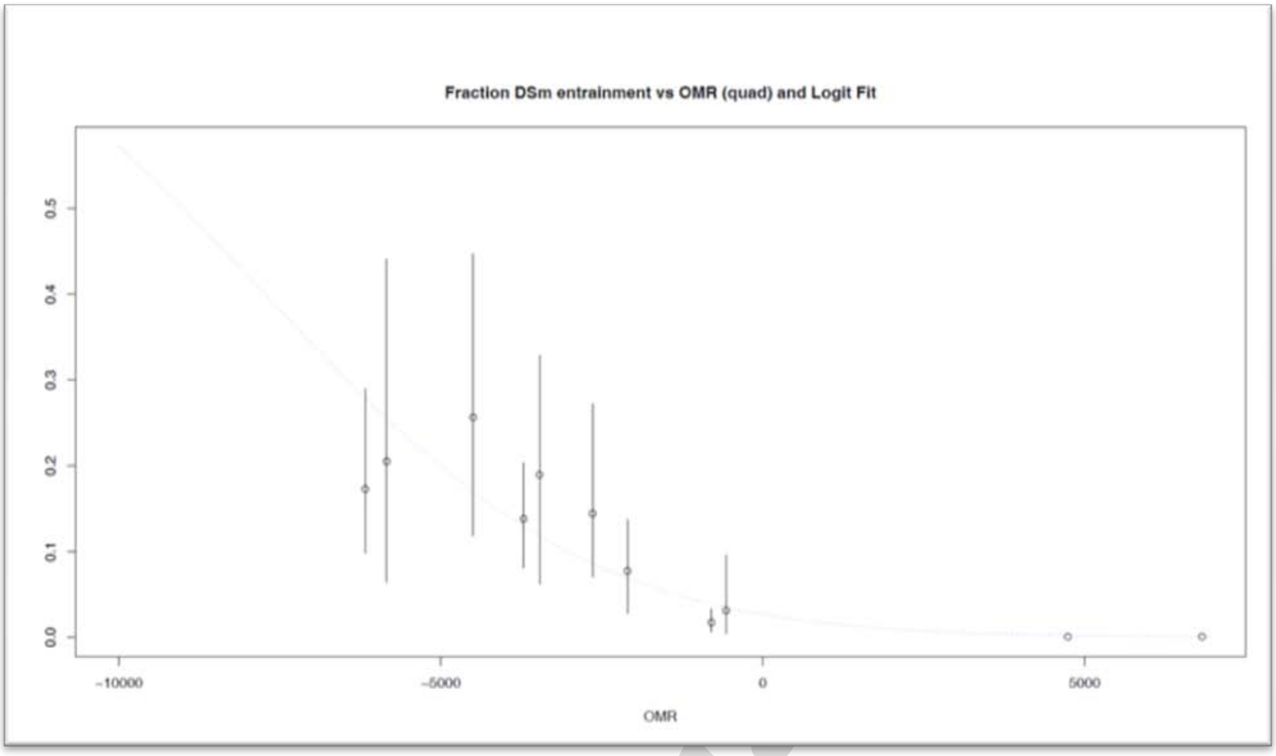

Figure 25. Relationship between Old and Middle river (OMR) flow and the proportional entrainment of age-0 delta smelt (proportional entrainment data provided by W. Kimmerer; plot provided by K. Newman).

The potential for entrainment of fishes rearing in the lower San Joaquin River can be visualized with PTM results based on neutrally buoyant particles. The Service understands that these results reflect predictions about water movement in the Delta rather than fish movement per se. However, the water movement data provide the best available indication of entrainment risk. In fact, Kimmerer (2008) showed that the entrainment estimates he derived from empirical flow and 20-mm data matched predictions of entrainment based on PTM simulations very well[9] (Figure 26). Thus, PTM provides a reliable estimate of entrainment for fish inhabiting the San Joaquin River and south Delta. It has been shown that larval fishes in the San Francisco Estuary can maintain positions in favorable habitats by swimming in concert with the tide (Bennett et al. 2002). Thus, delta smelt larvae have some capacity to avoid "going with the flow". This ability increases as the fish grow. However, a pelagic fish is only likely to avoid going in a particular direction in a tidal environment if it has a cue to avoid the conditions it is exposed to on either the ebbing or flooding tide. Thus, the close association between predictions based on neutrally buoyant particle movement and empirical fish distributions from the 20-mm Survey imply that delta smelt larvae do not perceive a habitat "problem" while they are tidally transported around the south Delta even though they are swimming to find and capture prey, avoid predators, etc. The young fish that have not been entrained do migrate out of the south Delta in the early summer to avoid warm water temperatures (Kimmerer 2008).

9 Note that the ptm results were not used to develop the proportional entrainment estimates. Thus, the data shown in Figure 26 are not depicting a circular argument.

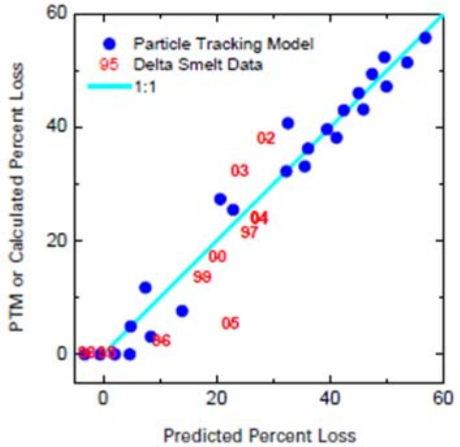

Figure 16. Larval/juvenile delta smelt. Predicted percent loss to the population by regression using log of Delta inflow and log of export flow as predictors (with interaction), and particle-tracking model results as the dependent variable (circles), with the line indicating a 1:1 relationship. The regression is: log (y) = 4.29 – (0.36 ± 0.17) log(inflow) – (0.90 ± 0.11) log(export flow) + (0.10 ± 0.03) log(inflow) × log(export flow), parameters with 95% confidence limits. Estimates of delta smelt losses from Figure 15 with no natural mortality (to match the particle tracking model results) are plotted against predictions from the above statistical model using mean flow conditions during the hatch period; numbers indicate years.

Figure 26. Copy of Figure 16 from Kimmerer (2008). The Figure compares the empirically derived age-0 delta smelt entrainment estimates for Banks and Jones (combined) against estimates of neutrally buoyant particle entrainment into those facilities based on DSM2 particle tracking modeling.

Based on existing summaries of PTM results, it appears that delta smelt cannot be protected from entrainment once they enter Old or Middle rivers (Figure 27). Particle fluxes into Old and Middle rivers are proportional to predicted entrainment into Banks and Jones pumping plants, the SWP and CVP diversions in the south Delta. The relationship deviates from the one to one line when loss to agricultural irrigation diversions is high. Thus, PTM indicates that almost all particles, and by extension larval fishes, that enter Old and Middle rivers will eventually be entrained somewhere; larval fishes will be entrained either at Banks, Jones, or one of numerous smaller agricultural irrigation diversions en route to Banks and Jones. Thus, currently available scientific evidence indicates that OMR flow limits cannot be used to ‘help’ larval fish migrate out of Old and Middle rivers if they are already there. Rather, OMR flow limits would be most effective if they minimized the hydrodynamic conditions that entrain young delta smelt into Old and Middle Rivers from the mainstem San Joaquin River.

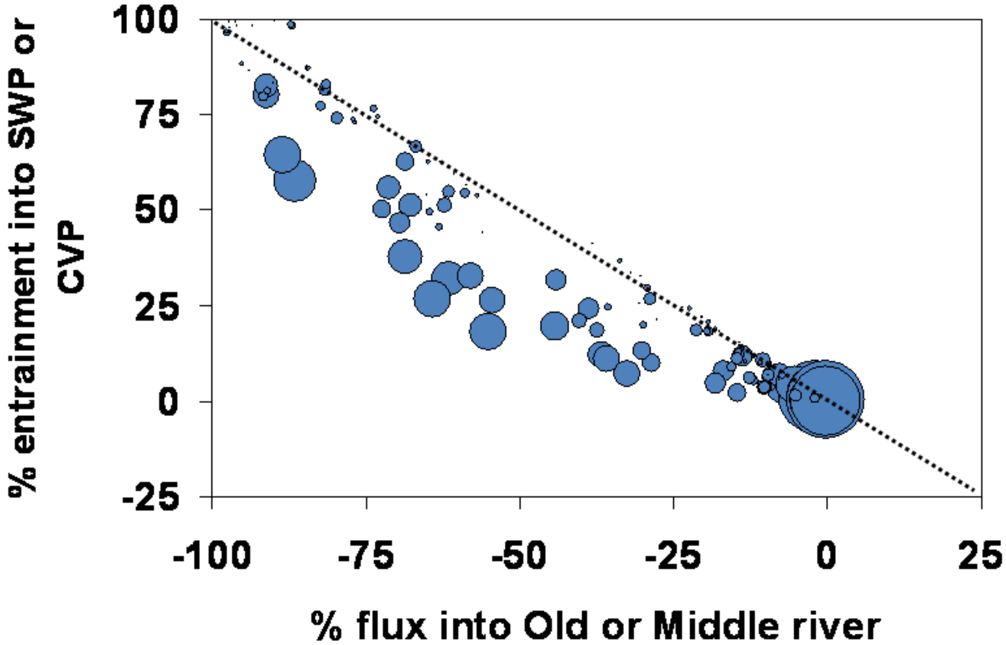

Figure 27. Scatterplot showing the relationship between flux into Old and Middle rivers and entrainment based on simulations using the DSM-2 particle tracking model. The plot demonstrates that particle flux into Old and Middle rivers is strongly linked to entrainment risk. Note that DSM-2 codes fluxes into Old and Middle rivers from elsewhere as negative percentages. The individual data points are sized according to their predicted entrainment into agricultural irrigation diversions. The dotted line is an approximate 1:1 line. Note that large bubbles at Old and Middle river fluxes ranging from about 25% to 90% are often associated with deviations from the 1:1 line. This occurs because particles can be lost to agricultural irrigation diversions in Old and Middle rivers before being transported all the way to Banks and Jones Pumping Plants. Data source: particle tracking model runs done to support the State Water Project's California Endangered Species Act (CESA) Incidental Take authorization for longfin smelt (DFG 2009).

