Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

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Interagency Program Quarterly Highlights

1997 Fall Dissolved Oxygen Conditions in the Stockton Ship Channel

Stephen P. Hayes and Jeannie S. Lee

Dissolved oxygen concentrations in the Stockton Ship Channel are closely monitored by staff of DWR's Bay-Delta Monitoring and Analysis Section during the late summer and early fall each year. Monitoring is conducted because D.O. levels can drop below 5.0 mg/L in the eastern channel due to low stream inflows, warm water temperatures, high biological oxygen demand, reduced tidal circulation, and intermittent reverse flow conditions in the San Joaquin River past Stockton. These low dissolved oxygen levels can cause physiological stress to fish and block upstream migration of salmon. A barrier is usually installed at the head of Old River during periods of projected low fall outflow to increase net flows down the San Joaquin River past Stockton. The barrier was not installed in fall 1997, a wet year, because of high fall flows in the San Joaquin River.

Surface and bottom D.O. levels in the Stockton Ship Channel were obtained on eight monitoring runs conducted from August 4, 1997, to November 17, 1997. Monitoring from August through October 1997 showed a distinct surface and bottom dissolved oxygen sag in the eastern end of the ship channel with the lowest values (5.0 mg/L or less) in and immediately west of the Rough and Ready Island area. High water temperatures and low flow conditions appear to have contributed to the low D.O. conditions in the eastern channel. Water temperatures ranged from 25-27°C in August, 23-26°C in September, and 16-24°C in October. Average daily flows in the San Joaquin River past Stockton ranged from -466 cfs to +198 cfs in August, -329 cfs to +117 cfs in September, and -233 cfs to +439 cfs in October.

Dissolved oxygen conditions gradu-

CONTENTS

Feeding Habits of Juvenile and Adult Delta Smelt from the Sacramento-San Joaquin River Estuary

Jenni Lott, DFG, Bay-Delta Division

The delta smelt is a federal and state threatened fish species endemic to the Sacramento-San Joaquin estuary. It is a small (generally <80mm) planktivore that ranges from western Suisun Bay, to the city of Sacramento on the Sacramento River and to Mossdale on the San Joaquin River. It has been the subject of recent legislation and the focus of extensive mitigation efforts. Despite this intense interest in delta smelt, little is known about its basic biology and ecology.

The zooplankton fauna in the estuary has changed drastically over the past 15 years due to the introduction of exotic zooplankton species and the effects of the proliferation of the Asian clam, *Potamocorbula amurensis* (Kimmerer *et al* 1994). Shifts in zooplankton composition can have a profound effect on the fish populations dependent on them for food.

The effect of the introduction on delta smelt will never be fully known as only limited studies were done on their feeding habits prior to these introductions (but see Moyle *et al* 1992). Zooplankton composition in the delta continues to change (Orsi 1997).

This study documents delta smelt feeding habits from 1974 and 1991-1996 and can be used to compare with future studies.

Study Fish

Delta smelt used in this diet analysis were collected as part of four different on-going surveys by the California Department of Fish and Game as part of the IEP: the fall and spring mid-water trawl surveys (FMWT and SMWT respectively), the townet surveys (TNS) and the 20mm surveys (20mm) (Table 1). All four surveys conduct extensive sampling in the northern estuary and the Delta. Each survey uses a different type of collection gear, is conducted at different times of the year and targets different sizes of delta smelt.

Complete description of the sampling regimes and gear types for each of these survey types can be found on the IEP web page (http://www.iep.ca.gov). Smelt from all four surveys were used to examine diet composition by length group and year. Smelt from 20mm surveys were used to examine diet selectivity, incidence of empty stomachs and geographical variation in feeding success.

Diet Analysis Procedures

For all four surveys, delta smelt were measured in the field (fork length) and preserved in 10% formalin. Information identifying date and place of capture was also recorded. In the laboratory, delta smelt were rinsed and soaked in freshwater prior to dissection. Delta smelt were re-measured in the laboratory and the entire digestive tract (fish <20mm) or the esophagus and stomach (fish (>20mm) were removed for analysis. All gut contents were identified under a dissecting microscope to the lowest possible taxon. In order to avoid counting the same organism more than once, only whole organisms, hind ends, or other body parts identifiable as distinctly different organisms, were counted. The total weight of each prey type present was calculated by multiplying the number present in the guts by the best available dry weight estimate for that prey type.

