Clupeidae

Kevin Fleming

Members of the family Clupeidae are found worldwide and occupy a variety of environments from freshwater to marine. The adults of most species form pelagic schools that migrate extensively to feed and spawn (Blaxter and Holliday 1963). Four species, 2 native and 2 introduced, are common in the San Francisco Estuary. Each of the 4 clupeids has different environmental requirements and uses the estuary differently. This chapter describes the distribution and abundance of 3 of the 4 clupeids: Pacific herring, Pacific sardine, and American shad. The 4th species, the threadfin shad, *Dorosoma petenensis*, is not abundant in our sampling area.

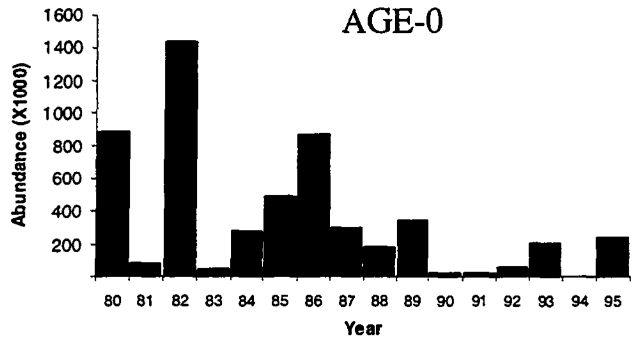
Pacific Herring

Introduction

The Pacific herring, *Clupea harengus*, is found along the Pacific coast from northern Baja California to Japan (Miller and Lea 1972). It is a pelagic schooling fish that uses bays and estuaries as both spawning and nursery areas. San Francisco Bay represents the only significant spawning area south of Puget Sound (Alderdice and Velsen 1971). Herring return to spawn in the same bays in which they were hatched, and the spawning stocks probably remain separate even outside of their spawning bays (Moser 1990), indicating that there is little genetic mixing of spawning populations. Since 1973, Pacific herring have supported a commercial roe fishery in San Francisco Bay (Spratt 1992). Much of the adult Pacific herring commercially fished in the Monterey area may belong to the San Francisco spawning stock (Moser 1990).

In California, Pacific herring mature at an earlier age than the more northern stocks. Young fish begin to enter the spawning population at 2 years, and by the 3rd year, all are mature (Spratt 1981). Mature herring may spend up to 3 weeks in the estuary before spawning and spawn only once during a season. After spawning, spent herring return to the ocean (Miller and Schmidtke 1956).

The maximum spawning temperature is about 10 °C (Alderdice and Velsen 1971). Throughout their range, the occurrence and abundance of Pacific herring appear to be related to the availability and extent of spawning salinity between 8‰ and 28‰. Laboratory experiments conducted on Pacific herring eggs from the San Francisco estuary show that optimal hatching success occurs around 16‰ (Griffin and others 1998). Spawning in the estuary takes place from November through March (Spratt 1981). Spawned eggs are adhesive and are attached most often to eelgrass and occasionally to other algae in intertidal and subtidal areas (Hardwick 1973, Miller and Schmidtke 1956). The distribution of eggs depends on the vegetation type and the substrate slope (Heagele 1986).



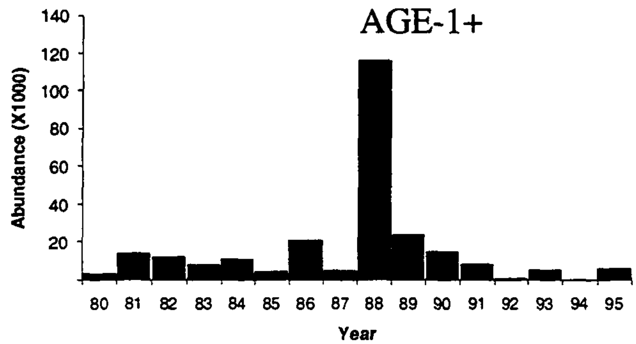


Figure 1 Annual abundance of Pacific herring: (A) age 0 and (B) age 1+. No index was calculated in 1994.

Methods

Data from the midwater trawl were used to describe abundance and distribution. Fish in the midwater trawl were categorized as age 0 or age 1+. The cutoff lengths used to separate these age classes were based on a visual inspection of the length frequency data. The following monthly cutoff lengths were used for January through December: 45, 50, 70, 85, 95, 105, 110, 120, 125, 125, 135, and 140 mm. The months used for the indices covered the periods when most of the age classes were collected. For age–0 fish, the index period was April through August and for age–1+ fish it was February through July.

Results

Abundance

The abundance index for age–0 fish varied from a high of 1,442 in 1982 to a low of 23 in 1990 (Figure 1, Table 1). There were secondary modes in 1980 and 1986 and an extended low from 1990 to 1992. Age–1+ fish were 5 times more abundant in 1988 than in the next highest year, 1989 (see Figure 1, Table 2). The lowest year was 1992. Abundance remained low from 1992 to 1995.

Table 1 Monthly abundance indices of age–0 Pacific herring captured in the midwater trawl from 1980 to 1995. The last column is the annual index, the mean abundance from April to August. The bottom row is the average seasonal abundance from 1981 to 1988.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Index*
1980		0	0	48591	344565	508224	474121	3051669	222892	26344	2999	5112	885434
1981	0	0	22728	118228	28083	64292	146185	64146	113273	29995	5951	538	84187
1982	0	0	23796	416899	2606934	1719439	2123126	341151	505831	270881	43760	7736	1441510
1983	0	0	0	7753	85990	112630	31674	4331	267	11252	12341	1061	48475
1984	0	0	1425	352506	745012	223521	70191	4891	25667	1104	1644	0	279224
1985	0	0	1589	236915	306460	1128977	579829	193268	447857	115598	13398	2789	489090
1986	0	0	2474	225087	600410	1330340	2141340	50071	67530	13079	5704	2831	869449
1987	0	0	0	152796	529051	535731	48077	206874	30811	27496	5692	1249	294506
1988	0	0	0	671800	155702	43230	58020	2216	8898	30348	4318	0	186194
1989	0	0	0	495140	892011	190730	60606	97113					347120
1990		0	179	40984	44744	14850	8727	4308	3805	1100			22723
1991		0	8295	56257	52346	25474	3396	2802	2133	544			28055
1992		0	0	175461	104602	9400	9073	6540	1011	6343			61015
1993		0	0	609745	123944	93782	179134	19287	12682	16825			205178
1994		0	820	89475									NA
1995				29774	199278	333107	415032		21030	36339	39457	610	244298
1981–1988	0	0	6502	272748	632205	644770	649805	108368	150017	62469	11601	2025	

