■ Interagency Ecological Program for the Sacramento-San Joaquin Estuary ■

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Simpson MR, Bland R. 1999. Techniques for accurate estimation of net discharge in a tidal channel. In: Proceedings of the IEEE Sixth Working Conference on Current Measurement; 1999 Mar 11–13, San Diego, California. p 125–130.

Smith PE, Cheng RT, Burau JR, Simpson MR. 1991. Gravitational circulation in a tidal strait. In: Proceedings of the American Society of Civil Engineers 1991 National Conference on Hydraulic Engineering; 1991 Jul 29–Aug 2, Nashville, Tennessee. p 429–34.

Smith PE, Oltmann RN, Smith LH. 1995. Summary report on the interagency hydrodynamics study of the San Francisco Bay-Delta Estuary, California. Interagency Ecological Program for the Sacramento-San Joaquin Estuary. Technical Report 45. Sacramento (CA): California Department of Water Resources. 72 p.

Stacey MT. 1996. Turbulent mixing and residual circulation in a partially stratified estuary [Ph.D. thesis]. Stanford (CA): Stanford University. Available from Stanford University.

Stacey MT, Monismith SG, Burau JR. 1999. Measurements of Reynolds stress profiles in unstratified tidal flow. Journal of Geophysical Research 104(C5):10933–49.

Tobin A, Schoellhamer DH, Burau JR. 1995. Suspended-solids flux in Suisun Bay, California. In: Espey WH, Combs PG, editors. Water Resources, American Society of Civil Engineers First International Conference on Water Resources Engineering; 1995 Aug 14–18, San Antonio, Texas. p 1511–5.

Walters RA, Gartner JW. 1985. Subtidal sea level and current variations in the northern reach of San Francisco Bay. Estuarine, Coastal and Shelf Science 21:17–32.

Warner JC, Schoellhamer DH, Burau JR. 1997. A sediment transport pathway in the back of a nearly semi-enclosed subembayment of San Francisco Bay, California. In: Wang SY, Carstens T, editors. Environmental and coastal hydraulics—protecting the aquatic habitat. Proceedings of the 27th Congress of the International Association of Hydraulic Research; 1997 Aug 10–15, San Francisco, California. p 1096–1101.

NOTES

Janet Thompson, U.S. Geological Survey. Conversation with author in 1999.

Jay Cuetara, U.S. Geological Survey. 1999 unpublished report.

ENVIRONMENTAL FACTORS INFLUENCING THE DISTRIBUTION AND SALVAGE OF YOUNG DELTA SMELT: A COMPARISON OF FACTORS OCCURRING IN 1996 AND 1999

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INTRODUCTION

The delta smelt (*Hypomesus transpacificus*) is listed as a threatened species under both the Federal Endangered Species Act (FESA) and the California Endangered Species Act. Through formal consultation under Section 7 of the FESA, USBR and DWR received a Biological Opinion from the USFWS, which allows for the incidental take of delta smelt arising through operation of the Central Valley Project and the State Water Project. The incidental take of delta smelt is estimated as part of the ongoing CVP and SWP fish salvage operations. Salvage levels of young delta smelt have exceeded incidental take levels every spring and summer since 1994, except in the high spring outflow years of 1995 and 1998 (Nobriga and others 1999). These high salvage levels have resulted in changes to project operations, often leading to the curtailment of water exports. An extended period of high salvage and export curtailment in 1999 raised substantial concerns and numerous questions that remain unanswered.

Previously, Nobriga and others (1999) described the high numbers of delta smelt salvaged at the State and federal Delta fish facilities in spring 1999 as "surprising since [the 1999 Delta inflow] hydrograph showed a similar pattern to 1996," a year of lower delta smelt salvage. However, additional work presented here shows this characterization was too general. In this article we provide a more thorough analysis of differences between 1996 and 1999 to help explain the differences in delta smelt salvage between these moderately high outflow years. We examined information from a variety of sources (Table 1) to assist with the interpretation of observed patterns. Overall, we found the differences in delta smelt salvage between spring 1996 and 1999 were due to differences in the smelt recruitment patterns and central and south Delta hydrodynamics.

Table 1 Data sources

Type of Assessment	*Agency*	*Data Source*
Delta smelt distribution	DFG	20-mm Survey
Delta smelt recruitment pattern	DFG	20-mm Survey
Water temperature	DFG	20-mm Survey
Specific conductance	DFG	20-mm Survey
Delta hydrodynamics	USGS	UVM flow data
Delta export and delta smelt salvage	DWR/DFG/ USBR	Delta fish salvage facilities

METHODS

Many of the conclusions we draw in this article are based on data from the IEP's 20-mm Survey. The 20-mm Survey has been conducted annually by DFG during the spring and summer since 1995. This survey samples for delta smelt at fixed stations throughout the upper estuary using a towed net. The net is designed to collect late larval and early juvenile stage delta smelt. See the DFG 20-mm website at http://www2.delta.dfg.ca.gov/data/20mm/2000/ for additional details regarding survey methods.

The USGS collected detailed flow measurements in Old and Middle rivers using ultrasonic velocity meters (UVM). These measurements, along with daily San Joaquin River inflow and export flows are used to describe Delta hydrodynamics during spring 1996 and 1999. Fifteen-minute interval time-series of tidal flow data are produced for each UVM station, but only tidally averaged (net flow) data are presented in this article. The tidally averaged flows for Old and Middle rivers are referred to as central Delta flows throughout this article. For a description of the use of UVMs to measure tidal flow refer to Oltmann (1998).

Distribution of Adult Delta Smelt

The distribution of adult delta smelt at the time of spawning directly affects the subsequent distribution of young delta smelt. Thus, understanding the factors affecting adult delta smelt distribution during the spawning period can help us to understand the patterns in young delta smelt recruitment and distribution. An examination of DFG spring midwater trawl data shows adult delta smelt distribution during the probable spawning period (February to May) does vary among years. In particular, the occurrence and spawning of adult delta smelt in the central and south Delta seems to vary considerably among years.

