Atherinidae

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Introduction

The silverside family, Atherinidae, occurs worldwide in tropical and temperate coastal areas. Many species are marine or estuarine but some live in freshwater. The marine and estuarine species are pelagic surface schoolers. They generally occur at depths <30 m and are most common at depths of <15 m.

On the west coast of the United States, there are 3 marine species of Atherinidae and 1 introduced freshwater species. The topsmelt, *Atherinops affinis*; the jacksmelt, *Atherinopsis californiensis*; and the grunion, *Leuresthes tenuis*, are marine species, and the inland silverside, *Menidia beryllina*, occurs in freshwater habitats. Only the topsmelt, jacksmelt, and inland silverside were collected in the San Francisco Estuary and are discussed here (Tables 1, 2, and 3).

Table 1 Catch of all atherinids collected with the midwater trawl at the original 35 stations

Year	Topsmelt	Jacksmelt	Inland Silverside	Total
1980	126	217		343
1981	68	1046	1	1115
1982	120	491		611
1983	384	505		889
1984	61	1107	2	1170
1985	1689	2747		4436
1986	89	706		795
1987	1688	673		2361
1988	149	468		617
1989	11	454		465
1990	17	415		432
1991	12	487		499
1992	4	250		254
1993	62	230		292
1994	11	94		105
1995	355	228		583
Total	4846	10118	3	15346

Table 2 Catch of all atherinids collected with the otter trawl at the original 35 stations

Year	Topsmelt	Jacksmelt	Inland Silverside	Total
1980	8	5		13
1981		7	1	8
1982	17	7		24
1983	12	5		17
1984		2	1	3
1985	2	8		10
1986	1	7		8
1987	4	4		8
1988	14	3		17
1989	2	23		25
1990	1	6		7
1991		4		4
1992		1		1
1993		2		2
1995	1	22		23
Total	62	106	2	171

Table 3 Catch of all atherinids collected with the beach seine from 1980 to 1986

Year	Topsmelt	Jacksmelt	Inland Silverside	Total
1980	5149	87	216	5452
1981	2785	347	644	3776
1982	4013	1200	262	5475
1983	7293	6056	315	13664
1984	10922	3802	2526	17250
1985	12702	1557	540	14799
1986	7850	10107	467	18424
Total	50918	23191	4975	79084

Atherinids are oviparous and fertilization is external. Eggs are deposited on vegetation in shallow nearshore habitats. The coastal species usually lay eggs on eelgrass in nearshore estuarine and bay habitats. The larvae school near the surface.

Atherinids are omnivorous and feed on diatoms, algae, mysids, copepods, and ostracods (Ruagh 1976). In turn, they are prey for many piscivorous birds such as pelicans, gulls, and the least tern, and piscivorous fish including yellowtail and kelp bass (Feder and others 1974).

The atherinids are not important commercially in California but are important to the recreational fishery. The marine species are one of the most common fishes taken by pier and shore anglers (Gregory 1992).

Topsmelt

Introduction

The topsmelt, *Atherinops affinis*, ranges from the Gulf of California to Vancouver Island, British Columbia (Miller and Lea 1972) and is one of the most abundant fishes in many Pacific coast estuaries (Frey 1971). It is found in estuaries and along the coast over sandy beaches, rocky reefs, mudflats, around piers, and in interspaces of kelp beds (Hart 1973, Feder and others 1974). The topsmelt forms schools of similar-sized fish at the surface in shallow water. It is found from the surface to 9.1 m but usually occurs at 1.2 m (Feder and others 1974). The larvae are planktonic but also school near the surface in shallow water.

Topsmelt are euryhaline and can withstand high salinity (Gregory 1992). In San Francisco Bay, the young-of-the-year (YOY) are common in mesohaline and oligohaline salinities (Wang 1986). In laboratory studies juveniles tolerated salinities from 2‰ to 80‰ although growth was severely impeded in hypersaline water (Middaugh and Shenker 1988). Spawning adults and YOY were found in southern California from 35‰ to 63‰ (Carpelan 1955) and in salt ponds in San Francisco Bay from 40‰ to 53‰. Juveniles and adults are eurythermal. The lower lethal temperature for juveniles is 10.4 °C and the upper lethal temperature is 31.7 °C (Doudoroff 1945, as cited in Frey 1971).

Adults move to shallow sloughs and mudflats from late spring to summer to spawn. Females mature and spawn at age 3 with some large females spawning in their 2nd year (Fronk 1969). Males usually mature at 2 years but the larger ones can mature at 1 year. Females may spawn more than once from April to October at 10 to 25 °C in San Francisco Bay (Schultz 1933 and Wang 1986). Fecundity is positively correlated with female parental size. Females are followed by several males when spawning (Feder and others 1974). The large demersal eggs are laid on blades of aquatic vegetation, usually eelgrass, and fertilized externally. Hatching time varies with temperature. The eggs hatch from 35 days at 13 °C to less than 9 days at 27 °C (Hubbs 1965).

Larvae are 4.3 to 4.9 mm long and juvenile characteristics are formed at 18.5 mm (Wang 1986). They grow fastest in their 1st year, becoming half the adult size. Topsmelt reach a maximum size of 366 mm TL (Miller and Lea 1972) and live to 7 to 8 years (Gregory 1992).

In the ocean, topsmelt are planktonic feeders and prey on crustaceans including amphipods and copepods. They clean barnacles and whale lice off grey whales (Swartz 1981). In the estuary, they feed on the bottom and consume plant material, algae, diatoms, and small crustacea (Fronk 1969). Topsmelt are preyed upon by yellowtail, halibut, croaker, sand bass, and piscivorous birds. They have little economic value but are among the most abundant fish available to pier and shore anglers (Gregory 1992).

Methods

The midwater trawl data from 1980 to 1988, and 1995, and the beach seine data from 1981 to 1986 were analyzed for annual abundance and distribution, and temperature and salinity distribution. The midwater trawl data from 1981 to 1988 and the beach seine data from 1981 to 1986 were used for seasonal abundance and distribution. The midwater trawl data from 1989 to 1994 were not used because sampling did not occur in November and December when topsmelt were abundant in the estuary. In 1995, we did not sample with the midwater trawl in August. The egg and larval data were used to show seasonal distribution.

Two age groups were separated by visual inspection of length frequencies. All fish <100 mm FL were classified as age 0 and those >100 mm FL were classified as age 1+. The index period for age–0 fish was July to December in both the midwater trawl and beach seine. The index period for age–1+ fish was July to December in the midwater trawl and January to September in the beach seine.

Results

Abundance in the Midwater Trawl

Age–0 topsmelt were most abundant in 1985 and 2nd most abundant in 1987 (Figure 1A, Table 4). Although 1995 was the 3rd most abundant year, the lack of August data probably biased the index high because August was typically a low index month. No age–0 fish were collected from March through October 1992.

The age–0 topsmelt abundance was low from January through July (Figure 2A, Table 4). They were usually collected beginning in August and were most abundant from late fall through December. Abundance decreased in late winter and they disappeared from our collections in May and June.

The age–1+ topsmelt abundance index was highest in 1983 and next highest in 1985 (Figure 1B, Table 5). Abundance trends are difficult to determine due to the lack of winter data from 1989 to 1994.

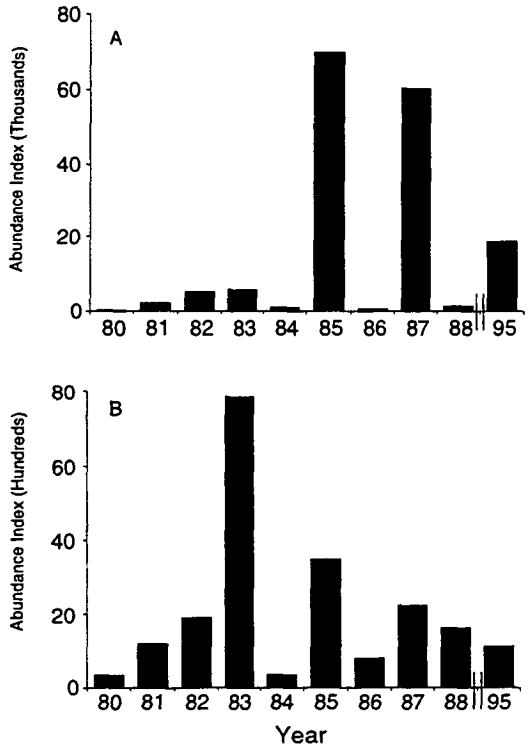

Figure 1 Annual abundance indices of topsmelt collected with the midwater trawl from 1980 to 1988 and 1995: (A) age 0, the index period was July to December; (B) age 1+, the index period was July to December

Table 4 Age–0 topsmelt monthly abundance indices collected with the midwater trawl from 1980 to 1995. The index period was July to December. "NI" indicates no index calculated due to incomplete sampling.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Index
1980		35019	6398	376	0	0	0	0	903	430	0	0	222
1981	915	0	0	215	0	0	7521	0	941	0	188	4595	2208
1982	546	0	0	0	0	0	108	4612	1317	2766	19736	2502	5174
1983	753	0	0	0	0	0	0	0	188	0	7151	26532	5645
1984	0	0	0	0	0	376	0	0	511	466	1317	3575	978
1985	565	188	0	0	0	0	1317	2070	109510	221995	77074	7903	69978
1986	0	8871	1882	4334	0	0	0	376	565	1694	753	296	614
1987	8516	376	565	565	0	0	0	888	338519	4247	4892	12419	60161
1988	5081	9409	923	1505	0	0	0	188	4122	188	1129	2823	1408
1989	376	1317	0	0	0	0	0	0					NI
1990		1505	358	0	0	0	0	0	376	565			NI
1991		0	0	0	0	0	0	0	0	2769			NI
1992		904	0	0	0	0	0	0	0	0			NI
1993		0	188	0	0	0	0	0	753	7151			NI
1994		0	1694	0									NI
1995				7151	0	0	0		0	13844	77957	1129	18586
1981–1988	2047	2356	421	827	0	47	1118	1017	56959	28920	14030	7581	

Age–1+ fish were collected throughout the year but catches were highly variable between years (Figure 2B, Table 5). Age–1+ abundance was bimodal; there was a small peak in June and July and a larger peak in November and December. Abundance was lowest in April and May, and high from October to December.

