Osmeridae

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This chapter describes trends in abundance and distribution for osmerid species collected in the San Francisco Estuary. For each species, abundance and distribution information is discussed in the context of life history. Analyses of larval abundance and distribution are presented for species with identifiable larvae collected in sufficient numbers.

Six species of Osmeridae, or true smelts, were collected from the San Francisco Estuary between 1980 and 1995 (Table 1): longfin smelt, *Spirinchus thaleichthys*; night smelt, *S. starksi*; delta smelt, *Hypomesus transpacificus*; wakasagi, *H. nipponensis*; surf smelt, *H. pretiosus*; and whitebait smelt, *Allosmerus elongatus* (Robins and others 1991, Stanley and others 1995). Night smelt, surf smelt, and whitebait smelt are marine species. The longfin smelt and delta smelt are euryhaline species, spending the early portions of their lives in freshwater and entering brackish water as late stage larvae or juveniles. Some longfin smelt migrate to marine waters during the middle of their lives. The wakasagi is the only non-native osmerid and has 2 life-history types in its native Japan, a completely freshwater type and an anadromous type (Hamada 1961, as cited in McAllister 1963). Wakasagi eggs from a reservoir in Japan were originally introduced into 6 California freshwater impoundments in 1959 (Wales 1962). It has since been introduced or spread to other waters, including the delta (Aasen and others 1998). Only 2 wakasagi have been captured, both by the midwater trawl: 107 mm at station #837 in December 1982 and 65 mm at station #431 in July 1995 (see Table 1). Other wakasagi may have been misidentified as delta smelt because of the close resemblance between the 2 species (Sweetnam 1995). No further discussion will be devoted to wakasagi. Trends in abundance and distribution for the remaining species are discussed in more detail in this section.

Table 1 Total catch by species and gear type for osmerids collected between January 1980 and December 1995. See the Methods chapter, Table 1 for duration of use for different gear types.

Species	*Plankton net larvae*	*Plankton net juveniles*	*Beach seine*	*Otter trawl*	*Midwater trawl*
Longfin smelt	130,741	6,376	215	45,548	54,459
Delta smelt	373	250	130	419	1,634
Surf smelt	2	0	498	12	93
Whitebait smelt	0	0	1	193	80
Night smelt	0	0	7	21	183
Wakasagi	0	0	0	0	2

Longfin Smelt

Introduction

The longfin smelt, *Spirinchus thaleichthys*, is a pelagic, estuarine fish which ranges from Moss Landing, Monterey Bay (R. Lea, personal communication, see "Notes") northward to Hinchinbrook Island, Prince William Sound, Alaska (McAllister 1963). In California, it is collected from San Francisco Bay, Humboldt Bay, and the Eel, Klamath, and Smith rivers (Frey 1971, Emmett and others 1991). In the early 1990s, the only California freshwater collections came from the Klamath River (M. Wallace, personal communication, see "Notes") and San Francisco Bay. The longfin smelt comprises a small portion of the "whitebait" fishery in San Francisco Bay and is not taken by sport fishers (Skinner 1962).

Maturity is reached at age 2 (Dryfoos 1965, Moulton 1974). In the late fall, maturing fish migrate from San Francisco Bay and coastal marine waters to Suisun Bay, Montezuma Slough, and the lower reaches of the Sacramento and San Joaquin rivers (Ganssle 1966, Radtke 1966, Wang 1986). Spawning probably takes place in fresh or slightly brackish water. Moyle (1976) reported that longfin smelt spawn in portions of Suisun Bay and the west delta between December and February, and Wang (1986) reported a December to June spawning period. Most appear to die after spawning, but a few females may live to spawn a 2nd time at age 3 (Dryfoos 1965, Moulton 1974, Moyle 1976). Adults reach a maximum size of about 150 mm TL (Miller and Lea 1972).

The eggs are adhesive and are probably released over a firm substrate (Moyle 1976). The larvae are pelagic and are most abundant in the upper layers of the water column (Wang 1986, Hieb and Baxter 1993). They are very common in Suisun Bay during spring (Wang 1986), but larval and juvenile distributions appear to be a function of freshwater outflow (Hieb and Baxter 1993). In April and May, juveniles are found downstream in San Pablo Bay (Ganssle 1966, Hieb and Baxter 1993). During late spring, summer, and fall, juvenile longfin smelt disperse throughout the estuary (Messersmith 1966, Aplin 1967, Hieb and Baxter 1993), and frequently venture into the Gulf of the Farallones (City of San Francisco Bureau of Water Pollution Control and CH2M Hill 1984, B. Sak, personal communication, see "Notes"). Juveniles tend to inhabit the middle and bottom strata of the water column (Moyle 1976).

The annual abundance of longfin smelt is significantly and positively correlated with the amount of freshwater flow during the spawning and larval periods (Stevens and Miller 1983, Hieb and Baxter 1993, Jassby and others 1995). Three factors were identified as potentially responsible for the high correlation: (1) a reduction in predation during high flows; (2) increased habitat availability which may improve survival by reducing intraspecific competition; and (3) an increase in nutrients stimulating the base of the food chain (Stevens and Miller 1983).

Methods

Duration of use varied by gear type and affected the annual and seasonal periods used in abundance and distribution analyses (see Methods chapter, Table 1). Although the incubation and larval periods extend from November to July (Wang 1986), most larvae appear to hatch in January or February (Hieb and Baxter 1993); therefore, larvae were assigned a January 1 birth date. Larvae were staged by the presence (yolk sac larvae or YSL) or absence of a yolk sac (post-YSL). In the plankton net, longfin smelt were classified as juveniles (that is, age 0) at ≥ 20 mm FL based upon complete fin ray development (Simonsen 1977). Catch per unit effort (CPUE) was calculated for each life stage (YSL, post-YSL, age 0). Monthly abundance was calculated as the product of mean CPUE by region and the region's weighting factor (volume) summed for all 5 regions (see Methods chapter, Tables 2 and 3). Annual abundance was calculated as the mean of January to May monthly abundance indices (YSL and post-YSL combined). To describe seasonal abundance, indices were averaged by life stage and month for 1981 to 1988 (years when sampling occurred in all 12 months) (see Methods chapter, Table 1). To describe annual distribution, total larval (YSL + post-YSL) CPUE was averaged by region for January to May. A significance of $P \leq 0.05$ was used for all analyses. To test for a relationship between freshwater outflow and larval geographic distribution, a Spearman rank correlation analysis was run on ranked average December to March Chipps Island outflow and ranked mean annual larval distribution. To calculate mean annual distribution, mean January to May CPUE by region was multiplied by region number (West Delta = 1, Suisun Bay = 2...South Bay = 5) for each region; these products were then summed and divided by the sum of the mean CPUEs for the regions.

Although the midwater and otter trawls collected longfin smelt, only otter trawl data were used to describe the abundance and distribution of the bottom-oriented, older age–0 and age–1 fish. Longfin smelt annual abundance indices for the 2 gears are well correlated: $r = 0.841$, $P < 0.001$, $n = 15$ for age–0 fish; $r = 0.984$, $P < 0.001$, $n = 15$ for age–1 fish (no midwater trawl index was calculated for either age group for 1994). To separate age classes, otter trawl length frequency data (mm FL) were tallied into 2 mm groups by month (January to December) and inspected to identify "breaks" or minima. At the minima, cutoff lengths were selected to separate fish into age–0 and age–1 classes. Cutoff lengths for separating age–0 from age–1 fish were as follows: 40, 42, 46, 52, 59, 67, 71, 75, 80, 83, 85, and 87 mm FL for January to December, respectively. Cutoff lengths for separating age–1 from age–2 fish were as follows: 90, 93, 96, 100, 105, 108, 111, 114, 117, 120, 123, and 125 mm FL for January to December, respectively.

The minimum size for inclusion into otter trawl abundance and CPUE calculations was 40 mm for longfin smelt. The CPUE was calculated for each station as the product of age specific catch divided by the tow area and 10,000, which yields catch per hectare (10,000 m^2). Monthly abundance was calculated as the product of mean CPUE by region and the region's weighting factor, then summed for all 5 regions (see Methods chapter, Tables 2 and 3). Annual abundance was calculated as the mean of monthly indices. May to October and February to October index periods were used to calculate annual abundance indices for age–0 and age–1 longfin smelt, respectively; these months represent the longest contiguous periods sampled annually (see Methods chapter, Table 1) when age–0 and age–1 longfin smelt were captured. No indices were calculated for age–2+ fish. No correction was made for missing data for September and October 1989, so the indices for age–0 and age–1 fish were probably biased high in that year. Annual distribution analyses were based on February to October monthly CPUE by region for both age–0 and age–1 fish. Seasonal abundance and distribution (geographical, salinity, and temperature) analyses were based upon data from 1981 to 1988, when all 12 months were sampled (see Methods chapter, Table 1).

Simple linear regression analyses were used to test for a relationship between outflow and age–0 longfin smelt abundance (Zar 1984). Abundance indices and outflows were log transformed to meet regression assumptions of equal variance. Seasonal salinity distribution was calculated for each age class as the monthly mean ±1 standard deviation of CPUE-weighted bottom salinity using 1981 to 1988 data. Seasonal temperature distribution was calculated similarly for salinity using CPUE-weighted bottom temperature.

Results

Catch and Length Analyses

In the plankton net, more than 130,000 larvae and 6,000 juveniles (age 0) were collected during the study period (see Table 1). Yolk sac larvae ranged in size from 4.2 to 9.6 mm TL, but 97% ranged from 5.0 to 7.9 mm TL ($n = 38{,}302$ measured). Post-yolk sac larvae ranged in size from 5.4. to 19.0 mm. Most post-yolk sac larvae were larger than 6.9 mm (95.3%; 66,690 measured). Juveniles in the plankton net ranged from 20 to 53 mm FL. In the beach seine, only 215 longfin smelt were caught, ranging in size from 24 to 101 mm FL.

The longfin smelt was the most abundant osmerid collected with either the otter or midwater trawl (see Table 1). Longfin smelt ranged in size from 17 to 154 mm FL in the midwater trawl and from 15 to 150 mm FL in the otter trawl. Cutoff lengths provided a good separation of age–0 and age–1 fish from April to June, but only an approximate separation in later months (Figure 1). Cutoff lengths provided only approximate separation of age–1 and age–2 fish due to length overlaps. In January, 2 additional year classes were also apparent: 90 to 124 (age 2) and ≥125 (age 3) (see Figure 1). Only 12 fish out of more that 45,500 captured in the otter trawl were ≥ 125 mm or age 3. Eleven of the 12 age–3 fish were captured from November to May, immediately before and during the longfin smelt spawning period.

