Evidence of Food Limitation in Larval Delta Smelt

Matt Nobriga, DWR

Understanding delta smelt population dynamics has proven to be a difficult task. The species has no significant stock-recruitment relationship, and relationships between abundance and X2 are not as strong as those found for other species (Jassby *et al* 1995). This suggests factors other than number of spawners and Delta outflow play important roles in determining year class strength.

Food supply may be one factor affecting the year class strength of delta smelt (Bennett and Moyle 1996). Food supply can be important to the survival of planktivorous fishes, especially the larvae, because spatial and temporal variations in prey abundance can affect survival through the larval stage (Lasker 1984; Limburg *et al* 1997). Zooplankton communities within the Delta have undergone substantial alterations over the past 20 years, principally through introduced exotic species (Kimmerer and Orsi 1996). Although not previously studied, the effects of zooplankton community changes on delta smelt may be important in understanding delta smelt population dynamics. This paper presents the results of a three-year study of larval delta smelt food habits. The study looked specifically at diet composition, diet shifts, electivities, and for possible associations between food supply and larval delta smelt distribution and abundance.

Methods

The study was based on examination of 1,552 larval delta smelt captured between 1992 and 1994 by the DFG Egg and Larval (EL) Survey. Larvae up to 20mm were organized by 1mm length groups. Gut contents of fish within the various length groups were enumerated and identified to lowest practical taxon. Prey numbers resulting from gut contents analyses were converted into dry weights using literature values and unpublished data from Jim Orsi (DFG).

Diet shifts were analyzed using an Index of Relative Importance, or IRI (see Lott, this issue, for the equation). The index assesses numeric percent, weight percent, and frequency of occurrence of gut contents. This allows for a standardized comparison for determining the importance of different sized prey. An IRI was calculated for each prey type consumed by fish within each length group (5-20mm) each year.

Diet electivity was assessed with Vanderploeg-Scavia electivity indices, E* (Lechowicz 1982) and Spearman rank correlations. The E* index equals zero when feeding is random on available prey, -1 when a prey item is completely avoided, and has a maximum value dependent on the number of prey types assessed. Four prey types were assessed in this study, resulting in a maximum index value of +0.6.

Two sets of electivity calculations were made. One for 5-6mm smelt and the other for 12-20mm smelt. Prey size varied with larval length, requiring different zooplankton databases for accurate prey density information. Neomysis/Zooplankton (NZ) Survey pump samples provided the best density information on rotifers and subadult copepods (nauplii and copepodids). The Clarke-Bumpus samples taken concurrently with the EL samples provided the best density information on adult-sized copepods. Prey eaten by 7-11mm smelt could not be definatively assigned to either zooplankton database, so 7-11mm larvae were not included in the electivity analyses. Electivity calculations for 5-6mm smelt were based on NZ data. Since the NZ samples were not taken at the same times as the larval samples, the 5-6mm electivity results should be considered "best available information."

Table 1. Spearman Rank Correlation Results for 12-20mm Delta Smelt Electivity Interactions between *E. affinis* and *P. forbesi*

Significant correlation coefficients (α=0.05) are shown in bold type

Comparison	Vanderploeg-Scavia E* for	
	E. affinis E* vs.	*P. forbesi* E* vs.
P. forbesi E*	**-1**	-
E. affinis/m^3	0.7827	-
P. forbesi/m^3	-	0.6377
Ratio of *E. affinis*/m^3 to *P. forbesi*/m^3	**0.8697**	**-0.8697**

Table 2. Numbers of 10-25mm Delta Smelt Caught in Different Delta Regions

Times of peak *E. affinis* abundance are shown in bold type.
Sampling effort was the same in each two week period.

	Sacramento River Channel	Sacramento River Sloughs	San Joaquin River	Montezuma Slough	Oth. Suisun
1993					
First half of April	0	2	0	0	1
Second half of April	0	6	4	17	14
First half of May	5	7	7	61	16
Second half of May	1	9	9	2	2
1994					
First half of April	0	0	5	1	0
Second half of April	13	21	77	2	0
First half of May	29	16	85	1	0
Second half of May	5	6	6	1	0