Monitoring the south Delta for evidence of spawning and then applying OMR limits is unlikely to be effective because (1) there are no available data on the distribution of delta smelt eggs; (2) the net efficiency of the 20-mm Survey is very low for hatch sized larvae (Kimmerer 2008); and (3) PTM simulations show that the ultimate entrainment of particles is closely tied to OMR flows during particle release (Figure 28),. In other words, if larvae get into Old and Middle rivers, the PTM indicates it is too late to get them out by changing OMR flows.

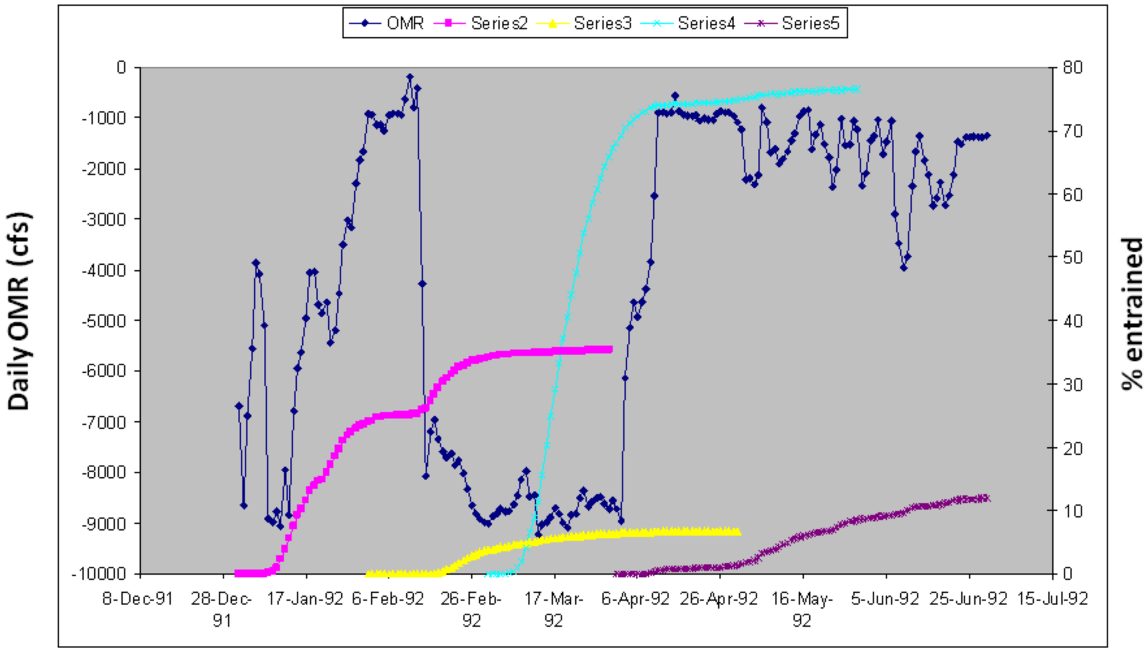

Figure 28. Time series plots of daily particle fate predicted from the DSM-2 particle tracking model for four different particle releases at trawl station 812 (see Figure 1 for location). The simulations used the actual hydrology from winter-spring, 1992, a dry year with a lot of variation in OMR flows. Particles were released on January 1 (Series 2), February 1 (Series 3), March 1 (Series 4), and April 1 (Series 5) and each of the four simulations was run for a total of 90 days. The dark blue line shows the daily mean OMR flow. The other lines show the accumulation of particles entrained at Banks and Jones. Note that the general magnitude of final particle loss was apparent in much less than 90 days and was closely associated with OMR flow at or very near the time of initial particle release. Data source: particle tracking model runs done to support the State Water Project's CESA Incidental Take authorization for longfin smelt (DFG 2009).

The risk of delta smelt entrainment into smaller agricultural irrigation diversions used mainly to irrigate crops within the Delta is also related to flow conditions. These in-Delta irrigation diversions generally have mean flow rates less than 1 cubic meter per second (Nobriga et al. 2004). The lower the Delta outflow, the higher the proportion of the young delta smelt population that overlaps the array of irrigation diversions in the Delta (Kimmerer and Nobriga 2008). However, the irrigation diversions are not currently considered to represent a substantial source of mortality because (1) they individually draw small quantities of water relative to channel volumes, and (2) densities of entrained fishes are circa 1-2 orders of magnitude lower than densities of fish from in-channel sampling (Nobriga et al. 2004).

In Suisun Marsh, water diversions are largely made to support waterfowl production. Based on hydrodynamic simulations, proximity to water diversions in the marsh is expected to correlate strongly with entrainment (Culberson et al. 2004), and substantial losses of delta smelt were reported for Roaring River before it was screened (Pickard 1982). Entrainment risk for delta smelt at Morrow Island in western Suisun Marsh, which is unscreened, is considered low because the habitat surrounding the diversions is often too saline (Enos et al. 2007).

Juveniles (~ July-December)

Conceptual background for juvenile rearing

Delta smelt larvae are present in the estuary in July. However, by this time most individuals are morphologically juveniles (Table 4). These juveniles are pelagic with a spatial distribution that varies with salinity, turbidity, water temperature, and possibly other habitat features (Moyle et al. 1992; Sweetnam 1999; Bennett 2005; Feyrer et al. 2007; Nobriga et al. 2008; Kimmerer et al. 2009; Sommer et al. 2011). Most of them will be 60-70 mm long by December. They are still considered juveniles at that time because their reproductive organs are not functional, but the delta smelt collected in the fall are often referred to as “adults” or “sub-adults”. The center of the juvenile delta smelt population during summer and fall is typically very near X2 (Moyle et al. 1992; Sweetnam 1999; Dege and Brown 2004; Sommer et al. 2011). However, some individuals continue to rear in fresher water in the Liberty Island- Sacramento River Deep Water Shipping Channel area (Sommer et al. 2011). This is probably due in large part to the comparatively turbid water in this region (Nobriga et al. 2005). A few individuals are also collected at salinities higher than 6 psu but these are low probability events (Feyrer et al. 2007; Nobriga et al. 2008). It is not known how long individual delta smelt occupy waters seaward of the low-salinity zone. However, delta smelt can tolerate salinities up to about 19 psu for short periods (Swanson et al. 2000), so it is not surprising that their spatial distribution relative to salinity has some variability around it in a tidally dispersive environment like the LSZ.

Table 4. Summary of mean delta smelt lengths in the 20 mm Survey for the sampling dates nearest to July 1, 1995-2011. Note that no July sampling occurred 2000-2002. Delta smelt are beyond the larval stage by the time they reach about 23-25 mm in length (Mager et al. 2004). Data source: http://www.dfg.ca.gov/delta

Year	Survey Number	Sampling dates	Mean Length (mm)
1995	6	July 3-10	30.5
1996	7	July 8-13	30.4
1997	8	July 8-13	36.9
1998	7	June 28-July 3	33.0
1999	7	July 6-10	25.7
2000	8	June 26-30	25.9
2001	8	June 25-30	30.0
2002	8	June 24-29	38.5
2003	8	June 30-July 3	29.7
2004	8	July 6-10	36.5
2005	9	July 5-9	37.1
2006	8	June 26-July 1	28.1
2007	9	July 2-7	41.2
2008	9	July 7-11	41.7
2009	9	June 29-July 2	31.8
2010	9	July 6-9	26.0
2011	9	July 5-8	24.9
2012	9	July 9-12	37.6

Delta smelt's juvenile rearing habitat has undergone profound changes which have led to increasingly degraded habitat conditions over time.

Alterations to LSZ bathymetry have changed the amount of freshwater flow needed to place the LSZ over structurally complex landscapes (~ 1850-present):

The first major change in the LSZ was the conversion of the landscape over which tides oscillate and river flows vary (Nichols et al. 1986). The ancestral Delta was a large tidal marsh-floodplain habitat totaling approximately 700,000 acres. Most of the wetlands were diked and reclaimed for agriculture or other human use by the 1920s. In the 1930s to 1960s, shipping channels were dredged deeper (~12 m) to accommodate shipping traffic from the Pacific Ocean and San Francisco Bay to ports in Sacramento and Stockton. These changes due to land reclamation and channel dredging left Suisun Bay/Marsh and the Sacramento-San Joaquin river confluence region as the largest and most bathymetrically variable places in the LSZ. This region remained a highly productive ecological nursery for many decades (Stevens and Miller 1983; Moyle et al. 1992; Jassby et al. 1995). However, the deeper landscape created to support shipping and flood control requires more freshwater outflow to maintain the LSZ in this large Suisun Bay/river confluence region than was once required (Gartrell 2010). Further, low outflows due to combinations and drought and water demand may have contributed to some of the food web changes discussed below (Winder et al. 2011). Presently, seasonal salinity intrusion reduces the temporal overlap of the LSZ (indexed by X2) with the Suisun Bay region, especially in the fall (Feyrer et al. 2007). Based on model forecasts of climate change and water demand, this trend is expected to continue (Feyrer et al. 2011).