Abundance in the Beach Seine

In the beach seine, the age–0 topsmelt annual abundance index was highest in 1985 (Figure 3A). This corresponds to the highest midwater trawl index. The lowest index was in 1981, but the indices did not vary much over the years. Age–0 fish were collected in every month except June 1981 and abundance peaked from July to October (Figure 4A and Table 6).

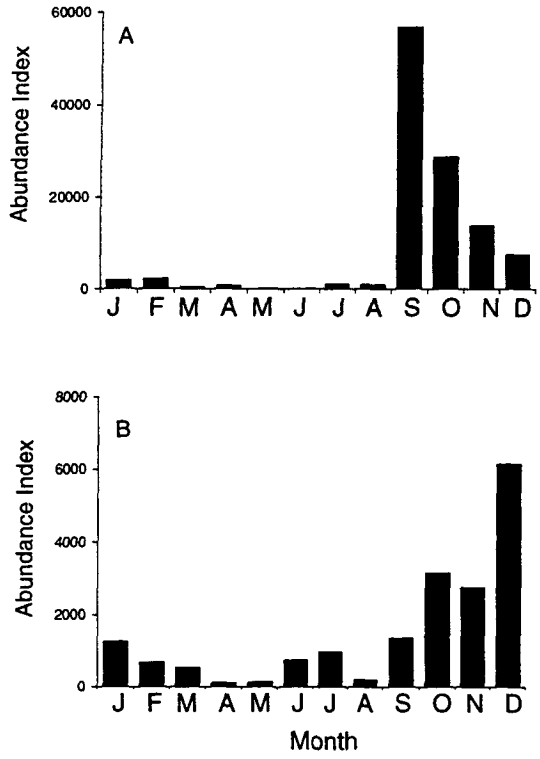

Figure 2 Seasonal abundance of topsmelt collected with the midwater trawl from 1981 to 1988: (A) age 0 and (B) age 1+

Table 5 Monthly abundance indices of age–1+ topsmelt collected with the midwater trawl from 1980 to 1995. The index period was July to December. Values are CPUE x 100. "NI" indicates no index calculated due to incomplete sampling.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Index*
1980		5208	1129	215	0	0	430	0	0	0	0	1637	345
1981	546	3053	0	215	753	0	2786	592	376	0	0	3475	1205
1982	1111	0	0	188	0	0	484	0	0	108	9414	1425	1905
1983	0	0	0	0	376	0	0	296	188	188	7381	39049	7850
1984	716	0	0	0	0	4704	0	376	646	0	188	941	359
1985	565	215	753	0	0	188	188	431	0	16936	2072	1317	3491
1986	0	565	0	0	0	376	2446	0	0	1694	108	619	811
1987	6196	188	2222	0	0	753	188	0	8541	941	2258	1505	2239
1988	941	1505	1433	565	0	0	1694	0	1129	5463	565	904	1626
1989	0	546	0	0	0	0	0	376					NI
1990		188	0	0	0	0	0	0	0	1370			NI
1991		0	0	0	0	0	0	0	0	0			NI
1992		716	0	0	0	0	0	0	108	0			NI
1993		0	188	0	0	0	188	0	0	7715			NI
1994		0	565	1263									NI
1995				565	0	0	1093		0	753	3816	0	1132
1981–1988	1259	691	551	121	141	753	973	212	1360	3166	2748	6154	

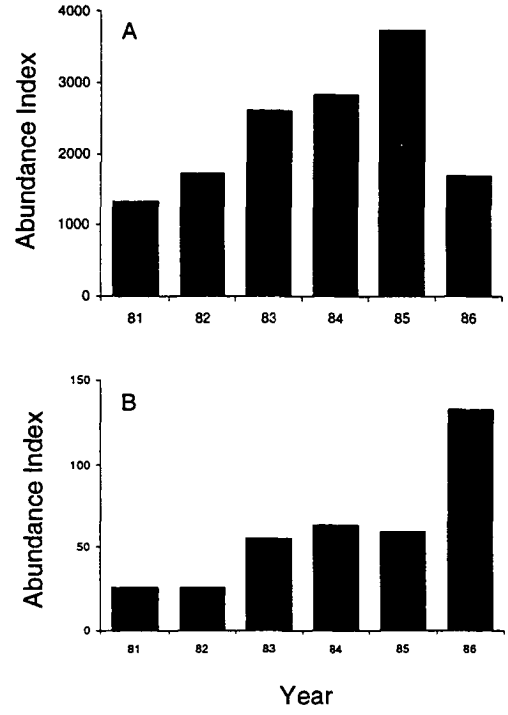

Figure 3 Annual abundance indices of topsmelt collected with the beach seine from 1981 to 1986: (A) age 0, the index period was July to December; (B) age 1+, the index period was January to September

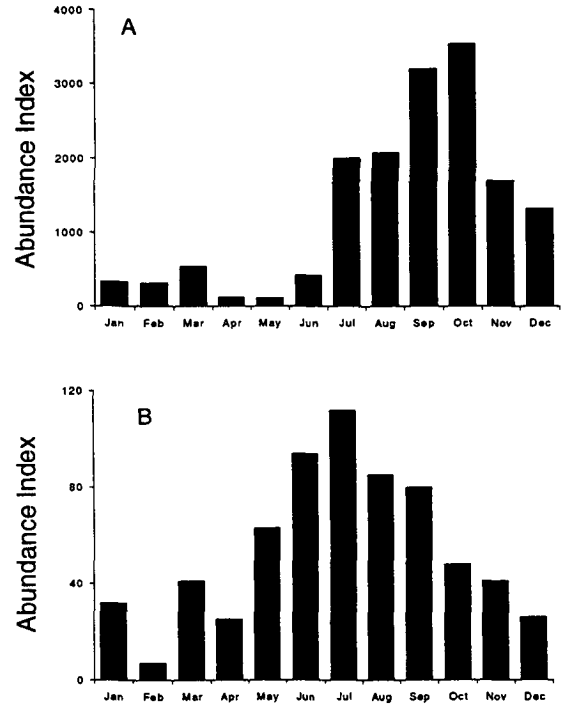

Figure 4 Seasonal abundance of topsmelt collected with the beach seine from 1981 to 1986: (A) age–0 fish and (B) age–1+ fish

Table 6 Monthly abundance indices of age–0 topsmelt collected with the beach seine from 1980 to 1986. The index period was July to December.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Index
1980								4043	1519	1838	1422	3274	
1981	910	1252	260	66	33	0	3284	114	1278	1285	1266	783	1328
1982	71	68	106	35	3	660	3855	2082	1654	1709	33	543	1731
1983	87	126	451	25	46	825	619	2743	5379	5685	784	113	2626
1984	10	142	815	111	171	676	1588	3175	3801	5211	2582	663	2839
1985	306	84	1031	64	276	233	1682	3816	3103	5107	3597	5429	3760
1986	600	209	573	431	140	69	988	558	4000	2271	1986	426	1705
1981–1986	331	314	539	122	112	411	2003	2081	3203	3545	1708	1326	

Table 7 Monthly abundance indices of age–1+ topsmelt collected with the beach seine from 1980 to 1986. The index period was January to September.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Index
1980								55	47	10	39	34	
1981	38	27	27	0	25	0	22	9	82	68	147	18	26
1982	4	3	53	14	46	13	43	5	48	29	5	11	26
1983	0	1	53	2	14	6	190	70	148	68	19	3	56
1984	2	4	30	29	165	154	147	14	17	73	22	21	64
1985	96	1	73	8	27	267	0	0	63	30	33	29	60
1986	43	10	5	94	94	103	254	437	152	57	45	65	133
1981–1986	31	8	40	25	62	91	109	89	85	54	45	25	61

In the beach seine, age–1+ topsmelt were most abundant in 1986, which follows the highest age–0 abundance by 1 year (Figure 3B). On average, abundance peaked from May to October (Figure 4B), but peak monthly abundance varied yearly. In some years abundance peaked in late summer and early fall and in other years, in spring and summer (Table 7). Age–1+ fish were collected in almost every month, but in 1981, none were collected in April and June, and in 1985 none were collected in July and August (see Table 7).

Distribution

Topsmelt larvae were collected from April to September from South to San Pablo bays (Figure 5). The highest CPUE was in South Bay in all months except April when they were collected only in San Pablo Bay.

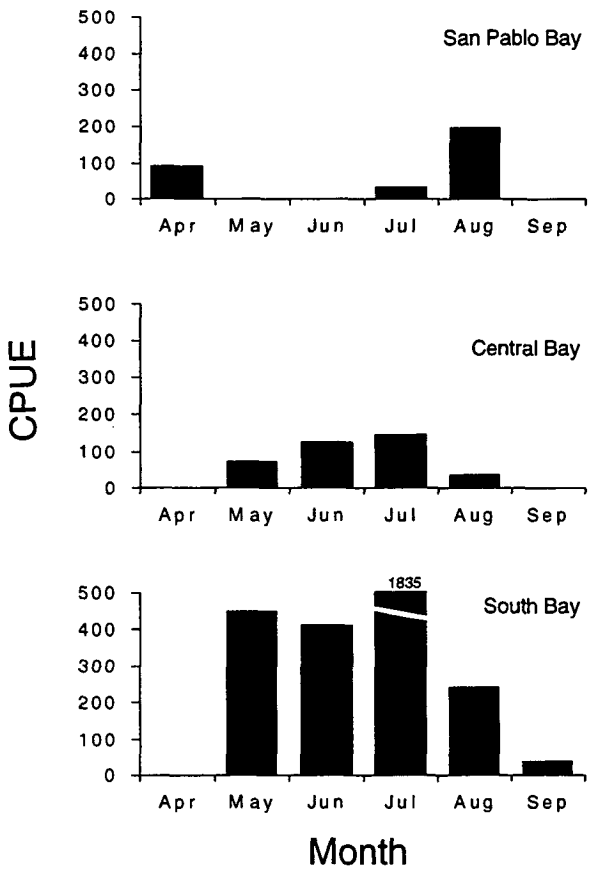

Figure 5 Seasonal distribution by region of larval topsmelt collected from 1980 to 1989

Age–0 topsmelt ranged from South to San Pablo bays but their distribution was centered in South Bay (Figure 6). In 1985 and 1987, when they were most abundant, they ranged to San Pablo Bay, but in very low abundance. In every year, the CPUE was highest in South Bay, except in 1982 when age–0 fish were equally distributed between South and Central bays.

