Bratovich

DFG EXHIBIT 60

Exhibit 60, entered by the California Department of Fish and Game
for the State Water Resources Control Board
1987 Water Quality/Water Rights Proceeding on the
San Francisco Bay/Sacramento-San Joaquin Delta

Delta Outflow Effects on the Abundance and Distribution of San Francisco Bay Fish and Invertebrates, 1980-1985

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Chapter 1. INTRODUCTION

Beginning in January 1980, the Department of Fish and Game began a field sampling program in San Francisco Bay as part of the Interagency Ecological Study Program. The sampling was designed to investigate the relationship between Delta freshwater outflow and abundance and distribution of fish and invertebrates. This effort was the first spatially and temporally comprehensive fishery study ever carried out in the Bay. Monthly samples were collected at sites throughout all embayments, including Suisun Bay, San Pablo Bay, Central Bay, and South Bay, from 1980 until the present.

As a result of this extensive study, much has been learned about fish and invertebrate ecology in San Francisco Bay. This report describes some findings from 1980 through 1985 as they relate to freshwater outflow from the Delta. Factors other than flow can affect fish and invertebrates, but the major objective of this study was to consider outflow as it influences Bay fishery resources.

This report does not present detailed information on all species collected during the study. Only the most abundant or important species are treated rigorously; however, data exist for other species as well. Also, data on striped bass and salmon have been integrated into other reports prepared for the Bay-Delta hearings, and are, therefore, not included here.

Study Area

The study area is bounded on the upstream end by the Highway 120 bridge on the San Joaquin River at Antioch and Sherman Island on the Sacramento River and on the downstream end by the Golden Gate bridge. The study area includes all of South San Francisco Bay above the Dumbarton Bridge (South Bay), Central Bay, San Pablo Bay, Suisun Bay, and Honker Bay (Figure 1). This area is referred to as the Bay or study area in this report. The study area was divided into 12 sections to facilitate analysis. Section 1 is at the southern end of South Bay, and section 12 is at the extreme upstream end of the study area. The area encompassing sections 11 and 12 is often referred to as the West Delta.

Characteristics of Delta Outflow

The Sacramento-San Joaquin river estuary receives runoff from a drainage basin of about 60,000 square miles, which covers 40 percent of the land area of California. Freshwater outflow to the estuary is highly seasonal, with high flows from November to May. Winter flows are generally from rain runoff, and spring flows are from snowmelt. More than 90 percent of the fresh water originates from the Sacramento and San Joaquin rivers (Porterfield et al., 1961); the remainder comes from local drainages of the Napa River, Petaluma River, Sonoma Creek, Coyote Creek, and waste water inflows.

Delta outflow is a calculated value expressed as cfs (cubic feet per second) at Chipps Island. It is based on the amount of water flowing into the Delta minus the amount exported from the Delta, the amount used within the Delta, and the amount lost to evaporation. Average monthly Delta outflow for the 1980-1985 study period is shown in Figure 2.

Figure 1. Study Area

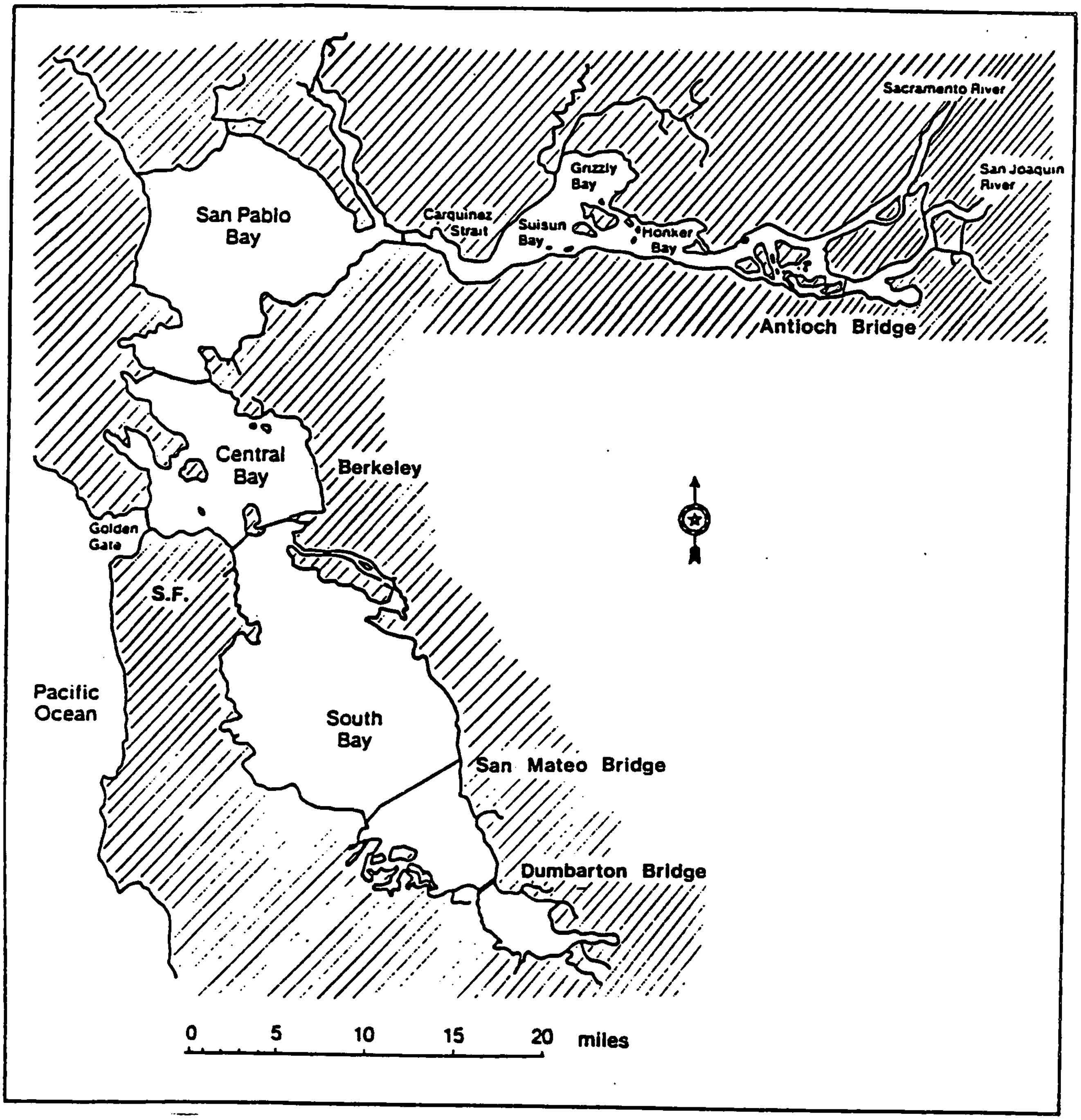
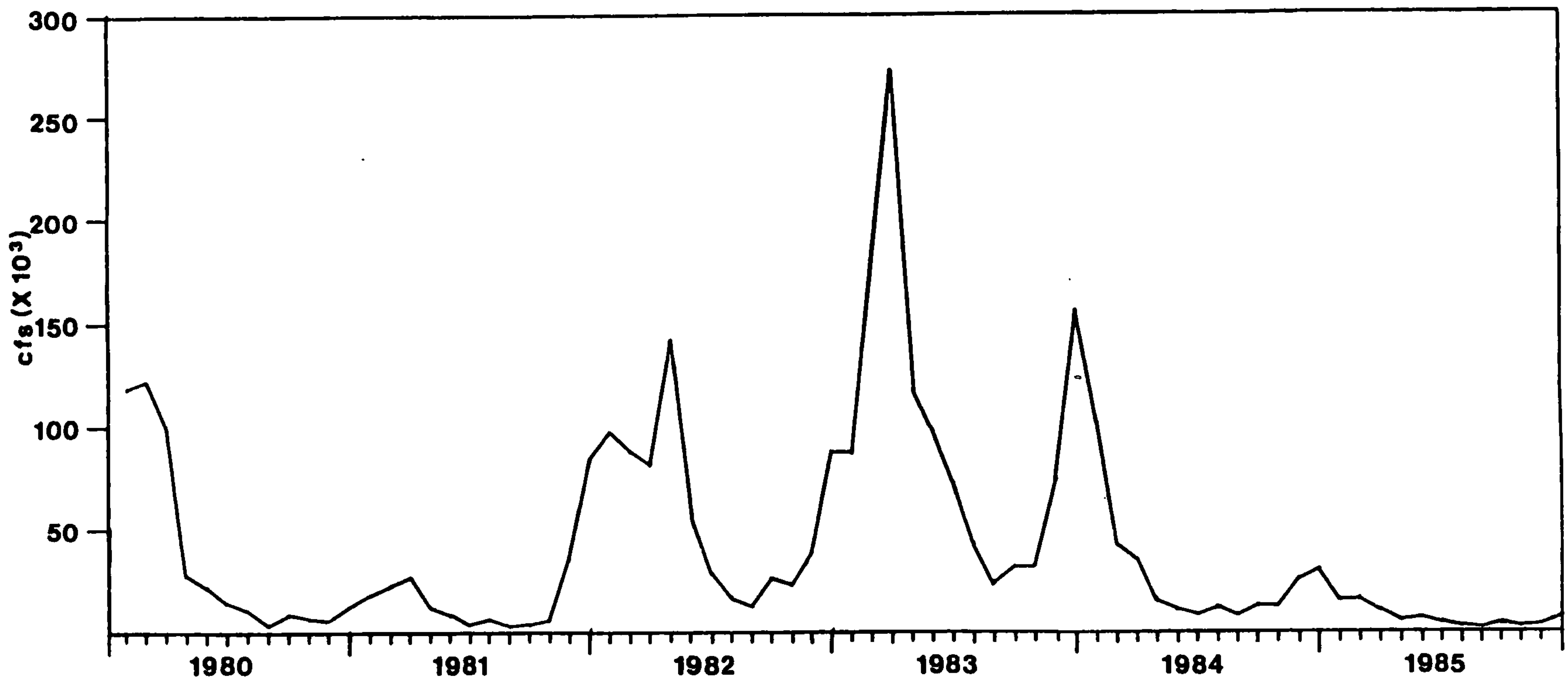


Figure 2. Average monthly outflow at Chipps Island, 1980-1985.



Each water year (October through September) is classified as to runoff by the California Department of Water Resources. Of the six years used in this study, 1980, 1982, 1983, and 1984 were wet years, and 1981 and 1985 were dry years (DWR Bulletins 120-80 through 120-85). Overall, 1984 was anomalous in that it was a wet year, but the amount of spring snowmelt was subnormal; hence, most of the runoff was during winter. El Niño conditions prevailed in 1982 and especially 1983; ocean waters were warmer than normal, and spring runoffs were high and occurred later than usual.

Estuarine Circulation

Tidal and nontidal currents affect circulation patterns in the estuary. Freshwater outflow and winds generate nontidal currents that are an order of magnitude less than tidal currents but are, nonetheless, important to the biology of the estuary (Conomos 1979). The northern reach of the bay is characterized by a gravitational circulation, driven by the longitudinal density (salinity) gradient, that consists of landward currents on the bottom and seaward currents at the surface. Thus, these currents are greatest in those areas of the estuary receiving the greatest amount of freshwater outflow. These currents will be referred to as residual or nontidal landward-flowing currents. As will be seen in the report, circulation patterns induced by winds, tides, and freshwater flow play a key role in distributing fish and invertebrates in the estuary.

Materials and Methods

Monthly samples were collected from 35 open water boat sites (Figure 3), 27 inshore seine sites (Figure 4), and 9 pier ringnet sites (Figure 5). Trawl samples from the open water sites started in January 1980, seine samples started in August 1980, and ringnet samples started in May 1982. To expedite results, analysis of adult fish, larval fish, adult shrimp, and adult crabs was confined to the period ending December 1985, and larval crustaceans to the period ending June 1984. Collections are still being made.

At each open water site a tow was made with a midwater trawl, an otter trawl, and an egg and larval net. The midwater trawl has a mouth opening of 3.6 m x 3.6 m and a 1.3 cm stretched mesh codend. It was towed and retrieved for 12 minutes in a manner that sampled all depths an equal amount of time. The otter trawl has 4.5 m head rope and the codend is 1.3 cm stretched mesh. It was towed for 5 minutes on the bottom and then retrieved at full speed. The egg and larval net is a 505 micrometer mesh plankton net with a mouth opening of 0.38 m^2. It is attached to a sled such that it is suspended 12 cm above bottom. It is towed on the bottom for 5 minutes and then retrieved at 9.1 meters/minute. The distance towed over the bottom was determined with a Loran C.

The volume of water sampled by the midwater trawl and otter trawl was determined by multiplying the mouth area by distance sampled. The distance through the water was obtained using a flowmeter suspended off the side of the boat. The volume of water sampled by the egg and larval net was determined by a similar manner except that the flowmeter was suspended in the mouth of the net. A temperature and electrical conductivity profile of the water column was taken at each sample site, except in 1980 when only surface temperature and electrical conductivity were measured.

Figure 3. Open water boat sample sites and study area sections.

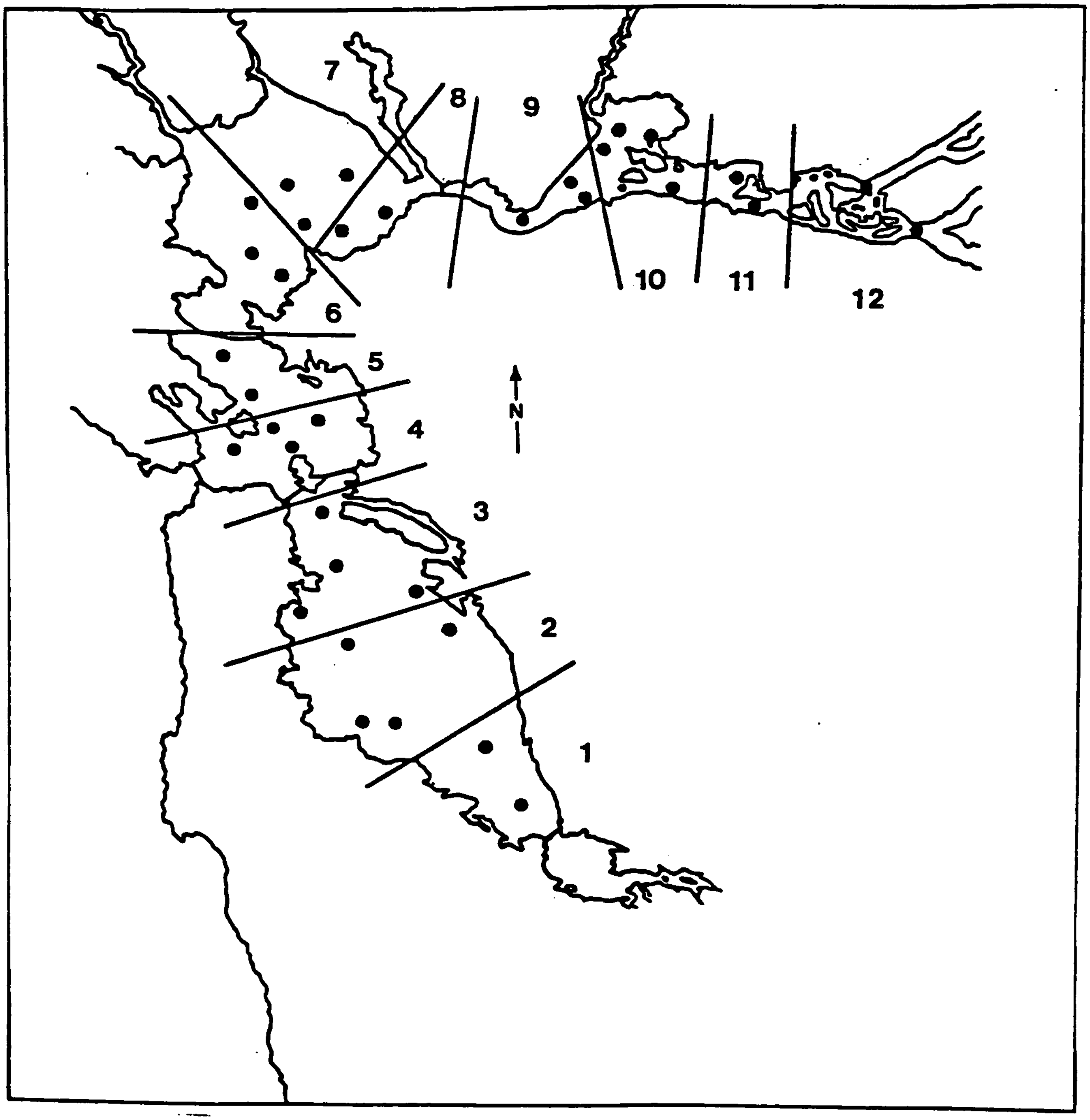


Figure 4. Inshore seine sample sites.

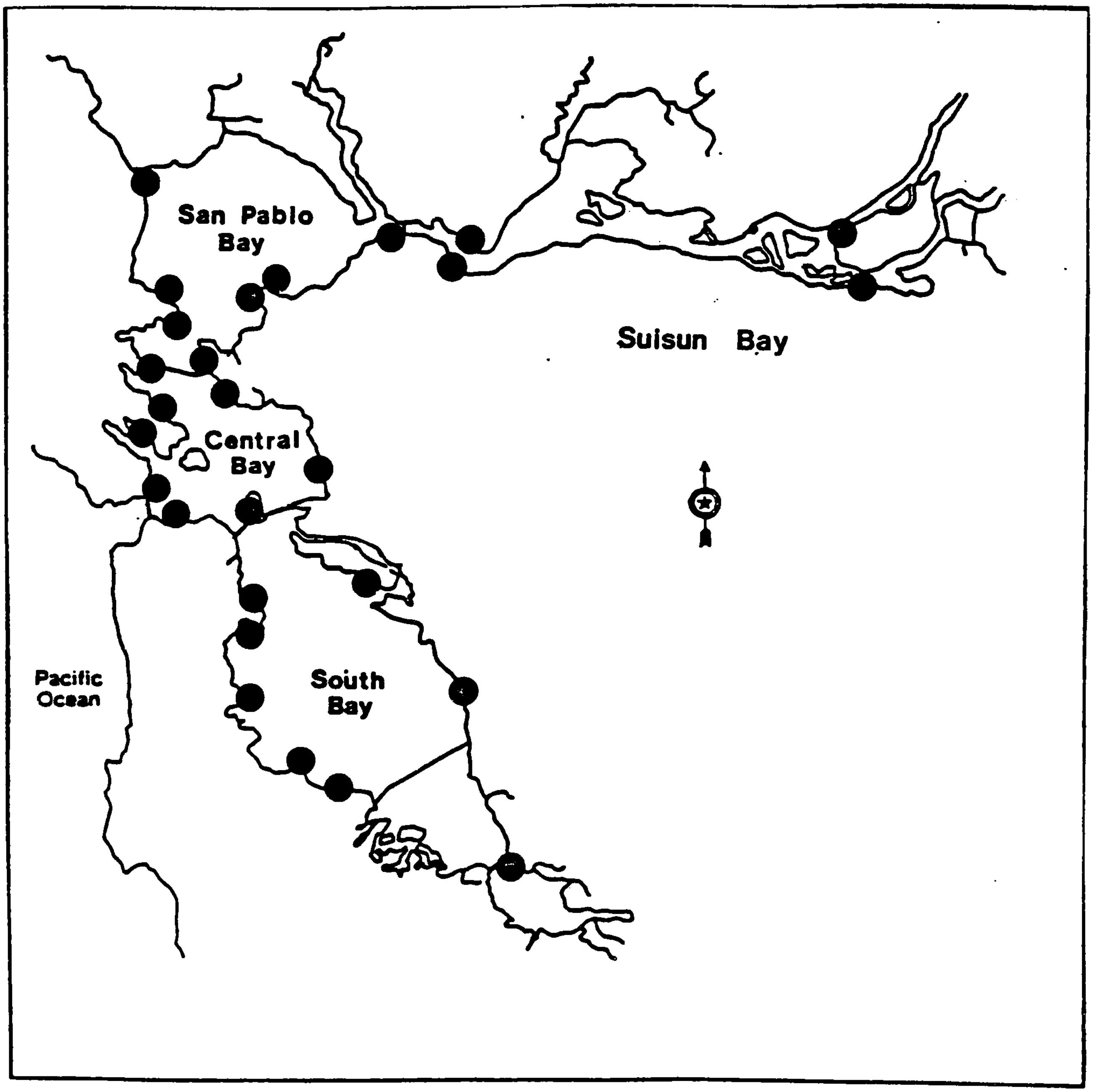
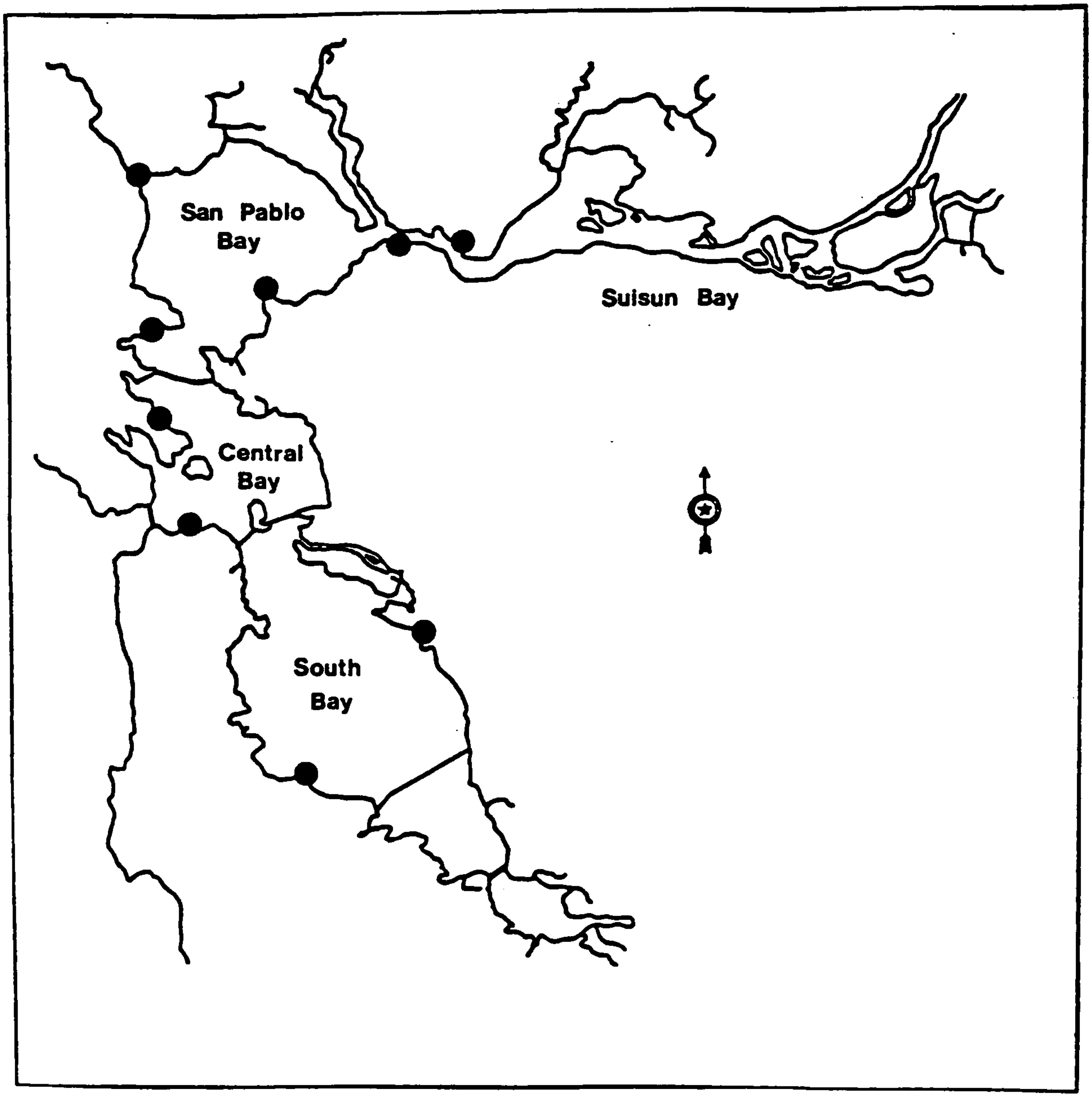


Figure 5. Pier ringnet sample sites.



At each inshore site, one or, if possible, two beach seine hauls were made with a 0.3 m delta mesh 15.2 x 1.2 m beach seine. All collections were made on flood tide. Surface temperature and electrical conductivity were measured and the area swept by the seine was recorded.

At each pier station, four 1-meter-diameter ringnets with 3.8 cm stretch mesh net were set for one 30-minute period. Each station was sampled as near as possible to slack tide. Temperature and electrical conductivity were measured at about 1 meter from the bottom.

Fish and crabs large enough to be easily identified were measured and released; others were taken to the laboratory for processing. Adult, juvenile, and larval fish, shrimp and crabs were identified to the lowest possible taxonomic level and were measured. Samples processed in the laboratory were subjected to a quality control check to determine if sample sorting and identification were acceptable. Data were recorded onto data sheets, proofed by two biologists, entered into a computer data base, proofed again, and edited. Electrical conductivities were converted into parts per thousand (ppt) salinity for use in several analyses. Figure 6 contains plots of temperature and salinity data for the study period.

The estimated volume and area of each sample site was determined from bathymetric maps and used in calculating the various indices. Catch-per-unit-effort (CPUE) was determined for each net to eliminate differing effort between collections. The otter trawl CPUE was based on the area swept by the net while it was on the bottom; CPUE for the midwater trawl and egg and larval net was based on volume of water filtered. In the beach seine, the volume of water filtered was used for pelagic species, and the area swept was used for demersal species.

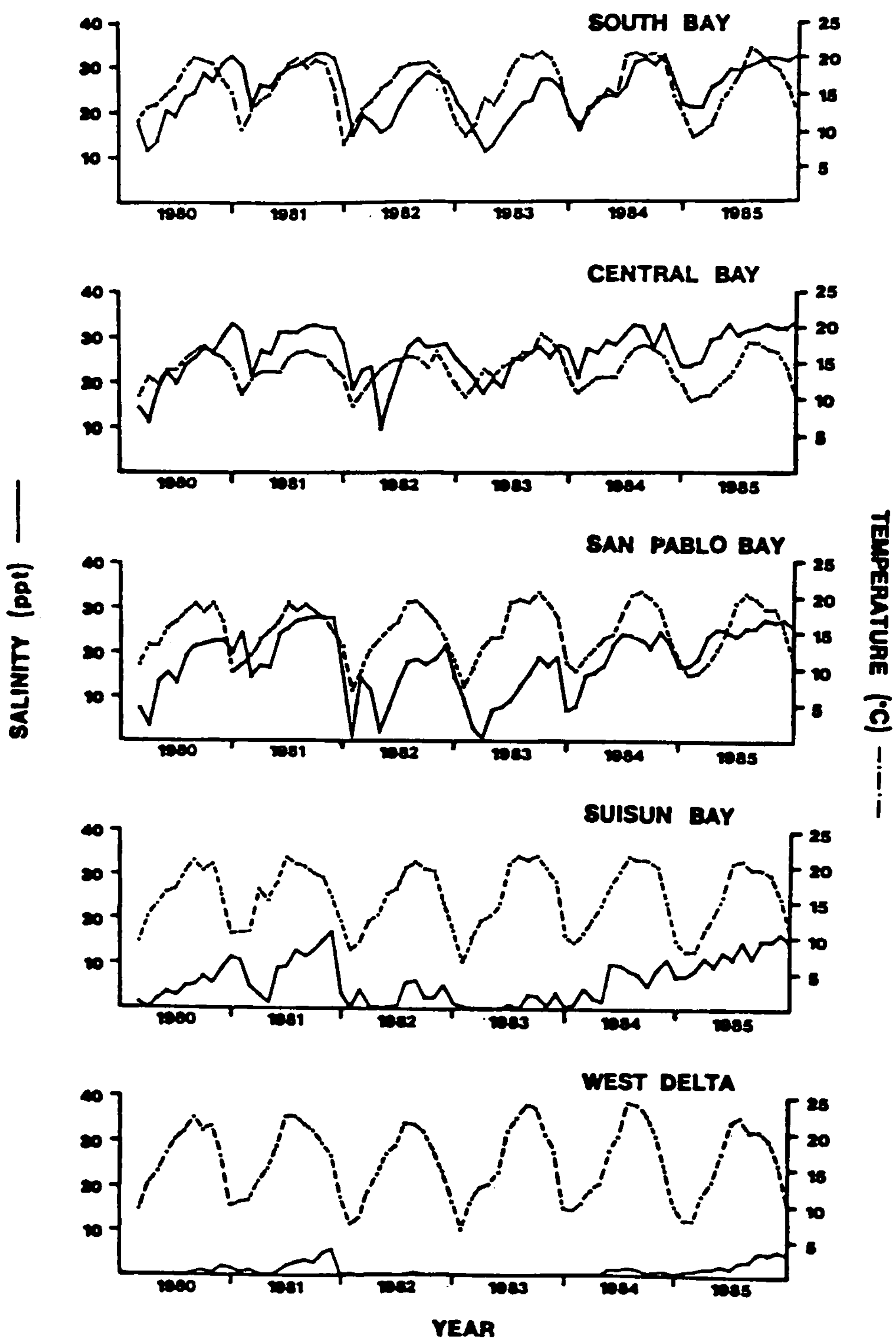


Figure 6. Salinity and Temperature Profiles

Mean bottom salinity (ppt) and temperature (°C) for each embayment at the time open water samples were collected. Only surface salinity and temperatures were measured in 1980.

Chapter 2. SELECTED INVERTEBRATES

Many invertebrate taxa were collected by the plankton net. Distribution and abundance of five of the taxa collected and analyzed are discussed in this chapter.

Euphausiids

Most euphausiids, also known as krill, are pelagic, and all are marine (Barnes, 1980). These shrimplike crustacea are an important food item for whales (Boden, Johnson, and Brinton, 1955), seals, penguins, other birds (Gross, 1977), and many plankton-feeding westcoast fishes such as: Pacific whiting (Merluccius productus) (Bailey, et al., 1982), "sardine" (Boden, Johnson, and Brinton, 1955), juvenile and adult salmon, and black rockfish (Sebastes melanops) (Brodeur, 1986).

The three species of euphausiids found during this study are associated with particular sectors of the current system of western North America (Brinton, 1981). Brinton grouped the species as follows (Figure 7): Nematoscelis difficilis, a northern species ranging from 35-40 degrees North; Thysanoëssa gregaria, an intermediate or subtropical species; and Nyctiphanes simplex, a nearshore species found off Baja California and Peru. The first two species are represented in the North Pacific Drift. The northern limit of Nyctiphanes simplex is usually Point Conception (north end of the Santa Barbara channel), but there have been excursions to the north (Brinton, 1959; Brinton, 1981) especially during the El Niño years of 1982 and 1983 (Brodeur, 1986).

Most euphausiids in the Bay were planktonic larval stages, although some juveniles were collected. Larvae in the plankton samples were broken into two subgroups: calyptopis and furcilia. The calyptopis subgroup usually has three stages; the furcilia has from five to seven stages, depending on the species (Knight, 1975; Boden, 1951). Larvae were not identified to species for lack of information and time to do so. Therefore, the calyptopis, furcilia, and juvenile stages were examined as a group. By speciating juveniles we were able to document in-Bay changes that reflected offshore patterns. Only data from 1980 through 1984 were available for analysis.

Euphausiid larvae are passive or weak swimmers. Therefore their distribution in the Bay indicates the extent that marine plankton can be distributed based only on physical processes (circulation patterns, wind stress, etc.). In this study, we attempted to document any connection between outflow and the abundance and distribution of these animals in the Bay.

Peaks in euphausiid abundance in the Bay occurred at different times from 1980 to 1984 (Figure 8). Generally, euphausiid larvae were present from January through May. Highest yearly abundance in the Bay was in 1983 (Figure 9). In 1983, euphausiids were also abundant in the Bay throughout the summer.

There was a significant correlation ($r=0.835$, $p<.05$) between yearly abundance indices of euphausiid in the Bay (Table 1) and yearly outflow (based on estimated flow past Chipps Island by DWR) (Figure 10).

A significant increase in juvenile abundance of Nyctiphanes simplex in 1983 corresponds to a similar increase

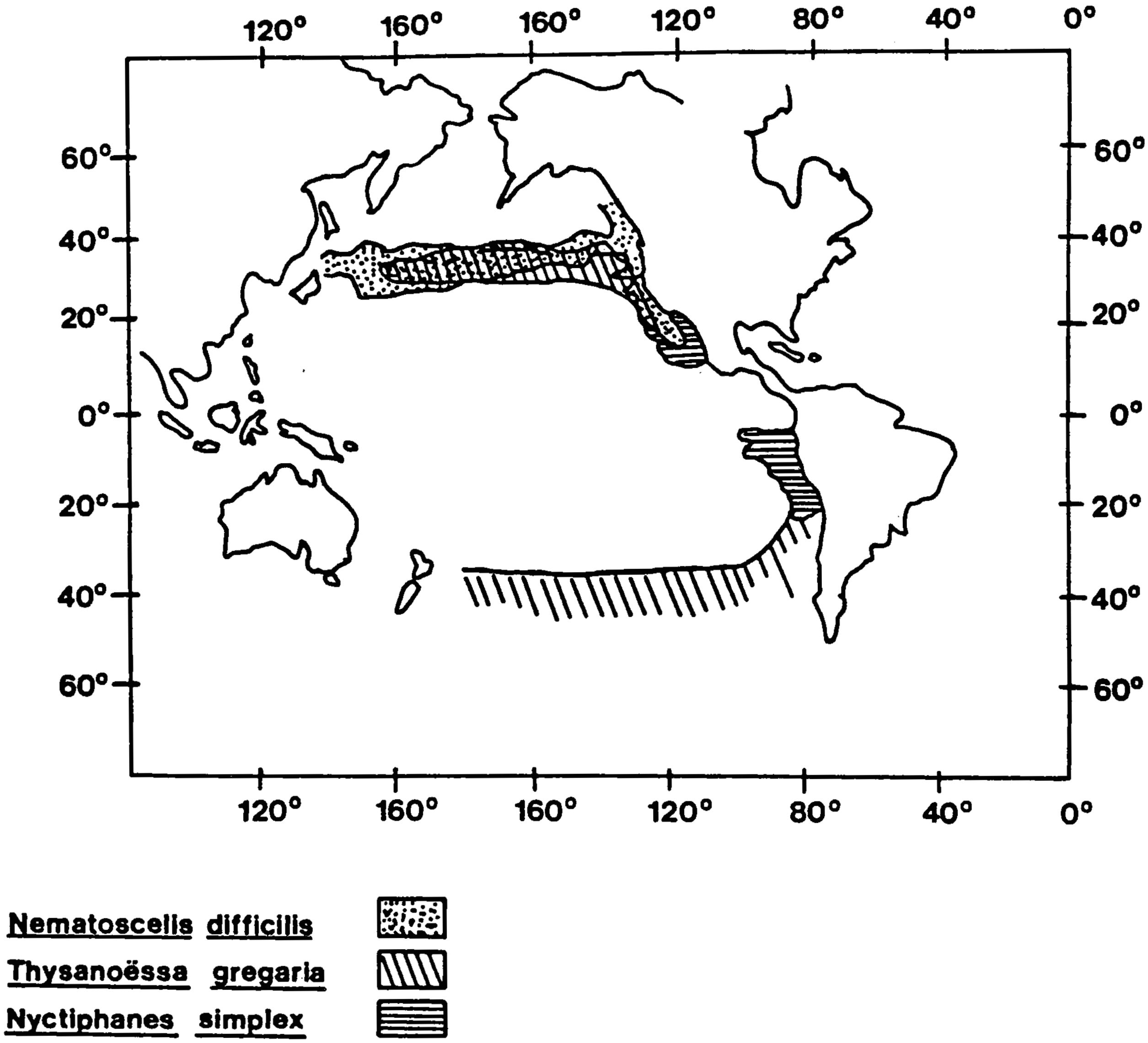


Figure 7. Pacific distributions of euphausiid species collected in San Francisco Bay, 1980 - 1984 (modified from Mauchline and Fisher, 1969).

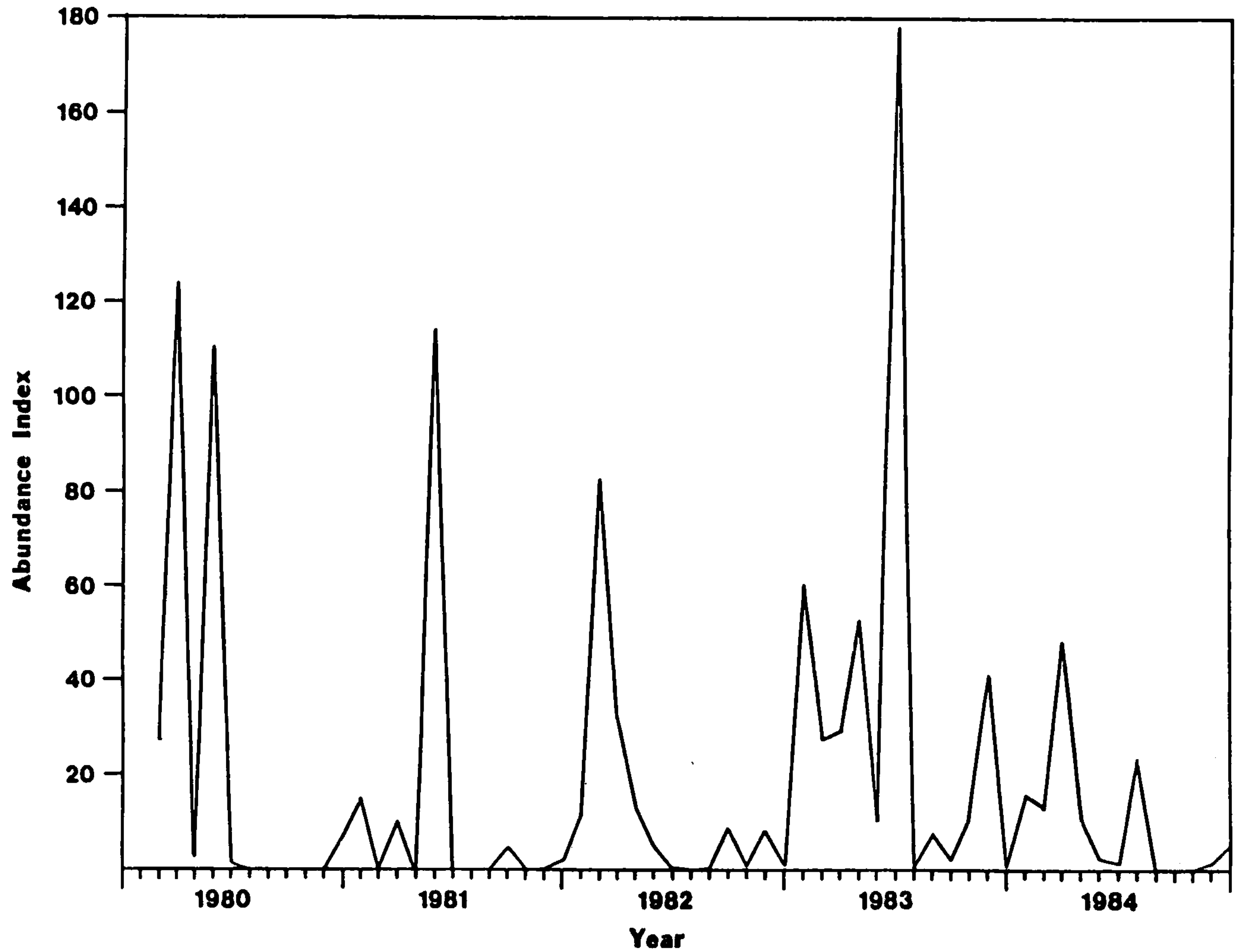


Figure 8. Monthly abundance indices of Euphausiids (calyptopis, furcilia, and juvenile stages combined), 1980 - 1984.

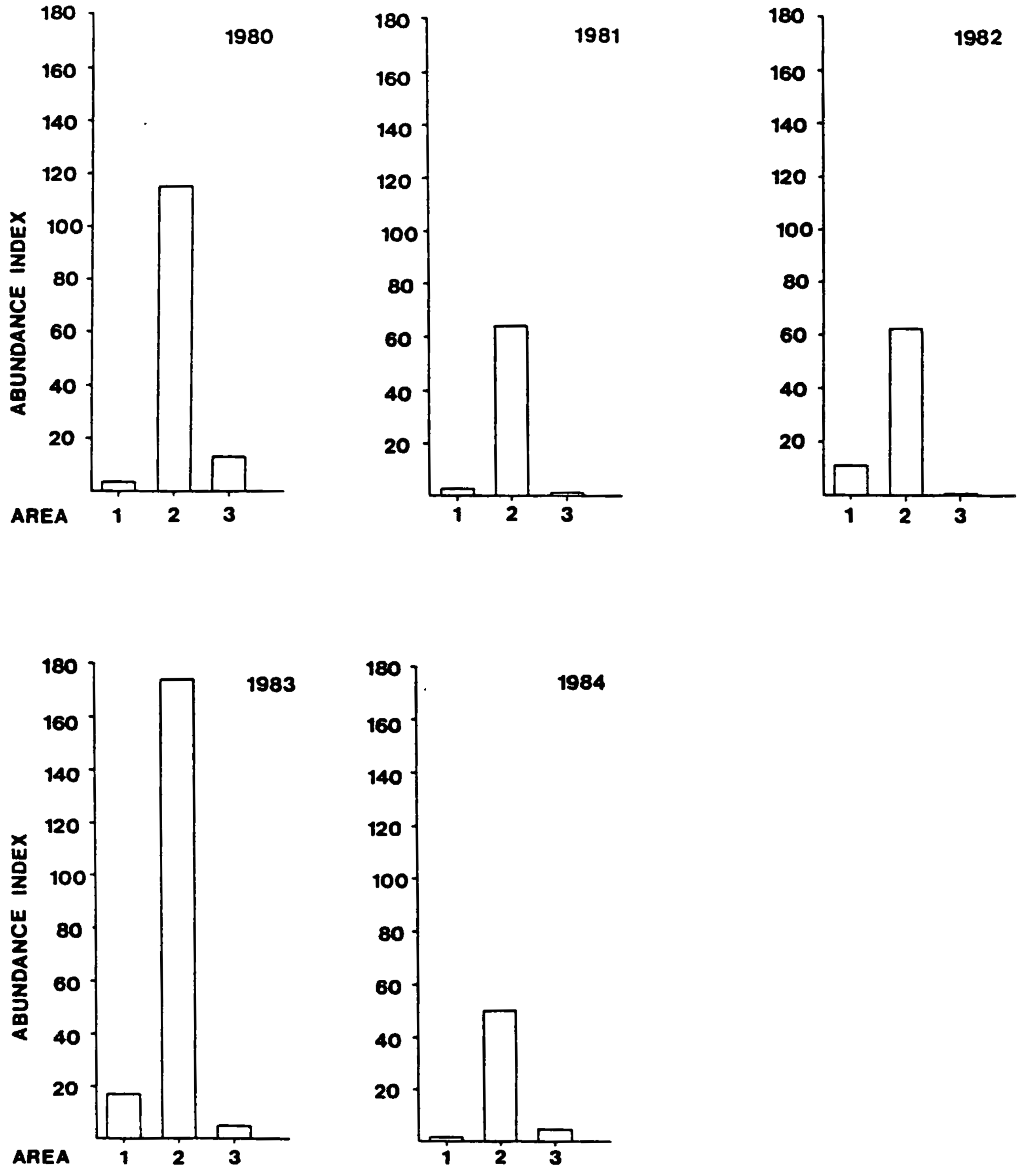


Figure 9. Euphausiid abundance indices (combined larval and juvenile stages), 1980 - 1984. Area 1 = South Bay, 2 = Central Bay, 3 = San Pablo Bay plus the Carquinez Strait sampling site.

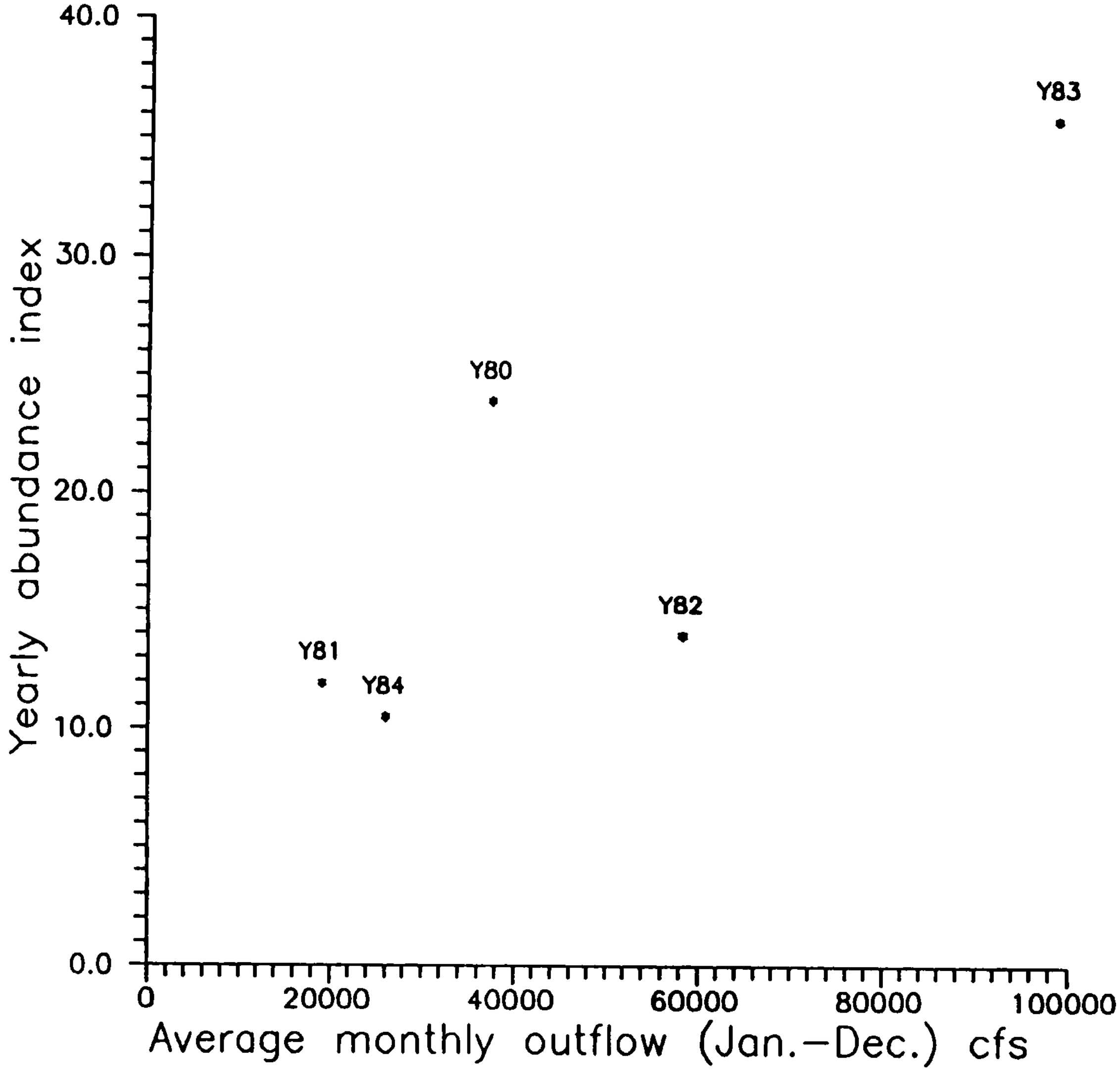


Figure 10. Annual abundance index of euphausiids (all stages combined) vs. outflow (January - December) (r = 0.835).

in this species offshore (Bordeur, 1986). Brodeur (1986) was the first to note the presence of Nyctiphanes simplex in Oregon and Washington waters. The extension of its normal range was due to the extreme El Niño condition of 1983.

Euphausiids usually occurred no farther south than mid-South Bay, but occasionally they were found at the southernmost sampling site. In January 1980 and June 1983, euphausiids were found at Carquinez Strait, their northern limit. In San Pablo Bay they were most common at the channel station, suggesting they were present in the inflowing marine layer at the bottom of the channel. The majority of the population was usually found in Central Bay (Figure 11).

Of the sampling sites in Central Bay, euphausiids were found less frequently off Berkeley and when there, they were less abundant. In 1981 no euphausiids were found at the Treasure Island sampling site, and they occurred only once off Berkeley. This suggests that in low flow years the incoming marine waters from the Golden Gate do not mix well with the eastern, shallow areas of Central Bay.

Table 1

YEARLY ABUNDANCE INDICES FOR EUPHAUSIIDS

	Larval Stage			
Year	**Calyptopis**	**Furcilia**	**Unidentifiable Juveniles**	**Combined Stages**
80	3.37	20.51	0.01	23.89
81	9.47	2.45	0.02	11.94
82	6.41	7.55	0.02	13.97
83	12.77	20.59	2.44	35.79
84	1.16	8.44	0.91	10.51

Juveniles

Year	**Nematoscelis difficilis**	**Nyctiphanes simplex**	**Thysanoëssa gregaria**	**Combined**
80	0.014	0.003	0	0.017
81	0.035	0.004	0.004	0.043
82	0.010	0	0.010	0.020
83	0.040	0.270	0.032	0.341
84	0.078	0	0.093	0.171

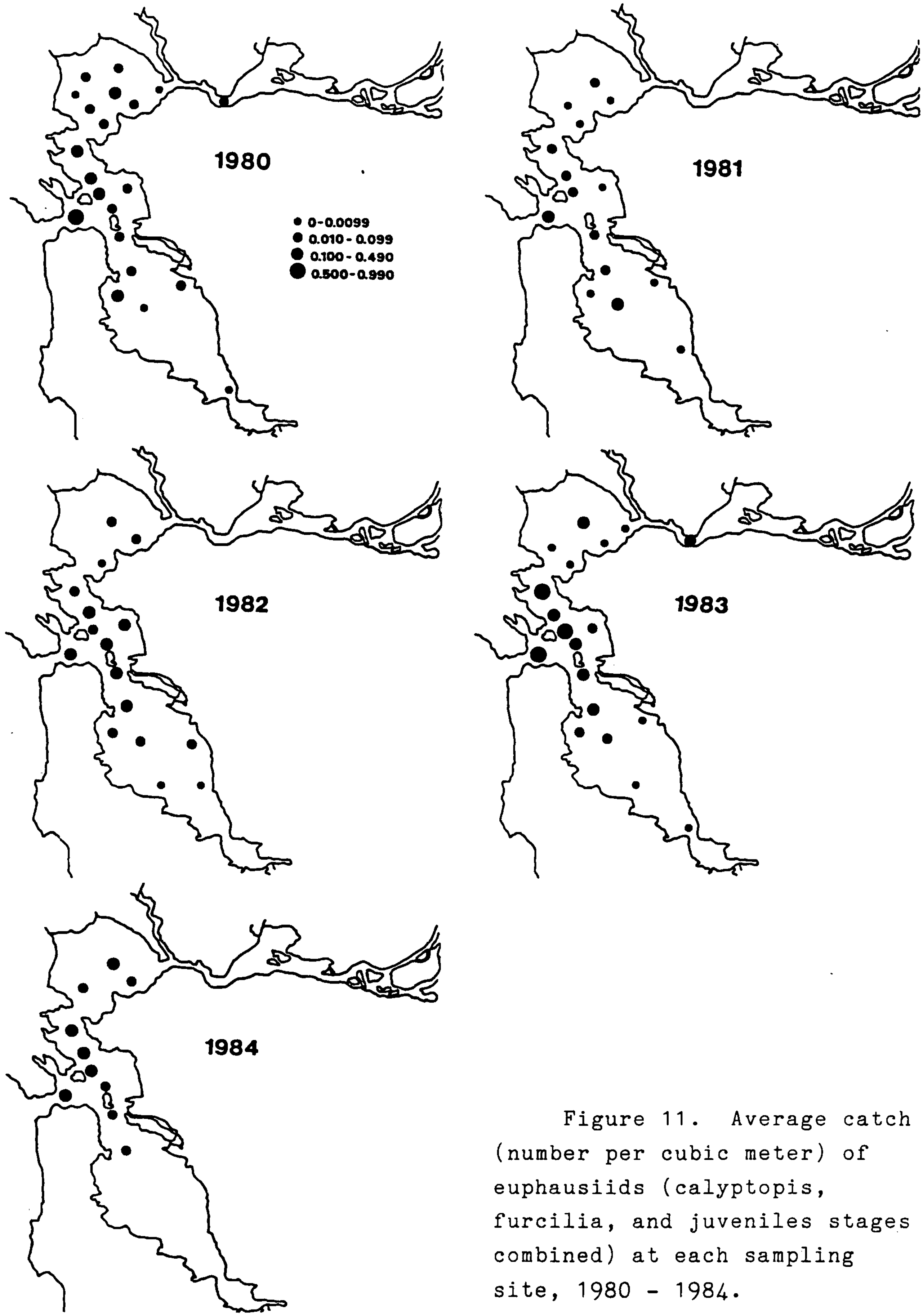


Figure 11. Average catch (number per cubic meter) of euphausiids (calyptopis, furcilia, and juveniles stages combined) at each sampling site, 1980 - 1984.

Summary

The distribution and abundance of euphausiid larvae did not increase in the Bay during the dry year 1981. Analysis of the five years of data showed that circulation of passive marine plankton into the Bay is not increased in dry years.

The higher abundance of N. simplex in the Bay during 1983 reflected offshore changes in species composition due to El Niño.

Yearly abundance and yearly outflow were positively correlated. Greater numbers of euphausiid larvae may be a result of greater outflow causing a higher rate of exchange through the Golden Gate. The positive correlation may be a result of El Niño effects instead of outflow.

Callianassa californiensis

Callianassa californiensis, the ghost shrimp, is the predominant species of Callianassa found in San Francisco Bay. It is a burrowing crustacean present in intertidal and subtidal sandy areas of bays and estuaries that have a predominantly marine influence (Johnson, 1980). C. californiensis is found in estuaries from Alaska to Baja California (Johnson, 1980). It is used as bait for surf fish, especially spotfin croaker (Roncador stearnsii) and diamond turbot (Hysopsetta guttulata) (Turner and Sexsmith, 1975). An average of 2,700 kg is taken yearly as bait in the San Diego and Los Angeles areas (Morris, Abbott, and Haderlie, 1980).

Adults attain a size of 5 to 8 cm, and are estimated to live 15 to 16 years (Turner and Sexsmith, 1975). C. californiensis has a larval period that lasts 6 to 8 weeks; they pass through five planktonic larval stages during this time (Johnson, 1980). According to Turner and Sexsmith (1975), breeding occurs year-round, but June and July are the optimum months.

Few adults were collected because of their burrowing habits, but larvae were abundant in our plankton samples. Larvae were found in the Bay mostly from January through August (Figure 12). They were present in low numbers through the rest of the year. The larval abundance tended to be bimodal.

Larvae had a wide distribution in the Bay, from the southernmost sampling site in South Bay to San Pablo Bay. Occasionally they were found in Suisun and Grizzly bays (February and November 1980, July 1981, August 1983, and May 1984). The highest densities of larvae were found at sampling sites in Central Bay (Figure 13). This corresponds to adult presence in the more marine areas of the Bay.

The yearly larval abundance in the Bay and yearly outflow had a significant negative correlation ($r=-0.899$; $p<0.05$) (Figure 14). Early stage larvae constituted the majority of larvae caught in the plankton net. This suggests that outflow had a major effect on abundance by carrying larvae out of the system.

Work by Johnson (1980) in the Salmon River estuary in Oregon found that early stage C. californiensis larvae were concentrated in surface waters and thus were easily flushed out of the estuary by tidal action. Johnson also found that the megalops stage (late larval-presettlement stage) entered the estuary in bottom flows on the flood tide. He suggested that these metamorphosed and settled before being swept out on the next tide.