Fish species introductions may have changed predator-prey dynamics (1879 to present)

Nothing is known about the historical role of predation on the population dynamics of delta smelt or longfin smelt. Fish eggs and larvae can be opportunistically preyed upon by many invertebrate and vertebrate animals so there has always been a very long list of potential predators of these species' eggs and larvae. Potential native predators of juvenile and adult delta and longfin smelt would also have included numerous bird and fish species.

The introduction of striped bass into the San Francisco Estuary in 1879 added a permanently resident, large piscivorous fish to the LSZ, a habitat that is not known to have had an equivalent predator prior to the establishment of striped bass (Moyle 2002). This likely changed predation rates on delta smelt and longfin smelt, but there are no data available to confirm this hypothesis. For many decades the estuary supported higher numbers of all three species than it does currently. This is evidence that the smelts are able to successfully coexist with striped bass. Further, striped bass recruitment is influenced by flow variation and the supporting food web in a manner similar to the smelts (Kimmerer et al. 2000; 2001; Loboschefsky et al. 2012). Thus, although it lives longer than the smelts and can reproduce more than once, it is likewise not expected to thrive under conditions that do not support a healthy LSZ ecosystem.
Predation is a common source of density-dependent mortality in fish populations (Walters and Juanes 1993; Rose et al. 2001). Thus, it is possible that predation was a mechanism that historically generated the density-dependence observed in delta smelt population dynamics

(Bennett 2005; Maunder and Deriso 2011). Because it is generally true for fishes, the vulnerability of delta smelt to predators is probably influenced by habitat conditions. Turbidity may be a key mediator of delta smelt's vulnerability to predators (Nobriga et al. 2005; 2008). Growth rates, which are an interactive outcome of feeding success and water temperature, are also well known to affect fishes' cumulative vulnerability to predation (Sogard 1997). Thus, if predation rate is best characterized as an aspect food web function and abiotic habitat suitability, it may be unrelated to striped bass abundance. This conclusion is supported by several recent studies that did not find evidence for a link between striped bass abundance estimates and population dynamics of delta smelt (Mac Nally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012) and longfin smelt (Mac Nally et al. 2010; Thomson et al. 2010). Several of these studies did find inverse correlations between largemouth bass abundance (or variables that included largemouth bass abundance) and delta smelt population dynamics. This might be evidence for a predatory effect of largemouth bass on delta smelt, but it also may simply reflect the greatly changing habitats in the Delta toward conditions that support largemouth bass and similar fishes and away from conditions that support delta smelt and other LSZ fishes (Nobriga et al. 2005; Moyle and Bennett 2008). This change is discussed below in the section on submerged aquatic vegetation.

Entrainment into water export diversions has increased the total mortality experienced by LSZ fish populations (1951 to present)

The amount of water diverted from the estuary has generally increased over time (Figure 29), and most of the increase during the 1950s and 1960s was due to CVP exports and since the latter 1960s, State Water Project (SWP) exports. There are two basic potential fishery impacts that result from water diversion from the Delta: ecosystem impacts and direct entrainment. From the ecosystem perspective, water diversions are unnatural 'predators' because they 'consume' organisms at every trophic level in the ecosystem from phytoplankton (Jassby et al. 2002) to fish (Kimmerer 2008). Unlike natural predators which typically shift their prey use over time in association with changes in prey fish density (Nobriga and Feyrer 2008), fractional entrainment losses of fishes to diversions are functions of water demand (e.g., Grimaldo et al. 2009a). Thus, water diversions not only elevate 'predation' mortality in an aquatic system, but they can do so in an atypical, density-independent manner. Additionally, the Project diversions and fish collection facilities in the south Delta are very large structures which attract large aggregations of actual predatory fish that prey on smaller species like delta smelt before they reach the fish salvage facilities and within these facilities (Gingras 1997). As discussed above, this gauntlet of predators may bias the salvage data that often are used to link the Project operations with entrainment (Castillo et al. 2010).

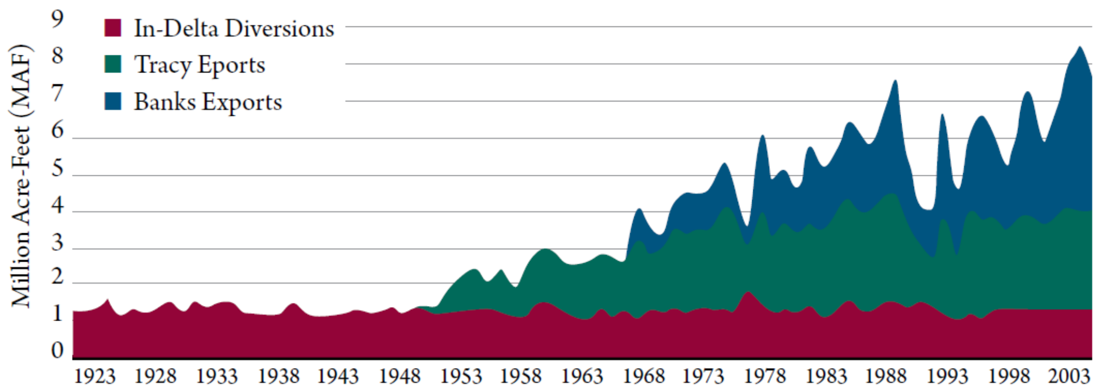

Figure 2.8. Delta Water Diversions and Exports. Delta diversions and exports have grown over time. In-Delta diversions for irrigation have been about the same since the early 1900s. Federal exports (Tracy) began in the early 1950s, and state exports (Banks) began in the late 1960s. (Source: URS Corporation 2007)

Figure 29. Source CALFED Science Program State of Science Report, 2008

Food web alterations attributable to the overbite clam have decreased the production of zooplankton that most efficiently support LSZ pelagic fish production (1987-present)

Major changes to the estuarine food web followed the invasion of the overbite clam. The overbite clam was first detected in 1986 and from 1987-1990 its influence on the ecosystem became evident. The first responses were step-declines in phytoplankton (especially diatom) biomass (Alpine and Cloern 1992; Jassby et al. 2002) and the density of two historically important zooplankton prey, *Eurytemora affinis* and *Neomysis mercedis* (Kimmerer et al. 1994; Kimmerer and Orsi 1996; Orsi and Mecum 1996). The grazing pressure applied by the overbite clam rippled through the historical zooplankton community that fueled fishery production in the LSZ (Kimmerer et al. 1996; Orsi and Mecum 1996; Kimmerer 2002a; Feyrer et al. 2003). This major change in the way energy moved through the ecosystem has likely facilitated the numerous subsequent invasions of the estuary by suppressing the production of historically dominant zooplankton, which increases the opportunity for invasion by other species that are less dependent on high densities of LSZ diatoms (Winder and Jassby 2011).

Longfin smelt abundance per unit of outflow has steadily declined following the overbite clam invasion. Delta smelt size at the end of their first calendar year of life also declined shortly after the overbite clam invasion. These trends provide circumstantial evidence for food limitation (Kimmerer 2002a; Bennett 2005).

The Projects entrain some food web production (about 4.5% on a daily average basis was attributed to all Project and non-project water diversion in the Delta; Jassby et al. 2002). However, diatom standing stocks and zooplankton densities have been most strongly affected by clam grazing and the species invasions it facilitated (Kimmerer et al. 1994; Jassby et al. 2002; Winder and Jassby 2011). Urban wastewater input impairs diatom bloom production (Wilkerson et al. 2006; Dugdale et al. 2007; Parker et al. 2012a,b). At times, *Microcystis* blooms and pesticides also impair the production of zooplankton eaten by delta and longfin smelt or their prey (Ger et al. 2009; Werner et al. 2010).

Proliferation of Submerged Aquatic Vegetation is a second food web alteration that has changed turbidity and nearshore fish assemblages (1980s to present)

For many decades, the Delta's waterways were turbid and the growth of submerged plants was apparently unremarkable. That began to change in the mid-1980s, when the non-native Brazilian waterweed *Egeria densa*, a fast-growing aquarium plant took hold in many shallow habitats (Brown and Michnuik 2007; Hestir 2010). *Egeria densa* and other non-native species of submerged aquatic vegetation (SAV) grow most rapidly in the summer and late fall when water temperatures are warm (> 20^{o}C) and outflow is relatively low (Hestir 2010). The large canopies formed by these plants have physical and biological consequences for the ecosystem (Kimmerer et al. 2008). First, dense SAV promotes higher water transparency. Increased water transparency leads to a loss of habitat for delta smelt (Feyrer et al. 2007; Nobriga et al. 2008). Second, dense SAV canopies provide habitat for a suite of non-native fishes, including largemouth bass, which now dominate many shallow habitats of the Delta and displace native fishes (Nobriga et al. 2005; Brown and Michniuk 2007). Finally, SAV colonization over the last three decades has led to a shift in the dominant freshwater food web pathways that fuel fish production (Grimaldo et al. 2009b). It is noteworthy that SAV-dominated habitats are comparatively productive (Nobriga et al. 2005; Grimaldo et al. 2009b), but most of the productivity they generate remains in the nearshore environment and therefore does not contribute much to the production of pelagic fishes like delta smelt and longfin smelt (Grimaldo et al. 2009b).