Examination of San Joaquin River hydrographs for the January through July period between 1994 and 1999 shows considerable variation among years (Figure 1). However, the San Joaquin River hydrographs for 1996 and 1999 were unlike the other years examined. In these years, San Joaquin River inflow to the Delta generally ranged over intermediate values (about 140 to 425 m^3/s or about 4,940 to 15,000 cfs) from late January through late May. In both of these years, DFG spring midwater trawl surveys found many adult delta smelt in the San Joaquin River system but relatively few in the Sacramento River system. We hypothesize the occurrence of intermediate flows on the San Joaquin River in late winter provided attractive conditions for adult delta smelt moving upstream to spawn. Maintenance of moderate flow levels through spring then provided favorable spawning and juvenile rearing conditions for delta smelt in the central and south Delta.

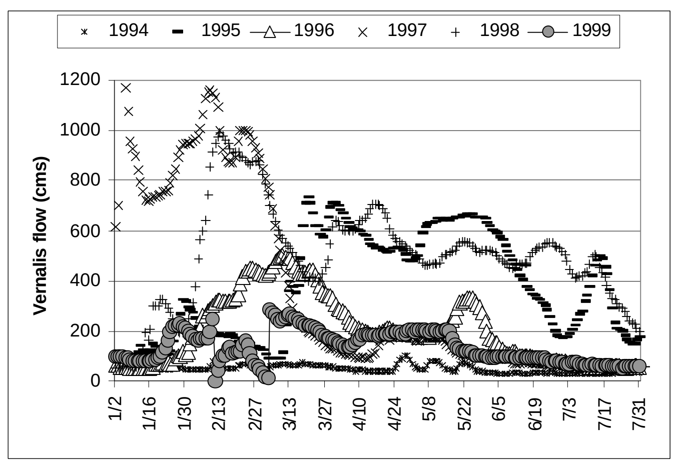


Figure 1 San Joaquin River flows at Vernalis, January 1 through July 31, 1994–1999

Overview of 1996 and 1999 Salvage Patterns

Salvage of young delta smelt at the SWP and CVP Delta fish facilities begins to be quantified each spring when the smelt reach a salvageable length of about 25 mm. Salvage continues into the summer until delta smelt residing in the Delta either: (1) move downstream away from the influence of the Delta export facilities; (2) maintain a position in an area of negative net flow thereby avoiding adverse environmental in the south Delta; or (3) are eventually entrained into the facilities. Obviously, natural mortality also affects the abundance of young delta smelt, but the three outcomes listed here are inferred from the observation that salvage eventually declined during the summer in 1996 and 1999 (Table 2) despite high values of negative central Delta flow (Figures 2B, 2D). Overall, delta smelt salvage at the SWP and CVP fish facilities was much lower and occurred for a shorter period in 1996 than in 1999.

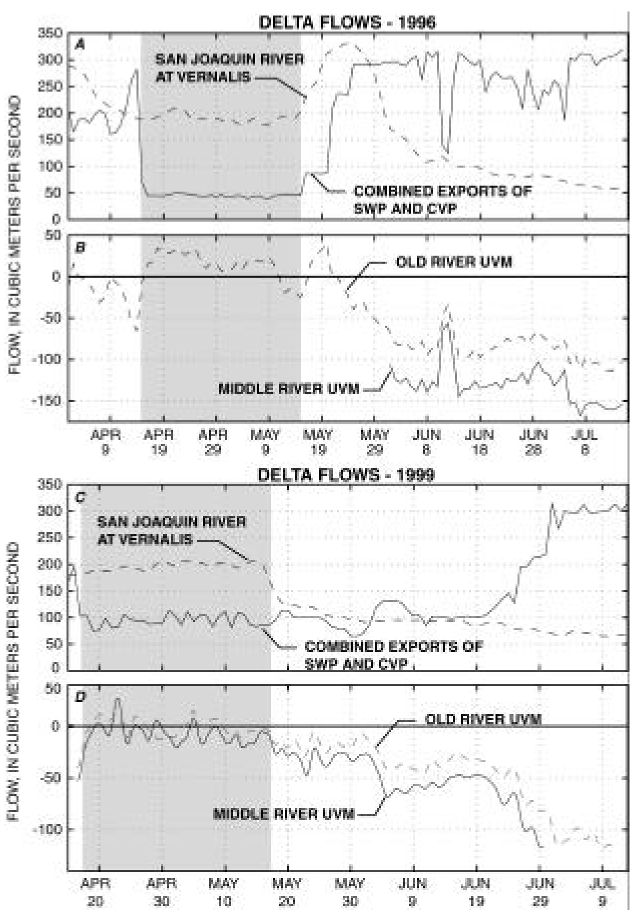


Figure 2 Delta daily and tidally averaged flows and VAMP periods (shaded in gray) for spring 1996 and 1999.

Table 2 Expanded combined monthly delta smelt salvage at the Delta facilities, May through August, 1996 and 1999

Month	*1996*	*1999*
May	30,099	58,943
June	9,465	73,368
July	148	20,272
August	0	48

Pattern of Apparent Delta Smelt Recruitment and Rearing

Delta smelt recruitment from egg to juvenile stages is not monitored in a rigorous manner. The best information we have to track recruitment patterns is length frequency data from the 20-mm Survey. Delta smelt length is a good proxy for age, at least up to 30 mm (Grimaldo and others 1998). However, the survey length frequencies are subject to severe gear bias. As its name implies, the 20-mm Survey is most effective at capturing delta smelt around 20 mm TL. The gear also collects smaller and larger smelt, but it does not provide accurate estimates of abundance relative to 20-mm smelt. Therefore the discussion below should be considered a description of "apparent" patterns of delta smelt recruitment to a size where they are susceptible to the 20-mm gear.

One of the major differences between the 1996 and 1999 salvage patterns was the length of time delta smelt salvage remained at high levels (see Table 2). This was obviously due in part to the extended delta smelt recruitment period described in more detail below. Specific factors that influence delta smelt recruitment have not been thoroughly examined. More research emphasis has been placed on understanding surrogate variables like X2 (Jassby and others 1995). Here we attempt to provide some new insight into these subjects by discussing the 1996 and 1999 recruitment and rearing patterns relative to X2, the interplay of salinity and water temperature, and Delta hydrodynamics.