Preliminary analysis of another data set (not yet fully worked up) suggested that older stage larvae were present only in deeper areas of the water column. Very few intermediate stages were found in either data set. This

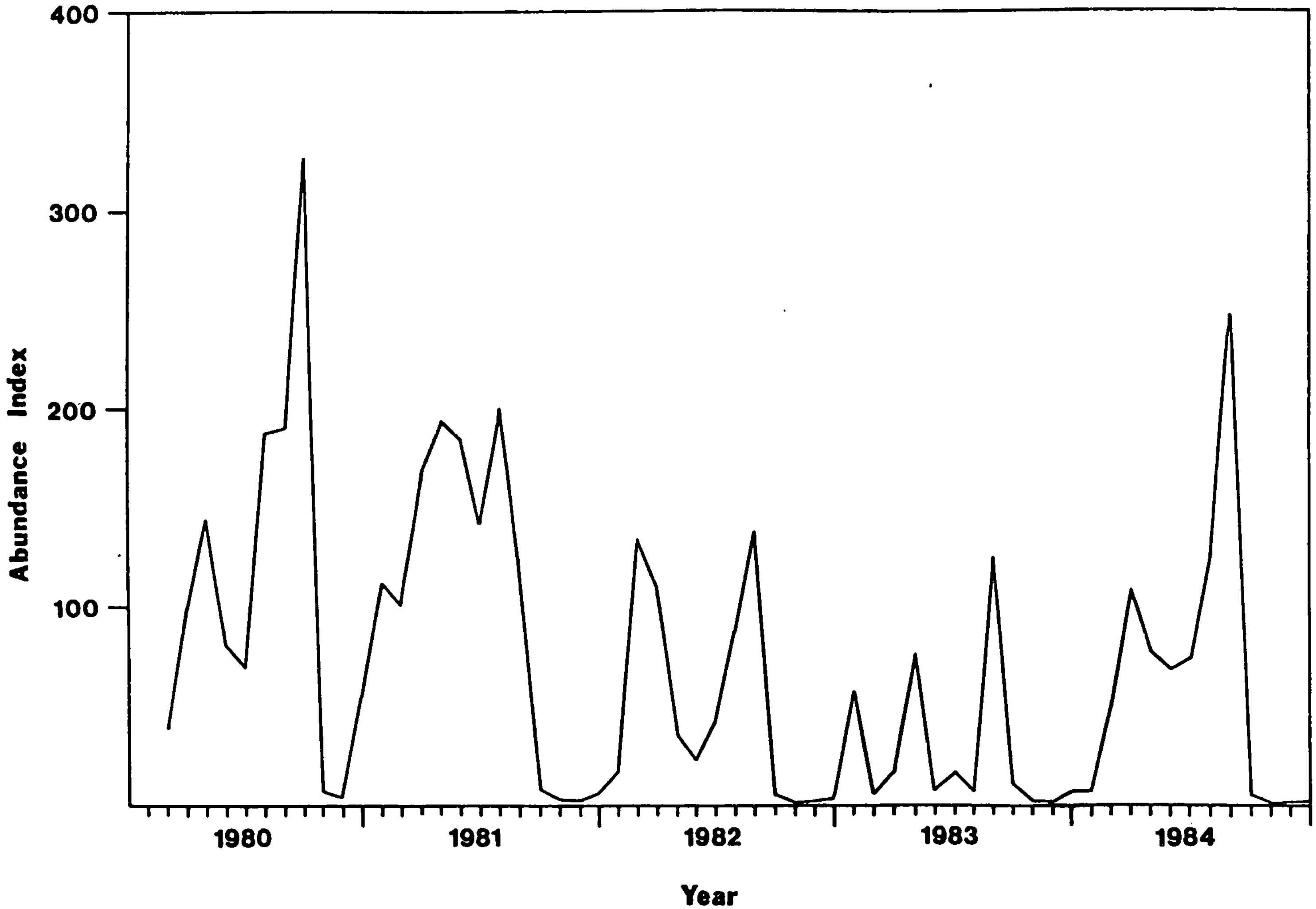


Figure 12. Monthly abundance indices of *Callianassa californiensis* larvae (combined larval stages), 1980 - 1984.

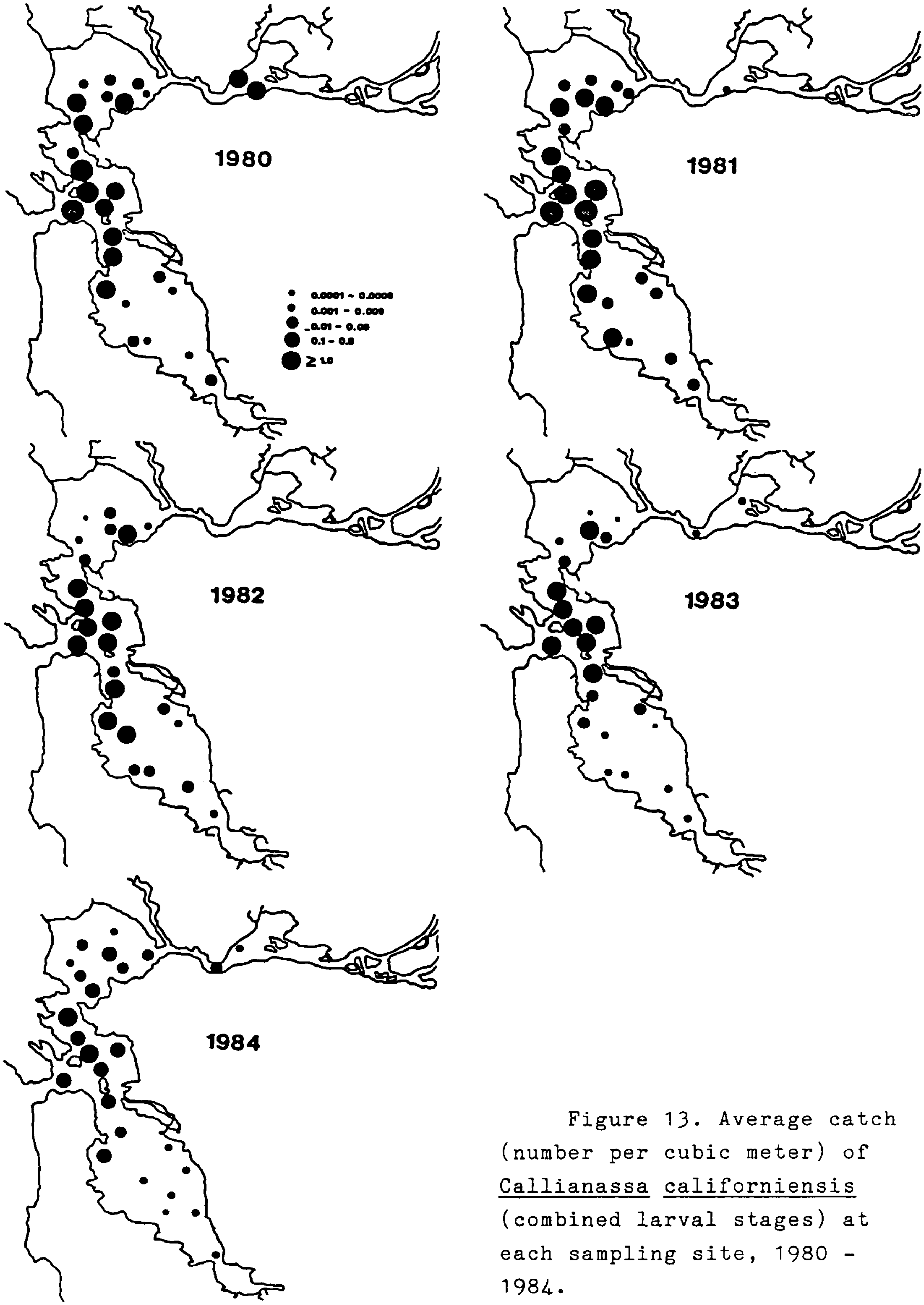


Figure 13. Average catch (number per cubic meter) of Callianassa californiensis (combined larval stages) at each sampling site, 1980 - 1984.

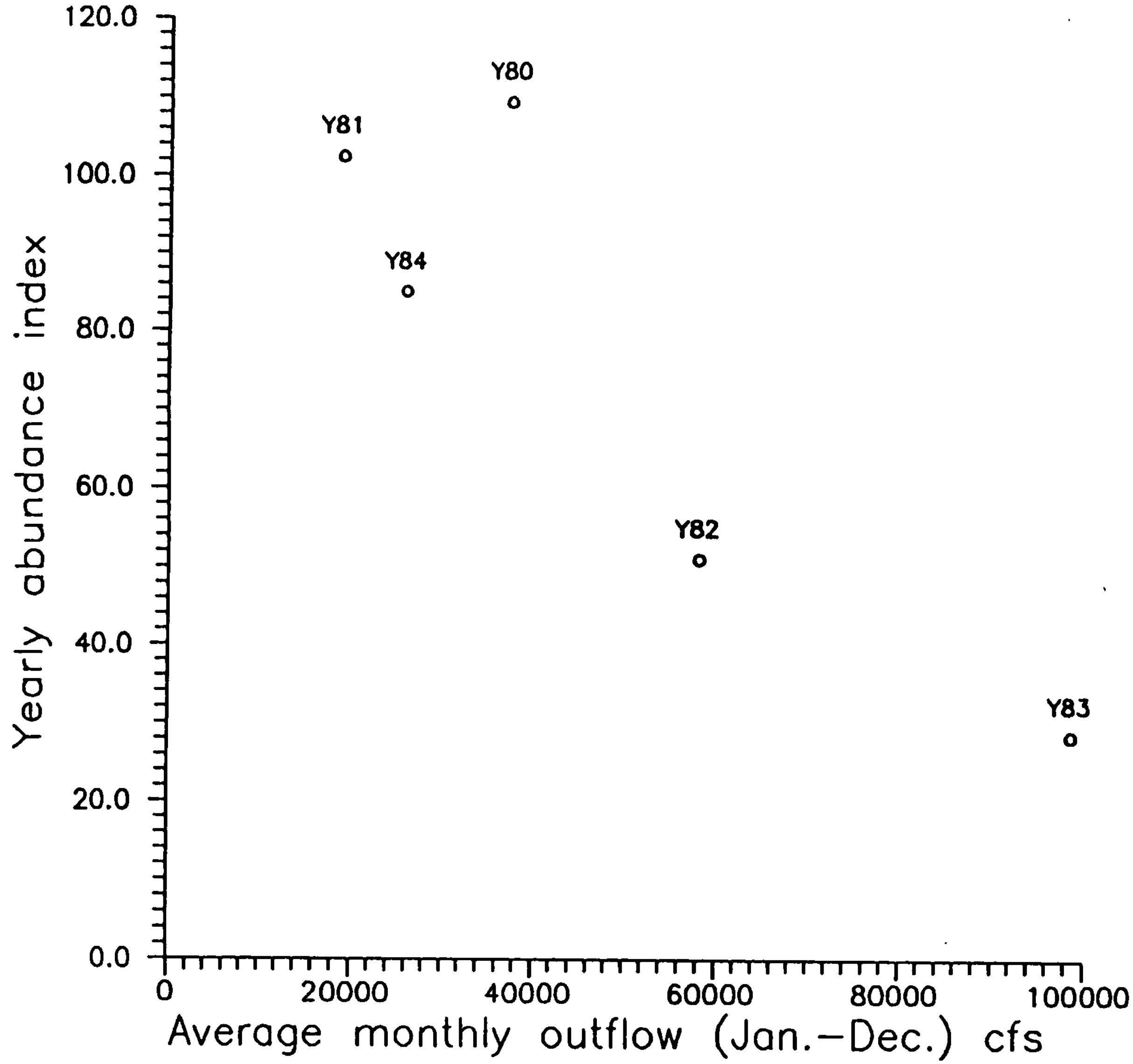


Figure 14. Annual (January - December) abundance indices of <u>Callianassa californiensis</u> larave (combined larval stages) vs. annual (January - December) outflow ($r = -0.899$, $p<0.05$).

suggests that older larvae return to the Bay in bottom flows. Therefore, behavior of C. californiensis larvae in the Bay is similar to that described for the Salmon River estuary (Johnson, 1980).

The pattern of emigration of early stage larvae and immigration of late stages is not uncommon to estuarine species. The oyster, Crassostrea virginica (Boicourt, 1982); the blue crabs, Callinectes sapidus (Boicourt, 1982; Epifanio and Dittel, 1982; Sandifer, 1975; Sulkin and Van Heukelem, 1982), Callinectes arcuatus (Epifanio and Dittel, 1982); the caridean shrimp, Crangon septemspinosa (Sandifer, 1975), Ovalipes ocellatus (Sandifer, 1975); and the brachyuran crab, Cancer irroratus (Sandifer, 1975), all have larval migrational patterns similar to that suggested for Callianassa californiensis (Johnson, 1980). This pattern has also been suggested for Crangon franciscorum (Hatfield, 1985).

Retention of larvae within the parent estuary has been thought to be beneficial to the population. The limited dispersal "allows exploitation of newly available habitat while retention of the majority of the larvae assures continuity of the species in the estuary" (Epifanio and Dittel, 1982). Yet it is apparent that estuary retention of larvae is not needed by all species. This is true for species that inhabit the lower estuary and coastal shelf (Epifanio and Dittel, 1982; Sandifer, 1975). Various theories for larval emigration from an estuary have been proposed (lower predation, higher food availability, slower evolutionary advancement to a true estuarine species), but none has been substantiated (Sandifer, 1975; Strathman, 1982).

The negative correlation between C. californiensis larvae and outflow suggests that outflow is useful, and perhaps a necessary aid, in emigration of early stage larvae.

Summary

Callianassa californiensis larvae were present in the Bay year-round but were most abundant from January through August. Larvae were widely distributed in the Bay, but the highest catches were in Central Bay.

A negative correlation was found between abundance of C. californiensis larvae and outflow. Outflow would appear to help move ghost shrimp larvae from the Bay.

Rhithropanopeus harrisii

R. harrisii is known as the "mud crab" on the east coast of North America and has been called "brackish-water crab" (Morris, Abbott, and Haderlie, 1980) on the west coast. On the Atlantic seaboard, they are found from Mirimichi estuary, Canada, to Lake Maricibo, Venezuela (introduced) (Costlow and Bookhout, 1971). R. harrisii were first reported in San Francisco Bay in 1940 (Jones in Morris Abbott, and Haderlie, 1980). They are now abundant in the sloughs of northern San Francisco Bay and can be found in the Delta up to Stockton (Ricketts, Calvin, and Hedgpeth, 1985). R. harrisii is a member of the pea crab family, Xanthidae. As the family name suggests, the adults are small in size, 19.1 mm for males, 10.6 mm for females (Morris, Abbott, and Haderlie, 1980).

Adult crabs can live quite well in fresh water, but they must return to salt water to breed (Barnes, 1980). Chamberlain (1962) found that most of the breeding population in Lake Ogleton, Maryland, were one year old; few were older.

R. harrisii proceeds through four larval stages (Chamberlain, 1962), all of which were found in the plankton net samples of this study. Duration of the larval period at 15 degrees C was 20 to

24 days (Chamberlain, 1962). Larvae undergo vertical migration to maintain their position in the upper estuary (Cronin, 1982).

In the Bay, R. harrisii larvae usually appeared in May, and by October few were found (Figure 15). Larvae were first found in San Pablo Bay, and peak abundance was usually in July in the Suisun-Grizzly Bay area. There was a negative correlation between yearly larval abundance and May-October outflow (p=-0.650) (Figure 16).

Summer outflow directly affected distribution of R. harrisii larvae. Higher densities were found at the upriver sites in 1981 (dry) (Figure 17). In 1983 (wet), distribution was farther downstream, ranging between San Pablo and Grizzly bays.

Total 1981 larval population abundance has probably been underestimated. The increase of densities found at upriver sites during 1981 implied that the distribution ranged outside the study area.

The period of time R. harrisii larvae were present in the Bay was similar to that found in Lake Ogleton, Maryland (Chamberlain, 1962), late May to early September.

Chamberlain (1962) found that optimum larval development conditions were a salinity range of 6 to 10 ppt at a temperature of 15 degrees C. In this study, larvae were found at an average bottom temperature range of 14.7 to 22.0 degrees C. Although larvae were found at a wide range of average bottom salinities, 0.7 to 27.6 ppt, they were most abundant at an average bottom salinity range of 2.3 to 23.0 ppt.

Summary

Larvae were present May through October in San Pablo, Suisun, and Grizzly bays. Larvae began to appear when average bottom temperatures reached 14.7 degrees C. Larvae were found where salinity and temperature were close to optimum development conditions.

Summer outflow directly affected distribution of larvae and negatively affected abundance.

Emerita analoga

Emerita analoga is also known as the sand crab (Cox and Dudley, 1968). In North America it is found on surf-exposed sandy beaches from Alaska to Baja, California (Perry, 1980). Adult E. analoga were occasionally collected in beach seine samples by this study from exposed beaches in the Bay near the Golden Gate area. Adult numbers in the Bay are unknown but are believed to be very low. Larvae found in the Bay are presumed to be from coastal waters.

Adults in the surf zone are the preferred food item for barred surfperch (Amphistichus argenteus), California corbina (Menticirrhus undulatus), and young black croaker (Cheilotrema saturnum). They are also eaten by many shore birds (e.g. semipalmated plover, snowy plover, western sandpiper, and sanderling) (Burton, 1979; Morris, Abbott, and Haderlie, 1980). In Southern California, an estimated 4,100 kg was taken for bait in 1967 (Morris, Abbott, and Haderlie, 1980).

A Southern California study found ovigerous (egg-bearing) females from February through September (Cox and Dudley, 1968). Burton (1979) collected ovigerous females in mid-June through late August in Monterey, California. Cox and Dudley (1968) noted that females in the laboratory carried eggs for a mean of 22.5 days. Boolootian, et al. (1959, in Dillery and Knapp, 1970) reported a period of 29 to 32 days for egg carrying (presumably in natural environment). Larvae have a 4-month planktonic life (Burton, 1979).

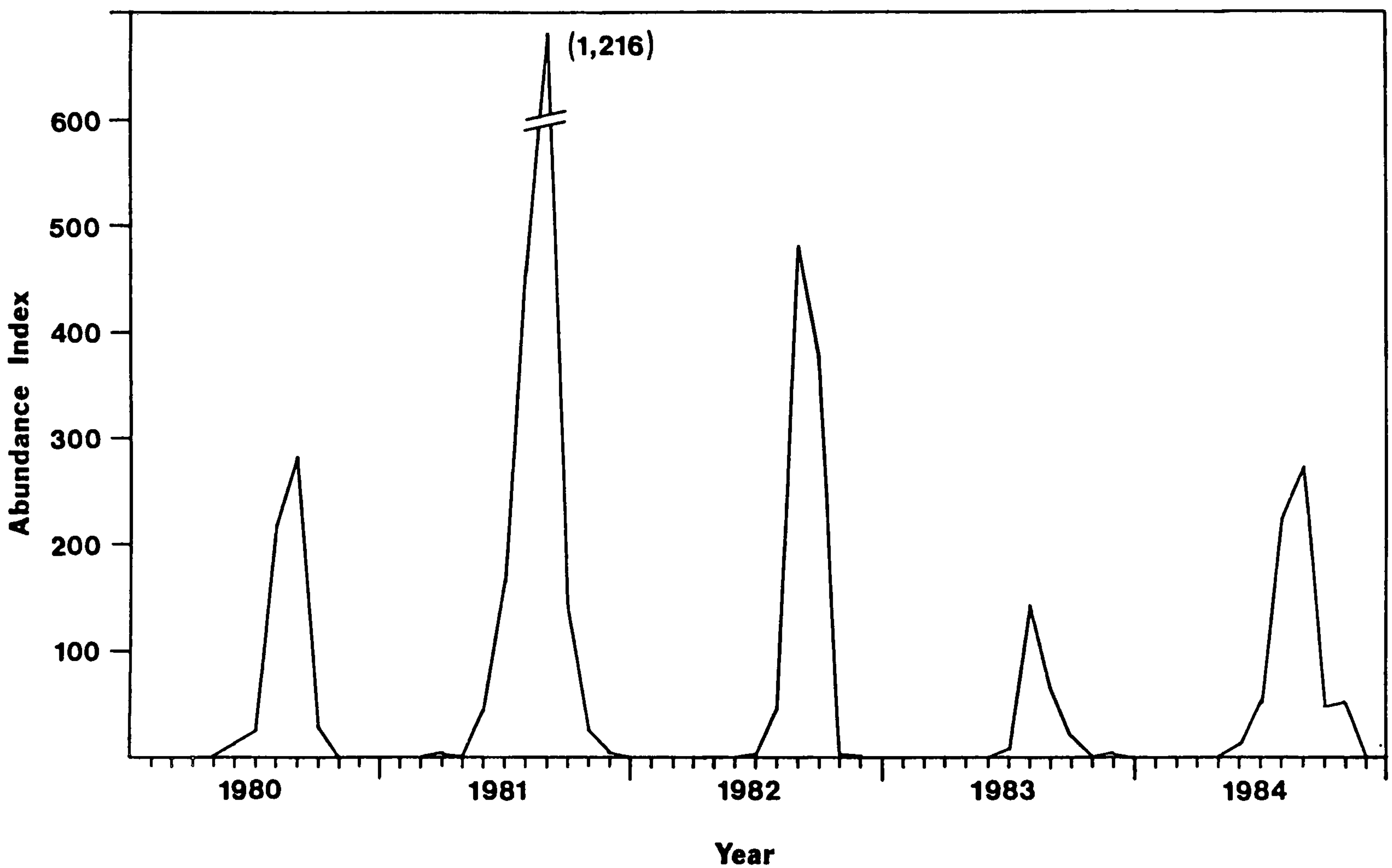


Figure 15. Monthly abundance indices of <u>Rhithropanopeus harrisii</u> larvae (combined larval stages), 1980 - 1984.

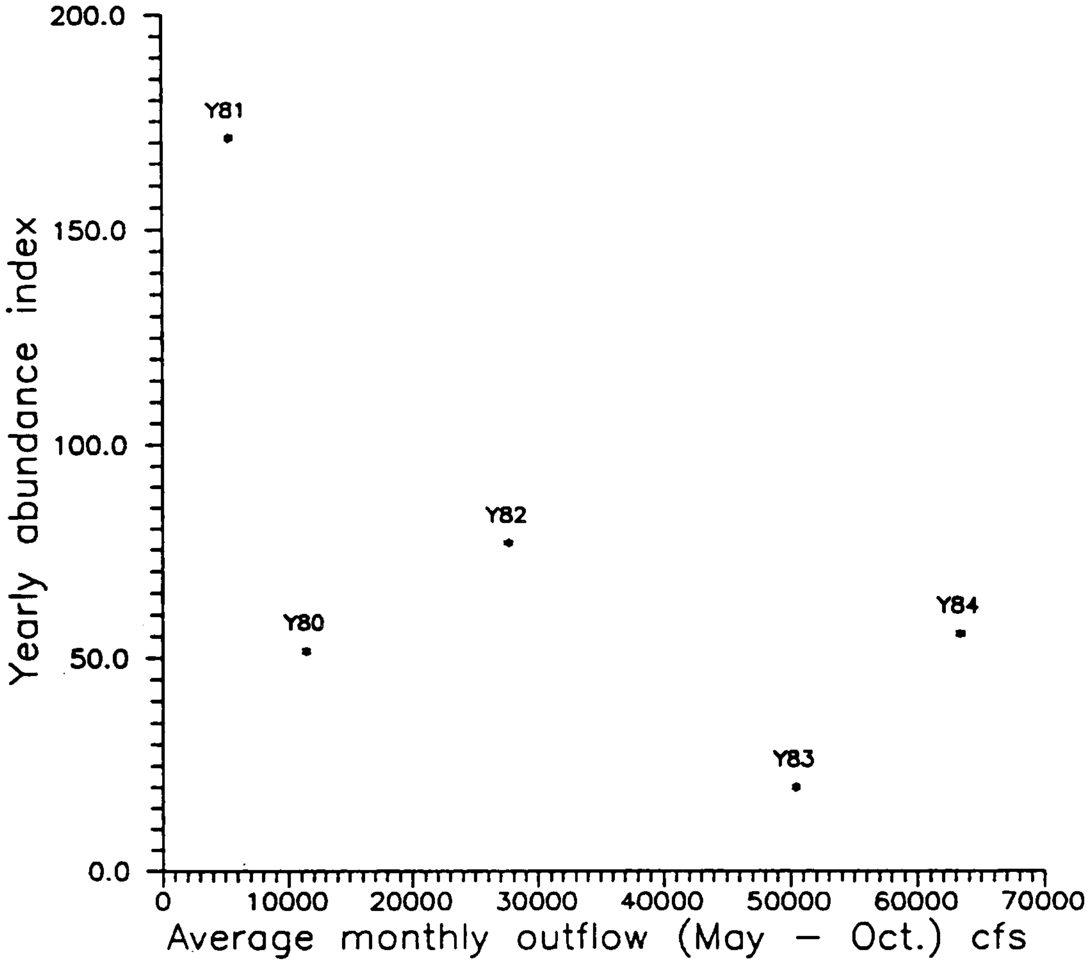
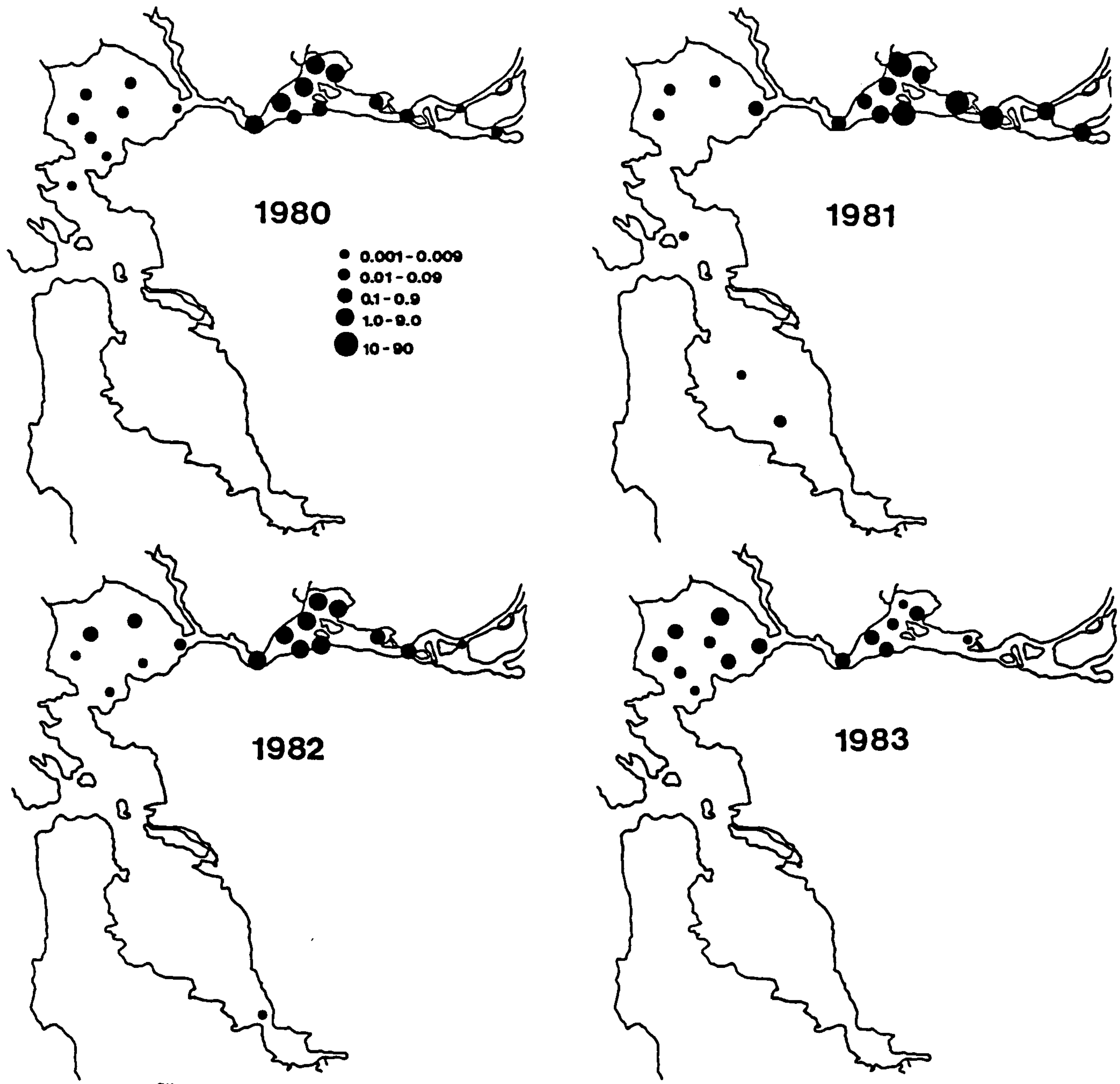


Figure 16. Annual abundance indices of Rhithropanopeus harrisii larvae (combined larval stages) vs. outflow (May - October) (r = -0.650).



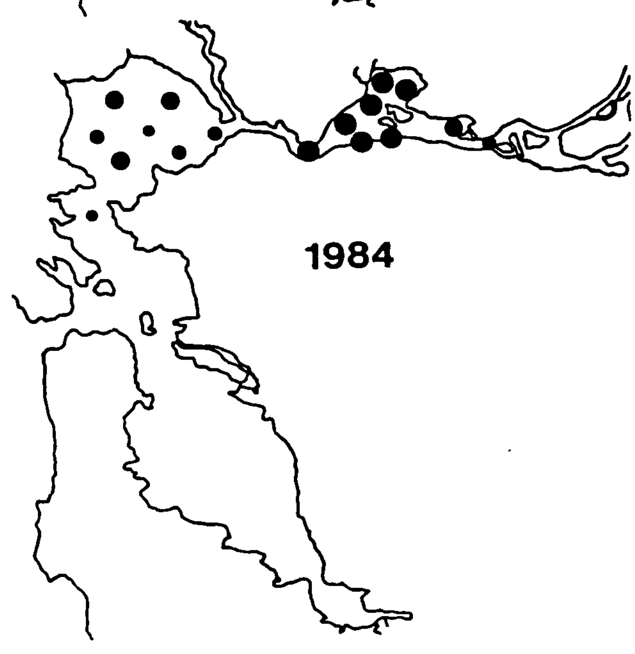


Figure 17. Average catch (number per cubic meter) of <u>Rhithropanopeus harrisii</u> larvae (combined larval stages) at each sampling site, 1980 - 1984.

Emerita analoga larvae were found in the Bay from about July to November (Figure 18). Most were found in Central Bay, but rarely and only in low numbers at the Berkeley and Angel Island sampling sites. They were found only as far south as mid-South Bay. The upstream limit was at Carquinez Strait (November 1981). Larvae were rarely found in San Pablo Bay (Figure 19).

Distribution of E. analoga larvae is similar to the winter distribution of euphausiid larvae. This is notable in that Emerita larvae are found in summer. E. analoga larvae were not found in high numbers at the sampling sites on the eastern side of Central Bay, indicating a low mixing rate with inflow from the Golden Gate.

A negative correlation was found between summer (July-September) outflow and E. analoga abundance (r=-0.576) (Figure 20).

A positive correlation was found between upwelling indices (July-September) and E. analoga abundance (r=0.579) (Figure 21). (See section on Cancer magister for explanation of upwelling, Chapter 4.) Neither correlation was strong, indicating that other factors influence the summer abundance of E. analoga larvae in the Bay.

Summary

Emerita analoga larvae were found in the Bay from July through November. Most were collected in Central Bay. Distribution of Emerita larvae suggests a low mixing rate between Golden Gate inflow and eastern Central Bay during the summer. Abundance of larvae in the Bay was not affected by outflow or offshore upwelling.

Sagitta euneritica

Sagitta euneritica is a Chaetognath, known as arrow-worms. Chaetognaths are an important predator on copepods (Barnes, 1980; Sameoto, 1971). We found that larvae of fish and shrimp were also part of S. euneritica's diet. Sameoto (1971) found Sagitta elegans to be the most important invertebrate predator in terms of numbers and biomass at all times of year in St. Margaret's Bay, Nova Scotia. Chaetognaths are also an important food item for herring in the North Sea (Gross, 1977).

Sagitta euneritica were found in the Bay in high numbers during 1980 to 1984. They were present from September or October through April or May; the abundance peaked in winter (Figure 22). In 1983 the summer abundance of S. euneritica was significantly higher ($p<0.05$) than the summer abundance of any other year studied (Table 2).

Table 2

SEASONAL AVERAGE MONTHLY ABUNDANCE INDICES OF SAGITTA EUNERITICA IN THE BAY

Year	January-March	April-June	July-September	October-December
1980	625.5	19.8	20.8	96.7
1981	746.5	93.1	10.2	225.7
1982	294.5	69.8	12.8	467.5
1983	182.4	256.8	171.7	504.2
1984	206.2	101.8	44.2	338.8

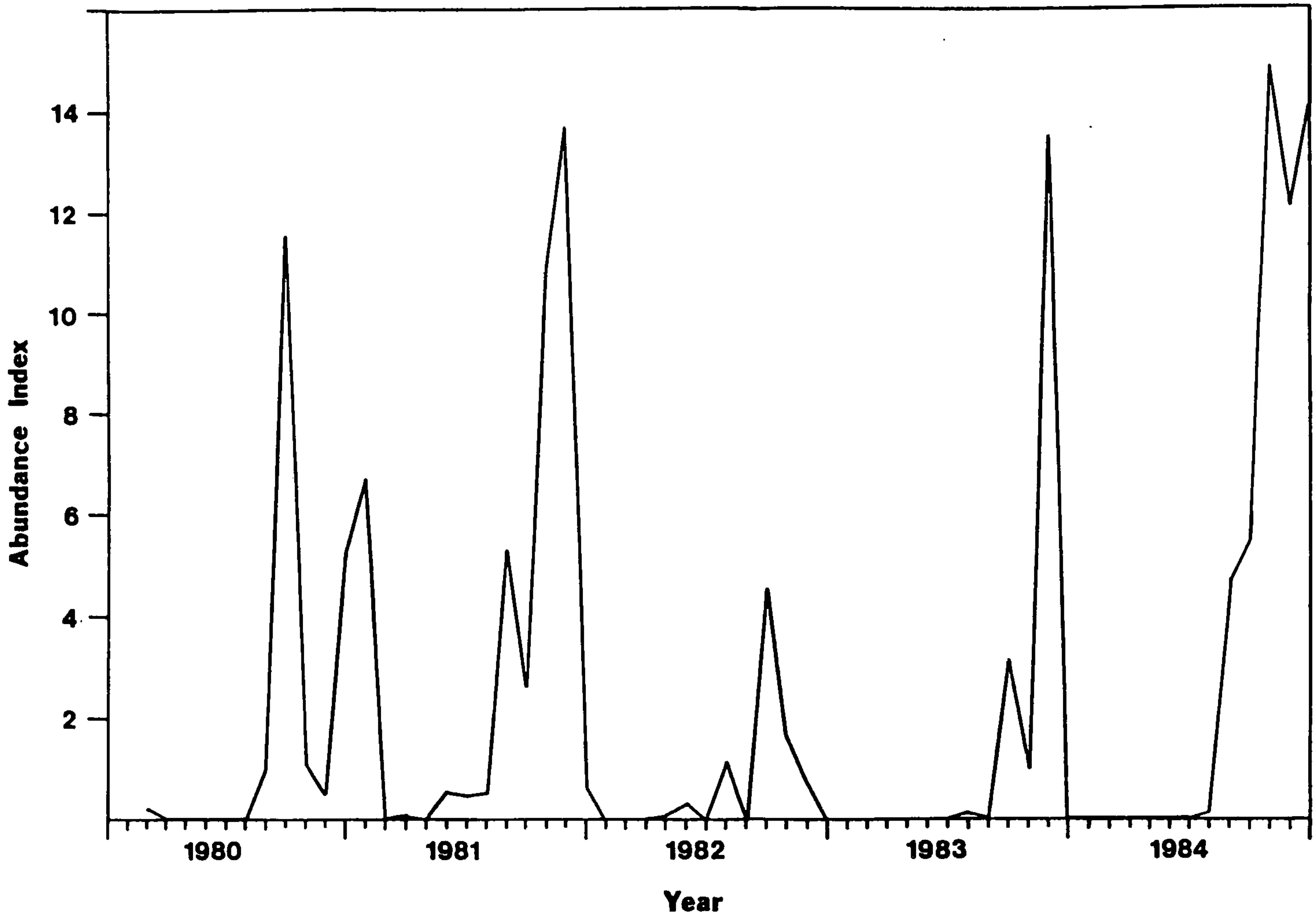


Figure 18. Monthly abundance indices of Emerita analoga larvae, 1980 - 1984.

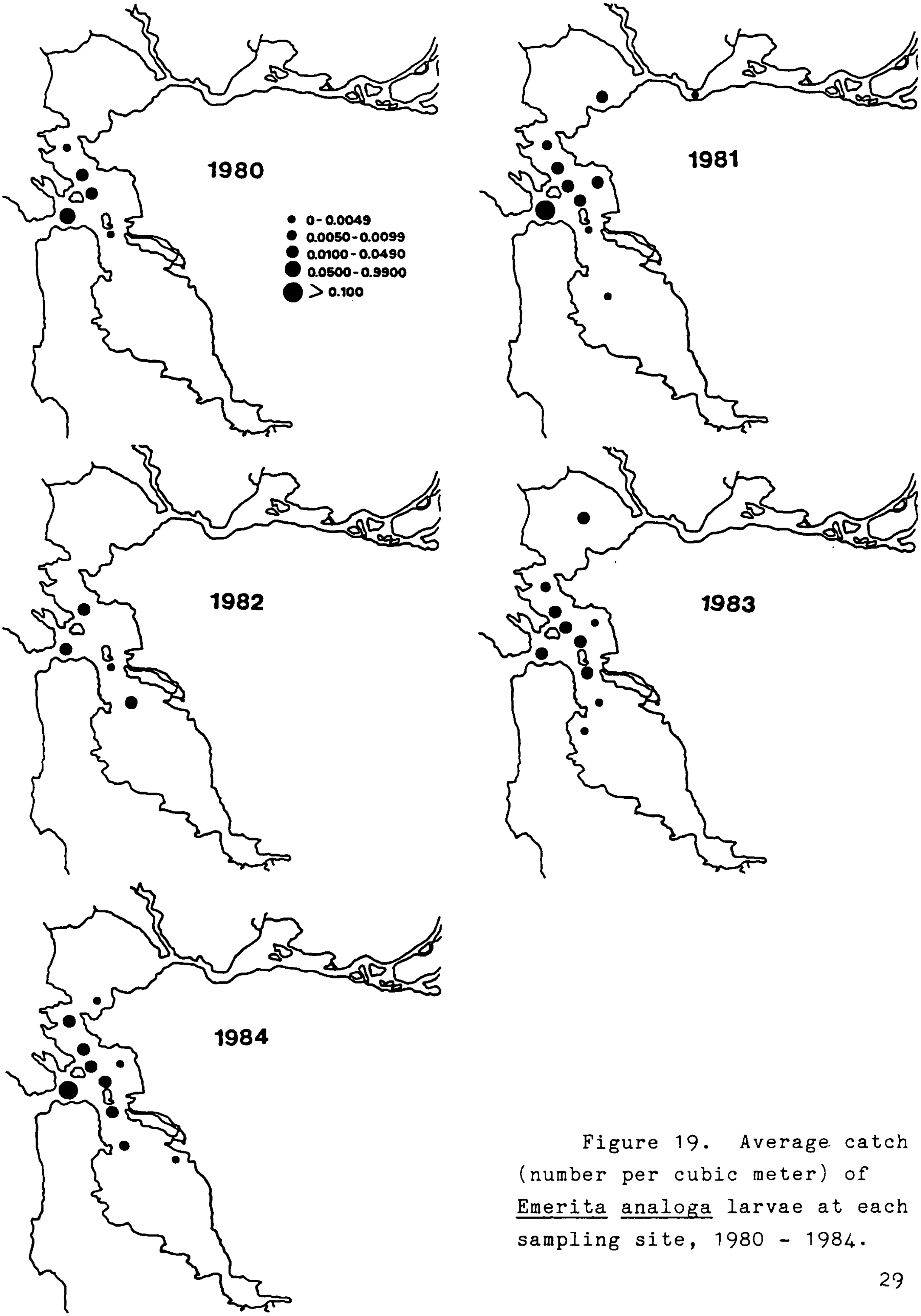


Figure 19. Average catch (number per cubic meter) of <u>Emerita analoga</u> larvae at each sampling site, 1980 - 1984.

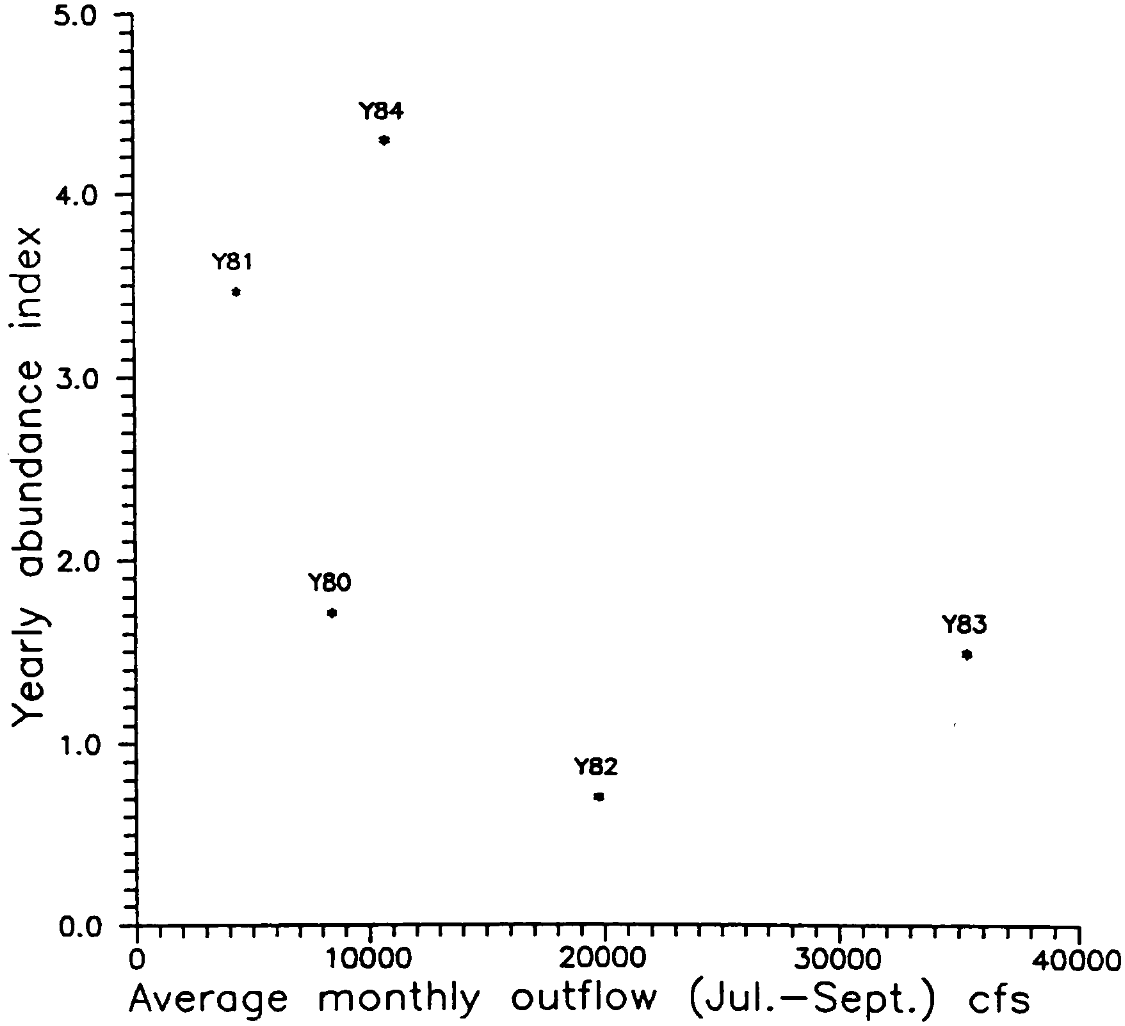


Figure 20. Annual abundance indices of <u>Emerita analoga</u> larvae vs. outflow (July - September) (r = -0.562).

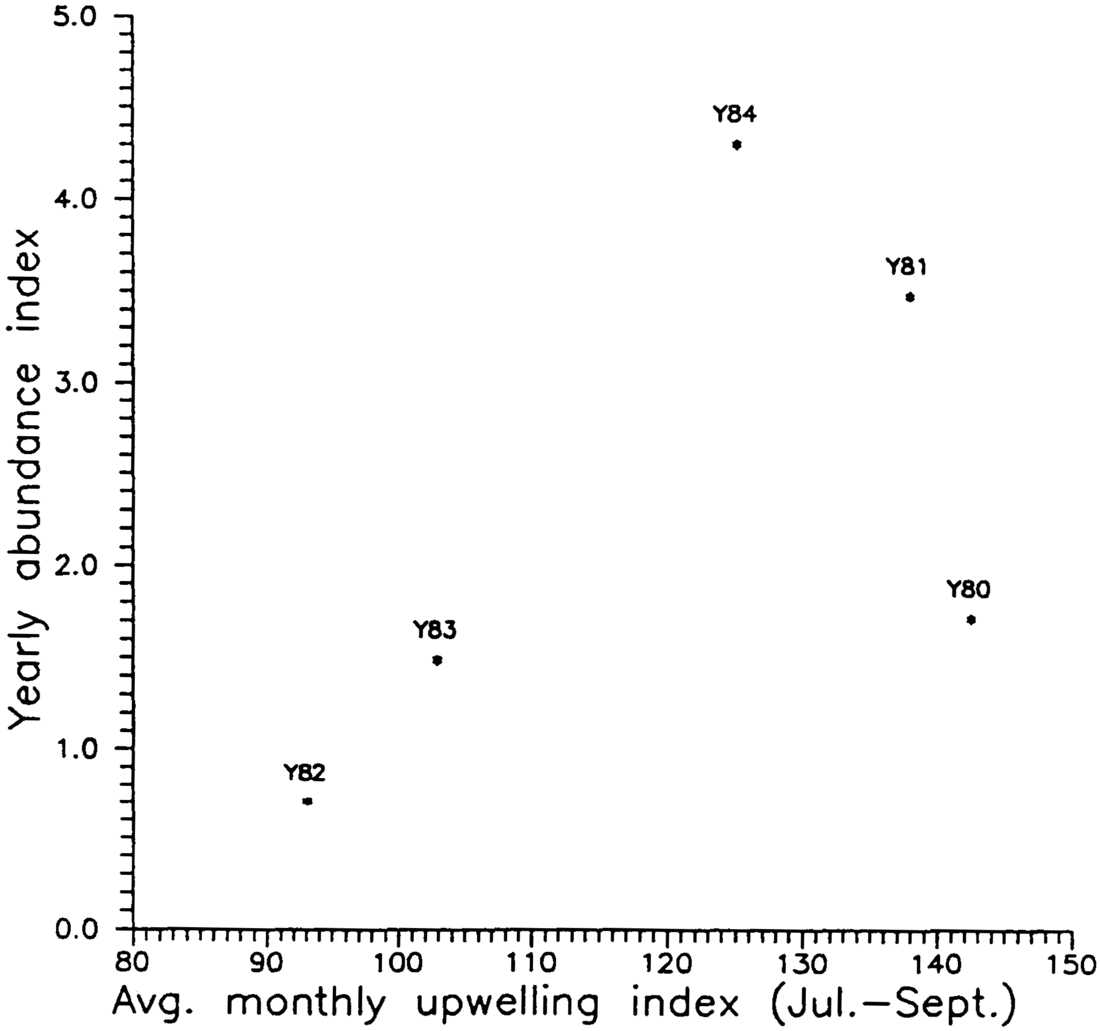


Figure 21. Annual abundance indices of <u>Emerita analoga</u> larvae vs. upwelling indices (July - September) (r = 0.579).

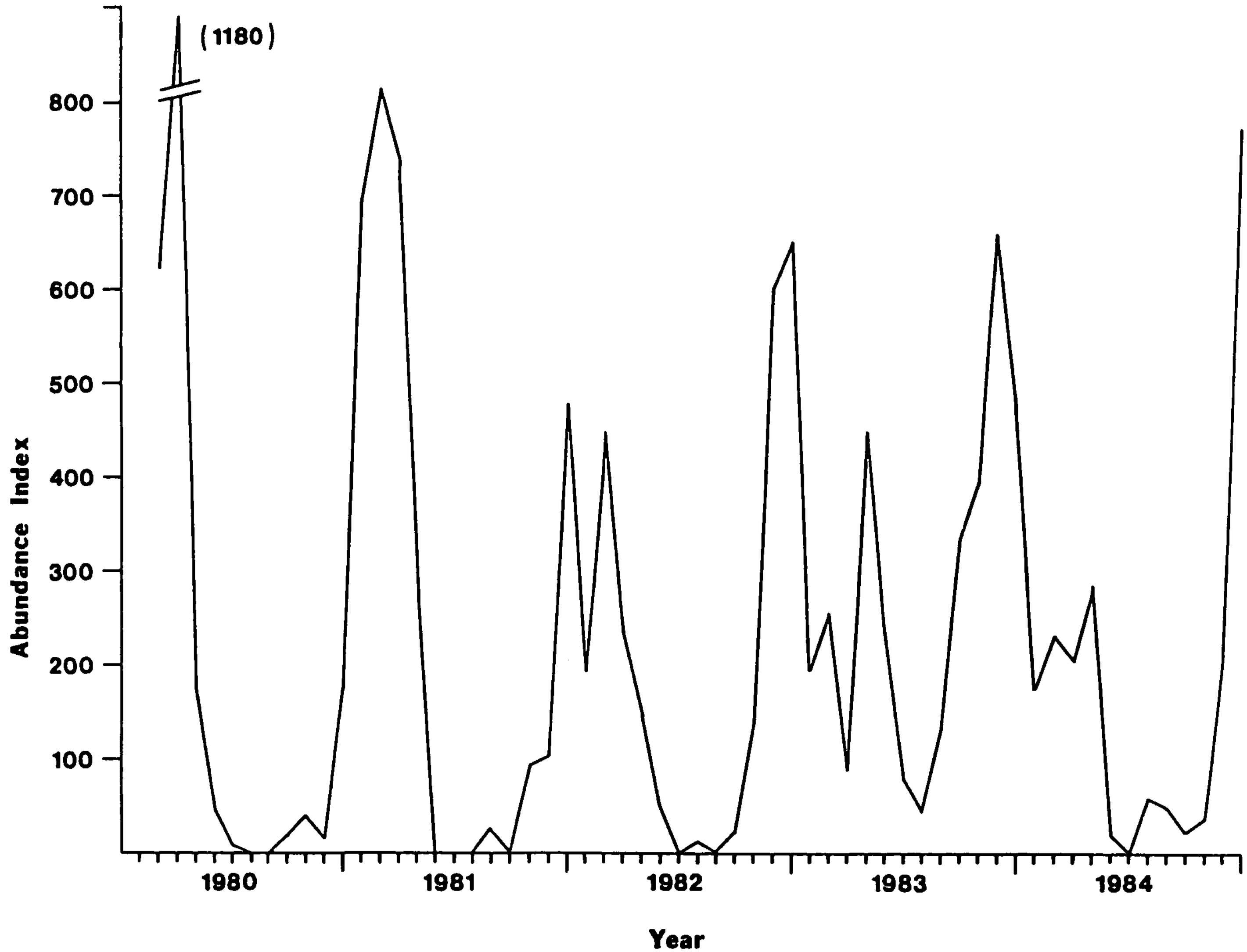


Figure 22. Monthly abundance indices of Sagitta euneritica, 1980 - 1984.

S. euneritica occurred throughout the Bay even though it is considered primarily a marine species (Figure 23). It was commonly found from the southernmost sampling site in South Bay to San Pablo Bay, and had been found at the Sacramento River (May 1983) and San Joaquin River (February 1981) sampling sites. S. euneritica occurred in Suisun and Grizzly bays from September through January during periods of low flow. Figure 24 shows the typical distribution of Sagitta during winter low flow periods. See Chapter 11 for further examples.

There was not a strong correlation between yearly abundance of S. euneritica and yearly outflow ($r=0.285$) or yearly upwelling indices ($r=-0.326$).

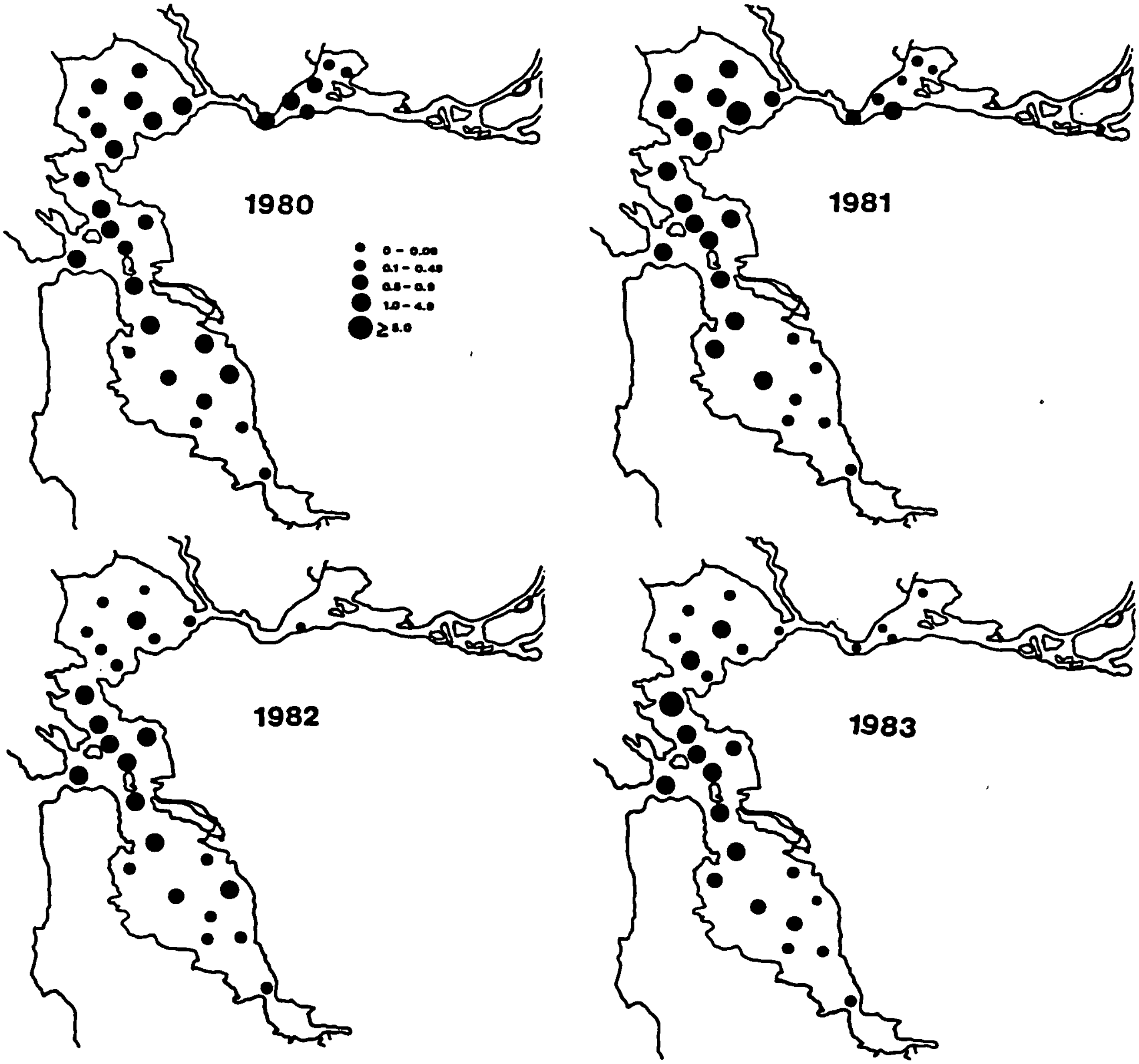
Six-month periods of low (May through October) and high (November through April) abundance were correlated with outflow for these periods. There was a significant positive correlation between May-October abundance and May-October outflow ($r=0.925$, $p<0.05$) (Figure 25). A negative correlation was found between abundance and outflow for the November-April period ($r=-0.665$) (Figure 26).

Sameoto (1971) found that the Sagitta elegans population in St. Margaret's Bay was greatly affected by outflow. He believed surface flushing of the surface layers was the most important factor in reducing the population. This apparently affected primarily young S. elegans, since the older animals were found at greater depths.

Although S. euneritica showed some reduction in numbers in January 1982 and March 1983 that could be attributed to outflow, their abundance in the Bay seemed little affected by flow. It was significant that Sameoto (1971) found larger animals deeper, allowing vertical distribution to help retain them in or move them up the estuary. This same behavior was seen in other planktonic invertebrates (Sandifer, 1975) to help them remain within an estuary. This may be how S. euneritica remained in the Bay during high flow periods. Fortier and Legett (1983) found that fish larvae undergo weak vertical migrations that were related to the vertical distribution of prey. S. euneritica may be following prey species migration, resulting in retention of the animal within the Bay.

The decline in abundance during summer may be due to increased temperatures, less immigration into the Bay, or increased mortality rate. Sameoto (1971) assumed a higher mortality rate to account for S. elegans decline in abundance during summer and fall. He saw a correspondence between increased bay temperature and increased fish predator numbers, and believed predation by young fish most affected S. elegans survival.