Reduced turbidity has decreased LSZ habitat suitability for delta smelt (1999-present)

The next major change was a change in estuarine turbidity that culminated in an estuary-wide step-decline in 1999 (Schoellhamer 2011). For decades, the turbidity of the modified estuary had been sustained by very large sediment deposits resulting mainly from gold mining in the latter 19^{th} century. The sediments continued to accumulate into the mid-20^{th} century, keeping the water relatively turbid even as sediment loads from the Sacramento River basin declined due to dam and levee construction (Wright and Schoellhamer 2004). The flushing of the sediment deposits may also have made the estuary deeper overall (Schroeter 2008) and thus a less suitable nursery from the 'static' bathymetric perspective. Delta smelt larvae require turbidity to initiate feeding (Baskerville-Bridges et al. 2004), and as explained above, older fish are thought to use turbidity as cover from predators. Thus, turbidity is a necessary water quality aspect of delta smelt habitat.

Predictions of warmer water temperature are likely to be very stressful to delta smelt and longfin smelt (present through long-term climate forecasts)

Delta smelt is already subjected to thermally stressful temperatures every summer. Water temperatures are presently above 20^{o}C for most of the summer in core habitat areas (Figure 30), sometimes even exceeding delta smelt's nominal lethal limit of 25^{o}C (Swanson et al. 2000) for short periods. Note that coldwater fishes begin to have behavioral impairments (Marine and Cech 2004) and lose competitive abilities (Taniguchi et al. 1998) prior to reaching their thermal tolerance limits. Thus, the estuary can already be considered thermally stressful to delta smelt and can only become more so if temperatures warm in the coming decades.

All available regional climate change projections predict central California will be warmer still in the coming decades (Dettinger 2005). The Service expects that warmer estuary temperatures will be yet another significant conservation challenge. Higher water temperatures will limit abiotic habitat suitability further than indicated by flow-based projections (e.g., Feyrer et al. 2011; Wagner et al. 2011). In addition, warmer water temperatures mean that higher prey densities will be required just to maintain present-day growth rates, which are already lower than they once were (Sweetnam 1999; Bennett 2005).

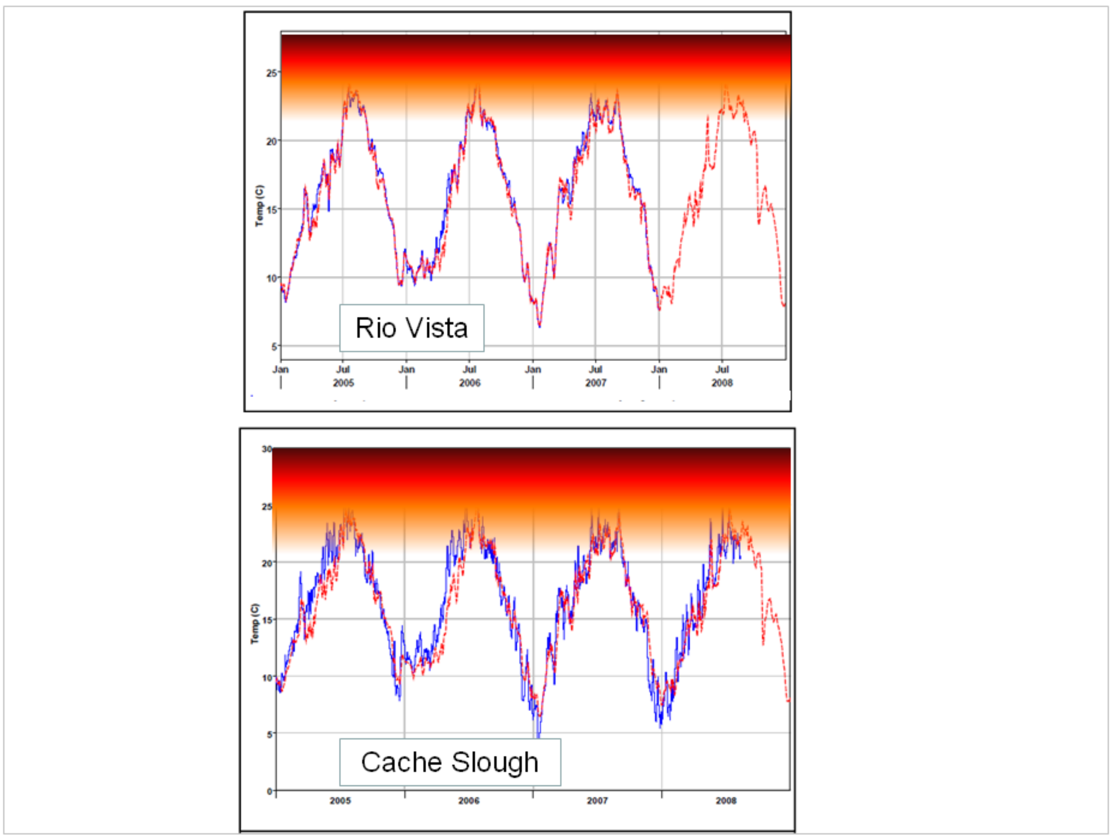

Figure 30. Source: Bay-Delta Conservation Plan, Chapter 5 Technical Appendix E. The red gradients were added by Service staff to show the temperatures where delta smelt health and survival can be impaired.

Contaminant exposures chronically impair food web production and fish health (ongoing)

Delta smelt's spawning migration coincides with early winter rains (Sommer et al. 2011). This 'first-flush' of inflow to the Delta brings sediment-bound pesticides with it (Bergamaschi et al. 2001), and peak densities of larvae and juveniles can co-occur with numerous pesticides (Kuivila and Moon 2004). Bennett (2005) reported that about 10% of the delta smelt analyzed for histopathological anomalies in 1999-2000 showed evidence of deleterious contaminant exposure, but this was low compared to the 30%-60% of these fish that appeared to be food-limited. Delta smelt can also be exposed to other toxic substances. Recent toxicological research has provided dose-response curves for several contaminants (Connon et al. 2009; 2011a,b). This research has also shown that gene expression changes and impairment of delta smelt swimming performance occur at contaminant concentrations lower than levels that cause mortality. Climatic scale flow variation (e.g., flood versus drought scale variation) affects the amount of methyl mercury entering the ecosystem and may have some influence on the meaningful dilution of ammonium from urban wastewater inputs. However, the Service is not aware of evidence that the amount of flow variation that can be sustainably provided by Project operations substantively influences contaminant dynamics in the estuary.

Invasive species may also affect contaminant dynamics. For instance, *Microcystis* blooms generate toxic compounds that can kill delta smelt prey (Ger et al. 2009) and accumulate in the estuarine food web (Lehman et al. 2010b). A second example is the biomagnification of selenium in the food web by *Corbula* (Stewart et al. 2004). This has been considered a potential issue for the clam's predators – namely sturgeon, splittail, and diving ducks (Richman and Lovvorn 2004; Stewart et al. 2004). However, it is not known whether this change in selenium dynamics negatively affects delta smelt, longfin smelt, or other fishes that do not directly prey on the clams.

Habitat suitability

Summer-fall hydrodynamics

The freshwater flows that enter the Delta as inflow and pass through it as outflow influence habitat suitability for delta smelt (Kimmerer et al. 2009; Feyrer et al. 2011). The combined CVP and SWP water systems began diverting water year-around from the Delta in 1968. Thus, the following analysis considers historical flow conditions based on summaries of the DAYFLOW database for the period 1968-2009/2010[10]. Delta inflows vary among years due largely to interannual differences in precipitation (Kimmerer 2004). However, the Projects often have considerable control over Delta inflows during most of delta smelt's juvenile life stage – particularly July-October, which are the 'base flow' months in the watershed (Kimmerer 2002b; 2004). Inflows have been variable during July-August, but with consistently higher minima since the mid-1990s (Figure 31). In contrast, inflows during September-December have been lower since the mid-1980s than they were prior. This is particularly apparent in November-December because peak flows are so much larger than low flows in these months due to occasional large autumn storms.

10 At the time this section was written, official DAYFLOW data were available through water year 2010 (i.e., September 2010).

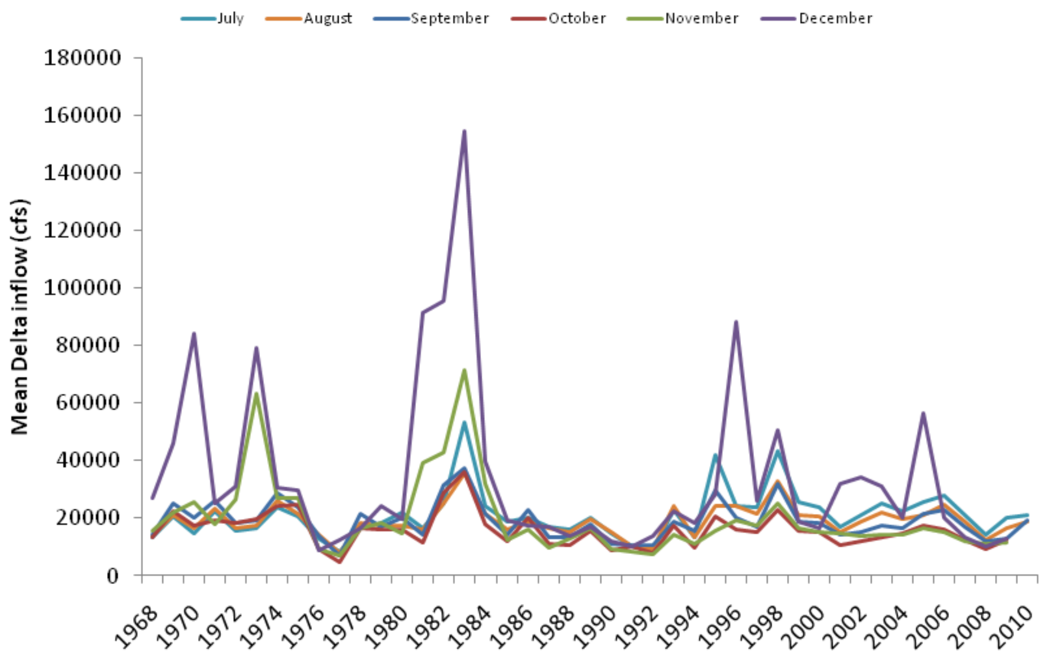

Figure 31. Time series of total Delta inflow for July-September, 1968-2010 and October-December, 1968-2009. Source: DAYFLOW database

As was the case for the winter months of January-March, Project exports have generally increased during July-December (Figure 32). Monthly exports first reached 400 TAF in July 1971. They first reached 500 and 600 TAF in July and August 1974. September exports specifically, first reached 500 and 600 TAF in 1976 and 1985. July-December exports have often ranged between 400-600 TAF per month since 1980. Monthly exports exceeded 700 TAF a few times during the mid-2000s. Summer-fall exports are typically less than 400-600 TAF per month during droughts (1976-1977; 1990-1992; 2007-2009).