Table 1. Summary of Delta Smelt Used for Diet Analysis by Survey

	20mm	TNS	FMWT	SMWT
Survey Period	Apr-July/Aug 1995-96	Jun-July/Aug 1974; 1993-96	Aug/Sept-Dec 1991-95	Jan-Mar/Apr/May 1992-96
Effective Capture Size	10-55mm	22-55mm	>45mm	>45mm
Length ± SD	20.8 ±9.2mm	37.6±7.6mm	51.8±7.7mm	62.5±5.5mm
Number	3,762	3,442	2,575	755

Diet Composition

Studies reporting on diet composition ideally calculate percent diet composition by number, by weight (or volume) and by frequency of occurrence (the percent of guts with food which contain a particular prey type). Each measure of diet composition has strengths and weaknesses. Percent composition by number (%N) may overemphasize small prey items of limited value, whereas percent composition by weight (%W) may overemphasize large prey items which may have less digestible material. Percent composition by frequency of occurrence (%FO) estimates how widespread the use of a particular prey item is for the sample population but may overemphasize the importance of common items. An Index of Relative Importance (IRI) which takes into account all three measures of diet composition was calculated for each prey type with the formula IRI=(%N + %W)*(%FO) (Table 2).

The diet of juvenile and adult delta smelt collected in these surveys consisted primarily of copepods (Table 2). Unspeciated calanoid copepodids (juvenile copepods) and the calanoid *Pseudodiaptomus* numerically dominated the diets of delta smelt captured in 20mm, TNS, and FMWT. The calanoid *Eurytemora*, calanoid and cyclopoid copepodids, the cyclopoid *Acanthocyclops* and the cladoceran *Daphnia* numerically dominated the diet of delta smelt captured in SMWT. Cumaceans were also an important prey item in the SMWT. Although cumaceans numerically accounted for only 4.6% of the diet, they are relatively large prey items that accounted for 15.8% of the diet by weight and were present in nearly 40% of the stomachs with food.

Seasonal and Annual Trends in Diet Composition

The diet of an individual delta smelt is limited both by its size in relation to the size of possible prey items and by the zooplankton species that are present. The delta smelt is an annual fish so not all size classes are present throughout the year. In addition, copepod and other zooplankton composition and abundance fluctuates widely throughout the year (Orsi 1997). To analyze seasonal and annual trends in diet variability, I grouped delta smelt from all surveys into five size classes based on diet similarity and life stage (10-14mm, 15-19mm, 20-24mm, 25-49mm and 50+mm) in order to decrease the effects of diet variation due to life stage and size. Figure 1 shows the relative IRI's for the major prey types for these five size classes.

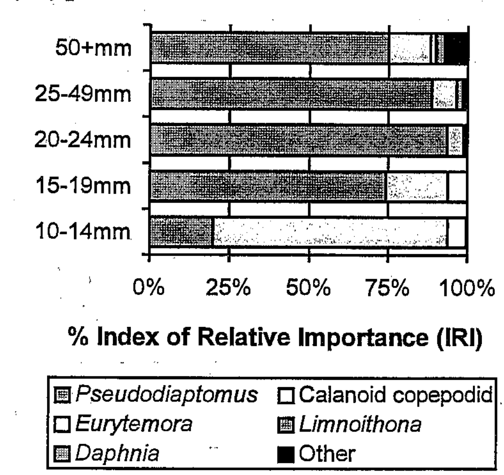

Figure 1
Relative IRI values for the major prey items by size class of delta smelt.

Table 2. Diet Composition of All Juvenile and Adult Delta Smelt in This Study

Percent by number (%N), percent by weight (%W), and percent by frequency of occurrence (%FO) are reported. An index of relative importance (IRI=(%N+%W)*%FO) is calculated for each prey type.