Table 2 Monthly abundance indices of age–1+ Pacific herring captured in the midwater trawl from 1980 to 1995. The last column is the annual index, the mean abundance from February to July. The bottom row is the average seasonal abundance from 1981 to 1988.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Index*
1980		8374	1442	3785	1713	0	750	0	0	0	0	0	2677
1981	1593	9940	2360	33271	2252	0	36637	0	0	0	0	591	14077
1982	9600	11170	4537	17361	38622	0	0	418	0	636	8378	8927	11948
1983	135239	30331	8648	3728	426	1489	324	0	557	2335	496	2659	7491
1984	0	22122	3165	5308	9868	23793	729	0	551	0	0	0	10831
1985	3336	2285	7121	4703	2936	0	4278	0	0	0	0	0	3554
1986	5248	14039	1073	2749	3436	231	101351	0	0	0	0	2394	20480
1987	11309	9904	2781	12328	2258	0	1435	0	0	0	125	3866	4784
1988	17274	646880	7286	26461	1191	13306	2766	0	563	571	2111	6579	116315
1989	130645	54144	87750	1301	158	612	0	0					23994
1990		80496	2986	2053	982	0	538	0	0	0			14509
1991		48321	756	234	106	696	0	0	0	0			8352
1992		3119	615	0	0	0	0	0	0	0			622
1993		2162	6360	21650	692	0	0	0	0	0			5144
1994		2133	2495	0									NA
1995				4593	7986	10640	0		0	0	119	6600	5805
1981–1988	22950	93334	4621	13239	7624	4852	18440	52	209	443	1389	3127	

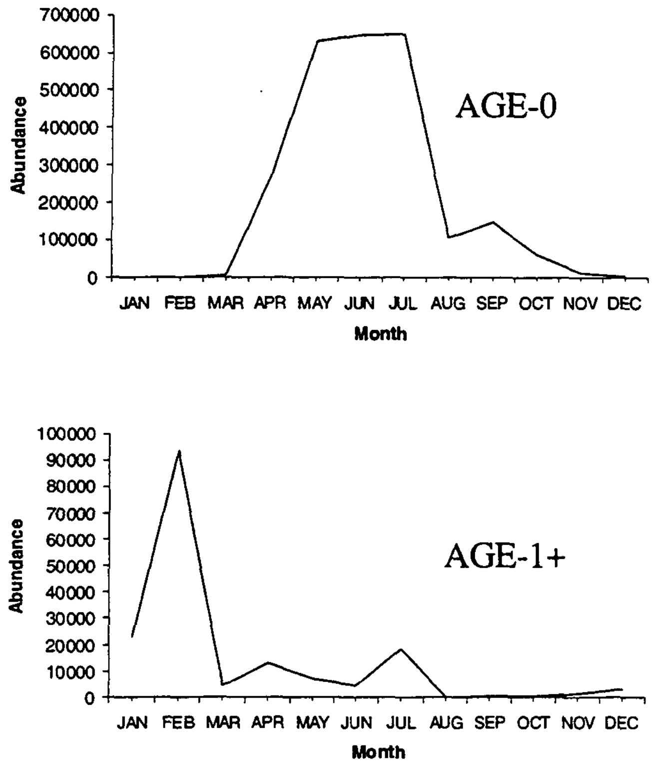


Figure 2 Seasonal abundance of Pacific herring from 1981 to 1988: (A) age 0 and (B) age 1+

Abundance showed different seasonal maxima for the 2 age classes. Age–0 Pacific herring peaked in late spring or early summer and were absent in January and February (Figure 2). The abundance of age–1+ fish peaked in January or February, except in 1986 when the peak came in July (see Table 2).

Distribution

The range of age–0 Pacific herring was greatest in May, concurring with their peak density (Figure 3). May was the only month they reached the west delta. They were usually most abundant in Central Bay and may have moved into Central Bay from South Bay in July. The Central Bay catch increased as catches in other regions decreased, peaked in June and July and then declined.

Age–1+ Pacific herring ranged farthest in January, the only month they were in the west delta (Figure 4). Most age–1+ fish were in Central or South bays. In all years except 1988, the age–1+ catch was highest in Central Bay (Figure 5). In 1988, catches were highest in South Bay. In several wet years, no age–1+ fish were caught in San Pablo Bay. Conversely, an upstream extension of age–1+ fish into Suisun Bay occurred in the dry years 1981, and from 1987 to 1992.