Seasonally, the center of distribution of age–0 topsmelt was in South Bay from January to April. They disappeared from the estuary (or at least from our sampling area) in May and June (Figure 7). In July, they reappeared in Central and South bays and in September and October, the CPUE was highest in South Bay. In November, they were distributed equally in South and Central bays. They were present but rare in San Pablo Bay from September to January.

Age–1+ topsmelt usually ranged from South Bay to San Pablo Bay but in 1980 they were also collected in Suisun Bay (Figure 8). The highest CPUE was in South Bay, except in 1980 and 1988, when they were equally distributed between South and Central bays, in 1982, when the highest CPUE was in Central Bay, and in 1987, when the highest CPUE was in San Pablo Bay.

The age–1+ topsmelt CPUE was usually highest in South Bay but in January and February, it was equal in South and Central bays (Figure 9). In August and September their center of distribution shifted to San Pablo Bay and they returned to South Bay in late fall and winter.

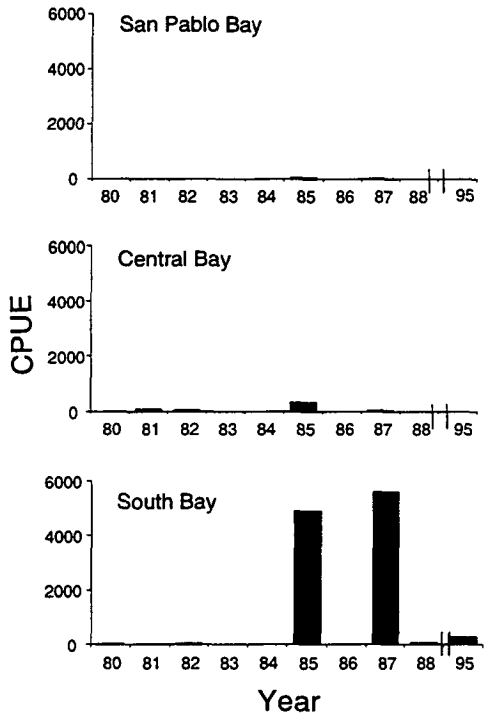

Figure 6 Annual distribution of age–0 topsmelt collected with the midwater trawl from 1980 to 1988 and 1995. Values are average CPUE x 100 from July to December.

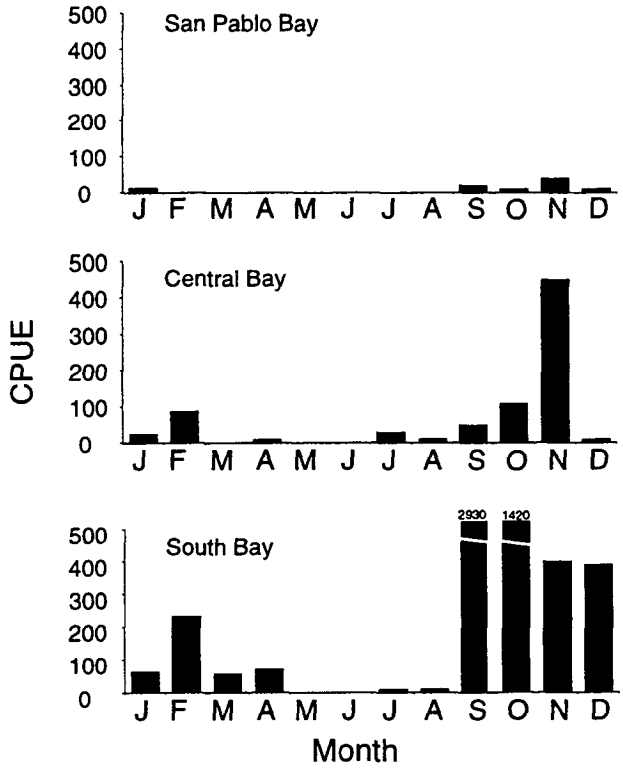

Figure 7 Seasonal distribution of age–0 topsmelt collected with the midwater trawl from 1980 to 1988 and 1995. Values are CPUE x 100.

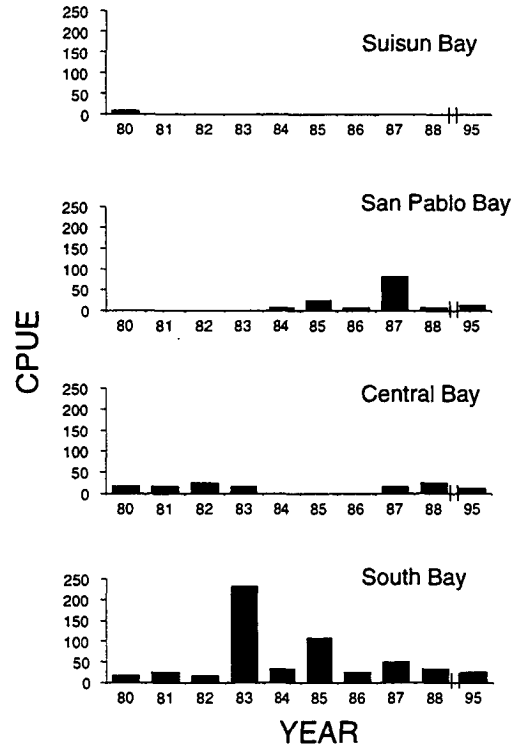

Figure 8 Annual distribution of age–1+ topsmelt collected with the midwater trawl from 1980 to 1988 and 1995. Values are CPUE × 100 from July to December.

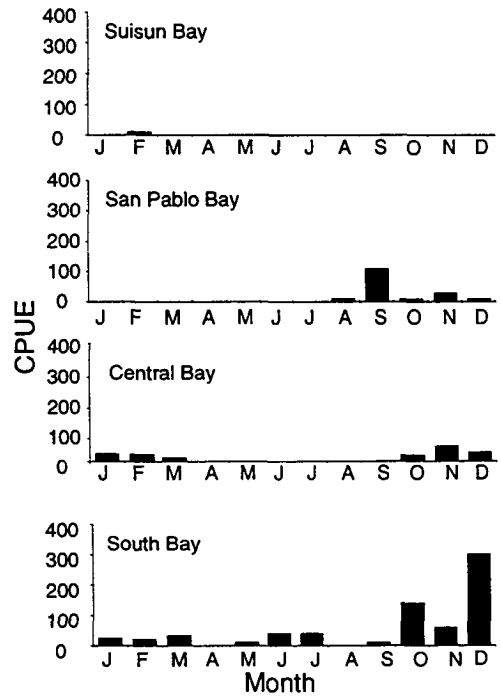

Figure 9 Seasonal distribution of age–1+ topsmelt collected with the midwater trawl from 1980 to 1988 and 1995. Values are CPUE × 100.

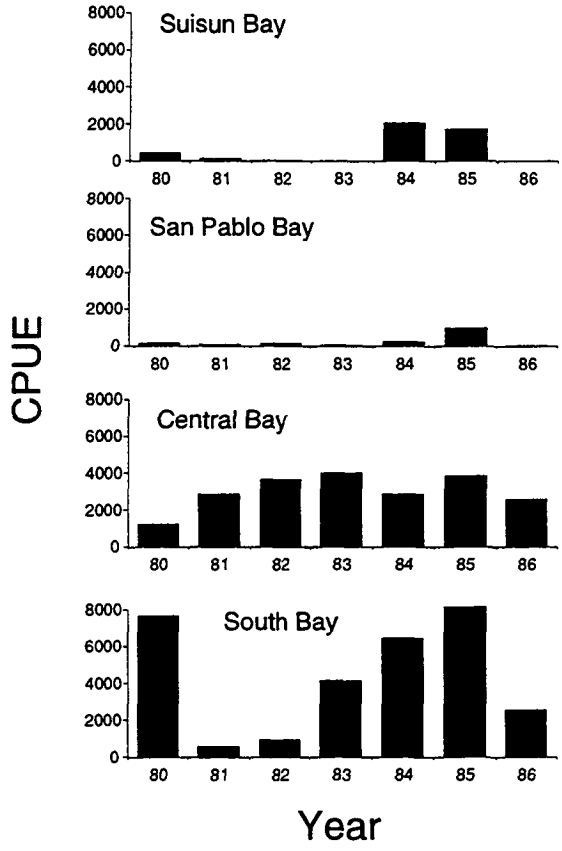

Figure 10 Annual distribution of age–0 topsmelt collected with the beach seine from 1980 to 1986. Index period was July to December.

Distribution in the Beach Seine

Age–0 topsmelt were collected in the beach seine from South to Suisun bays, except in 1983 and 1986 when none were collected in Suisun Bay (Figure 10). Their distribution was centered in South and Central bays in all years. In most years, the Suisun Bay CPUE was higher than the San Pablo Bay CPUE and in 1984 and 1985 it was almost as high as the Central Bay CPUE.

From January through April, the highest age–0 topsmelt CPUE was in South Bay and it shifted to Central Bay from May through July (Figure 11). In fall and winter the CPUE was highest in either South or Central bays and higher in Suisun Bay than San Pablo Bay.

The highest age–1+ topsmelt CPUE was in South Bay except in 1984 and 1985 when CPUE was highest in Central Bay (Figure 12). They ranged from South to Suisun bays in 1982, 1984, and 1985, and in 1986 they were collected only in South and Central bays.