The usual decline in abundance during summer was probably not due to temperature increases in the Bay. The average temperature in the Bay was highest when S. euneritica were appearing there (October and November) (Figures 6 and 24). The average temperature was high in Suisun and Honker bays during November 1980 through January 1981, yet S. euneritica were found in high densities (Figure 24). Salinity also seems to have little to do with abundance of S. euneritica in the Bay. They were present in winter when average salinity was low and in fall when average salinity was high. Since salinity and temperature do not appear to be a delimiting factor with S. euneritica, it is suggested that either the El Niño phenomenon had some effect on summer abundance in 1983 or some change caused by increased summer outflows allowed a decrease in mortality. It must be noted here that summer abundance of euphauiid larvae also increased in 1983. There may be some associating factor between both increases.



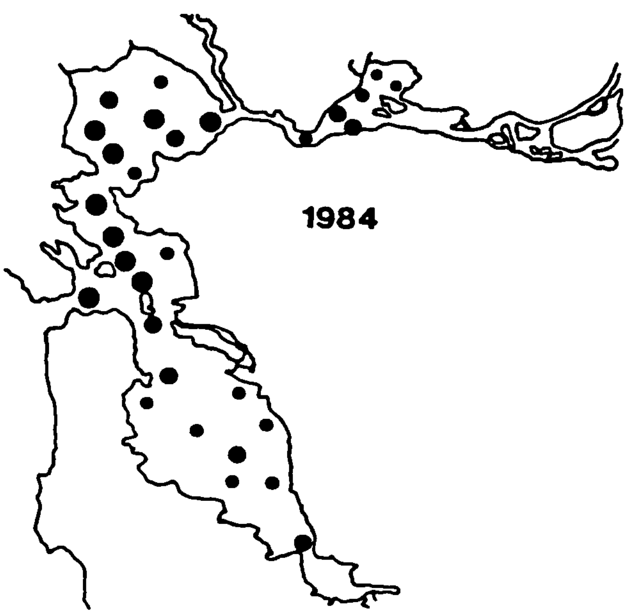


Figure 23. Average catch (number per cubic meter) of Sagitta euneritica at each sampling site, 1980 - 1984.

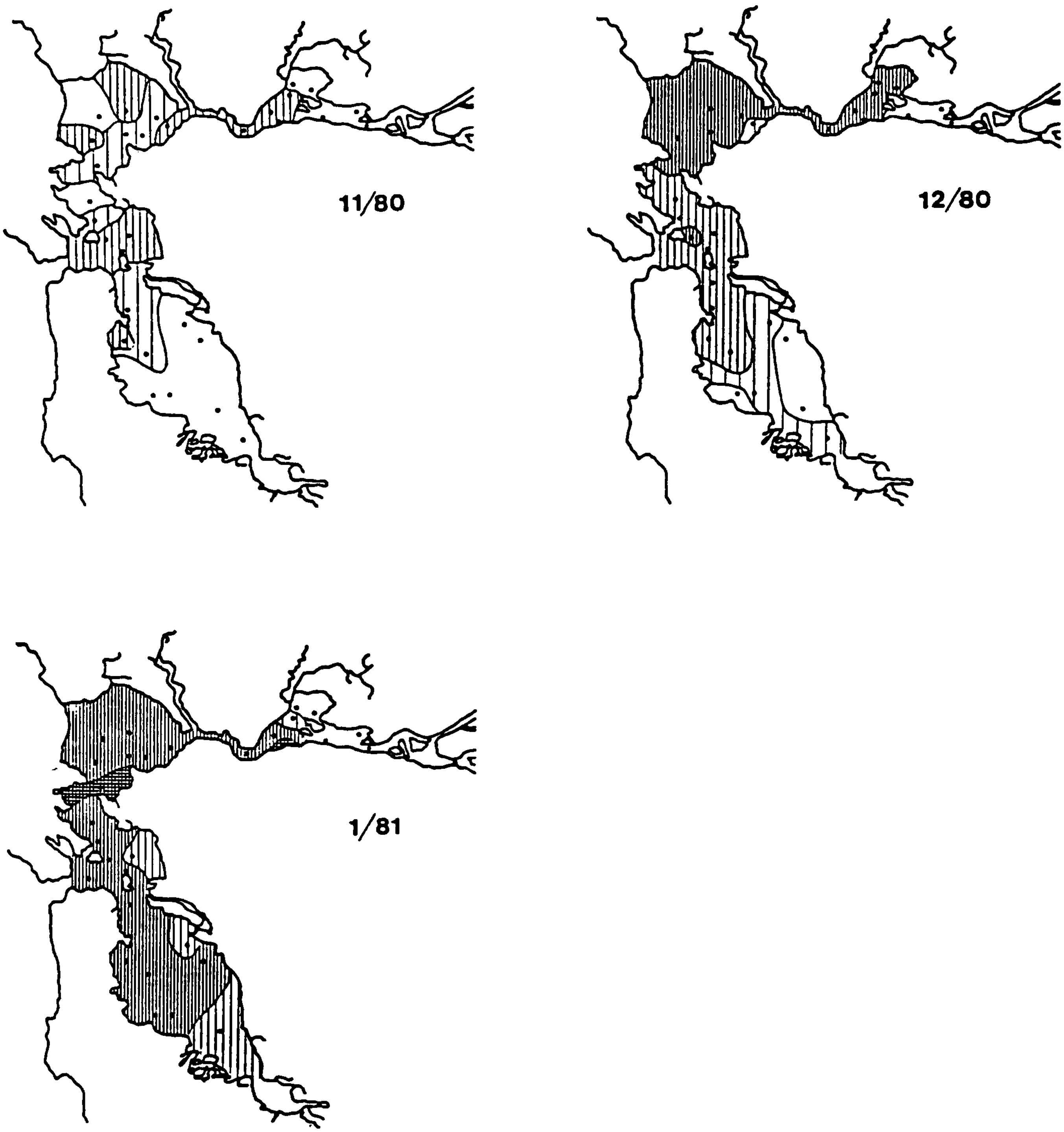


Figure 24. Catch (number per cubic meter) of <u>Sagitta euneritica</u> at each sampling site for November and December 1980 and January 1981. Contour lines were approximated by eye.

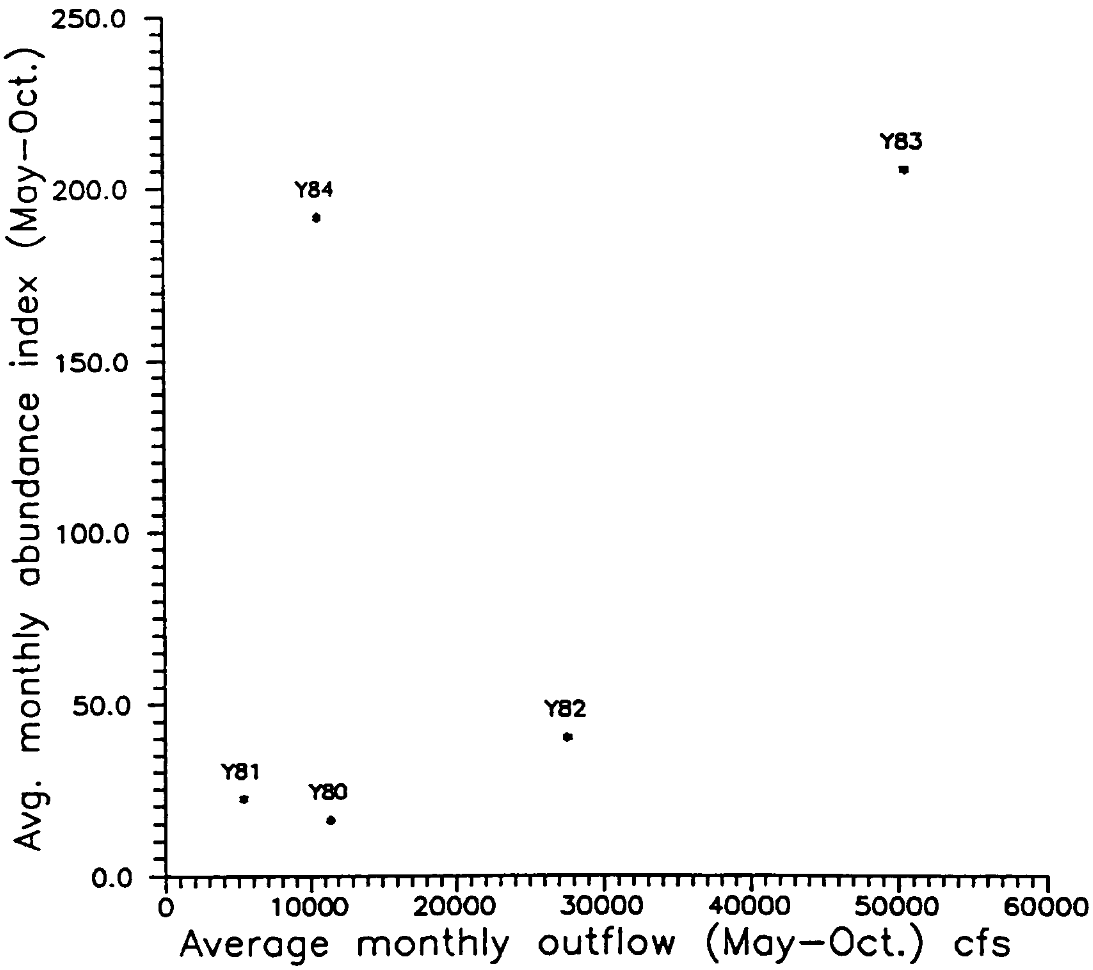


Figure 25. Average monthly abundance indices (May - October) of <u>Sagitta</u> <u>euneritica</u> vs. average monthly outflow (May - October) ($r = 0.925$, $p<0.05$).

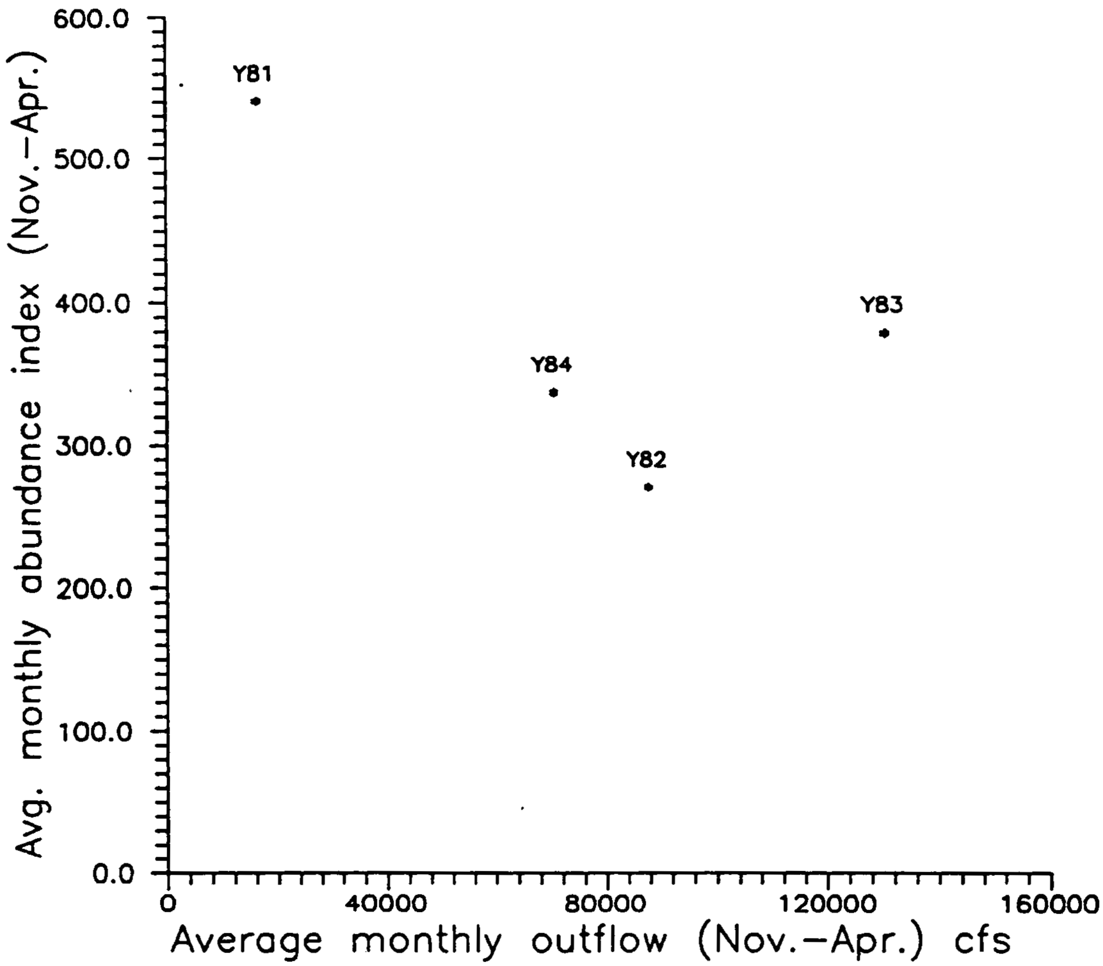


Figure 26. Average monthly abundance indices (November - April) of Sagitta euneritica vs. average monthly outflow (November - April) (r = -0.665).

Summary

Sagitta euneritica was usually found in the Bay from September through May; abundance peaked during winter. An unusually high abundance of *Sagitta* occurred during summer 1983. This high abundance may have been due to either El Niño effects or a decrease in the summer mortality rate.

Chapter 3. SHRIMP (CARIDEA)

This study has collected 14 species of true shrimp (Caridea) in San Francisco Bay (Table 3). The four most common species are considered for this report: Crangon franciscorum, C. nigricauda, Palaemon macrodactylus, and C. nigromaculata. Analysis has concentrated on C. franciscorum, because this species comprised almost 90 percent of the total shrimp catch, and more individuals of this species were collected in the otter trawl than any other species of invertebrate or fish.

Since the 1860s there has been a commercial fishery for shrimp in the Bay. C. franciscorum has dominated the comial catch, with other species being seasonally or locally important (Bonnet, 1932; Israel, 1936). Seines and set nets have been used, but only trawls are used now. Until the 1960s the catch was primarily used for food (fresh and dried), but now it is used for bait by sport fishermen. Catches peaked in 1935, with landings of about 3.5 million pounds (Figure 27).

Table 3

SHRIMP SPECIES COLLECTED IN THE OTTER TRAWL, 1980-1985

Scientific Name	% Total Catch	% Weighted Catch
Crangon franciscorum	89.8	84.6
Crangon nigricauda	6.2	10.9
Palaemon macrodactylus	2.5	1.6
Crangon nigromaculata	1.1	1.7
Heptacarpus cristatus	0.4	1.0
Lissocrangon stylirostris	0.1	0.2
Betaeus harrimani	<0.1	<0.1
Crangon munitella	<0.1	<0.1
Heptacarpus brevirostris	<0.1	<0.1
Heptacarpus palpator	<0.1	<0.1
Heptacarpus pictus	<0.1	<0.1
Heptacarpus taylori	<0.1	<0.1
Lysmata californica	<0.1	<0.1
Pandalus danae	<0.1	<0.1

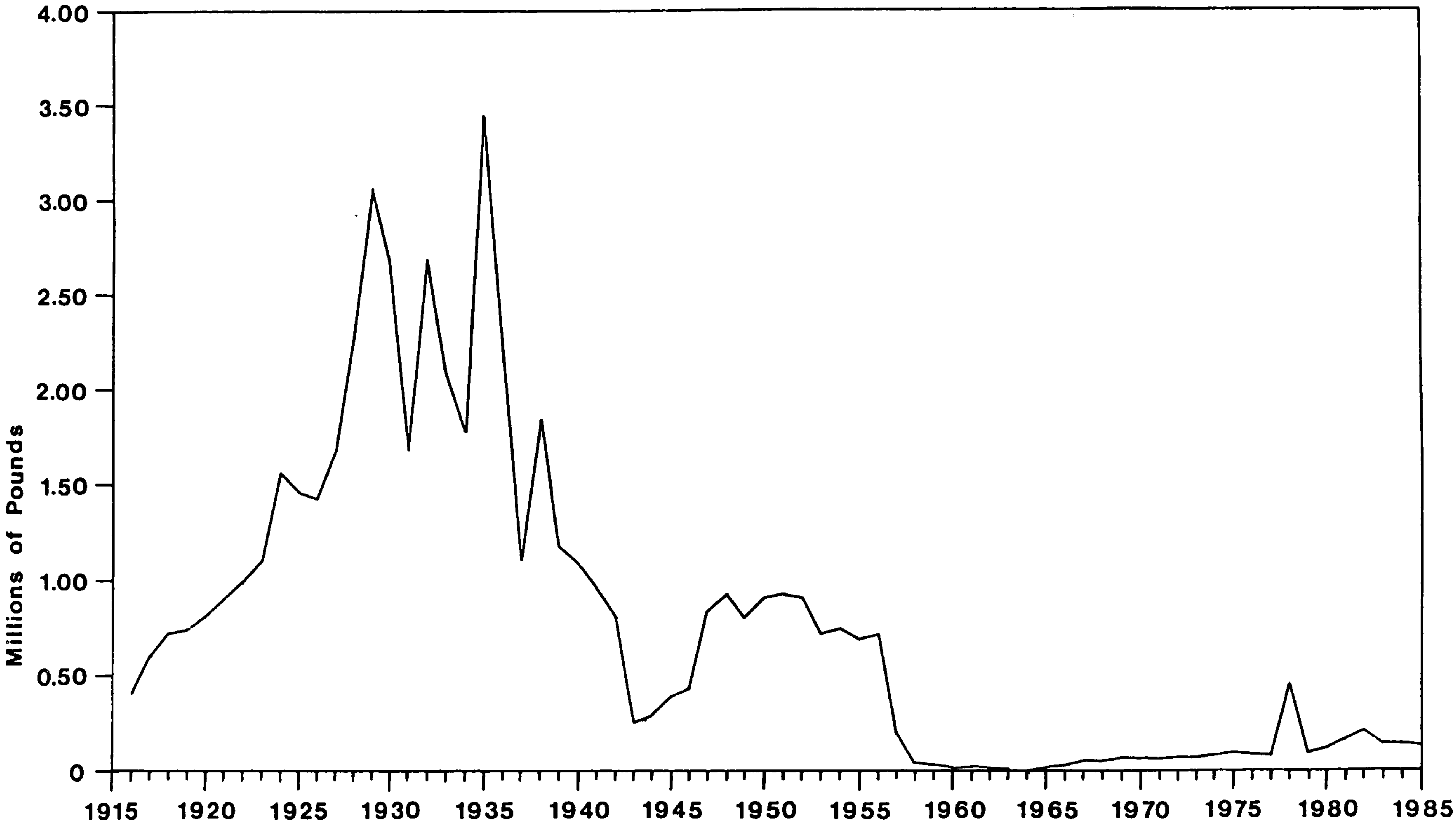


Figure 27. Commercial catch of bay shrimp in San Francisco Bay, 1916-1985.

Landings have not exceeded 250,000 pounds/year since 1957, except for 1978, which had landings of 475,000 pounds. The decrease in landings is primarily related to demand, and does not indicate a decrease in shrimp abundance in the Bay.

Shrimp are an integral component of the food web in the Bay. They are reported to be a food source for a variety of fishes, including striped bass (Johnson and Calhoun, 1952; Gannsle, 1966) staghorn sculpin (Boothe, 1967; Gannsle, 1966; Kinnetic Laboratories, 1985), green sturgeon, white sturgeon, American shad, brown smoothhound, Pacific tomcod, and white catfish (Gannsle, 1966). Crangon and Palaemon are opportunistic feeders that utilize many types of organisms, including mysids, amphipods, bivalves, copepods, polychaetes, crustacean larvae, fish larvae, insects, and plant material (Sitts and Knight, 1979; Siegfried, 1982; Wahle, 1985). Because of their high relative abundance, relatively short life span (1-2 years), and position in the food web, shrimp play an important ecological role in the Bay. Collection and analysis of shrimp data have been major components of this study.

Methods

The otter trawl and plankton net data were used for this analysis. Because of the mesh selectivity of the otter trawl (1.3 cm stretch mesh cod end), only shrimp greater than 10 mm (total length) are collected by this net. Shrimp between 10 and 20 mm are underrepresented in the otter trawl based on test trawls done during this study with a smaller mesh trawl, but all sizes are included in the data base. The plankton net collects larval, post-larval (6-10 mm), and juvenile shrimp. This net may not be the most effective net for collecting post-larval shrimp (which are at or near the bottom), but it is the only gear we have that samples this life stage.

Juvenile and adult shrimp were identified to lowest taxonomic level possible, sexed, and measured. All *Crangon franciscorum* less than 26 mm and other crangonids less than 19 mm were considered juveniles, although shrimp larger than this are immature. All ovigerous (egg-bearing) females were categorized as to egg stage (1-4) based on maturity of the embryos. For abundance analyses, the number of shrimp per 5-minute tow at each station was multiplied by a weighting factor that represents the area of that station in km^2.

There are five to seven larval stages for *Crangon* and seven larval stages for *Palaemon macrodactylus*. Because of difficulties in separating *Crangon* larval stages and species, we have combined stages I and II, IV and V, and VI and VII (stage III is not combined with any other stage). The species were also combined, although we can separate *C. nigricauda* from *C. franciscorum* for stages II and III with a high degree of certainty. The larval and post-larval catch for each station has been adjusted to express the catch as number per cubic meter of water filtered. This number was then multiplied by the station weighting factor for abundance analyses; volume weighting was used for larval stages and area weighting for post-larvae.

Baywide monthly abundance indices for all life stages were calculated by summing the weighted values for a month and dividing by the number of stations sampled that month. Annual indices were calculated in a similar manner (Table 4). Annual abundance indices for *Crangon* larvae were calculated by averaging the January-June weighted catches as larvae produced during this period would contribute to a year class.

Table 4

ANNUAL ABUNDANCE INDICES OF SHRIMP, BY SPECIES AND LIFE STAGE, 1980-1985

Species/Life Stage	1980	1981	1982	1983	1984	1985
Crangon franciscorum						
All sizes	4,318	2,536	8,468	9,300	6,819	1,329
Juveniles	559	137	720	1,490	779	26
Ovigerous females	71	116	155	285	490	81
Crangon spp.						
Post-larvae	0.08	0.17	0.16	1.66	0.70	0.08
Stage I + II	9.41	28.26	1.77	7.75	13.62	22.58
Stage III	0.82	0.75	0.01	0.27	0.97	4.62
Stage IV + V	0.20	0.17	0.03	0.02	0.21	1.02
Stage VI + VII	1.12	1.32	1.38	3.03	3.58	0.82
Crangon nigricauda						
All sizes	1,162	636	491	1,149	353	505
Juveniles	136	23	16	181	18	7
Ovigerous females	75	39	23	53	53	96
Crangon nigromaculata						
All sizes	44	15	31	358	130	62
Juveniles	0.3	0	0.1	0.9	0.9	1.6
Ovigerous females	0.7	0.3	0.1	2.0	1.2	6.4
Palaemon macrodactylus						
All sizes	125	116	82	32	171	93
Ovigerous females	21	14	11	1	16	12
Larvae	205	90	69	23	68	--

Crangon franciscorum

Crangon franciscorum is found near shore and in estuaries from San Diego to Alaska (Rathbun, 1904). Historically it has been the dominant species in San Francisco Bay (Schmitt, 1921; Bonnot, 1932; Israel, 1936; Gannsle, 1966). This species comprised almost 90 percent of the total shrimp catch and 85 percent of the total weighted catch during the study (see Table 3). This is also the largest shrimp commonly found in the Bay; in this study females attained a maximum length of 80 mm and males 71 mm. In Yaquina Bay, Oregon, females mature at about 48 mm and males at 34 mm (Krygier and Horton, 1975). Females probably live to 1.5 years and males to 1 year (Krygier and Horton, 1975; Kinnetic Laboratories, 1983). Israel (1936) reported both males and females to live about 1 year, but females grow faster than males.

Seven larval stages have been reported for C. franciscorum under laboratory conditions (Mondo, 1980). At room temperature (20 degrees C), it took 14 to 20 days for the larvae to develop to post-larvae. It probably takes 30 to 40 days for Crangon larvae to develop to post-larvae at Bay temperatures. Larvae are concentrated in the upper portion of the water column (Hatfield, 1985). Some females hatch more than one brood during their lifespan. Two distinct breeding seasons were found in Yaquina Bay based on abundance of ovigerous females (Krygier and Horton, 1975). Israel (1936) concluded that there is one very long breeding season in San Francisco Bay.

As with other species of crangonids, there is a seasonal migration of juvenile C. franciscorum to lower salinity, higher temperature water in spring and summer and of mature shrimp to higher salinity water in fall and winter (Israel, 1936; Krygier and Horton, 1975; Siegfried, 1980; Kinnetic Laboratories, 1983; Hatfield, 1985). Responses to changes in temperature and salinity are strongly interdependent, and researchers do not agree as to which factor, if either, is more important for Crangon. Krygier and Horton (1975) believed overall salinity to be more important than temperature for C. franciscorum in Yaquina Bay. Haefner (1976) proposed that decreasing water temperature in fall results in movement of C. septemspinosa from shallow to deeper areas of Chesapeake Bay. The seasonal migration of C. crangon (a European species) has been explained as a "search" for the warmest water mass (Havinga, 1930, as cited in Allen, 1966).

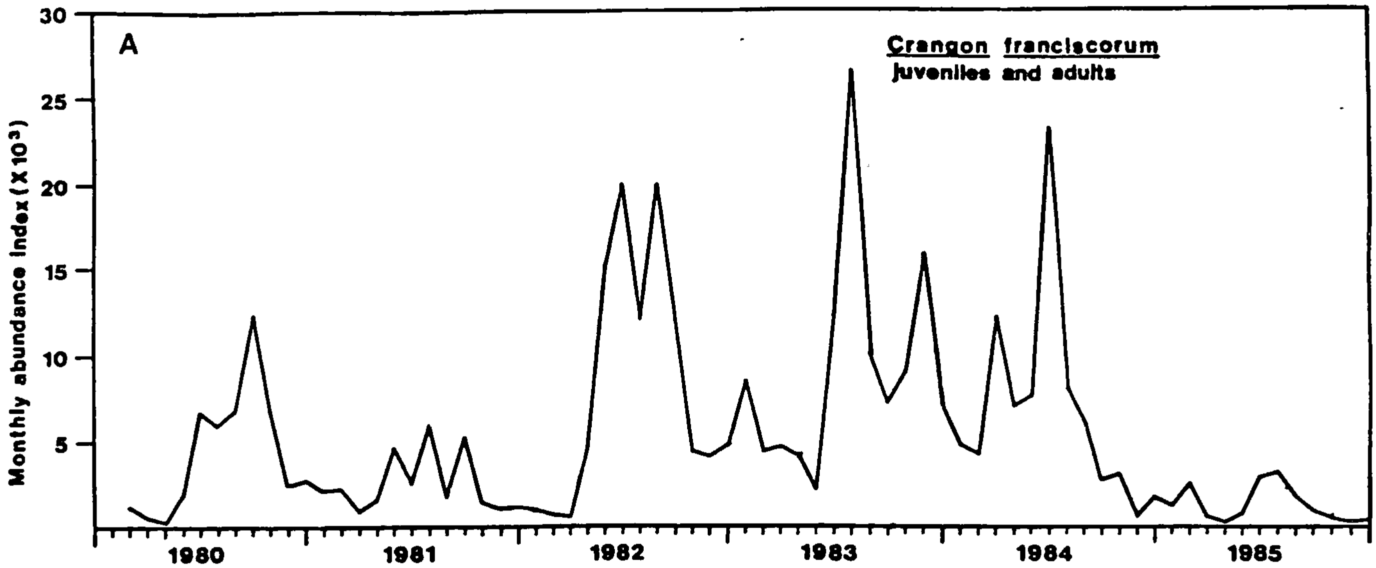
A possible mechanism for recruitment of C. franciscorum to the Bay was proposed by Hatfield (1985) based on data from the first 3 years of this study (1980-1982). She concluded that most of the reproductive population migrates outside the Bay in the winter, especially during years of high outflow. Of those larvae hatched inside the Bay during winter and spring, the early and mid-stages are carried from the Bay to the near-shore area. This results in the majority of late stage larvae and post-larvae being outside the Bay. The post-larvae are at or near the bottom, and their movement into the Bay is probably aided by tidal and non-tidal currents. The magnitude of Delta outflow would directly affect the number of post-larval shrimp entering the Bay and their subsequent distribution.

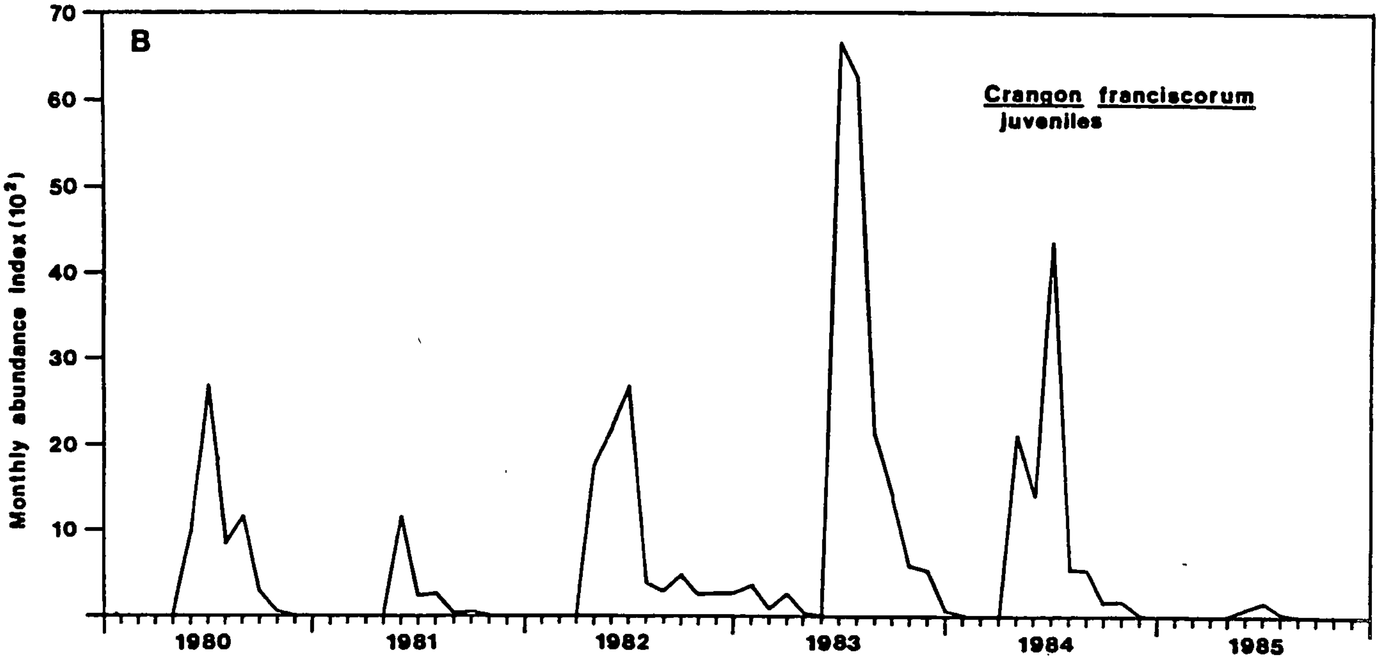
There were distinct seasonal and annual differences in C. franciscorum abundance in the Bay (Figure 28a). The greatest abundance was during summer, with the peak ranging from June to September. A large portion of this summer peak is immature shrimp. Abundance declines in fall and winter, when mature shrimp migrate to the near-shore area. A fall peak in abundance in 1982 and 1983 indicates the possibility of two distinct hatches. Annual abundance was highest in 1982 and 1983 and lowest in 1981 and 1985 (Table 4).

C. franciscorum were concentrated in San Pablo and Suisun bays (Figure 29). There was a distinct South Bay population every year, with shrimp concentrated in the southern portion of this embayment. In 1981, 1984, and 1985, this species utilized the area upstream of Carquinez Strait to a greater extent than in other years. Catches in San Pablo Bay were relatively low in 1981 and 1985, indicating a "shift" rather than an extension of C. franciscorum to the upstream areas.

Larval Abundance and Distribution

The seven larval stages of Crangon have been divided into four groups: stages I and II, stage III, stages IV and V, and stages VI and VII. Larval stages I and II usually were most abundant from February through June (Figure 30a). This is a very general trend, as the peak abundance in 1982 was in August. There was a small peak in November 1981, 1982, and 1983. The highest abundance index of these stages was in 1981, the lowest in 1982 (Table 4). Note that the abundance indices for Crangon larvae were calculated from January to June, as these





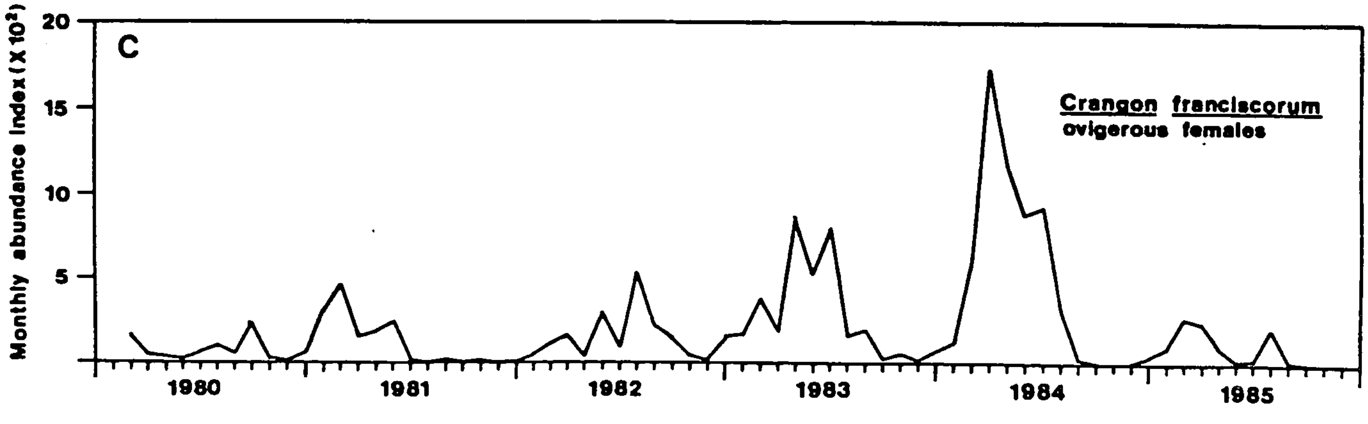


Figure 28. Monthly abundance indices of juvenile, adult, and ovigerous Crangon franciscorum, 1980-1985.

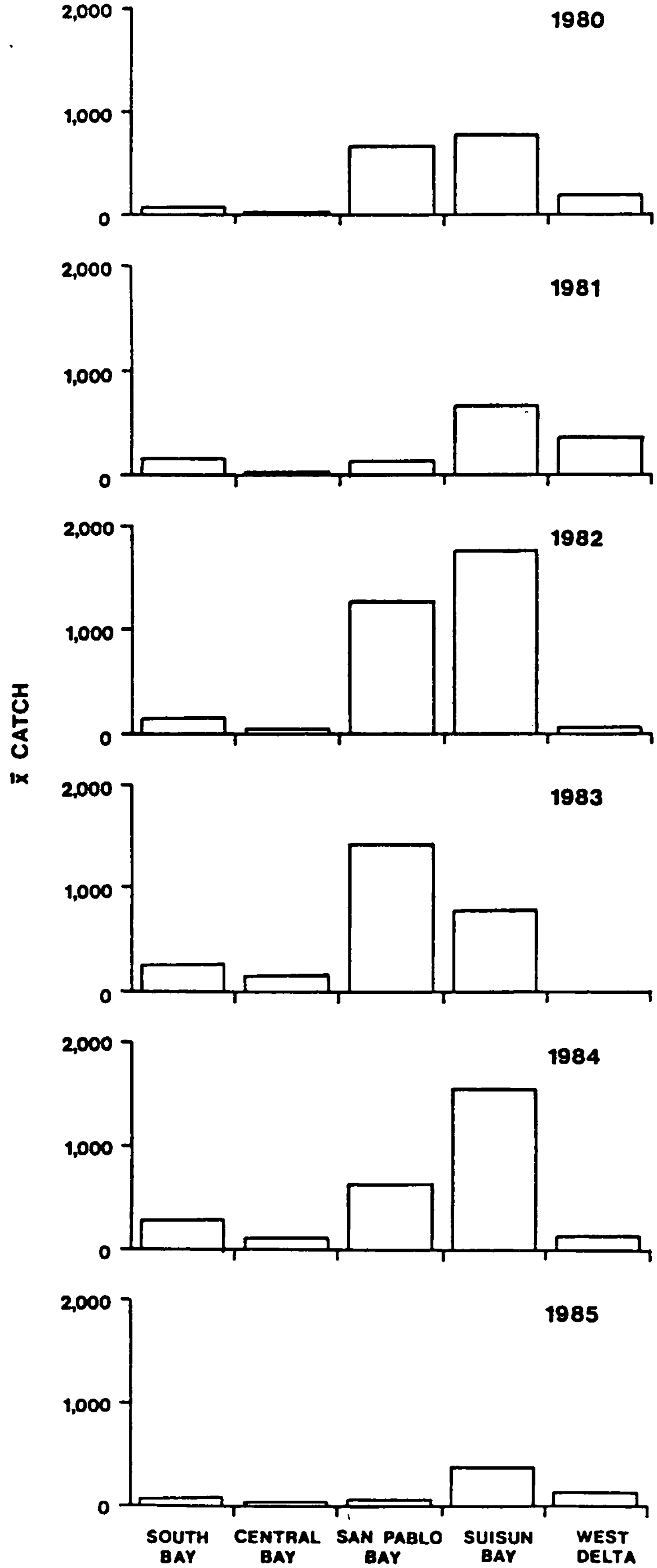
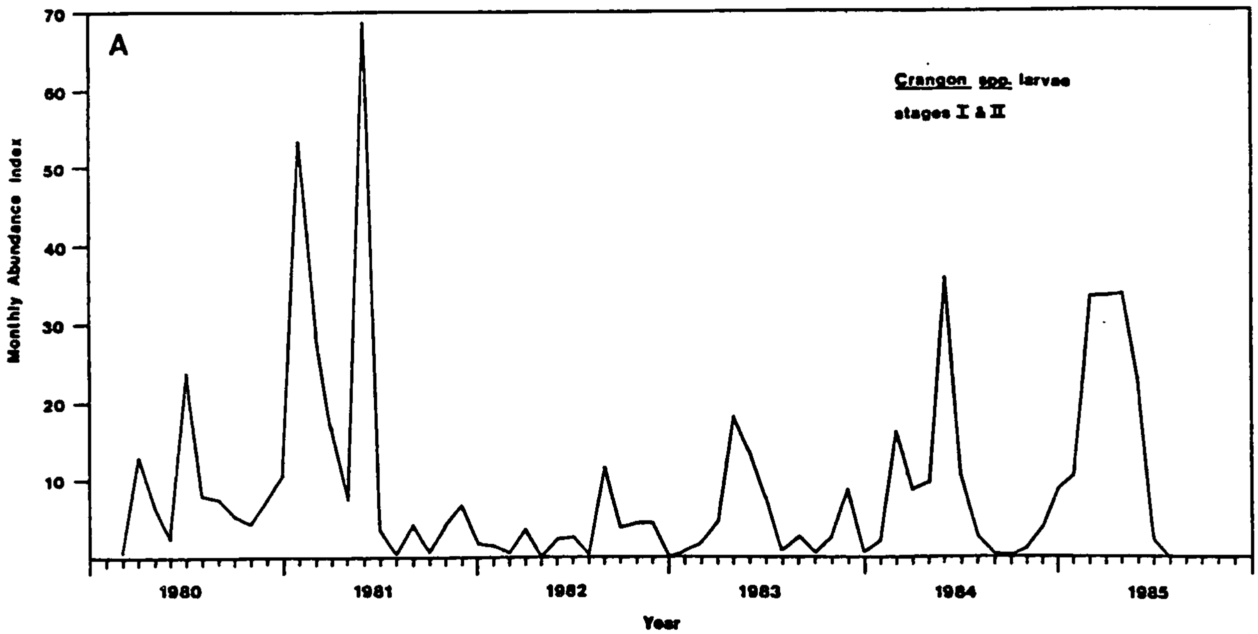


Figure 29. Distribution of juvenile and adult Crangon franciscorum.



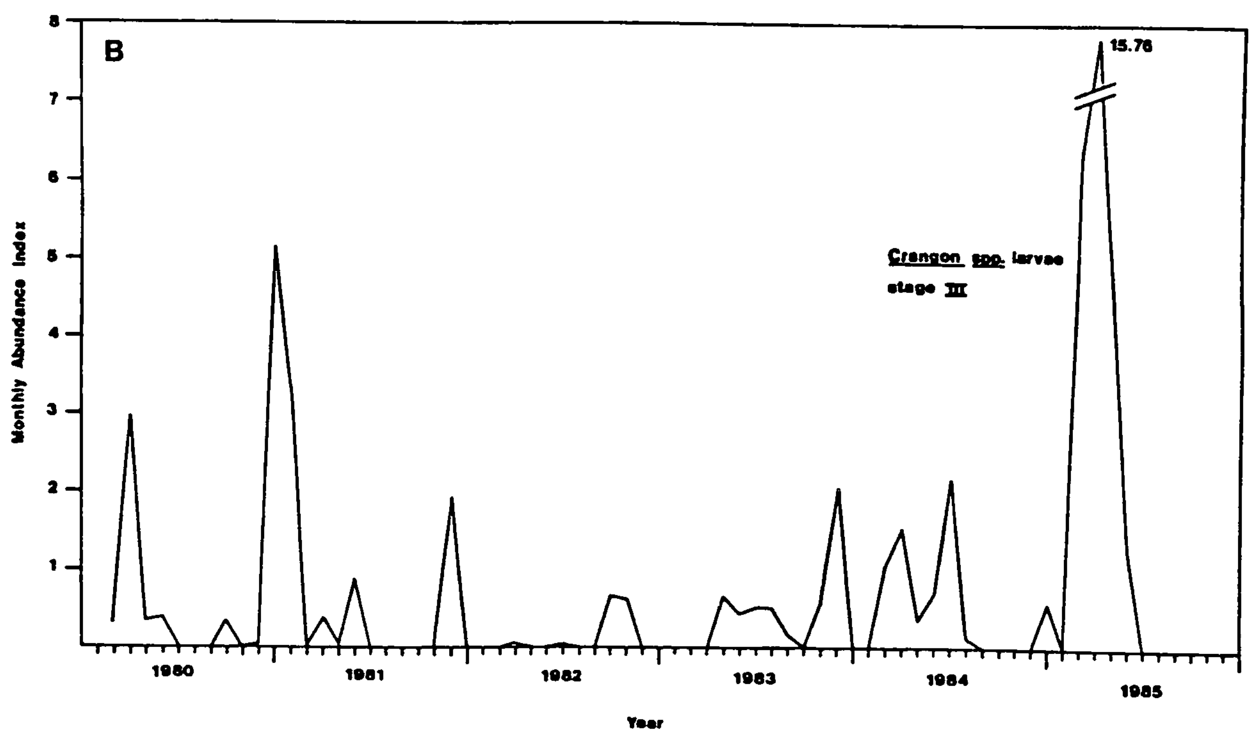


Figure 30. Monthly abundance indices, Crangon spp. stages I, II, and III larvae, 1980 - June 1985.

larvae would be expected to produce the majority of juveniles in a year class. These early stage larvae were present in South, Central, and San Pablo bays all years. They were concentrated in Central Bay every year except 1981, when the greatest catches were in South Bay. A few larvae were also collected upstream of Carquinez Strait in 1981.

Stage III is the larval stage at which we can separate C. franciscorum from C. nigricauda with a high degree of confidence. There was often a spring and fall peak in abundance of this stage (Figure 30b). When the two species are graphed separately (Figures 31a and b), it appears that C. nigricauda larvae were usually collected in the fall. Larvae collected in the summer were C. franciscorum. The lowest abundance index of stage III larvae was in 1982, the highest in 1985 (Table 4). This was similar to trends in abundance of stages I and II. Stage III larvae were also concentrated in Central Bay, with some larvae collected in South and San Pablo bays all years.

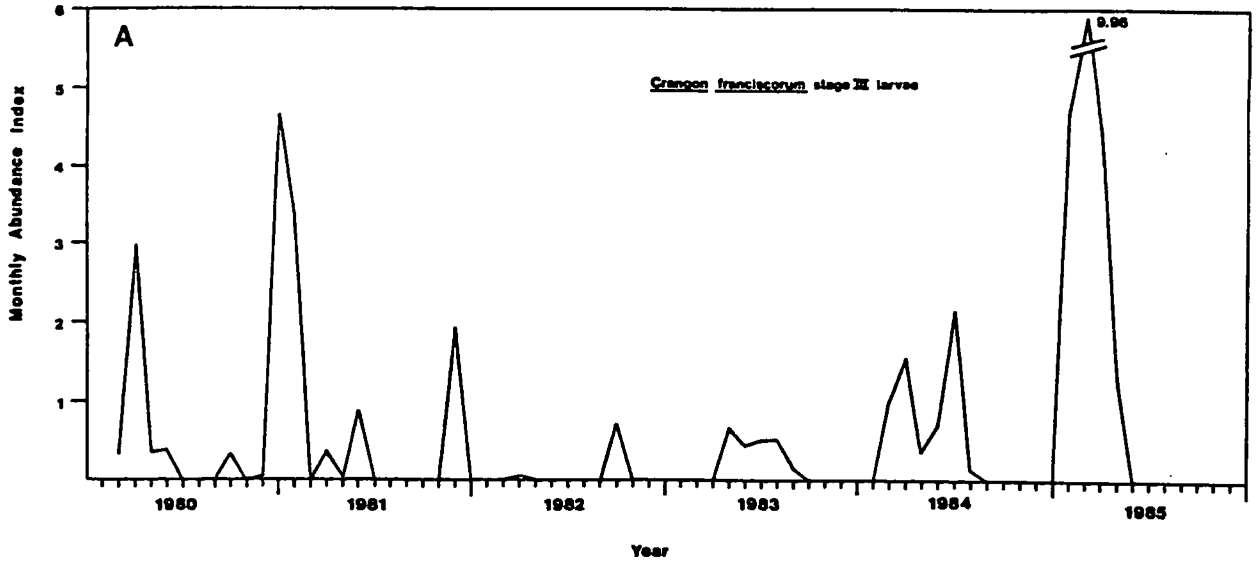
Crangon larval stages IV and V were relatively rare in the Bay, as the monthly abundance index did not exceed 1.0 at any time except fall 1980 and winter-spring 1985 (Figure 32a). The separate spring and fall peaks present for the earlier stages are apparent. We cannot speciate these stages, but composition of the peaks is probably similar to stage III. Trends in abundance were also similar to stage III, with the highest index in 1985 and the lowest indices in 1982 and 1983. Stage IV and V larvae were concentrated in Central Bay every year; in 1980 and 1982 no larvae were collected in South or San Pablo bays.

The last larval stages (VI and VII) had a distinctive spring abundance peak. This peak occurred in March 1981 (the lowest outflow year) and in June 1983 (the highest outflow year) (Figure 32b). There was also a small fall peak each year. The highest abundance indices were in 1983 and 1984; other years the indices were about 30 percent of the 1983-1984 indices (Table 4). Stage VI and VII larvae were concentrated in Central Bay in all years (Figure 33). They were also collected in South and San Pablo bays each year, with some larvae collected at the southernmost station in 1983.

There is little relationship between abundance of Crangon larvae and C. franciscorum ovigerous females. Egg stage 3 females from January to May (females most likely to produce larvae for the larval index period) were used for these correlations. Correlation coefficients range from -0.020 for stage I and II larvae to 0.886 ($p<0.01$) for stage VI and VII. One possible reason for this significant relationship is that late-stage larvae may be at or near the bottom and are more effectively sampled by the plankton-sled net than are other Crangon larval stages.

Post-Larval Abundance and Distribution

Post-larvae are the smallest juveniles (6-10 mm) and cannot be identified to species. Crangon franciscorum undoubtedly dominates the catch, but C. nigricauda and C. nigromaculata are also included. The correlation between the annual abundance index of post-larval and juvenile Crangon is significant ($r=0.875$, $p<0.05$). Peak abundance of post-larvae was from March to July (Figure 34), with the July peak occurring in 1983, the highest outflow year. The highest abundance index of this size class was in 1983, followed by 1984; the lowest abundance indices were in 1980 and 1985 (Table 4). This annual index is not significantly correlated with the annual abundance index of ovigerous females (all or any egg stages), although the relationship is positive. In 1982, the peak abundance of ovigerous C. franciscorum in the Bay occurred after the post-larval peak.



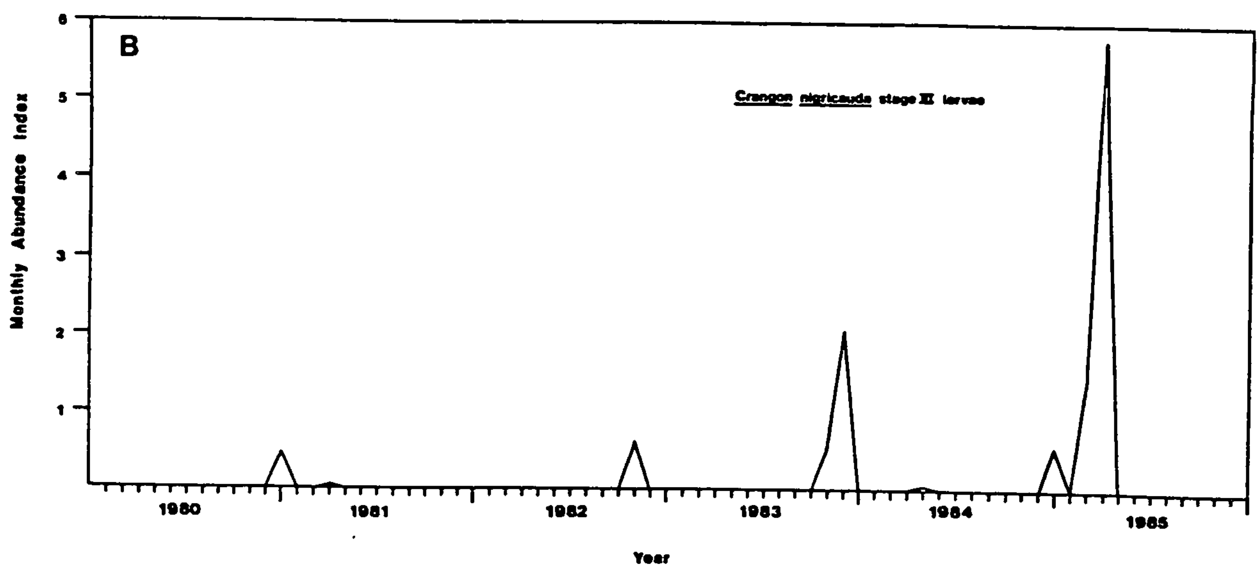
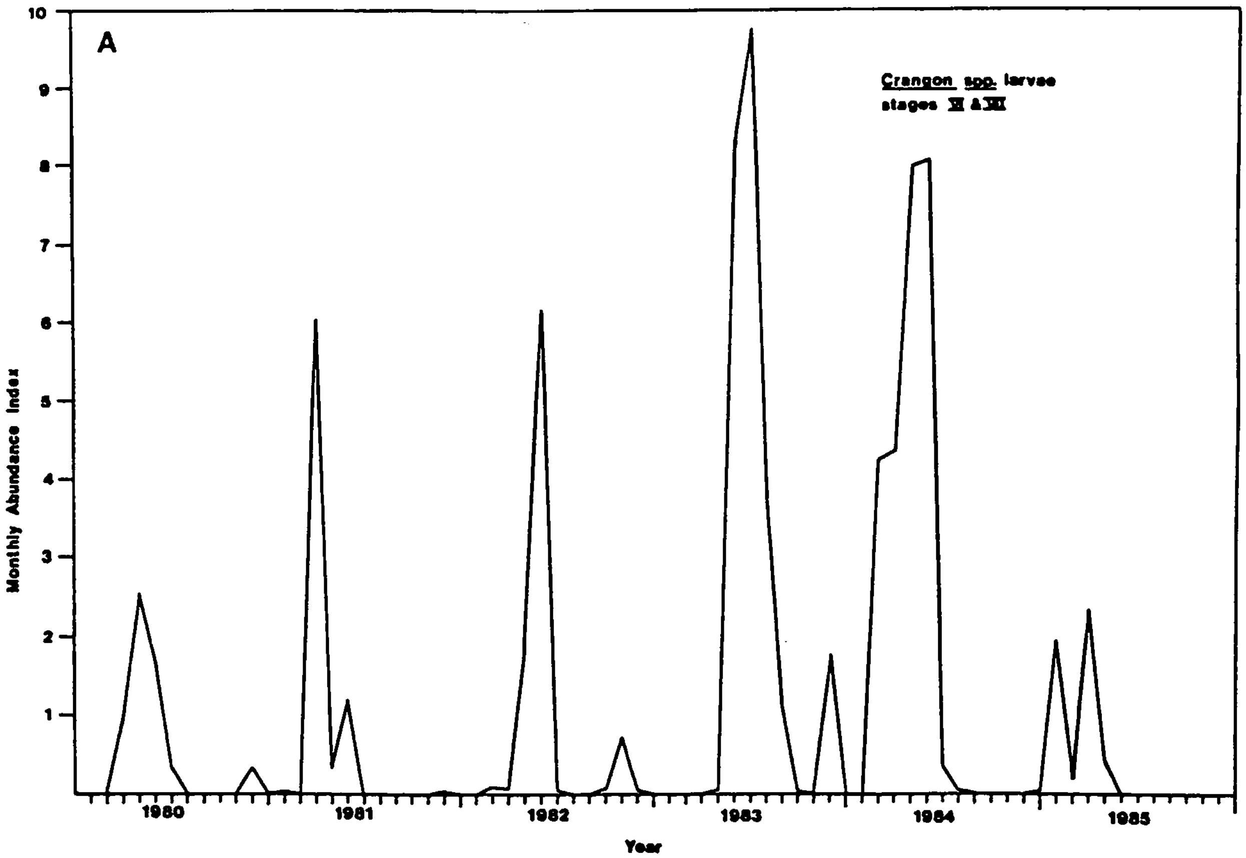


Figure 31. Monthly abundance indices, Crangon franciscorum and C. nigricauda stage III larvae, 1980 - June 1985.



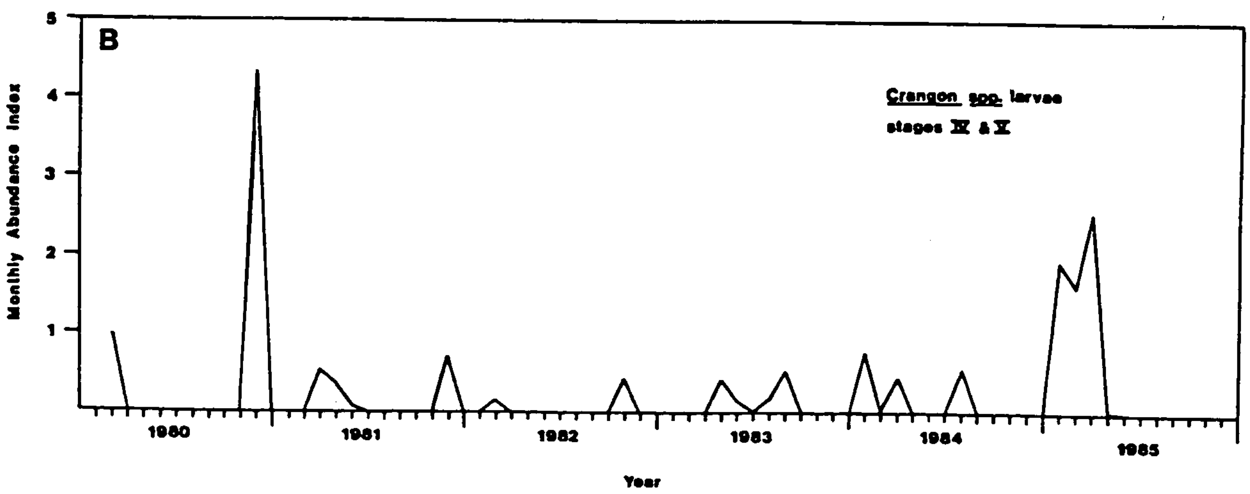


Figure 32. Monthly abundance indices, Crangon spp. stages IV, V, VI, and VII larvae, 1980 - June 1985.