Analyses were also completed to identify possible associations between food supply and larval smelt distribution and abundance. A modified IRI equation was used for these analyses to examine whether certain regions of the estuary might provide better feeding opportunities for larval smelt around the time of yolk-sac absorption. The modified index, IRC (Index of Regional Consumption), was calculated as follows for 6-8mm larvae in each of four regions (Suisun Bay, Sacramento River channel, Sacramento River sloughs, and San Joaquin River) each year:

$$IRC = (N/F + W/F)FI$$

where

N/F = (total number of prey items eaten/number of fish in the sample)*100

W/F = (total dry weight of all prey items eaten/number of fish in the sample)*100

FI = percent of fish in the sample that had at least one prey item in the gut

Results

Copepods comprised 97.2% of the diet by number and 99.3% by weight. Other organisms eaten rarely included cladocerans (1.1% of the diet by number and 0.6% by weight) and rotifers (1.7% of the diet by number and 0.1% by weight). A chironomid head capsule was found in a fish captured in 1994. Detritus particles and sand were found occasionally. Only one diatom was seen in 1,552 fish. No other evidence of plant food was found.

Diet by length group is presented in Figure 1. There was a distinct and generally consistent diet shift in all three years. First feeding delta smelt ate copepod nauplii and copepodids (juveniles), the smallest prey types. Calanoid and cyclopoid copepodids, which are larger than nauplii, were the most important prey items for 7-9mm smelt. The final diet shift to the largest prey, adult-sized copepods, occurred in 10-12mm larvae.

First feeding (5-6mm) larvae had the highest electivity (averaged over all three years) for cyclopoid copepodids (mean E* = 0.568). Mean electivity values for other prey items were: nauplii (-0.692), rotifers (-0.944), and calanoid copepodids (-0.967). High electivity values for cyclopoid copepodids may have resulted in underestimating the importance of nauplii. Comparison with NZ data shows nauplii were eaten 1.25 times more frequently than their occurrence relative to other prey types, so it is likely that some electivity exists for them. Larger larvae (12-20mm) had highest electivity (averaged over all three years) for *Eurytemora* (mean E* = 0.496). Mean electivity values for other prey items were: *Pseudodiaptomus* (-0.460), cyclopoids (-0.897), and *Sinocalanus* (-0.907).

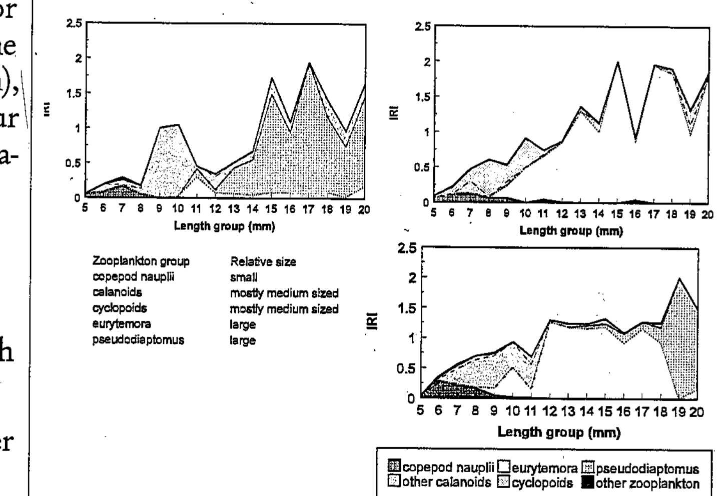


Figure 1
Larval delta smelt diet by length group. Other calanoida and cyclopoida are principally copepodids (juveniles). Other zooplankton is a combination of rotifers, cladocerans, and harpacticoid copepods.

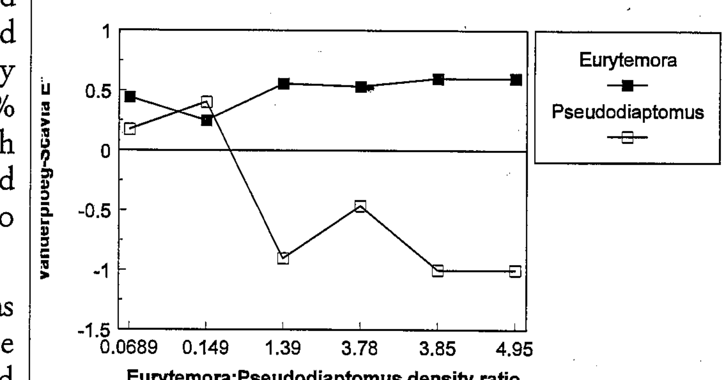


Figure 2
Electivity trend of 12-20mm delta smelt at different relative abundances of *Eurytemora* and *Pseudodiaptomus*. Note that the X-axis is not continuous. It is six discrete ratios from the six subsamples from which the electivity indices were calculated.