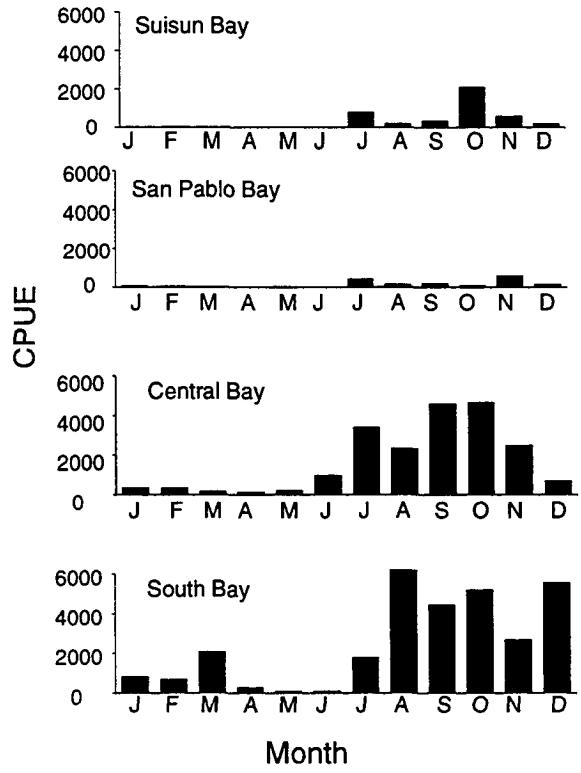

Figure 11 Seasonal distribution of age–0 topsmelt collected with the beach seine from 1981 to 1986

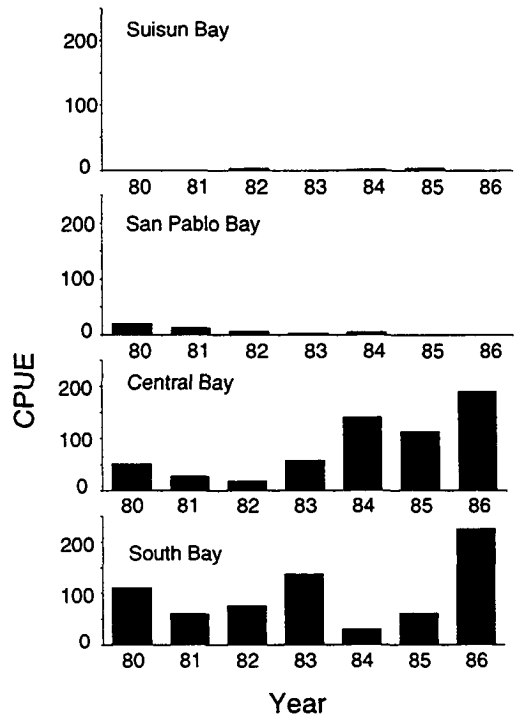

Figure 12 Annual distribution by region of age–1+ topsmelt collected with the beach seine from 1980 to 1986. Index period was January to September.

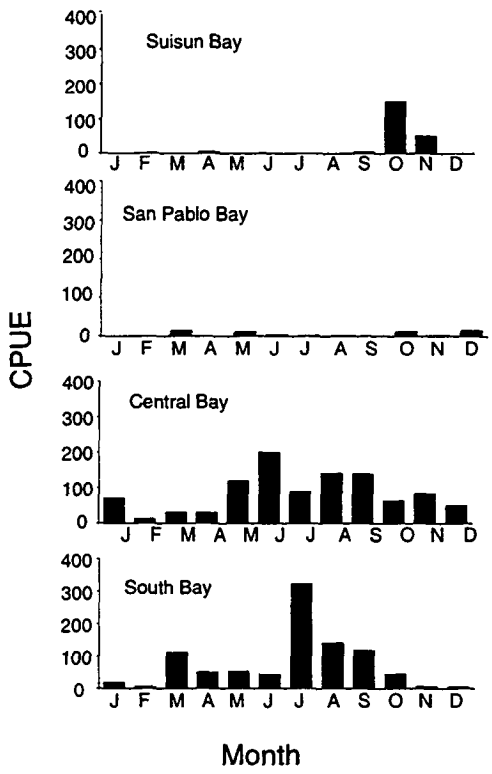

Figure 13 Seasonal distribution of age–1+ topsmelt collected with the beach seine from 1981 to 1986

The center of age–1+ topsmelt distribution shifted between South and Central bays in spring and early summer (Figure 13). From August to December, they were concentrated in Central Bay except for October, when the CPUE was highest in Suisun Bay.

Temperature and Salinity

In the beach seine, age–0 fish were found in a wider range of temperatures than age–1+ fish but at similar salinities (Figures 14 and 15). For age–0 fish, temperatures ranged from 5.9 to 33.8 °C, $\bar{\chi}$ = 18.7 °C (see Figure 14). Age–1+ fish were collected from 7.6 to 28.2 °C, $\bar{\chi}$ = 20.5 °C (see Figure 15).

Both age groups were collected in similar salinities. Age–0 fish were caught from 0.25‰ to 34.3‰, $\bar{\chi}$ = 26.0‰ (see Figure 14); age–1+ fish from 0.1‰ to 33.3‰, $\bar{\chi}$ = 26.1‰ (see Figure 15).

In the midwater trawl, age–0 fish were collected in similar temperatures and at slightly higher salinities than age–1+ fish (Figures 16 and 17). Age–0 fish were collected at 8.3 to 22.3 °C, $\bar{\chi}$ = 17.0 °C (see Figure 16). Age–1+ fish were found in 8.4 to 21.8 °C, $\bar{\chi}$ = 15.5 °C (see Figure 17).

Age–0 and age–1+ fish were taken at slightly different salinities. Age–0 fish were collected from 10.7‰ to 34.0‰, $\bar{\chi}$ = 29.0‰ (see Figure 16). Age–1+ fish were collected in salinities from 6.9‰ to 34.02‰, $\bar{\chi}$ = 25.7‰ (see Figure 17).

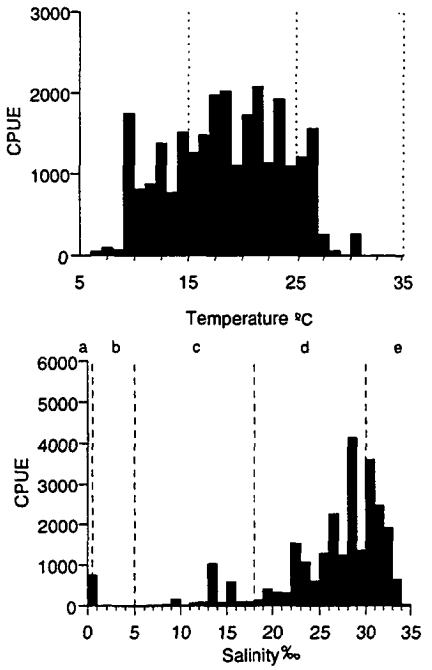

Figure 14 Temperature and salinity distribution of age–0 topsmelt collected with the beach seine from 1980 to 1986. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

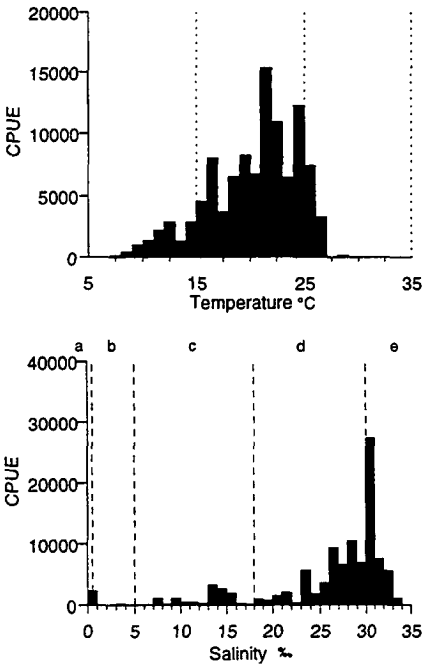

Figure 15 Temperature and salinity distribution of age–1+ topsmelt collected with the beach seine from 1980 to 1986. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

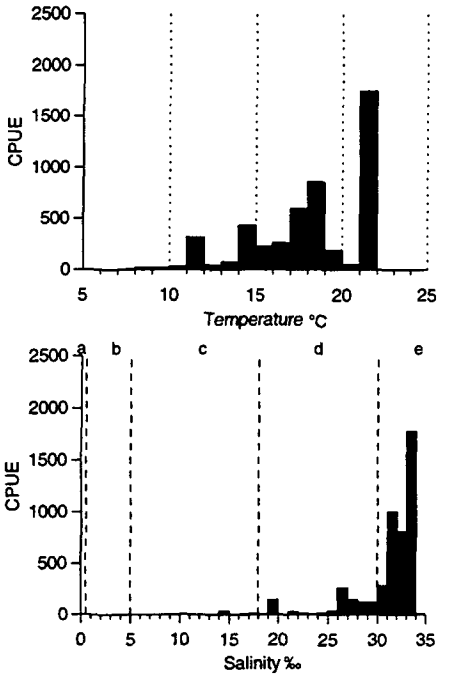

Figure 16 Temperature and salinity distribution of age–0 topsmelt collected with the midwater trawl from 1980 to 1988 and 1995. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

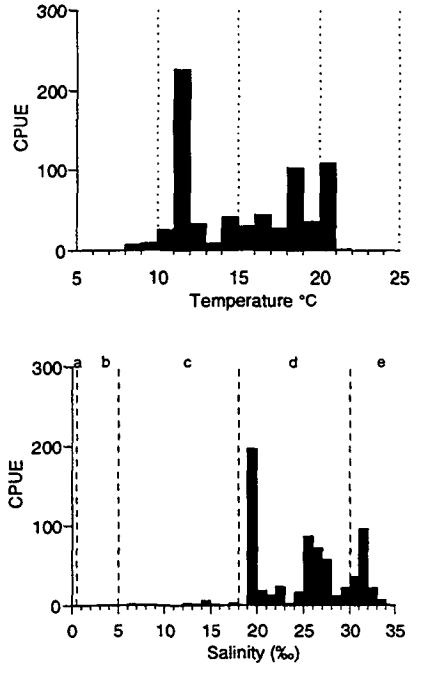

Figure 17 Temperature and salinity distribution of age–1+ topsmelt collected with the midwater trawl from 1980 to 1988 and 1995. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

Discussion

Topsmelt use the estuary as a nursery and a spawning ground. Some age–1+ fish appear to be resident in the estuary but some emigrate out of it. They are resident in shallow water as shown by the year-long catch in the beach seine. In late fall and winter, the increased midwater trawl catch shows that they move to deeper areas. In Coos Bay, Oregon, topsmelt move to the open ocean in August and September but in Newport Bay, California, they remain in the bay all year (Fronk 1969 and Frey 1971). The midwater trawl data shows movement of fish from shallows to channels but is not reliable for abundance trends because so few age–1+ fish were collected in it.