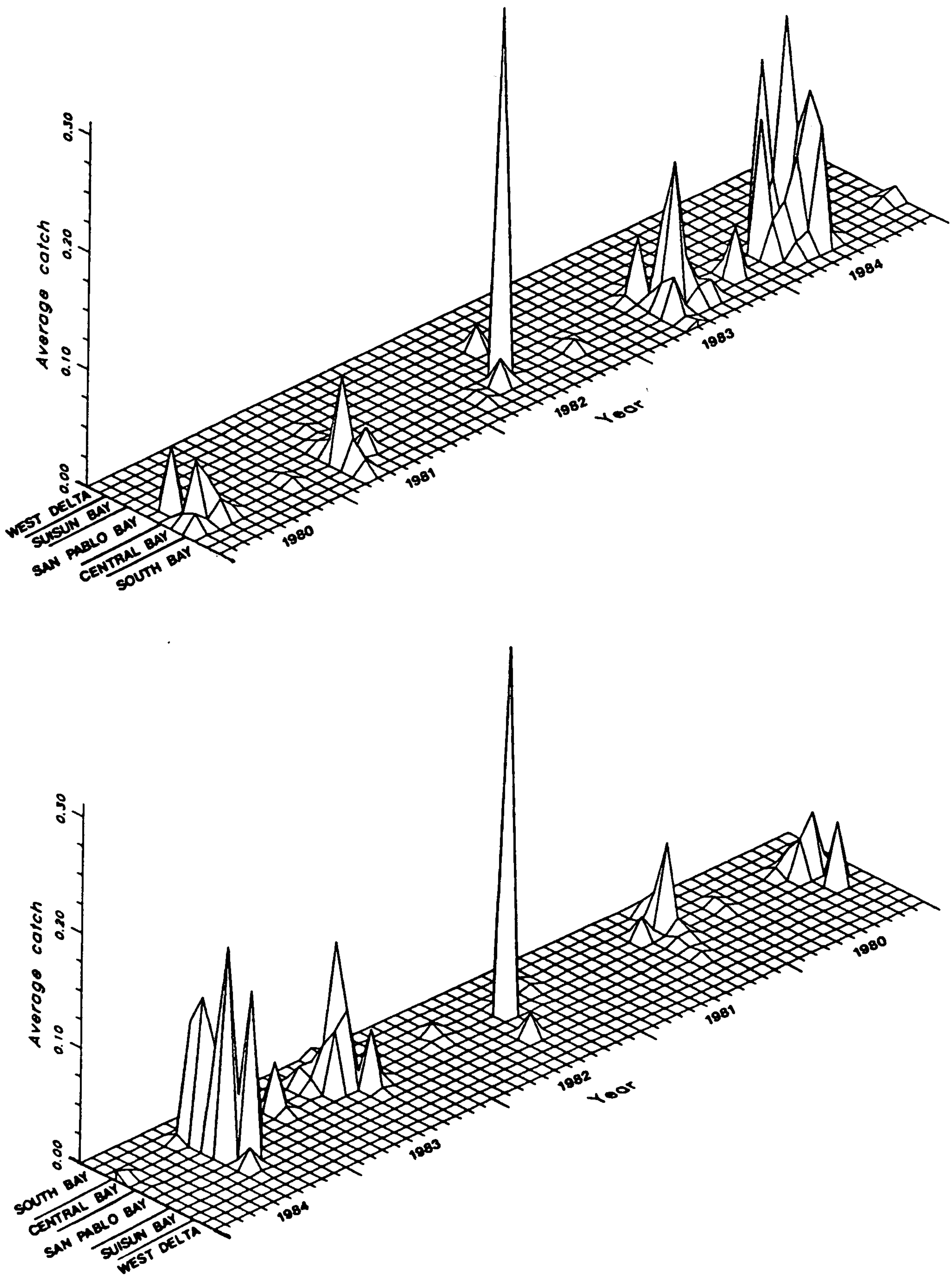


Figure 33. Distribution of Crangon spp. stage VI and VII larvae.

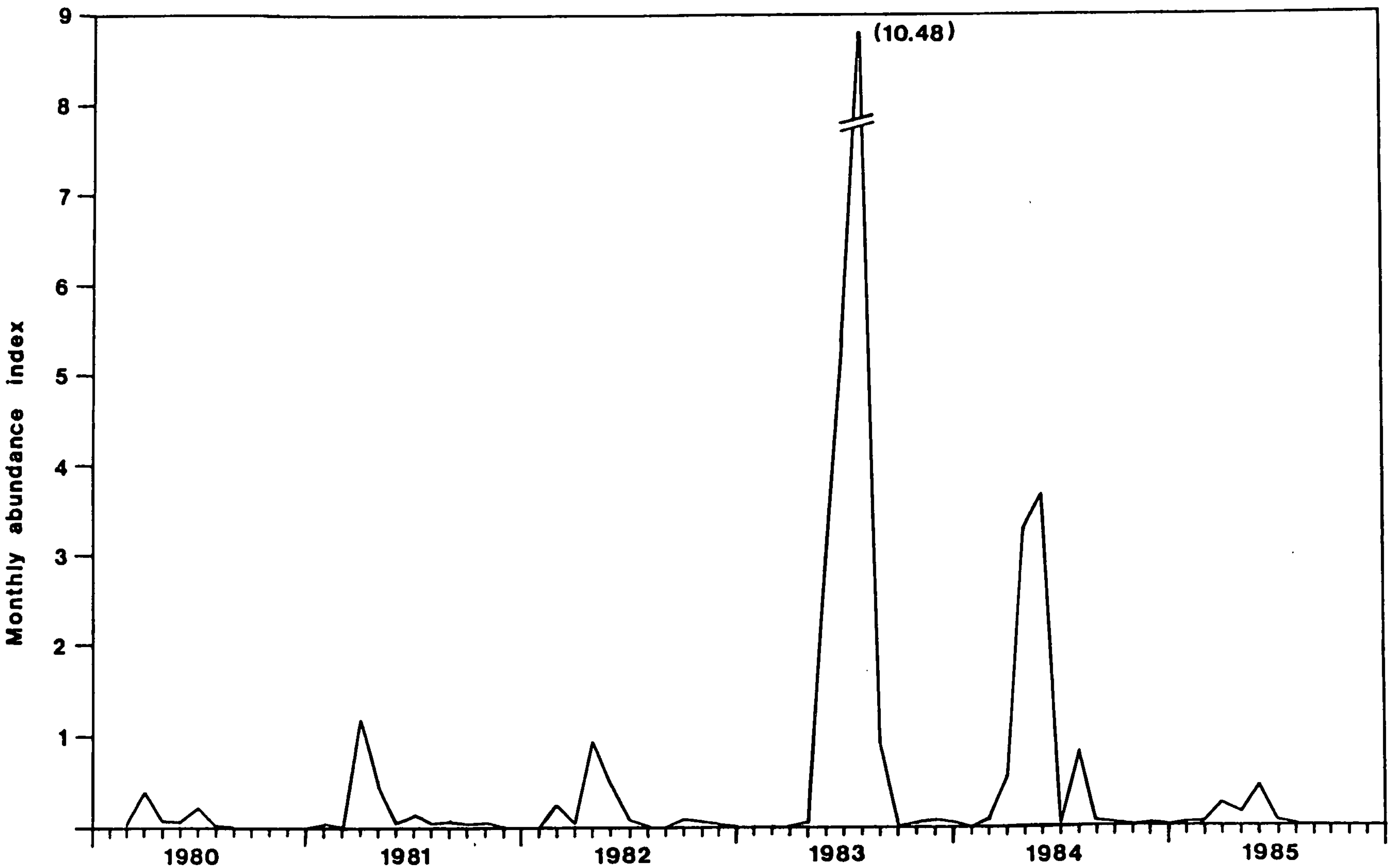


Figure 34. Monthly abundance indices of Crangon spp. post-larvae, 1980-1985.

Post-larvae were concentrated in Central Bay every year (Figure 35). During years of high abundance (1983 and 1984) and low outflow (1981 and 1985), post-larvae were collected upstream of Carquinez Strait.

Juvenile Abundance and Distribution

The abundance of juvenile Crangon franciscorum (10-25 mm) had seasonal and annual trends similar to those of all sizes (Figure 28b). The summer peak of abundance declined as the shrimp matured. This peak was usually from April to August, but in 1983 (year of highest outflow) it was from May to September. Only in 1982 were juveniles collected in significant numbers in winter. This was unexpected in that there was no peak in post-larval abundance during this period. The lowest annual abundance index of juveniles was in 1985, followed by 1981; the highest abundance index was in 1983 (Table 4). There is a significant correlation between annual abundance of juvenile C. franciscorum and post-larval Crangon ($r=0.876$, $p<0.01$). There is also a positive relationship between juvenile abundance and the annual abundance of ovigerous C. franciscorum ($r=0.551$).

C. franciscorum primarily utilized San Pablo and Suisun bays (Figure 36). In 1981, 1984, and 1985 they were concentrated in Suisun Bay. During years of higher abundance (1980, 1983, and 1984), more juveniles utilized South Bay than in 1981 or 1985. In 1982, few juveniles were collected in South Bay but there were relatively large catches in the rest of the study area.

Ovigerous Female Abundance and Distribution

Ovigerous Crangon franciscorum usually had a peak in abundance in spring and summer (Figure 28c). Timing of the peak was highly variable (February in 1981 and 1985; July in 1982). There was no well defined spring-summer peak in 1980.

Abundance of ovigerous females was lowest during fall and winter, when many mature shrimp migrate out of the Bay to the near-shore area. Some near-shore data are available from the San Francisco Ocean Outfall Monitoring program from October 1982 to June 1986 (San Francisco Bureau of Water Pollution Control, 1984, 1985, 1986, 1987). During these trawls at six stations about 4 to 6 miles south of the Golden Gate, a relatively high number of C. franciscorum and a large percentage of ovigerous females were present in February 1984 and 1986 (Figure 37). This shows that mature shrimp migrate out of the Bay in winter, although few were collected in February 1985 and there was no sample in February 1983. Our highest annual abundance index of ovigerous C. franciscorum was in 1984, and the lowest indices were in 1980 and 1985 (Table 4). The high abundance in 1984 was probably a result of the "good" 1983 year class.

Ovigerous C. franciscorum were concentrated in Central and San Pablo bays (Figure 38). Every year there was a distinct population at the southernmost portion of South Bay. There do not appear to be large interannual differences in distribution. Ovigerous females were not collected upstream of Carquinez Strait in 1983, the year of highest outflow.

One question is why a substantial number of post-larvae or juveniles were not collected in the fall, as would be expected from the summer peak abundance of ovigerous females in the Bay. Larvae were present year-round, with summer-fall abundance greater than winter-spring abundance some years. Kuipers and Dapper (1984) believed high mortality due to predation to be a major factor influencing summer-fall abundance of C. crangon post-larvae in

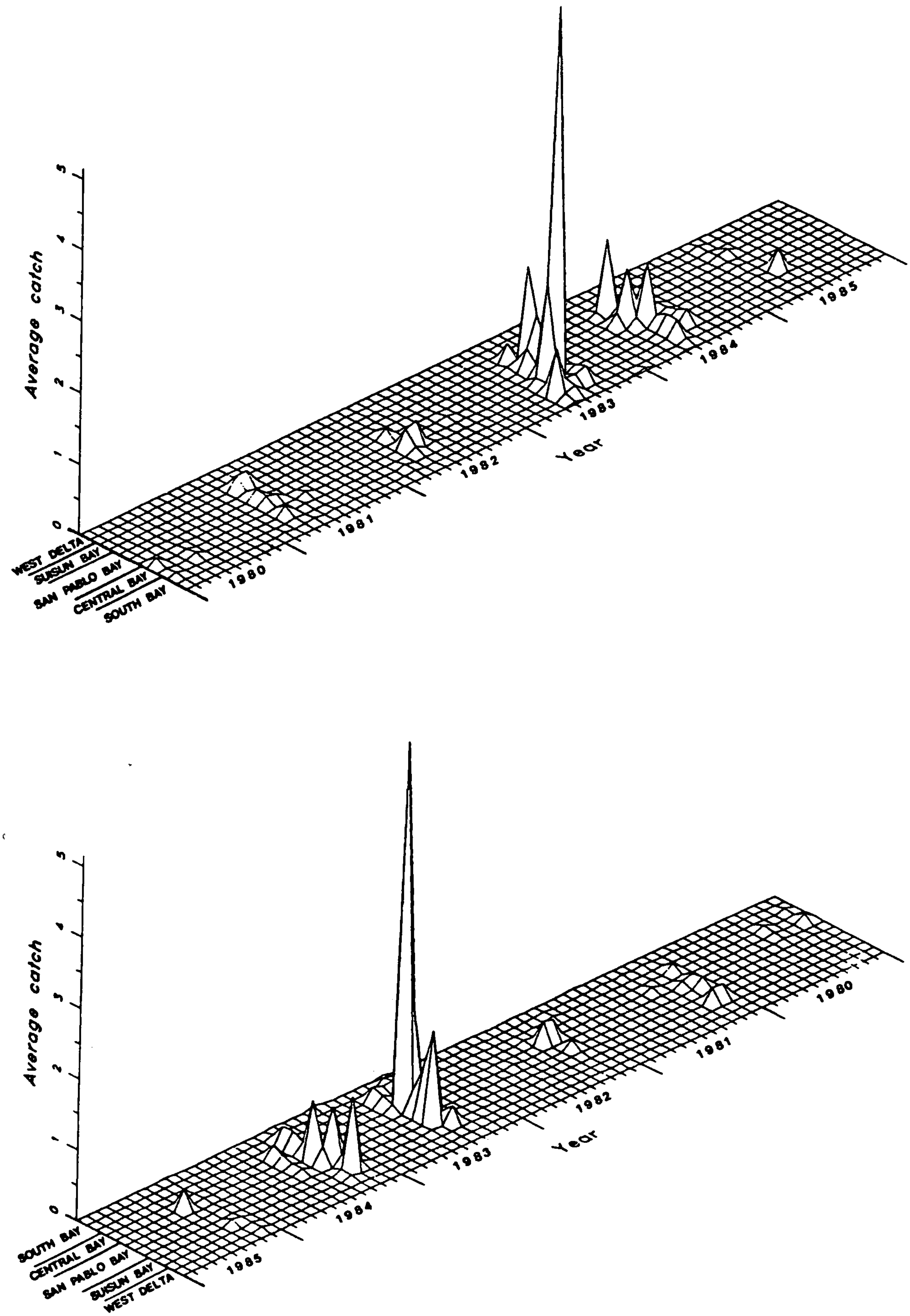


Figure 35. Distribution of <u>Crangon</u> <u>spp</u>. post-larvae.

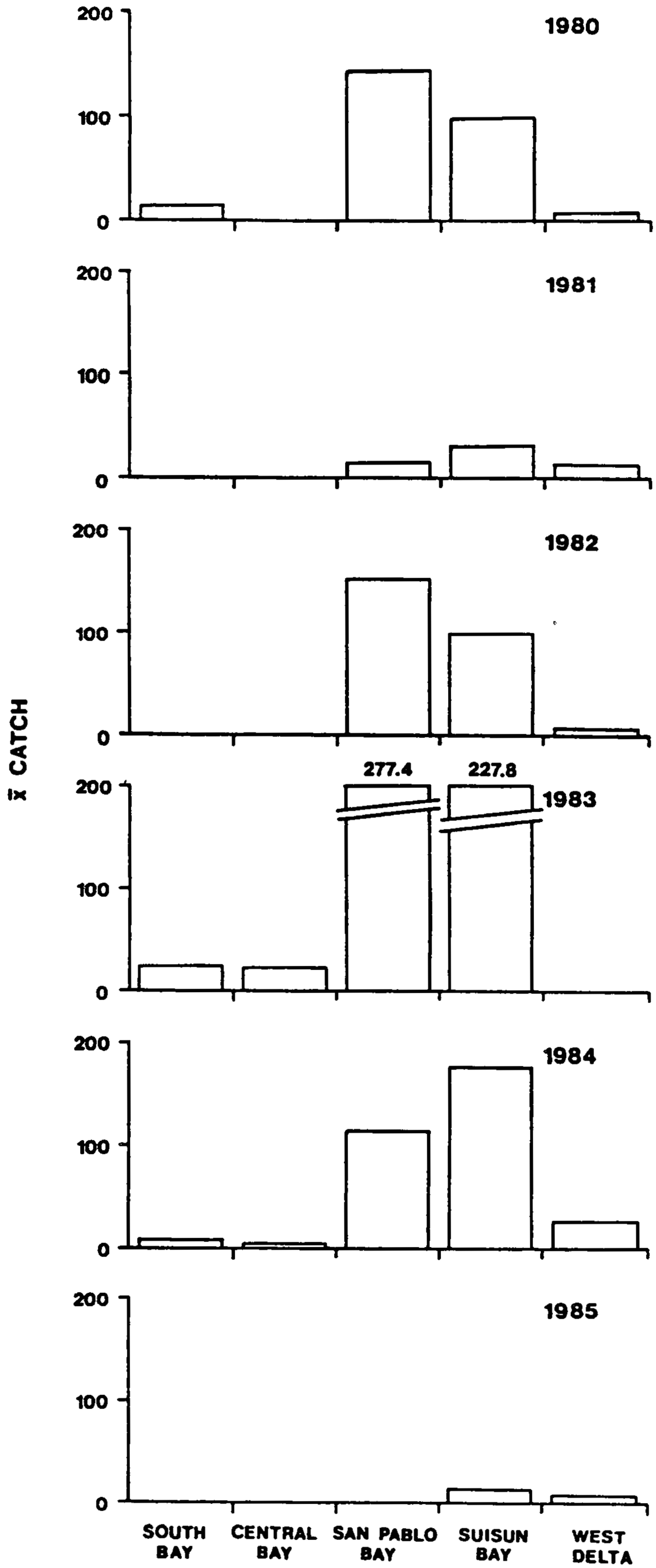


Figure 36. Distribution of juvenile Crangon franciscorum.

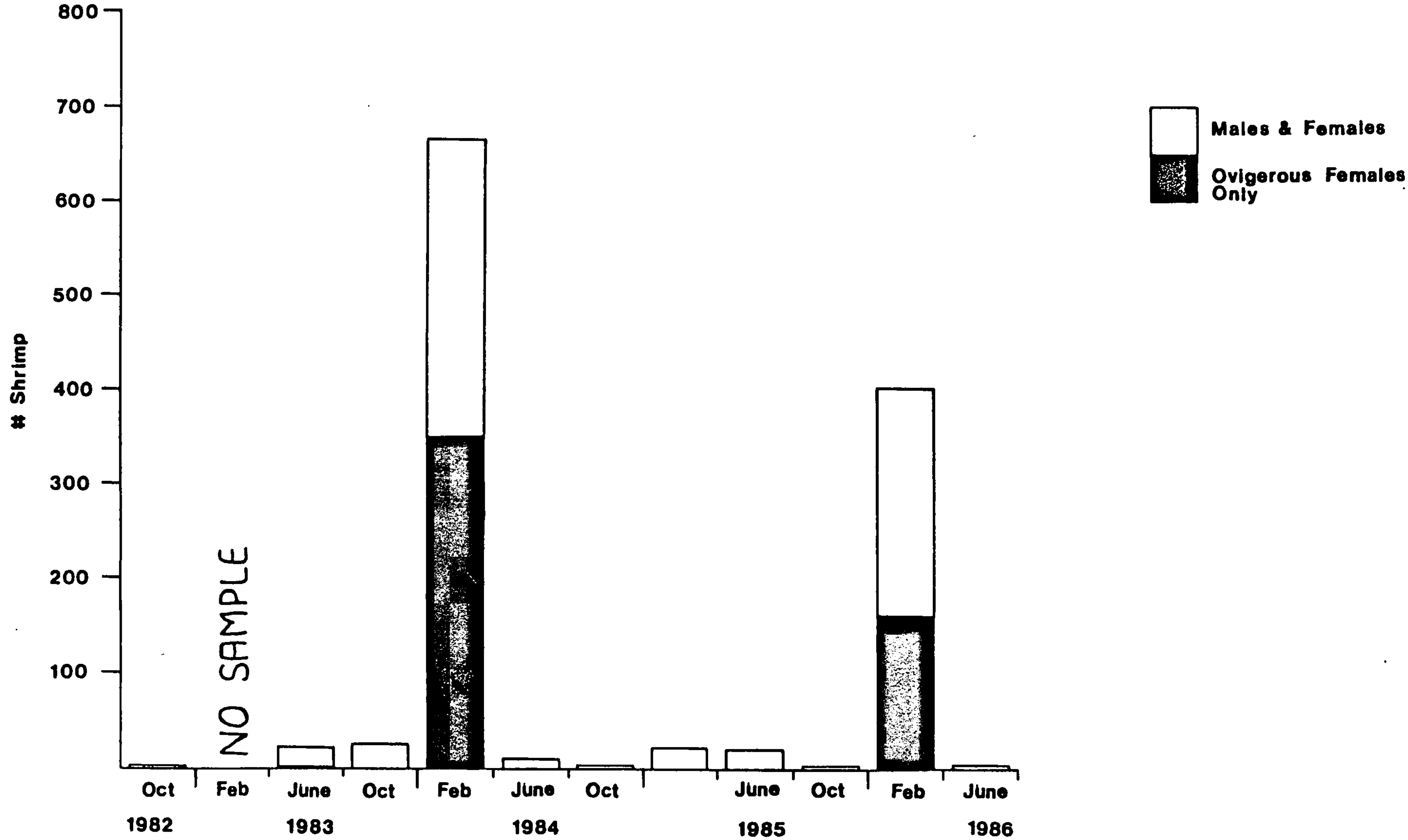


Figure 37. Catches of all sexes and ovigerous Crangon franciscorum at San Francisco Ocean Outfall Monitoring Program near-shore stations (1982-1986).

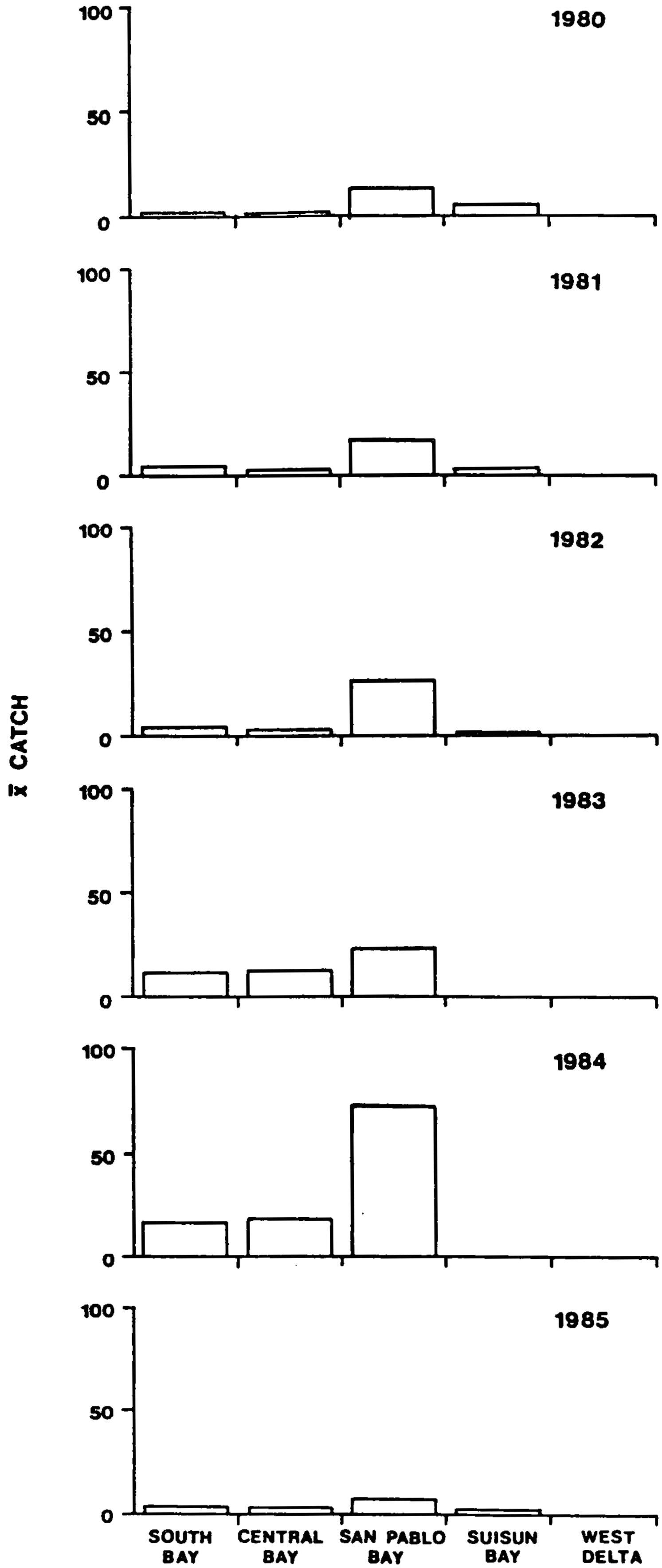


Figure 38. Distribution of ovigerous *Crangon franciscorum*.

the Wadden Sea tidal flats. This is also one of several hypotheses proposed by Kinnetic Laboratories (1985) to explain low fall abundance of juvenile C. franciscorum in South Bay.

Effects of Salinity and Temperature

Crangon franciscorum is classified as a euryhaline species, and we collected it at a wide range of salinities (0.1 to 34.3 ppt) and temperatures (6.3 to 23.9 degrees C). The greatest catches occurred at salinities less than 19 ppt and temperatures greater than 15 degrees C (Figure 39). Some shrimp were collected at relatively high salinities (over 30 ppt) and temperatures (over 20 degrees C); most of these were in South Bay.

Ovigerous females were collected at a narrower range of salinities (Table 5). The average salinity also increased by egg stage. This is consistent with the hypothesis that mature shrimp migrate to higher salinity waters.

C. franciscorum utilized Suisun Bay to greater extent in 1981 and 1985 than in other years. Salinities were generally between 10 and 15 ppt in this embayment in 1981 and 1985 (Figure 6). No shrimp were collected upstream of Suisun Bay in 1983 (and few in 1982), when salinities averaged less than 1 ppt in the western Delta.

Effects of Delta Outflow

Many factors may affect the abundance of Crangon franciscorum in the Bay:

* Currents that carry larvae and postlarvae away from or to a nursery area,
* Amount of suitable habitat available,
* Broodstock size,
* Predation,
* Food supply,
* Disease, and
* Parasites.

Delta outflow is one quantifiable parameter that would affect currents (both seaward- and landward-flowing), salinity regime (and consequently amount of suitable habitat), and possibly food supply and abundance of predators.

Larval Crangon abundance has a mixed relationship with winter-spring outflow. The early and mid-stage larvae have a strongly negative relationship with December-May outflow ($r=-0.823$ for stages I and II; $r=-0.627$ for stage III, $r=-0.654$ for stages IV and V). The late stage larvae (VI and VII) have

Table 5

AVERAGES AND RANGES OF SALINITY FOR CRANGON FRANCISCORUM OVIGEROUS FEMALES, BY EGG STAGE

Egg Stage	Average Salinity	Minimum Salinity	Maximum Salinity
1	20.0 ppt	0.1 ppt	33.8 ppt
2	20.2	0.6	33.3
3	23.3	3.4	34.3
4	24.6	3.7	34.3

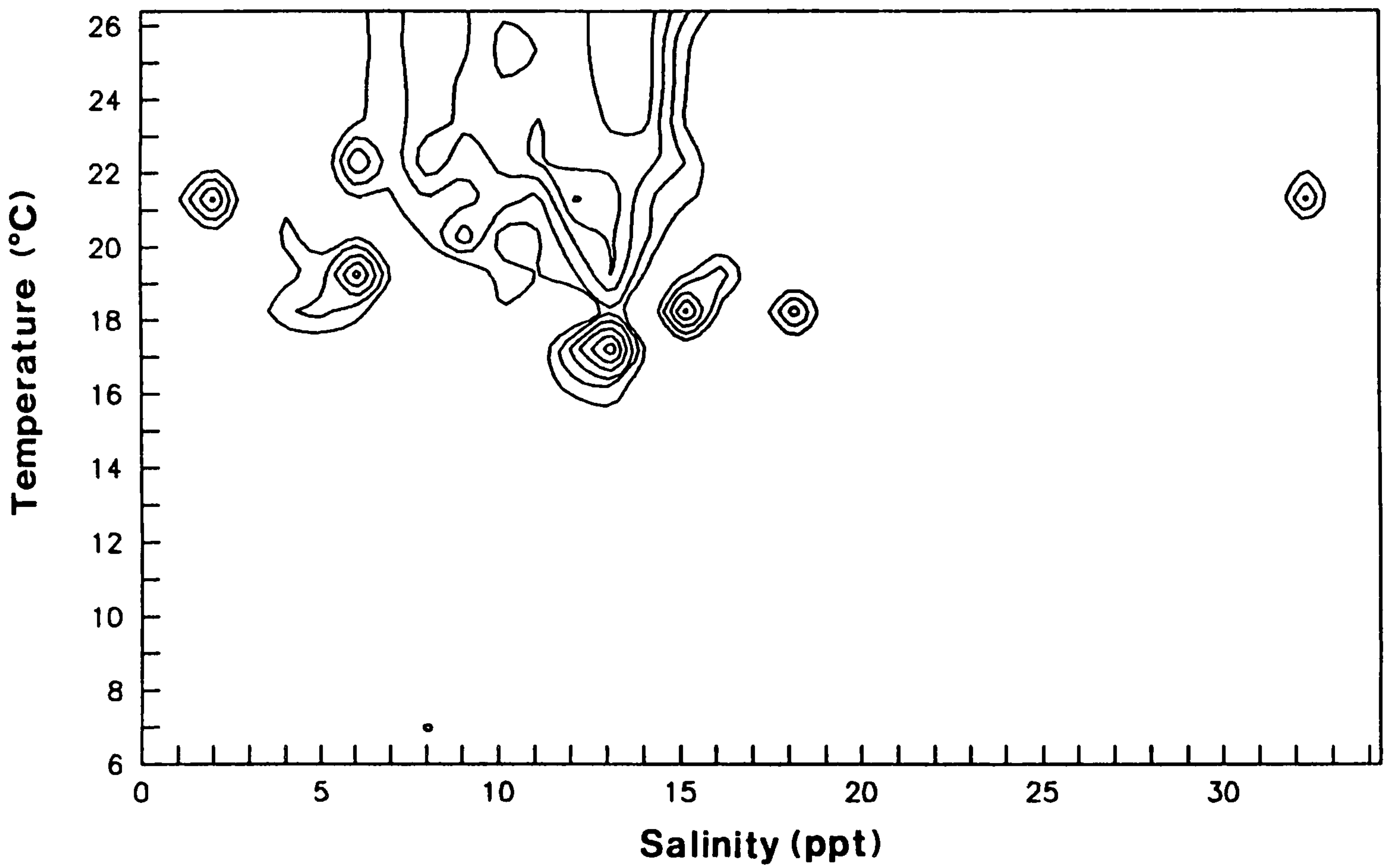


Figure 39. Mean catch of *Crangon franciscorum* vs. salinity and temperature (contours from 2000 to 8000, every 1000).

a positive relationship with December-May outflow (r=0.529). The December-May period was selected for this analysis because it is believed to most affect Crangon larval abundance. The negative relationship between early and mid-stage larvae (which are in the upper portion of the water column) and outflow is consistent with the recruitment mechanism for C. franciscorum proposed by Hatfield (1985). Larvae hatched inside the Bay are carried to the near-shore coastal area, especially during periods of high outflow.

Post-larval Crangon annual abundance has a strongly positive relationship with outflow (r=0.737). February-May outflow was used for this correlation because this period corresponds to the peak abundance of this size class. This relationship also supports the recruitment mechanism proposed by Hatfield (1985). If post-larvae utilize tidal and non-tidal currents to aid movement into the Bay, this positive relationship would be expected (assuming the magnitude of non-tidal currents is positively related to the magnitude of Delta outflow).

Annual abundance of juvenile C. franciscorum is strongly related to outflow (r=0.884, $p<0.01$) (Figure 40). Outflow for March-May was used for this correlation, as this period generally corresponds to peak abundance of juveniles. Annual abundance of all sizes of C. franciscorum also has a significant relationship with March-May outflow (r=0.818, $p<0.05$) (Figure 41). This is expected because shrimp from that year class (not the previous one) dominate the annual catch. There is not a strong relationship between abundance of ovigerous females (all or any egg stage) and outflow (although all the correlation coefficients were positive).

C. franciscorum may be more abundant upstream of our sampling sites and in tidally influenced sloughs during low outflow years. During two years of extremely low outflow (1931 and 1977), more C. franciscorum were collected upstream of our study area on the Sacramento and San Joaquin rivers than during years of higher outflow (Israel, 1936; Siegfried, 1980). We believe our trends in relative abundances are accurate, in part because post-larval and juvenile abundances were low in 1981 and 1985. Kinnetic Laboratories (1986) sampled South Bay sloughs monthly from December 1981 to November 1985 and reported significantly lower abundances during 1985. Midwater trawl data from San Pablo Bay, Suisun Bay, Montezuma Slough, and the western Delta (including areas upstream of our study area) show that Crangon shrimp had lower abundances in 1981 and 1985 than in 1980, 1982, 1983, or 1984. Samples were collected monthly from September through December; only in September 1985 were the greatest catches at an area upstream of our study area (California Department of Fish and Game, unpublished).

The magnitude of Delta outflow apparently affects the timing of the peak abundance of post-larvae and juveniles. In 1983 the peak abundance of these two size classes was one to two months later than in other years. Outflow may have been too high earlier in the year for post-larvae to enter the Bay.

There is some evidence that timing of the peak abundance of ovigerous females may also be related to the magnitude of Delta outflow. In 1981 and 1985, their peak abundance occurred in February; in other years it was from April to July. Winter salinities were higher in the Bay during 1981 and 1985 than in other years (Figure 6). The peak abundance of ovigerous females may have occurred earlier during low outflow years because of their preference for higher salinities.

Delta outflow also affects the amount of habitat available in the Bay for C. franciscorum. A higher proportion of the shrimp population was in

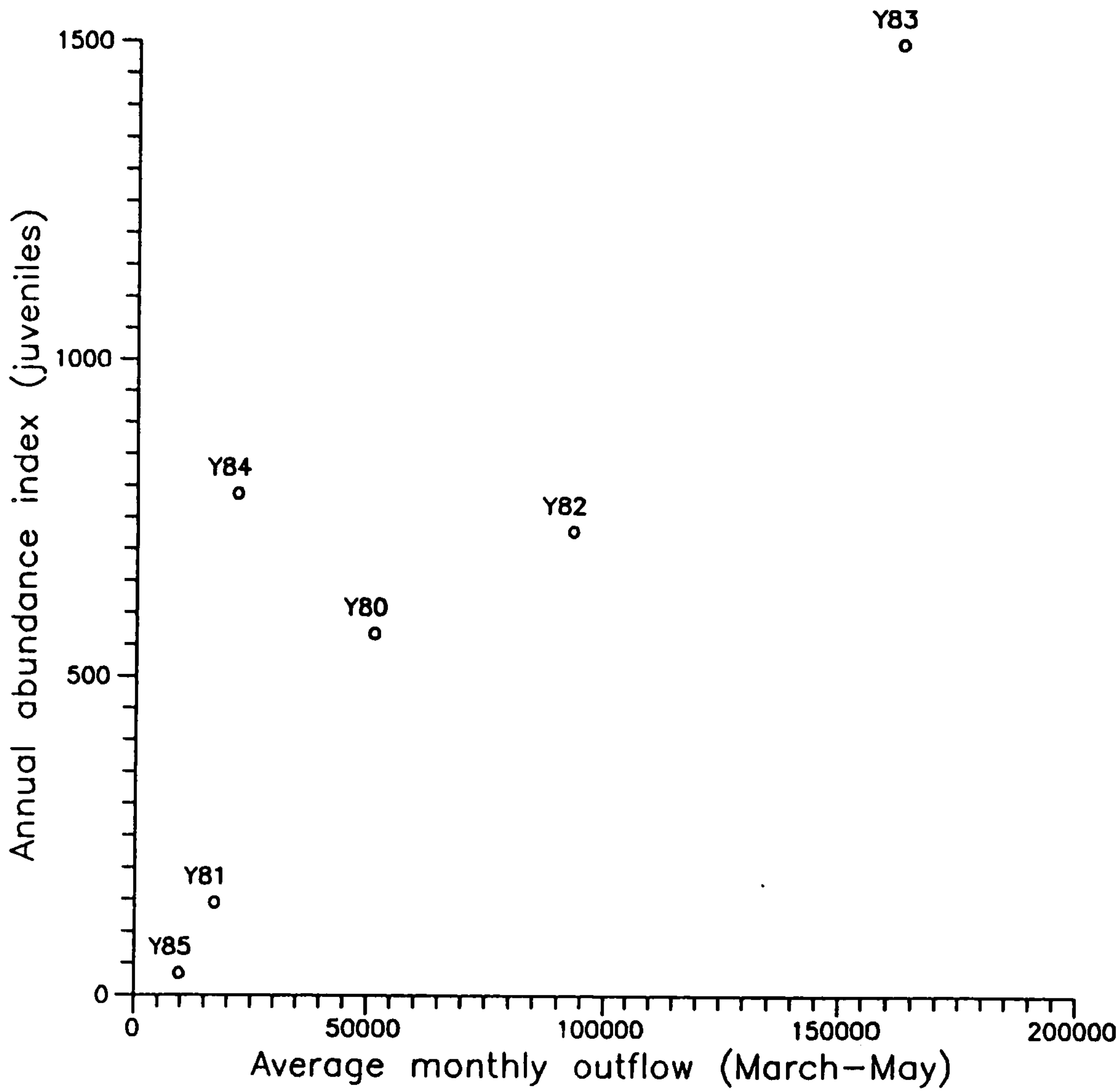


Figure 40. Annual abundance of juvenile <u>Crangon franciscorum</u> vs. outflow (r=0.884).

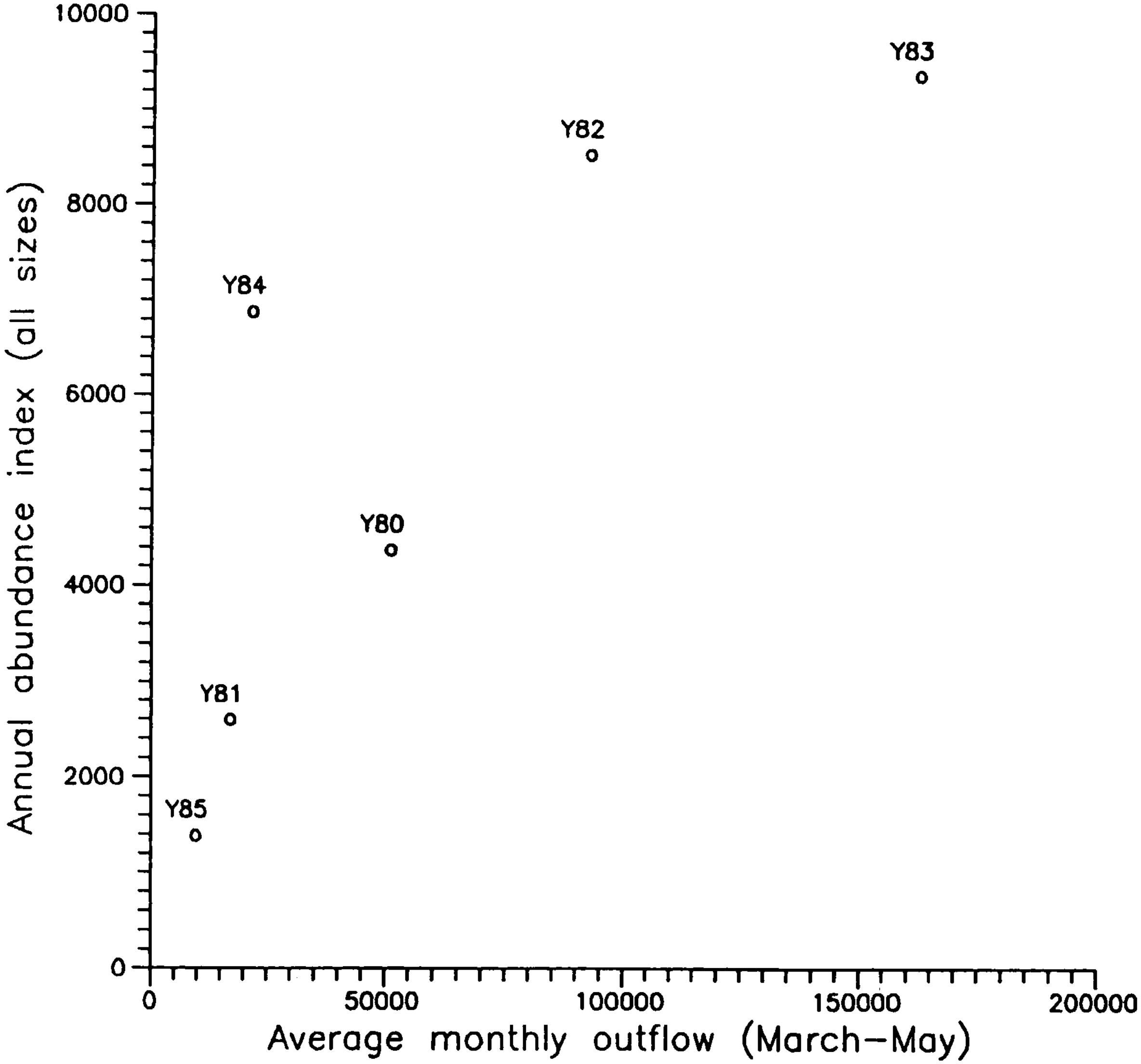


Figure 41. Annual abundance of all sizes of <u>Crangon</u> <u>franciscorum</u> vs. outflow (r=0.818).

Suisun Bay in 1981 and 1985, the years of lowest outflow, than in other years. This shift from San Pablo Bay, which has about three times the area of Suisun Bay, may play a significant role in the growth and survival of shrimp.

Summary

Crangon franciscorum was the most abundant species of shrimp collected by this study from 1980 to 1985. It accounted for almost 90 percent of all shrimp collected in the otter trawl.

C. franciscorum is a euryhaline species, occurring at a very wide range of temperatures and salinities. In the Sacramento-San Joaquin estuary this species was found to be concentrated at salinities less than 20 ppt and temperatures greater than 15 degrees C. Ovigerous females were collected at increasing salinities by increasing egg stage. This, in part, supports other studies that report a migration of mature shrimp to higher salinities.

Our data continue to support the recruitment mechanism proposed by Hatfield (1985) for C. franciscorum. The negative relationship between early and mid-stage larval abundance and December-May outflow indicates that these larvae are carried from the Bay, especially during years of high outflow. The positive relationship between post-larval abundance and Delta outflow may be evidence that the movement of this life stage into the Bay is aided by non-tidal currents. The magnitude of spring outflow also influences the timing of peak abundance of post-larvae and juveniles in the Bay. Interaction between the timing and magnitude of Delta outflow and post-larval abundance may be significant in controlling recruitment of C. franciscorum in the Bay.

The amount of suitable habitat available for C. franciscorum in the Bay is related to Delta outflow and the resultant salinity regime. Shrimp utilized Suisun Bay to a greater extent than San Pablo Bay during low outflow years. San Pablo Bay has about three times the area of Suisun Bay, and this shift could have a negative effect on the growth and survival of C. franciscorum.

Crangon nigricauda

Crangon nigricauda was the second most abundant shrimp collected in the study area from 1980 to 1985. It comprised about 6 percent of the total catch and 11 percent of the weighted total catch (Table 3). C. nigricauda ranges from Baja California to Alaska (Rathbun, 1904) and is found near-shore and in estuaries. This species is smaller than C. franciscorum, with a maximum length of 64 mm for females and 59 mm for males (this study). In Yaquina Bay, Oregon (Krygier and Horton, 1975) females mature at about 40 mm, males at 28 mm. Krygier and Horton also reported females to live a maximum of 1.5 years, males 1 year. C. nigricauda is less tolerant of low salinities than C. franciscorum, and is not distributed as far upstream in the Bay (Israel, 1936; Gannsle, 1966; Siegfried, 1980).

As with other crangonids, there are seasonal migrations of juveniles to lower salinity waters and adults to higher salinity waters (Israel, 1936; Krygier and Horton, 1975). Krygier and Horton (1975) concluded that temperature in the summer and salinity in the winter most affected distribution of adult C. nigricauda in Yaquina Bay. As hypothesized for other crangonids, the seasonal migration of C. nigricauda could be explained as a "search" for the warmest water mass.

Israel (1936) collected ovigerous females throughout the year, with peak abundance from April to September in San Francisco Bay. In Yaquina Bay, there are two peaks of ovigerous females, the first from December to

March and the second from May to August (Krygier and Horton, 1975).

Crangon nigricauda abundance often peaked twice annually, once in winter and once in summer (Figure 42). The highest annual abundance indices were in 1980 and 1983, with all other years relatively low (Table 4). The greatest catches of C. nigricauda were usually in Central Bay (Figure 43). This species utilized Suisun Bay to the greatest extent in 1985. The highest catches in South Bay were usually in winter and spring.

Larval Abundance and Distribution

The larvae of Crangon nigricauda cannot be separated from C. franciscorum, except at stages II and III. The trend was for a fall-winter abundance peak for C. nigricauda stage III larvae (Figure 31b). These larvae may have contributed to the population, as there was a small winter peak in juvenile abundance in 1982 and 1983. No correlations were made between larval abundance and any other abundance indices for this species.

Post-Larval Abundance and Distribution

Timing of the peak abundance of Crangon post-larvae was about one month before the peak abundance of C. nigricauda juveniles. The annual abundance index of C. franciscorum juveniles was 4 to 45 times greater than the C. nigricauda juvenile annual index, so the proportion of post-larvae that were C. nigricauda was highly variable.

Juvenile Abundance and Distribution

Crangon nigricauda juvenile abundance peaked at various periods (Figure 42b), but the trend was for a late spring to summer peak (April-August). Annual abundance was very high in 1980 and 1983 relative to the other years (Table 4). There is not a strong relationship between the annual abundance index of juveniles and ovigerous females (r=0.119). Juvenile C. nigricauda were concentrated in Central and San Pablo bays (Figure 44). They also utilized South Bay every year, but to a greater extent in 1980 and 1983 (years of high abundance). Juveniles were collected upstream of Carquinez Strait only in 1985, the lowest outflow year.

Ovigerous Female Abundance and Distribution

Peak abundance of ovigerous Crangon nigricauda was also highly variable (Figure 42c). There appears to be a winter-spring peak each year, followed by another peak in summer or fall. There was a general decline in ovigerous female abundance during the fall, but not as definite as for C. franciscorum. A migration of mature shrimp from the Bay is not evident from near-shore data as reported by the San Francisco Ocean Outfall Monitoring Program, as they collected few C. nigricauda. Krygier and Horton (1975) also did not collect many ovigerous females in the near-shore area, but noted the "disappearance" of ovigerous C. nigricauda from Yaquina Bay from mid-September to December.

The highest annual abundance index of ovigerous C. nigricauda was in 1985, the lowest in 1982 (Table 4). Ovigerous C. nigricauda were concentrated in South and Central bays (Figure 45). A few were collected in San Pablo Bay every year except 1983.

Effects of Salinity and Temperature

Crangon nigricauda was collected at a wide range of salinities (0.1-34.4 ppt) and temperatures (6.7-21.1 degrees C). The greatest catches were at salinities greater than 10 ppt and temperatures less than 18 degrees C (Figure 46).

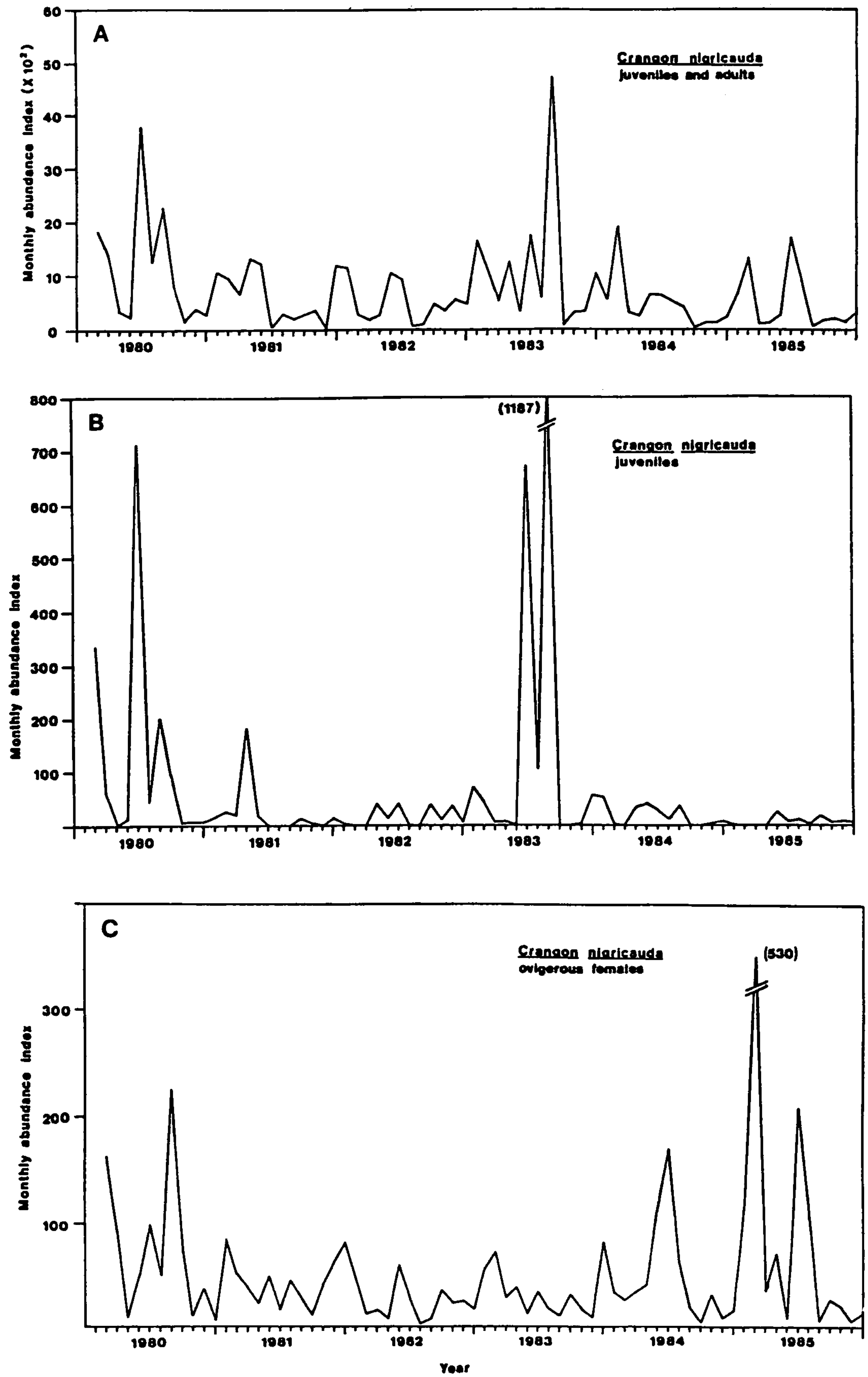


Figure 42. Monthly abundance indices of juvenile, adult, and ovigerous <u>Crangon nigricauda</u>, 1980-1985.

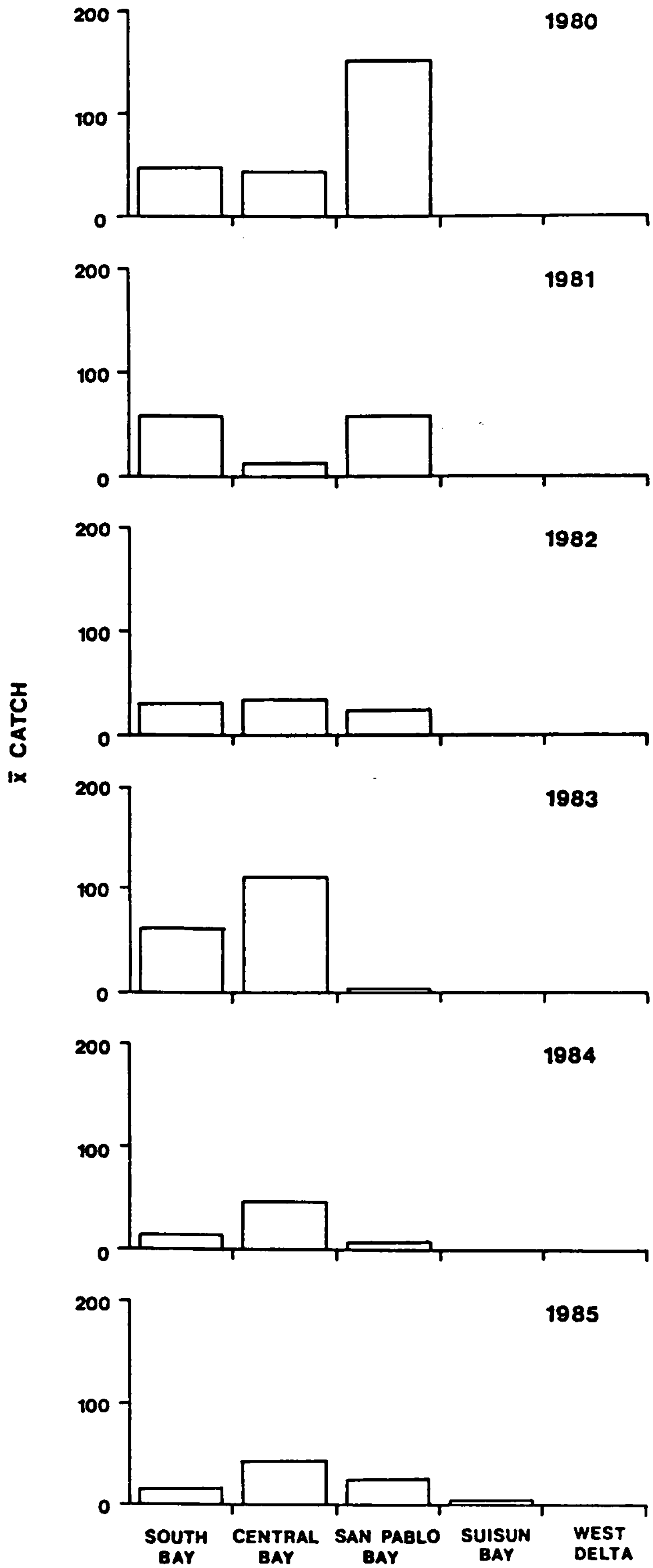


Figure 43. Distribution of juvenile and adult <u>Crangon nigricauda</u>.

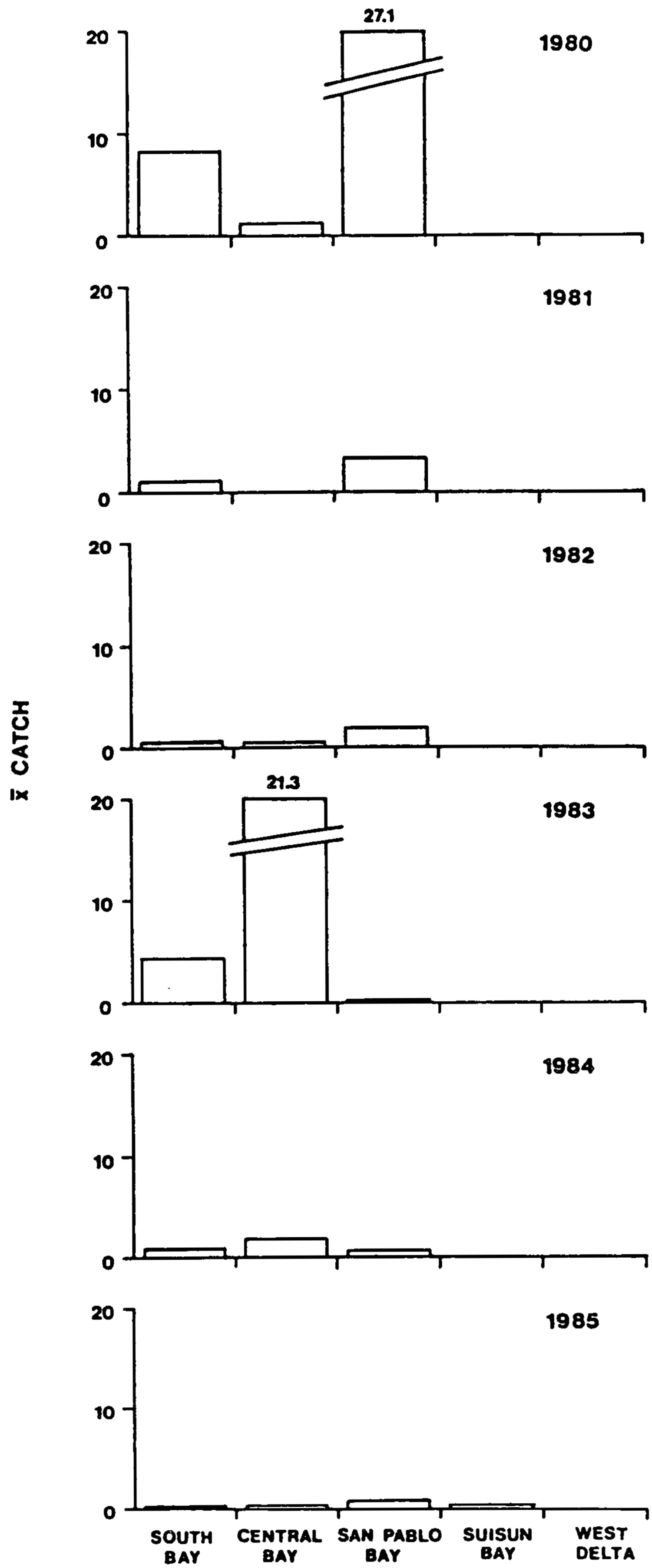


Figure 44. Distribution of juvenile _Crangon nigricauda_.