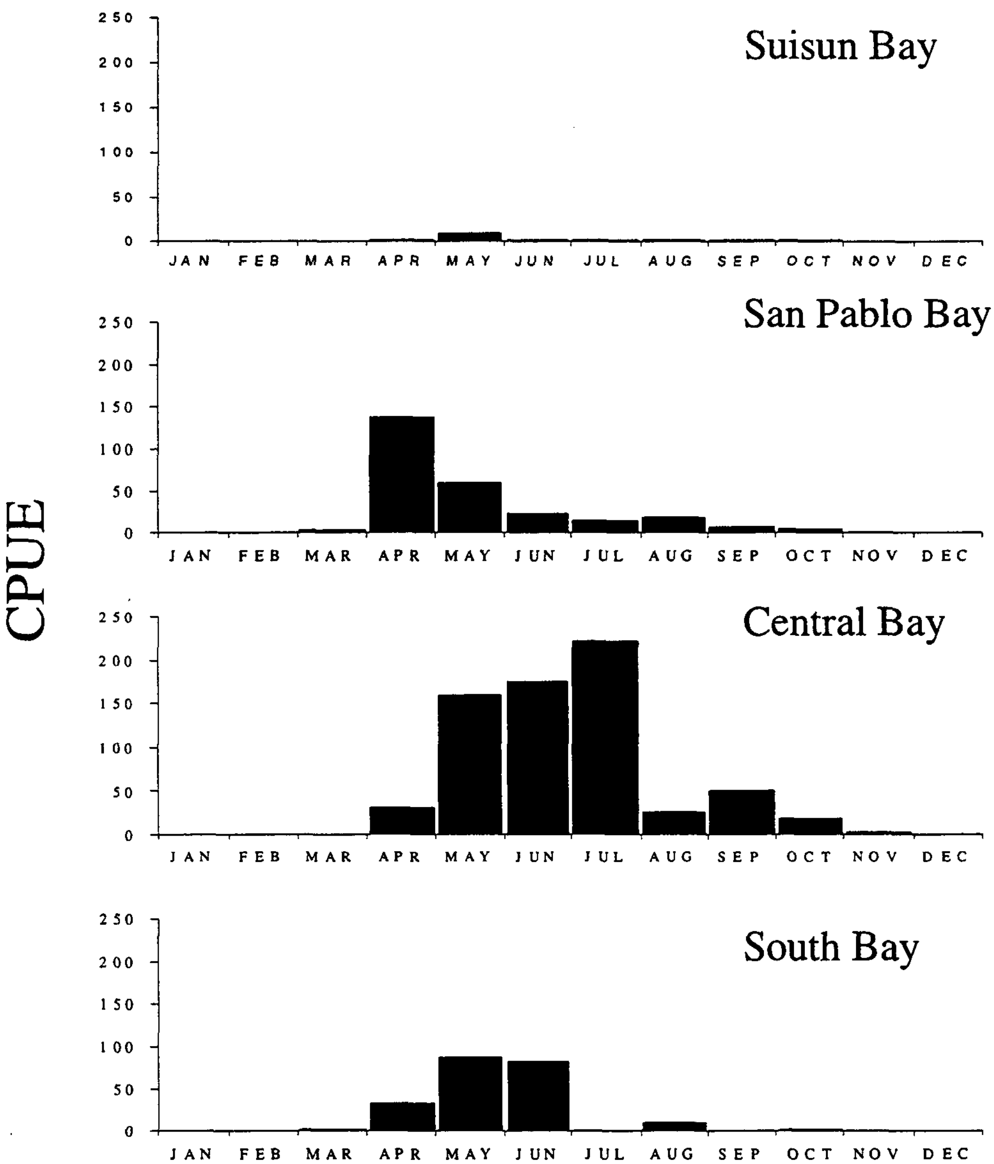


Figure 3 Seasonal distribution of age–0 Pacific herring by region. Values are the average CPUE for 1981 to 1988.

Temperature and Salinity

The salinities and temperatures that Pacific herring occurred in differed with fish size and time of year. The smallest age–0 fish (30 to 40 mm FL) were found most often at about 21‰ (Figure 6). As size increased so did the salinity at which they were found, up to 90 to 100 mm FL and about 28‰. Fish >100 mm FL were most often found in somewhat lower salinity. The decline in the salinity corresponded with the emigration of many of the larger age–0 fish to the ocean and reflects the salinities the "stragglers" were in. The age–1+ fish, whose residence time within the estuary is relatively brief, were found at a much narrower range of salinity from about 27‰ to 30‰. The temperature range of age–1+ fish varied from about 10.5 to 14.0 °C.