In 1996 the 20-mm Survey revealed a conspicuous large recruitment of delta smelt, particularly during surveys 3 and 4 (Figure 3A). Smaller peaks during surveys 4 and 5 are noticeable, but relatively few fish less than 20 mm were collected by survey 6, suggesting a cessation of spawning or recruitment through the early larval stage sometime before that survey.

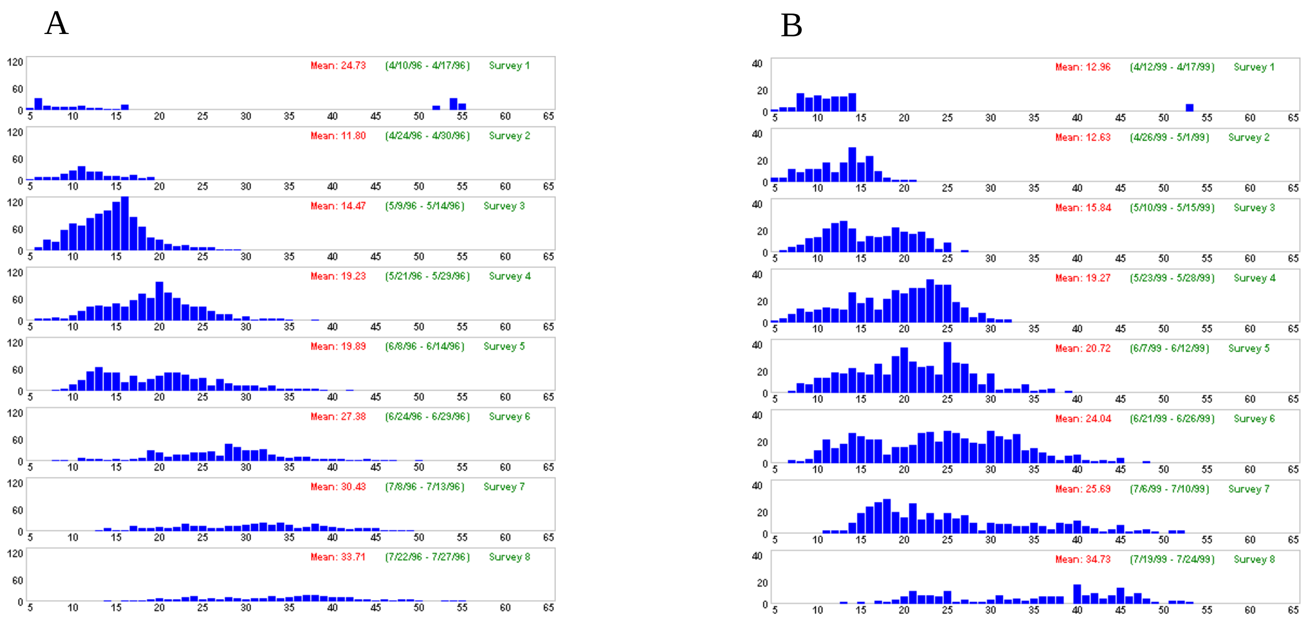


Figure 3 Delta smelt length frequency distributions from 20-mm surveys 1 through 8; (A) 1996 and (B) 1999

The apparent recruitment pattern was noticeably different in 1999 (Figure 3B, note the change in y-axis scale). There were multiple small peaks that are difficult to differentiate among surveys. Peaks in the number of fish less than 20 mm of comparable magnitude to the earlier surveys continued through surveys 6 and 7, suggesting modest levels of successful recruitment occurred through spring and into early summer in 1999. This protracted period of apparent recruitment resulted in a longer period of susceptibility to export entrainment for delta smelt in 1999 compared to 1996.

Delta Smelt Distribution Patterns Relative to X2 in 1996 and 1999

Delta smelt survival is weakly related to the position of X2, the distance upstream from the Golden Gate of the 2 psu isohaline (Moyle and others 1992; Sweetnam 1999). X2 is thought to be a surrogate for several factors important to delta smelt survival, including increased freshwater habitat area, increased transport to favorable habitat, decreased influence of water diversions, and at least historically, increased food availability (Bennett and Moyle 1996). Conditions are thought to be more favorable for delta smelt as X2 assumes a location farther downstream in Suisun Bay. Generally, X2 was farther downstream in 1996 than 1999 between April and July (Figure 4). However, most of the time the differences were fairly small. For example, during the VAMP periods in 1996 and 1999 (approximately mid-April through mid-May each year), the maximum differences in X2 position were about 2 km, a distance equal to about 10% of the length of Suisun Bay.