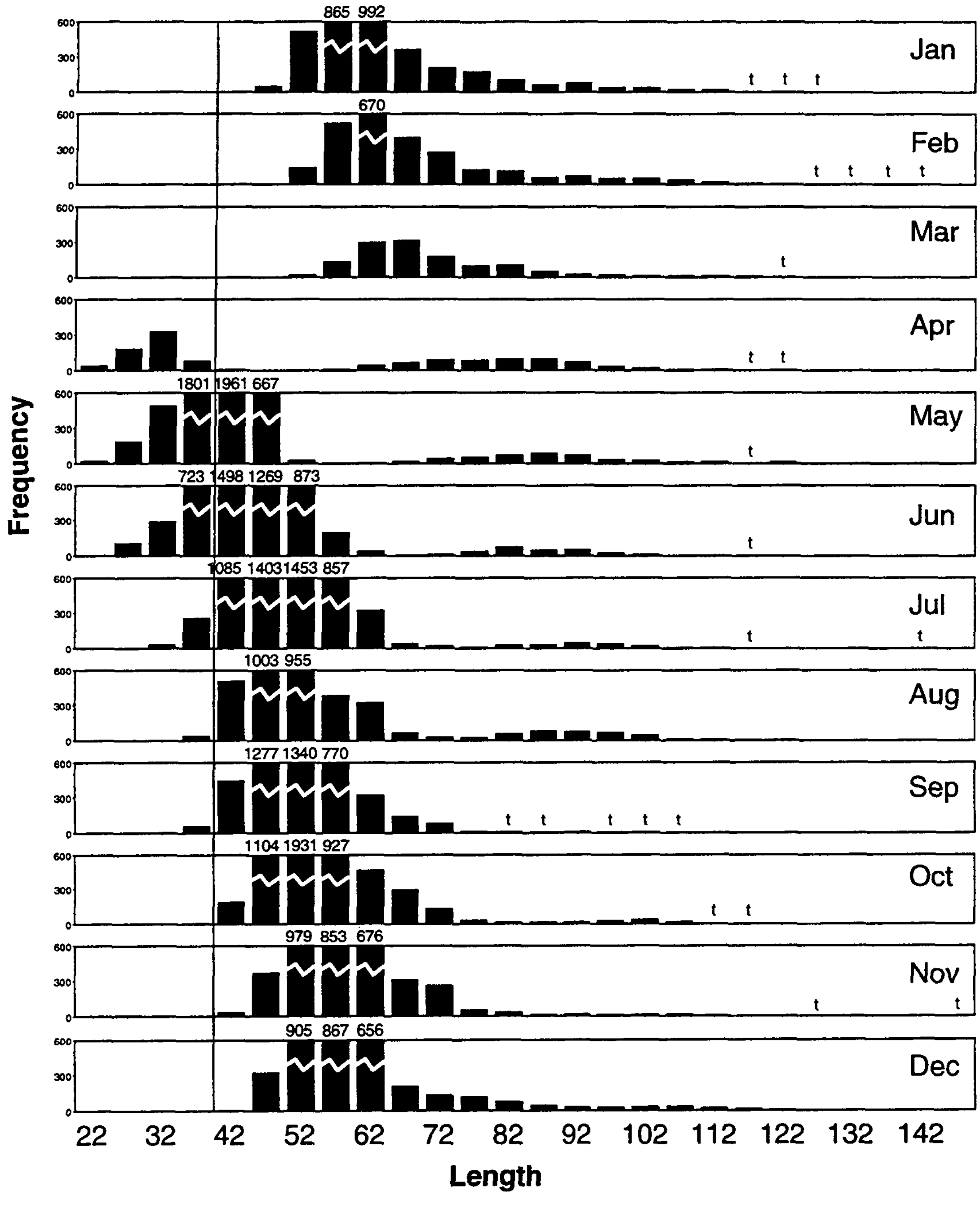

Figure 1 Length frequency (mm FL) by month of longfin smelt collected with the otter trawl from 1980 to 1995. Fish under the 40 mm (vertical line) were collected between 1980 and 1989, but were not included in index calculation. Numbers too small to show at this scale are indicated by "t" (trace).

Including fish <40 mm, examination of length-frequency modes indicates an apparent age 0 growth rate of between 5 and 10 mm per month for April to August, followed by growth at <5 mm per month for the rest of the year (see Figure 1). Most age–0 fish reached 40 mm by August. Faster growing age–0 fish attained 80 to 90 mm by December. Among age–1 fish, little growth occurred between January and March (<5 mm). After April, growth appeared to increase, but fish numbers decreased rapidly and the modes were difficult to follow.

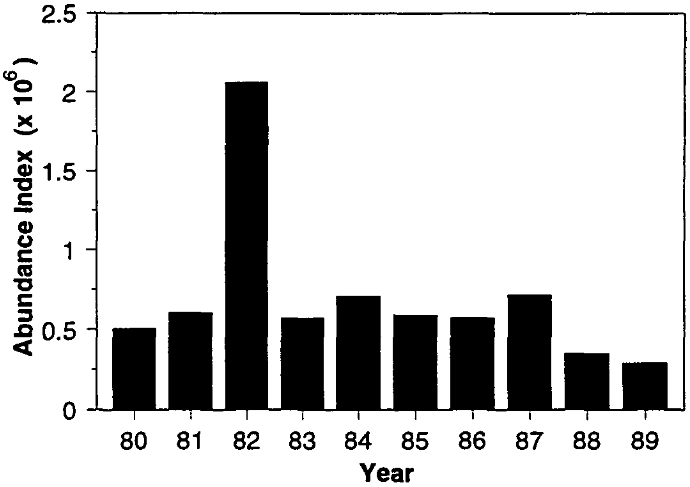

Figure 2 Annual abundance of longfin smelt larvae (YSL + post-YSL) collected with the plankton net from 1980 to 1989

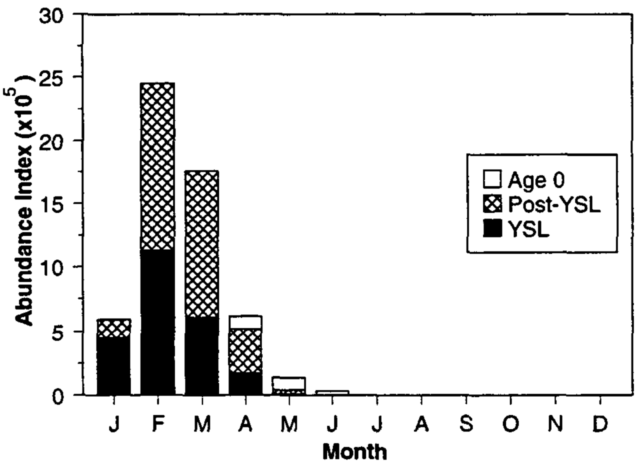

Figure 3 Seasonal abundance by life stage (YSL, post-YSL, Age 0) of longfin smelt collected with the plankton net from 1981 to 1988

Abundance and Distribution of Larvae

Except for the high abundance year 1982 and the low abundance years 1988 and 1989, larval abundance indices did not vary much annually (Figure 2). Although larval abundance peaked during the high outflow year 1982 and declined in 2 of the early years of the drought (for example, 1988 to 1989, see Figure 2), there was no relationship between December through March average monthly outflow and larval abundance ($r^2 = 0.21$, $P > 0.20$, $n = 10$). Generally, larvae were most abundant from January to April (Figure 3), but some were captured as early as November or as late as July (Table 2). Larval abundance peaked in February in 8 out of 10 years and in March in the remaining 2 years (see Table 2).

Table 2 Monthly abundance of longfin smelt larvae captured in the plankton net from 1980 to 1989. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1980 to 1989 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*Mar*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan–May*
1980		1,017,999	831,472	168,224	11,925	1,758	0	0	0	0	338	0	507,405
1981	451,862	1,068,828	1,297,281	177,568	28,772	0	431	0	0	0	531	0	604,862
1982	1,089,739	5,461,695	3,061,403	605,076	91,403	413	0	0	0	0	0	4,068	2,061,863
1983	72,882	988,726	937,592	709,509	149,028	1,184	0	0	0	0	0	608	571,547
1984	602,702	1,348,685	1,159,662	414,023	1,148	0	431	0	0	0	0	7,807	705,244
1985	708,428	1,078,978	688,366	473,275	1,738	0	0	0	0	0	0	1,607	590,157
1986	191,894	2,320,317	237,865	113,748	3,496	1,714	0	0	0	0	0	23,291	573,464
1987	473,212	714,149	1,741,008	647,810	6,880	1,505	0	0	0	0	0	0	716,612
1988	242,801	1,030,047	472,529	3,893	2,149	0	0	0	0	0	0	2,790	350,284
1989	175,435	362,991	332,118	157,508	4,567								206,524
1980–1989	445,439	1,539,242	1,075,930	347,063	30,111	730	96	0	0	0	97	4,463	

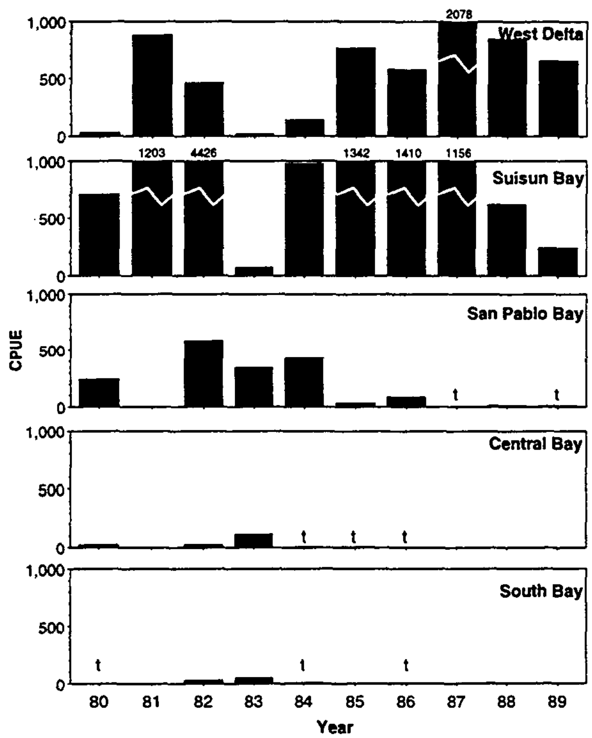

Figure 4 Annual distribution of longfin smelt larvae (YSL + post-YSL) collected in the plankton net from 1980 to 1989. Data are average January to May CPUE by region. When CPUE was too small to plot "t" was inserted in the graph. The years 1981, 1985, and 1987 to 1989 were classified as having low outflow and the remainder as having high outflow.

Larval distribution varied considerably from year to year, but larvae were always captured in the west delta and Suisun Bay, and less frequently farther downstream (Figure 4). The distribution of larvae was significantly correlated with average December to March outflow ($r_{spearman}$= 0.867, $P < 0.005$, $n = 10$).

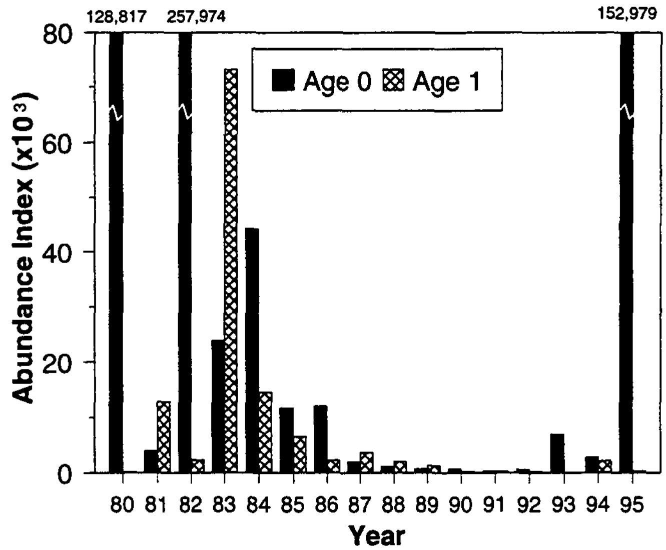

Figure 5 Annual abundance of age–0 and age–1 longfin smelt from the otter trawl from 1980 to 1995

In years with high outflows (that is, in 1980, 1982, 1983, 1984, and 1986), larvae were distributed in all regions of the estuary. They were only collected in South Bay during these high outflow years. During low outflow years, larvae were not collected in high densities outside of the west delta and Suisun Bay, though they were caught as far away as Central Bay in 1985.