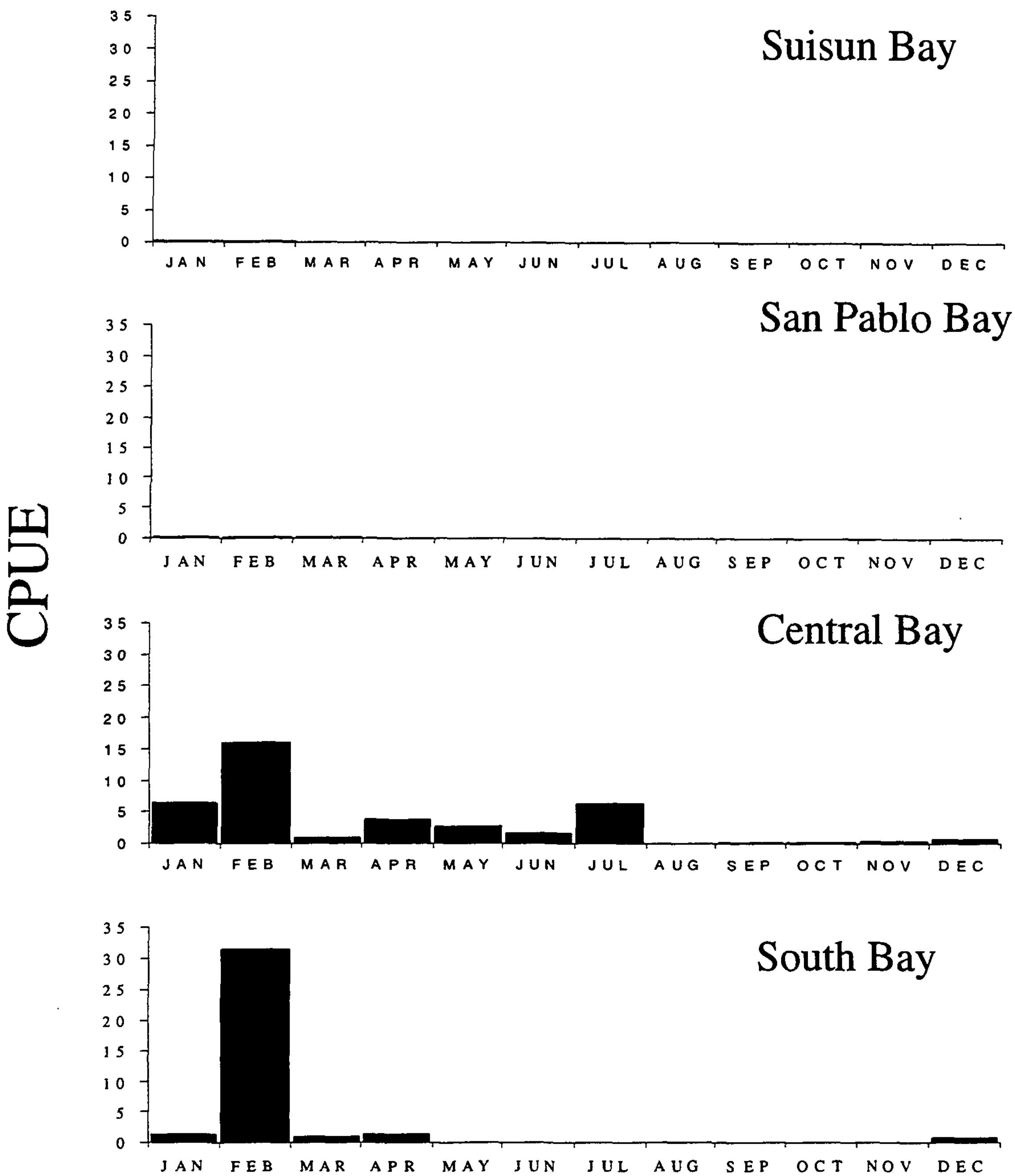


Figure 4 Seasonal distribution of age–1+ Pacific herring by region. Values are the average CPUE for 1981 to 1988.

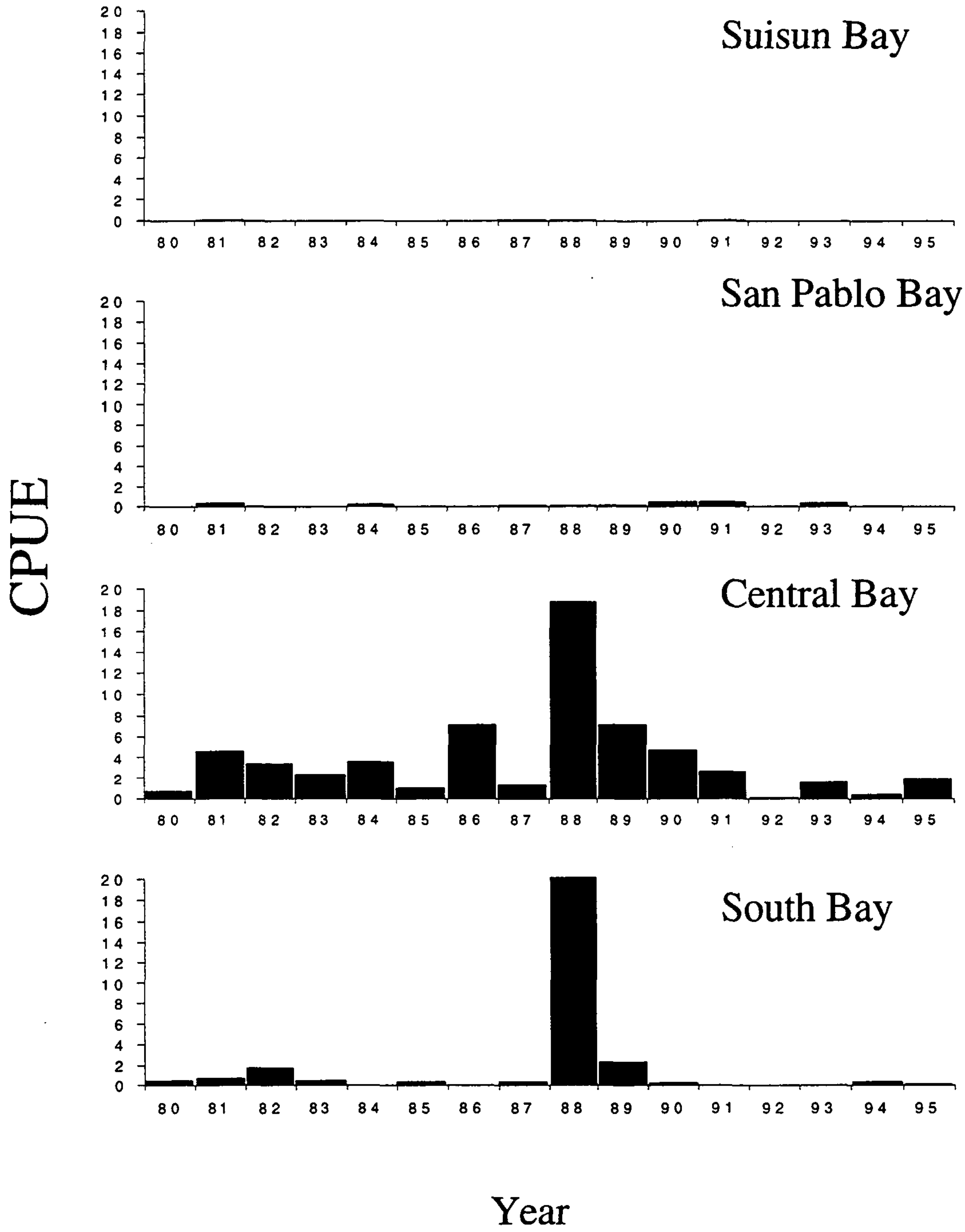


Figure 5 Annual distribution of age–1+ Pacific herring by region. Values are the average CPUE for February to October.