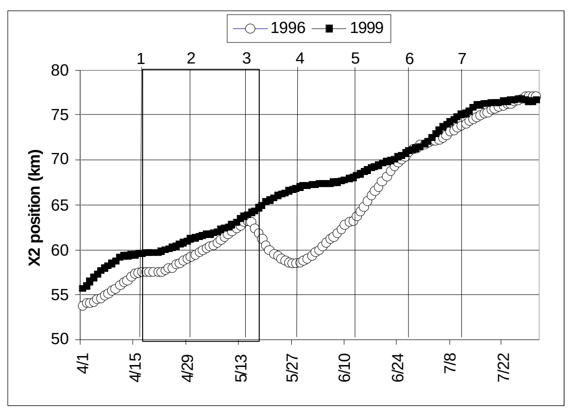
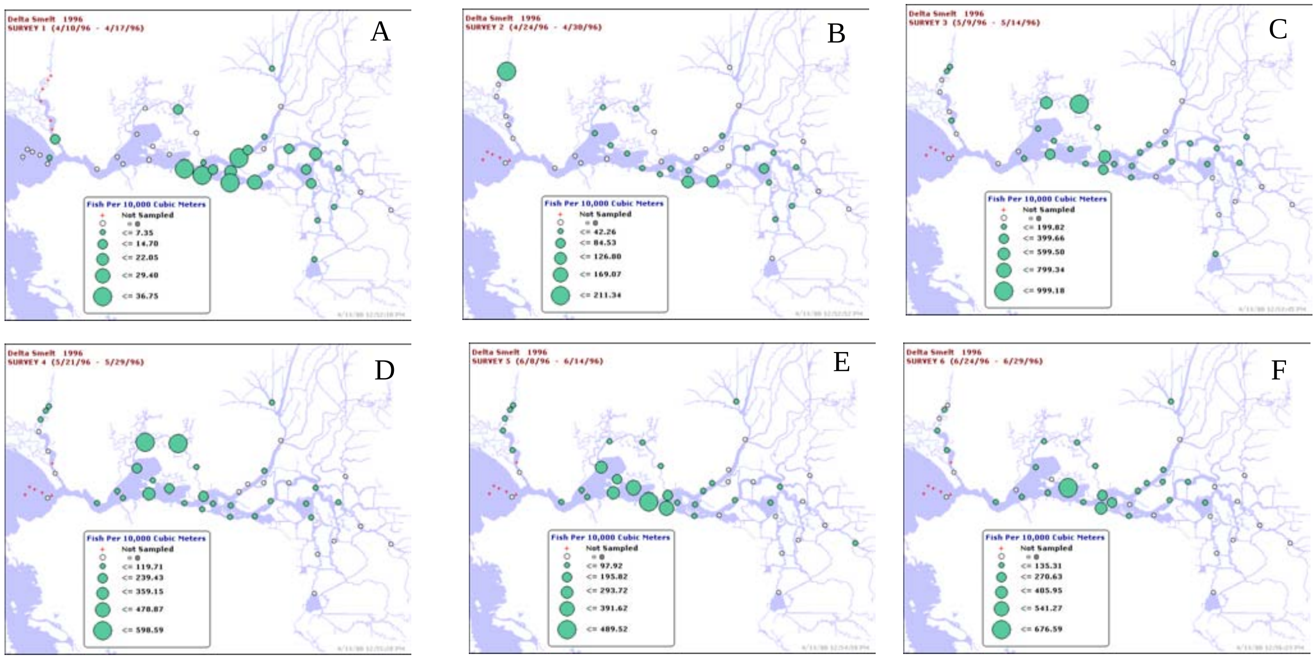


Figure 4 Daily X2 position, April 1 through July 31, 1996 and 1999. VAMP period shaded in gray.

More substantial differences in X2 position (up to 8.4 km) occurred during the month following the VAMP periods in 1996 and 1999 (Figure 4). The 1996 and 1999 20-mm Survey results from surveys 4 and 5 (Figures 5D, 5E and 6D, 6E, respectively) correspond to the period of these larger differences in X2 position between 1996 and 1999.



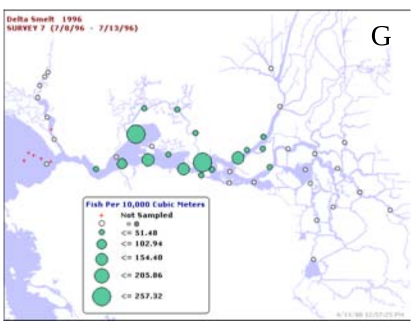


Figure 5 Delta smelt distribution from 1996 20-mm Surveys 1 through 7 (A through G)

The differences in the delta smelt distribution between surveys 4 and 5 in 1996 and 1999 reflect the differences in isohaline position; more delta smelt were distributed somewhat farther downstream in 1996 as was X2.

In 1996 and 1999 X2 position was very similar in late June and early July (Figure 4) during 20-mm Surveys 6 and 7 (Figures 5F, 5G, 6F, and 6G), corresponding to a position in the vicinity of Chipps Island. Not surprisingly, the distribution of the delta smelt covered similar ranges during this time. Peak abundance occurred at different stations during 20-mm surveys 6 and 7 in 1996 and 1999, but some interannual variation is expected.

Despite, the potential utility of X2 as an indicator for delta smelt distribution, it does not correlate well to delta smelt abundance (Jassby and others 1995). X2 by itself also does not provide much insight into why delta smelt were distributed differently at the end of the 1996 and 1999 VAMP periods. Nor does it provide particular insight into the reasons for the different apparent recruitment patterns in 1996 and 1999, or the reasons a larger proportion of the delta smelt population appeared to remain in the interior Delta in 1999 compared to 1996. The following discussion focuses on smaller-scale differences between 1996 and 1999 regarding the interplay of salinity, temperature, and Delta hydrodynamics to provide more insight into the factors affecting young delta smelt recruitment and rearing.

Recruitment Patterns Relative to Smaller-scale Physical Conditions in 1996 and 1999

Several studies examining larval fish recruitment through cohort analysis have found water temperature is a major determinant of cohort survival (Betsill and Van den Avyle 1997; Michaletz 1997; Secor and Houde 1995). Cohort analyses for delta smelt are underway (Dr. Bill Bennett personal communication, see "Note"), but here we look for evidence of temperature relationships using the DFG 20-mm Survey data.

We emphasize this is a less satisfactory method to the more direct cohort analysis approach.