The net effect of these inflow and export trends is clearer when plotted as the export to inflow ratio (E:I; Figure 33). The E:I is highly variable among months and years because both exports and inflows vary considerably. Nonetheless, with the possible exception of December, summer-fall E:I has generally been higher since the mid-1980s than it was prior. Since 2000, it has only dropped below 0.40 once during the months of July-November. These trends are very different than what has occurred during other times of the year (Figure 22). During January-March, E:I has not had any trend except to increase temporarily during droughts (1976-1977, 1987-1992). The E:I has decreased during April-May because of the VAMP, and it has shown no obvious long-term trend during June.

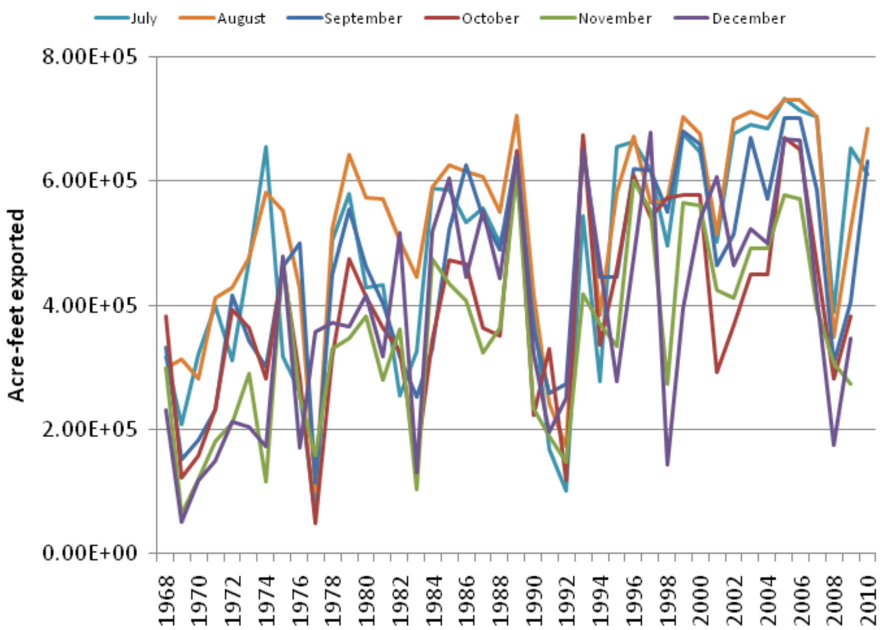

Figure 32. Time series of combined Project exports for July-September, 1968-2010 and October-December, 1968-2009. Source: converted from cfs data in DAYFLOW database

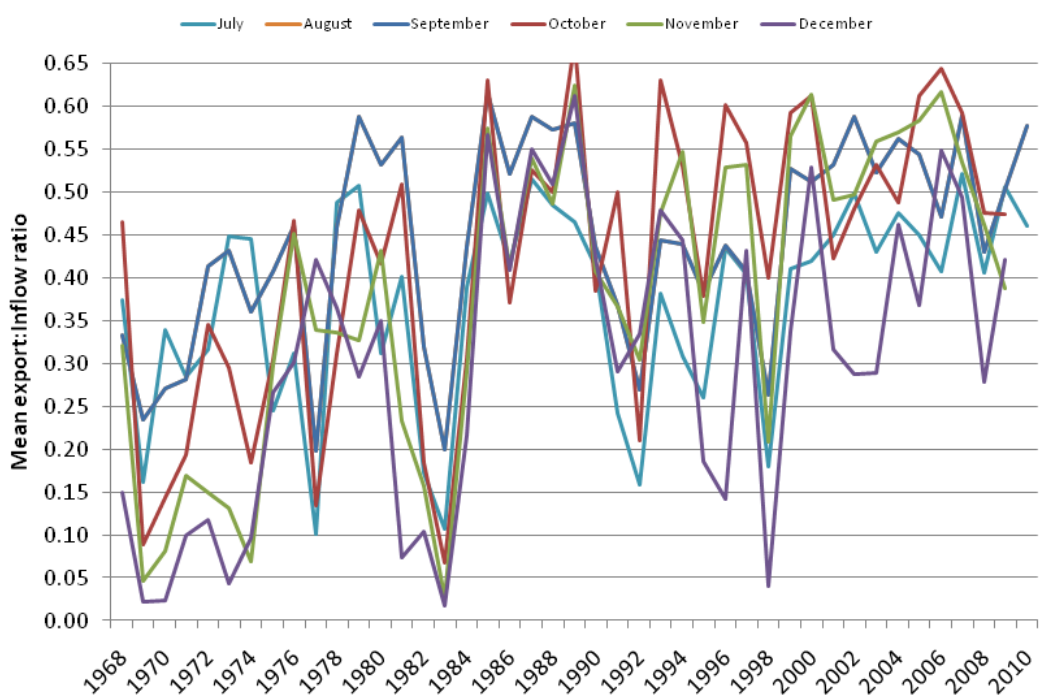

Figure 33. Time series of the monthly mean Export to Inflow ratio for July-September, 1968-2010 and October-December, 1968-2009. The upper limit of the y-axis (0.65) is the upper limit for this ratio set by the State Water Resources Control Board. Source: DAYFLOW database

The increased export flows relative to inflows translate into lower Delta outflow (Kimmerer 2004). This in turn allows the estuarine salinity distribution to move upstream. The salinity distribution of the San Francisco Estuary is often indexed using X2 (Jassby et al. 1995). The Board enacted a salinity standard that can be met using X2 location during February-June (SWRCB 1995). The Projects began operating to the standard in the mid-1990s. This can be seen in monthly time series of X2 (Figure 23). Since the mid-1990s, X2 has not migrated as far upstream as it did prior during February-June[11]. This is also true of January and July even though the salinity standard does not apply in these months. This is likely due to inertia in the location of X2; its average location does not move as quickly as Delta outflow changes (Jassby et al. 1995). It takes more Delta outflow to move X2 from a starting location to a downstream location than it takes to maintain it at the downstream location once it is there. Thus, the Projects may sometimes need to start moving X2 downstream in January to meet the February standard if precipitation is not sufficient to provide the needed outflow. The inertia also works in reverse, but the landward encroachment is even slower. If Delta outflow decreases in July, a month in which the Projects usually have a substantial influence on Delta outflow, then X2 will not immediately move upstream. Project influence is probably why upstream limits of July X2 have remained seaward of historical locations even though the Projects are not required to meet an X2 standard in July. By August, present-day X2 locations are more comparable to what they were prior to the mid-1990s (Figure 23). In contrast, September-December X2 locations have recently been persistently skewed toward the upstream end of where they occurred in the early years of combined Project pumping. This trend is particularly pronounced during October-December, during which the historical interannual variability in fall X2 location had largely disappeared by the mid-1980s. The trend toward increasing exports with decreasing inflows shown in Figure 31 to Figure 33 is a proximal cause of this change in X2 and is thus at least somewhat attributable to Delta flows.

The linkage of fall hydrodynamics to delta smelt habitat suitability

The Department of Fish and Game collects data on three water quality variables along with its trawl surveys: specific conductance, which is a surrogate for salinity; Secchi disk depth, which is a measure of water transparency, and water temperature. Feyrer et al. (2007) showed that the FMWT had most frequently collected delta smelt in water that had very low transparency and specific conductance that ranged from fresh water to about 10,000 microseimens per centimeter or about 6 psu. The approximate conversion between these salinity units is provided in Table 5. Feyrer et al. (2007) showed the water quality conditions that were historically associated with the highest chances of catching delta smelt were occurring at progressively fewer locations over time in the FMWT. This decline in the mixture of water quality conditions that provided the best chances of catching a delta smelt had occurred because the water transparency had been generally increasing, particularly in the south Delta, and because specific conductance had been generally increasing in Suisun Bay. The former was due mostly to changes in sediment inputs and outputs over time (Wright and Schoellhamer 2004; Schoellhamer 2011) and the proliferation of submerged aquatic vegetation (Hestir 2010). The latter was due to the hydrodynamic changes discussed above.

11 Note that downstream limits of X2 during winter and spring are driven by flood flows and are thus not under substantive control of the Projects.

Table 5. Approximate translation of specific conductance into oceanic salinity based on Obrebski et al. 1992. Note that a full conversion requires a correction for water temperature.