Prey Item	%N	%W	%FO	IRI
Copepoda				
copepod nauplii	0.22%	0.01%	5.29%	0.01
cyclopoid copepodid	2.61%	0.28%	15.62%	0.45
Acanthocyclops	1.45%	1.01%	10.65%	0.26
Oithona davisae	0.00%	0.00%	0.05%	0.00
Limnoithona spp.	6.30%	1.86%	12.16%	0.99
Other cyclopoid	0.97%	0.36%	12.17%	0.16
UnID cyclopoid	0.63%	0.23%	5.35%	0.05
calanoid copepodid	15.48%	5.70%	58.94%	12.48
Acartia spp.	0.33%	0.40%	0.08%	0.00
Diaptomus spp.	0.14%	0.13%	1.87%	0.01
Pseudodiaptomus spp.	56.82%	73.87%	70.21%	91.76
Eurytemora spp.	5.48%	4.12%	18.25%	1.75
Sinocalanus	0.98%	0.89%	16.47%	0.31
Osphranticum	0.14%	0.17%	2.32%	0.01
Acartiella	1.52%	1.38%	16.27%	0.47
Tortanus	0.35%	0.38%	6.19%	0.05
Other calanoid	0.00%	0.00%	0.04%	0.00
UnID calanoid	0.62%	0.53%	7.28%	0.08
Harpacticoids	0.46%	0.13%	11.39%	0.07
Cladocera				
Bosmina	0.04%	0.01%	1.04%	0.00
Daphnia spp.	2.78%	1.71%	9.56%	0.43
Diaphanosoma	0.10%	0.02%	3.56%	0.00
Ceriodaphnia	0.02%	0.00%	0.58%	0.00
Other cladocera	0.13%	0.05%	3.51%	0.01
UnID cladocera	0.45%	0.16%	4.56%	0.03
Malacostraca				
Mysids	0.24%	2.96%	6.88%	0.22
Cumaceans	0.62%	1.52%	6.46%	0.14
Isopods	0.00%	0.00%	0.12%	0.00
crab zoea	0.13%	0.16%	1.88%	0.01
Palaemon	0.03%	0.08%	1.36%	0.00
Crangon	0.00%	0.00%	0.04%	0.00
Gammarus	0.66%	1.21%	5.74%	0.11
Corophium	0.13%	0.16%	4.56%	0.01
Other malacostraca	0.01%	0.02%	0.30%	0.00
Miscellaneous zooplankton				
Annelid worms	0.02%	0.05%	0.66%	0.00
Rotifers	0.00%	0.00%	0.05%	0.00
Chironomid larvae	0.02%	0.06%	1.20%	0.00
Other Insect larvae	0.02%	0.05%	0.60%	0.00
Ostracods	0.00%	0.00%	0.09%	0.00
barnacle nauplii	0.05%	0.00%	0.30%	0.00
fish	0.03%	0.32%	0.66%	0.00
fish eggs	0.00%	0.00%	0.03%	0.00

Size Group 10-14mm

Delta smelt in the 10-14mm size class (n=811) were captured exclusively in 20mm surveys between April and July during 1995 and 1996. Calanoid copepodids were the major prey item in both years (Figure 2), accounting for nearly 60% of the prey items present. Calanoid copepodids along with copepod nauplii and the adult calanoids *Pseudodiaptomus* and *Eurytemora* accounted for 100% and 96.6% (1995 and 1996, respectively) of the total diet by numerical composition. Other prey items (present only in 1996) included cyclopoid copepodids, adult cyclopoids (*Limnoithona*), and unidentified adult calanoids and cladocerans.

Size Group 15-19mm

Delta smelt in the 15-19mm size class were captured mainly in the 20mm surveys (n=980) between April and July 1995 and 1996, but a very few fish were captured in the TNS surveys (n=5). Only the 20mm fish were used in the diet analysis. The three major prey items in both 1995 and 1996 were *Pseudodiaptomus*, calanoid copepodids and *Eurytemora* (Figure 2). Together these prey items accounted for 98.1% and 97.7% (1995 and 1996, respectively) of the total diet by numerical composition. In contrast to the 10-14mm fish, the smaller copepodids accounted for only 30.9% and the adult stages for 66.9% of the diet by number. Other prey items present (all accounting for <1%) included copepod nauplii, cyclopoid copepodids and adults (*Acanthocyclops* and *Limnoithona*), another adult calanoid copepod (*Sinocalanus*) and cladocerans (*Bosmina* and *Diaphanosoma*).