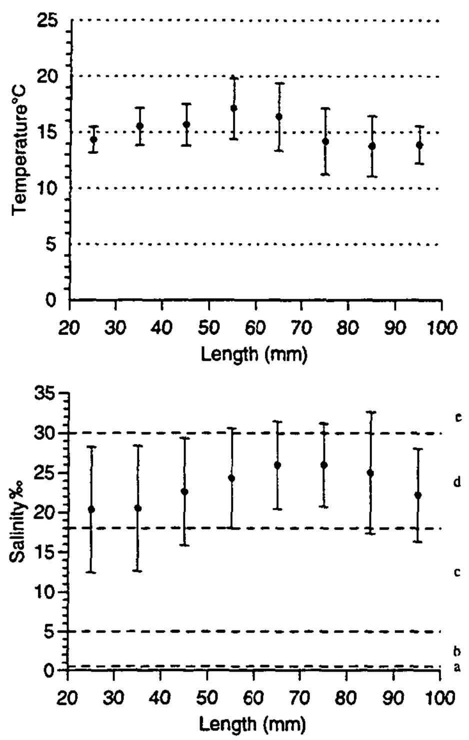


Figure 6 Temperature and salinity distributions of Pacific herring by length. The dots are the means and the bars are 1 standard deviation. The horizontal lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

Discussion

Freshwater flow directly affects the distribution of Pacific herring within the estuary. The distribution of age–1+ Pacific herring is limited by salinity. The age–1+ fish were typically found within the euhaline embayments of the estuary and were concentrated primarily in South and Central bays. Age–1+ fish were collected as far upstream as Suisun Bay during the drought when low winter outflows increased salinity in Suisun Bay to the mesohaline range.

Age–1+ fish had a predictable seasonal abundance pattern. Their seasonal abundance peak usually occurred in winter, but occasionally (for example in 1986) occurred later in the year. The interannual shifts in seasonal abundance reflected strengths of the various year classes within the age–1+ group. Mature Pacific herring (that is, 2 years and older), entered the estuary for only a short period during the winter to spawn. Juvenile (1 year old) herring stayed longer in the estuary. In most years, age–1+ fish were seldom found in the estuary beyond July and in 1992 were collected only in February and March.

Age–0 fish were found over a broader range of temperature and salinity than age–1+ fish, reflecting changes in their geographic distribution. Although spawned in Central and South bays, age–0 fish were often found in Suisun Bay and occasionally as far upstream as the west delta. Typically, peak catches of age–0 Pacific herring in regions other than the Central Bay occurred in spring. By summer, the catch of age–0 fish in these embayments decreased as the fish migrated towards Central Bay and abundance peaked there. Abundance in Central Bay decreased as age–0 fish left the estuary.

American Shad

Introduction

The American Shad, *Alosa sapidissima*, is native to the Atlantic coast. It was introduced to the Sacramento River in 1871 (Skinner 1962) and supported a commercial fishery until 1957. It ranges along the Pacific coast from Todos Santos Bay, Baja California, to Alaska and Kamchatka, Russia (Hart 1973, Miller and Lea 1972).

The American shad spends 3 to 5 years in the ocean before returning to the San Francisco Estuary to spawn in spring (Moyle 1976), after which a large percentage of adults die (Stevens 1966). The major spawning grounds are above Rio Vista in the Sacramento River and in its major tributaries, the Feather and American rivers. The San Joaquin River is not extensively used for spawning (Hatton 1940).

Methods

Midwater trawl catch data were used to describe abundance and distribution. Fish were separated into age–0 and age–1+ age groups based upon an examination of the length frequency data. The cutoff lengths for separating these groups were 30 mm FL for January to April and 70, 100, 130, 160, 200, 220, 240, 240 mm FL for May to December.

The annual abundance index period for the age–0 fish was July through October, the months with the greatest catches. Catches were too low to calculate an index for age–1+ fish. No sampling was done in 1994, nor from September to November in 1989.

Results

Length

During the 15 years of sampling, very few mature American shad were collected in these surveys. The large fish either avoided the nets or were in shallower water than is typically sampled in this survey. The largest American shad collected in the midwater trawl measured 550 mm FL and the smallest 27 mm FL.

Small shad began appearing in the midwater trawl in June and July. The smallest fish were collected in the west delta and were more numerous at shoal than channel stations. The mean size of the age–0 fish varied with location and increased downstream.

Outflow may have affected the size range of American shad in the estuary. In high outflow years, the mean size of the age–0 fish was smaller in all regions than in years with low outflows. This pattern was especially pronounced in 1983 and 1995, when the age–0 fish from Suisun Bay were on average about 20 mm smaller then age–0 fish from same area during the drought. High outflow may have reduced transit time of smaller fish through the estuary and moved them downstream faster.

Abundance

The annual abundance index of age–0 American shad was highest in 1982 and lowest in 1985 (Figure 7, Table 3). The indices tended to be higher in wet years. The peak in the monthly abundance index of age–0 fish varied from year to year. In 5 out of the 14 years that have an index, the peak occurred before September. In all of the years surveyed, a large proportion of the total annual index occurred catch during July and August.