Age–1+ fish disappeared from the midwater trawl from April through June but were still found in the beach seine. They moved into the shallows to spawn in March and April as shown by appearance of larval fish in April and May and the appearance of large numbers of age–0 fish in the beach seine in June. Spawning took place as early as April and continued until September. Age–0 topsmelt remained in the shallows through late fall and migrated to deeper areas in winter. Catches were very low throughout winter and spring, indicating they emigrated to the ocean.

Age–0 topsmelt were most abundant in the low outflow years, 1985 and 1987, but not in 1981, another low outflow year. It is difficult to determine what controls abundance, because no data was collected in winter during low outflow years and the beach seine data were limited to 1980 to 1986.

Age–0 topsmelt were collected in slightly higher salinities and warmer temperatures than age–1+ fish. This may be a reflection of seasonality of catches rather than actual environmental preferences because age–0 fish were collected primarily in summer when temperatures and salinities are high, whereas age–1+ fish were collected all year.

In this estuary, age–0 topsmelt reside in polyhaline to euhaline water. This disagrees with Wang (1986) who found age–0 fish in mesohaline and oligohaline water in San Francisco Bay.

To determine overall abundance trends of topsmelt in the estuary, we need to collect more data in winter and in shallow habitats to determine how salinity, temperature, and possibly outflow govern abundance and distribution.

Jacksmelt

Introduction

The jacksmelt, *Atherinops californiensis*, ranges from Santa Maria Bay, Baja California to Yaquina Bay, Oregon (Miller and Lea 1972, Eschmeyer and others 1983). It is a pelagic, schooling, marine species found within a few miles of shore. It prefers turbid water and is found in estuaries, bays, kelp canopy, and sandy beaches (Gregory 1992). During summer, large schools of juveniles reside in estuaries and bays; in fall, they migrate to coastal waters (Frey 1971). Juveniles and adults are found to 29 m but are usually concentrated at 1.5 to 15 m. The larvae also school near the surface and are pelagic. Temperature and salinity tolerances for the jacksmelt are unknown. Optimal growth is from 10‰ to 20‰ and the optimal salinity for survival is 15‰ (Middaugh and others 1990).

Jacksmelt are batch spawners. Adults move into bays and estuaries to spawn during late winter and early spring; however, in southern California they spawn all year with a peak in winter. Peak reproductive activ-

ity is from January to March in northern California (Middaugh and others 1990). In San Francisco Bay, spawning occurs from October through August and in San Pablo Bay, from September to April (Ganssle 1966). Spawning occurs more than once during the breeding season (Clark 1929). All jacksmelt are mature in their 3rd year and the larger individuals may mature at the end of their 2nd year. Eggs are adhesive and are laid on vegetation in shallow estuaries and bays (Frey 1971). Eggs may hatch in salinities as low as 5‰ and hatch within 7 days at 10 to 12 °C (Wang 1986).

The larval size range is 7.5 to 8.6 mm TL. Juvenile characteristics are formed at 25 mm (Clark 1929). They grow to 110 to 120 mm TL during their 1st year and 180 to 190 mm TL by the end of their 2nd year (Clark 1929). They live as long as 11 years and reach 445 mm TL (Miller and Lea 1972).

Jacksmelt are omnivorous. Larvae prey on copepods, diatoms, and bivalve veligers in southern California (Watson and Davis 1989). The adults prey on algae, benthic diatoms, mysids, copepods, and smelt eggs. In turn they are eaten by yellowtail, kelp bass, sharks, brown pelicans, and gulls. They have little commercial value but are part of an important recreational fishery on piers and jetties (Frey 1971).

Methods

The midwater trawl data from 1980 to 1995 (except for 1989 and 1994), and the beach seine data from 1981 to 1986 were analyzed for annual abundance and distribution, and temperature and salinity distributions. The 1981 to 1988 midwater trawl data and the 1981 to 1986 beach seine data were analyzed for seasonal abundance and distribution. The egg and larval data were used for supporting seasonal distribution.

Two age groups of jacksmelt were identified by visual inspection of length frequencies. Fish <110 mm FL were classified as age 0 and fish >110 mm were classified as age 1+. The index period for age–0 fish in the midwater trawl was July to October. The index period for age–0 fish collected in the beach seine was April to December.

The midwater trawl index period for age–1+ jacksmelt was February to June. All years except 1994 and 1995 were analyzed for annual abundance, temperature and salinity distributions. The 1981 to 1988 midwater trawl data were used for seasonal abundance and distribution analyses. Not enough age–1+ fish were collected in the beach seine for analyses.

Results

Abundance

In the midwater trawl, age–0 jacksmelt were most abundant in 1981, and 2nd most abundant in 1984 (Figure 18A, Table 8). They were most abundant from July to November and peaked in September in all years (Figure 19A). In most years age–0 fish were present in low numbers from late winter to early spring, but in 1981, 1985, and 1988 they were collected during these months (see Table 8).

Age–0 jacksmelt in the beach seine were most abundant in 1983 and 1986 (Figure 20A, Table 9). In all other years abundance was 10 times lower. They were collected throughout the year but were most abundant from April to July (Figure 20B). Abundance usually peaked in May or June except in 1986 when the peak was in April (see Table 9).

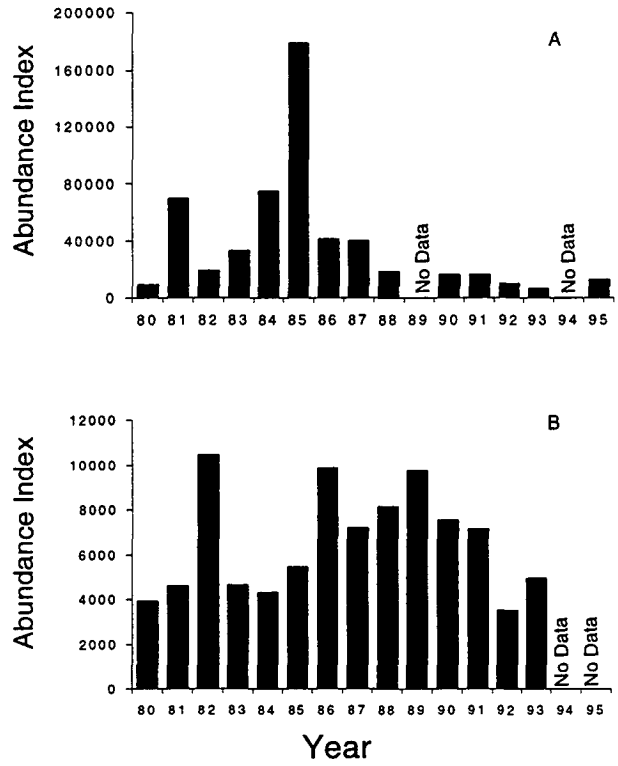

Figure 18 Annual abundance indices of jacksmelt collected with the midwater trawl from 1980 to 1995: (A) age 0, index period is July to October; (B) age 1+, index period was February to July

Table 8 Monthly abundance of age–0 jacksmelt collected with the midwater trawl from 1980 to 1995. Abundance index was July to October. "NI" indicates no index due to insufficient data.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Index*
1980		0	0	0	0	215	358	2529	27218	9707	6799	6958	9953
1981	0	2149	1228	645	188	10282	86675	45276	114491	33812	11145	0	70064
1982	1281	188	0	188	0	565	1388	27876	24493	24377	1195	3199	19534
1983	0	0	0	0	0	0	4298	5615	111860	10511	20667	2930	33071
1984	0	0	0	0	0	376	31739	105614	137833	25067	129729	860	75063
1985	0	358	188	188	2886	1156	8513	175241	230424	302178	187723	0	179089
1986	0	0	0	0	188	188	60446	68836	30114	6682	7818	2008	41520
1987	654	0	2507	188	1505	1373	62843	68841	20808	7794	1793	0	40072
1988	188	753	3581	1882	188	1452	5390	24838	11205	33567	1074	188	18750
1989	0	0	188	188	376	0	34733	49210					NI
1990		0	0	0	188	3727	17480	17216	27955	3055			16427
1991		0	0	0	0	188	1542	44471	14309	5179			16375
1992		0	0	0	188	0	4595	35352	1809	0			10439
1993		188	0	188	0	1093	6119	6086	10289	4451			6736
1994		1639	0	3539									NI
1995				3557	0	1505	25258		5840	7983	0	1299	13027
1981-1988	265	431	938	386	619	1924	32662	65267	85154	55499	45143	1148	

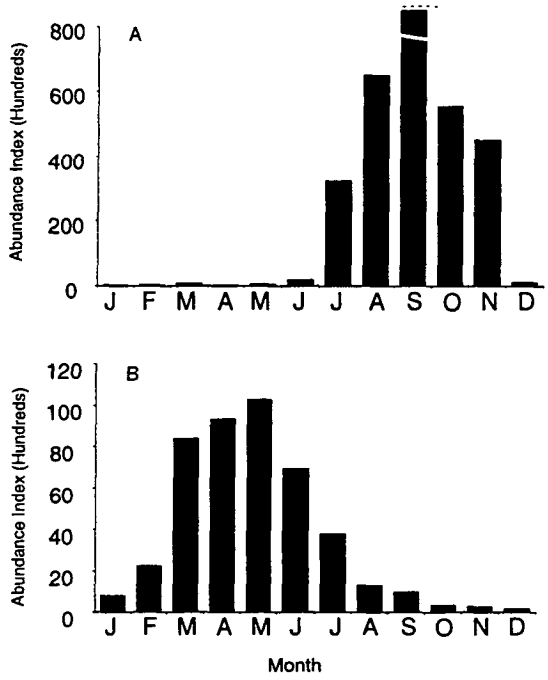

Figure 19 Seasonal abundance of jacksmelt collected with the midwater trawl from 1981 to 1988: (A) age 0 and (B) age 1+