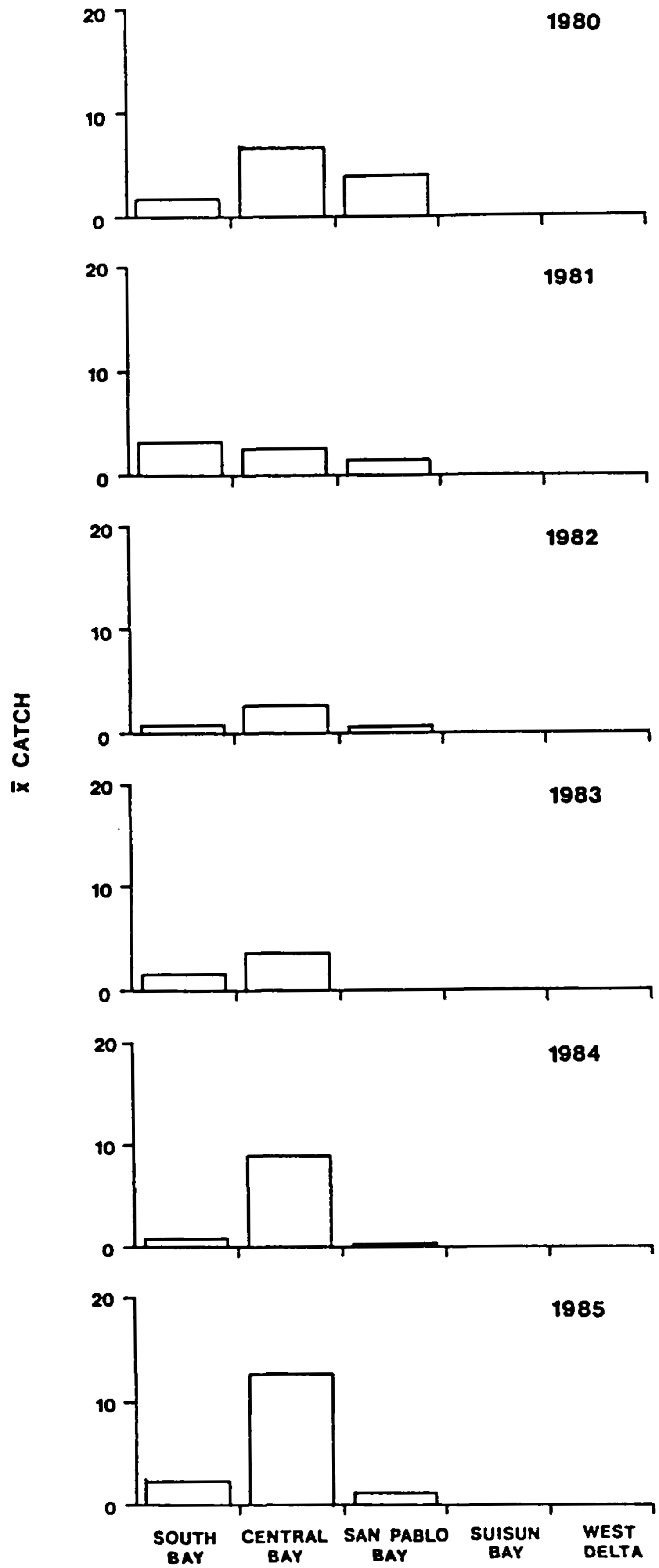


Figure 45. Distribution of ovigerous *Crangon nigricauda*.

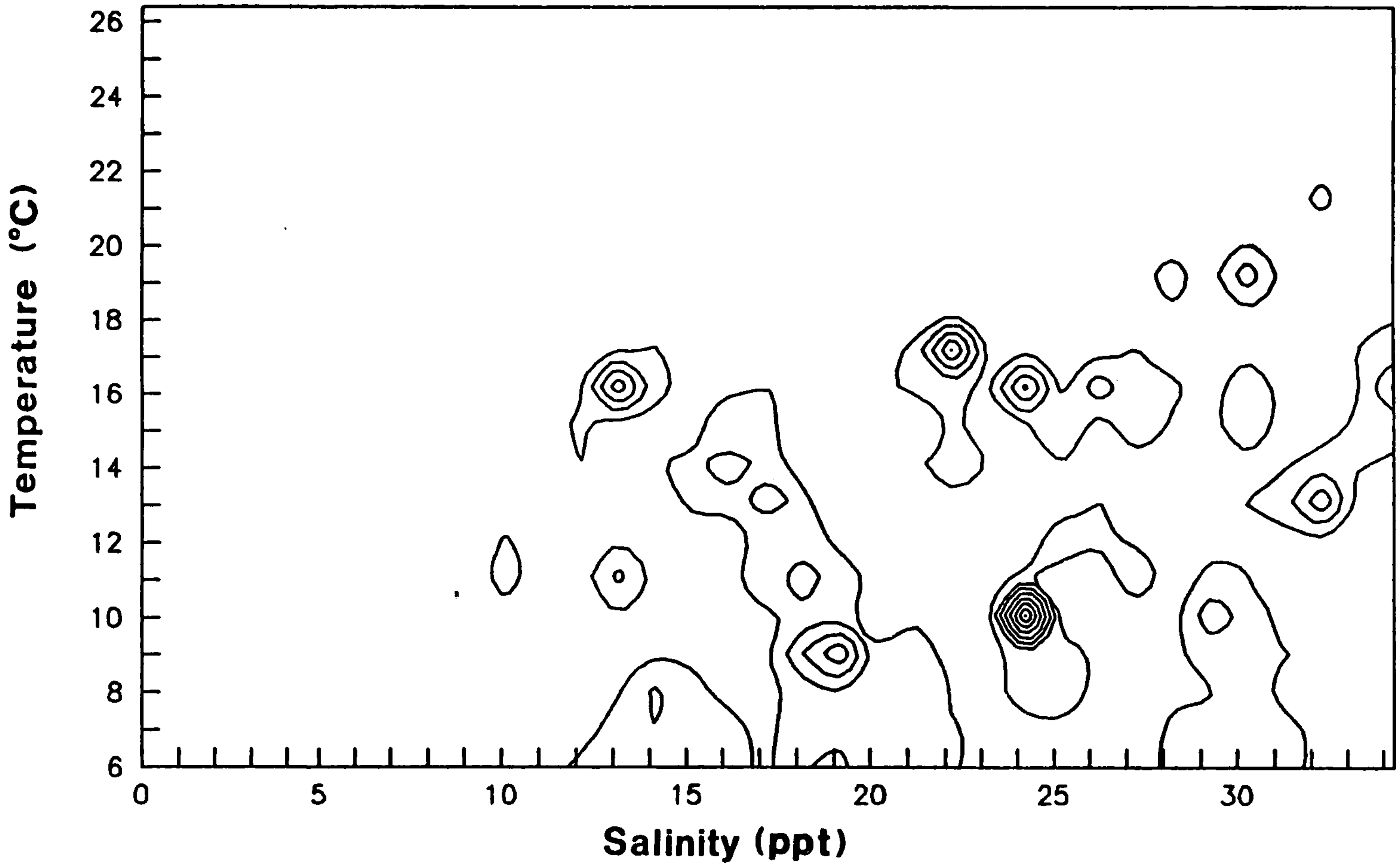


Figure 46. Mean catch of <u>Crangon</u> <u>nigricauda</u> vs. salinity and temperature (contours from 50 to 750, every 100).

The average salinity of ovigerous females was 24.8 ppt, which is higher than reported for ovigerous C. franciscorum.

Effects of Delta Outflow

Crangon nigricauda abundance is positively related to Delta outflow, but this relationship is not as strong as for C. franciscorum. Juvenile abundance has the highest correlation coefficient with outflow (r=0.724) (Figure 47). Outflow for March-May was chosen for this analysis because it corresponds to peak abundance of juveniles. Post-larvae probably move into the Bay from the near-shore area, aided by tidal and non-tidal currents, as proposed for C. franciscorum. The abundance of all sizes and sexes of C. nigricauda is not as strongly correlated with outflow as is juvenile abundance (r=0.582). There is a negative relationship between the annual abundance of ovigerous females and December-February outflow (r=-0.303). Again this outflow period was selected because it corresponds with the peak abundance of ovigerous females in the Bay.

Because of its preference for higher salinities, C. nigricauda only occasionally utilized the area upstream of Carquinez Strait. There may be more area available to this species in the Bay during low outflow years, but there were not more C. nigricauda in the Bay during these years. Although this species prefers higher salinities than C. franciscorum, it does not "replace" it during years that salinities are higher in the Bay.

Summary

Crangon nigricauda was the second most abundant species of shrimp collected by this study in the Bay. It accounted for 6 percent of all shrimp caught in the otter trawl. C. nigricauda was collected at higher salinities and lower temperatures than C. franciscorum, the most abundant shrimp species. It primarily utilized South, Central, and San Pablo bays. Juveniles were usually most abundant in the Bay from April to August. There is a strongly positive relationship between juvenile abundance and Delta outflow. This species may have the same recruitment mechanism proposed for C. franciscorum. C. nigricauda does not "replace" C. franciscorum during years of low Delta outflow.

Palaemon macrodactylus

Palaemon macrodactylus was the third most abundant shrimp species in this study, comprising about 3 percent of the total catch and 2 percent of the weighted total catch for 1980-1985 (Table 3). This species was introduced from the Orient in the 1950s (Newman, 1963); San Francisco Bay is thought to be its northern limit along the West Coast. P. macrodactylus is now common upriver of Carquinez Strait (Gannsle, 1966; Siegfried, 1980) and in the South Bay sloughs (Kinnetic Laboratories, 1986). It is apparently more tolerant of low salinities combined with low temperatures than is Crangon franciscorum (Siegfried, 1980). Seven larval stages have been reported for P. macrodactylus (Little, 1969). The main recruitment period in the estuary is from May to September (Siegfried, 1980).

The peak abundance of Palaemon macrodactylus in the Bay was usually from June to September (Figure 48a). It is assumed that many of these shrimp were immature, yet we did not collect many P. macrodactylus that we could not sex. The lowest annual abundance index was in 1983, the highest in 1984 (Table 4). This species was collected primarily upstream of Carquinez Strait and in the southernmost portion of South Bay (Figure 49). San Pablo Bay was utilized at various times, but not

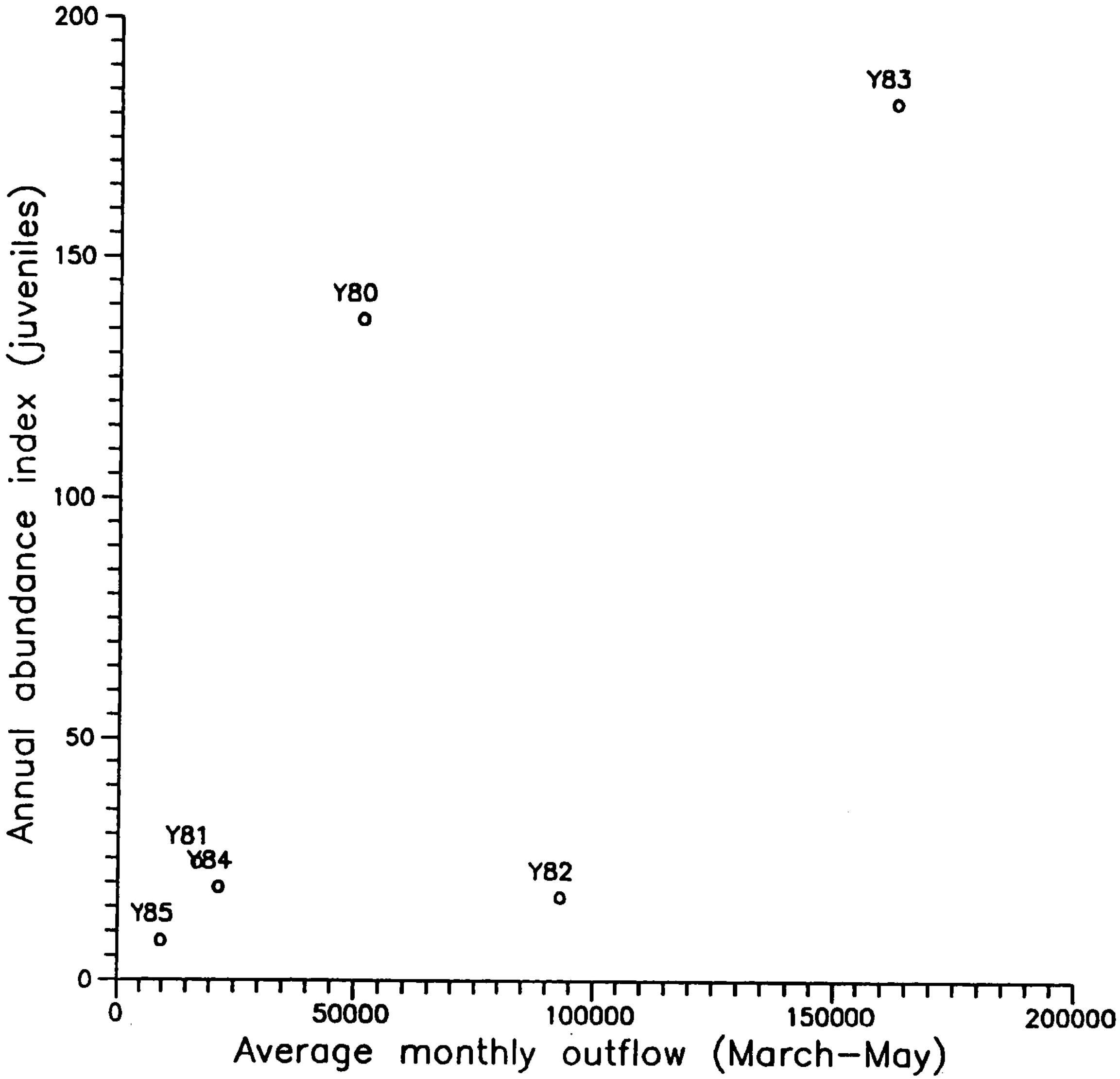


Figure 47. Annual abundance of juvenile Crangon nigricauda vs. outflow (r=0.724).

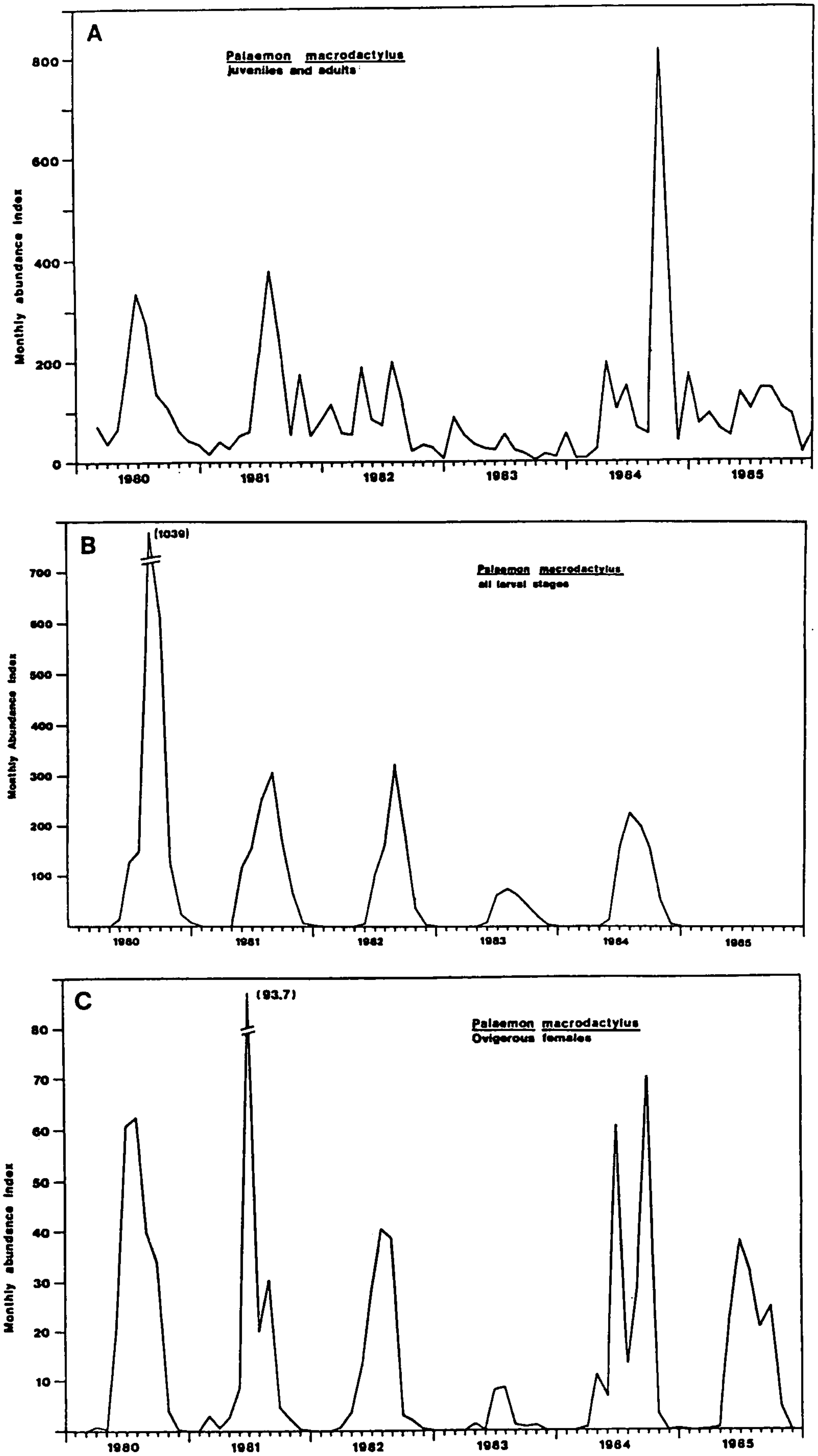


Figure 48. Monthly abundance indices of larval, juvenile, adult, and ovigerous Palaemon macrodactylus, 1980-1985.

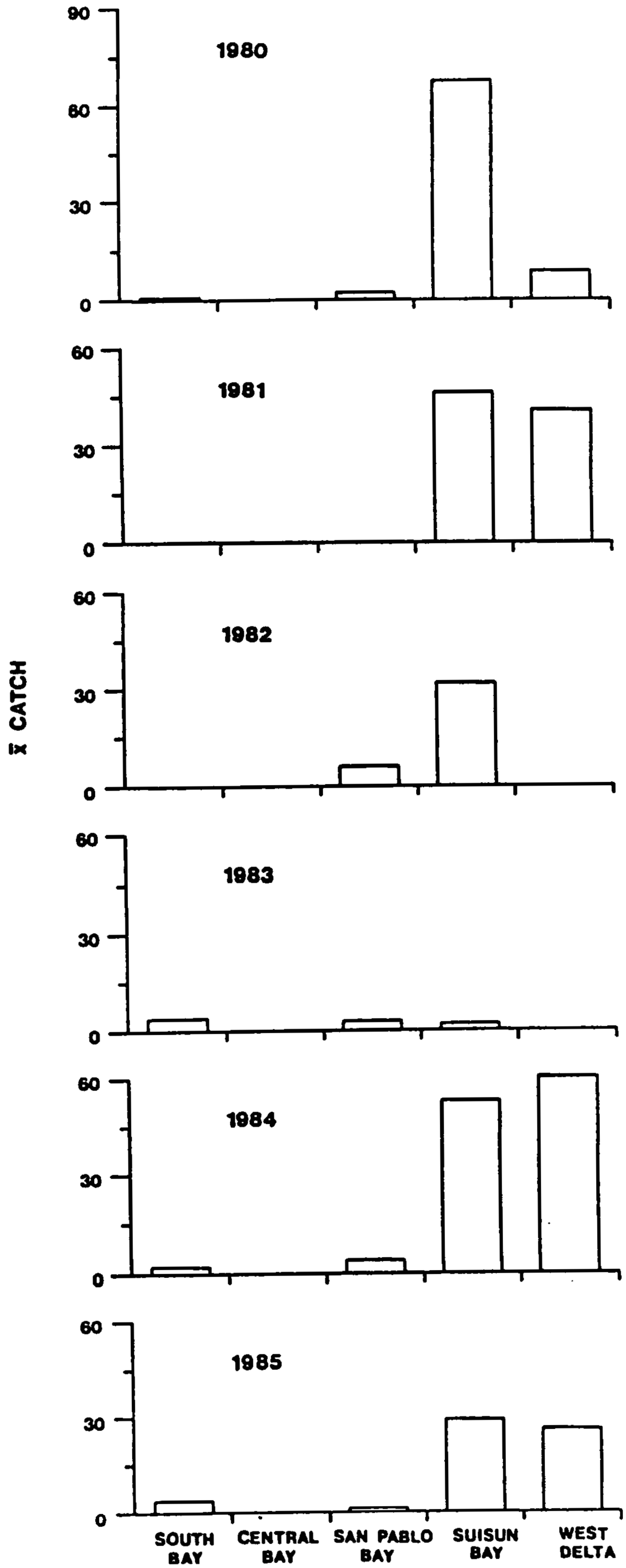


Figure 49. Distribution of juvenile and adult *Palaemon macrodactylus*.

during the summers of 1981 or 1985 when salinities averaged greater than 22 ppt in this embayment (Figure 6). In all years except 1982 and 1983, P. macrodactylus were collected at the stations farthest upstream. Shrimp were collected at these stations until November 1980, 1981, and 1984, and through December 1985, when salinities averaged greater than 1 ppt in this area.

Larval Abundance and Distribution

Larval Palaemon macrodactylus were most abundant from May to September (Figure 48b). Unlike Crangon larvae, they were not collected in all months. The highest annual abundance index was in 1980, about double any other year (Table 4). As with adults, the lowest abundance index was in 1983. There is a strong correlation between the annual abundance of larvae and ovigerous females (r=0.934). Few post-larvae were collected in the plankton net, so no data are presented for this size class.

Larvae were collected throughout the Bay (Figure 50). They were usually concentrated in Suisun Bay, but in 1983 the highest catches were in San Pablo Bay. There were relatively high catches at our southernmost station every year.

Ovigerous Female Abundance and Distribution

There was a distinct summer (May-September) peak abundance of ovigerous Palaemon macrodactylus in the Bay (Figure 48c). Abundance was very low in other months. The lowest annual abundance index of ovigerous females was in 1983, the highest in 1980 (Table 4). Ovigerous P. macrodactylus were concentrated upstream of Carquinez Strait, with relatively low catches in South and San Pablo bays (Figure 51). Ovigerous P. macrodactylus were not collected at the stations farthest upstream in 1982 and 1983.

Effects of Salinity and Temperature

Palaemon macrodactylus was collected at a wide range of salinities (0.1-33.9 ppt) and temperatures (6.3-23.8 degrees C). The greatest catches of shrimp were at salinities less than 15 ppt and temperatures over 17 degrees C (Figure 52). Ovigerous females were collected at an average salinity of 8.7 ppt, which is lower than averages reported for ovigerous Crangon franciscorum and C. nigricauda.

Effects of Delta Outflow

Palaemon macrodactylus abundance and distribution are affected by the magnitude of Delta outflow. Abundance of all sizes and abundance of ovigerous females are negatively affected by spring-summer outflow (May-August is used for these analyses because it corresponds to the peak abundance of this species). The correlation between annual abundance of all sizes and outflow is strongly negative, but not significant (r=-0.792) (Figure 53). There is a significant correlation between the annual abundance of ovigerous P. macrodactylus and outflow ($r=-0.823$, $p<0.05$) (Figure 54).

The negative effect of outflow was most apparent in 1983. It is possible that larvae were swept by currents to unsuitable habitat that year, but there were few ovigerous females present to contribute larvae. The highest abundance of P. macrodactylus was in 1984, a moderate outflow year, not during the lowest outflow years. Neither extremely high nor low outflow may be beneficial to this species.

P. macrodactylus were usually limited to the upper portion of the estuary and to South Bay. In 1982 and 1983, higher

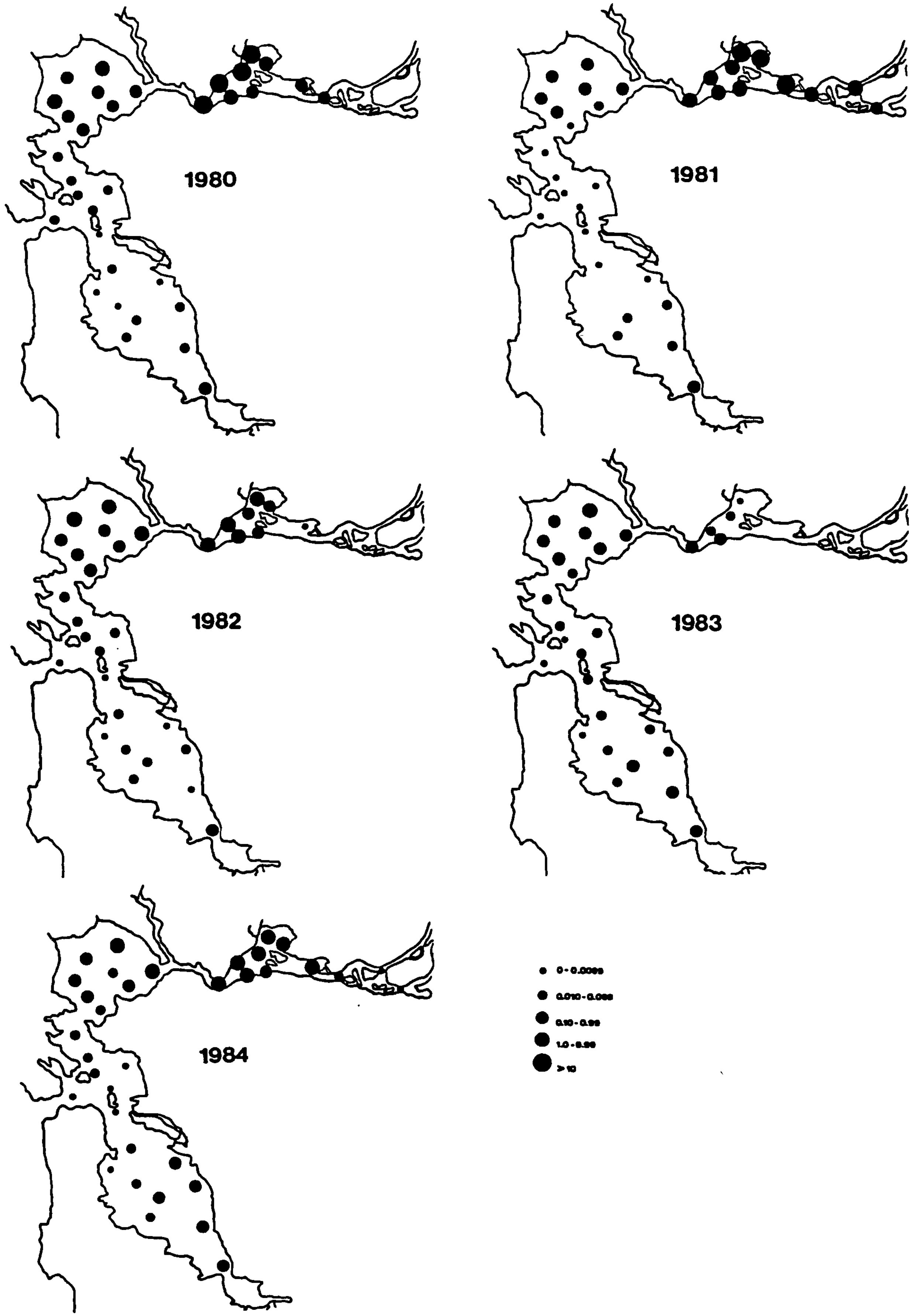


Figure 50. Distribution of larval Palaemon macrodactylus.

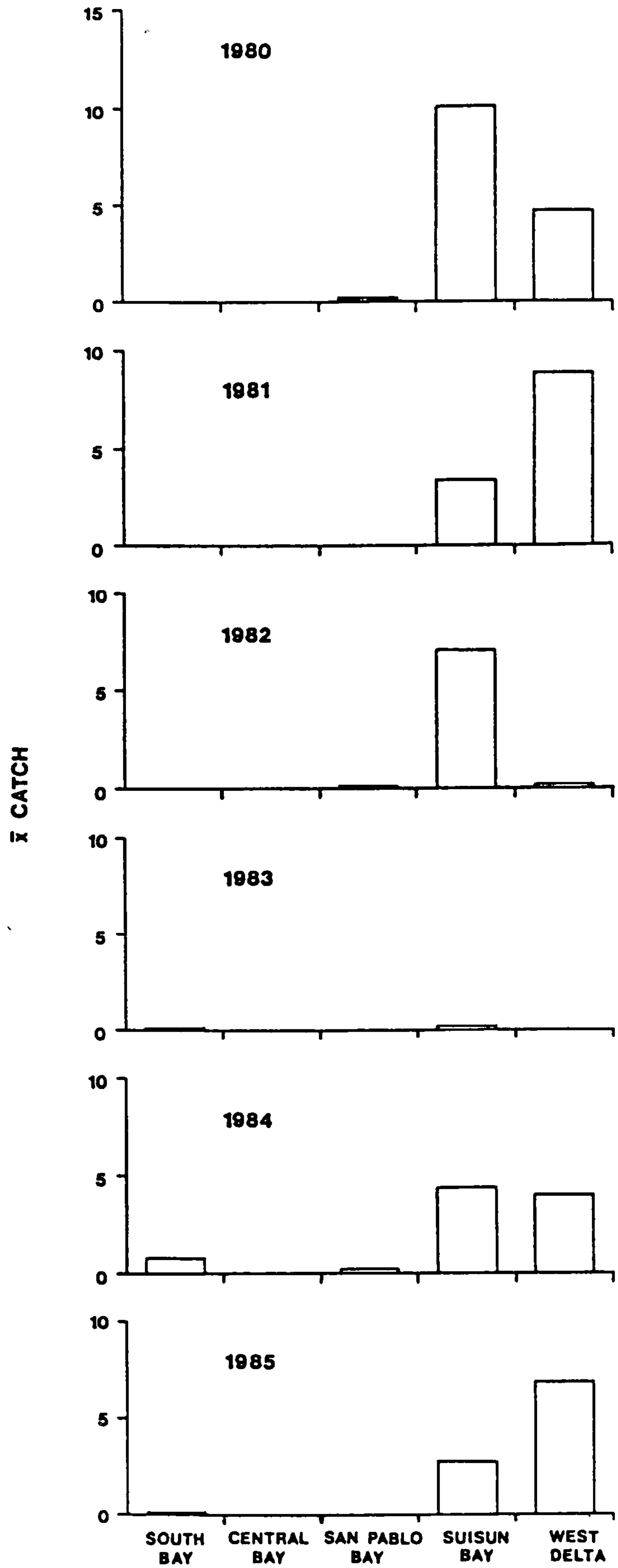


Figure 51. Distribution of ovigerous Palaemon macrodactylus.

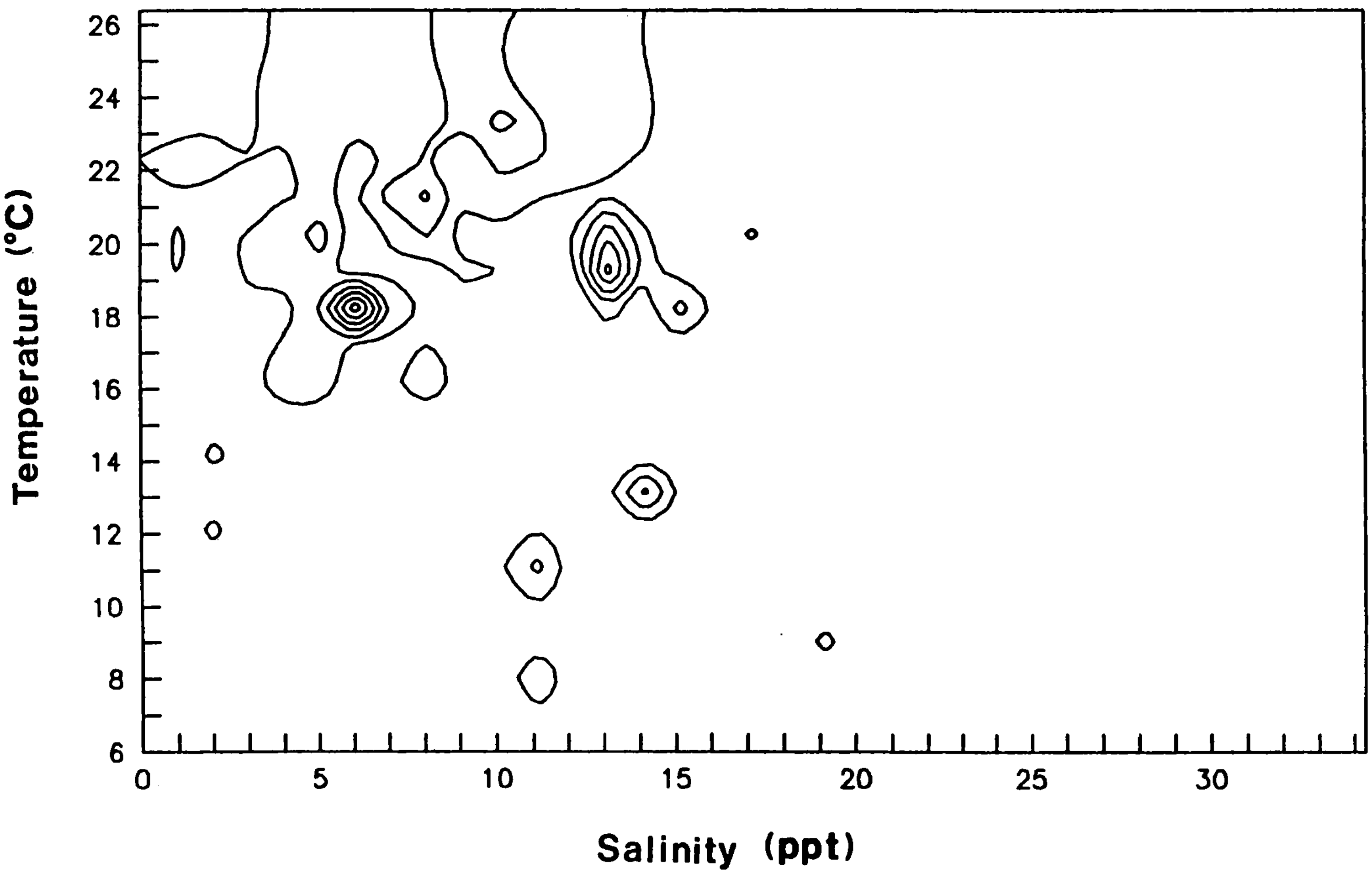


Figure 52. Mean catch of <u>Palaemon macrodactylus</u> vs. salinity and temperature (contours from 50 to 500, every 75).

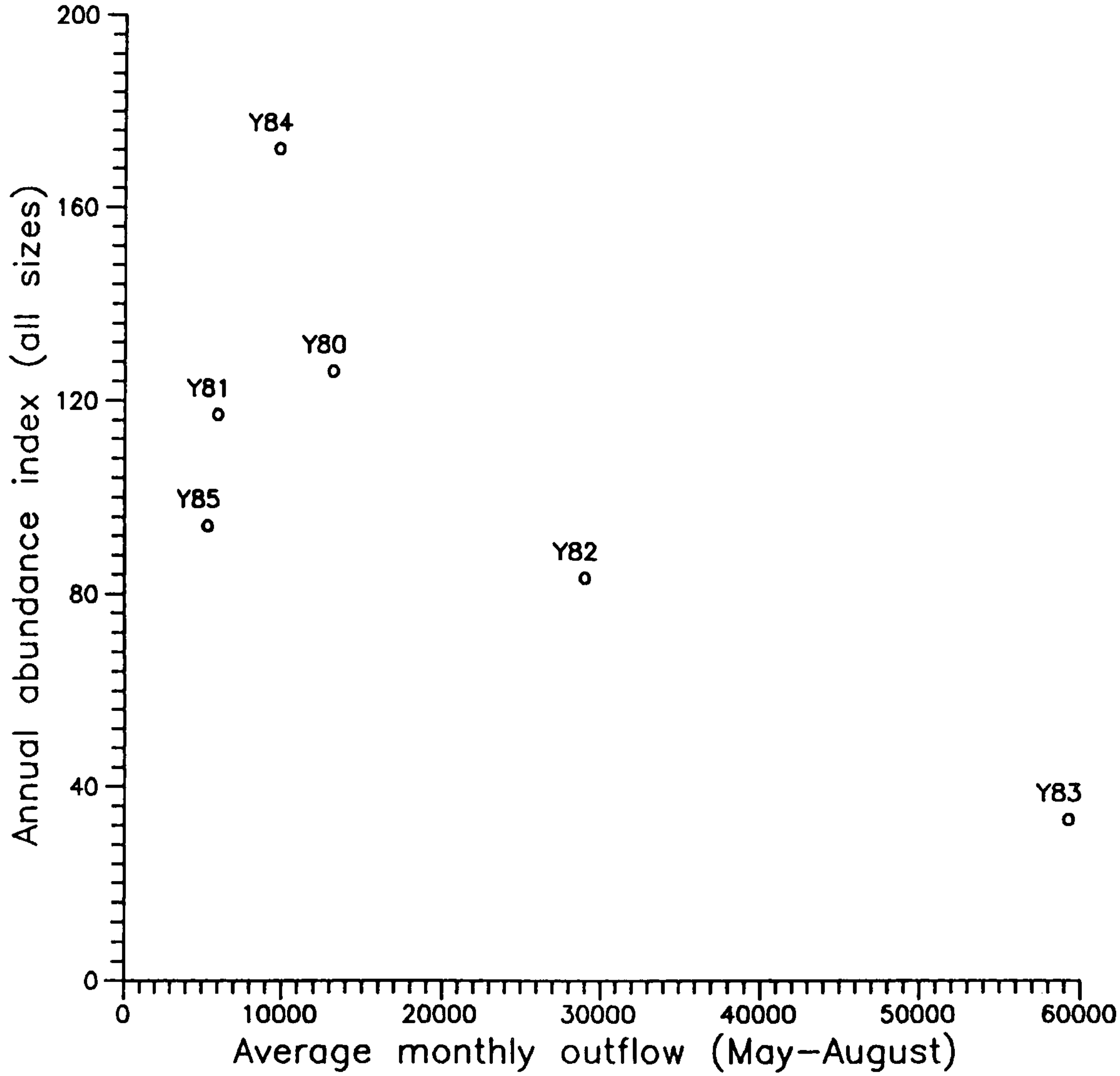


Figure 53. Annual abundance of all sizes of *Palaemon macrodactylus* vs. outflow (r=-0.792).

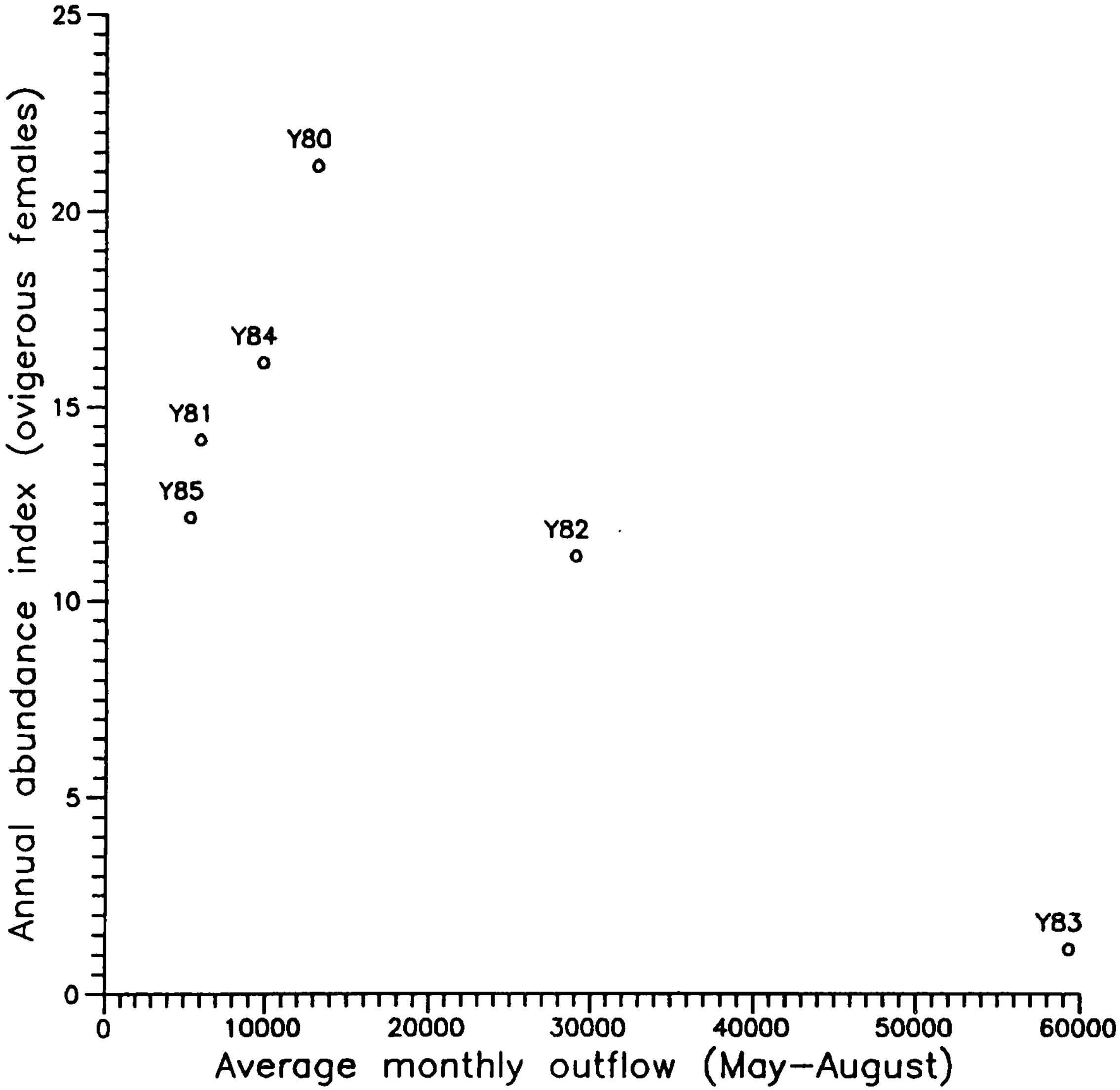


Figure 54. Annual abundance of ovigerous Palaemon macrodactylus vs. outflow (r=-0.823).

outflow shifted the population downstream. This movement may be in response to low salinities upstream in conjunction with more larvae being swept downstream these years and settling out lower in the Bay.

P. macrodactylus have been collected upstream of our study area and in tidal creeks and sloughs in large numbers during low outflow years. Siegfried et al (1978) found P. macrodactylus concentrated above Chipps Island in 1977, a very low outflow year. Downstream of Chipps Island, they were collected in Montezuma Slough and Suisun Cutoff, rather than in the channels. Midwater trawl data from 1980 to 1985 indicated that lowest abundances of P. macrodactylus were in 1982, 1983, and 1985; highest abundance was in 1984. Highest catches were in Montezuma Slough or in the Sacramento River upstream of our study area several months during 1981, 1984, and 1985 (California Department of Fish and Game, unpublished). Abundance of P. macrodactylus in the South Bay sloughs was higher in 1981 and 1985 than any other year from 1980 to 1985 (Marty Stevenson, Kinnetics Laboratory, personal communication). This species may be more abundant in the Bay during low outflow years (1981 and 1985) than our data indicate. This would strengthen the negative relationship between outflow and abundance.

Summary

Palaemon macrodactylus, an introduced species, was the third most abundant shrimp species collected by this study. It accounted for approximately 3 percent of the otter trawl catch. The peak abundance of adults and larvae occurred in the summer and fall months. P. macrodactylus primarily utilized the area upstream of Carquinez Strait and South Bay. There was a shift in distribution to areas farther downstream in 1982 and 1983. There is a strong negative relationship between abundance and spring-summer Delta outflow. Abundances of adults and larvae were significantly lower in 1983, the year of highest outflow. Years of moderate outflow (rather than low outflow) may be most beneficial to this species.

Crangon nigromaculata

Crangon nigromaculata, the fourth most abundant shrimp species collected by this study, comprised 1.1 percent of the total catch and 1.7 percent of the weighted total catch (Table 3). Its geographic range is more limited than C. franciscorum or C. nigricauda, as it has been collected from the Gulf of the Farallones to Baja California (Rathbun, 1904). C. nigromaculata was more abundant outside the Bay than inside, and was collected only in Central Bay and the northern portion of the South Bay by the "Albatross" survey in 1912 and 1913 (Schmitt, 1921). It has rarely been collected in the southernmost portion of South Bay (Kinnetic Laboratory, 1986); Gannsle (1966) did not collect this species in San Pablo Bay in 1963 and 1964. C. nigromaculata has been of minor importance to the shrimp fishery (Bonnot, 1931). Little is known of its life history or biology in San Francisco Bay.

Peak abundance of C. nigromaculata usually occurred from June to August (Figure 55a). Exceptions were in 1981 when a small peak occurred in January and in 1985 when the peak was in February. There was also a large peak in December 1983. Also in 1983, no shrimp were collected from March to June, followed by a dramatic increase in the abundance index. The annual abundance index of all sizes (juveniles and adults) was highest in 1983 and lowest in 1981 (Table 4). There may be a relationship between the size of one year class and the next, as the second highest abundance index was in 1984 and

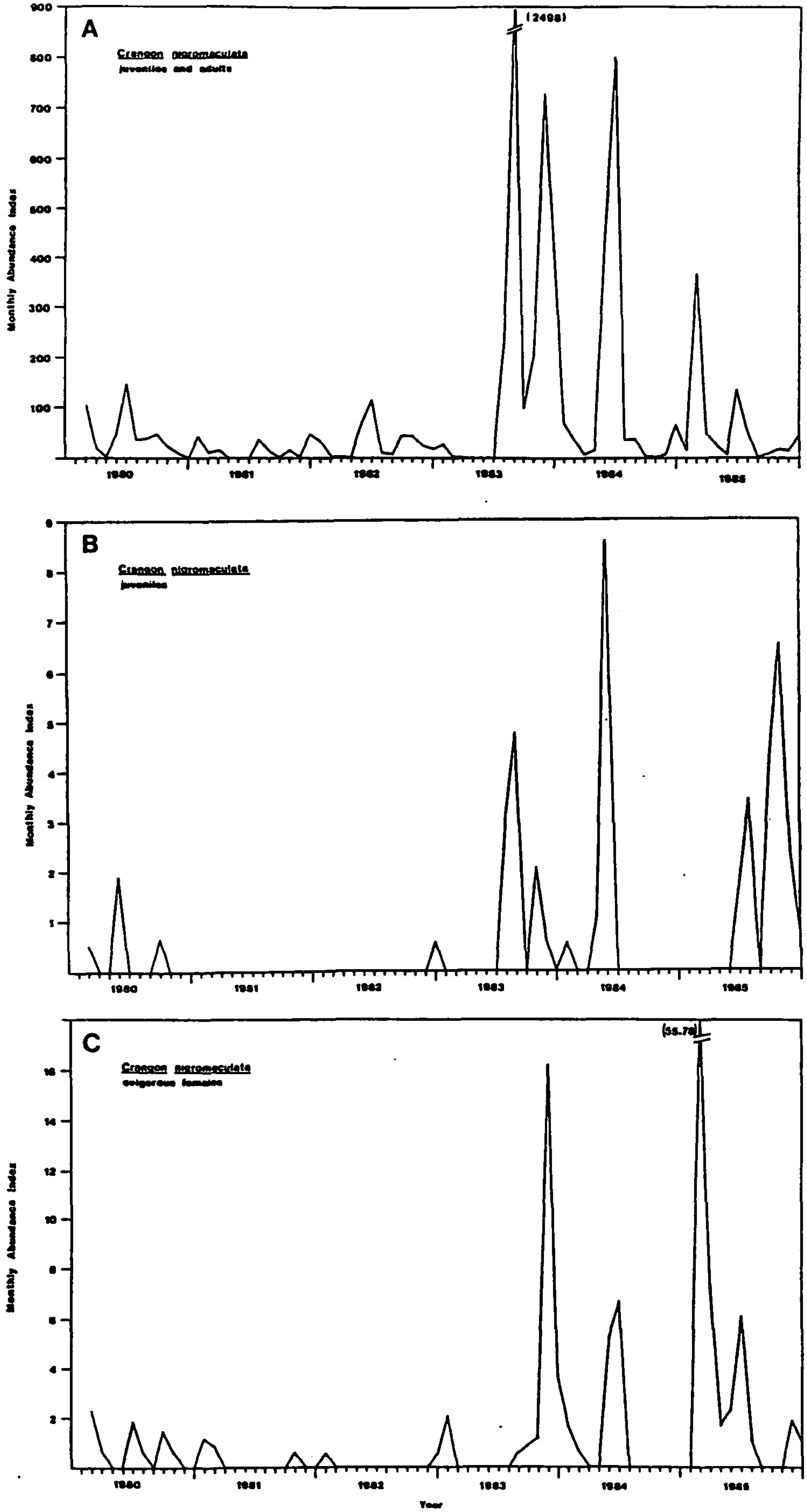


Figure 55. Monthly abundance indices of juvenile, adult, and ovigerous Crangon nigromaculata, 1980-1985.

the third highest in 1985. Since the Bay is at the northern limit of the range of C. nigromaculata, its abundance may be positively related to ocean temperature. Ocean temperatures were highest in 1983, during an El Niño event.

C. nigromaculata were collected in South, Central, and lower San Pablo bays (Figure 56). The greatest catches each year were in Central Bay. The southernmost portion of South Bay was not utilized in 1983 or 1984, the years of highest baywide abundance.

Juvenile Abundance and Distribution

Few juvenile Crangon nigromaculata were collected in the Bay. The peak abundance of juveniles was extremely variable, from April to October (Figure 55b). Several years had a spring peak and a late summer-fall peak. Juveniles did not occur later in 1983, as did C. franciscorum juveniles. The highest annual abundance index of juvenile C. nigromaculata was in 1985, the lowest in 1981 (Table 4). There is a significant correlation between the annual abundance index of juveniles and ovigerous females ($r=0.907$; $p<0.02$). Neither C. franciscorum nor C. nigromaculata had this strong relationship between juvenile and ovigerous female abundance.

Ovigerous Female Abundance and Distribution

Relatively few ovigerous Crangon nigromaculata were collected in the Bay. This life stage usually peaked in abundance in winter (Figure 55c). There was also a smaller summer peak in 1980, 1984, and 1985. As with juveniles, the highest annual abundance index was in 1985 (Table 4); the lowest was in 1982.

Crangon nigromaculata was the most numerous species of Crangon in the near-shore samples collected by the San Francisco Ocean Outfall Monitoring Program (San Francisco Bureau of Water Pollution Control, 1984, 1985, 1986, 1987). Their highest catch was in February 1984, the lowest in October 1984 (Figure 57). The lowest catches of ovigerous females were in October 1984 and 1985. We collected no ovigerous females during these months; this may be the period of lowest reproductive activity for this species.

Effects of Salinity and Temperature

Crangon nigromaculata was collected at a slightly narrower salinity range (4.5-34.3 ppt) and temperature range (7.8-20.2 degrees C) than C. franciscorum and C. nigricauda. This species was concentrated at salinities greater than 23 ppt and temperatures from 14 to 18 degrees C (Figure 58). Its relatively narrow salinity and temperature preference would limit C. nigromaculata to the central portion of the Bay. It may not utilize San Pablo Bay when salinities are less than 23 ppt because the temperatures in this embayment are too high (Figure 6).

Effects of Delta Outflow

Abundance and distribution of Crangon nigromaculata in the Bay are not strongly affected by Delta outflow. There is a positive relationship between the annual abundance index of all sizes of C. nigromaculata and March-May outflow ($r=0.587$). The occurrence of this species in the Bay may be affected by extremely high outflow, as no shrimp were collected from March to May 1983. Distribution of C. nigromaculata apparently is not affected by outflow and the resultant salinity regime. Its range did not expand to San Pablo Bay during years of low outflow.

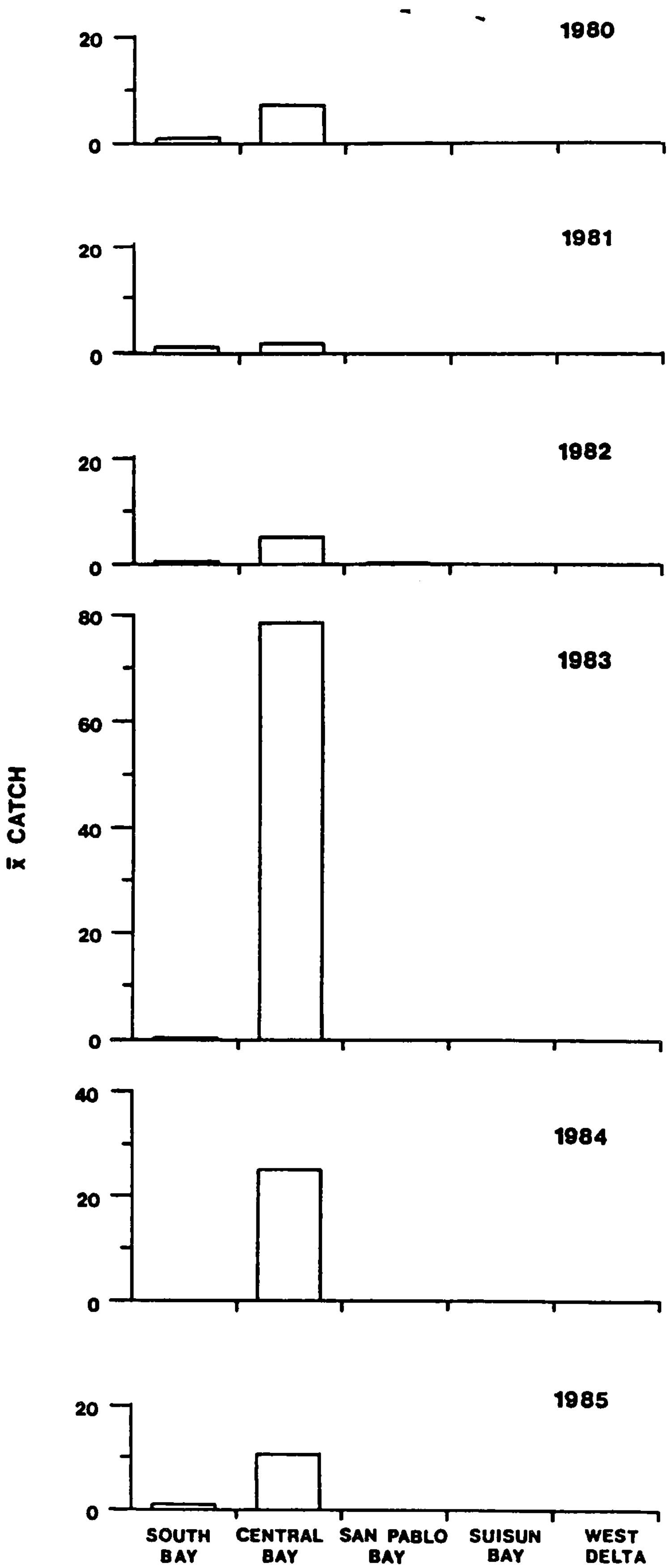


Figure 56. Distribution of juvenile and adult Crangon nigromaculata.