Abundance and Distribution of Age–0 and Age–1 Fish

Annual Abundance

The abundance of age–0 longfin smelt varied from a high of 257,974 in 1982 to a low of 244 in 1991 (Figure 5, Table 3). From 1980 to 1987, age–0 abundance alternated between high in even years and low in odd years, and declined steadily to 1991. Beginning in 1992, age–0 abundance started to increase, but odd years were higher than even years. In 1995, abundance returned to a level comparable to that of the early 1980s.

There was a significant and positive relationship between the abundance of age–0 longfin smelt and average December to May outflow ($r^2 = 0.772$, $P < 0.05$, $n = 16$). Over the period of larval sampling (1980 to 1989), age–0 abundance was also significantly and positively related to larval abundance ($r^2 = 0.425$, $P < 0.05$, $n = 10$). This relationship was strongly driven by the 1982 abundance indices.

Age–1 abundance varied from a high of 73,222 in 1983 to a low of 24 in 1993 (see Figure 5). In general, age–1 abundance lagged age–0 abundance by 1 year. However, during the drought of 1987 to 1992, age–1 abundance did not decline as steeply as age 0. Age–1 abundance also showed signs of a slight recovery in 1994 and 1995 (see Figure 5, Table 4).

Table 3 Monthly abundance of age–0 longfin smelt captured with the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (mean 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Oct*
1980		0	0	1078	8213	56770	258923	108942	185517	154535	118581	42046	128817
1981	0	0	0	0	173	2881	3299	8862	4435	4595	2001	4929	4041
1982	0	0	0	0	123319	170950	336405	279918	246844	390410	120106	338806	257974
1983	0	0	0	0	7036	25448	57754	30107	4415	18493	28345	27564	23876
1984	0	0	0	189	548	27686	24635	34657	14486	164097	8709	24842	44352
1985	0	0	0	0	1019	4915	4085	20164	2873	37678	42952	15052	11789
1986	0	0	0	0	30040	5640	17658	5170	5188	8940	24654	5720	12106
1987	0	0	0	0	2861	3383	819	975	2393	1560	1389	2420	1999
1988	0	0	0	0	625	2029	903	878	1802	342	766	1582	1097
1989	0	0	0	0	172	554	2621	584					983
1990		0	0	0	0	954	516	0	1455	1196			687
1991		0	0	0	250	583	0	542	0	90			244
1992		0	0	0	247	1599	1488	121	270	0			621
1993		0	0	0	3445	5338	2602	10783	14556	5352			7013
1994		0	0	0	0	514	2101	7378	5327	1738			2843
1995	0	0	0	0	263805	203328	106183		182259	9321	223910	24652	152979
1981–1988	0	0	0	24	20703	30367	55696	47591	35305	78264	28615	52614	

Table 4 Monthly abundance of age–1 longfin smelt captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (average 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		346	118	55	0	487	297	216	65	0	84	811	176
1981	39209	18305	14605	10756	3757	1309	2876	61702	352	2414	598	4738	12897
1982	4951	3804	6058	586	1818	0	216	8086	0	358	216	4136	2325
1983	433136	273635	231800	35664	30495	22944	22679	28149	1449	12185	8634	9782	73222
1984	37843	100191	12260	2859	2319	1265	1920	2396	216	7687	0	2764	14568
1985	13360	21991	7673	17102	3787	487	0	5381	1129	1287	3153	2689	6537
1986	10178	5767	789	1044	3565	939	7614	757	0	279	1642	1094	2306
1987	7735	4614	4661	13365	6131	2693	211	433	472	861	134	2183	3716
1988	19930	11562	670	2319	2753	1190	83	0	0	0	553	2041	2064
1989	1093	5251	2061	907	540	192	2496	0					1635
1990		1167	55	236	62	0	0	0	0	0			169
1991		1002	297	83	565	0	0	0	0	211			240
1992		154	446	792	379	0	216	0	0	0			221
1993		216	0	0	0	0	0	0	0	0			24
1994		6389	6461	1019	2983	1637	514	0	270	216			2165
1995	604	1139	1132	0	919	0	0		0	0	297	380	399
1981 – 1988	70793	54984	34815	10462	6828	3853	4450	13363	452	3134	1866	3678	

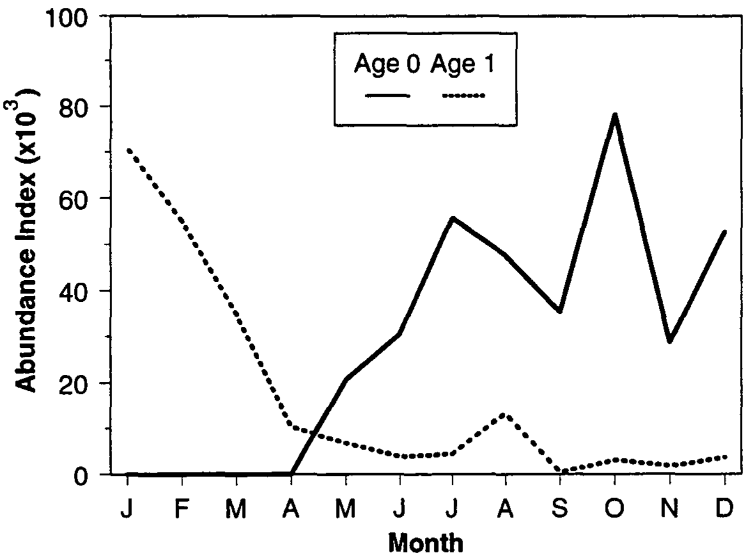

Figure 6 Seasonal abundance of age–0 and age–1 longfin smelt collected with the otter trawl. Data are monthly abundance indices averaged for 1981 to 1988.

Seasonal Abundance

Longfin smelt first reached 40 mm and began contributing to the age–0 abundance index in April (see Figure 1, Figure 6). Age–0 abundance increased in early summer as more age–0 fish reached 40 mm and then varied without trend for the rest of the year. Age–1 abundance was initially high in January, but declined rapidly through winter and early spring and less rapidly during summer, culminating in very low abundance in and after September (see Figure 6).

Annual Distribution

The annual distribution of age–0 longfin smelt was slightly broader than for larvae, extending through all regions in 10 of 16 years sampled, compared to 5 of 10 years for larvae (Table 5, compare to Figure 4). Moreover, age–0 fish were collected in Central Bay in all years and in South Bay in 13 of 16 years, indicating continued dispersal after the larval stage, particularly during low outflow years. Five of the 6 years when age–0 fish were not distributed estuary-wide were low outflow years with low abundance. Peak density of age–0 fish was in San Pablo or Central bays, except in low outflow years (1987 to 1989, and 1992, see Table 5), whereas peak density of larvae occurred in the west delta or Suisun Bay in all years except 1983 (see Figure 4).

Age–1 longfin smelt were found in all regions in 8 of 16 years (Table 6). Age–1 CPUEs were somewhat more uniform across regions than those of age–0 fish, and age–1 fish used South Bay slightly more than age–0 fish, especially in 1983 and 1984.

Table 5 Annual distribution of age–0 longfin smelt collected by the otter trawl from 1980 to 1995. Data are average February to October CPUEs by region for original stations.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
1980	1	60	439	75	46
1981	<1	10	1	6	2
1982	1	206	749	264	2
1983	1	54	28	2	0
1984	<1	119	20	9	9
1985	1	29	3	14	2
1986	2	14	25	9	1
1987	<1	3	1	9	2
1988	0	2	1	1	4
1989	0	2	<1	1	4
1990	<1	1	<1	1	0
1991	0	1	<1	1	0
1992	<1	1	1	<1	2
1993	<1	15	8	2	1
1994	<1	8	<1	<1	0
1995	10	395	46	10	1
Mean	1	55	84	26	5

Table 6 Annual distribution of age–1 longfin smelt collected with the otter trawl from 1980 to 1995. Data are average February through October CPUEs by region for original stations.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
1980	0	1	<1	1	<1
1981	2	37	15	25	14
1982	<1	8	2	5	<1
1983	108	90	166	8	0
1984	19	38	7	8	1
1985	3	13	10	25	3
1986	1	6	4	4	0
1987	<1	8	10	8	2
1988	1	4	4	6	2
1989	1	4	3	1	<1
1990	<1	<1	<1	<1	0
1991	1	<1	<1	1	0
1992	0	1	1	1	0
1993	0	<1	0	0	0
1994	1	7	2	1	1
1995	<1	1	1	0	1
Mean	9	13	14	6	2

Table 7 Seasonal distribution of age–0 longfin smelt collected with the otter trawl from 1981 to 1988. Data are average CPUEs by month and region for original stations.

Month	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
January	0	0	0	0	0
February	0	0	0	0	0
March	0	0	0	0	0
April	0	0	0	0	0
May	3	22	73	71	2
June	<1	56	79	105	3
July	<1	137	155	23	1
August	0	89	181	19	3
September	1	26	177	39	1
October	1	146	263	100	15
November	1	53	57	124	21
December	25	22	257	34	5
Mean	3	46	103	43	4

Seasonal Distribution

When age–0 longfin smelt reached 40 mm in May they were present throughout the sampling area (Table 7); however, substantial use of South Bay occurred almost exclusively during high outflow years (for example, in 1980, 1982, 1983, 1986, and 1995; see Table 5). Age–0 density was usually highest in San Pablo Bay and next highest in Central and Suisun bays. A few age–0 fish were present in South Bay in summer and early fall, but the highest CPUE occurred there in December. A downstream movement in the spring and summer was indicated by increasing CPUE in Central Bay from May to July and in San Pablo Bay from May to August in conjunction with decreases in Suisun Bay and the west delta during the same period. The increased CPUE in Suisun Bay and the west delta from September to November suggests an upstream movement in fall.

Age–1 fish were present in all regions in winter (Table 8). After February or March, when CPUE was decreasing throughout the estuary, they left the west delta and then South Bay. By July, no age–1 fish were taken in South Bay or the west delta, and CPUE was much reduced in San Pablo and Suisun bays. Although CPUE in Central Bay fluctuated widely, it was usually higher there than in any other region during summer and early fall. Few age–1 fish were present in the estuary during September, but beginning in October and continuing to December, CPUE increased in all regions.

Salinity and Temperature

The distribution of age–0 longfin smelt along the salinity gradient changed seasonally. In May and June, age–0 fish were found in monthly mean salinity of 14‰ to 15‰ (Figure 7). During summer and fall, the monthly means increased to 24‰ and 28‰; in November and December, respectively, their salinity range returned to the spring levels. The upstream movement in October and November caused the downward shift in their salinity distribution. The mean temperature at which age–0 longfin smelt were found ranged from 16 to 18 °C in late spring, summer and fall, to about 11.5 °C in winter (Figure 8).

Table 8 Seasonal distribution of age–1 longfin smelt collected by the otter trawl from 1981–1988. Data are average CPUEs by month and region for original stations.