Specific conductance (μS/cm)	Approximately salinity (psu or parts per thousand)
187	0.105
910	0.5
1750	1.0
3400	2.0
5075	3.0
6750	4.0
8400	5.0
10,000	6.0

The correspondence of declining delta smelt capture probabilities and changing water quality is an indicator of declining habitat suitability. This linkage was made more explicit by Feyrer et al. (2011). Feyrer et al. (2011) showed how the predicted probability of capturing a delta smelt in the FMWT varied for each year of the survey (1967-2008; Figure 34). The cluster of lines with the higher probabilities of delta smelt occurrence represent years of relatively high FMWT indices; the cluster with lower probabilities are years of relatively low FMWT indices. This analysis showed that historical capture probabilities reached about 0.5 or 50 percent at a specific conductance between 3 and 3.5 on a $\log_{10}$ scale. This is about 1000-3200 microseimens per centimeter or about 0.5 to 2 psu. During years of lower abundance, there is less evidence of a peak in catch relative to salinity, but there is a slight increase in capture probability at $\log_{10}$ specific conductance between 3.5 and 4.0, or 3200 to 10,000 microseimens per centimeter; about 2-6 psu. The chances of catching a delta smelt decrease rapidly at specific conductance corresponding to more than about 6 psu.

Probabilities of delta smelt occurrence are also highest where the Secchi disk depths are lowest (Figure 34). This is most pronounced in high abundance years, but still apparent in most low abundance years as well. As with specific conductance, the high and low abundance years converged on near zero chance of delta smelt detection where Secchi depths approach 1 meter (0 on a log scale). The basic reason for these combined trends is that water transparency has increased the most at the freshwater sampling stations (Feyrer et al. 2007), though water clarity has increased somewhat throughout the estuary (Schoellhamer 2011).

Next, Feyrer et al. (2011) developed a unit less delta smelt habitat suitability index based on the FMWT. This was an improvement over the Feyrer et al. (2007) version which did not factor geography into the index. Each year's index is the predicted chance of catching a delta smelt based on specific conductance and Secchi depth at each of 73 FMWT sampling stations multiplied by a corresponding areal estimate represented by each station. These areas can be seen as polygons in Figure 35. The Figure provides an example of how much predicted habitat suitability for delta smelt improves in Suisun Bay when X2 is downstream of the Sacramento-San Joaquin river confluence.

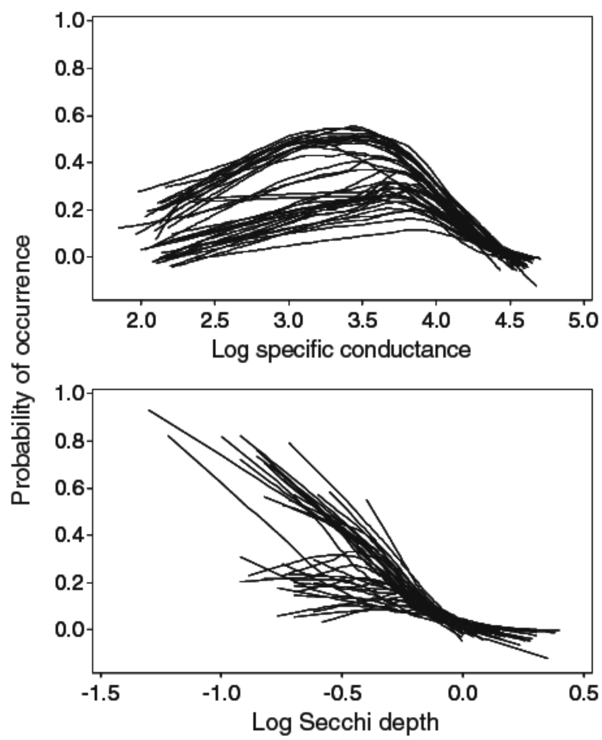

Fig. 1 Plot of the GAM response predictions (probability of occurrence) against specific conductance and Secchi depth. Individual lines are LOESS smooths drawn through the points for individual years

Figure 34. Source: Feyrer et al. (2011); GAM refers to generalized additive modeling of the Fall Midwater Trawl data for delta smelt, 1967-2008.

The fall habitat suitability index showed evidence of a step-decline in the mid-1980s (Figure 36; top panel "A"). This corresponded in time with the hydrodynamic changes discussed above (Figure 31 to Figure 33). The habitat index reflects long-term trends in both salinity and water transparency. Feyrer et al. (2011) plotted their habitat index versus average September-December X2 as a means of determining how strongly Delta flow conditions can influence delta smelt habitat suitability (Figure 36; middle panel "B"). The rationale was that because the Projects can control X2 location during periods of low Delta outflow (SWRCB 1995), this would test how well the Projects could control abiotic habitat suitability for delta smelt. The habitat index is related to fall X2, but in a nonlinear way. Generally speaking, the habitat index is low whenever X2 is upstream of 80 km (near Broad Slough at the confluence of the Sacramento and San Joaquin rivers). The habitat index increases when X2 is downstream of 80 km, but the rate of increase per km of X2 appears to slow down considerably once X2 move seaward of about 75 km (Chipps Island).

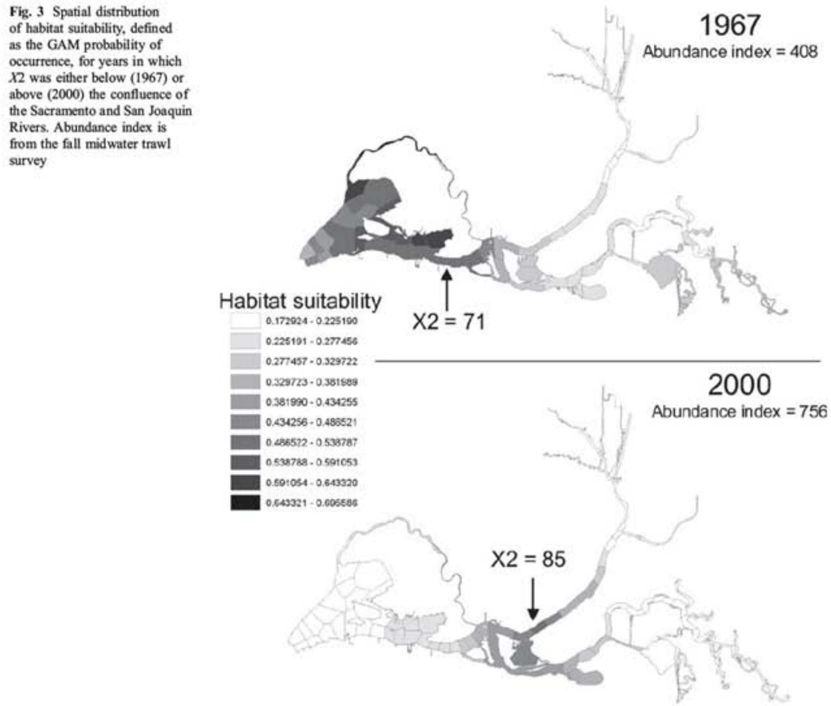

Figure 35. Maps showing the spatial distribution of estimated delta smelt habitat suitability for two example years in the Department of Fish and Game's Fall Midwater Trawl Survey. 1967 was a high outflow fall with an average fall X2 location of 71 km; 2000 was a low outflow fall with an average X2 location of 85 km.

The GAM analyses performed by Feyrer et al. (2007; 2011) and others (e.g., Nobriga et al. 2008; Kimmerer et al. 2009) are reporting concurrent associations of fish catches and water quality. Thus, they show that some of the variation in delta smelt catch is explained by environmental conditions that occurred during the sampling. Feyrer et al. (2011) showed that despite being based on presence or absence of delta smelt, their resultant habitat index was correlated with the FMWT abundance index (Pearson r = 0.51; *P* = 0.001; Figure 36; bottom panel "C"). However, this is an expected outcome because delta smelt abundance and presence-absence are correlated. The point in showing this association was to demonstrate that although the linkage is variable and inherently based on a circular argument (because catch was used to define habitat suitability), there is nonetheless a correlation between the FMWT indices and the habitat indices, which are nonlinearly related to fall X2. The FMWT index is one of the best available predictors of the next year's 20-mm and Summer Townet indices (Maunder and Deriso 2011; Miller et al. 2012). This suggests that fall habitat conditions may have some influence on egg supply available to produce the next generation of smelt. Note that some authors have tried to use fall specific conductance or X2 as a covariate to explain additional variation in the relationship between successive delta smelt abundance indices (Feyrer et al. 2007; Mac Nally et al. 2010; Thomson et al. 2010; Miller et al. 2012). However, it is not necessary to make this second analytical step to link fall habitat to delta smelt population dynamics. Fall habitat conditions influence the FMWT index itself. Thus, when a FMWT index is plotted against an index of the following generation's abundance, the fall habitat effect is already built into the relationship. In fall of 2011, X2 remained downstream of 79 km for much of the season. The 2011 delta smelt FMWT index was 343, the highest index since 2001. The 2011 FMWT index was 11.8 times higher than the 2010 index, even though the 2011 20mm Survey (spring relative abundance) and STNS (summer relative abundance) indices for delta smelt were only about twice as high in 2011 as they were in 2010.