Spearman rank correlations were used to analyze electivities of 12-20mm smelt towards *Eurytemora* and *Pseudodiaptomus* (Table 1). *Pseudodiaptomus* E* values were inversely proportional to *Eurytemora* E* values (r_s = -1; p=0.00). Delta smelt electivity for these copepods was not correlated to their individual densities; however, *Eurytemora's* E* values were correlated to its environmental density relative to *Pseudodiaptomus'* environmental density (p=0.0244). The inverse relationship between the E* values for the two copepods results in a negative correlation between the *Pseudodiaptomus* E* values and the *Eurytemora:Pseudodiaptomus* density ratio (p=0.0244). Examination of the electivity trend at different relative densities of the two copepods showed that similar electivity for both only occurred when Pseudodiaptomus' density was much higher than *Eurytemora's* (Figure 2). Overall these results suggest that *Eurytemora* is the most elected prey of 12-20mm delta smelt, but its election is a function of its abundance relative to the abundance of *Pseudodiaptomus*.

Catch trends for 5-8mm delta smelt, with IRC values for post yolk-sac larvae, are presented in Figure 3. These data presentations are similar to the approach used by Kimmerer (1997) to examine "apparent mortality" in striped bass. The assumption is that steeper declines between the two length groups are evidence of higher mortality rates. The key point is that steep declines in catch occur at lengths that yolk-sac absorption occurs (Doroshov and Mager 1995). Sacramento River larvae tended to have steeper slopes and lower IRC values than larvae from other regions. San Joaquin River larvae had negative "apparent mortality" in 1992 and 1994. This is presumably an artifact of cross-Delta transport. However, IRC values for San Joaquin River larvae were typically high, indicating relatively good feeding conditions.

Mean regional densities of zooplankton most commonly eaten by 5-8mm delta smelt are shown in Figure 4. High IRC values each year occurred in regions of high prey density. This suggests that smelt larvae were better fed where prey concentrations were higher.

The confounding effects of flow on larval distribution make determining actual mortality rates impossible. It is also very possible that high densities of zooplankton and smelt larvae co-occur simply because Delta hydrology affects both similarly. However, critical period theory predicts that larval survival at first feeding is affected by food supply (Diana 1995), with well-fed populations expected to have higher survival rates than food-stressed populations. A significant relationship was found between IRC (an index of how well fed a group of fish is) and catch per tow of 7-8mm delta smelt (Figure 5). The results of the same analysis done on 6mm larvae was not significant (r^2 = -0.09, p = 0.688), indicating that food supply becomes important when yolk-sacs are absorbed.

Evidence of a food supply effect was also found in larger larvae. In 1993 and 1994 high densities of 10-25mm smelt were found in areas of higher than average *Eurytemora* abundance (Figure 6). In 1993, a wet year, this area was Montezuma Slough, while in 1994, a critically dry year, it was the San Joaquin River. In both years, *Eurytemora* density declined significantly between the first and second two weeks of May (1993: t = 4.15, p = 0.003; 1994: t = 2.97, p = 0.013). Catches of 10-25 mm delta smelt declined significantly at the same times (1993: t = 3.66, p = 0.006; 1994: t = 4.31, p = 0.001).

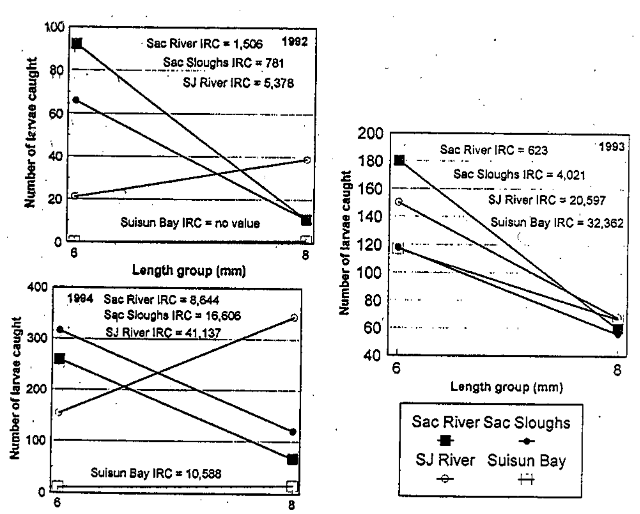


Figure 3
Numbers of delta smelt larvae caught in four Delta regions. The length groups represent yolk-sac (5-6mm) and post yolk-sac sized (7-8mm) larvae. IRC values are for post yolk-sac larvae.