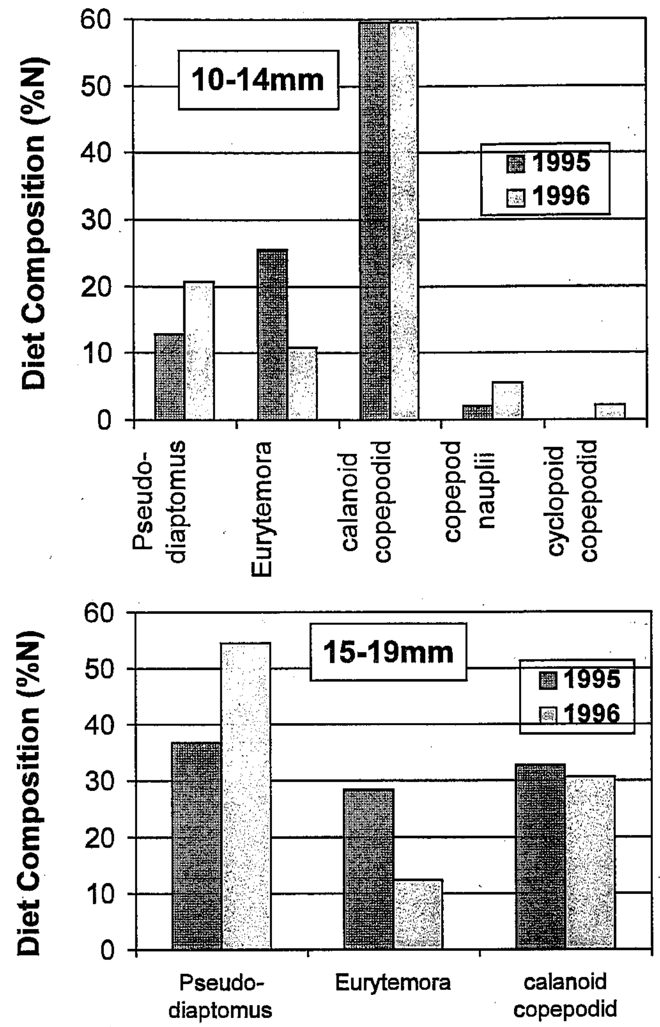

Figure 2
Diet composition of 10-14mm and 15-19mm delta smelt by percent number (%N). Prey items contributing less than 1% of the diet in both years were omitted.

Table 3. Diet Compositon by Number (%N) of 25-49mm Delta Smelt by Month

Diets for June and July 1974 are reported separately from the other data which were collected between 1993 and 1996.

Prey Item	June >74	Jul >74	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Pseudodiaptomus spp.			57.0	77.8	56.7	69.3	71.3	64.5	50.8	17.9
Eurytemora spp.	92.7	87.7	1.0	0.0	0.0	0.0		0.0	1.7	11.3
calanoid copepodid	3.7	8.3	20.2	8.2	15.0	16.9	14.0	28.2	13.9	8.6
Limnoithona spp.			10.4	2.1	22.0	8.3	3.1	3.3	5.7	1.0
cyclopoid copepodid	0.2	0.2	2.7	0.1	0.1	0.1	0.1	0.1	18.4	28.5
copepod nauplii	0.0	0.1	1.7	0.2	0.1	0.1	0.2	0.6	0.0	1.0
Acanthocyclops	0.0		1.0	0.0	0.0	0.1	0.0	0.0	2.1	6.6
Sinocalanus			0.5	2.5	2.1	1.5	0.4	0.0		
Acartiella				0.7	1.1	0.6	3.7	1.2	2.7	0.7
Harpacticoids	2.5	2.7		0.7	0.1	0.4	1.7	0.2	0.1	2.6
Daphnia	0.0		1.4	0.0	0.1	0.0			0.1	0.3
Mysids	0.2	0.4	2.3	0.6	0.5	0.1	0.2	0.2	0.0	0.3
Gammarus				6.2	0.1	0.0	0.1	0.1		0.3

The diets of both the 10-14mm and 15-19mm delta smelt shifted from *Eurytemora* to *Pseudodiaptomus* from April to July (Figure 3). *Pseudodiaptomus* was rare in the fish caught in April but by June it had completely replaced *Eurytemora* in the diet. There is also a seasonal diet shift from copepodids to adult copepods in the 15-19mm size group.

Size Groups 20-24mm, 25-49mm and 50+mm

Delta smelt in the 20-24mm size class were captured in the 20mm surveys (n=766), TNS surveys (n=98) and FMWT surveys (n=1) between April and August in 1993-1996 and in June 1974. Delta smelt in the 25-49mm size class were captured in the 20mm surveys (n=986), TNS surveys (n=3155), FMWT surveys (n=992) and SMWT surveys (n=9) in 1974, 1992-1996. Delta smelt in the 50+mm size class were captured in the 20mm surveys (n=35), TNS surveys (n=184), FMWT surveys (n=1582) and SMWT surveys (n=746) between 1991 and 1996. The delta smelt captured in the 1974 TNS study were analyzed separately.