Month	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
January	64	115	187	49	22
February	48	91	160	34	15
March	100	25	22	21	5
April	5	21	28	20	3
May	3	14	18	19	3
June	3	4	11	11	0
July	0	16	7	1	0
August	0	57	5	1	1
September	0	1	1	1	0
October	0	12	2	2	2
November	0	7	1	2	1
December	1	9	6	6	4
Mean	19	31	37	14	5

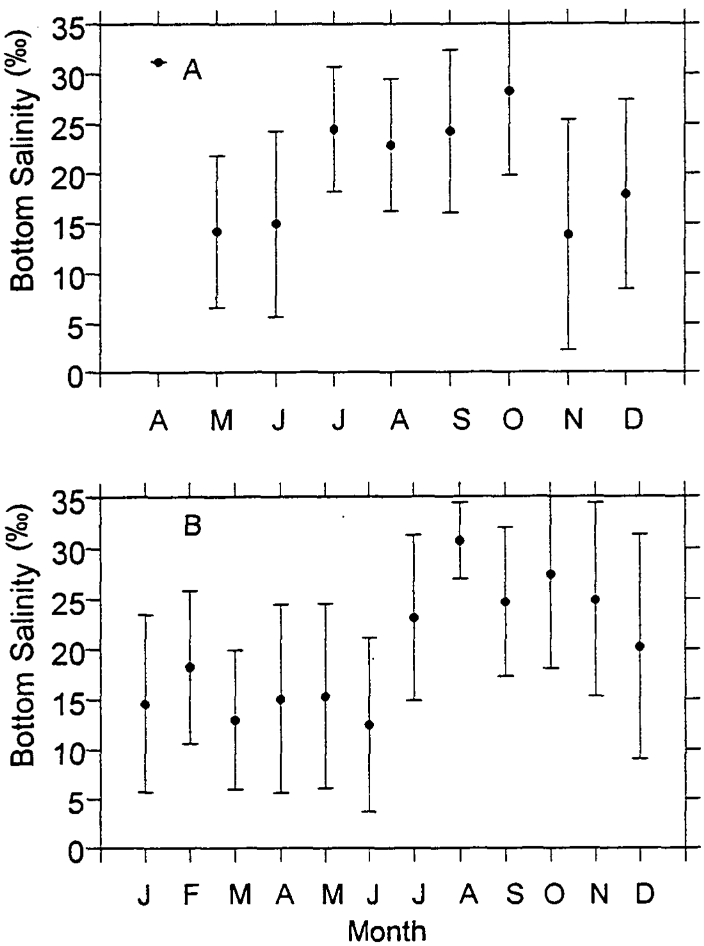

Figure 7 Salinity (‰) distributions of (A) age–0 and (B) age–1 longfin smelt collected with the otter trawl. Data are monthly mean (±1 standard deviation) CPUE-weighted bottom salinity by month and age class for 1981 to 1988.

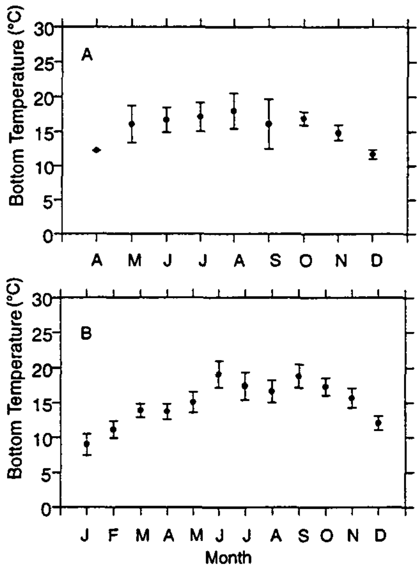

Figure 8 Temperature (°C) distributions of (A) age–0 and (B) age–1 longfin smelt collected with the otter trawl. Data are mean (±1 standard deviation) CPUE-weighted bottom salinity by month and age class for 1981 to 1988.

Age–1 longfin smelt inhabited intermediate salinities from January through June (means were 12.5‰ and 18.2‰), were found in higher salinities to a mean of 27.4‰ in October, and then at slightly reduced salinities in November and December (see Figure 7). The monthly mean temperature ranged from about 9 °C in January to about 19 °C in June (see Figure 8).

The salinity distributions of age–0 and age–1 fish were strongly influenced by the large 1982 year class during the high outflow of winter and spring 1983. There was a tendency for age–1 longfin smelt to move to euhaline waters of Central Bay during summer and early fall.

Discussion

Longfin smelt inhabit the estuary throughout their lives, though many also inhabit local coastal areas particularly during the late summer and fall (City of San Francisco Bureau of Water Pollution Control and CH2M Hill 1984; B. Sak, personal communication; S. Ralston, personal communication, see "Notes"). Longfin smelt responded to high freshwater outflow with a broader distribution of early life stages and increased abundance. The winter to early spring spawning period results in larvae hatching either during or immediately before annual peak outflows (Williams 1989, Hieb and Baxter 1993). Surface-oriented, early stage larvae are then transported downstream by winter and spring outflows (Wang 1986, Hieb and Baxter 1993, this study). These same outflows reduce salinity in Suisun, San Pablo, and occasionally Central and South bays, increasing nursery habitat for longfin smelt (Hieb and Baxter 1993, Unger 1994). Older larvae and small age–0 fish inhabit the middle and bottom strata of the water column, as evidenced by the high otter trawl catch (Wang 1986, Hieb and Baxter 1993, this study). This limits further downstream transport in spring and initially places age–0 fish in areas with bottom salinities of about 15‰ (see Figure 7). Variations in timing of spawning and in the magnitude and timing of outflows act to disperse larvae geographically.

Winter spawning and the initial salinity distribution of age–0 fish indicate that longfin smelt may avoid interspecific competition by spawning earlier in the year than most species and by inhabiting salinities mainly outside the tolerance range of potential marine and freshwater competitors. The higher the outflow, the larger the area of low and intermediate salinity habitat where longfin smelt may have a competitive advantage (Hieb and Baxter 1993, Unger 1994). Few species spawn during the winter and have planktonic larvae. Of the species with high winter larval densities, white croaker and northern anchovy larvae are distributed farther seaward in the estuary but Pacific herring larvae share the same habitats as longfin smelt larvae (CDFG 1987). The yellowfin goby is another potential competitor, yet its peak spawning is slightly later in the year. It spawns in more saline waters of Central and South bays, and its yolk sac larvae are bottom oriented before dispersing throughout the water column as post-yolk sac larvae (Wang 1986, CDFG 1987), so potential competition is delayed until late in the larval period. Of the abundant species having planktonic larvae, striped bass, prickly sculpin, shimofuri goby, arrow and cheekspot gobies, and jacksmelt spawn later in the year (Wang 1986, CDFG 1987). Thus, only Pacific herring and yellowfin goby appear to be potential competitors.

The distribution of age–1 longfin smelt appears to be influenced by high water temperatures. Age–1 longfin smelt have been collected in salinities from freshwater to sea water, but their distribution generally contracts from estuary-wide in the winter to mainly Central Bay by late summer and fall (see Table 8). Water temperatures in South Bay and the west delta generally reach their maxima between July and September and age–1 longfin smelt are rare during this period. The shift toward Central Bay during summer and reduced abundance in all regions suggests relatively high mortality, reduced catchability, or emigration to coastal habitats. Of these, emigration definitely occurs. Otter trawl sampling in the Gulf of the Farallones routinely captures longfin smelt in fall, and has captured them occasionally in spring, especially during years of high abundance (B. Sak, personal communication, see "Notes"). Size frequency information indicates that both age–0 and age–1 fish can be found in the Gulf of the Farallones, but age–1 fish are more frequently collected there. The National Marine Fisheries Service conducts a spring midwater trawl survey to assess juvenile rockfish abundance off the central California coast. In the course of 11 spring surveys (1983 to 1993), 32 longfin smelt were identified from 1 tow in June 1984 off the Marin County coast (S. Ralston, personal communication, see "Notes"). Thus, the open coast can provide some habitat for longfin smelt, but their principal habitat remains in the estuary.

Night Smelt

Introduction

The night smelt, *Spirinchus starksi*, is a pelagic marine fish which ranges from Point Arguello, California, northward to Shelikof Bay, southeast Alaska (Dryfoos 1965). It spawns at night in the surf over coarse sand from January through September (Fitch and Lavenberg 1971, Frey 1971). Eggs are demersal and adhesive, and incubation takes about 2 weeks (Fitch and Lavenberg 1971). Night smelt larvae were collected off Newport, Oregon, in June and July, and young juveniles were collected off Moolack Beach, Oregon, in October (Hearne 1983). It reaches a maximum length of 139 mm (Miller and Lea 1972) and is an important commercial and sport fish (Fitch and Lavenberg 1971). Due to overlapping preferences in spawning habitat and timing, night smelt and surf smelt are frequently caught together in the surf using A–frame dip nets. The night smelt is sold for human consumption and to oceanaria for consumption by fish, birds, and mammals (Fitch and Lavenberg 1971, Moyle 1992).

Methods

Data from the midwater trawl, otter trawl, and beach seine were combined for length frequency (mm FL). Abundance and distribution were based on total catch.

Results

Only 194 night smelt were collected in sampling between 1980 and 1995 (see Table 1). These fish ranged in size from 49 to 150 mm FL (Table 9). Of these, 159 came from 1 midwater trawl tow at station #216 in Central Bay in July 1980. Five fish from this tow were above the maximum length of 139 mm reported by Miller and Lea (1972): 3 were 140 mm and 2 were 150 mm. During all years only 2 additional night smelt were collected in July and none were taken from August to November. After the large 1980 catch, most of the other night smelt were collected in 1983 (6), 1992 (5) or 1993 (12). Excluding the large 1980 catch, 74% of the fish (n = 35) were collected between February and April, and abundance was highest in Central Bay: South Bay = 12, Central Bay = 15, San Pablo Bay = 8.

Table 9 Length frequency (mm FL) by month for night smelt collected with the beach seine, midwater trawl, and otter trawl from 1980 to 1995

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
40 - 49	1						1						2
50 - 59				2								1	3
60 - 69				5									5
70 - 79	1	2	1										4
80 - 89			1	3		1							5
90 - 99		2	1		2	1	2						8
100 - 109		1	1	1			14						17
110 - 119		1	3				25						29
120 - 129		2			1		53						56
130 - 139							61						61
140 - 149							3						3
150 - 159							2						2
Total	2	8	7	11	3	2	160	0	0	0	0	1	194

Discussion

The night smelt is an uncommon visitor to the estuary. However, it is commonly collected just outside the estuary in the Gulf of the Farallones (B. Sak, personal communication, see "Notes"). There was some question about the species identification of the extremely high catch in July 1980. The large number of fish and the collection of 5 fish larger than the known maximum size leads to speculation that these fish were misidentified longfin smelt. However, age–1 and older longfin smelt were generally not collected in high numbers in July, so the question persists.

The relative rarity of night smelt in the estuary combined with its similarity to the more abundant longfin smelt makes it probable that some night smelt were overlooked among large catches of longfin smelt. The relatively high night smelt catches in 1992 and 1993 occurred when longfin smelt abundance was low and interest in smelt was high due to a petition for listing the longfin smelt under the Endangered Species Act (USFWS 1993).

Delta Smelt

Introduction

The delta smelt is endemic to the delta, Suisun Marsh, Suisun Bay, and adjoining sloughs in the lower Sacramento and San Joaquin rivers. During periods of high freshwater outflow it occasionally ventures into San Pablo Bay (Ganssle 1966). It is presently not harvested from the estuary by sport or commercial fishers, though it once was (Moyle 1992).