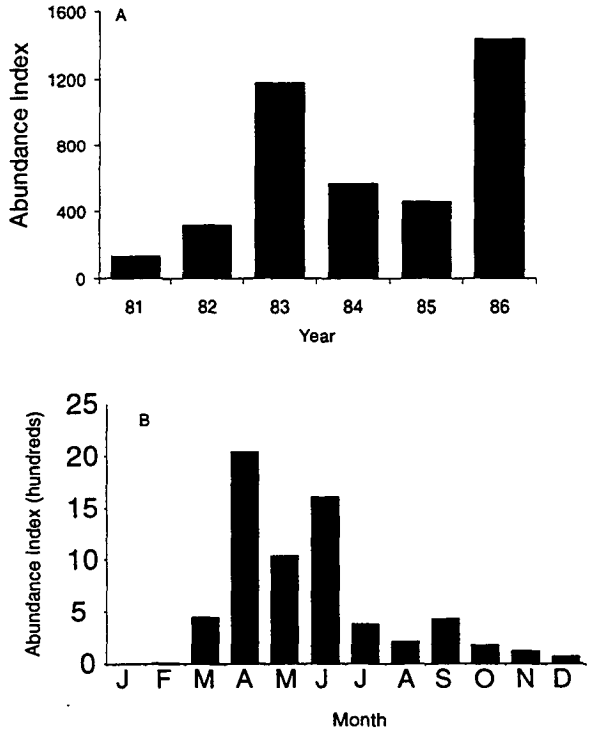

Figure 20 (A) Annual abundance indices of age–0 jacksmelt collected with the beach seine from 1980 to 1986. The index period was April to December. (B) Seasonal abundance of age–0 jacksmelt in the beach seine from 1981 to 1986.

Age–1+ jacksmelt were most abundant in the midwater trawl in 1982, 1986, and 1989 (see Figure 18B, Table 10). They were most abundant from March to July and peaked in April or May in all years (see Figure 19B, Table 10). They were collected throughout the year, except from October to December in some years (see Table 10).

Table 9 Monthly abundance indices of age–0 jacksmelt in the beach seine from 1980 to 1986. Abundance index was from April to December. No sampling from January to July 1980.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Index
1980								43	99	2	13	0	
1981	0	24	0	265	104	547	7	2	64	67	95	77	136
1982	4	4	20	75	418	1473	165	78	542	36	13	0	311
1983	3	28	0	15	825	6482	425	650	1613	263	35	3	1146
1984	0	1	29	933	2692	488	144	140	81	319	95	267	573
1985	5	1	0	254	1375	339	972	314	290	44	484	22	455
1986	5	0	2651	10708	836	315	585	91	22	350	15	50	1441
1981–1986	3	10	450	2042	1042	1607	383	213	435	180	123	70	

Table 10 Monthly abundance of age–1+ jacksmelt collected with the midwater trawl from 1980 to 1995. The abundance index period is February to July. "NI" indicates no index calculated due to insufficient data.

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Index
1980		753	2508	6720	5926	4805	2797	1290	323	0	376	0	3918
1981	1290	3367	5175	6520	4224	6900	1492	1506	431	0	376	376	4613
1982	188	2478	11079	10544	28335	7150	3137	807	654	0	0	0	10454
1983	0	376	5321	8463	8181	3952	1613	376	2257	716	1425	0	4651
1984	1791	1093	6959	5053	6349	3100	3335	2126	108	431	188	0	4315
1985	376	904	7060	5863	7027	6262	5693	1828	1120	215	0	215	5468
1986	1317	3027	14999	6996	11280	15563	7500	404	888	923	0	546	9894
1987	1237	2786	6334	14221	10294	6195	3280	2707	1944	215	108	188	7185
1988	296	4050	10261	17258	6656	6308	4272	716	484	296	188	0	8134
1989	188	716	5230	32061	10756	6640	3173	646					9763
1990		3459	12786	8507	13632	4758	2161	592	1827	323			7551
1991		2033	4569	6444	10055	11104	8786	1157	1604	108			7165
1992		4254	3540	3362	4706	3881	1299	672	1290	2293			3507
1993		3619	6118	4543	11514	1936	2017	995	2552	1049			4958
1994		3933	4445	12025									NI
1995				9173	1703	4973	1138		2205	1765	0	1621	NI
1981-1988	812	2260	8399	9365	10293	6929	3790	1309	986	350	286	166	

Distribution

Jacksmelt larvae ranged from South to Suisun bays (Figure 21). They were collected in all months but were most abundant from October to April. In all months, the highest CPUE was in Central Bay. From May to September larval jacksmelt were not collected in Suisun Bay.

In the midwater trawl, age–0 jacksmelt ranged from South Bay to San Pablo Bay (Figure 22). The CPUE was highest in Central Bay in most years, except in 1981 when it was slightly higher in San Pablo Bay, and in 1986, 1991, 1992, and 1995 when it was highest in South Bay. In 1982, jacksmelt were almost equally distributed in Central and South bays. In 1993, the CPUE was highest in Central Bay but about equal in South and San Pablo bays.

CPUE of age–0 jacksmelt was highest in South Bay in late spring and summer and the center of distribution shifted to Central Bay from midsummer to winter (Figure 23). They extended their distribution into San Pablo Bay in summer but were not present there from January to April.

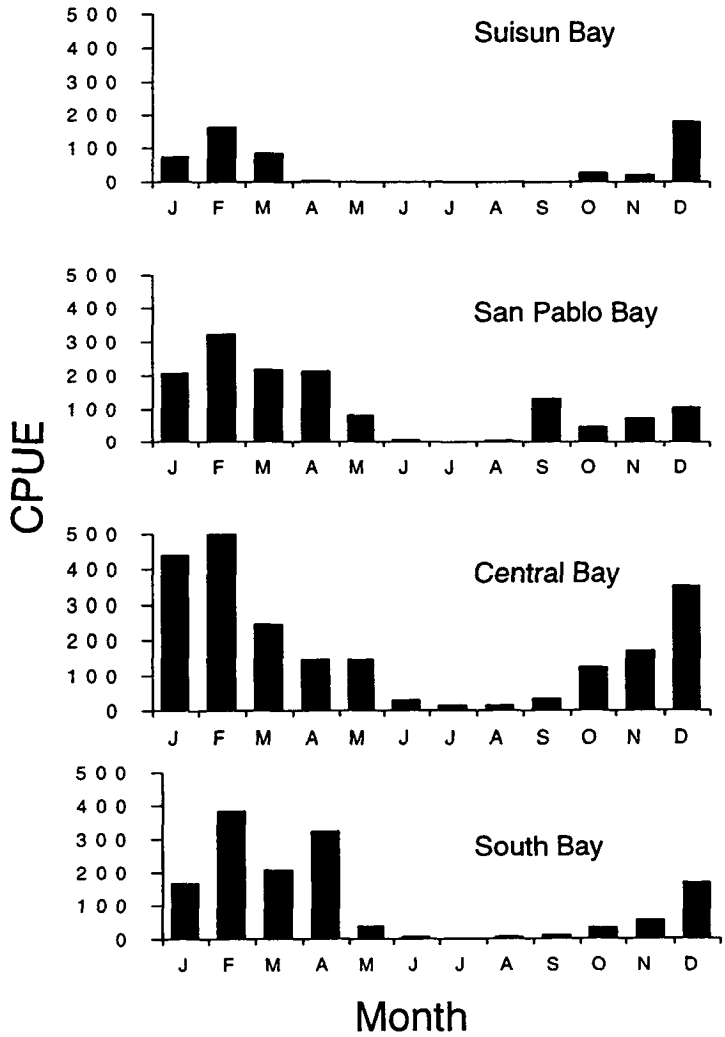

Figure 21 Seasonal distribution by region of larval jacksmelt from 1980 to 1989

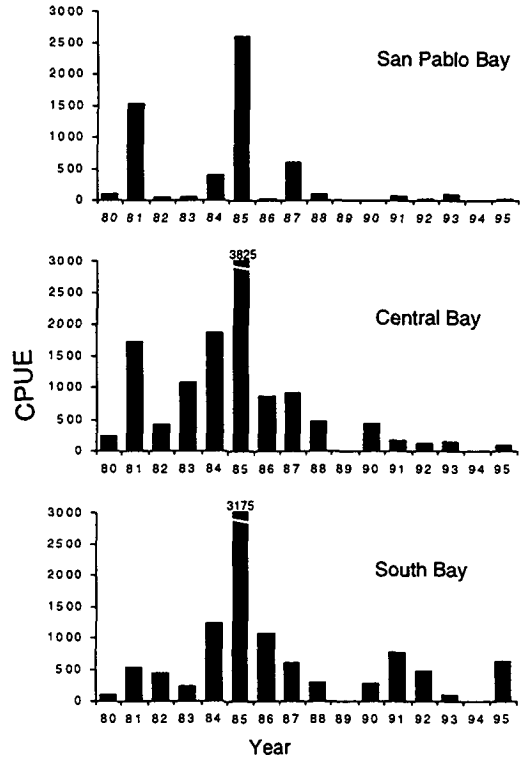

Figure 22 Annual distribution by region of age–0 jacksmelt collected with the midwater trawl from 1980 to 1995. Abundance index was July to October.