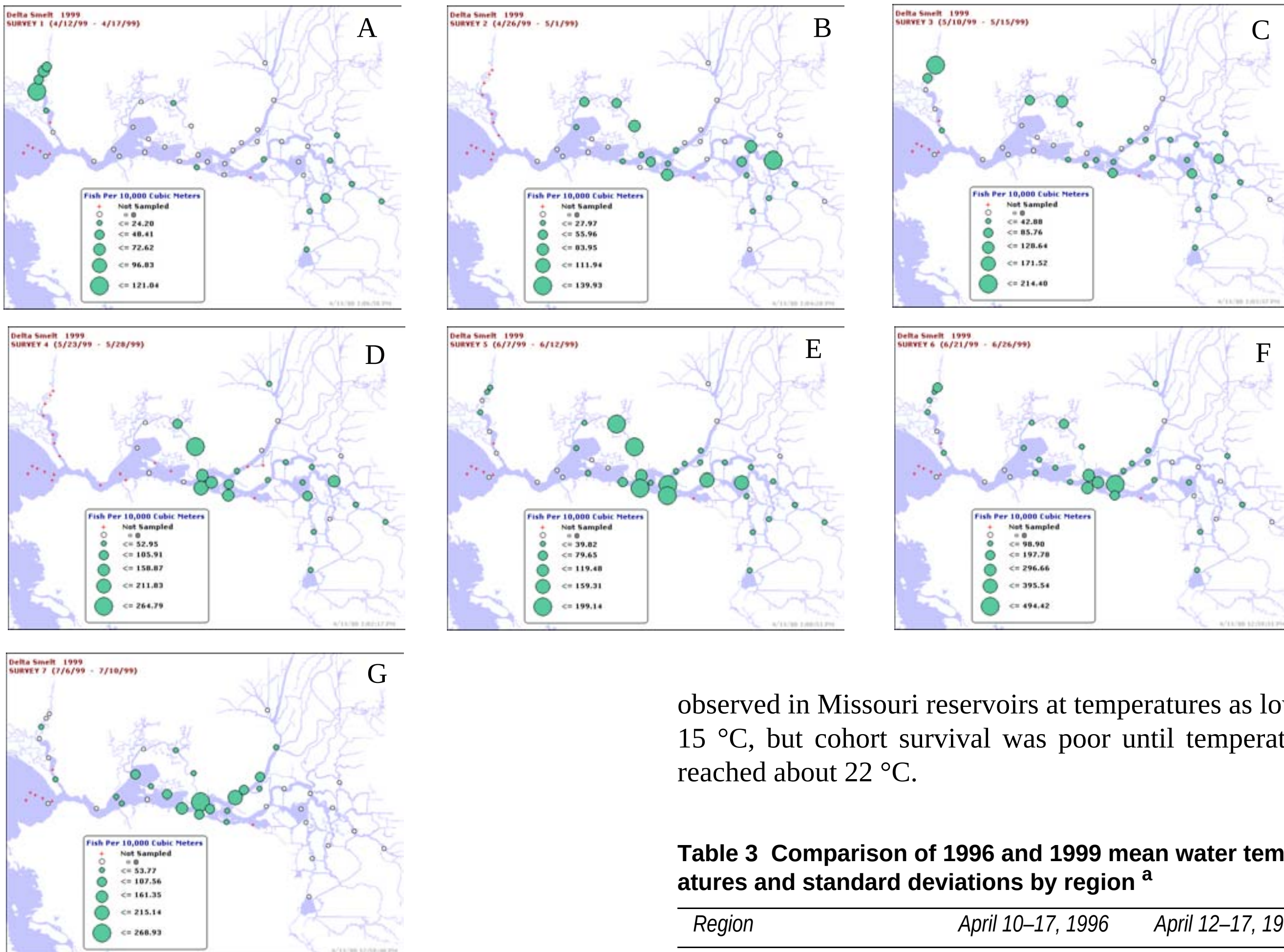


Figure 6 Delta smelt distribution from 1999 20-mm Surveys 1 through 7 (A through G)

With the exception of the Napa River, water temperatures were warmer in all survey areas during the first 20-mm survey in 1996, suggesting an earlier warming of the Delta relative to 1999 (Table 3). Appropriate temperatures system-wide could have prompted spawning over a wide area early on in 1996 (Figure 5A), potentially contributing to the large early season spawning peak (see Figure 3A). In 1999, comparably warm temperatures were only recorded in the Napa River, where the highest densities of smelt larvae were observed during the first 20-mm survey (Figure 6A). These findings suggest a potential relationship between water temperature and delta smelt recruitment past the larval stage. The critical temperature appears to be about 15 °C, even though larvae have been reported at considerably lower water temperatures (Wang 1986). A similar result was reported for threadfin shad (Betsill and Van den Avyle 1997). Larvae were first observed in Missouri reservoirs at temperatures as low as 15 °C, but cohort survival was poor until temperatures reached about 22 °C.

Table 3 Comparison of 1996 and 1999 mean water temperatures and standard deviations by region [a]

Region	*April 10–17, 1996*	*April 12–17, 1999*
Napa River	15.5 (*n* = 1)	16.3 " 0.8
Suisun Bay	16.9 " 1.2	14.8 " 0.6
Confluence	15.5 " 0.5	13.8 " 0.8
Central Delta	16.1 " 0.3	12.2 " 0.3
South Delta	17.9 " 0.2	13.2 " 1.1

[a] Data taken from 20-mm Survey 1.

The extended recruitment period in 1999 may have also been temperature-related. Larval threadfin shad survival (Betsill and Van den Avyle 1997) and larval striped bass mortality (Secor and Houde 1995) were both described as quadratic functions of temperature, where survival was lower (or mortality higher) on either side of an optimum temperature range. Average water temperature data collected during the 20-mm Survey indicate 1996 and 1999 went back and forth regarding which year had the cooler temperatures (Table 4). However, the rapid warming of Delta waters between surveys 4 and 5 in 1996 may have been sufficient to cause the cessation of spawning (or may have substantially reduced egg and larval survival). This relationship between recruitment and water temperature is speculative and should be researched further. Other factors, like food availability, may also have contributed to the recruitment differences between 1996 and 1999; however, sufficient comparative data on other environmental factors were not available.

Table 4 Average surface water temperatures and standard deviations from all stations sampled during the 20-mm Surveys 3 through 6, 1996 and 1999

Survey Number (Month)	*1996*	*1999*
3 (May)	19.1 " 1.1	16.5 " 0.7
4 (May)	16.9 " 1.4	18.7 " 1.4
5 (June)	22.0 " 1.5	18.5 " 1.1
6 (June)	20.4 " 1.7	21.5 " 1.6

Young Delta Smelt Rearing Relative to Smaller-scale Physical Conditions in 1996 and 1999

Grimaldo and others (1998) found a significant positive relationship among the age, size, and location of young delta smelt collected in 1996. Older, larger individuals were found in greater proportions in Suisun Bay, while size and age declined among delta smelt collected farther upstream. These results suggest rearing delta smelt actively seek specific habitat conditions as they grow. Grimaldo and others (1998) hypothesized the older smelt were seeking a particular salinity range. As discussed in the X2 section, the position of the low salinity zone is thought to be a major environmental factor affecting juvenile and pre-spawning adult delta smelt distribution (Moyle and others 1992; Sweetnam 1999). However, the possibility of ontogenetic changes in delta smelt's response to factors influencing distribution has not been explicitly studied.