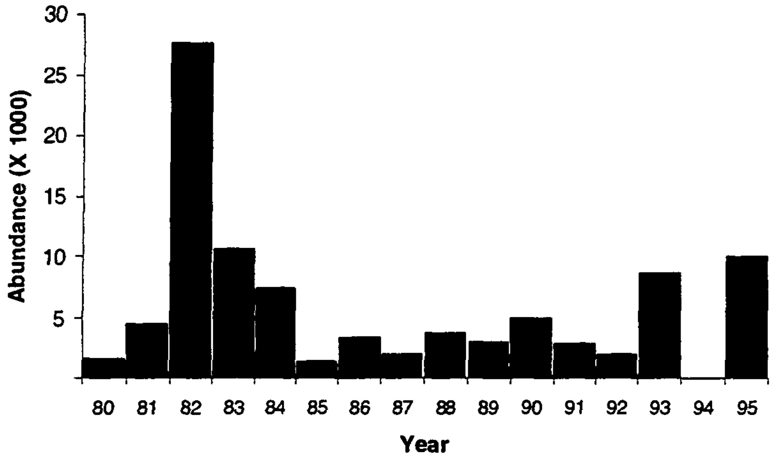


Figure 7 Annual abundance of age–0 American shad

Table 3 Monthly abundance indices of age–0 American shad captured in the midwater trawl from 1980 to 1995. The last column is the annual index, the mean abundance from July to October. The bottom row is the average seasonal abundance from 1981 to 1988.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Index*
1980		0	0	0	0	0	289	924	4178	1460	5204	1668	1713
1981	0	0	0	0	0	0	0	3363	6105	8359	3127	1110	4457
1982	0	0	0	0	0	64	10496	53578	25929	20096	18422	13048	27525
1983	0	0	0	0	0	0	516	8313	23353	10077	4608	6389	10565
1984	0	0	0	0	0	0	18092	5955	3812	1957	851	1038	7454
1985	0	0	0	0	0	0	0	1840	1497	2188	2540	1150	1381
1986	0	0	0	0	0	0	0	1940	4668	6865	1829	3942	3368
1987	0	0	0	0	0	0	795	3088	2736	1718	1235	1478	2084
1988	0	0	0	0	0	0	3054	7208	1947	2855	2690	1786	3766
1989	0	0	0	0	0	0	540	5350					2945
1990		0	0	0	0	0	176	6408	11523	1711			4954
1991		0	0	0	0	0	0	2443	2763	5877			2771
1992		0	0	0	0	0	3229	1951	1761	958			1975
1993		0	0	0	0	0	548	16640	10412	6819			8604
1994		0	0	0									NA
1995				0	0	0	72		20370	9528	29921	3903	9990
1981–1988	0	0	0	0	0	8	4119	10661	8756	6764	4413	3743	

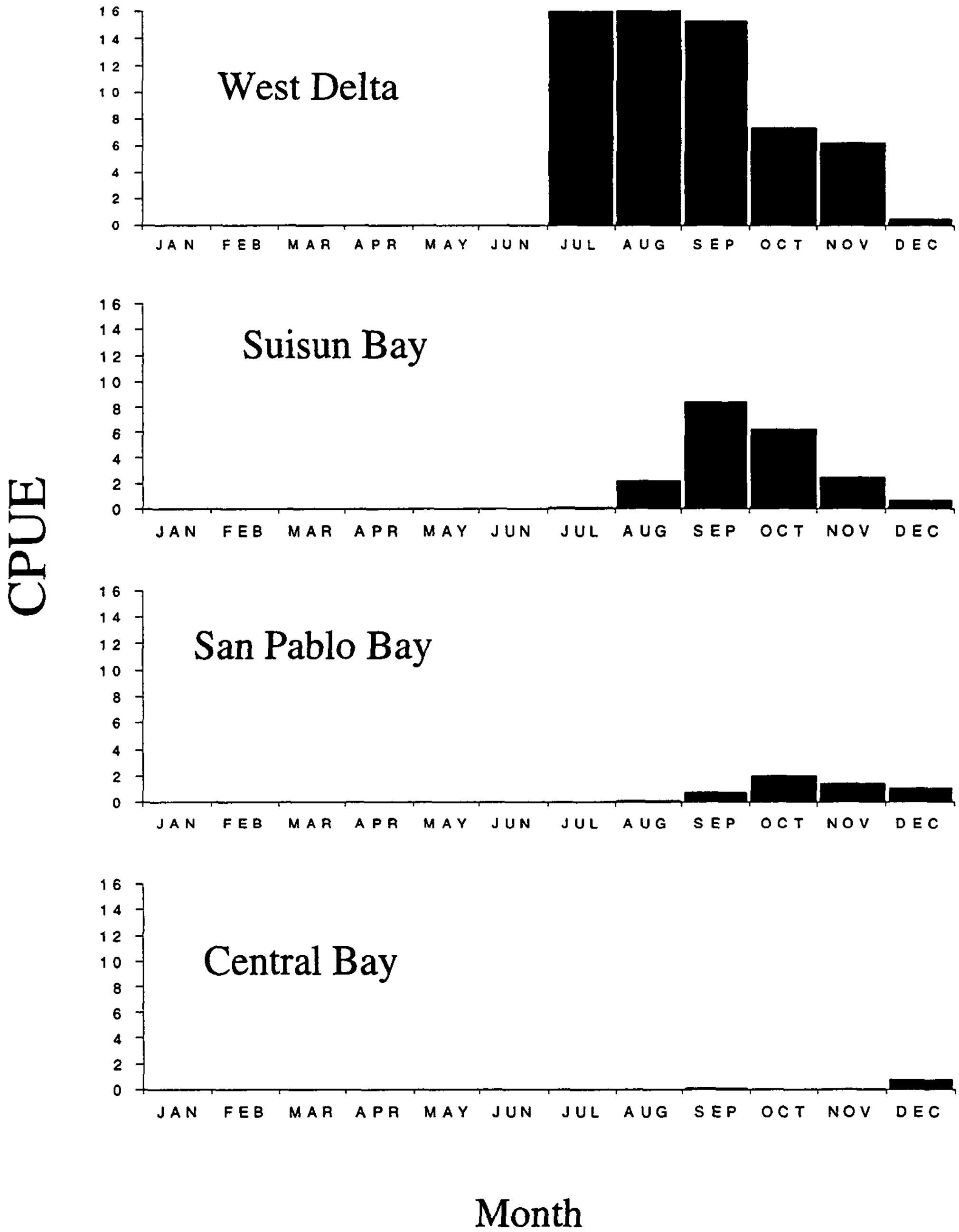


Figure 8 Seasonal distribution of age–0 American shad by region. Values are the average CPUE for 1981 to 1988.

Distribution

The distribution of age–0 American shad followed a recurring seasonal pattern. They first appeared in the west delta in July, where the catch usually peaked in July and August (Figure 8). As the year progressed, the catch in the west delta decreased and the downstream catch increased. Distribution varied little over the years (Figure 9). Most of the fish were collected in the west delta. The proportions of the total catches in regions downstream of the west delta increased in high outflow years.