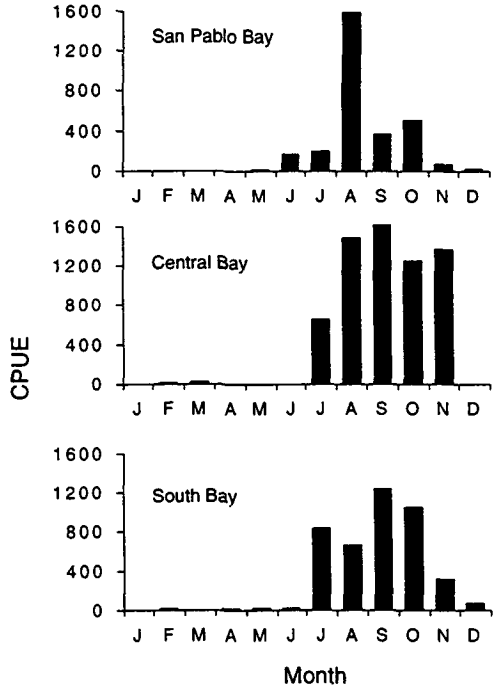

Figure 23 Seasonal distribution by region of age–0 jacksmelt collected with the midwater trawl from 1981 to 1988

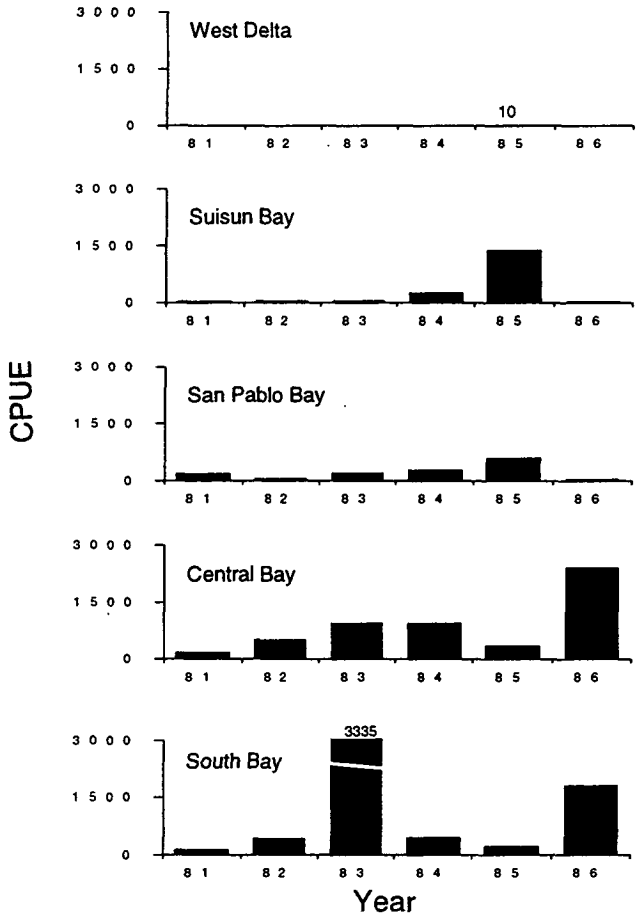

Figure 24 Annual distribution by region of age–0 jacksmelt collected with the beach seine from 1981 to 1986. *Index period was April to December.*

In the beach seine, age–0 fish ranged from South to Suisun bays except in 1985, when a single collection at station 857 was made in the west delta (Figure 24). The distribution varied greatly from year to year. They were concentrated in Central Bay, except in 1981 when highest concentrations were in Central and San Pablo bays, and in 1983 and 1985 when the age–0 fish moved to South Bay and Suisun Bay.

In the beach seine, age–0 fish were collected from South to Suisun bays in every month, except from January to March when none were collected in San Pablo and Suisun bays (Figure 25). Age–0 fish were collected in the west delta only in November. They were concentrated in Central Bay from March to May and CPUE was highest in either South Bay or Central Bay the rest of the year. In November and July, their distribution shifted to Suisun Bay, but this high CPUE was due to large catches at only a few stations in 1985.

Age–1+ jacksmelt ranged from South to San Pablo bays but CPUE was usually highest in South Bay and next highest in San Pablo Bay (Figure 26). In 1980, they were equally distributed in South and San Pablo bays and in 1985 and 1992 the highest CPUE was in San Pablo Bay. In 1994 and 1995, there was insufficient data for the index period to show the annual distribution.

Seasonally, CPUE was highest in spring in South and Central bays and highest in summer in San Pablo Bay (Figure 27). Age–1+ jacksmelt left San Pablo Bay in August and Central Bay in October but were still present in South Bay in December.

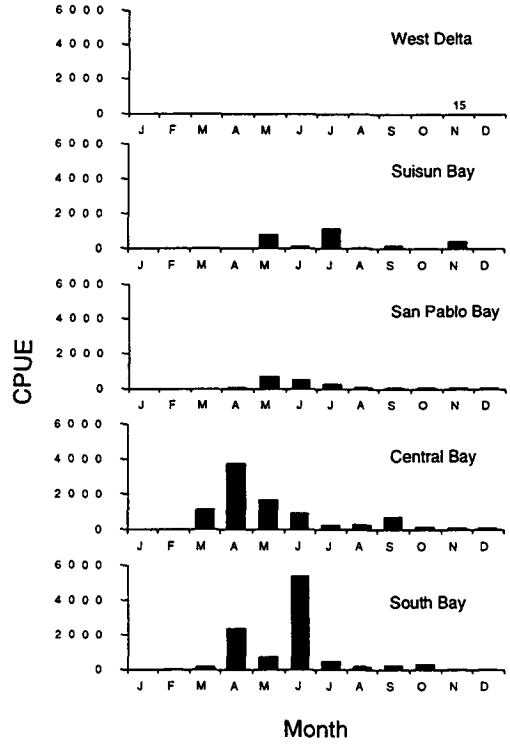

Figure 25 Seasonal distribution by region of age–0 jacksmelt collected with the beach seine from 1981 to 1986

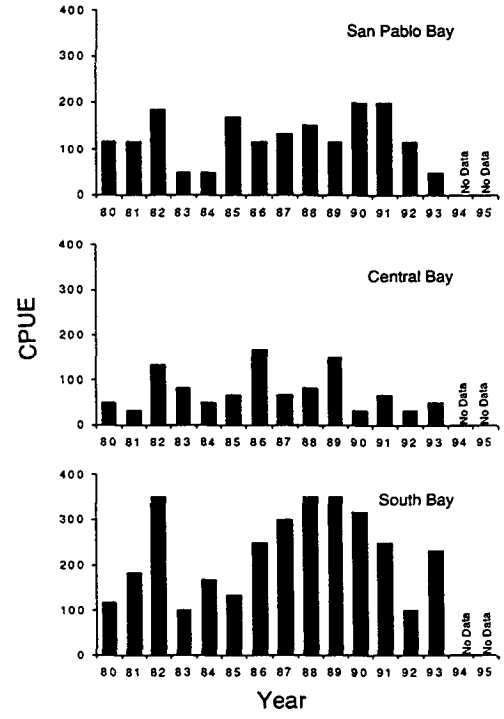

Figure 26 Annual distribution by region of age–1+ jacksmelt collected with the midwater trawl from 1980 to 1993. The index period was February to July.

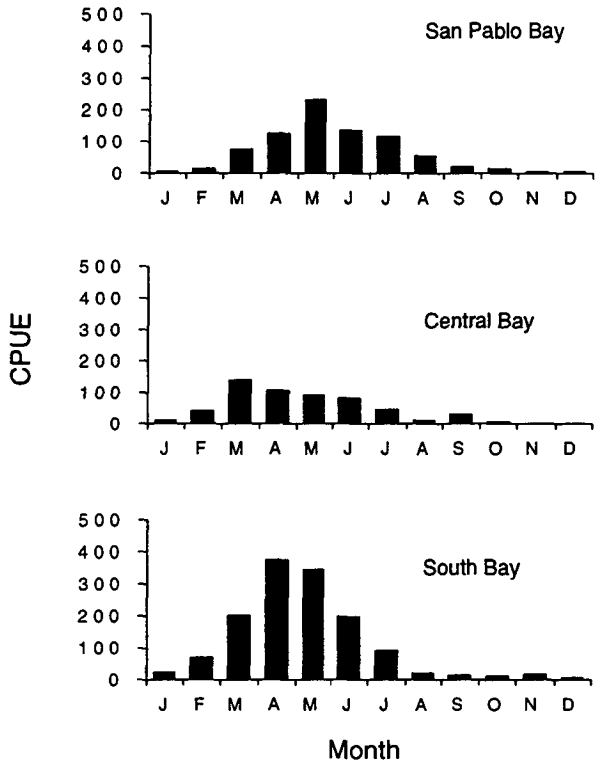

Figure 27 Seasonal distribution by region of age–1+ jacksmelt collected with the midwater trawl from 1981 to 1988

Temperature and Salinity

Collection temperatures for age–0 jacksmelt differed between the midwater trawl and beach seine (Figures 28A and 29A). In the beach seine, they were collected from 6.6 to 30.5 °C, $\bar{\chi}$ = 20.6 °C and in the midwater trawl, from 8.8 to 22.2 °C, $\bar{\chi}$ = 18.0 °C.

In the midwater trawl, age–0 fish were collected at higher salinities than in the beach seine (Figures 28B and 29B). Salinity ranged from 7.2‰ to 34.3‰, $\bar{\chi}$ = 29.3‰ in the midwater trawl, and from 0.2‰ to 34.3‰, $\bar{\chi}$ = 21.8‰ in the beach seine.

In the midwater trawl, age–1+ fish were collected from cooler temperatures and lower salinities than age–0 fish (Figure 30A): 8.2 to 21.6 °C, $\bar{\chi}$ = 15.9 °C and 3.5‰ to 33.5‰, $\bar{\chi}$ = 24.0‰.