Like all osmerids, the delta smelt is a cool water fish. Moyle and others (1992) reported that it was not collected in the field at temperatures over 23 °C. Its critical thermal maxima are lower than that of chinook salmon and are affected by salinity (Swanson and Cech 1995). Delta smelt tolerated slightly higher water temperatures at 4 ppt than at zero salinity. It would be worthwhile to study the interplay between salinity and temperature further, especially as they relate to conditions occurring in the Delta.

In an initial attempt to investigate the interplay between salinity and temperature, we used delta smelt relative abundance anomalies calculated from 20-mm Surveys 3 through 6 in 1996 and 1999. We used surveys 3 through 6 because these were the surveys that had average delta smelt lengths closest to 20 mm, hopefully reducing size bias due to gear selection. The anomalies were calculated by subtracting the average delta smelt density (number of fish per 10,000 m^3 of water) at all stations sampled for each survey, from the density at each individual station (similar to Obrebski and others 1992). Values greater than zero indicate above average relative abundance and provide a means of assessing the environmental conditions present where higher than average delta smelt abundance was recorded.

The delta smelt abundance anomalies relative to log-transformed specific conductance are shown in Figure 7. Although higher than average relative abundance of delta smelt was occasionally found where surface specific conductance corresponded to salinity greater than 6 ppt (log specific conductance > 4) (Napa River), almost 90% of the positive anomalies were recorded from stations where the surface specific conductance corresponded to a salinity of less than 1 ppt (<3.2 log specific conductance). It is very likely that surface and bottom specific conductance (which was not measured) were different at many of these sites. However, this principally freshwater distribution suggests the possibility that delta smelt may not require, or even be seeking, brackish water habitat this early in their life cycle.

The anomalies also show an interesting pattern in relation to water temperature (Figure 8). In all but one survey in 1996 and 1999, the distribution of positive anomalies is "bounded" between 16 °C and 24 °C (60.8 °F and 75.2 °F), with evidence of a time trend in 1999. In 1999, positive anomalies from the earliest survey (3) are skewed toward the warmer temperatures sampled, while positive anomalies from survey 6 are skewed toward the cooler temperatures sampled. Positive anomalies from the middle two surveys all fall within the range defined by surveys 3 and 6. The trend is less evident in 1996 because water temperatures were cooler during survey 4 than survey 3. Nonetheless, the positive anomalies are still generally bounded as described for 1999. This suggests delta smelt may seek a fairly narrow temperature range.

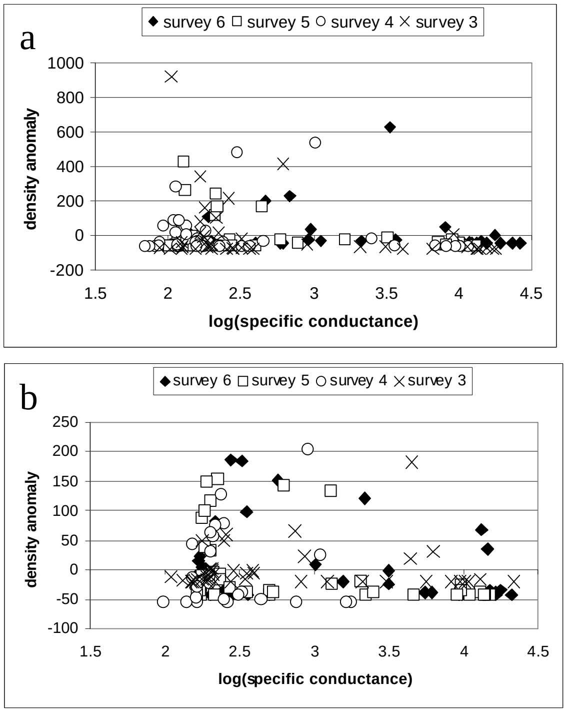


Figure 7 Log$_{10}$(surface specific conductance) versus anomalies of delta smelt relative abundance from 20-mm Surveys 3 through 6, (a) 1996 and (b) 1999

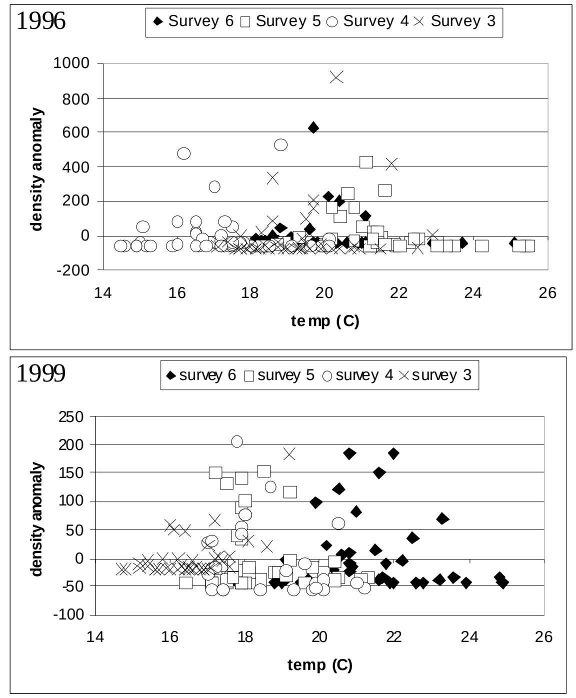


Figure 8 Surface water temperatures versus anomalies of delta smelt relative abundance from 20-mm Surveys 3 through 6, 1996 and 1999

This analysis could be biased by project operations since the warmest temperatures were usually recorded in the south Delta. Nonetheless, Swanson and Cech's (1995) research suggests a limit should be expected near the mid-20s (°C), since it is reasonable to expect fish leave areas near lethal temperatures.

Delta Hydrodynamics

We also think the differences in 1996 and 1999 salvage patterns were partly due to differences in Delta hydrodynamics, particularly differences associated with the VAMP. There are three remarkable hydrodynamics-salvage phenomena. First, there were clear differences in central Delta flows during the 1996 and 1999 VAMP periods. Second, there were clear differences in the export ramp-up following the VAMP pulse flow periods that resulted in relatively rapid increases in negative central Delta flow in 1996 compared to 1999. Again, this occurred despite an X2 position that was farther downstream in 1996 compared to the equivalent period in 1999. Third, peaks in salvage density corresponded to abrupt changes in central Delta flows.