Delta smelt mature at about 1 year, at 55 to 70 mm (Moyle and others 1992). In winter and spring, prespawning adults appear to concentrate in eastern Suisun Bay and the west delta (Ganssle 1966, Moyle 1976), and then disperse into dead-end sloughs and delta channels to spawn (Radtke 1966). Moyle (1976) collected ripe fish from December through April, mostly in February and March. Wang (1991) observed mature adults on Central Valley Project fish screens from late December to early April, but believed that spawning took place between mid-February to late June or early July, with the peak in late April and early May. Most delta smelt die after spawning, but the presence of a few adult fish later in the year suggests that some may live to spawn again at age 2 (Moyle 1976).

Delta smelt spawn mainly in freshwater, but some spawning may occur in slightly brackish water (Wang 1991). Eggs are demersal and adhesive, attaching singly to plants or other firm substrates (Moyle 1976). Larvae are about 5.5 to 6.0 mm TL at hatching and are planktonic (Wang 1986). Stevens and others (1990) hypothesized that, in "normal" outflow years, freshwater outflow transports larval delta smelt to the entrapment zone where growth and survival are presumably maximized because of the abundance of zooplankton (Siegfried and others 1979). Juveniles appear to move to the western delta and Suisun Bay during summer (Messersmith 1966, Radtke 1966, Wang 1991, Sweetnam and Stevens 1993). This movement may be related to the location of the entrapment zone, which moves from year to year depending on outflow (Moyle and others 1992, Sweetnam and Stevens 1993). The California Department of Water Resources and U.S. Bureau of Reclamation (1994) analyzed the salinity distribution of delta smelt and found that abundance peaks at 0.2‰ to 1.0‰, immediately upstream of the entrapment zone.

Growth is rapid; fish reach 40 mm by June (Wang 1991) and 50 to 70 mm by December (Erkkila and others 1950). The delta smelt is reported to reach a maximum size of 126 mm (Stevens and others 1990). Sampling by Radtke (1966) indicates that delta smelt are surface-oriented as juveniles and adults. Recent reviews of delta smelt biology and ecology can be found in Moyle and others (1992), Sweetnam and Stevens (1993) and in California Department of Water Resources (1994).

Methods

Delta smelt mature soon after the first of the year (Moyle 1976, Wang 1991); therefore, fish caught after 1 January were classified as adults. To separate age classes, length frequency data (mm FL) from the midwater trawl were combined into 5-mm intervals and inspected to locate numerical minima. At the minima, cutoff lengths were selected to provide the best separation of age–0 and adult fish. Cutoff lengths for separating age–0 from adult fish were as follows: 40, 50, 50, 50, 50, 55, 65, 70, 75, 80, 80, and 80 mm FL for January through December, respectively. Apparent growth rate estimates were based on monthly shifts in length modes.

Annual larval abundance was the mean CPUE (number per 1000 m^3 filtered by the plankton net) for Suisun Bay and west delta regions only, and for the months March to July. Abundance in 1989 was based upon incomplete sampling. Seasonal abundance was the mean monthly CPUE by life stage (that is, yolk sac, post-yolk sac, and age 0) for Suisun Bay and west delta stations from 1980 to 1988. Annual distribution was the mean CPUE by region for March to July. No correction was made for no sampling done in June and July 1989.

Only delta smelt ≥30 mm FL were used to calculate age–0 CPUE. For the midwater trawl, CPUE was calculated as the number of fish per 10,000 m^3 of water filtered. Annual abundance indices were based upon June to October and February to June periods for age–0 and adult fish, respectively. For age–0 fish, no indices were calculated for 1989 or 1994 due to insufficient data and the 1995 index was based upon incomplete sampling (no sampling in August, see Methods chapter, Table 1). For adults, no indices were calculated in 1994 and 1995 due to missing data. Annual distribution was calculated as the average CPUE by region for June through October and February through August for age–0 and adult fish, respectively. Seasonal abundance and distribution analyses were based upon 1981 to 1988 data when 12 months were sampled. All salinity and temperature statistics were calculated from average water column measurements and weighted by CPUE. Again, only 1981 to 1988 data were used.

Results

Length

There was little overlap in the length frequency distributions of age–0 and adult delta smelt, which allowed accurate separation of year classes (Figure 9). Few delta smelt <30 mm were caught by any gear and all were caught before September. Length mode shifts indicated that age–0 fish grew 5 to 10 mm per month from June to October. Little growth occurred from October through the next April, then growth increased to about 5 mm per month between April and July. Age–0 delta smelt grew to 50 to 78 mm FL by December. The capture of 3 delta smelt >100 mm indicated that some survived to age 2, or older in the case of the 122 mm fish (see Figure 9).

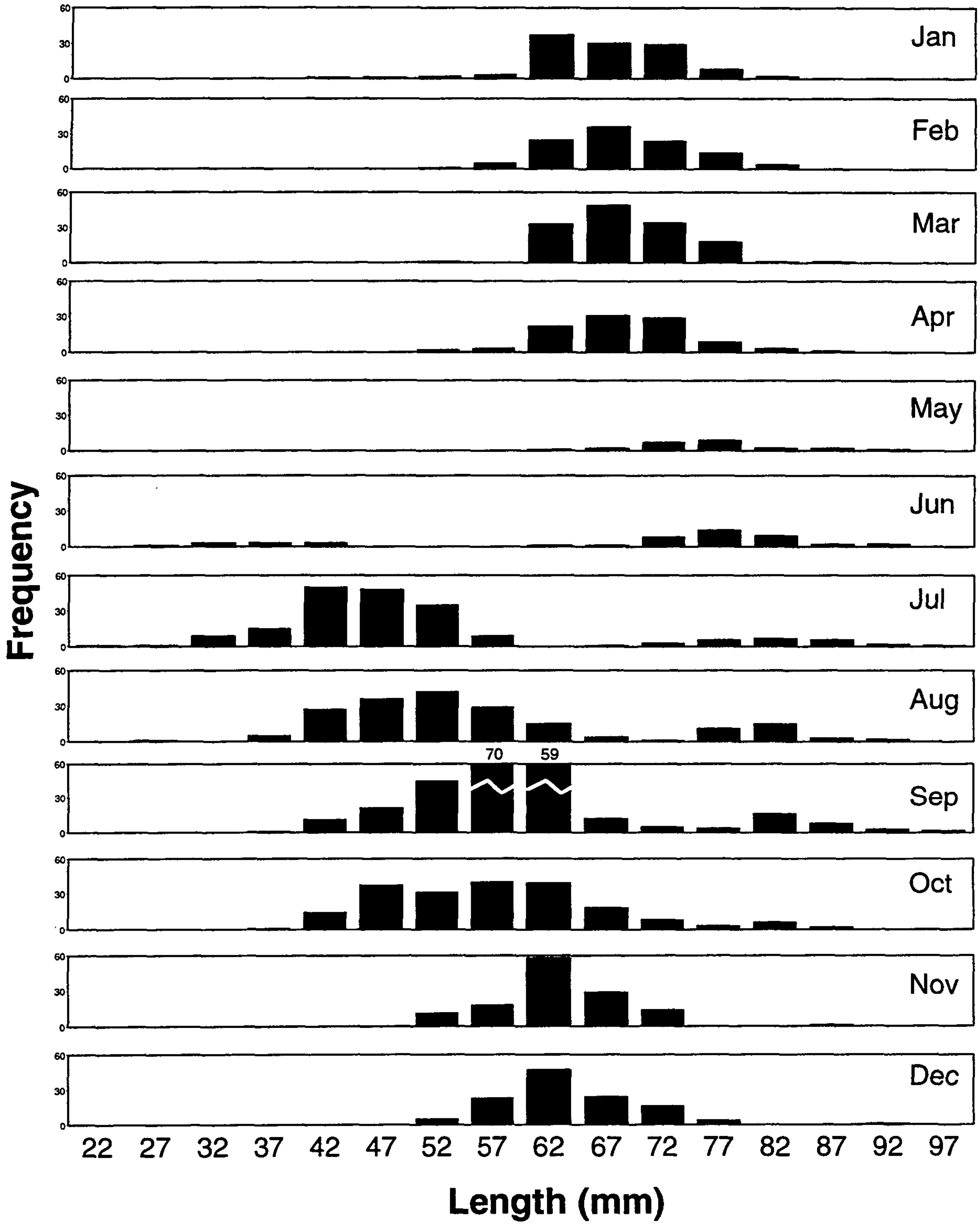

Figure 9 Length frequency (mm FL) distribution by month for delta smelt collected with the midwater trawl from 1980 to 1995. Fish under the 30 mm minimum length were collected between 1980 and 1989, but are not included in CPUE calculation. A fish 122 mm in length caught in September was not included.

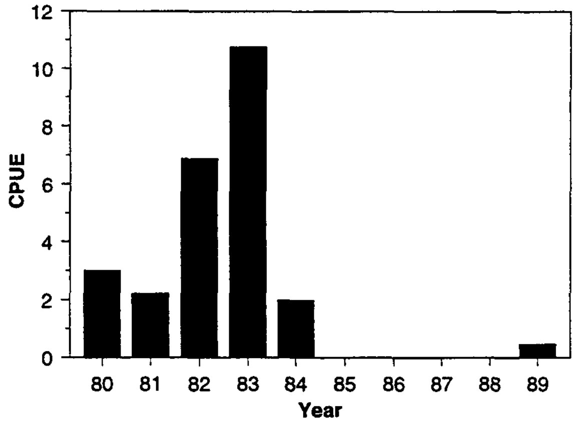

Figure 10 Annual abundance of delta smelt larvae collected with the plankton net from 1980 to 1989. Data are mean March to July CPUE for Suisun Bay and the west delta only. No correction was made for not sampling in June and July 1989.

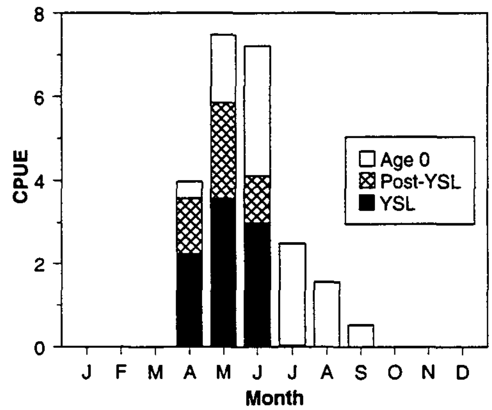

Figure 11 Seasonal abundance of delta smelt by life stage for fish collected with the plankton net from 1980 to 1988. Data are mean CPUE by month and life stage for Suisun Bay and the west delta.

The high catch in the midwater trawl compared to the otter trawl (see Table 1) indicates most delta smelt were distributed at mid-depth and surface, and not on the bottom.

Abundance and Distribution of Larvae

Delta smelt larvae were collected each year from 1980 to 1984, and again in 1989 (Figure 10). Except for 1984, when high flows occurred early and 1986 when flows were extremely high, larval abundance was greater in high rather than in low outflow years. No larvae were collected in the low outflow years 1985, 1987 and 1988, or in the extremely high outflow year 1986 (see Figure 10). Larvae were collected from April to July, with a peak in May (Figure 11). Larval delta smelt were never caught downstream of Suisun Bay and larval densities in the west delta were always as high or higher than those in Suisun Bay (Figure 12).