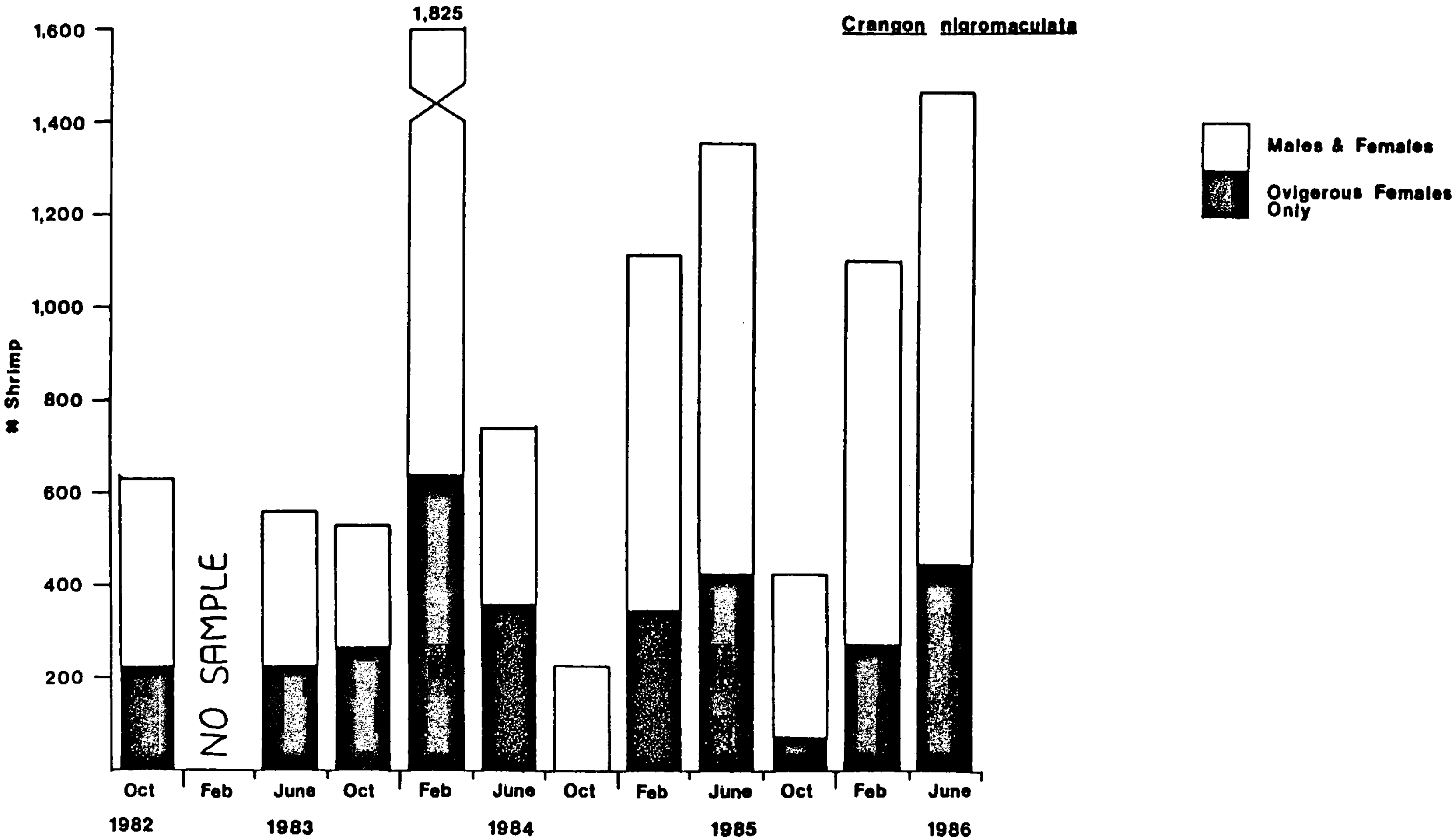


Figure 57. Catches of all sexes and ovigerous Crangon nigromaculata at San Francisco Ocean Outfall Monitoring Program near-shore stations (1982-1986).

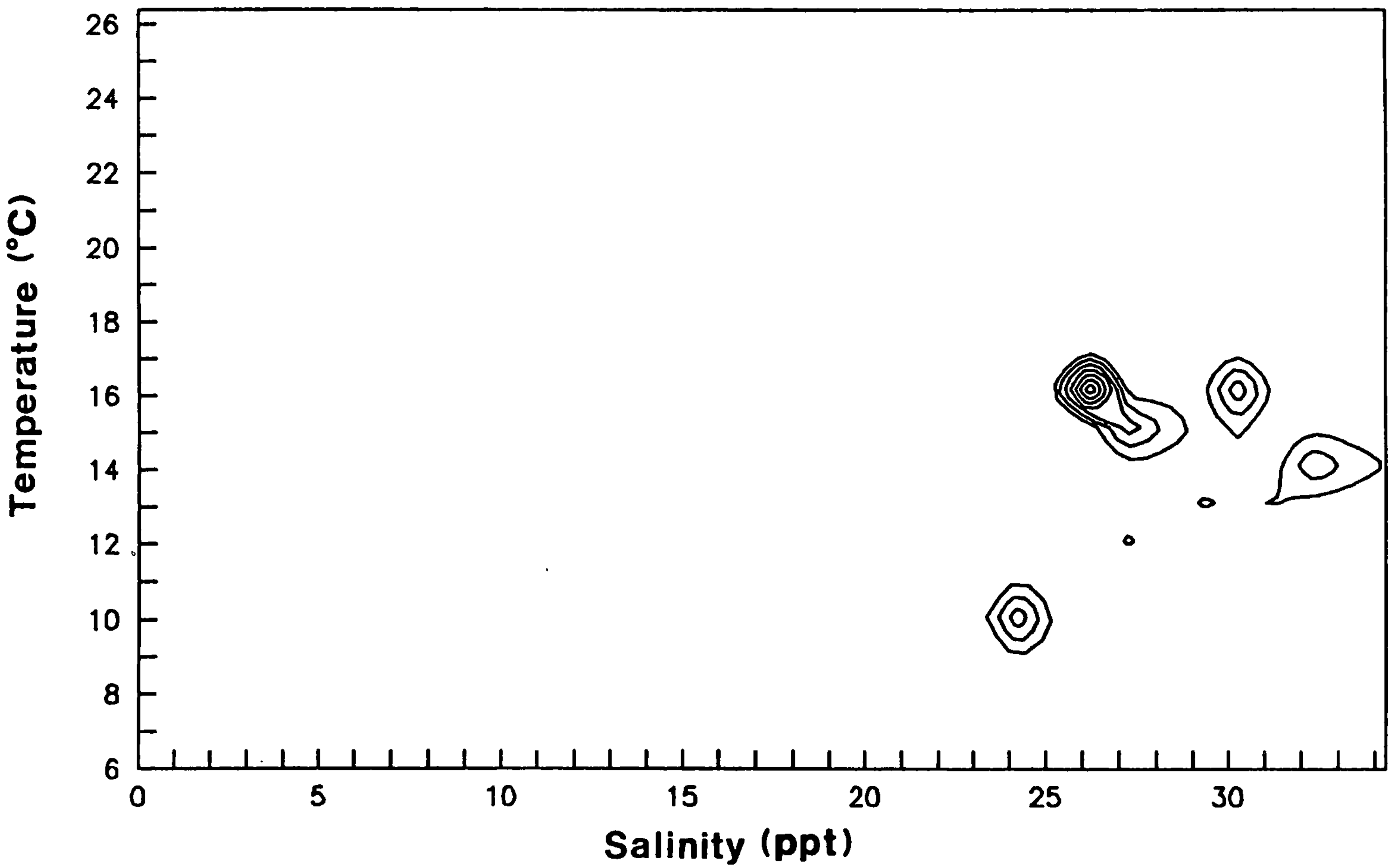


Figure 58. Mean catch of <u>Crangon</u> <u>nigromaculata</u> vs. salinity and temperature (contours from 50 to 750, every 100).

Summary

Crangon nigromaculata had the narrowest salinity and temperature range of the four species of shrimp included in this report. It primarily utilized South and Central bays, and did not extend its range to San Pablo Bay during years of low outflow. Its period of peak abundance was usually during summer.

There is a positive relationship between annual abundance of C. nigromaculata and March-May Delta outflow, but the trend was for higher annual abundances from 1983 to 1985. As with C. nigricauda, this species did not "replace" the euryhaline C. franciscorum during low outflow years.

Chapter 4. CANCER CRABS

This study has collected four species of cancrid crabs in San Francisco Bay: *Cancer magister* (Dungeness crab), *C. productus* (red rock crab), *C. antennarius* (brown rock crab), and *C. gracilis* (slender crab). From 1980 to 1986, the Dungeness crab was the most abundant species collected, and it is the focus of this report.

Cancer crabs are omnivores, preying on a variety of organisms. In San Francisco Bay, Dungeness crabs consumed polychaetes, bivalves, crustaceans (shrimp, barnacles, isopods, amphipods, crabs), fish, algae, and detritus (Tasto, 1983). A variety of fishes have been reported to prey on *Cancer* crabs in the Bay. Included are staghorn sculpin, starry flounder (Boothe, 1967; Reilly, 1983a), white sturgeon (McKechnie and Fenner, 1971), brown rockfish (Ryan, 1986), brown smoothhound, leopard shark, bat ray, big skate, green sturgeon, Pacific tomcod, white croaker, pile perch, white seaperch, and English sole (Reilly, 1983a). Most of the crabs eaten are small (less than 40 mm wide for Dungeness crab), but larger crabs are vulnerable whenever they molt (Reilly, 1983a).

There is a commercial fishery for Dungeness crabs off the central and northern California coasts. No sport fishery is allowed for Dungeness crabs in the Bay.

C. antennarius and *C. productus* support a sport fishery in the Bay, primarily off piers and jetties. *C. gracilis*, the smallest species, is taken only occasionally. The legal minimum size for species other than Dungeness is 4 inches (carapace width), and this species rarely grows this large. There is a small commercial fishery for *C. productus* and *C. antennarius* in central California coastal waters.

Methods

Cancer crabs were collected in the otter trawl, beach seine, and ring nets by this study (the ring net survey began May 1982). Carapace width was measured to the nearest millimeter with calipers (excluding the tenth anterolateral spine for Dungeness crabs; including the tenth spine for all other species). All crabs greater than 19 mm wide were sexed.

The beach seine data were not used for this analysis because relatively few crabs were collected by this net. The otter trawl data were used for distributional analyses, as there are 35 boat stations and only 9 ring net sites.

For all species except Dungeness, annual abundance indices were calculated as crabs/tow (otter trawl) or crabs/set (ring net) from January to December. For Dungeness crab, annual indices were calculated from the May to December catch of juveniles (as crabs/tow or crabs/set). This period was selected because juvenile Dungeness crabs were always collected by May, and their numbers often decreased significantly after December.

Delta outflow and upwelling index are two parameters used in this analysis. The outflow period selected was based on the months that megalops and first instar crabs are present. Outflow is believed to affect these life stages, as they possibly use landward-flowing bottom currents to enter the Bay and move up the estuary.

The upwelling index is calculated from monthly atmospheric pressure data (see Bakun, 1973, for details). This index is an indication of the amount of water moving from depth (as m^3/seconds per 100 meters of coastline) as a result of

Ekman transport of surface water. A positive index indicates offshore transport of surface water (resulting in upwelling of deeper water); a negative index indicates onshore transport (resulting in downwelling of water).

Monthly means (from Mason and Bakun, 1986) for latitudes 36 degrees north (by Pt. Arena) and 39 degrees north (by Pt. Sur) were averaged for January to March for Dungeness crab. This period was selected because this is when the larvae are present and vulnerable to oceanic currents.

Dungeness Crab

The Dungeness crab (Cancer magister) ranges from Pt. Conception to the Aleutian Islands (Hoopes, 1973; Dahlstrom and Wild, 1983). It is fished for commercially in the San Francisco area by boats based in Bodega Bay, San Francisco Bay, and Princeton. Landings from this area reached a peak of almost 9 million pounds during the 1956-1957 season and have declined to under 2 million pounds each season since 1961-1962 (Figure 59).

Possible reasons for this decline include long-term changes in the oceanographic climate, increased predation by coho salmon, increased pollutants (especially in the Bay and the near-shore area), and intensive fishing pressure which has lowered the population below a threshold level (Farley, 1983). This is a male-only fishery, with a minimum carapace width of 159 mm (6-1/4-inches) as measured in front of the tenth antero-lateral spine.

There is also a small sport fishery for this species, but no Dungeness crabs may be taken from San Francisco Bay.

Dungeness crab larvae hatch in winter in coastal waters. Peak hatching occurs from late December to early January in the Gulf of the Farallones. The last larval stage (megalops) and newly settled first instar crabs are brought by currents to the near-shore area and into the Bay from March to June (Reilly, 1983b).

The dominant near-shore current is the southern moving California Current; during winter it is displaced offshore by the northern moving Davidson Current. Usually by April the wind direction shifts and the Davidson Current disappears. There is also onshore and offshore movement of surface water due to Ekman transport (movement of water at right angles to the wind direction). Offshore transport is strongest from April to August, the period that the California Current is the strongest. Net flow is southerly, because the California Current transport is about 10 times greater than Ekman transport (Richard Parrish, NMFS, Monterey, as cited in Reilly, 1983b).

A tagging study by Collier (1983) showed that Bay-reared crabs grow about twice the rate of ocean-reared crabs. Bay-reared crabs had an average carapace width of about 100 mm after one year, which is the size of sexual maturity. Tasto (1983) concluded that increased food availability, particularly crustaceans, may be responsible for this rapid growth in addition to warmer Bay temperatures (overall 5 degrees C higher than the ocean).

Estimates of the number of juvenile crabs in the Bay as a percentage of the total number of juveniles in the Bay and the Gulf ranged from 38 to 82 percent for 1975-1978 (Tasto, 1983). Juvenile crabs utilize about the same amount of area (500 km^2) in the Bay and Gulf. Juvenile crabs stay in the Bay for 1 to 1.5 years and then migrate to the ocean (Tasto, 1983). Bay-reared crabs probably are recruited to the fishery 1.5 years after they migrate from the Bay (3 years after hatching). Ocean-reared crabs enter the fishery 4 to 5 years after hatching.

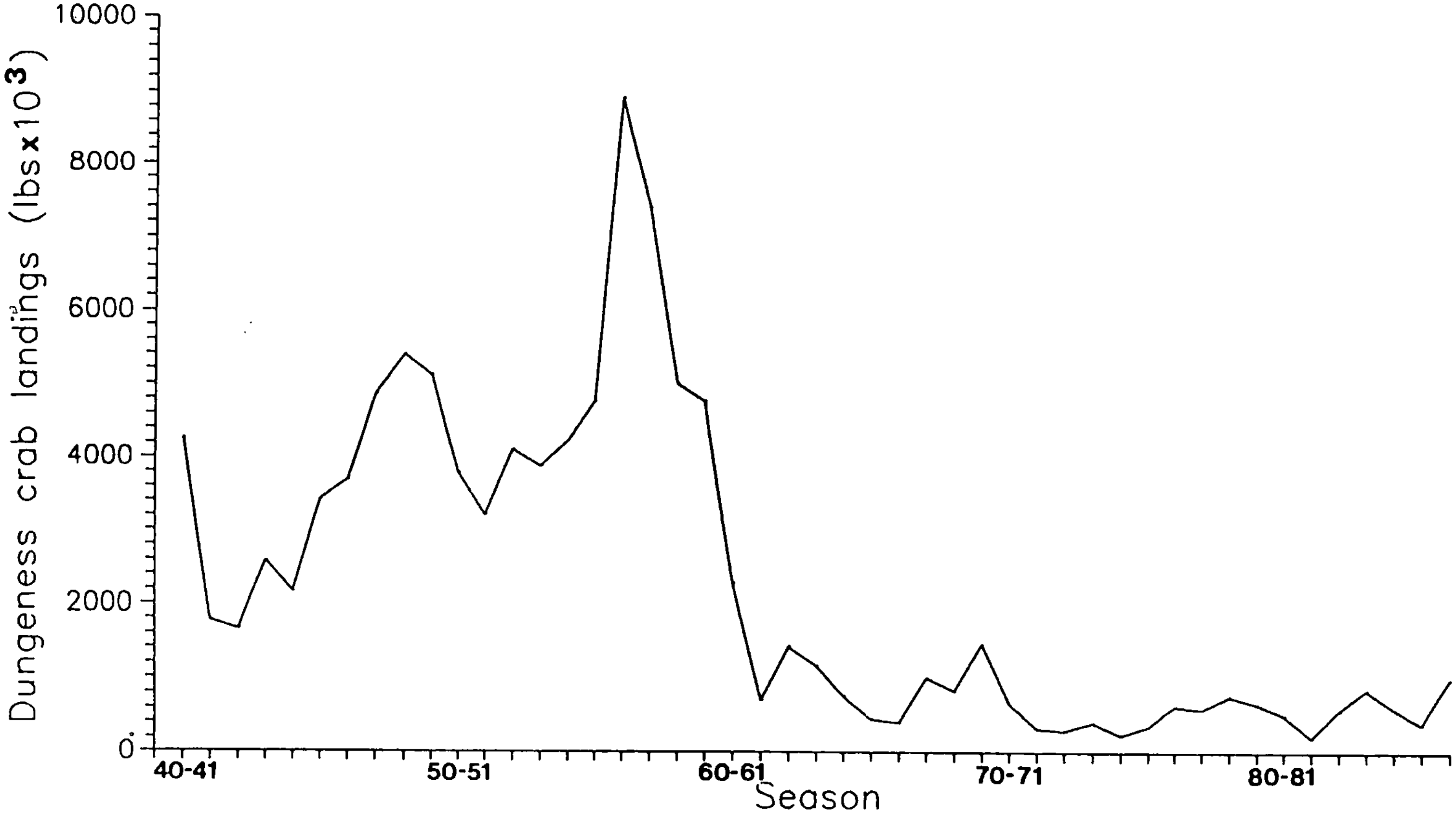


Figure 59. Commercial landings of Dungeness crab, San Francisco Bay area, 1940-1986.

Abundance

Juvenile Dungeness crabs had distinct seasonal abundance trends in the Bay. Peak catch in the otter trawl was usually during May or June (Figure 60) and peak catch in the ring net was usually during September (Figure 61). The otter trawl caught a larger percentage of small crabs (<20 mm) than the ring nets from April through June. Juvenile Dungeness crabs move from the channels of South, Central, and San Pablo Bays to the shoals over a 2- to 3-month period.

Most juvenile crabs leave the Bay by the next spring or summer, which supports the 1 to 1.5 year residence time proposed by Tasto (1983). There may be some movement of crabs out of the Bay during periods of extremely high outflow. The ring net catch had an extreme drop in crabs/set in March 1983 and February 1986, when large pulses of fresh water moved through the Bay. The otter trawl catch also decreased during these months, but the decrease was not as dramatic.

There were significant differences in annual abundance of Dungeness crabs. Lowest abundance was in 1983 and 1986; the highest was in 1984 and 1985. There appears to be little difference in abundance from 1980 to 1982 for the otter trawl (we have no data for 1980 and limited data for the 1981 year class from the ring nets).

A correlation between the annual abundance index (ring net) and March-May outflow was significant ($r=-0.851$, $p<0.05$) (Figure 62). The same correlation with the otter trawl index was also negative, but not significant (-.596).

A correlation between the ring net abundance index and the January-March upwelling index was significant ($r=0.965$, $p<0.01$) (Figure 63). The correlation with the otter trawl index and upwelling was also positive, but not significant ($r=0.752$).

This large interannual variation in crab abundance is probably attributable to several factors. Tasto (1983) concluded that year class strength inside the Bay was directly related to megalopal year class strength that spring in the Gulf of the Farallones. Reilly (1983b) found evidence of offshore movement of larvae and onshore movement of megalops, but he did not conclude how the megalops return to the coast (the Ekman current is usually offshore, not onshore, during April and May). He did propose that the estuarine plume could sweep larvae too far offshore during high outflow years for the megalops to return to the near-shore area. This may explain the negative relationship between outflow and juvenile crab abundance in the Bay.

Another hypothesis is that larvae are swept so far north by relatively strong Davidson Current during years of intense storms that they cannot be brought back to the nursery area by the subsequent southward California Current (Lough, 1976; Johnson et al., 1986). A positive relationship between the winter upwelling index and crab abundance indicates that this is a possible mechanism, as a negative upwelling index indicates strong northward currents (Bakun, 1973). The Davidson and California currents may dominate larval distribution along the West Coast.

Distribution

Dungeness crabs were collected at all stations downstream of Honker Bay except one station in South Bay and one in Suisun Bay. No crabs were collected upstream of Carquinez Strait by the otter trawl in 1980, 1982, or 1983, when salinities were generally less than 10 ppt in this area. Tasto (1983) reported no crabs collected at salinities less than 10 ppt, but we

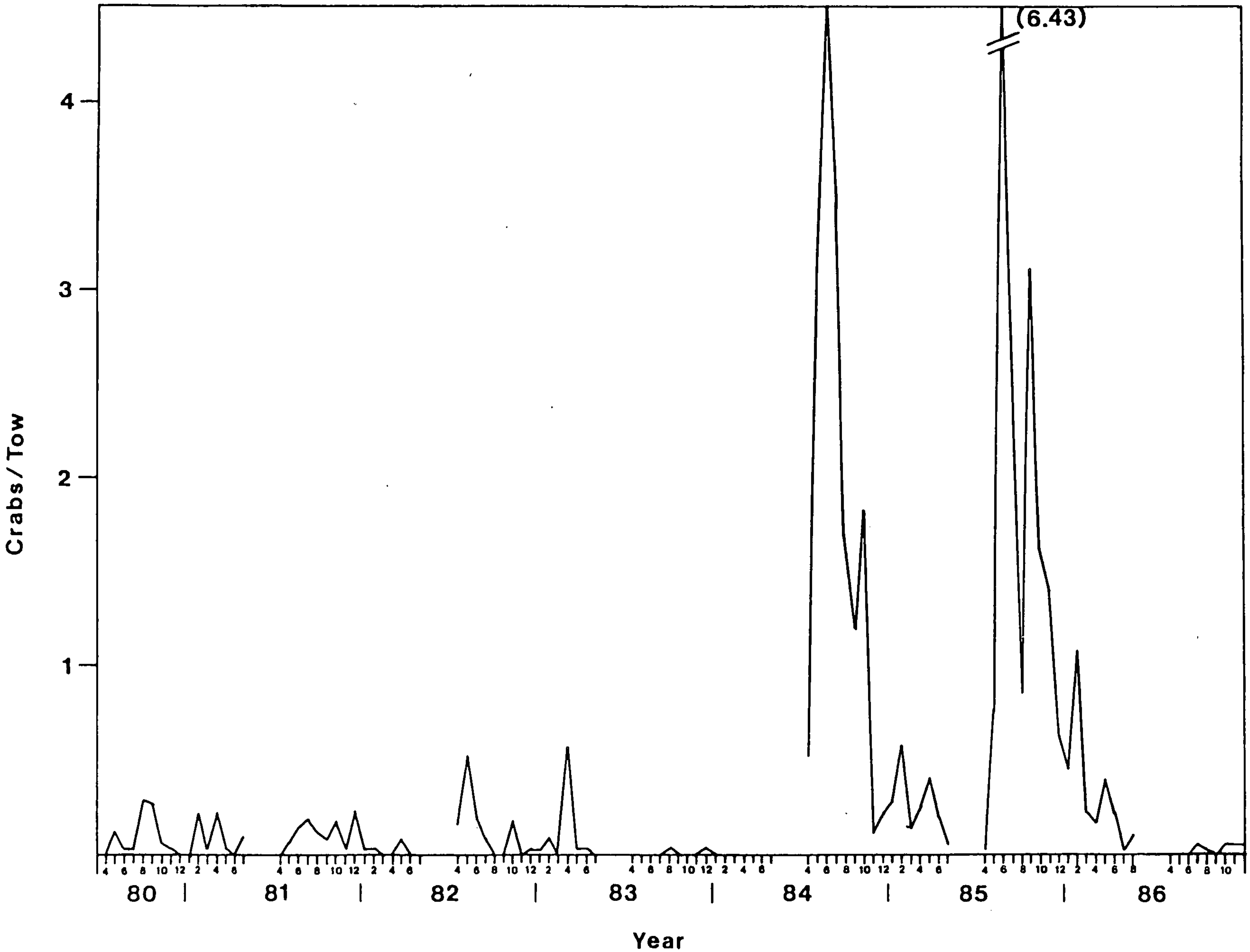


Figure 60. Juvenile Dungeness crab catch, otter trawl, 1980-1986.

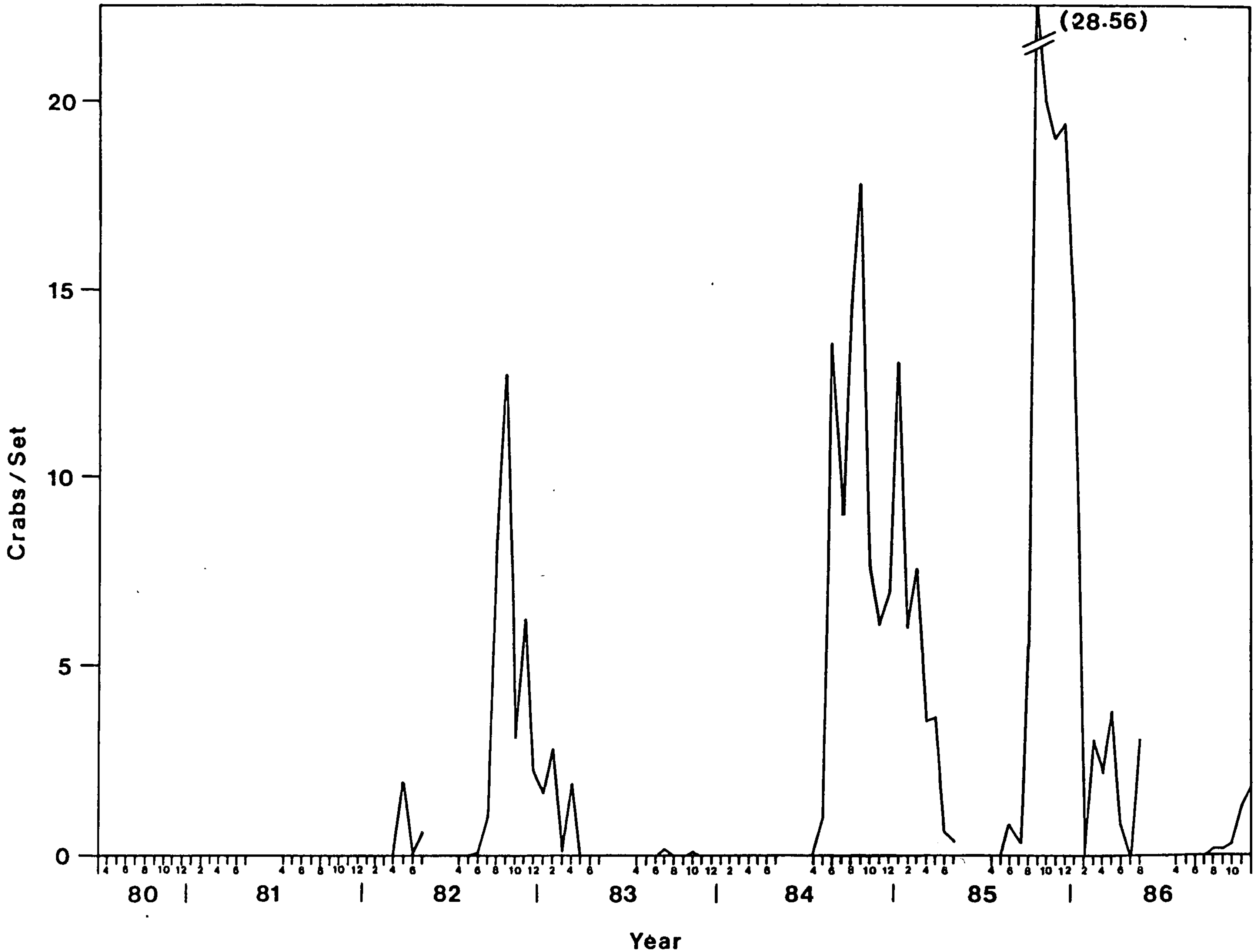


Figure 61. Juvenile Dungeness crab catch, ring nets, 1982-1986.

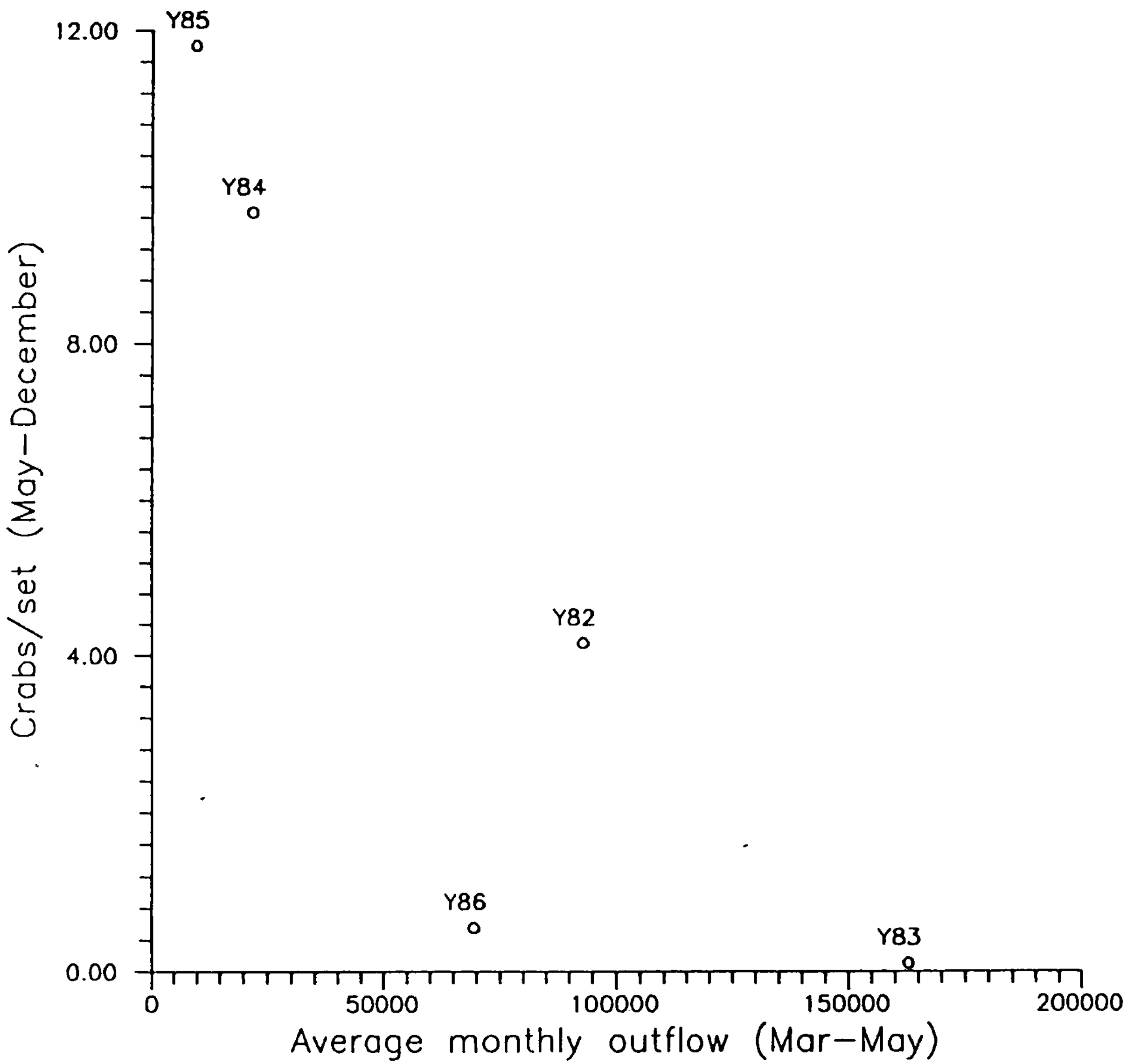


Figure 62. Annual abundance of juvenile Dungeness crabs (ring net) vs. outflow (r=-0.851).

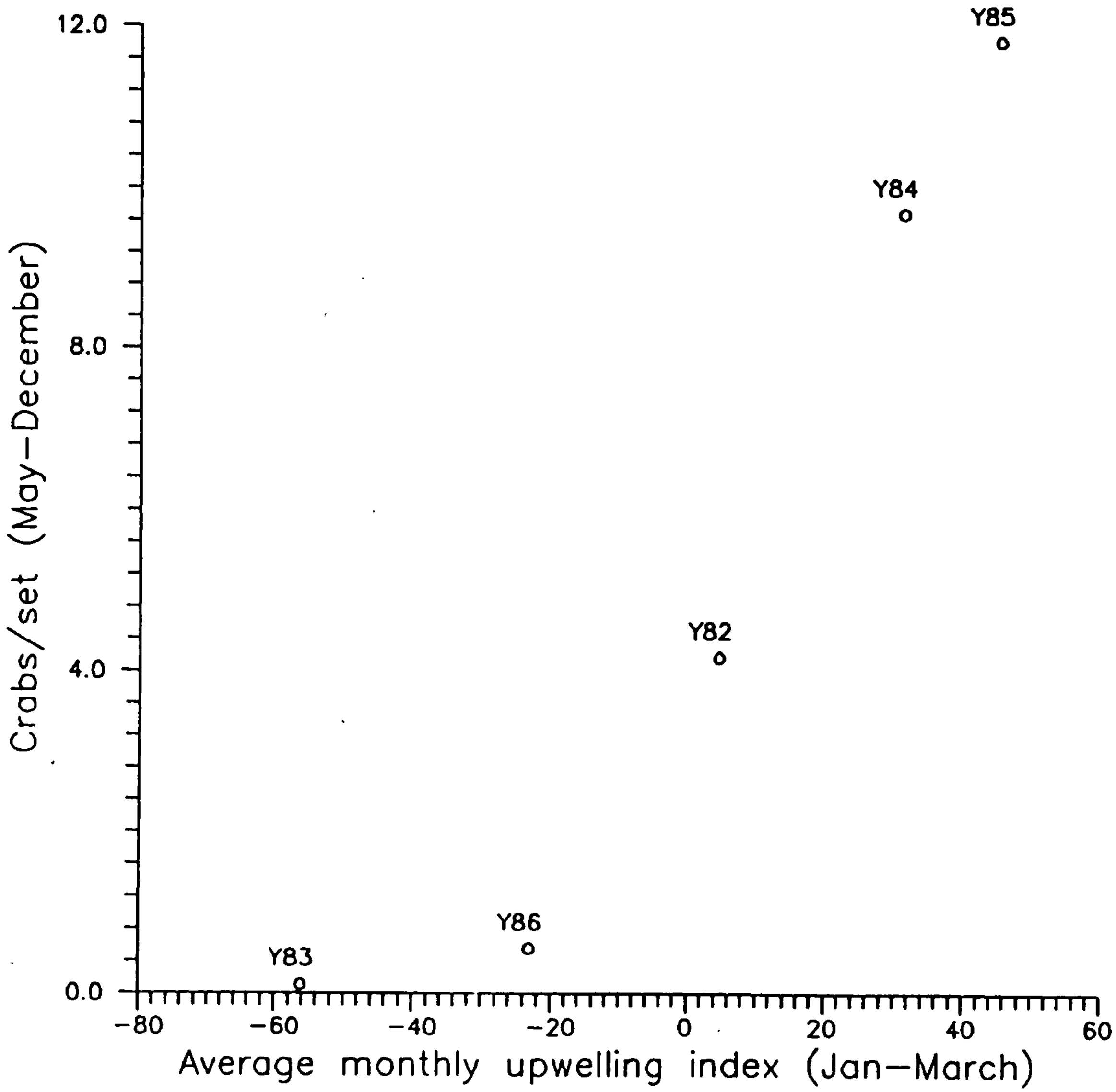


Figure 63. Annual abundance of juvenile Dungeness crabs (ring net) vs. upwelling index (r=0.965).

occasionally collected crabs at salinities slightly lower than this. There is no evidence of crabs being more abundant in South Bay these years. During 1981, 1984, and 1985 (low outflow years), crabs were collected upstream of Carquinez Strait (Figure 64). In 1981, 9 percent (3 crabs) were collected in this area; in 1984, 1 percent (8 crabs); and in 1985, 25 percent (160 crabs).

Summary

San Francisco Bay is an important nursery area for Dungeness crabs. Bay-reared crabs grow about twice as fast as ocean-reared crabs, and they contribute to the ocean fishery 1 to 2 years sooner than ocean-reared crabs. Bay-reared crabs probably grow faster because of warmer temperatures and a greater food supply.

There is a negative relationship between outflow and juvenile crab abundance in the Bay. The estuarine plume may carry larvae too far offshore for the megalops to return during high outflow years. The same winter storms that result in high outflow also result in a stronger Davidson Current. During these years Dungeness crab larvae may be swept too far north to return with the subsequent California Current to the Gulf of the Farallones.

Dungeness crabs expanded their distribution in the Bay during years of low outflow. They were collected upstream of Carquinez Strait during 1981, 1984, and 1985, when salinities were generally greater than 10 ppt in this area.

Cancer antennarius

Cancer antennarius (the brown rock crab) ranges from Oregon to Baja California (Morris et al., 1980). It mainly inhabits rock intertidal and subtidal areas along the outer coast. This was the least abundant species collected by the otter trawl (Table 6), and ranked third in abundance in the ring net survey (Table 6).

The highest catches were in the northern portion of South Bay and in Central Bay. Most juvenile crabs (<50 mm) were collected in August and September.

Carroll (1982) reported larvae to hatch during spring and early summer off the central California coast. We collected larvae and mature crabs (including ovigerous females) in the Bay. C. antennarius does not use the Bay strictly as a nursery area, as Dungeness crab does.

There is a negative correlation between annual abundance of C. antennarius (otter trawl) and May-July outflow ($r=-0.388$ all sizes; $r=-0.331$ juveniles). As with Dungeness crab and C. productus, there were relatively low abundances in 1982 and 1983. Otter trawl abundance in 1986 was also low, but the ring net abundance was relatively high.

Ocean conditions (current strength, El Niño) may play some role in determining year class strength of C. antennarius in the Bay.

Cancer gracilis

Cancer gracilis (the slender crab) ranges from Alaska to Baja California (Schmitt, 1921). This species was collected only occasionally in the ring net, but it ranked second in abundance in the otter trawl (Table 6).

This is the smallest species of Cancer crab we collected, and it may be displaced from rocky or protected areas in the Bay to less preferred open areas by the larger species (R. Tasto, DFG, personal communication).

Peak abundance of juvenile C. gracilis (<20 mm) was during May and June. There appears to be little relationship

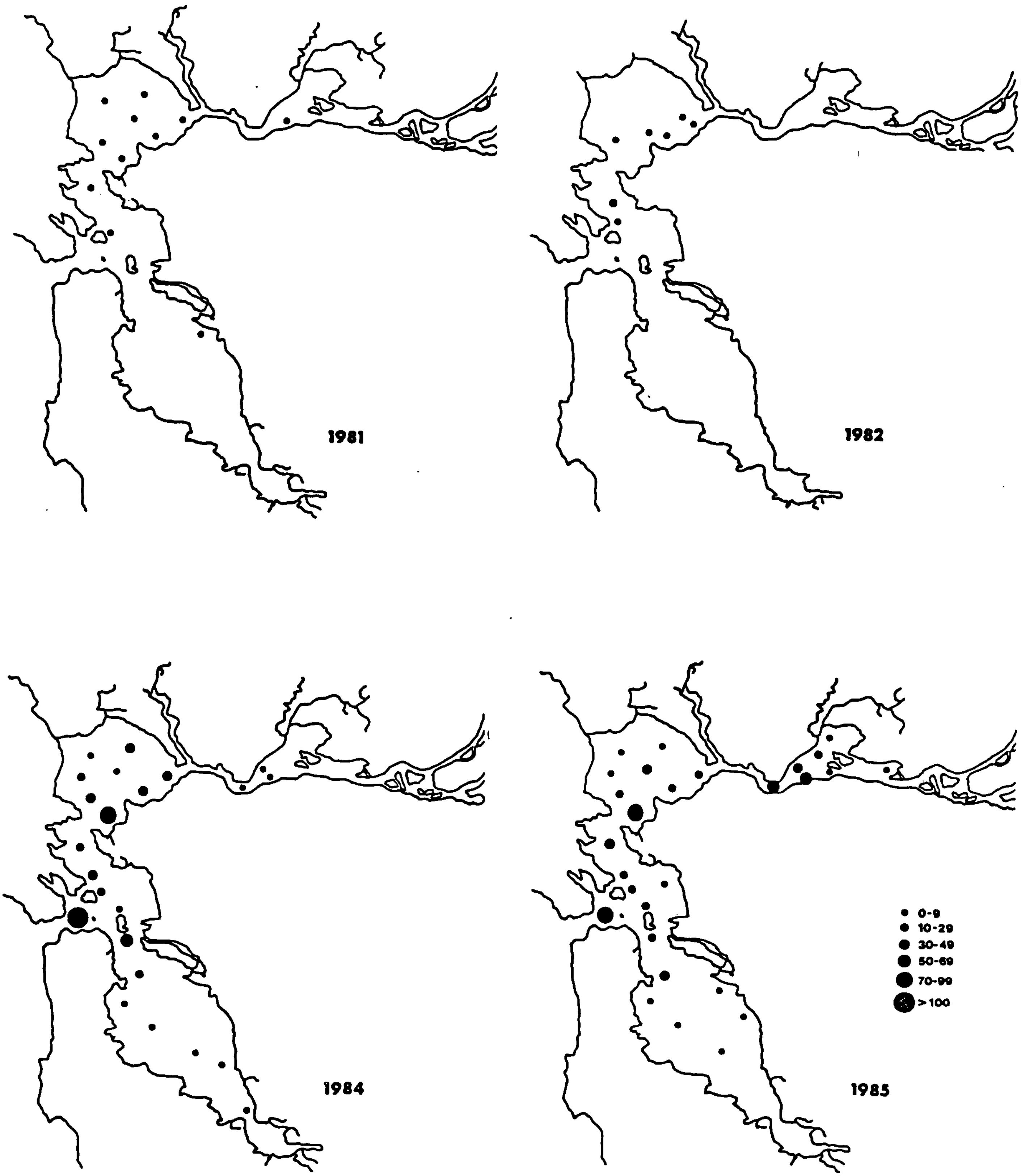


Figure 64. Distribution of juvenile Dungeness crabs (otter trawl). Dots represent catch/tow at each station, May-December.

between annual abundance (otter trawl) and outflow (r=0.286, juveniles; r=-0.244, all sizes; March-May outflow).

Annual abundance was low for 1980-1982 relative to 1983-1986. This is similar to the abundance trends for other species, except 1983 was not a "good" year for C. antennarius, C. magister, or C. productus. As with C. antennarius, C. gracilis was concentrated in the northern portion of South Bay and in Central Bay. There was no apparent increase in catch in San Pablo Bay in 1981, 1984, or 1985 (the years of lowest outflow).

Cancer productus

Cancer productus (the red rock crab) ranges from Alaska to San Diego, California (Morris et al., 1980). It is primarily found in bays and along the coast, associated with rocky substrates. It is not known what portion of the Bay area C. productus population utilizes the bay versus the near-shore coastal area. Larvae and mature crabs (including ovigerous females) were collected in the Bay.

This species ranked second in abundance in the ring net (Table 7) and third in abundance in the otter trawl (Table 6).

C. productus has five larval stages (Trask, 1970), but we collected only stages I, II, and III in the plankton net. Larvae were collected throughout the year, with peak abundance in winter and spring (Figure 65). The highest annual abundance of larvae was in 1981, the lowest in 1982. There is a negative correlation between annual abundance of larvae and January-March outflow (r=-0.700). Larvae may be carried from the Bay during higher outflow years. C. productus larvae were concentrated in Central Bay; occasionally larvae were collected upstream of Carquinez Strait. The few megalops collected were found primarily in Central Bay from March through June.

Juvenile C. productus (<50 mm) had a peak abundance from June to August. The lowest annual abundance of this size class was in 1982 and 1983, the El Niño years. There is a negative relationship between annual abundance (otter trawl) and May-July outflow (r=-0.616, juveniles; r=-0.618 all sizes). As with C. magister and C. antennarius, year class strength may be determined in part by ocean conditions. The highest catches of C. productus were in South, Central, and San Pablo bays. This species is more widely distributed in the Bay than C. antennarius or C. gracilis.

Table 6

ANNUAL ABUNDANCES OF CANCER ANTENNARIUS, C. GRACILIS, AND C. PRODUCTUS, OTTER TRAWL (CRABS/TOW)

	1980	1981	1982	1983	1984	1985	1986
C. antennarius (all sizes)	0.101	0.047	0.010	0.015	0.071	0.033	0.007
C. antennarius (< 50 mm)	0.098	0.037	0.005	0.015	0.067	0.024	0.007
C. gracilis (all sizes)	0.035	0.103	0.044	0.182	0.333	0.240	0.174
C. gracilis (< 20 mm)	0.003	0.005	0.034	0.080	0.079	0.064	0.095
C. productus (all sizes)	0.014	0.032	0.005	0.010	0.055	0.071	0.088
C. productus (< 50 mm)	0.014	0.027	0.002	0.005	0.040	0.050	0.081

Table 7

ANNUAL ABUNDANCES OF CANCER ANTENNARIUS, C. GRACILIS, AND C. PRODUCTUS, RING NET (CRABS/SET)

	1980	1981	1982*	1983	1984	1985	1986
C. antennarius (all sizes)	-	-	0.113	0.095	0.296	0.491	0.407
C. antennarius (< 50 mm)	-	-	0	0.009	0.028	0.009	0.176
C. gracilis (all sizes)	-	-	0.014	0.019	0.037	0.009	0.130
C. productus (all sizes)	-	-	0.155	0.067	2.509	4.315	0.806
C. productus (< 50 mm)	-	-	0	0	0.185	0.148	0.157

*Ring net survey started in May 1982

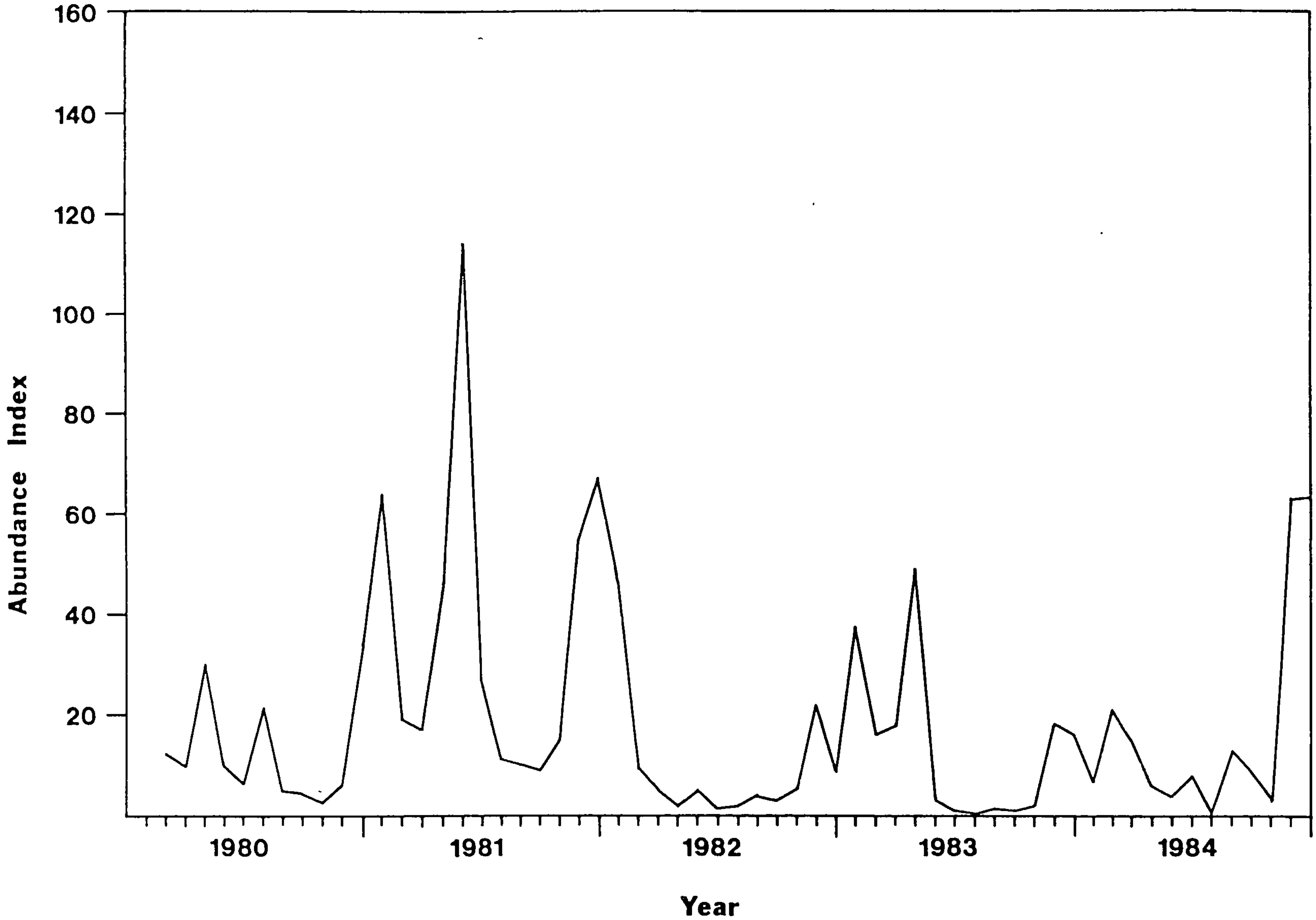


Figure 65. Monthly abundance indices of <u>Cancer productus</u> larvae, 1980-1984.

Chapter 5. ANALYSIS OF FISH CATCH AND FISH PERCENTAGE CATCH

During the period January 1980 to December 1985, 137 taxa of fish, representing 122 species, were collected (see Appendix A). The remaining 15 taxa represent family and genus level identifications of juvenile rockfish and larval fish. There were probably more than 200 species of fish in San Francisco Bay during this period, but some were not collected because they reside in rocky intertidal and subtidal areas that we did not sample.

During the sampling period, the otter trawl collected 144,385 individuals, representing 85 species (Table 8), the midwater trawl collected 620,645 individuals, representing 72 species (Table 9); the beach seine collected 124,482 individuals, representing 66 species (Table 10); and the egg and larval net collected 752,224 individuals, representing 62 taxa (Table 11).

Several points need to be made about the data used in compiling Tables 8-11. The catch data used is the sum catch per year, and are not corrected for effort. The 1980 beach seine catches appear low, because beach seine collections did not begin until August 1980. Identification of larval gobies is difficult, and this is reflected by the number of groups (i.e., goby complex and arrow/cheekspot goby) used over the years. Our ability to identify larval gobies has improved since the start of the study.

Topsmelt were the most abundant species of fish collected in the beach seine; in fact, more were collected in the beach seine than in the midwater trawl. Overall, topsmelt, Pacific herring, northern anchovy, jacksmelt, striped bass, Pacific staghorn sculpin, inland silverside, and arrow goby comprised 90 percent of the catch. The species composition of those fish making up 90 percent of the catch varied between years. Topsmelt was the only species in the top 10 percent every year. Pacific herring, northern anchovy, jacksmelt, striped bass, Pacific staghorn sculpin, inland silverside, shiner perch, arrow goby, dwarf perch, threadfin shad, bay pipefish, and yellowfin goby were in the top 10 percent only in some years.

Midwater trawl catches were almost completely dominated by northern anchovies. The only exception was 1982, when longfin smelt and Pacific herring catches were greater. Northern anchovies made up 90 percent of the catch in 1981 and 1984. In other years, northern anchovies, longfin smelt, Pacific herring, and striped bass made up 90 percent of the catch.

Longfin smelt, northern anchovy, striped bass, shiner perch, English sole, white croaker, Pacific staghorn sculpin, bay goby, speckled sanddab, and yellowfin goby made up 90 percent of the otter trawl catch. The group of fish making up the top 10 percent was remarkably consistent during the six years. Only two species, starry flounder and Pacific herring, were occasional members of this group.

For all years, over 90 percent of the larval fish catch consisted of Pacific herring, northern anchovy, unidentified smelts, yellowfin goby, and longfin smelt. Striped bass was also among those making up 90 percent of the catch in 1980 and 1983. Pacific herring were the most common in all years except 1980 and 1984. When considered as a group, gobies were in the top three most abundant species in all years, and the most abundant in 1980 and 1984. The fact that gobies are so common in the larval catch and not in the other nets is attributed to the burrowing behavior of both juveniles and adults.