For these size classes, *Eurytemora* was the dominant prey item in June and July 1974. In contrast, *Eurytemora* was almost completely replaced by *Pseudodiaptomus* during these months in 1992-1996. *Pseudodiaptomus* was the dominant prey item overall (excluding 1974) and calanoid copepodids were of secondary importance. Other important prey items varied by size class and by year. For instance, *Eurytemora* (1995), *Limnoithona* (1994), and *Sinocalanus* (1993) were important for 20-24mm delta smelt (Figure 4a). *Limnoithona* was also important for 25-49mm delta smelt (Figure 4b), but not as important for 50+mm delta smelt (Figure 4c). The 50+mm delta smelt showed a greater diversity in diet than the smaller size classes (Figure 4) and also a greater variability from month to month and year to year.

The late spring shift from *Eurytemora* to *Pseudodiaptomus* in the estuary is reflected in the diets of the 20-24mm fish, but not in the diets of 25-49mm smelt. This may be because delta smelt (25mm) are large enough to prey efficiently on *Pseudodiaptomus* when they first appear in the spring making preferential selection of the smaller *Eurytemora* unnecessary. However, the diet of 25-49mm delta smelt does reflect the other end of this cycle

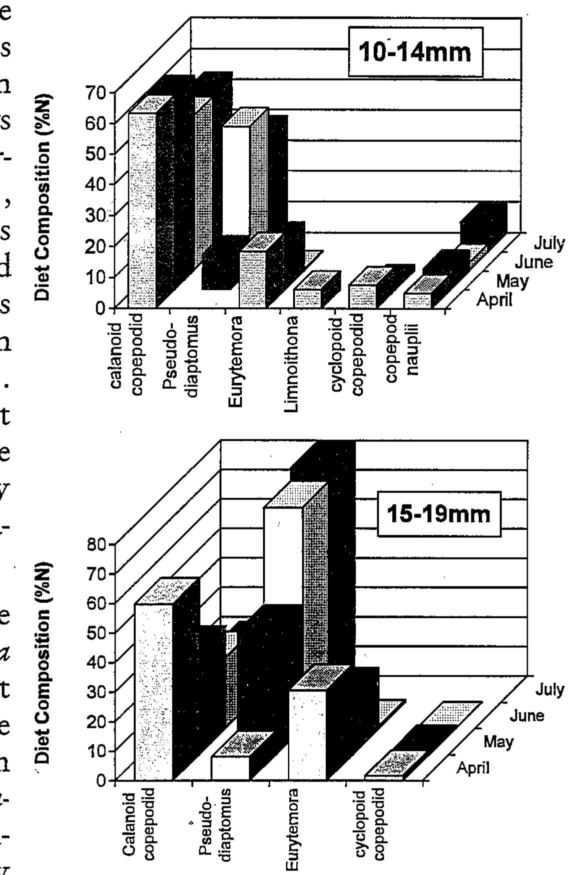

Figure 3
Diet composition of 10-14mm and 15-19mm delta smelt collected in 1995 and 1996 by month of capture. Prey types contributing less than 1% of the diet in all months were omitted.