As stated above, San Joaquin River inflow was slightly higher during much of winter and spring 1996 compared to 1999, and 1996 had a late May pulse flow which did not occur in 1999. However, potentially important details of how inflow to the Delta translates into Delta outflow can be clouded by the proportion of flow coming from the Sacramento and San Joaquin basins and by the level of water project exports. The tidally-averaged UVM central Delta flow data (Figures 2B, 2D) are a direct measure of flow at the Old and Middle river stations adjacent to Bacon Island and, therefore, provide an unambiguous measure of Delta hydrodynamics.

The USGS UVM data show an interesting contrast between the VAMP periods in 1996 and 1999. Central Delta flow (only data from Old River UVM available for 1996) was typically positive during the VAMP period in 1996 (Figure 2B), but fluctuated around zero during the 1999 VAMP period in Old River, to slightly negative values in Middle River in 1999 (Figure 2D). These differences were primarily due to lower export levels during the VAMP period in 1996 compared to 1999 (Figures 2A, 2C). The proportion of larvae successfully spawned in different regions of the estuary is unknown, but presumably positive Delta flow in 1996 would have helped move larvae spawned in the central and south Delta farther downstream. The 20-mm survey data from 1996 and 1999 appear to support this hypothesis. The timing of 20-mm Survey 3 approximately corresponded to the end of the VAMP periods in both 1996 and 1999. The results from the third survey for each year (Figures 5C, 6C) show a substantially greater proportion of the delta smelt population was located at or downstream of the confluence in 1996 (93%) than in 1999 (68%).

There is a second important hydrodynamic contrast illustrated in the central Delta flow data. The increase in San Joaquin River flow following the 1996 VAMP only briefly maintained positive values of central Delta flow because of the relatively rapid export ramp-up (Figures 2A, 2B). By the first week of June, negative central Delta flows were at levels not observed in 1999 until July (Figure 2D). Thus, if larvae hatched in the interior Delta after the 1996 VAMP period, they would have likely been entrained to the facilities before reaching a size they would be counted (25 mm). This may not have been the case in 1999. The lower magnitude of negative central Delta flow (Figure 2D) combined with a protracted period of recruitment are thought to have allowed more delta smelt to rear in the central and south Delta up to and beyond 25 mm TL. The net result was an extended period of high delta smelt salvage.

Additional evidence to support our hypothesis is provided by the work of Grimaldo and others (1998), who calculated the ages of delta smelt collected during 20-mm Surveys 7 and 8 in 1996. A re-analysis of these data indicates 62% of delta smelt collected in these surveys were born during the VAMP period when Delta exports were low (Figure 9). Keep in mind that by surveys 7 and 8 most delta smelt had grown too large to be sampled effectively by the 20-mm gear; thus the proportion of fish born before and during VAMP is seriously underrepresented in this analysis.

Comparison of salvage and flow data also shows peaks in delta smelt salvage density coincided with abrupt changes in central Delta flow. In 1996, salvage density (Figure 10A) showed one distinct peak during mid-May that coincided with the installation and removal of the head of Old River barrier. Installing the barrier changed the flow direction in Old River. Most of the time however, salvage density was #1 smelt/10,000 m^3 because most of the young smelt were located in downstream habitats by this time (Figure 5C).

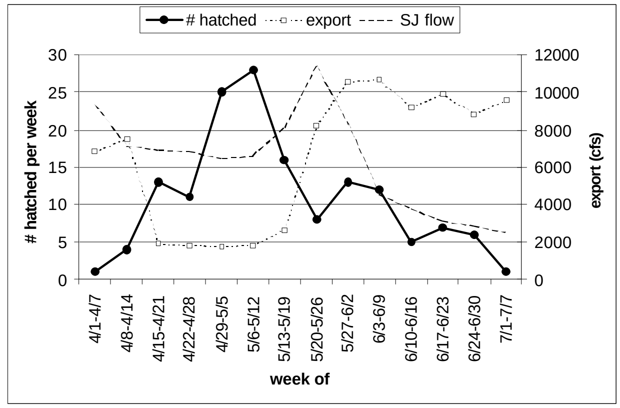


Figure 9 Estimated number of delta smelt hatched per week, San Joaquin River flow at Vernalis, and combined Delta exports, April 1 through July 7, 1996

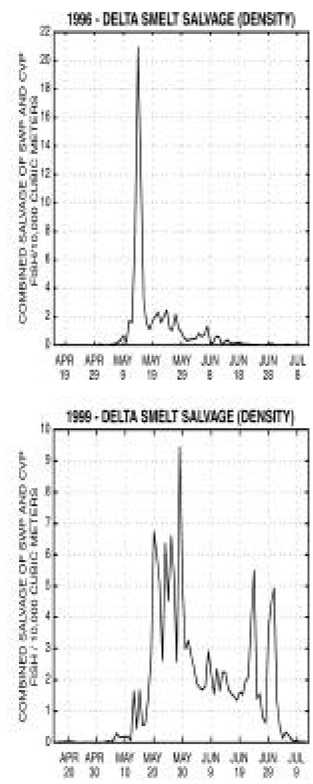


Figure 10 Expanded combined SWP and CVP salvage of delta smelt per 10,000 cubic meters of water exported from April through July in 1996 and 1999

This contrasts with 1999 when salvage density remained $2 smelt/10,000 m^3 for most of a 50-day period from mid-May to early July (Figure 10B). As in 1996, the peaks in salvage density in 1999 were associated with changes in Delta hydrodynamics. The first large peak in salvage density occurred after the VAMP period, when central Delta flow became consistently negative as a result of the decrease in San Joaquin River flow (Figures 2C, 2D). Salvage density actually declined during the next increase in negative central Delta flow, but increased again when exports were quickly ramped up at the end of June.