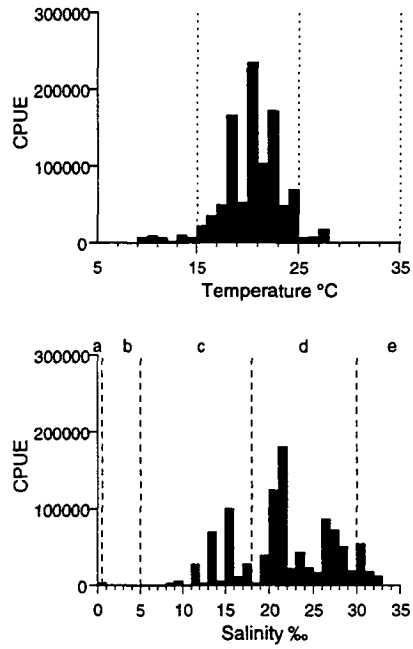

Figure 28 Temperature and salinity distributions of age-0 jacksmelt in the beach seine. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

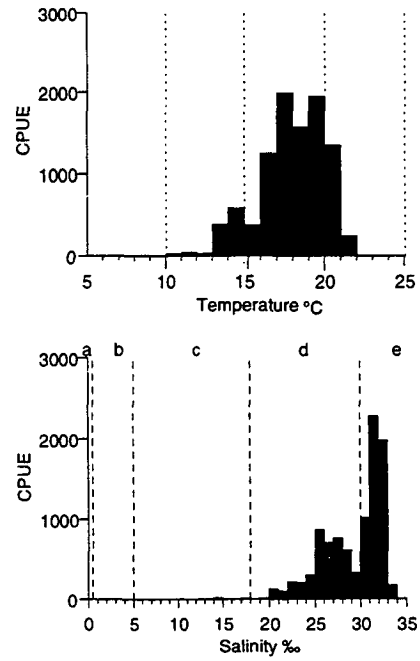

Figure 29 Temperature and salinity distributions of age–0 jacksmelt collected with the midwater trawl. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

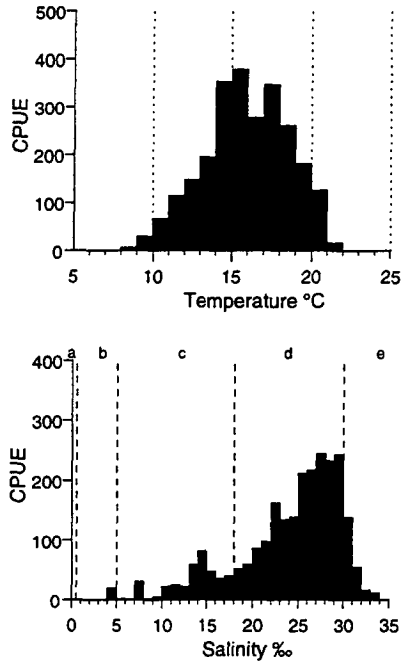

Figure 30 Temperature and salinity distributions of age–1+ jacksmelt collected with the midwater trawl. The vertical lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

Discussion

Jacksmelt use the estuary primarily as a spawning and nursery area but some remain there all year. The low winter catch may be due to movement into the shallows or out of the estuary to the coast. Our gear is ineffective in catching age–1+ fish in the shallows as shown by the low beach seine catches. However, Baxter (1980) found that jacksmelt juveniles and adults reside in the estuary in summer and move to coastal water in fall.

Jacksmelt adults move to shallows to spawn. Larvae were present throughout the year and age–0 fish were collected in all months in the beach seine, demonstrating that spawning may occur all year. The larvae were most abundant from December to April, and age–0 fish were most abundant from April through July. Reproductive activity appeared to peak in January and February. Catch of age–0 fish decreased after June and a 2nd peak occurred in September, indicating that spawning may take place more than once in a season. These results agree with the findings of other studies that report different spawning seasons: January to March (Middaugh and others 1990) and September to April (Ganssle 1966).

Age–0 fish seemed to expand their distribution to San Pablo Bay in the low outflow years 1981, 1985, and 1987, but not in 1988. From August to October, they used San Pablo Bay when the salinities there were at annual maxima, but were not quite as high as the salinities in South and Central bays. In general, salinity was <28‰ in San Pablo Bay and >30‰ in South and Central bays during these months.

The age–0 beach seine and midwater trawl geographical distributions differed. It is unclear what governed the distribution pattern of age–0 fish and the adult spawning area as the distribution varied from year to year. Low midwater trawl gear efficiency may affect the catches of age–0 and age–1+ jacksmelt. For

example, age–0 fish were collected in the beach seine in Suisun Bay and the west delta but no age–0 or age–1+ fish were collected there with the midwater trawl.

Age–0 fish caught in the beach seine were in less saline water and were found over a wider salinity range than those taken in the midwater trawl. This is due to the wider geographical distribution of fish caught in the beach seine and the limitation of beach seining from 1980 to 1986, when wet years predominated.

Age–1+ fish were collected in lower salinities than age–0 fish but it is not clear what governed their abundance and distribution. The lack of data during the drought years makes it difficult to determine if outflow affected distribution. However, age–1+ abundance remained relatively constant during the drought, whereas age–0 abundance declined during the drought and remained relatively low after it.

Inland Silverside

The inland silverside, *Menidia beryllina*, is native from the Gulf of Mexico to the Mississippi River basin to Oklahoma and Tennessee. It is also found along the Atlantic Coast from Massachusetts to Vera Cruz, Mexico (Moyle 1976, Middaugh and Hemmer 1992). It was introduced into the Blue Lakes and Clear Lake, California in 1967 (Cook and Moore 1970), and small lakes in Alameda and Santa Clara counties in 1968. It has since moved into the Sacramento–San Joaquin Delta and San Francisco Bay.

It is most abundant in the littoral zone of warm water lakes and reservoirs. It schools by size on the surface and occurs in the top 2 meters of the water column. It prefers protected areas over sand or gravel. The inland silverside feeds primarily on zooplankton including cladocerans, instars of chironomid midges and gnats during the day, and amphipods and insect larvae at night (Bachen and Elston as cited in Moyle 1976).

The inland silverside is short-lived and grows quickly, reaching half of its total length in its 1st year. It reaches a maximum of 150 to 160 mm TL. Females grow faster than males and most spawn and die in their second summer. Like the topsmelt and jacksmelt, spawning occurs over beds of aquatic plants or among emergent vegetation. The reproductive season varies according to latitude, and fecundity is positively related to maternal size (Middaugh and Hemmer 1992).

Inland silversides were collected primarily in the beach seine in the San Francisco Estuary (see Tables 1, 2, and 3). Only 4 were collected in the otter trawl and 3 in the midwater trawl compared to 4,982 in the beach seine. They were collected in and upstream of Carquinez Strait and were most abundant from July to October. Sizes ranged from 16.0 to 104 mm. They were collected in salinities ranging from 0.1‰ to 33.1‰, but only 150 fish were found in salinities >20‰. The temperature range for inland silverside was 5 to 25 °C.

References

Baxter, J.L. 1980. Inshore fishes of California. California Department of Fish and Game, Sacramento, California.

Carpelan, L.H. 1955. Tolerance of the San Francisco topsmelt, *Atherinops affinis affinis*, to conditions in salt-producing ponds bordering San Francisco Bay. California Department of Fish and Game 41:279–284.

Clark, F.N. 1929. The life history of the California Jack Smelt, *Atherinopsis californiensis*. California Department Fish and Game, Fish Bulletin 16.

Cook, S.F., Jr., and R.L. Moore. 1970. Mississippi silversides, *Menidia audens* (Atherinidae), established in California. Transactions of the American Fisheries Society 99:70–73.

Doudoroff, P. 1945. The resistance and acclimatization of marine fishes to temperature changes. Experiments with *Fundulus* and *Atherinops*. Biological Bulletin 88:197-206.

Eschmeyer, W.N., E.S. Herald, and H. Hammann. 1983. A field guide to Pacific Coast fishes of North America from the Gulf of Alaska to Baja California. Houghton Mifflin Co., Boston, Massachusetts.

Feder, H.M., C.H. Turner, and C. Limbaugh. 1974. Observations on fishes associated with kelp beds in southern California. Pages 48–60 *in*: H.W. Frey, editor. California Department Fish and Game, Fish Bulletin. 160.

Frey, H.W., editor. 1971. California's living marine resources and their utilization. California Department of Fish and Game, Sacramento, California.

Fronk, R.H. 1969. Biology of *Atherinops affinis* littoralis in Newport Bay. M.S. thesis, University of California, Irvine, California.

Ganssle, D. 1966. Fishes and decapods of San Pablo and Suisun Bays. Pages 69–94 *in*: D.W. Kelly, compiler. Ecological studies of the Sacramento–San Joaquin Estuary, Part 1. Zooplankton, zoopenthos, and fishes of San Pablo and Suisun bays, zooplankton and zoobenthos of the delta. California Department Fish and Game, Fish Bulletin 183.

Gregory, P.A. 1992. California's living marine resources and their utilization. Pages 78–79 *in*: W.S. Leet, C.M. Dewees, and C. W. Haugen, editors. California Department Fish and Game, Sacramento, California.

Hart, J.L. 1973. Pacific Fishes of Canada. Fisheries Resource Board of Canada, Bulletin 180.

Hubbs, C. 1965. Developmental temperature tolerance and rates of four southern California fishes, *Fundulus parvipinnis*, *Atherinops affinis*, *Leuresthes tenuis*, and *Hypsoblennius* sp. California Fish and Game 51:113–122.

Middaugh, D.P. and J.M. Shenker. 1988. Salinity tolerance of young topsmelt, *Atherinops affinis*, cultured in the laboratory. California Fish and Game 74: 232–235.

Middaugh, P.D., M.J. Hemmer, J.M. Shenker and T. Takita. 1990. Laboratory culture of Jacksmelt, *Atherinopsis californiensis*, and topsmelt, *Atherinops affinis* (Pisces: Atherinidae), with a description of larvae. California Fish and Game 76:4–13.

Middaugh, P.D., and M.J. Hemmer. 1992. Reproductive Ecology of the Inland Silverside, *Menidia beryllina*, (Pisces: Atherinidae) from Blackwater Bay, Florida. Copeia 1992:53–61.

Miller, D.J., and R.N. Lea. 1972. Guide to the coastal marine fishes of California. California Department Fish and Game, Fish Bulletin 157.

Moyle, P.B. 1976. Inland fishes of California. University of California Press, Berkeley, California.

Ruagh, A.A. 1976. Feeding Habits of Silversides (Family Atherinidae) in Elkhorn Slough, Monterey Bay, California. M.A. Thesis, California State University, Fresno, California.

Schultz, L.P. 1933. The age and growth of *Atherinops affinis oregonia*, Jordan and Snyder and of other subspecies of bay-smelt along the Pacific coast of the United States. University of Washington Publications in Biology 2:45–102.

Swartz, S.L. 1981. Cleaning symbiosis between topsmelt, *Atherinops affinis*, and gray whale, *Eschrichtius robustus*, in Lagun San Ignacio, Baja California Sur, Mexico. Fishery Bulletin 79: 360.

Wang, J.C.S. 1986. Fishes of the Sacramento–San Joaquin Estuary and adjacent waters, California: A guide to the early life histories. Interagency Ecological Study Program for the Sacramento–San Joaquin Estuary, Technical Report 9.

Watson W. And L.D. Davis. 1989. Larval fish diets in shallow coastal waters off San Onofre, California. Fishery Bulletin 87:569–591.