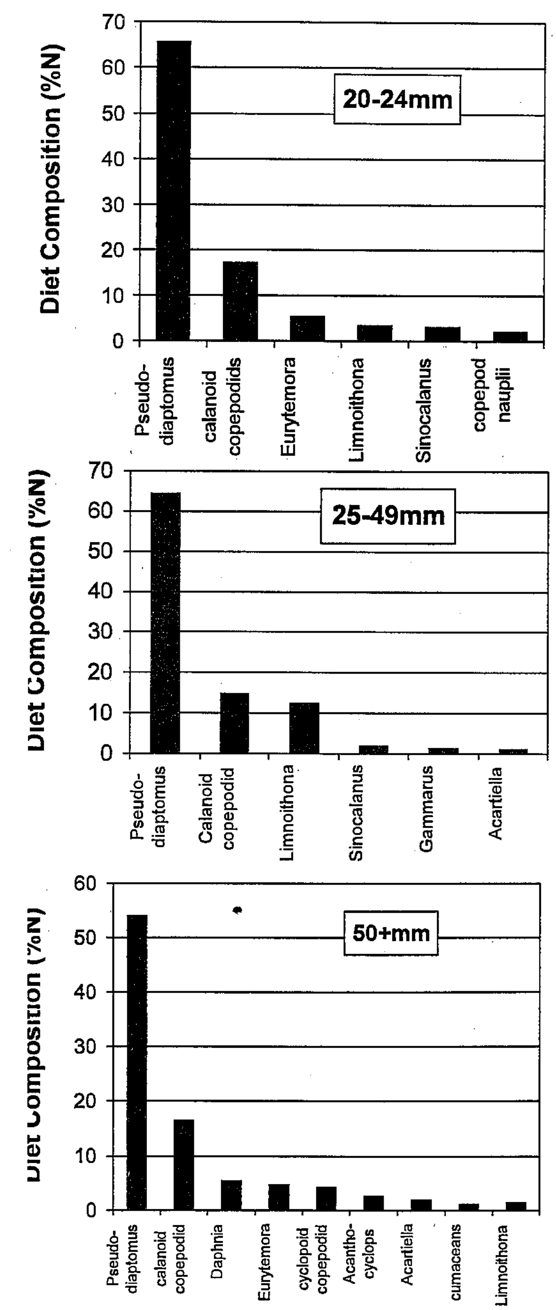

Figure 4
Diet composition of (a) 20-24mm (1993-96), (b) 25-49mm (1992-96), and (c) 50+mm (1991-96) delta smelt. Prey items contributing less than 1% by number were omitted.

when *Pseudodiaptomus* abundance declines in the late fall and *Eurytemora* abundance begins to increase (Table 3).

Diet Selectivity

Diet selectivity is a measure of prey types eaten in relation to prey available in the environment. If delta smelt are not selectively feeding, the proportion of a prey type in their diet should be the same as the proportion of that prey type in the environment. Prey types that are avoided will have a much lower proportion in the diet than in the environment whereas prey types that are selected will have a much higher proportion in the diet than in the environment.

Diet selectivity of delta smelt was examined with the Vanderploeg-Scavia electivity index (E*). E* index values range from -1 (complete avoidance) to 0 (random feeding) to +1 (complete preference) when an infinite number of prey items are examined. I examined diet selectivity for the delta smelt collected in the 20mm survey that had a concurrent zooplankton sample taken. The Clarke-Bumpus net used to collect zooplankton samples is inefficient at capturing very small zooplankton, such as rotifers and nauplii, and large or benthic organisms, such as mysids, cumaceans and amphipods. Therefore, electivity indices were calculated for the nine most important diet items (all of which are mid-sized) as determined by the overall IRI values (Table 2). Delta smelt were grouped by year, month and two size groups (<25mm (small) and (25mm (large)) for this analysis. As I examined only nine prey types, possible E* values ranged from -1 to 0.8, with 0 indicating random feeding.

During both years, small delta smelt strongly selected for *Eurytemora* in April then shifted to a strong selectivity for *Pseudodiaptomus* by July (Figure 5). They also showed sporadic selectivity for calanoid copepodids and *Limnoithona*, whereas *Daphnia*, *Acartiella*, and *Acanthocyclops* were strongly selected against. Large delta smelt positively selected *Eurytemora* and *Daphnia* in April and May 1995 and April 1996 (although sample sizes were very low). Later in the season, they showed strong positive selectivity for *Limnoithona* and a moderate selectivity for *Pseudodiaptomus* (Figure 5). The shift to *Pseudodiaptomus* from *Eurytemora* lags behind the change in their relative abundance in the estuary (Figure 6). However, even when *Eurytemora* showed a resurgence in abundance in June 1996, both size groups continue to select strongly against them.

Feeding Success

Feeding success was examined by looking at the percentage of delta smelt with no food in their guts and the average number of prey items per fish that did contain food. There was a large increase in the number of delta smelt with empty stomachs in the 20-24mm size range in both 1995 and 1996 (69.6% and 86.8%, respectively)(Figure 7). The percentage of fish with empty stomachs ranged from 17-49% for smaller fish (<20mm) and from 6-39% for larger fish (>24 mm). The feeding success of the 20-24mm fish was significantly lower than those of both smaller and larger fish (chi-square test, p<0.0005). This holds true for all of the 20mm surveys and for all areas of the Delta during these years and is not restricted to a single survey. Not only were there fewer fish with food in this size range, but fish with food had a lower average number of prey items than would be expected for their size. It appears that 20-24mm delta smelt (the approximate size when or right after larvae complete metamorphosis to juveniles) face a very critical foraging period. The numbers of delta smelt caught in the next larger size group (25-29mm) dropped off sharply in 1996 and declined slightly in 1995, suggesting that delta smelt may experience greater mortality at this critical size, possibly due to their low foraging success.