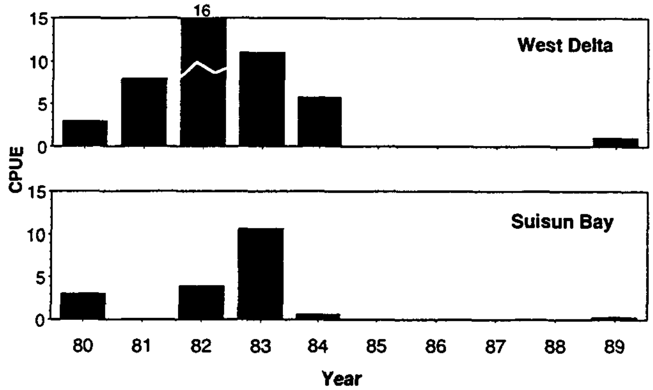

Figure 12 Annual distribution of delta smelt larvae collected with the plankton net from 1980 to 1989. Data are average March to July CPUE by region. Larvae were only collected in the west delta and Suisun Bay.

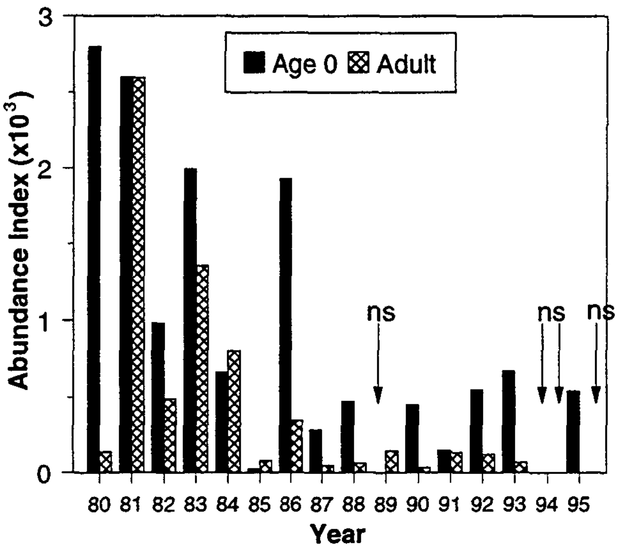

Figure 13 Annual abundance of age–0 and adult delta smelt collected with the midwater trawl from 1980 to 1995. Due to insufficient sampling, no age–0 indices were calculated for 1989 or 1994 and no adult indices were calculated for 1994 and 1995.

Abundance and Distribution of Age–0 Fish and Adults

Annual Abundance

Age–0 delta smelt abundance varied from a high of 2,799 in 1980 to a low of 24 in 1985 (Figure 13, Table 10). Abundance indices varied widely from year to year, but after 1986, they were never more than 25% of the maximum index and were generally lower than pre–1986 indices (see Figure 13). There was no indication of a relationship between abundance and freshwater outflow.

Adult abundance indices varied from a high of 2,594 in 1981 to a low of 34 in 1990 (see Figure 13, Table 11). Similar to those of age–0 fish, adult indices varied widely from year to year and abundance was generally lower after 1986 (see Figure 13). Although adult abundance was significantly correlated with the abundance of age–0 fish in the previous year ($r = 0.635$, $P < 0.05$, $n = 11$), variation in age–0 abundance explains only 40% of the variation in adult abundance.

Table 10 Monthly abundance of age–0 delta smelt captured in the midwater trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (average 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jun–Oct*
1980		0	0	0	0	0	4127	2712	4913	2245	4028	464	2799
1981	0	0	0	0	0	59	810	4198	6269	1661	825	2471	2599
1982	0	0	0	0	0	118	2535	910	625	733	531	1794	984
1983	0	0	0	0	0	0	0	413	1415	8147	1120	285	1995
1984	0	0	0	0	0	0	177	649	2158	346	633	566	666
1985	0	0	0	0	0	0	118	0	0	0	0	3467	24
1986	0	0	0	0	0	0	169	3610	3170	2689	700	1138	1928
1987	0	0	0	0	0	0	1099	0	313	0	4482	0	282
1988	0	0	0	0	0	0	0	0	1607	761	761	0	474
1989	0	0	0	0	0	0	372	59					144
1990		0	0	0	0	0	0	1064	861	338			453
1991		0	0	0	0	0	0	254	85	397			147
1992		0	0	0	0	423	2327	0	0	0			550
1993		0	0	0	0	0	1441	236	1035	651			673
1994		0	0	0									
1995				0	0	0	756		1192	228	1230	2679	544
1981–1988	0	0	0	0	0	22	614	1223	1945	1792	1132	1215	

Table 11 Monthly abundance of adult (age–1) delta smelt captured in the midwater trawl from 1980 to 1995. Annual abundance indices are in the far right column. Seasonal abundance indices are in the bottom row (average 1981 to 1988 monthly abundance).

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Jun*
1980		169	337	0	169	0	177	59	169	0	0	0	135
1981	2565	5361	2963	1720	321	2604	912	0	769	59	0	0	2594
1982	4301	992	707	379	261	118	202	59	85	0	0	118	491
1983	2494	933	4881	671	85	226	118	825	825	0	118	0	1359
1984	167	574	1638	1584	236	0	118	118	877	287	0	0	806
1985	592	169	169	0	0	59	144	338	169	169	0	0	79
1986	254	177	1405	0	0	169	0	0	0	0	0	0	350
1987	676	0	118	118	0	0	592	0	85	0	0	0	47
1988	0	254	59	0	0	0	0	0	85	0	0	0	63
1989	85	85	0	0	372	254	0	169					142
1990		0	169	0	0	0	0	118	0	0			34
1991		431	169	59	0	0	85	254	0	0			132
1992		144	287	0	0	169	59	287	0	0			120
1993		169	177	0	0	0	59	59	0	0			69
1994		177	438	59									
1995				59	59	0	381		169	0	0	0	
1981–1988	1381	1058	1493	559	113	397	261	168	362	64	15	15	

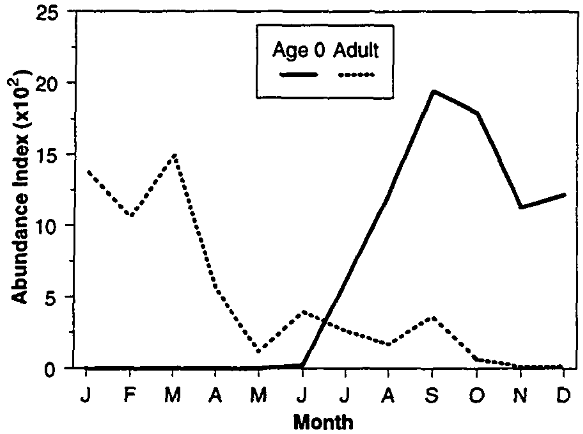

Figure 14 Seasonal abundance of age–0 and adult delta smelt collected with the midwater trawl sampling. Data are monthly abundance indices averaged from 1981 to 1988.

Seasonal Abundance

Age–0 fish first reached the 30 mm minimum length in June and continued to grow to size through September (see Figure 9). Their seasonal abundance also increased to a peak in September, then declined through the rest of the year (Figure 14). From year to year, the month of peak abundance varied from July to December (see Table 10). During several low outflow years (1985, 1987, 1988, and 1992) age–0 fish were not collected on 1 or more surveys between August and December (see Table 10).

Adult delta smelt abundance was initially high in January and remained so through March, before declining and fluctuating at a lower level from May to September (see Figure 14). After September, adult delta smelt were very rare. Adults were absent on 1 or more surveys between January and August in every year except 1982 and 1983 (see Table 11).

Annual Distribution

Age–0 delta smelt were collected from the west delta to San Pablo Bay (Table 12). They were captured in San Pablo Bay only during the high outflow years of 1983, 1993 and 1995. In several low outflow years (1987, 1988, and 1991), age–0 fish were rare or absent in the catch from Suisun Bay. Age–0 CPUE was generally higher in Suisun Bay before 1985 and in the west delta after 1985 (see Table 12).

Similar to age–0 fish, adult delta smelt were collected from the west delta to San Pablo Bay (Table 13). Adults were only collected in San Pablo Bay during the high outflow years 1982, 1983, 1984 and 1986, but were present in Suisun Bay and the west delta in all years. During the aforementioned high outflow years and 1993, adult CPUE for Suisun Bay was about equal to or higher than CPUE for the west delta, whereas during low outflow years CPUE was highest in the west delta (see Table 13).

Table 12 Annual distribution of age–0 delta smelt collected with the midwater trawl from 1980 to 1995. Data are mean June to October CPUE by region. Sampling was insufficient in 1989 to calculate an index, no sampling was conducted in 1994 and CPUE in 1995 was based upon data from 4 of 5 months (no sampling in August).

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
1980	0	0	0	5.18	1.53
1981	0	0	0	3.58	3.60
1982	0	0	0	1.80	0.53
1983	0	0	1.70	1.13	0
1984	0	0	0	1.13	0.53
1985	0	0	0	0.05	0
1986	0	0	0	1.07	5.60
1987	0	0	0	0.03	1.07
1988	0	0	0	0	1.87
1989	---	---	---	---	---
1990	0	0	0	0.35	1.13
1991	0	0	0	0.03	0.53
1992	0	0	0	0.70	0.87
1993	0	0	0.03	0.95	0.80
1994	---	---	---	---	---
1995	0	0	0.03	0.47	1.34

Table 13 Annual distribution of adult delta smelt collected with the midwater trawl from 1980 to 1995. Data are mean February through August CPUE by region. Sampling was not sufficient to allow calculation of annual distribution for 1994 and 1995.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
1980	0	0	0	0.17	0.19
1981	0	0	0	2.15	3.67
1982	0	0	0.02	0.71	0.14
1983	0	0	0.54	1.20	0.33
1984	0	0	0.29	0.64	0.24
1985	0	0	0	0.04	0.43
1986	0	0	0.04	0.29	0.33
1987	0	0	0	0.07	0.33
1988	0	0	0	0.02	0.14
1989	0	0	0	0.04	0.43
1990	0	0	0	0.04	0.10
1991	0	0	0	0.07	0.43
1992	0	0	0	0.11	0.33
1993	0	0	0	0.09	0.10
1994	---	---	---	---	---
1995	---	---	---	---	---

Table 14 Seasonal distribution of age–0 delta smelt collected with the midwater trawl. Data are mean CPUE by month and region for 1981 to 1988.

Month	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
January	0	0	0	0	0
February	0	0	0	0	0
March	0	0	0	0	0
April	0	0	0	0	0
May	0	0	0	0	0
June	0	0	0	0.05	0
July	0	0	0	0.88	0.79
August	0	0	0	1.36	2.29
September	0	0	0	1.86	4.21
October	0	0	1.06	1.34	0.96
November	0	0	0	0.88	2.83
December	0	0	0.02	1.20	2.50
Mean	0	0	0.09	0.63	1.13

Table 15 Seasonal distribution of adult delta smelt collected the midwater trawl. Data are mean CPUE by month and region for 1981 to 1988.

Month	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
January	0	0	0.10	1.69	1.96
February	0	0	0.09	1.51	0.83
March	0	0	0.63	1.33	1.29
April	0	0	0.03	0.89	0.46
May	0	0	0	0.13	0.21
June	0	0	0.02	0.14	1.25
July	0	0	0	0.17	0.71
August	0	0	0	0.27	0.17
September	0	0	0	0.45	0.58
October	0	0	0	0.05	0.17
November	0	0	0	0.03	0
December	0	0	0	0.03	0
Mean	0	0	0.07	0.56	0.64

Seasonal Distribution

Age–0 delta smelt ≥30 mm were first caught in Suisun Bay in June and in the west delta in July (Table 14). They remained in Suisun Bay and the west delta throughout the year. The presence of age–0 fish in San Pablo Bay resulted from a broader distribution of fish in high outflow years, rather than from migration into the bay.