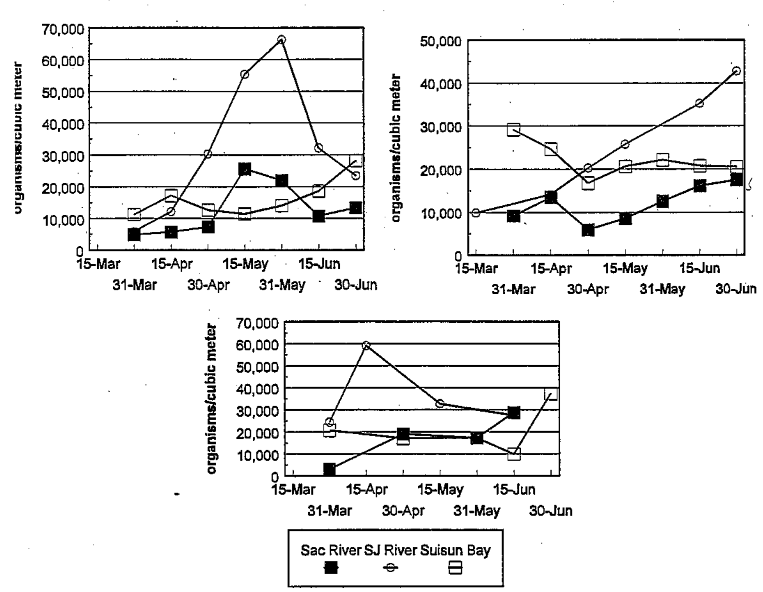


Figure 4
Mean densities of mircozooplankton (copepod nauplii, calanoid, and cyclopoid copepodids) most commonly eaten by first feeding delta smelt larvae as measured by DFG Neomysis/Zooplankton project. Most of the smelt larvae eating these prey items were captured between March 1 and May 15 each year.

Conclusion

The key finding of this study is that food supply appears to have an effect on larval delta smelt survival. This conclusion is supported by new data on the prey requirements of young smelt. The larvae require prey of certain sizes as they grow. (Unlike striped bass larvae, they are not able to capture adult-sized copepods at first feeding.) Additionally, delta smelt larvae have highest electivity for native copepods that have undergone long-term declines in abundance (Obrebski *et al* 1992). Delta smelt larvae did not show much electivity for any introduced species, even though juveniles do (see Lott, this issue).

This study provides evidence that there is a critical feeding period for delta smelt larvae that coincides with yolk-sac absorption, a phenomenon suspected of occurring in most fishes with a similar life history (Diana 1995). Another period of high larval mortality may occur each spring when *Eurytemora* declines in the estuary. An additional bottleneck may also occur as the smelt transition out of the larval stage (see Lott, this issue).

The question remains whether these bottlenecks are affecting year class strength. Since critical larval periods occur during spring, effects should be noticeable in the summer townet index. Delta smelt year class strength is estimated by the fall midwater trawl index, but there is a significant relationship between the two indices (Figure 7). Summer townet indices have remained low since the introductions of *Potamocorbula* and *Pseudodiaptomus* in 1986 and 1987, respectively, indicating that fewer smelt now survive into the summer. The predicted result should be lower recruitment as measured by the fall MWT index.

However, this has not always been the case. The linear relationship between the two indices has deteriorated substantially since 1986 (r^2 has dropped from 0.37 to 0.19), perhaps due to a sporadic period of increased summer mortality that remains to be explained.

Acknowledgments

I would like to thank Dale Sweetnam, Jim Orsi, Lee Miller, and Jenni Lott of DFG for the use of data and review of my results. I would also like to thank Randy Brown, Ted Sommer, and Zach Hymanson of DWR for review of the paper.