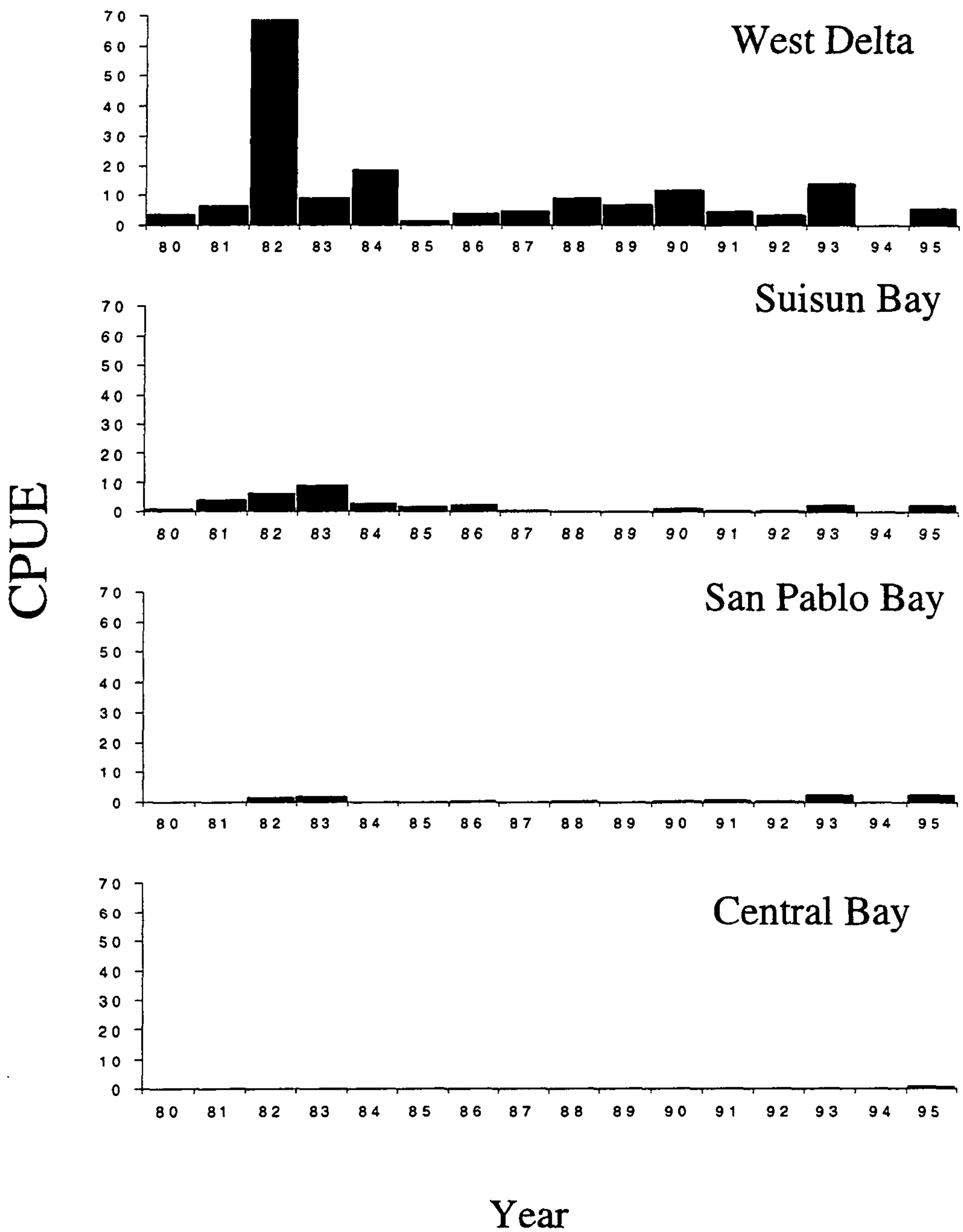


Figure 9 Annual distribution of age–0 American shad by region. Values are the average CPUE for July to October.

Temperature and Salinity

Age–0 American shad were collected over broad temperature and salinity ranges (Figure 10). The salinity the fish occurred in increased as they grew and emigrated. The smallest American shad were collected at a mean salinity of 0.16‰. The mean collection temperature showed an inverse relationship with size; the smallest fish were collected at a mean temperature of 21.3 °C.

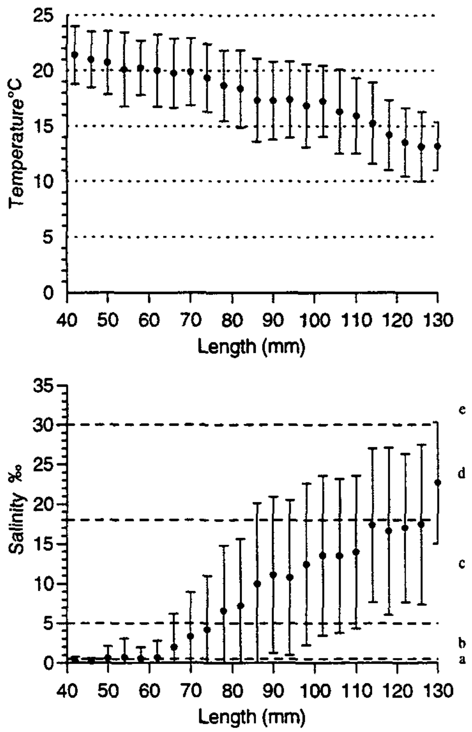


Figure 10 Temperature and salinity distributions of American shad by length. The dots are the means and the bars are 1 standard deviation. The horizontal lines on the salinity graph mark the boundaries of the Venice system ranges: (a) limnetic, (b) oligohaline, (c) mesohaline, (d) polyhaline, and (e) euhaline.

Discussion

Age-0 American shad migrated seaward through the estuary from June through December and experienced wide ranges of salinity and temperature. As they moved farther downstream the salinity at which they were caught increased and the temperature decreased. The annual abundance indices correlated significantly and positively with river flow ($r = 0.86$, $P < 0.05$, $n = 13$). This agrees with the relationship found by Stevens and Miller (1983) using data from the Fall Midwater Trawl Survey. Age-0 fish also appeared earlier in the year in our sampling area and were smaller during high outflow years.

The relationship between American shad abundance and outflow as measured by the Fall Midwater Trawl index was weakened during the early 1990s because the indices for these years were much greater than those predicted by the relationship based on earlier years. However, the Bay Study indices for the 1990s showed a continued significant relationship with outflow and differed significantly from the Fall Midwater Trawl indices ($r = 0.57$, $P < 0.05$, $n = 15$). The 2 studies produced different abundance indices because of differences in areas and months sampled. Neither study sampled the entire range of the fish nor all the months of peak abundance in all years. Hence, data from both studies need to be combined to obtain a complete picture of distribution and abundance.