Table 8. Otter Trawl Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
longfin smelt	40834	28.28	11326	37.75	1268	6.73	17029	48.27	7212	27.45	2663	14.86	1336	8.31
northern anchovy	25268	17.50	3006	10.02	8937	47.44	4319	12.24	2231	8.49	2571	14.35	4204	26.15
striped bass	17212	11.92	1083	3.61	2187	11.61	2292	6.50	6770	25.77	3188	17.79	1692	10.52
shiner perch	11222	7.77	1651	5.50	1927	10.23	3164	8.97	1667	6.35	1010	5.64	1803	11.21
English sole	10415	7.21	2256	7.52	1389	7.37	1102	3.12	949	3.61	2389	13.33	2330	14.49
bay goby	6484	4.49	837	2.79	501	2.66	1360	3.85	2357	8.97	1088	6.07	341	2.12
white croaker	6279	4.35	2360	7.87	340	1.80	333	0.94	607	2.31	1319	7.36	1320	8.21
Pacific staghorn sculpin	5829	4.04	1217	4.06	263	1.40	1531	4.34	702	2.67	894	4.99	1222	7.60
speckled sanddab	4744	3.29	2598	8.66	206	1.09	680	1.93	549	2.09	262	1.46	449	2.79
starry flounder	3301	2.29	1178	3.93	258	1.37	618	1.75	655	2.49	392	2.19	200	1.24
yellowfin goby	2685	1.86	866	2.89	154	0.82	377	1.07	323	1.23	863	4.82	102	0.63
Pacific herring	2355	1.63	611	2.04	243	1.29	1093	3.10	73	0.28	91	0.51	244	1.52
plainfin midshipman	1840	1.27	174	0.58	311	1.65	324	0.92	457	1.74	306	1.71	268	1.67
California tonguefish	827	0.57	111	0.37	12	0.06	101	0.29	404	1.54	147	0.82	52	0.32
brown rockfish	427	0.30	106	0.35	73	0.39	26	0.07	52	0.20	121	0.68	49	0.30
white catfish	381	0.26	20	0.07	7	0.04	12	0.03	292	1.11	42	0.23	8	0.05
walleye surfperch	378	0.26	28	0.09	184	0.98	91	0.26	37	0.14	22	0.12	16	0.10
Pacific tomcod	374	0.26	90	0.30	75	0.40	155	0.44	53	0.20	1	0.01	0	0.00
brown smoothhound	323	0.22	48	0.16	48	0.25	79	0.22	73	0.28	38	0.21	37	0.23
delta smelt	248	0.17	77	0.26	63	0.33	42	0.12	48	0.18	10	0.06	8	0.05
white sturgeon	247	0.17	5	0.02	1	0.01	70	0.20	64	0.24	88	0.49	19	0.12
leopard shark	221	0.15	53	0.18	39	0.21	59	0.17	47	0.18	20	0.11	3	0.02
whitebait smelt	176	0.12	0	0.00	0	0.00	59	0.17	98	0.37	9	0.05	10	0.06
pile perch	171	0.12	36	0.12	34	0.18	38	0.11	35	0.13	9	0.05	19	0.12
dwarf perch	147	0.10	14	0.05	30	0.16	50	0.14	48	0.18	5	0.03	0	0.00
splittail	146	0.10	7	0.02	1	0.01	23	0.07	45	0.17	34	0.19	36	0.22
big skate	132	0.09	18	0.06	18	0.10	32	0.09	31	0.12	16	0.09	17	0.11
barred surfperch	131	0.09	13	0.04	29	0.15	16	0.05	48	0.18	19	0.11	6	0.04
American shad	130	0.09	22	0.07	12	0.06	20	0.06	43	0.16	11	0.06	22	0.14
white seaperch	103	0.07	17	0.06	35	0.19	12	0.03	10	0.04	24	0.13	5	0.03
bat ray	93	0.06	13	0.04	20	0.11	22	0.06	12	0.05	17	0.09	9	0.06
cheekspot goby	88	0.06	0	0.00	7	0.04	11	0.03	29	0.11	18	0.10	23	0.14
California halibut	84	0.06	8	0.03	8	0.04	9	0.03	7	0.03	20	0.11	32	0.20
bay pipefish	79	0.05	20	0.07	8	0.04	7	0.02	9	0.03	7	0.04	28	0.17
lingcod	74	0.05	12	0.04	10	0.05	1	0.00	1	0.00	37	0.21	13	0.08
threadfin shad	73	0.05	7	0.02	6	0.03	6	0.02	14	0.05	20	0.11	20	0.12
chameleon goby	71	0.05	0	0.00	10	0.05	3	0.01	8	0.03	21	0.12	29	0.18
Pacific lamprey	68	0.05	7	0.02	38	0.20	8	0.02	9	0.03	5	0.03	1	0.01
diamond turbot	66	0.05	19	0.06	9	0.05	11	0.03	9	0.03	9	0.05	9	0.06
bigscale logperch	66	0.05	0	0.00	5	0.03	4	0.01	18	0.07	17	0.09	22	0.14
channel catfish	54	0.04	1	0.00	1	0.01	1	0.00	29	0.11	13	0.07	9	0.06
prickly sculpin	41	0.03	2	0.01	0	0.00	8	0.02	23	0.09	8	0.04	0	0.00
topsmelt	39	0.03	8	0.03	0	0.00	17	0.05	12	0.05	0	0.00	2	0.01
black perch	36	0.02	0	0.00	13	0.07	3	0.01	4	0.02	12	0.07	4	0.02
river lamprey	34	0.02	0	0.00	0	0.00	0	0.00	10	0.04	16	0.09	8	0.05
jacksmelt	34	0.02	5	0.02	7	0.04	7	0.02	5	0.02	2	0.01	8	0.05
surf smelt	32	0.02	7	0.02	15	0.08	9	0.03	1	0.00	0	0.00	0	0.00
green sturgeon	26	0.02	9	0.03	1	0.01	5	0.01	5	0.02	4	0.02	2	0.01
threespine stickleback	25	0.02	6	0.02	2	0.01	5	0.01	11	0.04	1	0.01	0	0.00
sand sole	24	0.02	3	0.01	1	0.01	2	0.01	7	0.03	6	0.03	5	0.03

Table 8. Otter Trawl Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
tule perch	23	0.02	10	0.03	2	0.01	3	0.01	1	0.00	1	0.01	6	0.04
curlfin sole	21	0.01	1	0.00	1	0.01	3	0.01	6	0.02	3	0.02	7	0.04
showy snailfish	21	0.01	2	0.01	4	0.02	4	0.01	9	0.03	1	0.01	1	0.01
spiny dogfish	21	0.01	3	0.01	3	0.02	5	0.01	4	0.02	4	0.02	2	0.01
bonehead sculpin	20	0.01	0	0.00	6	0.03	1	0.00	4	0.02	8	0.04	1	0.01
arrow goby	19	0.01	4	0.01	0	0.00	2	0.01	8	0.03	4	0.02	1	0.01
common carp	19	0.01	1	0.00	1	0.01	6	0.02	8	0.03	1	0.01	2	0.01
Pacific sanddab	14	0.01	1	0.00	0	0.00	0	0.00	9	0.03	1	0.01	3	0.02
California lizardfish	13	0.01	0	0.00	0	0.00	0	0.00	12	0.05	1	0.01	0	0.00
chinook salmon	10	0.01	1	0.00	5	0.03	2	0.01	2	0.01	0	0.00	0	0.00
rubberlip seaperch	9	0.01	2	0.01	3	0.02	2	0.01	0	0.00	2	0.01	0	0.00
spotted cusk-eel	7	0.00	0	0.00	0	0.00	0	0.00	0	0.00	3	0.02	4	0.02
unidentified rockfish	7	0.00	2	0.01	4	0.02	0	0.00	0	0.00	1	0.01	0	0.00
calico surfperch	5	0.00	5	0.02	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Sacramento squawfish	4	0.00	1	0.00	0	0.00	1	0.00	2	0.01	0	0.00	0	0.00
Sacramento sucker	3	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	3	0.02
night smelt	3	0.00	2	0.01	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
kelp greenling	3	0.00	0	0.00	0	0.00	2	0.01	0	0.00	0	0.00	1	0.01
brown Irish lord	3	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	3	0.02
silver surfperch	3	0.00	3	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
moquitofish	2	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	1	0.01
pygmy poacher	2	0.00	1	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00
inland silverside	2	0.00	0	0.00	1	0.01	0	0.00	0	0.00	1	0.01	0	0.00
saddleback gunnel	2	0.00	2	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
goldfish	2	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	1	0.01
unidentified rockfish	2	0.00	2	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
scalyhead sculpin	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
longjaw mudsucker	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
rainbow seaperch	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
onespot fringehead	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.01	0	0.00
rainwater killifish	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
Pacific pompano	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
red Irish lord	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
bluegill	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
*** Total ***														
	144385		30000		18837		35280		26272		17918		16078	

Table 9. Midwater Trawl Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
northern anchovy	497282	80.12	63945	74.11	94928	90.55	13198	22.26	63335	79.48	171220	93.52	90656	84.35
longfin smelt	44732	7.21	9618	11.15	2972	2.83	20127	33.95	8444	10.60	1995	1.09	1576	1.47
Pacific herring	42146	6.79	9424	10.92	1575	1.50	18093	30.52	937	1.18	5040	2.75	7077	6.58
striped bass	12158	1.96	837	0.97	1733	1.65	4057	6.84	3232	4.06	1913	1.04	386	0.36
jacksmelt	7864	1.27	216	0.25	1048	1.00	489	0.82	505	0.63	1107	0.60	4499	4.19
shiner perch	3793	0.61	405	0.47	1150	1.10	790	1.33	302	0.38	320	0.17	826	0.77
American shad	2638	0.43	164	0.19	325	0.31	1247	2.10	519	0.65	274	0.15	109	0.10
topsmelt	2448	0.39	127	0.15	68	0.06	119	0.20	384	0.48	61	0.03	1689	1.57
plainfin midshipman	1443	0.23	49	0.06	30	0.03	79	0.13	1036	1.30	72	0.04	177	0.16
white croaker	1273	0.21	471	0.55	70	0.07	39	0.07	163	0.20	379	0.21	151	0.14
delta smelt	1056	0.17	202	0.23	319	0.30	171	0.29	219	0.27	108	0.06	37	0.03
yellowfin goby	636	0.10	180	0.21	38	0.04	172	0.29	36	0.05	195	0.11	15	0.01
walleye surfperch	462	0.07	41	0.05	209	0.20	72	0.12	22	0.03	78	0.04	40	0.04
chinook salmon	445	0.07	34	0.04	39	0.04	142	0.24	96	0.12	55	0.03	79	0.07
threadfin shad	377	0.06	37	0.04	28	0.03	30	0.05	219	0.27	46	0.03	17	0.02
starry flounder	290	0.05	107	0.12	29	0.03	61	0.10	48	0.06	37	0.02	8	0.01
bay goby	202	0.03	63	0.07	13	0.01	74	0.12	13	0.02	27	0.01	12	0.01
Pacific pompano	181	0.03	10	0.01	97	0.09	52	0.09	20	0.03	2	0.00	0	0.00
Pacific staghorn sculpin	166	0.03	20	0.02	22	0.02	59	0.10	23	0.03	21	0.01	21	0.02
night smelt	160	0.03	159	0.18	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
splittail	150	0.02	9	0.01	15	0.01	49	0.08	35	0.04	33	0.02	9	0.01
white sturgeon	122	0.02	16	0.02	9	0.01	22	0.04	23	0.03	41	0.02	11	0.01
English sole	112	0.02	17	0.02	22	0.02	42	0.07	11	0.01	3	0.00	17	0.02
surf smelt	90	0.01	44	0.05	14	0.01	20	0.03	9	0.01	2	0.00	1	0.00
bat ray	89	0.01	24	0.03	23	0.02	10	0.02	8	0.01	12	0.01	12	0.01
whitebait smelt	58	0.01	0	0.00	0	0.00	6	0.01	8	0.01	8	0.00	36	0.03
white seaperch	42	0.01	11	0.01	23	0.02	3	0.01	3	0.00	1	0.00	1	0.00
Pacific tomcod	25	0.00	6	0.01	1	0.00	16	0.03	2	0.00	0	0.00	0	0.00
threespine stickleback	24	0.00	6	0.01	1	0.00	12	0.02	5	0.01	0	0.00	0	0.00
pile perch	20	0.00	3	0.00	5	0.00	5	0.01	2	0.00	1	0.00	4	0.00
speckled sanddab	14	0.00	5	0.01	0	0.00	8	0.01	1	0.00	0	0.00	0	0.00
common carp	13	0.00	7	0.01	1	0.00	4	0.01	0	0.00	1	0.00	0	0.00
white catfish	13	0.00	2	0.00	0	0.00	0	0.00	1	0.00	10	0.01	0	0.00
brown smoothhound	13	0.00	3	0.00	4	0.00	0	0.00	1	0.00	4	0.00	1	0.00
lingcod	9	0.00	1	0.00	0	0.00	2	0.00	1	0.00	2	0.00	3	0.00
rainbow trout	9	0.00	4	0.00	0	0.00	2	0.00	2	0.00	0	0.00	1	0.00
leopard shark	9	0.00	1	0.00	3	0.00	2	0.00	1	0.00	1	0.00	1	0.00
spiny dogfish	7	0.00	2	0.00	1	0.00	0	0.00	1	0.00	2	0.00	1	0.00
Pacific lamprey	7	0.00	1	0.00	1	0.00	2	0.00	2	0.00	0	0.00	1	0.00
green sturgeon	6	0.00	1	0.00	1	0.00	4	0.01	0	0.00	0	0.00	0	0.00
big skate	6	0.00	0	0.00	6	0.01	0	0.00	0	0.00	0	0.00	0	0.00
diamond turbot	5	0.00	1	0.00	1	0.00	3	0.01	0	0.00	0	0.00	0	0.00
bay pipefish	5	0.00	1	0.00	2	0.00	0	0.00	1	0.00	0	0.00	1	0.00
brown bullhead	4	0.00	4	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
inland silverside	3	0.00	0	0.00	1	0.00	0	0.00	0	0.00	2	0.00	0	0.00
sand sole	3	0.00	1	0.00	0	0.00	0	0.00	2	0.00	0	0.00	0	0.00
river lamprey	3	0.00	0	0.00	0	0.00	0	0.00	1	0.00	2	0.00	0	0.00
unidentified sunfishes	2	0.00	0	0.00	0	0.00	0	0.00	2	0.00	0	0.00	0	0.00
California lizardfish	2	0.00	0	0.00	0	0.00	0	0.00	2	0.00	0	0.00	0	0.00
Sacramento squawfish	2	0.00	0	0.00	1	0.00	0	0.00	1	0.00	0	0.00	0	0.00

Table 9. Midwater Trawl Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
California tonguefish	2	0.00	0	0.00	0	0.00	1	0.00	1	0.00	0	0.00	0	0.00
cheekspot goby	2	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	0.00	0	0.00
California halibut	2	0.00	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
chameleon goby	2	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	1	0.00
brown rockfish	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
bonehead sculpin	1	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
barred surfperch	1	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
goldfish	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00
coho salmon	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
black bullhead	1	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00
black perch	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
Pacific barracuda	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
prickly sculpin	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
queenfish	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
chub mackerel	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
silver surfperch	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00
rainwater killifish	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
tule perch	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
calico surfperch	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
dwarf perch	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
wakasagi	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
Pacific sardine	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00
*** Total ***														
	620645		86284		104833		59287		79683		183080		107479	

Table 10. Beach Seine Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
topsmelt	42860	34.16	5147	63.39	2784	19.38	4013	24.24	7292	26.46	10922	41.41	12702	39.08
Pacific herring	21576	17.19	2	0.02	34	0.24	5288	31.95	199	0.72	2121	8.04	13932	42.86
northern anchovy	18738	14.93	503	6.19	5433	37.81	2667	16.11	7037	25.53	2196	8.33	902	2.77
jacksmelt	13049	10.40	87	1.07	347	2.42	1200	7.25	6056	21.97	3802	14.41	1557	4.79
striped bass	5228	4.17	137	1.69	1413	9.83	261	1.58	2647	9.60	727	2.76	43	0.13
Pacific staghorn sculpin	4553	3.63	40	0.49	537	3.74	1044	6.31	189	0.69	1252	4.75	1491	4.59
inland silverside	4503	3.59	216	2.66	644	4.48	262	1.58	315	1.14	2526	9.58	540	1.66
arrow goby	3286	2.62	159	1.96	1083	7.54	172	1.04	945	3.43	637	2.42	290	0.89
shiner perch	2461	1.96	618	7.61	529	3.68	181	1.09	482	1.75	248	0.94	403	1.24
yellowfin goby	2339	1.86	176	2.17	216	1.50	401	2.42	309	1.12	1163	4.41	74	0.23
dwarf perch	1618	1.29	467	5.75	523	3.64	190	1.15	135	0.49	161	0.61	142	0.44
threespine stickleback	1000	0.80	100	1.23	110	0.77	121	0.73	449	1.63	189	0.72	31	0.10
threadfin shad	667	0.53	8	0.10	10	0.07	15	0.09	608	2.21	25	0.09	1	0.00
bay pipefish	567	0.45	138	1.70	158	1.10	43	0.26	47	0.17	121	0.46	60	0.18
surf smelt	508	0.40	4	0.05	87	0.61	270	1.63	42	0.15	38	0.14	67	0.21
chinook salmon	380	0.30	0	0.00	84	0.58	80	0.48	170	0.62	26	0.10	20	0.06
walleye surfperch	347	0.28	67	0.83	49	0.34	15	0.09	166	0.60	18	0.07	32	0.10
splittail	235	0.19	0	0.00	5	0.03	77	0.47	140	0.51	10	0.04	3	0.01
English sole	218	0.17	29	0.36	47	0.33	74	0.45	18	0.07	39	0.15	11	0.03
longfin smelt	213	0.17	91	1.12	53	0.37	38	0.23	25	0.09	6	0.02	0	0.00
bay goby	205	0.16	22	0.27	79	0.55	60	0.36	15	0.05	0	0.00	29	0.09
delta smelt	120	0.10	8	0.10	9	0.06	3	0.02	87	0.32	13	0.05	0	0.00
starry flounder	114	0.09	23	0.28	11	0.08	8	0.05	20	0.07	40	0.15	12	0.04
rainwater killifish	90	0.07	24	0.30	14	0.10	6	0.04	8	0.03	14	0.05	24	0.07
American shad	72	0.06	3	0.04	2	0.01	13	0.08	47	0.17	5	0.02	2	0.01
moquitofish	60	0.05	0	0.00	6	0.04	19	0.11	29	0.11	3	0.01	3	0.01
Sacramento squawfish	59	0.05	11	0.14	14	0.10	2	0.01	16	0.06	14	0.05	2	0.01
cheekspot goby	56	0.04	10	0.12	11	0.08	4	0.02	3	0.01	4	0.02	24	0.07
white croaker	53	0.04	0	0.00	0	0.00	7	0.04	11	0.04	4	0.02	31	0.10
barred surfperch	49	0.04	7	0.09	7	0.05	1	0.01	14	0.05	3	0.01	17	0.05
tule perch	49	0.04	2	0.02	29	0.20	1	0.01	2	0.01	1	0.00	14	0.04
diamond turbot	37	0.03	1	0.01	3	0.02	4	0.02	5	0.02	10	0.04	14	0.04
pile perch	27	0.02	3	0.04	4	0.03	0	0.00	6	0.02	7	0.03	7	0.02
California halibut	25	0.02	0	0.00	0	0.00	0	0.00	2	0.01	16	0.06	7	0.02
black perch	15	0.01	2	0.02	8	0.06	1	0.01	0	0.00	4	0.02	0	0.00
brown rockfish	12	0.01	3	0.04	3	0.02	5	0.03	0	0.00	1	0.00	0	0.00
white seaperch	10	0.01	1	0.01	7	0.05	0	0.00	0	0.00	0	0.00	2	0.01
Pacific sandlance	9	0.01	0	0.00	3	0.02	0	0.00	0	0.00	0	0.00	6	0.02
sand sole	7	0.01	2	0.02	0	0.00	1	0.01	0	0.00	1	0.00	3	0.01
chameleon goby	7	0.01	0	0.00	0	0.00	0	0.00	0	0.00	3	0.01	4	0.01
night smelt	7	0.01	0	0.00	1	0.01	0	0.00	6	0.02	0	0.00	0	0.00
rubberlip seaperch	5	0.00	4	0.05	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
speckled sanddab	5	0.00	2	0.02	0	0.00	1	0.01	1	0.00	1	0.00	0	0.00
bat ray	5	0.00	0	0.00	0	0.00	1	0.01	2	0.01	2	0.01	0	0.00
penpoint gunnel	5	0.00	0	0.00	5	0.03	0	0.00	0	0.00	0	0.00	0	0.00
rainbow trout	4	0.00	0	0.00	0	0.00	1	0.01	0	0.00	2	0.01	1	0.00
longjaw mudsucker	3	0.00	0	0.00	0	0.00	0	0.00	2	0.01	1	0.00	0	0.00
hitch	3	0.00	0	0.00	0	0.00	0	0.00	3	0.01	0	0.00	0	0.00
cabezon	2	0.00	1	0.01	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
white catfish	2	0.00	0	0.00	0	0.00	0	0.00	2	0.01	0	0.00	0	0.00

Table 10. Beach Seine Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
common carp	2	0.00	0	0.00	1	0.01	0	0.00	1	0.00	0	0.00	0	0.00
rockpool blenny	2	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	2	0.01
striped kelpfish	2	0.00	0	0.00	2	0.01	0	0.00	0	0.00	0	0.00	0	0.00
fluffy sculpin	1	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
calico surfperch	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
bonehead sculpin	1	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
channel catfish	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
prickly sculpin	1	0.00	0	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00
kelp greenling	1	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Sacramento blackfish	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
striped mullet	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
largemouth bass	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
silver surfperch	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00
unidentified sunfishes	1	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00
unidentified rockfish	1	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
leopard shark	1	0.00	0	0.00	1	0.01	0	0.00	0	0.00	0	0.00	0	0.00
*** Total ***	125482		8120		14368		16552		27560		26376		32506	

Table 11. Larval Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
Pacific herring	387366	51.50	24862	29.65	54641	48.06	211563	73.08	32167	46.97	9501	15.60	54632	40.24
yellowfin goby	80824	10.74	12	0.01	5513	4.85	11681	4.03	2385	3.48	21748	35.70	39485	29.08
northern anchovy	64383	8.56	11733	13.99	9883	8.69	2704	0.93	14031	20.49	6758	11.09	19274	14.19
unidentified smelts	59506	7.91	767	0.91	11509	10.12	38370	13.25	1165	1.70	5264	8.64	2431	1.79
goby complex	48838	6.49	31720	37.83	17118	15.06	0	0.00	0	0.00	0	0.00	0	0.00
longfin smelt	34109	4.53	5993	7.15	91	0.08	6459	2.23	4517	6.60	7149	11.73	9900	7.29
arrow/cheekspot goby	24893	3.31	0	0.00	6098	5.36	4333	1.50	4776	6.97	5327	8.74	4359	3.21
striped bass	17787	2.36	4736	5.65	3019	2.66	4736	1.64	2780	4.06	1503	2.47	1013	0.75
prickly sculpin	8032	1.07	773	0.92	545	0.48	2014	0.70	3134	4.58	1138	1.87	428	0.32
bay goby	4951	0.66	888	1.06	1444	1.27	803	0.28	607	0.89	693	1.14	516	0.38
white croaker	4567	0.61	1119	1.33	422	0.37	354	0.12	893	1.30	489	0.80	1290	0.95
jacksmelt	3813	0.51	515	0.61	1998	1.76	612	0.21	269	0.39	343	0.56	76	0.06
Pacific staghorn sculpin	3206	0.43	276	0.33	604	0.53	481	0.17	229	0.33	369	0.61	1247	0.92
arrow goby	3061	0.41	7	0.01	6	0.01	3046	1.05	1	0.00	0	0.00	1	0.00
threadfin shad	1994	0.27	13	0.02	194	0.17	797	0.28	653	0.95	233	0.38	104	0.08
chameleon goby	1475	0.20	2	0.00	156	0.14	91	0.03	249	0.36	249	0.41	728	0.54
cheekspot goby	406	0.05	0	0.00	0	0.00	406	0.14	0	0.00	0	0.00	0	0.00
English sole	394	0.05	28	0.03	1	0.00	294	0.10	45	0.07	0	0.00	26	0.02
delta smelt	373	0.05	33	0.04	27	0.02	126	0.04	163	0.24	24	0.04	0	0.00
unidentified rockfish	354	0.05	56	0.07	45	0.04	111	0.04	81	0.12	27	0.04	34	0.03
common carp	349	0.05	31	0.04	29	0.03	283	0.10	5	0.01	1	0.00	0	0.00
topsmelt	246	0.03	16	0.02	164	0.14	22	0.01	21	0.03	6	0.01	17	0.01
diamond turbot	194	0.03	49	0.06	25	0.02	7	0.00	54	0.08	14	0.02	45	0.03
starry flounder	162	0.02	59	0.07	8	0.01	34	0.01	14	0.02	13	0.02	34	0.03
longjaw mudsucker	131	0.02	3	0.00	57	0.05	24	0.01	19	0.03	17	0.03	11	0.01
cabezon	97	0.01	15	0.02	22	0.02	20	0.01	4	0.01	14	0.02	22	0.02
bigscale logperch	80	0.01	4	0.00	1	0.00	18	0.01	52	0.08	3	0.00	2	0.00
unidentified sunfishes	73	0.01	4	0.00	2	0.00	1	0.00	24	0.04	3	0.00	39	0.03
California halibut	63	0.01	2	0.00	1	0.00	1	0.00	44	0.06	8	0.01	7	0.01
unidentified pricklebacks	54	0.01	9	0.01	7	0.01	11	0.00	1	0.00	2	0.00	24	0.02
striped kelpfish	50	0.01	21	0.03	19	0.02	6	0.00	3	0.00	1	0.00	0	0.00
unidentified fish	39	0.01	9	0.01	5	0.00	4	0.00	15	0.02	1	0.00	5	0.00
American shad	37	0.00	0	0.00	0	0.00	8	0.00	29	0.04	0	0.00	0	0.00
bonehead sculpin	33	0.00	15	0.02	12	0.01	4	0.00	0	0.00	1	0.00	1	0.00
unidentified sculpins	26	0.00	8	0.01	4	0.00	3	0.00	3	0.00	8	0.01	0	0.00
splittail	25	0.00	1	0.00	0	0.00	6	0.00	18	0.03	0	0.00	0	0.00
northern lampfish	23	0.00	17	0.02	0	0.00	2	0.00	2	0.00	0	0.00	2	0.00
lingcod	22	0.00	3	0.00	2	0.00	9	0.00	6	0.01	1	0.00	1	0.00
unidentified flounders	22	0.00	16	0.02	2	0.00	2	0.00	0	0.00	0	0.00	2	0.00
unidentified clinids	18	0.00	0	0.00	0	0.00	2	0.00	0	0.00	2	0.00	14	0.01
sand sole	16	0.00	3	0.00	0	0.00	7	0.00	2	0.00	0	0.00	4	0.00
onespot fringehead	15	0.00	3	0.00	0	0.00	3	0.00	7	0.01	2	0.00	0	0.00
threespine stickleback	12	0.00	2	0.00	0	0.00	3	0.00	7	0.01	0	0.00	0	0.00
unidentified clupeidae	10	0.00	10	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
kelp greenling	10	0.00	2	0.00	4	0.00	1	0.00	3	0.00	0	0.00	0	0.00
brown Irish lord	9	0.00	9	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
inland silverside	9	0.00	0	0.00	0	0.00	4	0.00	0	0.00	3	0.00	2	0.00
Pacific tomcod	9	0.00	9	0.01	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
bluegill	9	0.00	0	0.00	0	0.00	9	0.00	0	0.00	0	0.00	0	0.00
unidentified gobies	9	0.00	0	0.00	0	0.00	0	0.00	1	0.00	3	0.00	5	0.00

Table 11. Larval Fish Catch and Percentage Catch

Common Name	Total Catch	Total %	1980 Catch	1980 %	1981 Catch	1981 %	1982 Catch	1982 %	1983 Catch	1983 %	1984 Catch	1984 %	1985 Catch	1985 %
painted greenling	7	0.00	0	0.00	1	0.00	5	0.00	0	0.00	1	0.00	0	0.00
Sacramento sucker	6	0.00	0	0.00	0	0.00	0	0.00	4	0.01	2	0.00	0	0.00
red brotula	6	0.00	3	0.00	1	0.00	2	0.00	0	0.00	0	0.00	0	0.00
Sacramento squawfish	5	0.00	0	0.00	0	0.00	5	0.00	0	0.00	0	0.00	0	0.00
white sturgeon	4	0.00	1	0.00	0	0.00	0	0.00	3	0.00	0	0.00	0	0.00
tidepool sculpin	4	0.00	0	0.00	1	0.00	3	0.00	0	0.00	0	0.00	0	0.00
blue lanternfish	2	0.00	0	0.00	0	0.00	1	0.00	0	0.00	1	0.00	0	0.00
blackeye goby	2	0.00	0	0.00	1	0.00	0	0.00	1	0.00	0	0.00	0	0.00
northern clingfish	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
surf smelt	1	0.00	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	0	0.00
Pacific blacksmelt	1	0.00	0	0.00	0	0.00	1	0.00	0	0.00	0	0.00	0	0.00
Pacific argentine	1	0.00	0	0.00	0	0.00	0	0.00	0	0.00	1	0.00	0	0.00
*** Total ***	752224		83859		113682		289492		68487		60923		135781	

Chapter 6. TRUE SMELTS

Worldwide, the family Osmeridae, or true smelts, contains about 13 species of small, planktivorous fish (Herald, 1971). Six species are common along the California coast (Miller and Lea, 1972); five of these were collected during our 6-year study. Of these five species, three are primarily marine: whitebait smelt (Allosmerus elongatus), surf smelt (Hypomesus pretiosus), and night smelt (Spirinchus starksi). A fourth species, delta smelt (Hypomesus transpacificus), is primarily freshwater (Wang, 1986; Miller and Lea, 1972, Moyle, 1976).

Longfin smelt (Spirinchus thaleichthys), on the other hand, are anadromous and as juveniles and adults are distributed throughout the Bay/Delta system and occasionally into the Gulf of the Farallones (this study, City of San Francisco, unpublished data). Only longfin smelt will be discussed in detail in this report because they were the only relatively abundant Osmerid smelt species in the catch from any of the nets (Table 12).

The Bay/Delta system is the southernmost within the species range, which includes several estuaries along the Pacific coast as far north as Prince William Sound, Alaska. Most of these populations are anadromous, but there are landlocked populations (Moulton, 1974). California has at least two populations in addition to the Bay/

Table 12

CATCH AND PERCENT OF OVERALL FISH CATCH, BY GEAR, OF OSMERID SPECIES, 1980 THROUGH 1985

	Otter Trawl		Midwater Trawl		Seine	
	Number	Percent	Number	Percent	Number	Percent
Delta Smelt	248	0.17	1,056	0.17	120	0.10
Longfin Smelt	40,834	28.28	44,732	7.21	213	0.17
Night Smelt	3	*	160	0.03	7	0.01
Surf Smelt	32	0.02	90	0.01	508	0.40
Whitebait Smelt	176	0.12	58	0.01	0	0.00
Total	41,293		46,096		848	
Percent all fish		28.60		7.38		0.67

* Indicates a percent of overall fish catch rounding to less than 0.01.

Delta population, one in the Eel River estuary and another in Humboldt Bay.

No comprehensive studies have been made of the life history of longfin smelt in the study area, but results of general fisheries studies (Ganssle, 1967; Moyle, 1976) suggest that the life history in this area is similar to that of other, better studied populations. Mature adults nearing the end of their second year apparently move from the lower parts of the estuary into the interior Delta, lower rivers, and freshwater marshes, where they spawn primarily in December to February (Radtke, 1966; Moyle, 1976). After the adhesive eggs hatch, the pelagic larvae are quickly dispersed downstream by streamflow. Generally longfin smelt are concentrated in Suisun and San Pablo bays during the first 1.5 years of life, feeding primarily on Neomysis mercedes. For the most part they spawn only once and die, but a few females appear to live a third year and spawn a second time.

Longfin smelt are edible, but there are no significant commercial or sport fisheries for the species. However, their great abundance and small maximum size (4-5 inches) undoubtedly makes them important prey for Bay predators.

Gear Limitations and Effort Correction

Longfin smelt were abundant in all sampling gear except the beach seine (Table 12). They comprised the greatest proportion of overall fish catch in the otter trawl (28 percent) during the 6 years of sampling, but were also a major component of the overall midwater trawl fish catch (7 percent). About 13 percent of yolk-sac larvae, 3 percent of post larvae, and 34 percent of juveniles collected in the egg and larval net were identified as longfin smelt.

Beach Seine

The small number of longfin smelt caught in the beach seine (213 fish in 6 years) indicates that they are not abundant in the littoral areas of the Bay. Therefore, data from this gear were not used in characterizing their distribution and abundance.

Egg and Larvae Net

Larval delta smelt and longfin smelt are not reliably differentiated. This poses a problem in examining distribution and abundance of the larval stages of these two species, because they are likely to occur together in the study area, particularly in upper Suisun Bay and the West Delta. However, the catch of juvenile fish of these two species in the egg and larval net was composed of 96 percent longfin smelt. Because of the numerical dominance of longfin smelt in the juvenile catch, we have assumed in our larval distribution and abundance analysis that all osmerid larvae collected in the study area were longfin smelt.

Since larval longfin smelt are pelagic and distributed throughout the water column, we measured the effort associated with the tows as the volume of water filtered by the net during each tow.

Otter Trawl and Midwater Trawl

Both the otter trawl and midwater trawl are effective in catching juvenile and adult longfin smelt. We chose the otter trawl data to characterize their distribution and abundance, because on the whole the otter trawl catch per unit effort has been consistently higher than that of the midwater trawl, indicating greater efficiency. The otter trawl also samples more consistently between stations of different depth.

Longfin smelt are reported to favor the deeper strata of the water column during daylight hours (Dryfoos, 1965), but they are not demersal. Therefore, we used the volume of water filtered by the otter trawl as the measure of effort, which was based on the open area of the mouth of the net and the distance traveled through the water.

Larval Distribution and Abundance

During this study nearly 40,000 larval longfin smelt were collected, with the numbers about evenly divided between the yolk-sac and post larval forms. Together, the two forms comprised about 5 percent of the total larval fish catch.

Larval longfin smelt were caught from November through June, with the greatest concentrations in January through May (Figure 66). March was the month of peak abundance in 1981 and 1982, while February was the month of peak abundance in the other 4 years of the study. The data suggest a protracted spawning season, as there were high concentrations of larval longfin smelt for 3 to 4 months each year.

Spatial distribution of larval longfin smelt within the study area varied considerably from year to year. As Figure 67 illustrates, the area of peak abundance was as far downstream as mid-San Pablo Bay in 1983 and as far upstream as mid-Suisun Bay in 1981 and 1985. In all years but 1981, larval smelt were collected in all embayments.

Larval longfin smelt were not consistently found in greater concentrations at either channel or shoal stations, although the overall mean density was slightly higher at shoal stations than at channel stations (623.9/10,000 versus 525.7/10,000 m^3).

Young-of-Year Distribution and Abundance

Young-of-Year (YOY) fish are presumed to be less than 1 year old based on their length and assuming a January 1 hatch. A January 1 hatch is assumed because peak larval abundance is generally in February and it takes about 40 days for the eggs to hatch (Moyle, 1976). For each survey period, a cut-off length was established to separate YOY from adults, based on the length frequency distribution during that survey period for all years combined (Figure 68).

The earliest that YOY fish appeared in significant numbers in the otter and midwater trawls during the study was April; by May YOY are generally the numerically dominant age group in the trawl samples (Figure 68).

Figure 69 illustrates the spatial distribution of YOY longfin smelt each year during May and June, when the smelt average about 40 mm fork length. In every year but 1983 and 1985, the highest concentration during May and June was in mid-San Pablo Bay (area 7). In 1985, a very dry year, the highest concentration was farther upstream in lower Suisun Bay (area 9); in 1983, a very wet year, highest sample densities were found in lower San Pablo Bay (area 6). South Bay had relatively few fish in May and June in all years except 1983.

During their first year, YOY smelt appear to become progressively more widespread in the Bay (Figures 70, 71, and 72). In summer and fall of most years, they were found in significant numbers in every embayment.

The mean CPUE of YOY longfin smelt during the study was slightly higher at shoal stations than at channel stations, 49.9 versus 40.8 (Table 13).

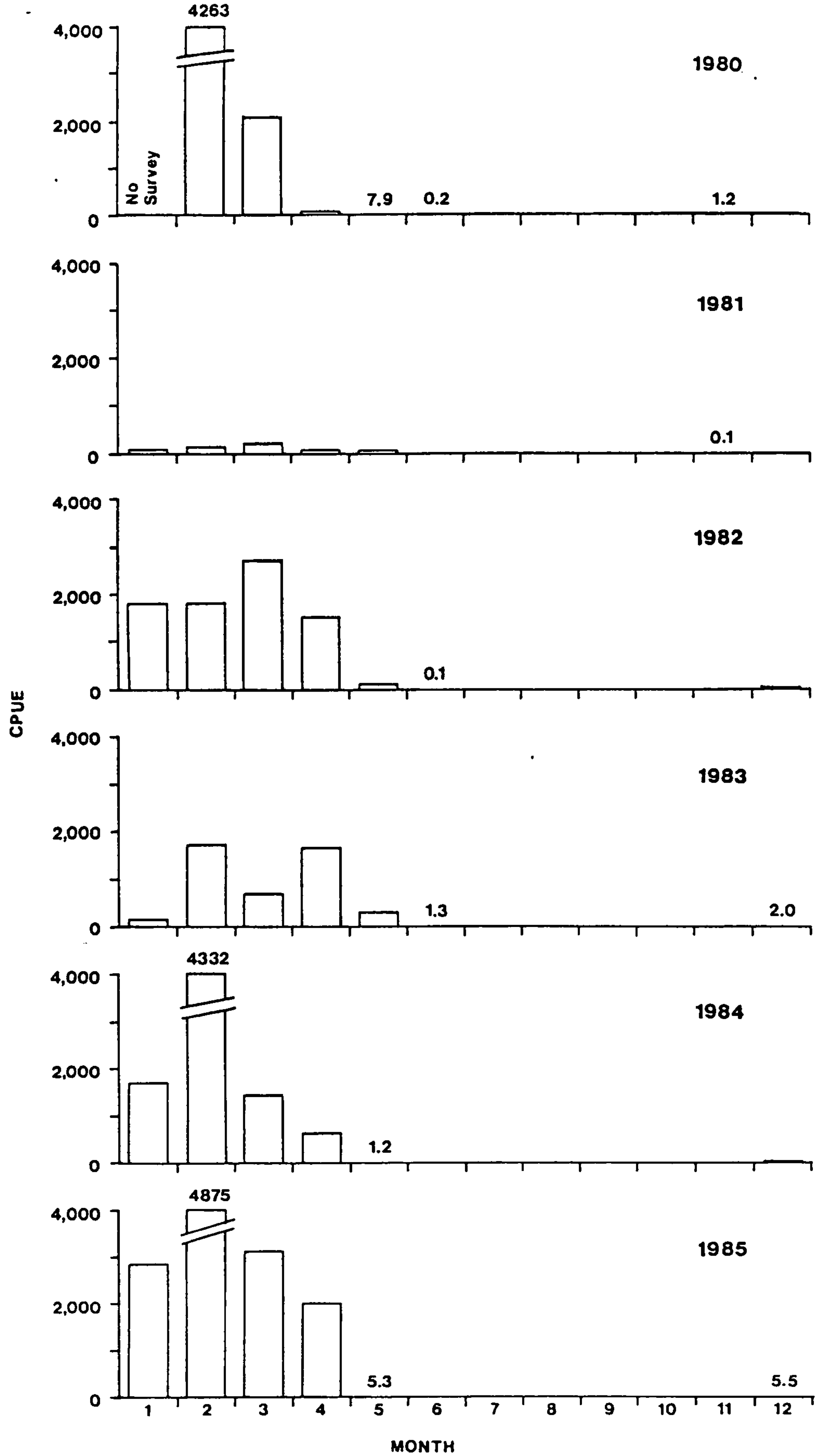


Figure 66. Seasonal distribution of larval longfin smelt each year. Yolk-sac and post larvae are combined.

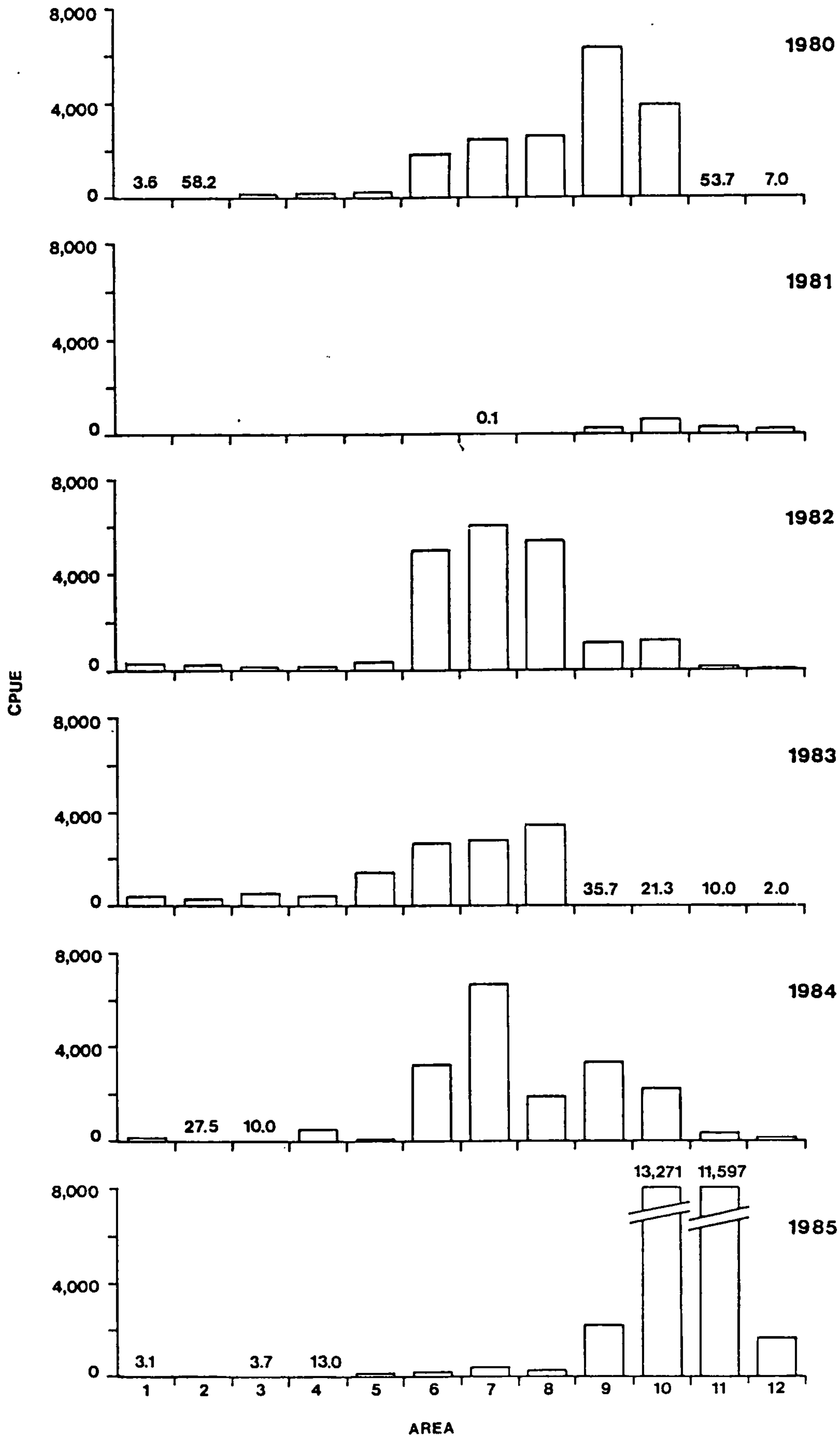


Figure 67. Spatial distribution of longfin smelt larvae each year during the period January through May. Yolk-sac and post larvae are combined.

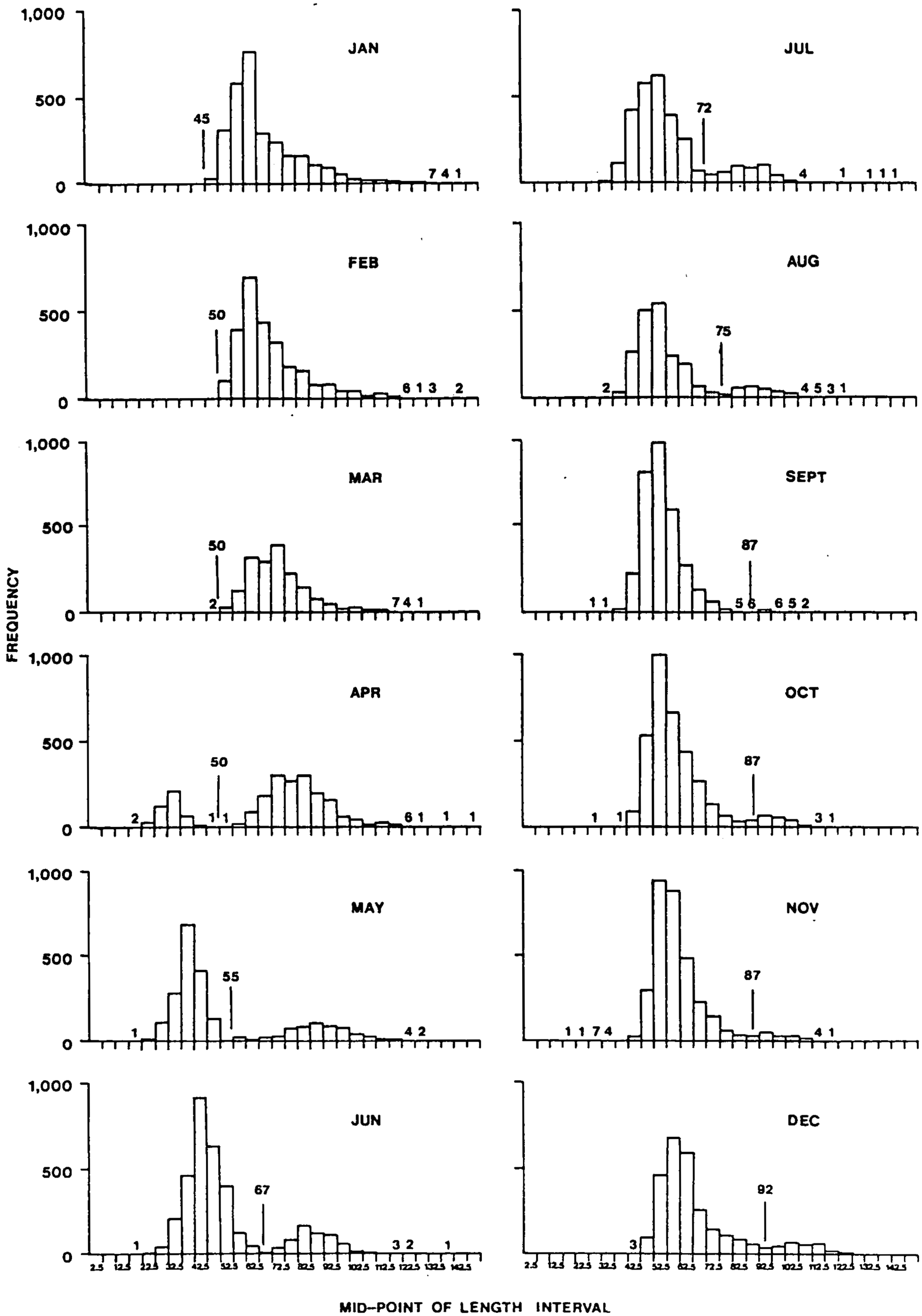


Figure 68. Length frequency distribution of longfin smelt caught in the otter trawl and midwater trawl, all years included. Lengths used for separating YOY from adults are shown for each month.

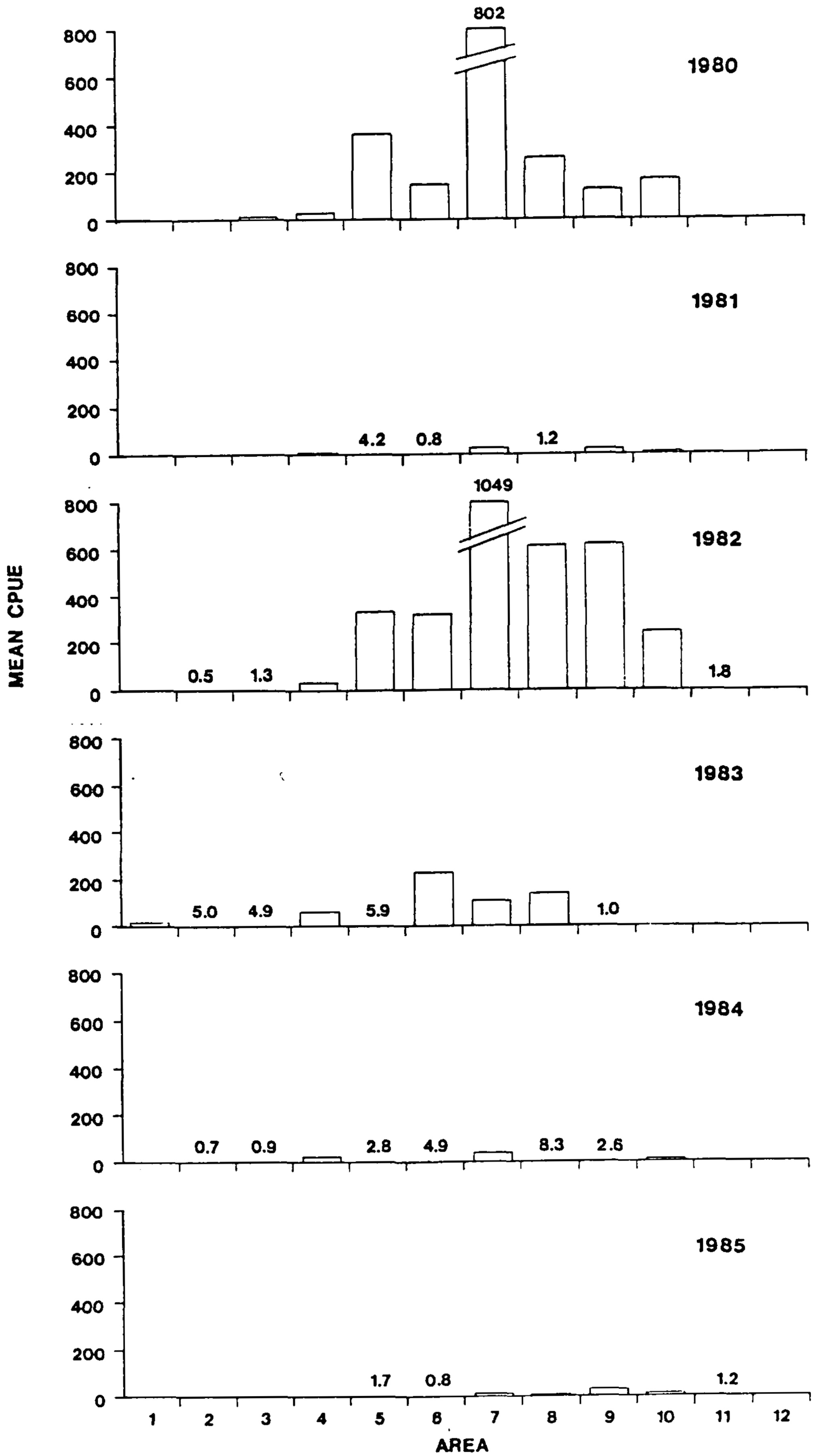


Figure 69. Spatial distribution of YOY longfin smelt during May and June.

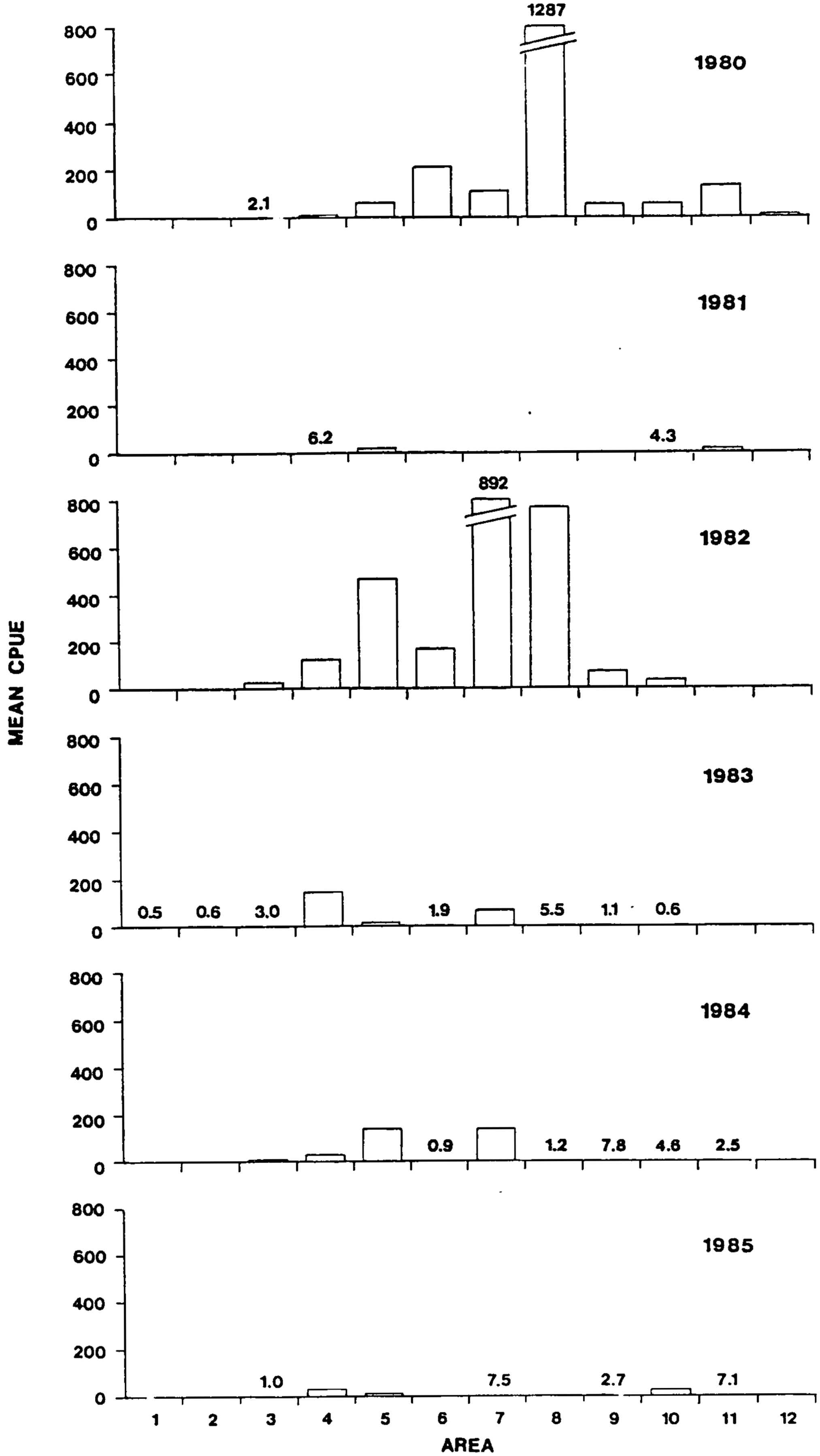


Figure 70. Spatial distribution of YOY longfin smelt during July and August.

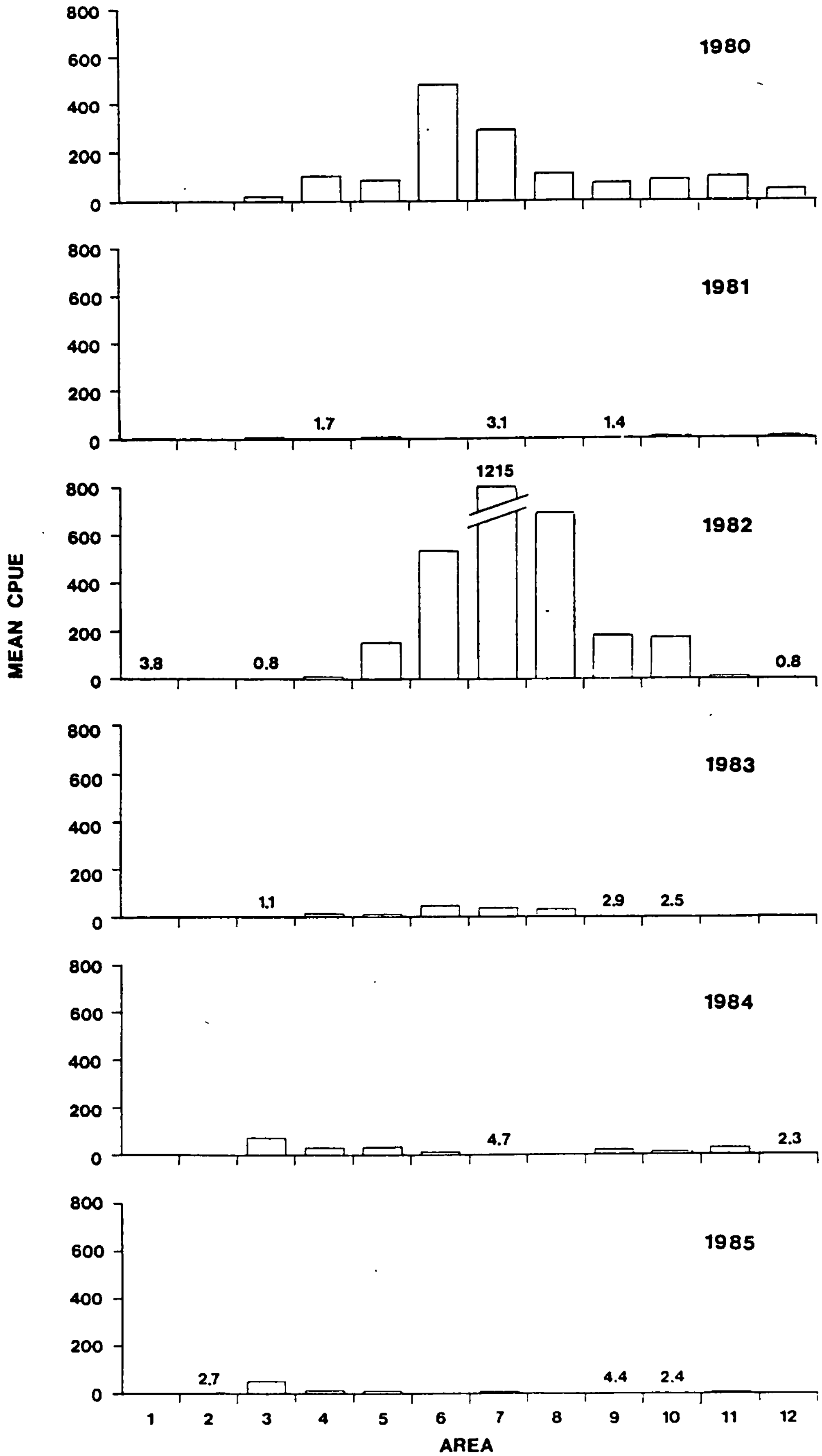


Figure 71. Spatial distribution of YOY longfin smelt during September and October.