Adults were captured in Suisun Bay and the west delta from January through early fall (Table 15). By late fall, the few adults remaining were in Suisun Bay. Adults were in San Pablo Bay only during the winter and spring of high outflow years; by April, few adult delta smelt remained in San Pablo Bay.

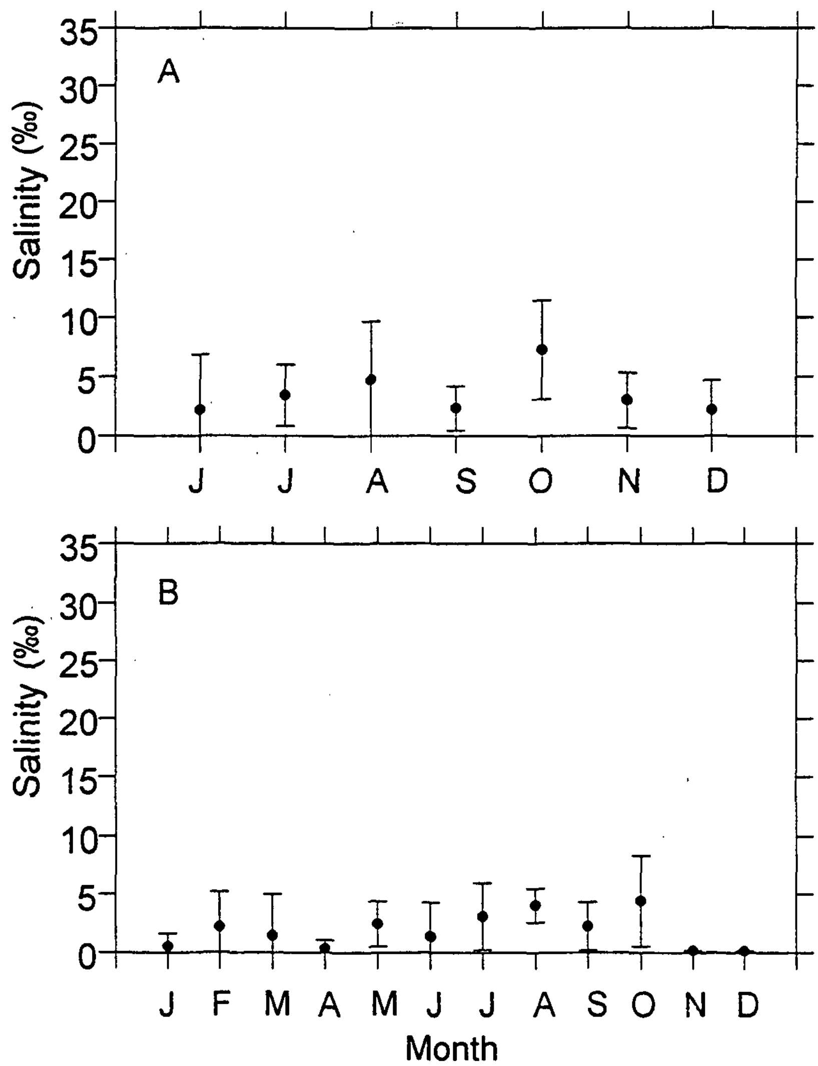

Figure 15 Salinity (‰) distributions of (A) age–0 and (B) adult delta smelt collected with the midwater trawl. Data are monthly mean ±1 standard deviation CPUE-weighted salinity by month and age class for 1981 to 1988.

The seasonal salinity distribution of age–0 delta smelt was fairly stable—the means ranged from about 2‰ to 7‰ (Figure 15). A slight increase occurred during late summer and fall. Age–0 fish were captured in salinities as high as 13.9‰. For adults the means ranged from freshwater to about 5‰. The salinity range of adults increased slightly and irregularly from January to October. Adults were captured in salinities as high as 18.4‰.

The temperature distributions of both age groups were very similar during months when both were present (Figure 16). For both age groups, July to September means ranged from about 20 to 23 °C. Maximum temperatures were 22.8 and 23.1 °C for age–0 and adult fish, respectively.

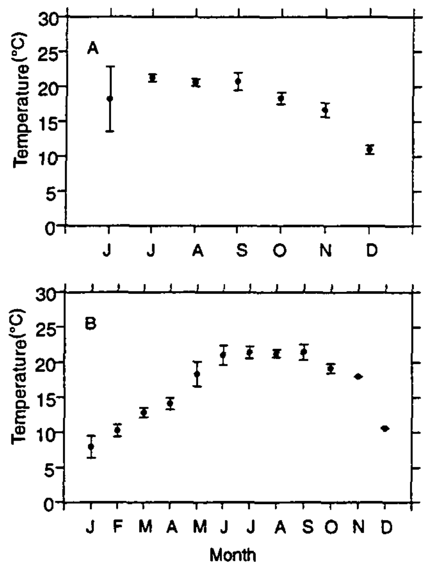

Figure 16 Temperature (°C) distributions of (A) age–0 and (B) adult delta smelt collected with the midwater trawl. Data are monthly mean ±1 standard deviation CPUE-weighted temperature by month and age class for 1981 to 1988.

Discussion

Except for a short upstream spawning migration, delta smelt spend their entire lives in tidal fresh and brackish waters of the delta, Suisun Bay, and Suisun Marsh (Moyle 1976), and appear to have mechanisms for maintaining their position. Unlike longfin smelt, delta smelt larvae do not develop an air bladder until they are relatively large, 16 to 18 mm TL (Wang 1991). The lack of a well-developed air bladder probably hinders their ability to control their position in the water column. Their buoyancy would facilitate transport downstream and larvae might be lost if high outflows pushed them into a strong, salinity-stratified area. To compensate, spawning should take place during or after high outflow events in areas where larvae might not be immediately swept away. As flows subside, "entrapment zone" circulation should act to limit the downstream transport of larvae until they are large enough to control their position (Peterson and others 1975). This hypothesis was supported by the distribution of delta smelt larvae, which was upstream of the study area in most low outflow years (Wang 1991, see Figure 10). Moderately high spring flows in the otherwise low outflow year of 1989 led to the capture of delta smelt larvae in the west delta and Suisun Bay. In comparison, early hatching and buoyant longfin smelt larvae were distributed into San Pablo Bay, occasionally farther, in almost all low outflow years (see Figure 4). The ratio of juveniles to larvae is another indication of the relative abundance of larvae in the water column and their susceptibility to downstream transport. If both life stages are pelagic, then larvae should far outnumber juveniles. This was the case for longfin smelt, but not for delta smelt: the longfin smelt juvenile to larvae ratio in the plankton net was 1:20; the delta smelt ratio was 2:3 (see Table 1). This low ratio for delta smelt suggests that most of their larvae rear in areas outside the main river channels sampled by the plankton net or upstream of the study area. Larvae rearing in dead-end sloughs or shallow water areas would be less susceptible to downstream transport that might carry them beyond suitable habitat. Another equally plausible interpretation of the low delta smelt ratio is that larval delta smelt were not accurately identified and separated from the large number of longfin smelt larvae caught. Consistent and accurate identification of longfin smelt and delta smelt larvae did not occur until about 1991 (Wang 1991).

Delta smelt abundance indices may have been biased in low outflow years because a larger part of the population was upstream from the sampling area. An upstream shift in spawning in dry years could have been responsible for the absence of larvae in plankton samples after 1984 (with the exception of 1986, a wet year). Adults spawned upstream from the study area during the drought based on the distribution of larvae in other studies (Wang 1991). The upstream distribution shift for age–0 and adult fish during the 1987–1992 drought (see Tables 12 and 13) also was detected by the CDFG fall midwater trawl survey (Sweetnam and Stevens 1993).

Delta smelt appear suited for life in tidal fresh and brackish water. Their recently observed "stroke and glide" preferred swimming motion is very energy efficient (Swanson and others 1997) and suited to a fish that follows the tide to remain in a preferred salinity range (Sweetnam and Stevens 1993). In the laboratory, delta smelt tolerated temperatures from 7 to 8 °C above acclimation temperature to a maximum of 28.9 °C and chronic exposure (12 h) to salinities from 0‰ to 19‰ (Swanson and Cech 1995). These tolerances were beyond the salinity and temperature maxima observed by the Bay Study.

Surf Smelt

Introduction

The surf smelt, or day smelt, ranges from Long Beach, California, northward to Prince William Sound, Alaska (Miller and Lea 1972). It is a minor component of both the sport and commercial marine fishery catch in the San Francisco Bay area (Oliphant and others 1990), but from central California northward, surf smelt are taken by recreational fishers in greater numbers than any other species, and have even ranked among the top species (Frey 1971).

Although surf smelt are not commonly collected in San Francisco Bay (see Table 1), estuaries provide an important habitat elsewhere within their range (Emmett and others 1991) and San Francisco Bay may be an important habitat for the local population. Surf smelt are more common north of the Bay area (Frey 1971, Moyle 1992).

Spawning in California takes place between March and October with occasional spawns at other times (McAllister 1963, Hearne 1983, Moyle 1992); however, Wang (1986) reported that spawning appeared limited to fall and winter months in the San Francisco Bay area. In Puget Sound, Penttila (1978) observed different local stocks spawning at different times and that females were capable of spawning more than once per season; thus, some spawning occurred all year.

Eggs are demersal and adhesive and attach to sand grains, shell or rock (Hart and McHugh 1944, Penttila 1978). Hatching occurs in 2 to 4 weeks depending upon temperature and wave action (Penttila 1978, Moyle 1992). Newly hatched larvae are about 3 mm long. Little is known of their life history between hatching and maturity. Surf smelt reach maturity between age 1 and 3; males predominate among 1-year-old spawners (Penttila 1978). Few individuals appear to live beyond age 3 (Penttila 1978). They reach a maximum size of about 305 mm in California, but only 222 mm in British Columbia (Hart 1973). Such large individuals are probably 3- to 5-year-old females, as females are larger than males (Penttila 1978).

Methods

Length data (mm FL) from the beach seine, otter trawl, and midwater trawl catches were combined into 10 mm groups to determine which age groups used the estuary and when they were present. Spawning was assumed to occur about 3 months prior to the capture of 30 to 40 mm fish. May, the 1st month of assumed spawning, was selected as the birth month of all fish. Age–0 fish were classified as age–1 after April 30. Cutoff lengths for separating age–0 from age–1+ fish were as follows: 50, 60, 65, 70, 75, 80, 85, 90, 100, 110, 120, and 130 for June through May, respectively. Length data also were separated by gear type to investigate the use of inshore areas (beach seine) and offshore areas (otter and midwater trawls). Annual abundance and distribution were based upon beach seine catch by station and year. No corrections were made for varying effort between regions or years. Effort was very similar from year to year, but between regions effort varied by the number of stations present (see Figure 2 in the Methods chapter).