Literature Cited

Bennett, W.A., and P.B. Moyle. 1996. Where have all the fishes gone? Interactive factors producing fish declines in the Sacramento-San Joaquin estuary, in Hollibaugh, J.T. (Ed.), San Francisco Bay: the Ecosystem. Pacific Division/American Association for the Advancement of Science. 542 pp.

Diana, J. S., 1995. Biology and ecology of fishes. Cooper Publishing Group, Carmel, IN, 441 pp

Doroshov, S., and R. Mager, 1995. Laboratory culture of delta smelt. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary

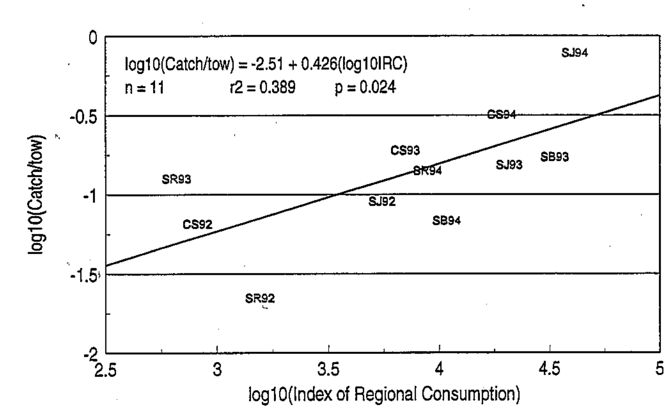


Figure 5
Relationship between Index of Regional Consumption (IRC) and catch per tow for larval delta smelt. Data points are a region (SR=Sacramento River, SJ-San Joaquin River, CS=Cache Slough, and SB=Susisun Bay) and a year (92=1992, 93=1993, 94=1994).

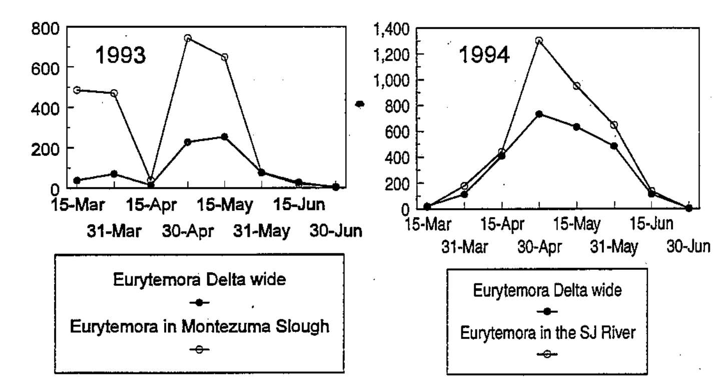


Figure 6
Mean density (organisms per cubic meter) of *Eurytemora* at all delta stations combined, and of *Eurytemora* in the area of highest 10-25mm delta smelt abundance for 1993 (Montezuma Slough) and 1994 (San Joaquin River).

Newsletter, autumn 1995: 31 pp.

Jassby, A. D., W. J. Kimmerer, S. G. Monismith, C. Armor, J. E. Cloern, T. M. Powell, J. R. Schubel, and T. J. Vendlinski, 1995. Isohaline position as a habitat indicator for estuarine populations. Ecological Applications 5: 272-289.

Kimmerer, W. J., 1997. Flow effects and density dependence in striped bass. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary Newsletter, autumn 1997: 31 pp.

Lasker, R., 1984. The role of a stable ocean in larval fish survival and subsequent recruitment, in R. Lasker (Ed.), Marine fish larvae: morphology, ecology, and relation to fisheries. University of Washington Press, Seattle, WA. 131 pp.

Lechowicz, M. J., 1982. The sampling characteristics of electivity indices. Oecologia 52: 22-30.

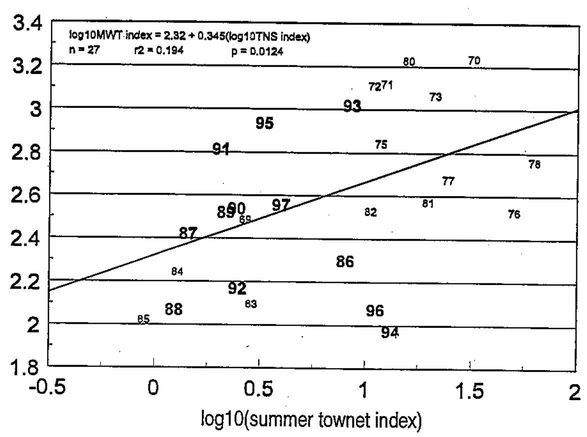
Limburg, K. E., M. L. Pace, D. Fischer, and K. K. Arend, 1997. Consumption, selectivity, and use of zooplankton by larval striped bass and white perch in a seasonally pulsed estuary. Transactions of the American Fisheries Society 126: 607-621.