An estimated 48,780 delta smelt were salvaged during the last week of June and first week of July 1999. This was the last large young delta smelt salvage event of the season and it primarily occurred in between 20-mm Surveys 6 (June 21 to 26) and 7 (July 6 to 11). As stated above, increasingly negative central Delta flow during summer means there are basically two kinds of young delta smelt —those that move (or stay) downstream away from the influence of the export facilities, and those that will eventually be entrained to the facilities (the minority in both years).

During Survey 6 in 1999, some delta smelt were collected from Franks Tract and stations 915 and 910 in the south and east Delta respectively (see Figure 6F). By Survey 7 (see Figure 6G), no delta smelt were collected from the San Joaquin system upstream of Sherman Island. The UVM velocity data were used to estimate that during this period, water could travel from Frank's Tract to the export facilities in about two days. We think the late June and early July 1999 salvage event represented the removal of delta smelt that remained in the interior Delta beyond survey 6.

SUMMARY AND CONCLUSIONS

Moderate winter and spring San Joaquin River flow may provide attractive conditions for spawning adult delta smelt. The presence of high numbers of adults in the DFG spring midwater trawl surveys in 1996 and 1999 relative to other years suggests this is the case. So far in 2000, San Joaquin River flows have been similar to 1996 and 1999, and we expect to see that substantial delta smelt spawning in the central and south Delta.

Our re-analysis of the 1996 and 1999 delta smelt salvage patterns suggests differences in salvage were due to the interaction of two main factors: (1) a relatively long apparent recruitment period in 1999 relative to 1996; and (2) differences in VAMP and post-VAMP hydrodynamics within the interior Delta, which probably facilitated the retention of a larger proportion of the smelt population in 1999.

We are not certain what factors contributed to differences in the apparent recruitment patterns of delta smelt observed between 1996 and 1999; however, we think water temperature differences and central Delta flow differences were important factors. Water temperature and environmental factors other than flow cannot be effectively managed. However, Delta hydrodynamics can be managed. San Joaquin River flow forecasts for 2000 are very similar to both 1996 and 1999, about 200 m^3/s. As stated above, the differences in central Delta flows between 1996 and 1999 were primarily due to different levels of project exports. Preliminary modeling results from the DWR Technical Modeling Group (not shown) predict the central Delta flow pattern for the 2000 VAMP period will resemble the 1999 pattern. In other words, the tidally-averaged central Delta flows are forecast to be near zero to slightly negative. We recommend maintaining project exports during the VAMP to achieve sustained positive central Delta flows. Positive central Delta flows should help move larvae that hatch in the central and south Delta downstream away from the influence of the export facilities once pumping resumes at the end of the VAMP period.

Comprehensive analyses like the one presented in this paper are limited by the available data. These limitations could be substantially reduced with a more comprehensive monitoring program and new research elements designed to improve our understanding of delta smelt recruitment dynamics (some of which is underway). Despite the large differences in salvage between 1996 and 1999, both years had similar summer tow-net indices, which were among the highest post-decline values. This further emphasizes the need to put research effort into understanding the factors influencing delta smelt recruitment. We suggest the following:

- Cohort analysis based on comparisons of delta smelt otolith microstructure from various surveys. Ideally, this would involve an egg and larval survey as well.

- Annual monitoring of feeding success.

- Studies to determine whether ontogenetic shifts exist in the delta smelt's response to factors influencing distribution patterns. The interplay of salinity and temperature should be emphasized.

REFERENCES

Bennett WA, Moyle PB. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin estuary. In: Hollibaugh JT, editor. San Francisco Bay: the ecosystem. San Francisco (CA): Pacific Division, American Association for the Advancement of Science. p 519–42.

Betsill RK, Van Den Avyle MJ. 1997. Effect of temperature and zooplankton abundance on growth and survival of larval threadfin shad. Trans Am Fish Soc 126:999–1011.

Grimaldo L, Ross B, Sweetnam D. 1998. Preliminary results on the age and growth of delta smelt (*Hypomesus transpacificus*) from different areas of the estuary using otolith microstructure analysis. IEP Newsletter 11(1):25–8.

Jassby AD, Kimmerer WJ, Monismith SG, Armor C, Cloern JE, Powell TM, Schubel JR, Vendlinski TJ. 1995. Isohaline position as a habitat indicator for estuarine populations. Ecol App 5:272–89.

Michaletz PH. 1997. Factors affecting abundance, growth, and survival of age-0 gizzard shad. Trans Am Fish Soc 126:84–100.

Moyle PB, Herbold B, Stevens DE, Miller LW. 1992. Life history and status of delta smelt in the Sacramento-San Joaquin Estuary, California. Trans Am Fish Soc 121:67–77.

Nobriga M, Veldhuizen T, Hymanson Z. 1999. Delta smelt concerns result in changes in SWP and CVP operations. IEP Newsletter 12(3):33–4.

Obrebski S, Orsi JJ, Kimmerer W. 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin Estuary. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 32. Sacramento (CA): California Department of Water Resources. 42 p.

Oltmann RN. 1998. Measured flow and tracer-dye data showing anthropogenic effects on the hydrodynamics of south Sacramento-San Joaquin Delta, California, spring 1996 and 1997. USGS Open-File Report 98–285. Sacramento (CA): U.S. Geological Survey. 16 p.

Secor DH, Houde ED. 1995. Temperature effects on the timing of striped bass egg production, larval viability, and recruitment potential in the Patuxent River (Chesapeake Bay). Estuaries 18:527–44.

Swanson C, Cech JJ, Jr. 1995. Environmental tolerances and requirements of the delta smelt, *Hypomesus transpacificus*. Final Report to the California Department of Water Resources. 77 p.

Sweetnam DA. 1999. Status of delta smelt in the Sacramento-San Joaquin Estuary. California Fish and Game 85: 22–7.

Wang JCS. 1986. Fishes of the Sacramento-San Joaquin Estuary and adjacent waters, California: a guide to the early life histories. Interagency Ecological Program for the Sacramento-San Joaquin Estuary Technical Report 9. Sacramento (CA): California Department of Water Resources. unnumbered.

NOTE

Dr. Bill Bennett. Bodega Marine Laboratory, University of California, Davis. E-mail communication with Matt Nobriga on April 5, 2000.