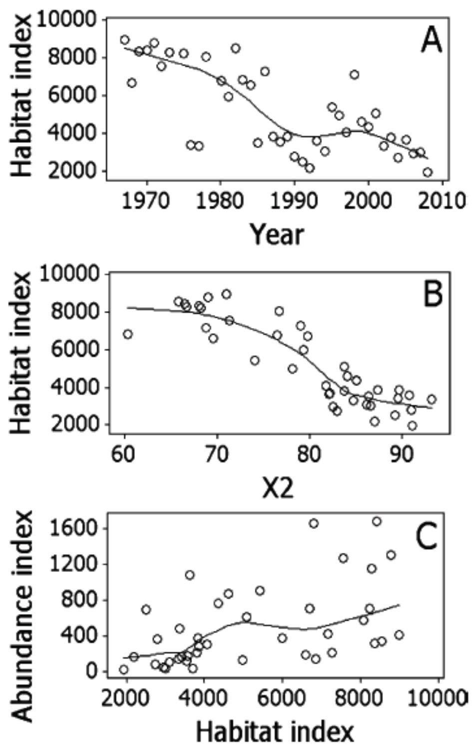

Fig. 2 Plots of the habitat index time series (**a**), relationship between *X*2 (km) and the habitat index (**b**), and relationship between the habitat index and delta smelt abundance measured as the fall midwater trawl index. Curves are LOESS smooths

Figure 36. Time series of a delta smelt habitat index based on the Department of Fish and Game's Fall Midwater Trawl (FMWT) Survey, 1967-2008, and relationships of the index with the geographic location of the 2 psu salinity isohaline (X2) and and FMWT abundance index for delta smelt. Figure copied from Feyrer et al. (2011).

Feyrer et al. (2011) showed that the hydrologic modeling done to support this consultation provides an imperfect representation of present-day hydrodynamic conditions. Nonetheless, the modeling shows that the combination of a 2030 level of development and the sea-level rise that is predicted to occur by 2030 due to climate change, decrease predicted habitat suitability for delta smelt in all but critical water years (Figure 37). The comparison between Scenarios A and B isolates the influence of Delta flows on delta smelt's habitat index because it compares the Projects' modeled baseline to a predicted 2030 operation without including the climate changes explored in Scenarios C-G. Note that Feyrer et al. (2011) estimated future values of the index by using the predicted X2 locations output by the CALSIM II model and predicting the habitat index from X2 using the relationship shown in Figure 36 panel “B”.

The comparison of Scenarios A and B shows that outflow-induced changes in X2 cause most of the predicted change in the habitat index. In wet years, the median habitat index in Scenario B is just over 4000, which is about half the value of the median in Scenario A (just under 8000). In above-normal, below-normal, and dry water year types, not only do predicted median habitat indices decline, but the variability that occurs in Scenario A is greatly reduced in Scenario B.

Fig. 5 Box plots of the habitat index values for each scenario across water year types. The *box plots* show medians and first and third quartiles. *Whiskers* show the highest or lowest values in the upper or lower limits, respectively. Table 1 provides details on the modeled outflow scenarios

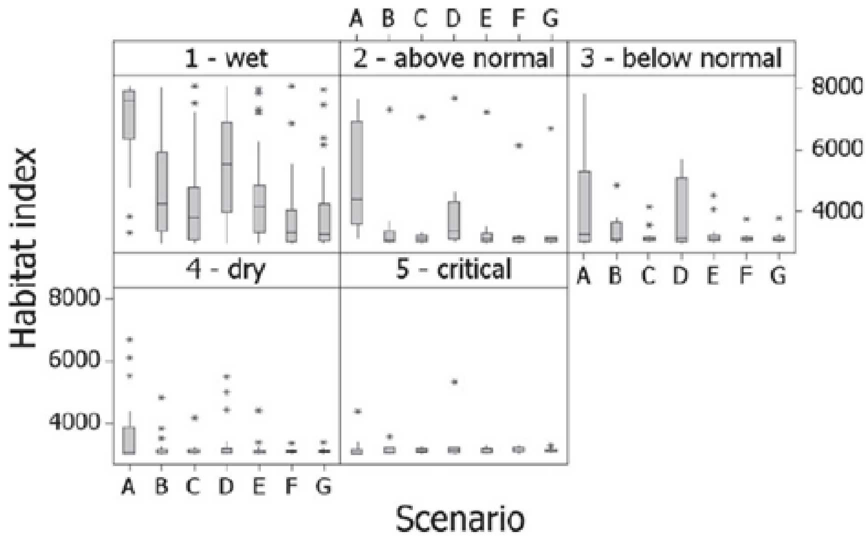

Figure 37. Comparisons of the hydrologic simulation model CALSIM II results for delta smelt fall habitat index by water year type from Feyrer et al. (2011). Scenario A = 2005 level of development, current sea level; Scenario B = 2030 level of development, current sea level; Scenario C = 2030 level of development, 0.33 m increase in sea level and 10% increase in tidal range; Scenarios D-G, same as Scenario C except, Scenario D = higher mean precipitation and somewhat warmer weather than present; Scenario E = higher mean precipitation and warmer weather than Scenario D; Scenario F = lower mean precipitation and temperatures equivalent to Scenario D; Scenario G = lower mean precipitation and temperatures equivalent to Scenario E.

Limitations of the habitat index

The delta smelt habitat index discussed above is based on two abiotic habitat characteristics (salinity and water transparency). Two other abiotic habitat attributes have been evaluated in the generalized additive modeling framework. Water temperature is an important aspect of delta smelt habitat suitability in the summer (Nobriga et al. 2008), but not in the fall (Feyrer et al. 2007). This is likely because lethal temperatures do not often occur in the estuary during September-December so there is little opportunity for temperature to constrain delta smelt distribution. Additionally, water depth is not an important aspect of delta smelt’s summer habitat (Kimmerer et al. 2009). However, including it did improve the fit of Kimmerer et al.’s (2009) fall habitat model. The caveat to this statement is that Kimmerer’s FMWT analysis explained less than or equal to 4 percent of the variability in delta smelt catch. When so little variance is explained, any increment of variability makes a difference. Note that the Feyrer et al. (2007; 2009) analyses of the same data explain up to 25 percent of the variance. The Service does not know why this discrepancy exists between these two analyses of the FMWT data.

Delta smelt habitat suitability is also influenced by biotic variables (food supply, predation, and possibly disease). The degree to which biotic habitat attributes might confound conclusions based on the abiotic habitat index is unknown. The reason that Feyrer et al. (2007; 2011) did not explicitly include any biotic variables in their analyses is simple and was acknowledged by the authors – biotic variables like zooplankton prey data have not historically been taken concurrently with the FMWT. Further, there are no existing data that can be used to quantify predation rates or disease trends during summer-fall, though some scientists have made speculative attempts to quantify prey and predator abundances using data from other times of year or other imperfectly matched sampling programs (Mac Nally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012). However, it should be noted that biotic and abiotic habitat attributes cannot always be easily separated. For instance, the prey density needed for delta smelt to grow at a given rate is affected by water temperature (e.g., Lantry and Stewart 1993). As a second example, the predation rates on delta smelt are hypothesized to be influenced by both water temperature and water transparency based on studies of salmonid fishes (e.g., Gregory and Levings 1998; Marine and Cech 2004).

Life Cycle Models for Delta Smelt

Density dependence in the Delta Smelt Population

Several statistical life cycle models for delta smelt have been published over the past several years (Mac Nally et al. 2010; Thomson et al. 2010; Maunder and Deriso 2011; Miller et al. 2012). These models are all correlation-based, but they have each employed different statistical approaches and have not tested the same suites of variables (usually called covariates in the cited papers). Thus, there is not a lot of concurrence in the conclusions drawn using these tools (Table 6). Overall, the collective results of these four papers show that results depend (1) on what variables get tested, and (2) what assumptions are made about density dependence.

Table 6. Summary of delta smelt life cycle model results published between 2010 and 2012. Covariates are general descriptions of the variables that the authors attempted to correlate with delta smelt abundance or survival. Different authors often used different forms of covariates that are listed under the same name in this table so the variables are nominally similar, but not necessarily equivalent. Note that Miller et al. (2012) in particular often tested multiple versions of covariates that are given one name in this table (e.g., summer temperature or spring copepods). Question marks denote covariates where the description in the paper is not adequate to determine if the variable was tested; the entrainment terms in Maunder and Deriso (2011) may be highly congruous with OMR flows. Miller et al. (2012) used proportional entrainment estimates as adjusted by Miller (2011). Like Kimmerer's (2008) entrainment estimates, the estimates reported in Miller et al. (2012) are highly congruous with OMR flows – particularly in the spring, though the relationship is not linear. Dark green shading depicts covariates that were strongly correlated with delta smelt survival over some life cycle interval. Mac Nally et al. and Thomson et al. defined this as an odds ratio > 3; for Maunder and Deriso, support was considered strong (by the Service) if the covariate was retained in more than 3 of their top 6 models using different density dependence assumptions; strong support in the Miller et al. models were those factors retained in the best-fitting models. Note that summer copepods was originally included in

their best-fitting models, but then fall copepods was added and the authors reported that variable worked better. Both are shown as strongly supported here because they likely are highly correlated. Light green shading is used to depict covariates that had weaker statistical support as described by Mac Nally et al. and Thomson et al. (odds ratios between about 1 and 3) and covariates that were retained in 1-3 of Maunder and Deriso's top 6 models. Miller et al. did not report their data in a way that would allow a clear determination of variables with lesser support. Note that PDO is the acronym for the ocean index known as the Pacific Decadal Oscillation.