Merz, J. E. and C. D. Vanicek, 1996. Comparative feeding habits of juvenile chinook salmon, steelhead, and Sacramento squawfish in the lower American River, California. California Fish and Game 82: 149-159.

Obrebski, S., J. J. Orsi, and W. Kimmerer, 1992. Long-term trends in zooplankton distribution and abundance in the Sacramento-San Joaquin Estuary. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary Technical Report 32: 42 pp.

Orsi, J. J., 1995. Radical changes in the estuary's zooplankton caused by introductions from ballast water. Interagency Ecological Studies Program for the Sacramento-San Joaquin Estuary Newsletter, summer 1995: 19 pp.

Figure 7
Relationship between the summer tow net index and fall midwater trawl index for delta smelt 1969-1997. Data points since the introductions of *Potamocorbula* and *Pseudodiaptomus* (1986-1997) are in bold type.



Going Surfing

Randall Brown, DWR

Effective February 1, 1998, Pat Coulston, IEP's Program Manager, will assume a new position with the Department of Fish and Game's Region III. Pat will be assigned to the region's Monterey office and probably will be found on a surf board during many of those evenings and weekends when the surf is up.

Pat has been Program Manager since 1994; prior to that he worked in the IEP's San Francisco Bay and fish facilities elements. Before coming to DFG in the mid-1980s, he worked in the Bay/Delta with a private consulting firm.

Pat's performance in all his IEP assignments has been characterized by vision, technical competence, dedication, enthusiasm, and an unfailing (well, almost unfailing) infectious cheerfulness. The IEP has evolved considerably over the past few years and much of this positive evolution is due to Pat's personal contribution. We will miss him but wish him and his family all the best in their move to the coast and in their new jobs. We hope he will be able to attend some of the annual Asilomar meetings to keep in touch with Bay/Delta people and programs.

San Joaquin Salmon

Tim Ford, Turlock Irrigation District

In response to my request, the IEP's Central Valley Salmon Team recognized the San Joaquin Basin Resource Monitoring and Coordination Group as a satellite team. (Satellite teams are included under the auspices of the Central Valley Salmon Team to increase coordination and information exchange among salmonid monitoring and research activities. Satellite teams may receive IEP funding but are not controlled by the IEP.) This group has met quarterly since December 1996 with the purpose of facilitating monitoring coordination and information exchange in the Stanislaus, Toulumne, and Merced rivers and the mainstem San Joaquin River between the mouth of the Merced and Mossdale.

I have been the coordinator of this group which has included representatives of DFG, DWR, SWRCB, USFWS, USBR, water districts, environmental groups and private consultants. Meetings have addressed salmon related activities as well as habitat monitoring, modeling and research. The group is co-sponsoring a February 4, 1998, monitoring/research/restoration workshop for the San Joaquin system.

Preliminary Results on the Age and Growth of Delta Smelt (*Hypomesus transpacificus*) from Different Areas of the Estuary Using Otoltith Microstructure Analysis

Lenny Grimaldo and Bonnie Ross, DWR and Dale Sweetnam, DFG

Introduction

For many estuarine fishes, recruitment is related to larval growth rates (Houde 1987). Even small changes in growth rates can translate into tenfold changes in annual abundance (Houde 1987; Rutherford, Houde, Nyman 1997). For delta smelt (*Hypomesus transpacificus*), Moyle *et al* (1992) hypothesized that the growth of delta smelt rearing in the more productive, shallow waters of Suisun Bay would be greater than delta smelt rearing in the less productive, deep channels of the Delta. Support for this hypothesis emerged in 1994 when Hanson Environmental found delta smelt collected from Suisun Bay were larger than delta smelt collected from the lower Sacramento River, suggesting that Suisun Bay might provide good habitat. Without data on individual age, however, it is unknown if the fish collected in Suisun Bay were larger because of increases in growth rate or because fish from Suisun Bay were older than fish collected from upstream locations.