Pacific Sardine

Introduction

The Pacific Sardine, *Sardinops sagax*, is primarily a coastal marine species. It ranges from Guaymas, Mexico to Kamchatka, Russia (Miller and Lea 1972). Individual fish travel long distances; fish tagged off southern California have been recovered a few months later in British Columbia. The speed of movement is related to the size of the fish. Larger sardines travel faster and farther than smaller fish (Clark and Janssen 1945). It is mostly older fish that make long journeys, up the coast during spring and summer and down the following winter. One- and two-year-old fish are generally not found in large numbers north of central California (Clark 1952).

The Pacific sardine spawns throughout its range but most spawning takes place off southern California (Scofield 1934) from January through September at temperatures between 12.5 to 16.0 °C (California Cooperative Sardine Research Program 1950).

The commercial fishery along the California coast was intensive and short-lived; after peaking in the mid-1930s, both the catch and effort declined. The fishery in San Francisco Bay began in 1916 and ended in the early 1950s. The fishery in the Pacific Northwest ended after 1948 (Murphy 1966).

Methods

Only midwater trawl data was used. Pacific sardines were not separated into age classes and because of the sporadic nature of the catch and the absence of several months of data, no index period for was set. Instead, the index was the sum of all the months available.

Results and Discussion

Prior to 1993, few Pacific sardine were caught in the estuary. From 1980 to 1992, only 21 Pacific sardines were collected and 12 of these were taken during a single tow within Central Bay. In 1993, the catch increased dramatically. Despite the curtailed sampling effort in 1994 the total catch of Pacific sardines from 1993 to 1995 far surpassed the total 15–year catch for many of the more "common" species that we normally encountered.

Although catches were somewhat higher during spring and summer, there was no strong seasonal trend. Commercial catches during the 1930s in San Francisco Bay also indicated little seasonal variation, with only a slight drop occurring in January and February.

Pacific sardines were collected over a broad salinity range from 15.7‰ to 31.7‰, mean 23.2‰, and were never collected upstream from San Pablo Bay. Most were in Central Bay; only in 1994 were they more abundant in South Bay. The collection temperatures ranged from 12.1 to 18.1 °C, mean 15.1 °C.

References

Alderdice, D.F. and F.P.J. Velsen. 1971. Some effects of salinity and temperature on early development of pacific herring *(Clupea pallasi)*. Journal Fisheries Research Board of Canada 28:1545–1562.

Blaxter, J.H.S. and F.G.T. Holliday. 1963. The behaviour and physiology of herring and other clupeids. Pages 261–393 *in*: F.S. Russell, editor. Advances in Marine Biology. Academic Press, New York & London.

California Cooperative Sardine Research Program. 1950. Progress Report for 1950. Clark, F.N. 1952. Review of the California sardine fishery. California Department of Fish and Game 38:367–380.

Clark, F.N. and J.F. Janssen. 1945. Movements and abundance of the sardine as measured by tag returns. California Department of Fish and Game, Fish Bulletin 61.

Clark, F.N. 1952. Review of the California sardine fishery. California Department of Fish and Game 38:367–380.

Griffin, F.J., M.C. Pillai, C.A. Vines, J. Kääriä, T. Hibbard–Robbins, R. Yanagimachi and G.N. Cherr. 1998. Effects of Salinity on Sperm Motility, Fertilization, and Development in the Pacific Herring, *Clupea pallasi*. Biology Bulletin 194:25–35.

Hardwick, J.E. 1973. Biomass estimates of spawning herring, *Clupea harengus pallasi*, herring eggs, and associated vegetation in Tomales Bay. California Fish and Game 59:36–61.

Hart, J.L., editor. 1973. Pacific fishes of Canada. Fisheries Research Board of Canada, Bulletin 180.

Hatton, S.R. 1940. Progress report on Central Valley fisheries investigation, 1939. California Fish and Game 26:335–373.

Heagele, C.W. 1986. Proceedings of the fifth Pacific coast herring workshop, October 29–30, 1985. Canadian Journal of Fisheries and Aquatic Sciences.

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

Miller, D.J. and J. Schmidtke. 1956. Report on the distribution and abundance of Pacific herring (*Clupea pallasi*) along the coast of central and southern California. California Fish and Game 42:163–187.

Moser, M. 1990. Biological tags for stock separation in Pacific herring (*Clupea harengus pallasi* Valenciennnes) and the possible effects of "El Niño" current on parasitism. Alaska Sea Grant College Program, Anchorage, Alaska.

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

Murphy, G.I. 1966. Population biology of the Pacific sardine (*Sardinops caerulea*). Proceedings of the California Academy of Sciences, Fourth Series 34:1–84.

Scofield, E C. 1934. Early life history of the California Sardine (*Sardinops caerulea*) with special reference to the distribution of eggs and larvae. California Division of Fish and Game, Fish Bulletin 41.

Skinner, J.E. 1962. An historical view of the fish and wildlife resources of the San Francisco Bay area. California Department of Fish and Game, Water Projects Branch Report No. 1, Sacramento, California.

Spratt, J.D. 1981. Status of the Pacific herring *Clupea harengus pallasii*, resource in California 1972–1980. R.N. Tasto, editor. Sacramento, California.

Spratt, J.D. 1992. The evolution of California's herring roe fishery: Catch allocation, limited entry, and conflict resolution. California Fish and Game 78:20–44.

Stevens, D.E. 1966. Distribution and food habits of the American shad, *Alosa sapidissima*, in the Sacramento–San Joaquin Delta. Pages 97–107 *in*: J.L. Turner and D.W. Kelley, compilers. Ecological Studies of the Sacramento–San Joaquin Delta. Part II. California Department of Fish and Game, Fish Bulletin 136.

Stevens, D.E. and L.W. Miller. 1983. Effects of river flow on abundance of young chinook salmon, American shad, longfin smelt, and delta smelt in the Sacramento–San Joaquin River System. North American Journal of Fisheries Management 3: 425–437.