Geographic differences in foraging success were evaluated for three size groups of delta smelt (<20mm, 20-24mm, >24mm) from the 20mm surveys (Figure 8). All three size groups showed significant differences in foraging success among areas of the estuary (chi-square tests, all p<0.0005). For delta smelt <20mm, San Pablo Bay and the Mokelumne River appear to be poorest areas for feeding success (although sample size was very small) whereas Honker Bay, Montezuma Slough and the confluence of the Sacramento and San Joaquin rivers appear to be the best. The 20-24mm fish appear to have the poorest feeding success in Suisun Bay, Montezuma Slough and the central Delta and the best feeding success in Grizzly Bay and the Napa River. Delta smelt 25mm forage poorest in San Pablo Bay and the Lower San Joaquin River and best in Grizzly Bay. Foraging success in these areas also varies from year to year (Figure 8).

Summary

Delta smelt feed primarily on juvenile and adult copepods, especially the calanoids *Eurytemora* and *Pseudodiaptomus*. The dominant calanoid in the estuary changes seasonally in the late spring from *Eurytemora* to *Pseudodiaptomus*. Delta smelt feeding preference also changes from *Eurytemora* to *Pseudodiaptomus* but not immediately. Small juvenile delta smelt feed primarily on the small copepodid stages of calanoid copepods but adults of the small cyclopoid copepod, *Limnoithona tetraspina*, have become a prey item for juveniles since their introduction in 1992. As delta smelt increase in size, their diet shifts to the larger adult copepods and becomes more varied, especially in the late winter and early spring months. Delta smelt in the 20-24mm size range experience a severe drop in foraging success which may be associated with their metamorphosis to juveniles. Foraging success for all sizes of smelt varies with area of the estuary and between years.

Acknowledgments

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Continued on page 42

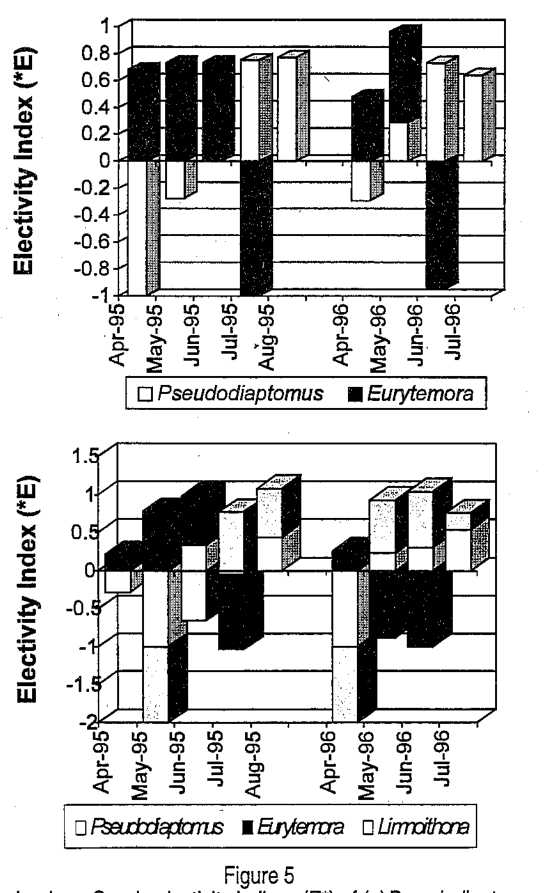

Figure 5
Vanderploeg-Scavia electivity indices (E*) of (a) *Pseudodiaptomus* and *Eurytemora* for small (<25 mm) delta smelt and of (b) *Pseudodiaptomus, Eurytemora,* and *Limnoithona* for larger smelt (25mm) captured in the 20mm surveys by month of capture.