The primary objective of this study was to investigate the age and growth of juvenile delta smelt using otolith microstructral analysis to determine if growth rates differ among locations in the Sacramento-San Joaquin Estuary. Secondarily, diet composition and zooplankton density were analyzed to investigate factors important to the growth and distribution of delta smelt.

Methods

Field Methods. Delta smelt were collected during Department of Fish and Game (DFG) 20mm Surveys 7 (July 10-13) and 8 (July 24-27) in 1996 (Figure 1). In these surveys, delta smelt were collected with a 1,600 micron plankton stretched mesh net measuring 5.1 meters long and mounted on a townet frame (a frame with skids and a mouth opening of 1.5 m^2). Zooplankton samples were collected by a 197 micron Clarke-Bumpus net mounted on top of the townet frame. All zooplankton and fish were preserved in 45% ethanol and taken to the DFG Bay-Delta office for identification. All fish collected were sorted and osmerids were identified to species.

Laboratory Processing. Delta smelt were placed in petri dishes with 2 ml ethanol and measured to the nearest 0.10mm SL. The saccular otoliths (largest pair) were removed using a scalpel. Otoliths removed from fish <20mm SL were mounted in cytoseal and remained unsectioned. Larger otoliths were mounted then sectioned with a low speed saw with a diamond wafering blade. Frontal sections were cut on a plane containing the core and rostrum. Sectioned

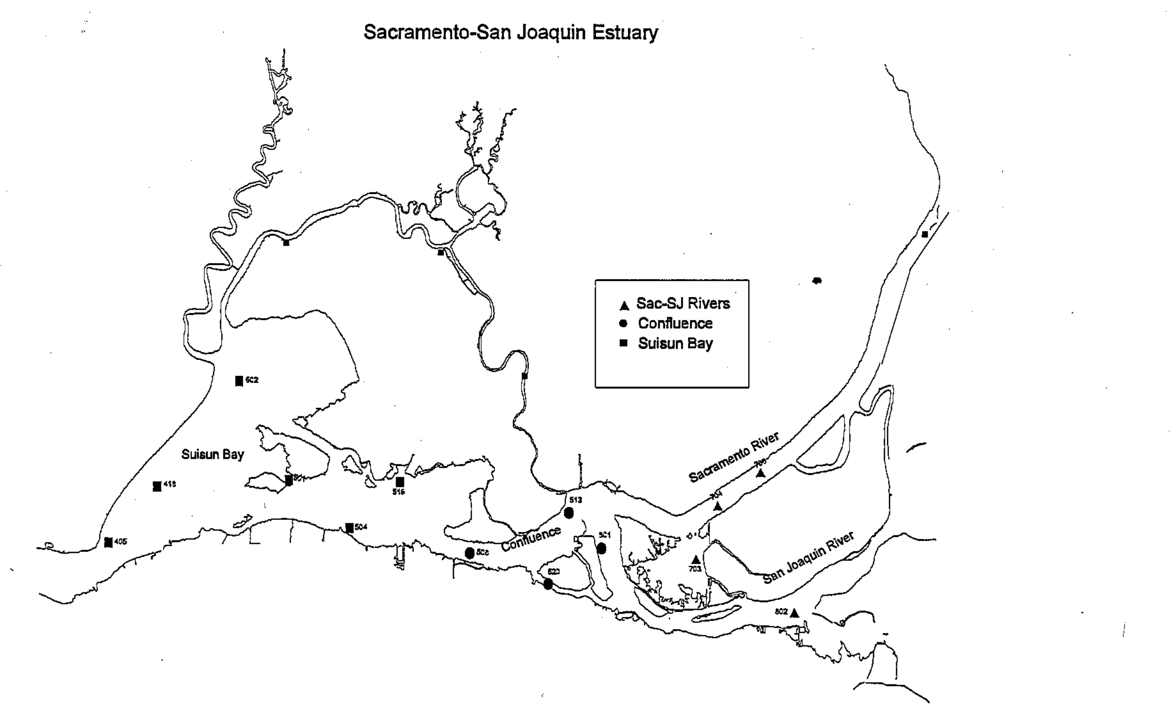


Figure 1
Stations where delta smelt were collected for otolith analysis in July 1996 (DFG 20mm survey).