Results

Only 2 larvae were identified from plankton samples and both were captured in Central Bay, 1 in November 1980 and the other in March 1986. Surf smelt caught in the estuary ranged from 15 to 235 mm FL, but most were between 30 and 100 mm (Table 16). Small age–0 fish (<40 mm) were collected from August to March (see Table 16). Age–0 fish appeared to grow rapidly from November to May, most reaching 70 to 90 mm FL before they dropped out of the catch between May and July as age–1 fish. From July to January, very few age–1 fish (>80 mm, assuming a May hatch date) were collected (see Table 16). Beginning in January or February and extending through June, a few age–1 fish were caught. Again, these fish disappeared from the catch by July.

Table 16 Length frequency (mm FL) by month for surf smelt collected with the beach seine, midwater trawl, and otter trawl from 1980 to 1995. A single fish at 235 mm in May is not included.

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
10 - 19											1		1
20 - 29	1	1						1		1			4
30 - 39	7		1					17	7	19	25	28	104
40 - 49	33	5	9	3				5	1	23	23	117	219
50 - 59	5	6	15	6		1					2	10	45
60 - 69	1	4	8	14	4						2	3	36
70 - 79	1	2	8	17	19	5					1		53
80 - 89	1		7	18	23	9		1					59
90 - 99		1	3	8	6	1	1						20
100 - 109				5	1								6
110 - 119				4					2			2	8
120 - 129				1	1							1	3
130 - 139			1										1
140 - 149		2		2			1				1		6
150 - 159			1	3	2							1	7
160 - 169	1	1	1		2	2							7
170 - 179						1							1
Total	50	22	54	81	59	19	2	24	10	43	55	162	581

Table 17 Length frequency distribution of surf smelt collected with the midwater trawl, otter trawl, and beach seine from 1980 to 1995. One 235 mm fish from the midwater trawl catch is not included.

Length	*Midwater*	*Otter*	*Beach Seine*	*Total*
10 - 19			1	1
20 - 29			4	4
30 - 39			104	104
40 - 49		1	218	219
50 - 59		1	44	45
60 - 69	9	1	26	36
70 - 79	13		40	53
80 - 89	10	2	47	59
90 - 99	8	3	9	20
100 - 109	2	1	3	6
110 - 119	6	1	1	8
120 - 129	2		1	3
130 - 139	1			1
140 - 149	6			6
150 - 159	6	1		7
160 - 169	7			7
170 - 179	1			1
Total	72	11	498	581

Most of the total catch was collected with the beach seine and was composed of age–0 fish (Table 17). A few larger age–0 fish and virtually all the age–1 and older fish were collected in the midwater trawl.

Age–0 surf smelt were most abundant in 1982 (Table 18). Annual catch was moderate in the remaining years from 1981 to 1985, and low in 1980 and 1986. From 1981 through 1986, the annual catch was composed primarily of age–0 fish collected from January to June (that is, spawned in the previous year). In 1980, beach seining was only conducted from August to December, so no 1979 year class fish were collected.

Table 18 Surf smelt abundance (annual catch) by region and station for fish collected with the beach seine from August 1980 through December 1986. Station #274 in Central Bay was not sampled after 1981.

Region	*Station #*	*1980*	*1981*	*1982*	*1983*	*1984*	*1985*	*1986*	*Station Total*	*Region Total*
South	169		2	1	1				4	39
	170		1	13				1	15	
	171	3		3					6	
	172		1	1					2	
	178			1	1				2	
	179		1	6	1			2	10	
Central	173		2	48		2	33		85	402
	177		1		2				3	
	251		5	25	4	2	17		53	
	262		22				2		24	
	263		1	4	3	29	1		38	
	264		3	4	1		3		11	
	265			4	2	2	3		11	
	266			1					1	
	274		2						2	
	275		4	3	1			5	13	
	276			37	4	1		2	44	
	352		22	88	2	1	3	1	117	
San Pablo/ Carquinez Strait	353		10		4		2	1	17	57
	354			8	6	1	1		16	
	367		1	1	4				6	
	368	1	5	3	6		1	1	17	
	456						1		1	
Total		4	83	251	42	38	67	13	498	

Otter and midwater trawl sampling was not done during many fall and winter months from 1989 through 1994 (otter trawling in all months was reinstated in 1995, but caught few surf smelt), making it impossible to provide a reliable index of abundance from these gear types. Nevertheless, no surf smelt were caught in either trawl from 1993 through 1995. The combined annual catch from the midwater and otter trawls ranged from 1 to 29 fish from 1980 through 1992.

In the beach seine, most surf smelt were caught in Central Bay, but sizeable numbers were also collected in both South and San Pablo bays (see Table 18). One individual was collected as far upstream as Carquinez Strait, and in trawling gear, 3 were collected in Suisun Bay.

Discussion

Surf smelt appear to use beaches within the estuary as an extension of their juvenile foraging area. The collection of fish <60 mm almost exclusively in the beach seine indicates that shallow, protected water may be important habitat for juvenile surf smelt. The lack of surf smelt catch during the summer and limited catch during early fall months indicates that the estuary may not be suitable habitat during these periods, possibly because of high temperatures. Bays and estuaries provide habitat for surf smelt throughout their range, but residence times appear to increase farther north. In Yaquina Bay, juvenile surf smelt (37 to 87 mm TL) ranked 4th in abundance in intertidal areas, and as in San Francisco Bay, they were collected primarily between November and May (Bayer 1981). Farther north in the Columbia and Squamish estuaries, surf smelt are residents all year (Levy and Levings 1978, Bottom and others 1984). In the Columbia Estuary, surf smelt are most abundant during the summer (Bottom and others 1984), opposite of the winter-spring high abundance period found in the San Francisco Estuary (see Table 16), again suggesting temperature is controlling distribution.

The relative lack of larvae and small juveniles (<30 mm) suggests that little or no spawning takes place in the estuary. This conclusion is supported by the relative lack of reproductive-sized fish (>120 mm) at any time (see Table 16). Penttila (1978) believed that moderate temperatures and wave action were necessary for successful hatching, and that prolonged direct exposure to sunlight led to desiccation and heat mortality. Therefore, reduced solar radiation (cloudy weather or direct shading) and cooling through wave action or water seepage through the substrate were important survival factors for eggs deposited during summer and fall. Of these factors, fog in particular, is more prevalent on the coast than in the estuary and several important spawning areas are known to exist on San Mateo County and Sonoma County coastal beaches (Frey 1971).

Whitebait Smelt

Introduction

The whitebait smelt ranges from San Francisco Bay, California, northward to the Strait of Juan de Fuca, Washington (Hart 1973, Hearne 1983). Little is known of its life history. It is believed to spawn subtidally over a sandy bottom (Moyle 1992). Hubbs (1925) observed that the young remained translucent (postlarval) until they reached "about 3 inches" (about 76 mm) in length. They live 1 to 3 years (Moyle 1992) and reach a maximum of approximately 229 mm (Hart 1973). Although catch records for the true smelts are lumped into the category "whitebait smelt," it is unlikely that many true whitebait smelt are caught commercially (Moyle 1992).

Methods

Whitebait smelt were considered post-larvae until they reached 75 mm FL, based upon Hubbs (1925) and field observations. Length data were tallied into 5 mm intervals and grouped by month and year. Total catch for all gear types was summed for each year to provide an annual index. Data for all stations were used for Table 1, but only data from original 35 stations were otherwise used.

Results

Whitebait smelt collected in the estuary ranged from 43 to 122 mm FL; most (74%) fell into the post-larval size range (<75 mm; Table 19). The smallest individuals (45 to 50 mm FL) were collected between August and December.

Table 19 Length frequency (mm FL) distribution of whitebait smelt collected with all gear types from 1980 to 1995

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
45 - 49								1	1	2		1	5
50 - 54	9	3						1		1			14
55 - 59	17	1							2			12	32
60 - 64	52	3		1							1	35	92
65 - 69	17	3	2							1	2	14	39
70 - 74	3	2	3									4	12
75 - 79	3	1	3	1		1							9
80 - 84		1	1	7									9
85 - 89				11	1	1							13
90 - 94				7									7
95 - 99		2		4	1				1				8
100 - 104		1			2								3
105 - 109		3			1								4
110 - 114	1	4			2							2	9
115 - 119		3											3
120 - 124		2											2
Total	102	29	9	31	7	3	0	2	4	4	3	68	261

No whitebait smelt were collected in 1980, 1981, or 1991 to 1995 (Table 20). Five even-year year classes (1982, 1984, 1986, 1988, and 1990) accounted for 97% of the total catch of 261 fish. All whitebait smelt caught from 1982 through 1984 were from the 1982 year class. The 1982 year class comprised 87% of the 194 post-larval fish (<75 mm) and 72% of the total catch. There was no evidence of a 1983 year class. The 1984 year class made up all the fish collected in 1985 (Table 20). The 1985 year class was made up of the single large fish (85 to 89 mm) collected in 1986. The 1986 year class was comprised of the 4 smallest fish in 1986, the 4 largest in 1987, and 2 of the 3 largest in 1988. Five fish from a 1987 year class were captured in 1987 and 1988. The 1988 year class was composed of the 2 smallest fish in 1988 and all 3 fish in 1989. The 1990 year class was composed of the entire 1990 catch. Sixty percent (n = 10) of the fish caught from August through October were taken in 1990.

Table 20 Annual length frequency (mm FL) distribution for whitebait smelt collected with the beach seine, midwater trawl, and otter trawl from 1980 to 1995. No fish were collected in 1980, 1981, or 1991 to 1995.

Length	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*Total*
45 - 49	1						1		3	5
50 - 54		12							2	14
55 - 59	12	18			2					32
60 - 64	33	51		3	1	2	2			92
65 - 69	15	18		1	1	2	1		1	39
70 - 74	4	2		4				2		12
75 - 79		2		4		1	1	1		9
80 - 84		1		8						9
85 - 89				12	1					13
90 - 94				7						7
95 - 99			2	4			2			8
100 - 104			1	2						3
105 - 109			3	1						4
110 - 114		2	6				1			9
115 - 119			3							3
120 - 124			2							2
Total	65	106	17	46	5	5	8	3	6	261

Table 21 Annual catch of whitebait smelt by region collected with the beach seine, midwater trawl, and otter trawl from 1980 to 1995. No fish were collected in 1980, 1981, or 1991 to 1995. No correction was made for unequal sampling effort in different years.

Region	*1982*	*1983*	*1984*	*1985*	*1986*	*1987*	*1988*	*1989*	*1990*	*Total*
San Pablo	7		1	11	1	2	2	1	1	26
Central	44	95	14	32	3	2	6	2	4	202
South	14	11	2	3	1	1			1	33
Total	65	106	17	46	5	5	8	4	6	261

During the study period, 77% of the whitebait smelt were collected in Central Bay, and 13% and 10% were taken in South and San Pablo bays, respectively (Table 21). Their distribution outside of Central Bay shifted into South Bay during the high outflow years 1982 and 1983, then into San Pablo Bay during the low outflow years 1985, 1987, and 1988 (see Table 21).

Discussion

The whitebait smelt is rarely caught in the estuary (see Table 1), or in local coastal waters (Moyle 1992). The lack of small post-larvae (<40 mm) in the catch makes it unlikely that any spawning takes place in the estuary. The estuary appears to be an extension of their coastal nursery and foraging habitat. They entered the estuary sporadically, primarily during winter and spring, but once in the estuary they remained for 2 to 5 months. Some of the 1982 and 1986 year class fish even re-entered the Bay to spend a second winter and spring. Like other marine smelt, they remained primarily in Central Bay. The succession of even-year cohorts suggests a 2-year maturity schedule.

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