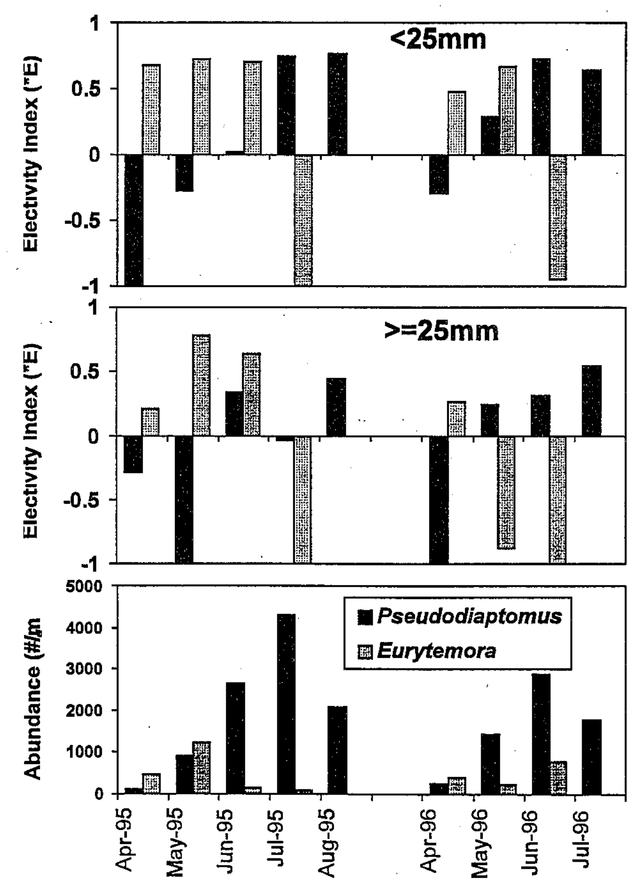

Figure 6
Electivity indices (E*) for small (<25mm) and larger (25mm) delta smelt by month for *Eurytemora* and *Pseudodiaptomus* in comparison to environmental abundance (#/m^3).

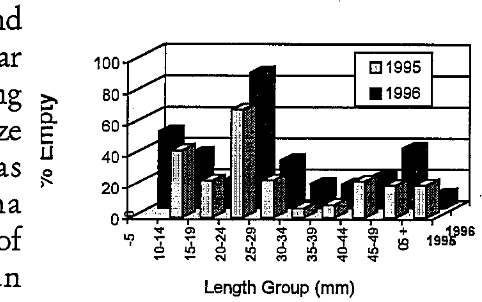

Figure 7
Percent of delta smelt with empty stomachs by 5mm length group for fish from 1995 and 1996 20mm surveys.

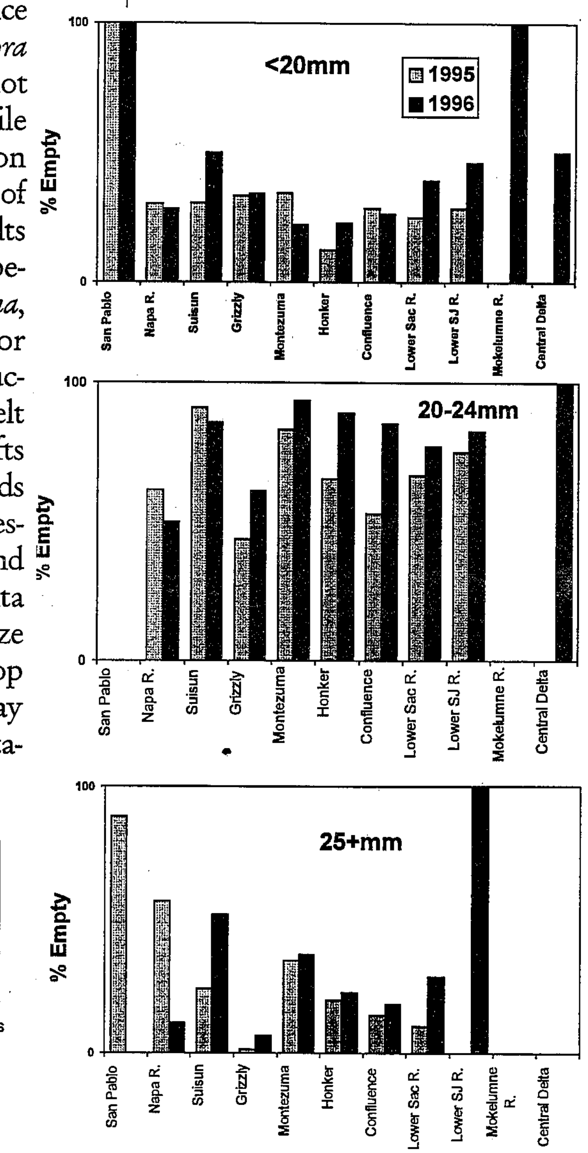

Figure 8
Percentage of delta smelt from the 1995 and 1996 20mm surveys with empty stomachs for 3 size groups by geographic area of the esturary.

SJC-461

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Interagency Ecological Program for the Sacramento-San Joaquin Estuary

Newsletter

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