Covariate	Mac Nally et al. (2010)[a]	Thomson et al. (2010)[a]	Maunder and Deriso (2011)[b]	Miller et al. (2012)[a]	Miller et al. (2012 v2)[c]
Prior abundance (density dependence)	FMWT-FMWT	FMWT-FMWT	FMWT-20mm-TNS-FMWT	FMWT-FMWT-FMWT	FMWT-FMWT-TNS-FMWT
WINTER					
Winter copepods[prey]	Not tested	Not tested	Not tested		
Adult entrainment[entr]	Not tested	Not tested		Not tested	Not tested
Winter exports[entr]			Not tested	Not tested	Not tested
Winter Limnoithona[prey, comp]	Not tested	Not tested	Not tested		
Winter OMR flow[entr]	Not tested	Not tested	???		Not tested
Winter PDO[hab]			Not tested	Not tested	Not tested
Winter Secchi depth[hab]	Not tested				Not tested
SPRING					
Spawning days (~ spring)[hab]					
Spring chlorophyll[hab]			Not tested	Not tested	Not tested
Spring copepods[prey]					
Spring entrainment[entr]	Not tested	Not tested		Not tested	Not tested
Spring exports[entr]			Not tested	Not tested	Not tested
Spring Limnoithona[prey, comp]	Not tested	Not tested	Not tested		
Spring nonnatives[pred]	Not tested	Not tested			
Spring OMR flow[entr]	Not tested	Not tested	???		Not tested
Sprng other zooplankton[prey]			Not tested	Not tested	Not tested
Spring Secchi depth[hab]	Not tested	Not tested	Not tested		
Spring temperature[hab]	Not tested	Not tested			
Spring X2[hab, entr]			Not tested	Not tested	Not tested
SUMMER					
Summer anchovies[comp]			Not tested	Not tested	Not tested
Summer copepods[prey]					
Summer lrgmouth bass[pred]			Not tested	Not tested	Not tested

Summer Limnoithna[prey, comp]			Not tested		
Summer mysid shrimp[prey]			Not tested		
Summer PDO[hab]	Not tested		Not tested	Not tested	Not tested
Summer silverside[pred, comp]			Not tested	Not tested	Not tested
Summer temperature[hab]					
Maximum summer temp[hab]	Not tested	Not tested			
FALL					
Fall copepods[prey]	Not tested	Not tested	Not tested		
Fall delta smelt fork length	Not tested	Not tested			
Fall Limnoithona[prey, comp]	Not tested	Not tested	Not tested		
Fall nonnatives[pred]	Not tested	Not tested			
Fall Secchi depth[hab]			Not tested		Not tested
Fall X2[hab]			Not tested		Not tested
MULTIPLE SEASON					
Adjusted entrainment[entr]	Not tested	Not tested	???		
Adult striped bass[pred]					
Overbite clam[comp]			Not tested		Not tested

[a]Results based on a one year time step (fall to fall)
[b]Results based on a 0.33 year time step (fall to spring to summer to fall)
[c]Results based on a 0.5 year time step (fall to summer to fall)
[prey]Delta smelt prey item
[pred]Delta smelt predator
[comp]Delta smelt competitor
[hab]Delta smelt habitat component other than predator or prey
[entr]Source or index of entrainment loss

The concept of density-dependence and how it has affected the delta smelt is important because it gets erroneously used as a reason not to protect particular life stages from sources of mortality (Kimmerer 2011). Density dependence refers to situations in which vital rates like growth and reproduction change with the abundance of an organism (Rose et al. 2001). Density dependence is not always obvious in abundance data, but it is likely a universal aspect of population ecology because no organism can increase to infinite abundance. Typically (i.e., absent Allee effects), growth and reproductive rates speed up as abundance decreases and slow down or even decline as abundance increases. The basic reason is that crowding leads to faster disease transmission, higher rates of cannibalism and resource limitation, and greater attraction of predators. However, fish do not need to be abundant to have population dynamics that reflect density dependence (Walters and Juanes 1993). Fish have to balance getting enough to eat with the risk of becoming food themselves. The numbers of fish that can be supported in a system are therefore context-dependent; the optimal balance between eating and getting eaten depends on what fish species, what life stage, what the prey and predator densities are, what condition the habitat is in, etc.

Statistically speaking, evidence for density dependence is provided by any of several nonlinear correlations between abundance at one point in time and abundance at a future point in time. In contrast, evidence for density independent population dynamics is provided by a linear relationship (when data are not transformed in any way) between abundance at one point in time and abundance at a future point in time. It is unclear whether density-dependence has occurred between delta smelt generations because statistical assessments of the relationship between the adult stock and the next generation of recruits (juveniles) result in similar fits for linear (density-independent) and nonlinear (density-dependent) relationships (Bennett 2005; Maunder and Deriso 2011; Figure 38). One reason for this is that delta smelt population dynamics may have changed over time. Previous papers have reported a delta smelt step-decline during 1981-1982 (Moyle et al. 1992; Thomson et al. 2010). Prior to this decline, the stock-recruit data are consistent with “Ricker” type density-dependence where increasing adult abundance resulted in *decreased* juvenile abundance (Figure 38). Since the decline, recruitment has been positively and essentially linearly related to prior adult abundance, suggesting that reproduction has been basically density-independent for the past 30 years. This means that since the early 1980s, more adults translates into more juveniles and fewer adults translates into fewer juveniles without being ‘compensated for’ by density-dependence between generations. This interpretation of the data contrasts the conclusions of Maunder and Deriso (2011) and Miller et al. (2012).

In contrast to the transition among generations, the scientific evidence supports the hypothesis that, at least over the history of Interagency Ecological Program (IEP) fish monitoring, delta smelt has experienced density-dependence during the juvenile stage of its life cycle, i.e., between the summer and fall (Bennett 2005; Maunder and Deriso 2011; Figure 38). From a species conservation perspective, the most relevant aspect of this juvenile density dependence is that the carrying capacity of the estuary for delta smelt has declined (Bennett 2005).

Thus, the Service believes that the delta smelt decline has occurred for two basic reasons. First, the compensatory density-dependence that historically enabled juvenile abundance to rebound from low adult numbers stopped happening. This change had occurred by the early 1980s as described above. The reason is still not known, but the consequence of the change is that for the past several decades, adult abundance drives juvenile production in a largely density-independent manner. Thus, if adult numbers or adult fecundity decline, juvenile production will also (Kimmerer 2011). Second, because juvenile carrying capacity has declined, so juvenile production hits a ‘ceiling’ at a lower abundance than it once did. This limits adult abundance and possibly per capita fecundity, which cycles around and limits the abundance of the next generation of juveniles. The mechanism causing carrying capacity to decline is likely due to the long-term accumulation of deleterious habitat changes – both physical and biological – during the summer-fall (i.e., associated with the kinds of covariates listed in Table 6).

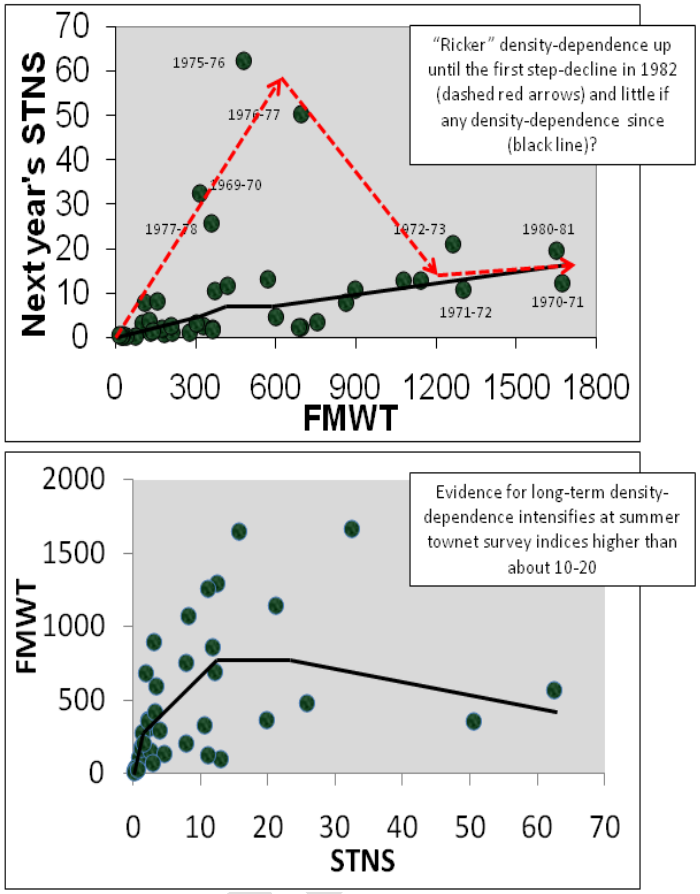

Figure 38. Upper Panel: plot of the FMWT index for delta smelt vs. the following year's summer townet survey (STNS) index. The "pre-decline" years based on Kimmerer (2002a) are individually labeled. The red arrows reflect the Service's hypothesis that a "Ricker" type curve would best fit the data through 1981. The black line is a trace of the LOWESS spline that the Systat software program fit to the data. Lower Panel: plot of the STNS index for delta smelt vs. the FMWT index determined a few months later in the same calendar year. The black line is a trace of the LOWESS spline fit to the data.

Conclusions

- In conclusion, we suggest that the Board model and evaluate a range of flow objectives that could be incorporated in the WQCP. Our suggested evaluation should include flow objectives that are likely to improve habitat conditions for delta smelt, longfin smelt, and other native estuarine biota and put the Bay-Delta ecosystem on a path toward recovery.

- For adult delta smelt, negative Old and Middle River (OMR) flows contribute to entrainment risk during spawning migrations.

- For age-0 delta smelt OMR flows are a suitable index of the hydrodynamic conditions that *drive* entrainment loss.

- The Service recognizes that multiple factors have contributed to the substantial long-term degradation of the low-salinity zone (LSZ). Nonetheless, Delta outflow remains an extremely important aspect of LSZ habitat suitability for delta smelt, particularly during low flow periods.

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