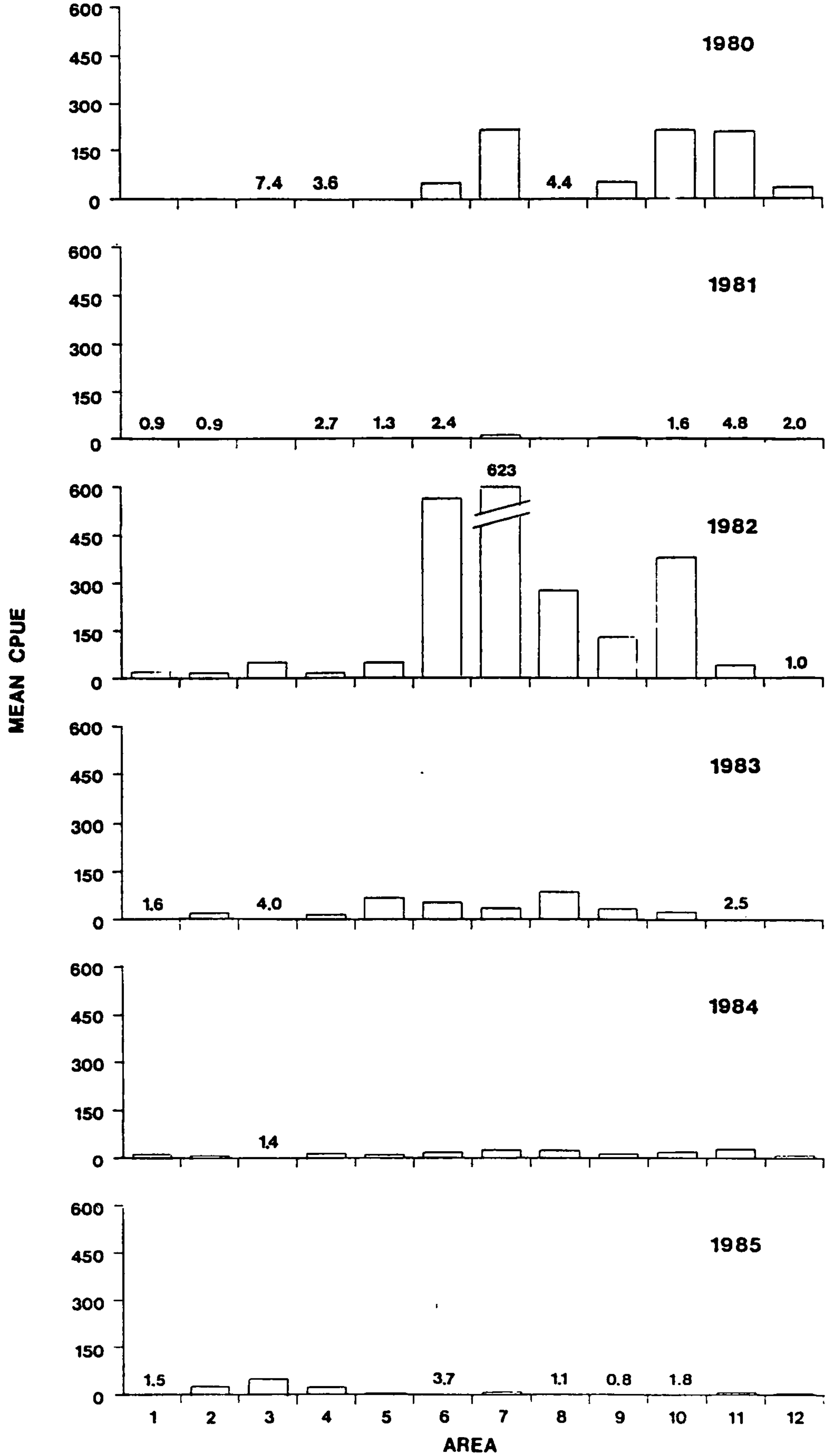


Figure 72. Spatial distribution of YOY longfin smelt during November and December.

Table 13

MEAN CPUE OF YOUNG-OF-YEAR LONGFIN SMELT AT CHANNEL AND SHOAL STATIONS

Year	Channel Stations	Shoal Stations
1980	81.9	102.2
1981	3.4	1.8
1982	123.8	170.9
1983	12.4	23.9
1984	18.3	5.6
1985	12.2	1.5
All Years	40.8	49.9

Table 13 gives the appearance that in the two dry years (1981 and 1985) fish were found in greater densities in channel stations, while in the three wet years they were more concentrated in the shoal stations. We believe this apparent difference is a result of the distribution of our channel and shoal stations. Specifically, in wetter years a large proportion of the YOY smelt are in San Pablo Bay, which has a higher proportion of shoal stations than other embayments.

Adult Distribution and Abundance

Longfin smelt have a relatively simple life cycle. They are spawned in the winter of one year, mature toward the end of their second year, spawn that winter, then most die. In this study, adults are those in their second year plus the relatively few that live beyond their first spawning effort.

In their second spring, longfin smelt were concentrated anywhere from upper Central Bay to lower Suisun Bay depending on the year (Figure 73). In their second summer and fall, they tended to be farther downstream, typically concentrated in Central Bay (Figures 74 and 75). As their second full winter approaches, they would be expected to be farther upstream as they move toward the spawning ground in the lower rivers. Our data suggest a tendency toward this upstream movement, but in November and December many adult longfin smelt were still low in the estuary (Figure 76).

Adult longfin smelt appear to favor deeper water, but are found in significant numbers at both shallow and deep stations. Table 14 shows that mean CPUE was greater in all years at channel stations, and for all years combined the mean CPUE was 20.4 in channel stations and 14.4 in shoal stations.

Table 14

MEAN CPUE OF ADULT LONGFIN SMELT AT CHANNEL AND SHOAL STATIONS

Year	Channel Stations	Shoal Stations
1980	2.5	2.3
1981	17.5	5.3
1982	5.2	0.7
1983	68.6	56.6
1984	18.2	15.9
1985	8.9	4.1
All Years	20.4	14.4

Effects of Salinity

Longfin smelt have commonly been described as euryhaline, and our data support this description. Both juveniles and adults were captured in the full range of salinities in the study area (Figure 77), and the mean CPUE at the different salinity ranges was remarkably similar, especially for YOY fish.

When the juveniles first become susceptible to the trawling gear in May, the mean CPUE for all years was highest at salinities of less than 12 ppt. However, in subsequent months their salinity distribution became more generalized (Figure 78).

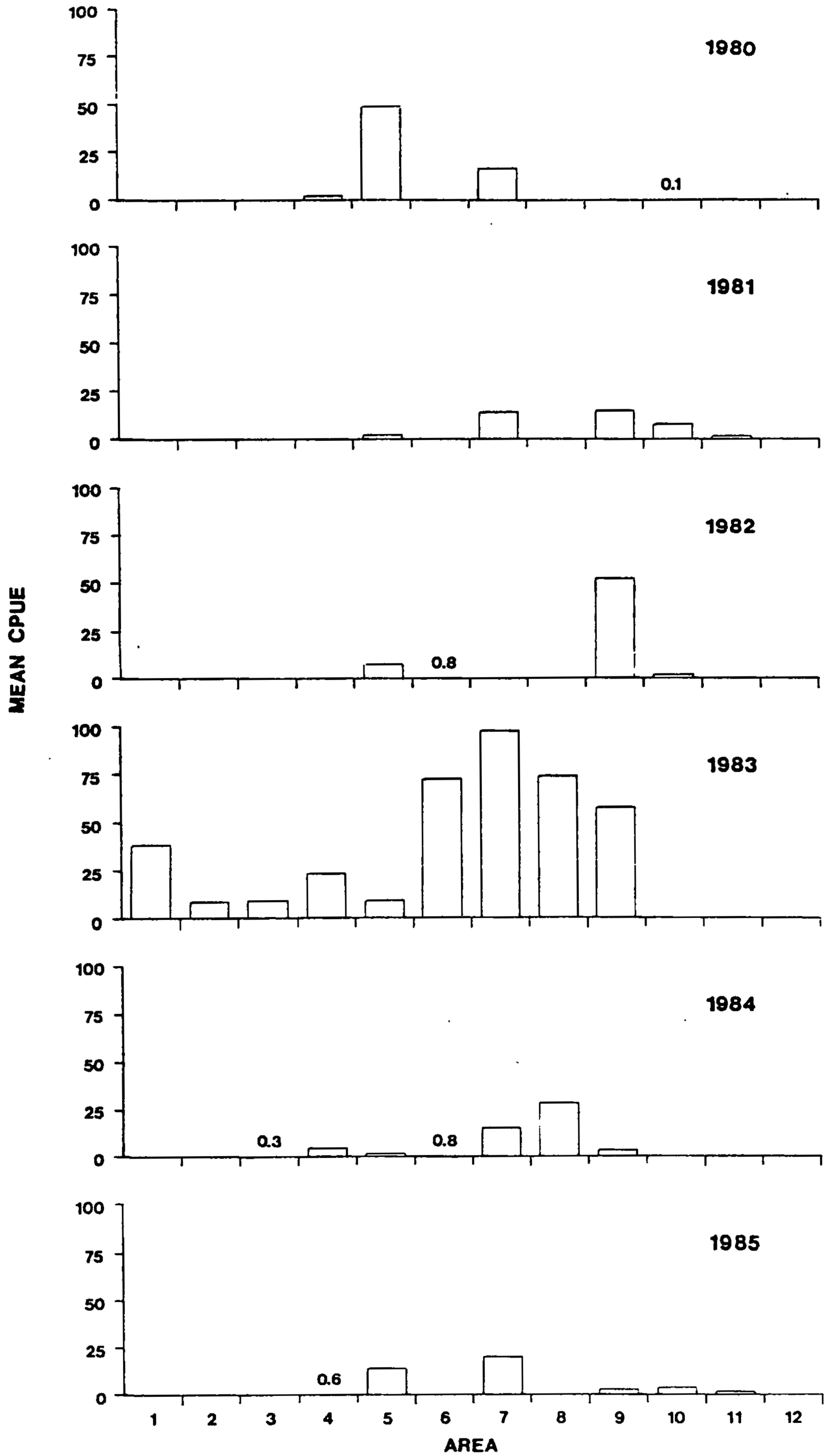


Figure 73. Spatial distribution of adult longfin smelt during the months May and June.

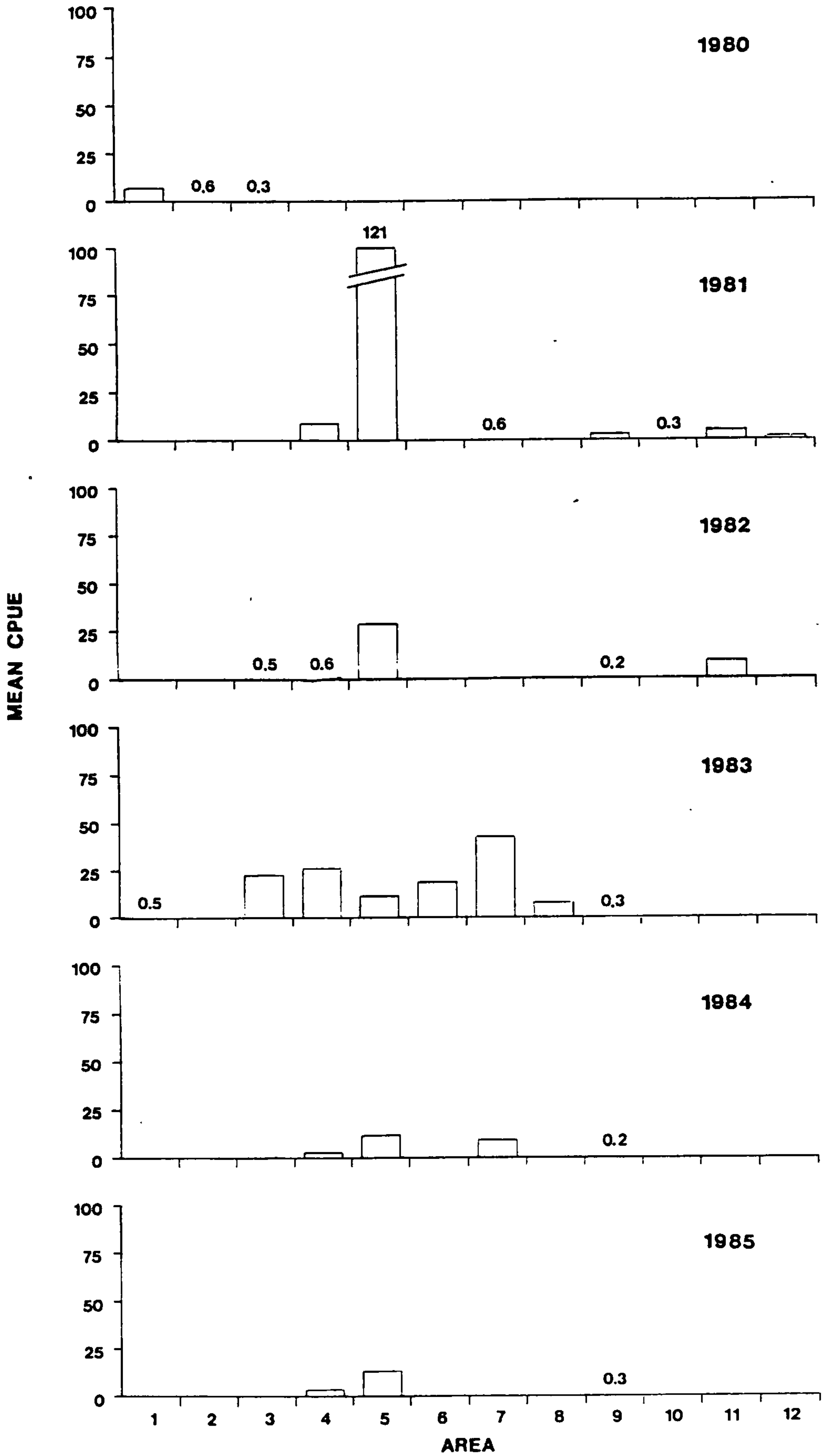


Figure 74. Spatial distribution of adult longfin smelt during the months July and August.

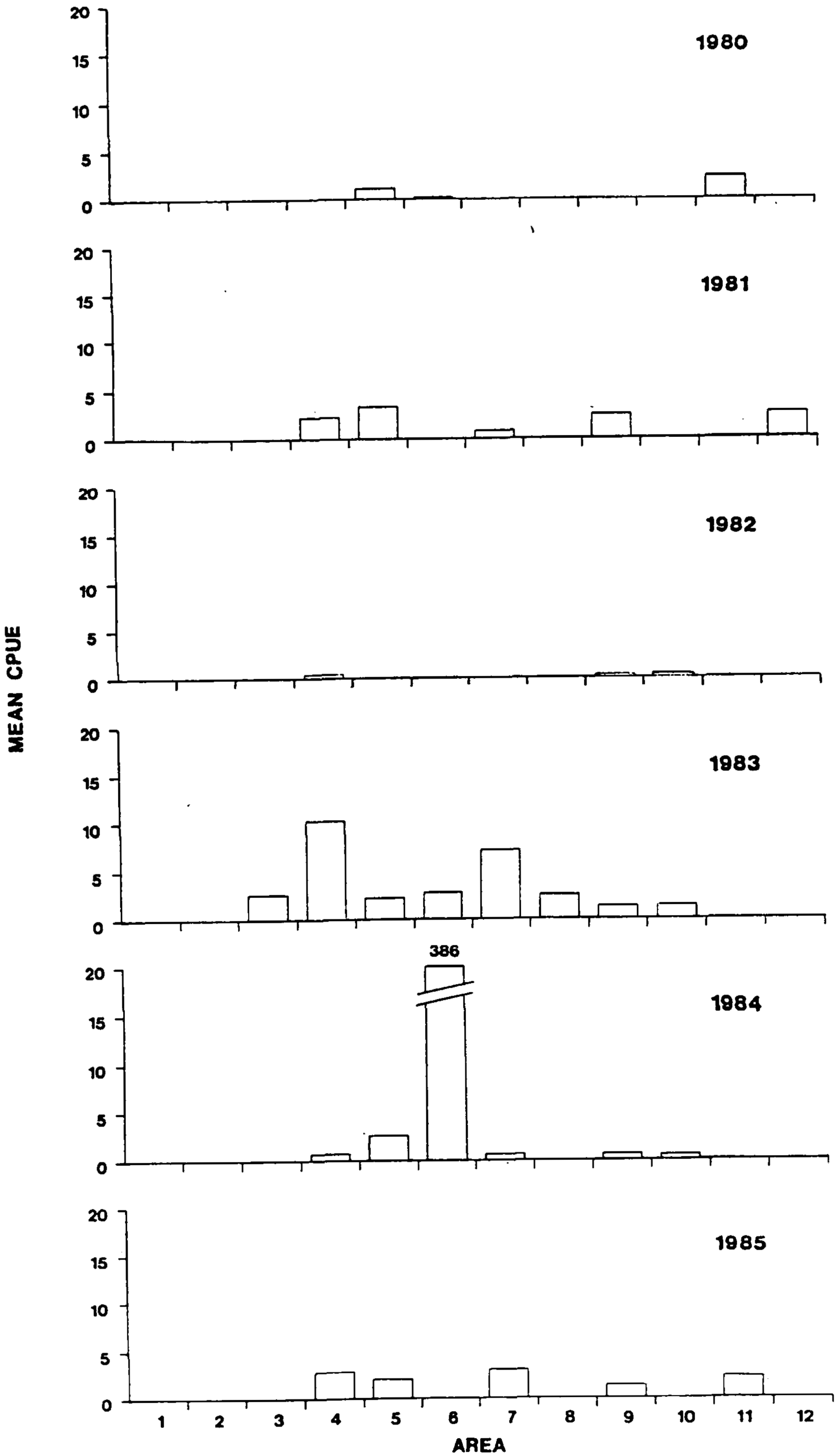


Figure 75. Spatial distribution of adult longfin smelt during the months September and October.

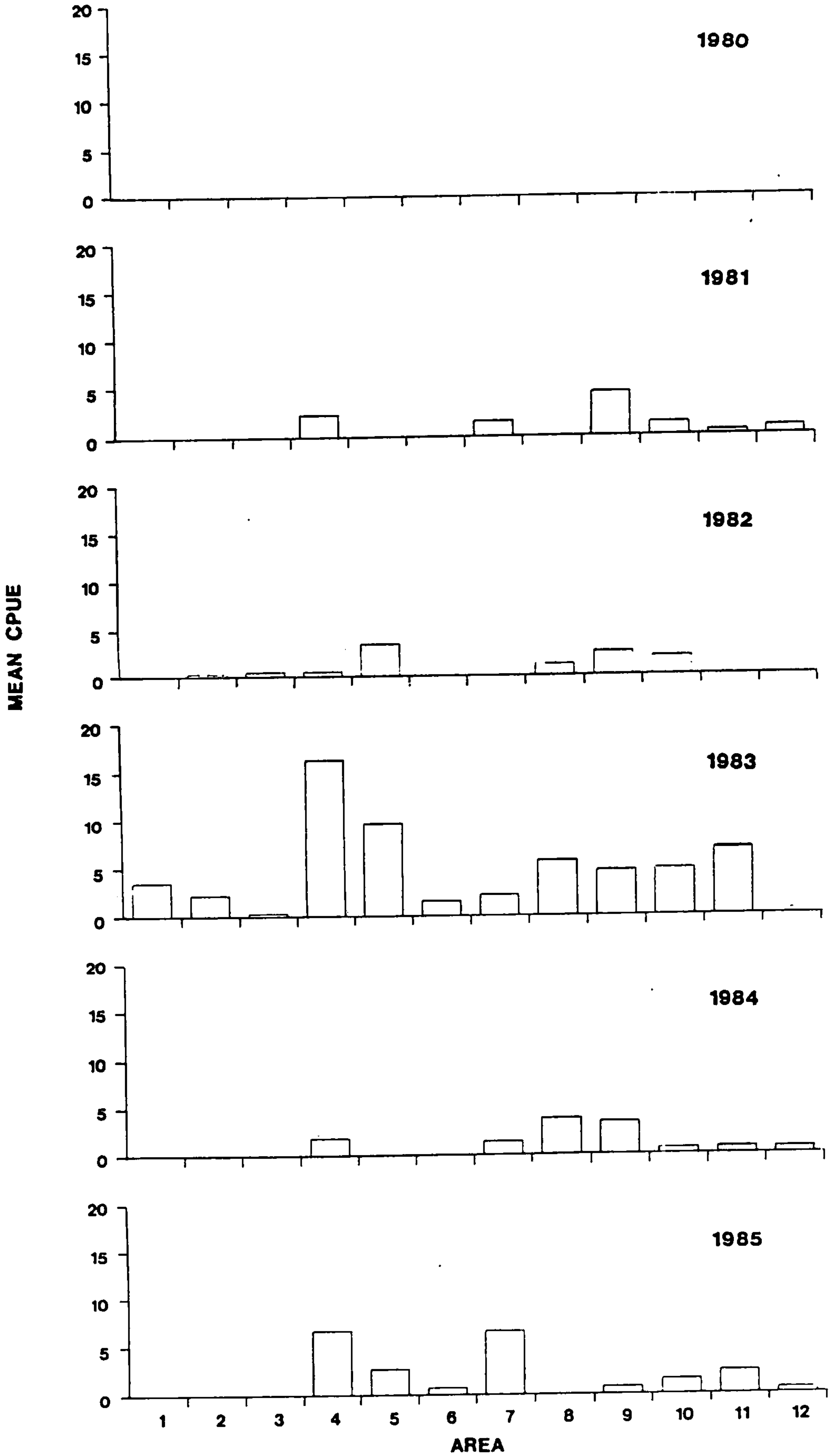


Figure 76. Spatial distribution of adult longfin smelt during the months November and December.

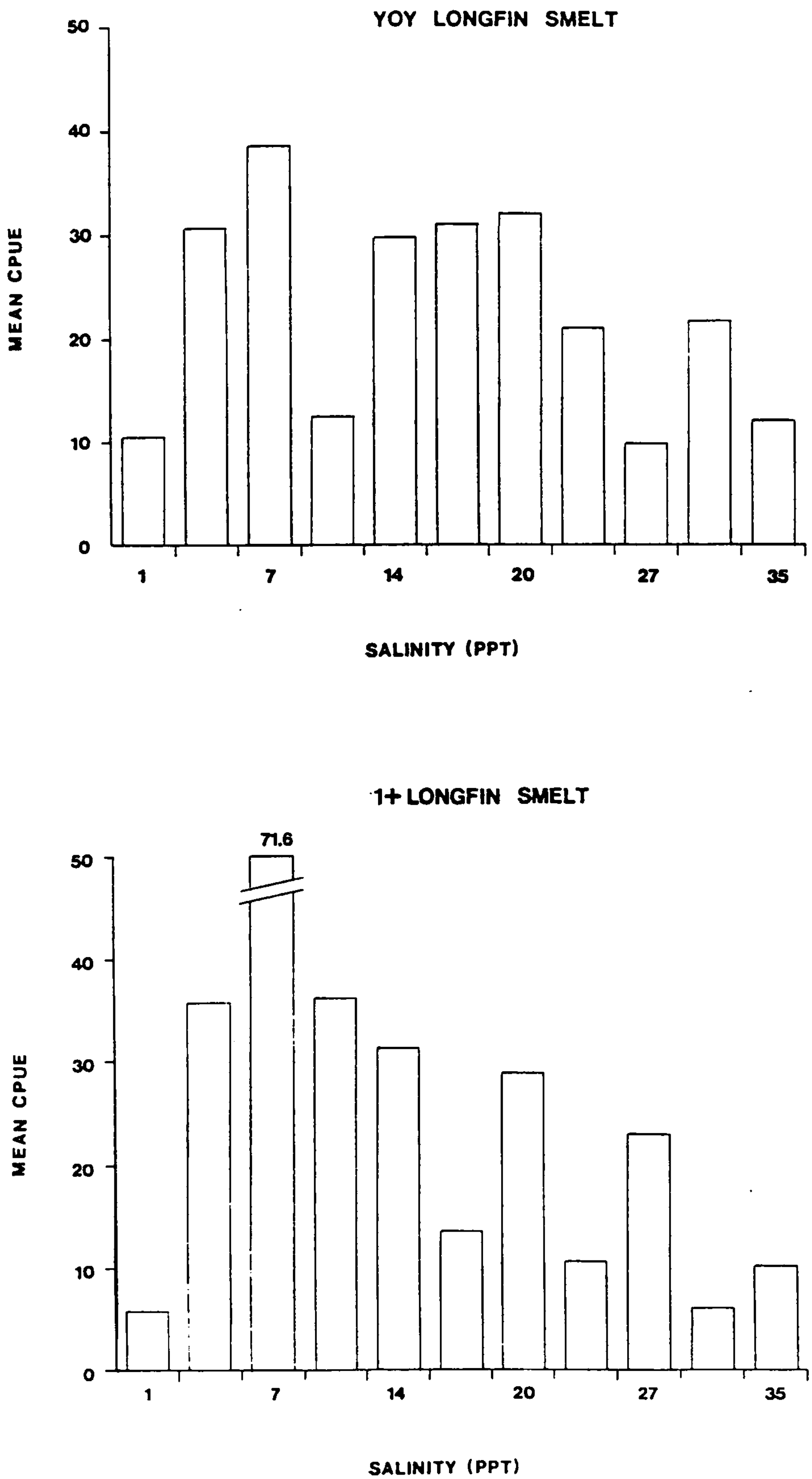


Figure 77. Mean CPUE of YOY and adult longfin smelt vs. salnity, 1980-1985.

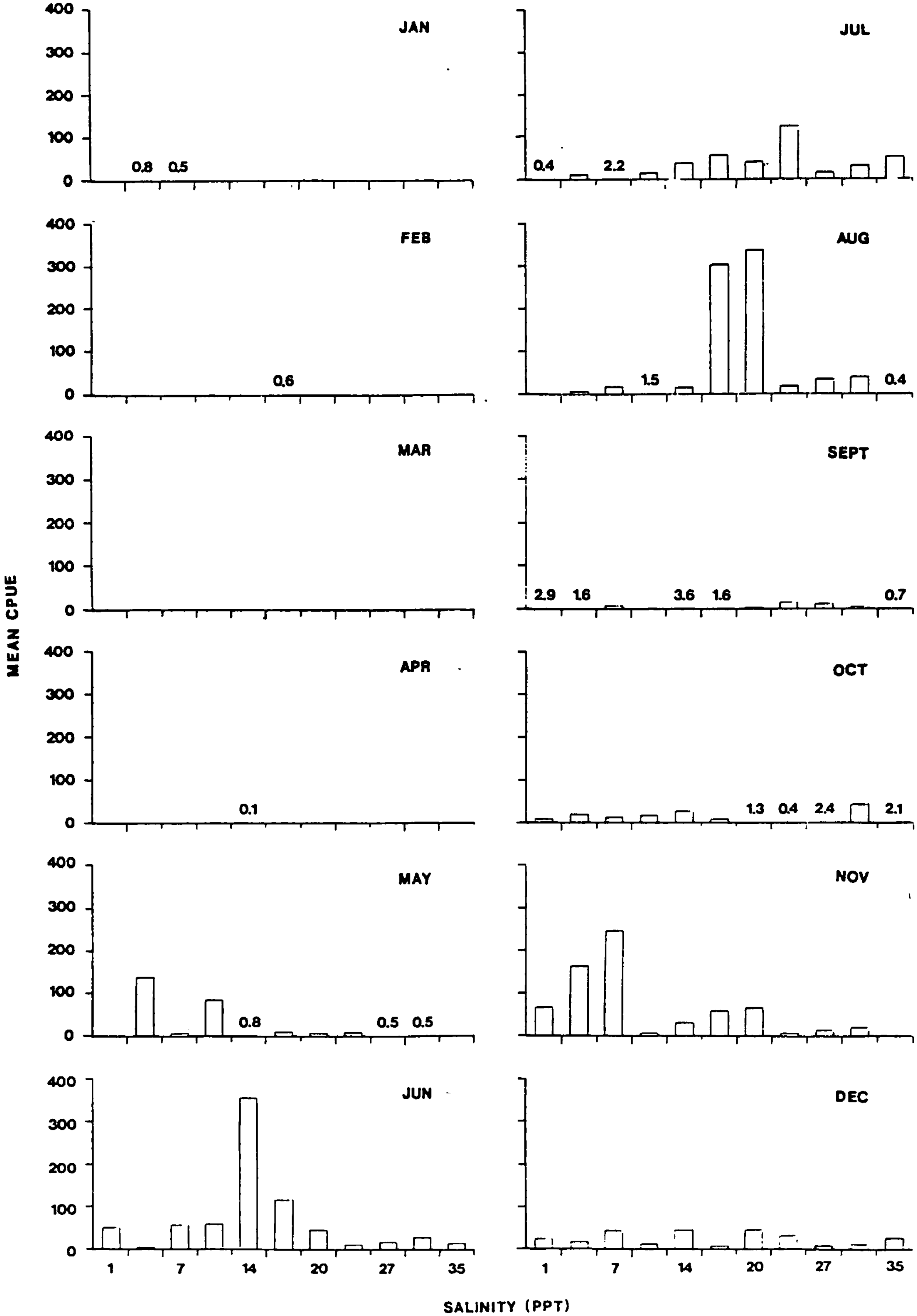


Figure 78. Mean CPUE of YOY longfin smelt vs. salinity, by month. All years included.

The overall mean CPUE for adult longfin smelt was highest at salinities in the 3 to 12 ppt range (Figure 77), but this was not consistent among survey periods (Figure 79).

Effects of Delta Outflow on Distribution

There is considerable variation from year to year in the spatial distribution of larval longfin smelt, and we suspect these differences are due to the magnitude of Delta outflow. Figure 67 shows that in the two dry years, 1981 and 1985, highest concentrations of larval longfin smelt were above Carquinez Strait. In the two wet years, 1982 and 1983, highest concentrations were in San Pablo Bay, and larval smelt were distributed throughout every subembayment.

Juvenile and adult distributions seem to be more consistent from year to year than that of larvae, but the very low numbers in the two dry years make it difficult to compare annual differences on the basis of outflow levels. We do know, however, that the high flows in 1983 had the effect of "moving" young fish out of the Bay into the Gulf of the Farallones (City of San Francisco, unpublished data).

Effects of Delta Outflow on Abundance

Using an annual index of longfin smelt abundance based on a fall midwater trawling program from San Pablo Bay upstream, Stevens and Miller (1983) recognized a strong positive association between longfin smelt abundance and spring-summer Delta outflow. The data collection efforts reported by Stevens and Miller (1983) have continued, resulting in 6 years of overlap between their sampling program and this one. Figure 80 illustrates the association between the fall abundance of longfin smelt as indicated by Stevens and Miller's (CDFG) index and the mean area weighted CPUE from our otter trawl samples during the same months. The strong positive association suggests that despite differences in the areas sampled and gear used, the two studies are measuring the same trends in smelt abundance.

Stevens and Miller have collected 17 years of data that can be used to examine the association between longfin smelt abundance and Delta outflow. Figure 81 shows that the previously reported strong positive association of Delta outflow and longfin smelt abundance continues with the exception of 1983.

We believe the removal of 1983 from the correlation of outflow and abundance is justified because the abundance of YOY longfin smelt in 1983 was substantially underestimated by both sampling programs because many, perhaps most, of the fish were outside San Francisco Bay in summer and fall that year. Evidence for this possibility comes from otter trawl data collected since 1982 by the City of San Francisco (unpublished), which showed an unusually high occurrence of YOY longfin smelt at their study area 6 miles south of the Golden Gate and 4 miles offshore in 1983.

The work by Stevens and Miller shows that fall abundance of longfin smelt in the Bay/Delta system is positively associated with the magnitude of Delta outflow during the previous spring and summer. More specifically, this association exists for YOY longfin smelt, since they make up the bulk of the catches in the fall of most years. However, their study did not include information on specific age groups, abundance during other times of the year, or abundance relative to other life stages.

Out study provides 6 years of data for examining:

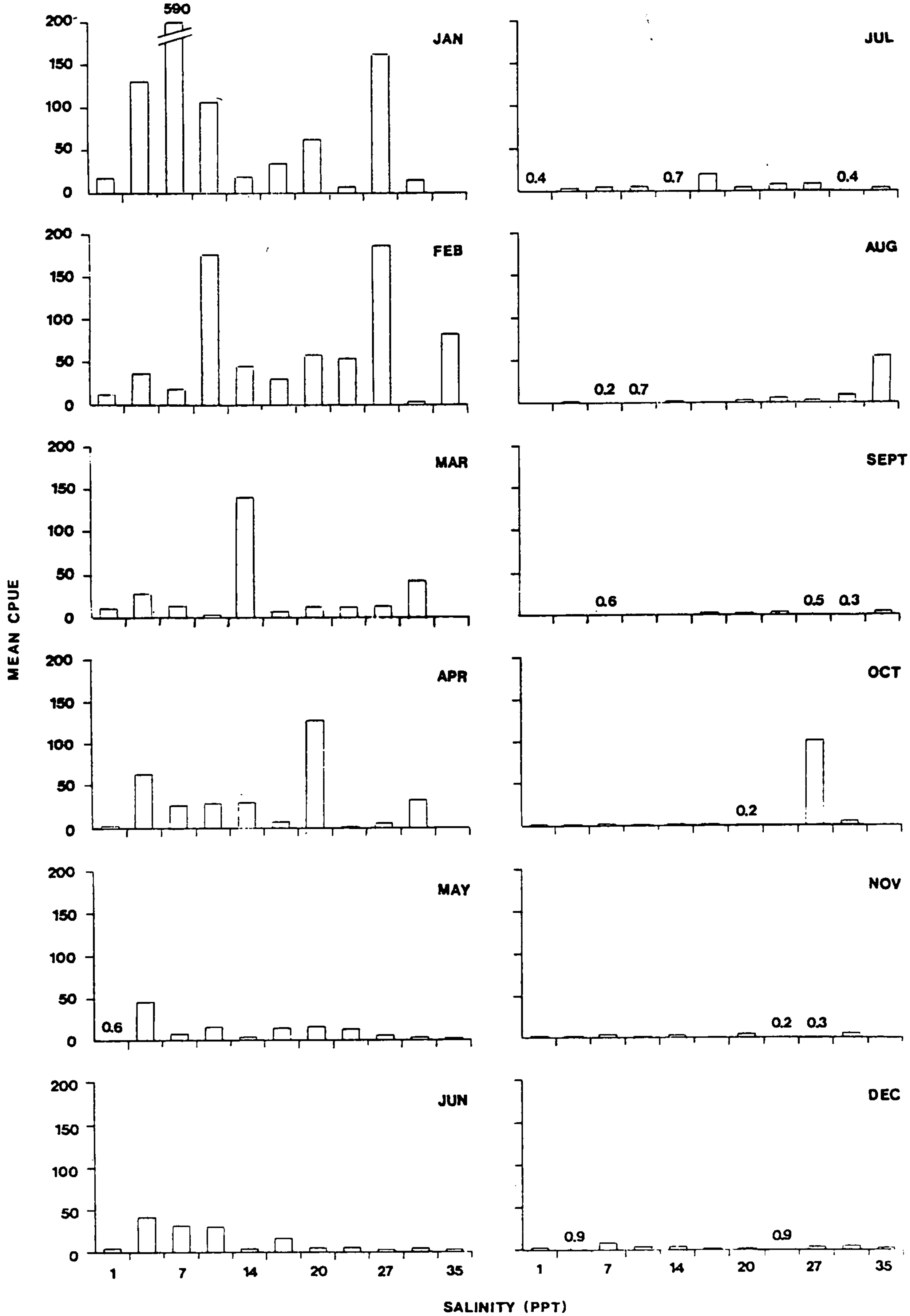


Figure 79. Mean CPUE of adult longfin smelt vs. salinity, by month. All years included.

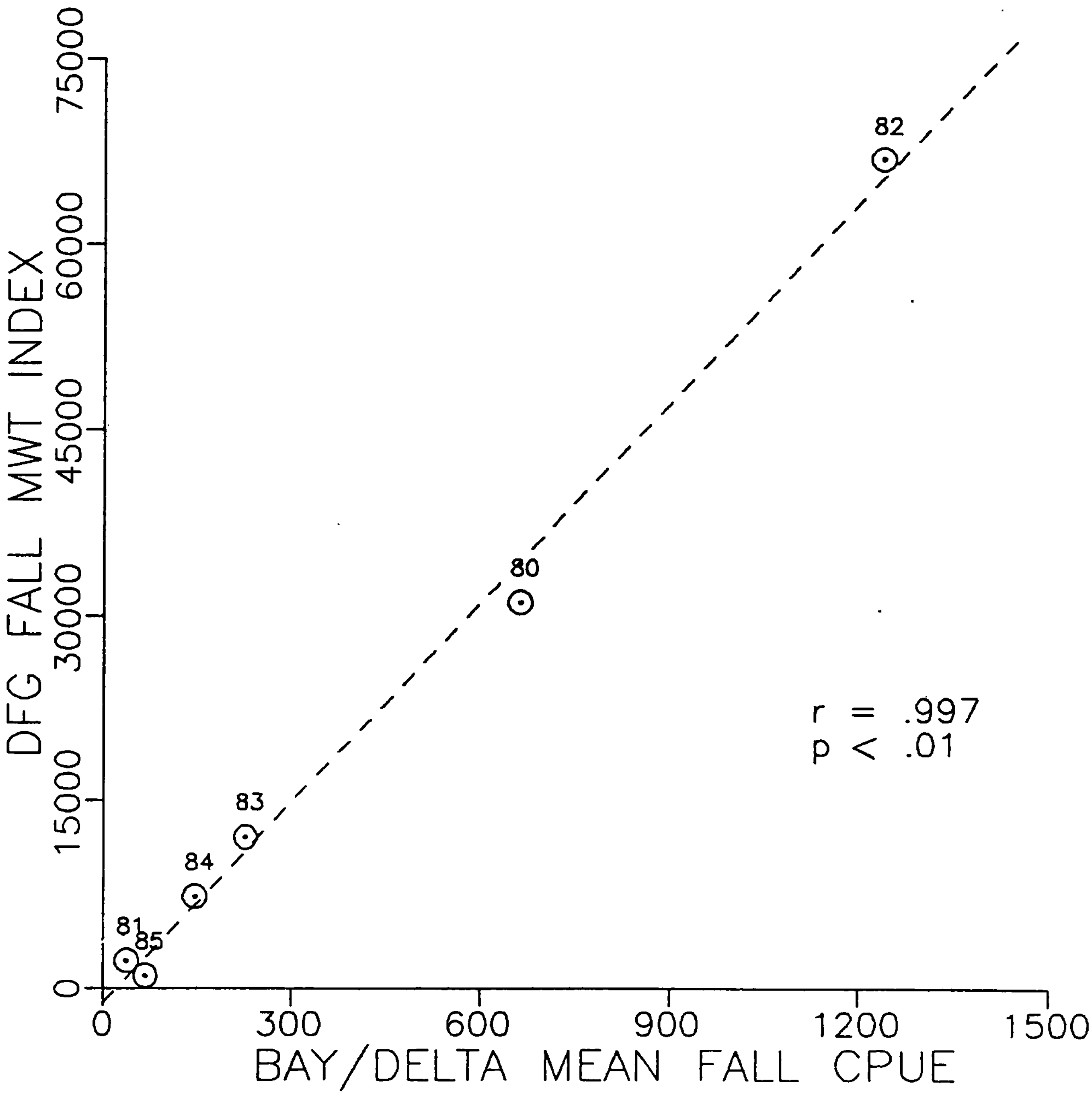


Figure 80. Correlation of CDF&G's fall midwater trawl index of longfin smelt abundance and the mean area-weighted CPUE during the months September through December.

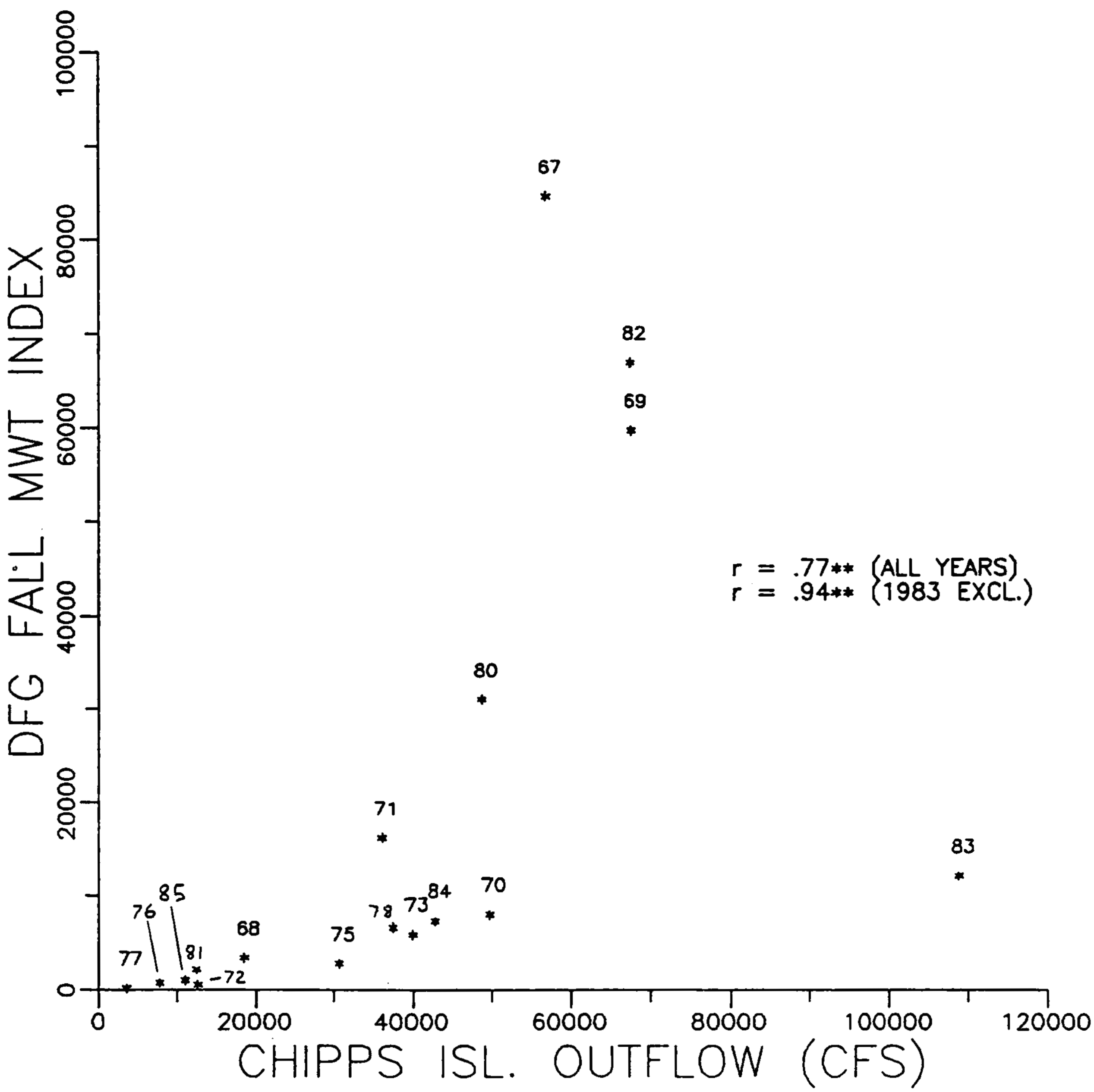


Figure 81. Correlation of CDF&G's fall midwater trawl index of longfin smelt abundance and mean daily outflow during the preceding December through August. Correlation coefficients are for log-transformed indices of abundance (** indicates significance at $p < .01$).

* The association of outflow and the abundance of individual lifestages, and

* The relationships between the abundances of different lifestages, which could provide clues as to why the observed association of fall YOY abundance and spring-summer outflow exists.

During the six years of this study there was a 28-fold variation in January-April abundance of larval smelt. However, the abundance of larvae was not nearly as strongly associated with Delta outflow (Figure 82) as was the fall abundance of juveniles and adults. The slight indications of a positive association for larvae are due primarily to a low abundance in 1981, which were offspring of a very poor year class. We have only five years of data to compare larval abundance to mature adult abundance in the previous summer (prior to migration), but there is an indication of a positive association (r=0.65 n.s., n=5).

If abundance of larvae in the study area is primarily determined by abundance of adults prior to spawning (and not by Delta outflow), the positive association of outflow and fall YOY abundance would seem to be determined by survival of larvae through the spring and summer. We calculated the ratio of spring larval abundance to fall YOY abundance, and found that it was strongly associated with December through August Delta outflow (r=0.95, $p<0.01$, n=5).

It appears that relative year class strength is set by the first fall of life, as the abundance of adults in fall is strongly associated with the number of YOY the previous fall (r=0.992, $p<0.01$, n=5).

Together, the relationships described above suggest the possibility that year class strength of longfin smelt is determined by survival of fish from the larvae stage through their first few weeks and months as juveniles, and that this survival is influenced by the magnitude of delta outflow prior to and during that period.

Summary

Longfin smelt have several characteristics that make them a good subject for examining the influences of Delta outflow on Bay/Delta fish:

* They are one of the most abundant and ubiquitous fish species in the Bay, implying trophic importance.

* They are essentially confined to the Bay/Delta system.

* They have a relatively simple life cycle.

* Except for very young juveniles, they are vulnerable to the sampling gear.

Our work, and that of others, suggests that longfin smelt populations are strongly affected by the magnitude of Delta outflow. Further, the evidence suggests that longfin smelt populations in the study area are controlled by survival of juvenile fish through their first spring and summer, which is significantly correlated with the magnitude of Delta outflow during that winter, spring, and summer.

Stevens and Miller (1983) identified five factors to explain the positive association of Delta outflow and abundance of several species of fish. Two of those factors seem applicable to longfin smelt:

* High flows appear to result in greater dispersal of young longfin smelt following hatching. This could reduce intraspecific competition.

* High flows may increase the levels of nutrients in the Bay that form

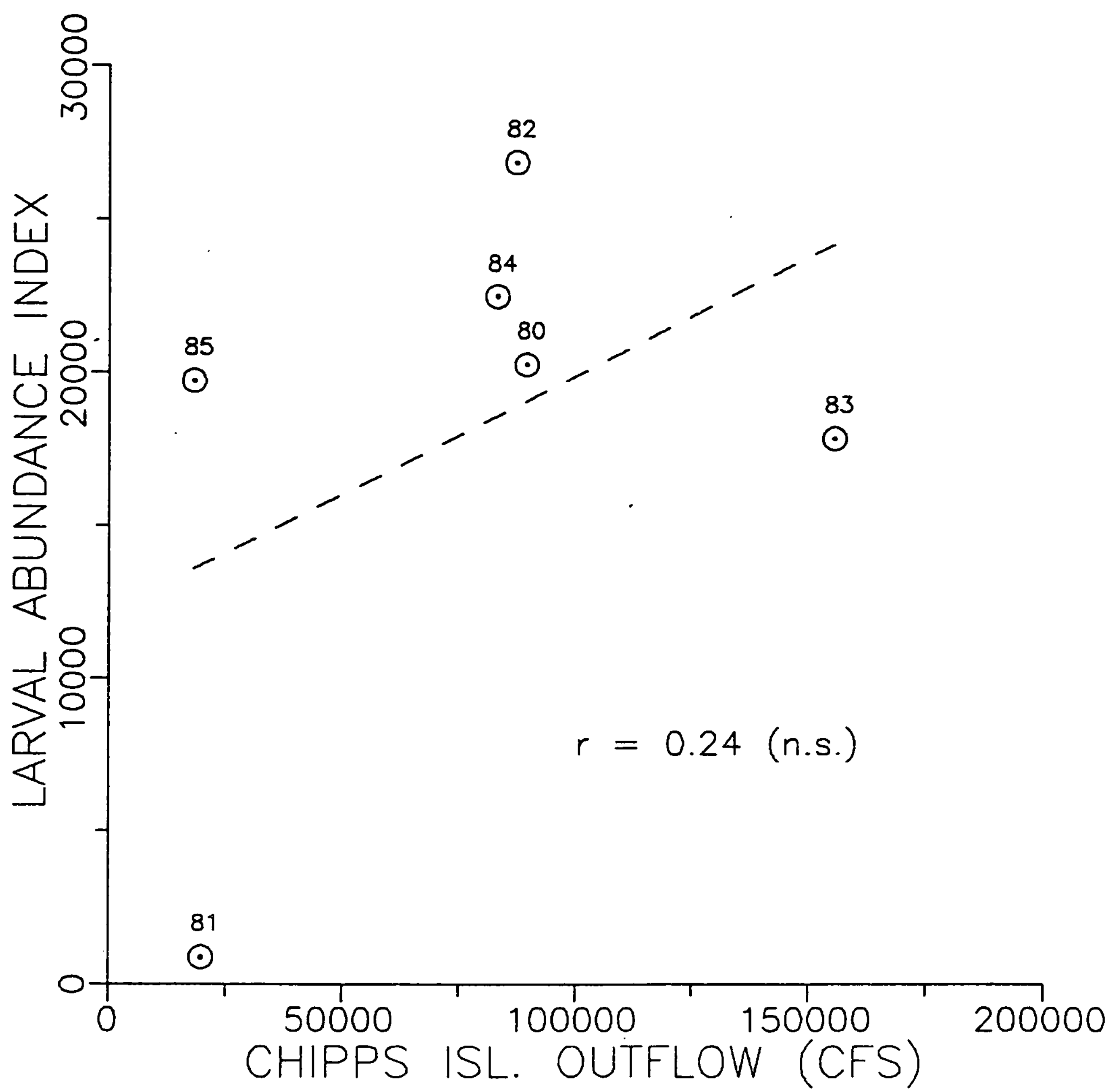


Figure 82. Correlation of larval longfin smelt abundance and Delta outflow. Abundance is the mean weighted CPUE for the months January through April. Delta outflow is the mean estimated monthly outflow at Chipps Island for the months December through March.

the basis of the food chain, thereby increasing overall productivity and the survival of young smelt. For example, the abundance of Neomysis mercedis and Eurytemora sp. in the Bay/Delta, which are likely to be important food items for young longfin smelt, is negatively associated with salinity levels which are inversely related to the magnitude of Delta outflow (Knutson and Orsi, 1983).

Chapter 7. PELAGIC FISH

Much of the time, major portions of the Bay are essentially marine environments, at least with respect to salinity levels. Associated with these marine areas of the Bay are four of the most abundantly collected species during this study, northern anchovy (Engraulis mordax), Pacific herring (Clupea harengas), topsmelt Atherinops affinis), and jacksmelt (Atherinopsis californiensis). Each of these four species uses the Bay differently, but are similar in other ways. All are abundant, have a small maximum size, and are planktivorous feeders. These characteristics make them an important trophic link between planktonic organisms and the many piscivorous game and commercial species in the Bay.

Northern Anchovy

The northern anchovy (Engraulis mordax) is a pelagic, predominantly coastal marine species found in the Pacific Ocean from British Columbia to Baja California. Anchovies are most abundant in near-shore water, but eggs and larvae have been collected 300 miles off shore (Turner and Sexsmith, 1967).

Three distinct subpopulations of northern anchovy have been identified off the West Coast of North America (Vrooman et al., 1981). The northern subpopulation occurs along the coast of Oregon and California south to about Monterey Bay; the central subpopulation ranges from northern Baja north to San Francisco Bay. These subpopulations overlap from San Francisco to Monterey, and anchovies from both subpopulations probably enter San Francisco Bay.

Northern anchovies spawn in the California current primarily in winter and spring at water temperatures from 10 to 23 degrees C (Hart, 1973). Anchovies are capable of spawning all year, but frequency and number of eggs spawned each year are variable. Multiple spawnings are possible only at optimal temperatures (13-18 degrees C) and maximum fecundity is achieved only when food for adults is abundant. Within the preferred temperature range, anchovies may be constrained to a seasonal reproductive cycle by dietary requirements that exceed available zooplankton production (Brewer, 1978). Off the coast of Washington and Oregon, spawning season is only 2 months (mid-June to mid-August) even though environmental conditions favorable for spawning occur during 5 to 6 months (Laroche and Richardson, 1980; Richardson, 1981).

Circumstantial evidence for anchovy spawning in San Francisco Bay system was reported by Eldridge (1977), Sitts and Knight (1979), and Wang (1981), all of whom collected small larvae in the estuary. McGowan (1986) verified anchovy spawning by collecting eggs during monthly sampling in 1978 and 1979 at five locations in the bay, some of which were too remote from the Golden Gate for eggs to have been transported from the ocean by currents.

Northern anchovies spawn at night near the surface. Distinctive ellipsoidal eggs hatch in 2 to 4 days, depending on temperature. Eggs and larvae, which are about 3 mm long at hatching, are carried by currents. Yolk is absorbed in 36 hours, and the mouth becomes functional by the fourth day (Bolin, 1936).

Larval anchovies feed on early life stages of copepods. Young larvae have very high food density requirements, 37 times that of older larvae (Hunter, 1972). Schooling is well established by the time larvae are 13 to 15 mm (Hunger and Coyne, 1982), corresponding with changes in visual, respiratory, and locomotor ability. At 25 mm, larvae resemble adults.

Brewer (1978) reported 18 degrees C as the optimum temperature for larval growth, with an acceptable range of 12 to 24 degrees C and no difference in growth rate from 14 to 20 degrees C. Methot and Kramer (1979) found no correlation between growth rate and temperature (13 to 16 degrees C) from samples collected in the Southern California Bight and pointed out growth in the sea is frequently limited by food supply.

Spawning occurs near the surface, and eggs, with a specific gravity slightly less than seawater (Bolin, 1936), may experience net downstream transport in the surface water. Several hours before hatching, eggs sink slowly (Bolin, 1936), hence newly hatched larvae may be subject to net upstream transport in density currents nearer the bottom. Since the egg and larval net used in our studies samples near the bottom and through the water column, evaluation of this hypothesis would be difficult with available data.

Along the California coast, anchovies grow to an average of (Collins, 1969):

115 mm in 1 year,
125 mm in 2 years,
132 mm in 3 years,
138 mm in 4 years, and
144 mm in 5 years

Percentages of female anchovies sexually mature at different ages are (Clark and Phillips, 1952):

Age	Percent
1	10
2	40
3	75
4	95
5	99
6	100

Based on these mean sizes, most anchovies caught in the study area by the midwater trawl were young-of-year, and the rest were age 1 through age 3 and had not achieved full reproductive potential.

Adult anchovies feed by filtering and by biting, depending on the density and size of prey (Leong and O'Connell, 1969; Hunter and Dorr, 1982). A significant portion of natural mortality of anchovy eggs is predation by adult anchovies (Hunter and Kimbrell, 1980).

Brewer and Smith (1982) suggested recruitment from a particular region may not be a direct function of the abundance of eggs or larvae within an area because environmental factors favoring spawning by adults (appropriate temperature; abundance of available calories such as large zooplankton) may not coincide with requirements for larval survival (food of appropriate size and adequate density and the absence of predators, including adult anchovies). Currents may carry eggs or larvae away from spawning areas into environments either more or less favorable for larval growth and survival.

Anchovies can tolerate a wide range of temperatures. Adults have been collected in water from 8 to 25 degrees C and have been maintained for several weeks in the laboratory at 28 degrees C. Surface water temperatures at sampling locations in the study area ranged from 6.5 to 25.5 degrees C, and when adult or YOY anchovies were collected, temperatures ranged from 7.5 to 23.5 degrees C. In this study anchovies were most abundant at temperatures from about 12 to 22 degrees C. They are not found where food supply is inadequate to meet metabolic requirements at ambient temperatures (Brewer, 1976).

Anchovies can tolerate the highest salinities in the estuarine system, but intolerance for fresh water apparently limits the upstream extent of their distribution. Although considered a marine species, the northern anchovy is probably the most abundant fish in San Francisco Bay (Herrgesell et al., 1983).

Anchovies support a moderate commercial fishery (Smith and Kato, 1979), which has stabilized at around 385 tons (Herrgesell et al., 1983). Most of the catch is packed and frozen as bait, but some is used as live bait in the local sport fishery for striped bass and halibut. Live and dead anchovies are used for bait in the commercial albacore tuna fishery.

McGowan (1986) estimated the adult spawning biomass in San Francisco Bay was 767 tons in July 1978 based on his estimate of egg abundance and fecundity parameters of anchovy stocks in the ocean. However, he did not sample upstream of the Richmond-San Rafael Bridge, so this estimate is probably low.

Small and seasonally abundant, the northern anchovy is probably the most important forage fish for other resident and migratory fish species in the estuarine system, including salmon, jacksmelt, and striped bass (Smith and Kato, 1979).

Methods

Eggs and post-yolk-sac larvae were the lifestages examined from the egg and larval net catches. Midwater trawl catches were used to characterize distribution and abundance of young-of-year and adult anchovies. Otter trawl data were not used.

The otter trawl caught more anchovies than the midwater trawl when catches were low, but caught consistently fewer when CPUE exceeded 1,000/10,000 m^3. This suggested most anchovies were in the water column, and midwater trawl catches would provide more information.

Unweighted catch per unit effort (catch/10,000 m^3) was used to evaluate temporal and spatial distribution. An annual abundance index was calculated using catch per unit effort weighted by the water volume at each station represented. Indices were calculated for individual bays by summing the annual average weighted CPUE for all stations within each bay and dividing the quotient by 10^3 for midwater trawl and larval indices and 10^6 for the egg index. The systemwide index is the sum of the five bay indices.

Abundance and Distribution of Adults and Young-of-Year

YOY and adult anchovies occurred in the Bay at all times of the year, but were most abundant from April through October (Figure 83). The northern anchovy abundance index for the study area, derived from midwater trawl catches, ranged from 172 to 1,100 from 1980 through 1985 (Table 15). The index varied slightly from 1980 to 1983, and in 1984 increased to 1,100, almost four times the 1980-1983 average. The 1985 index was 60 percent less than the 1984 index and was equal to the 6-year average. There was no significant trend ($p>0.05$) in the index over the 6-year period.

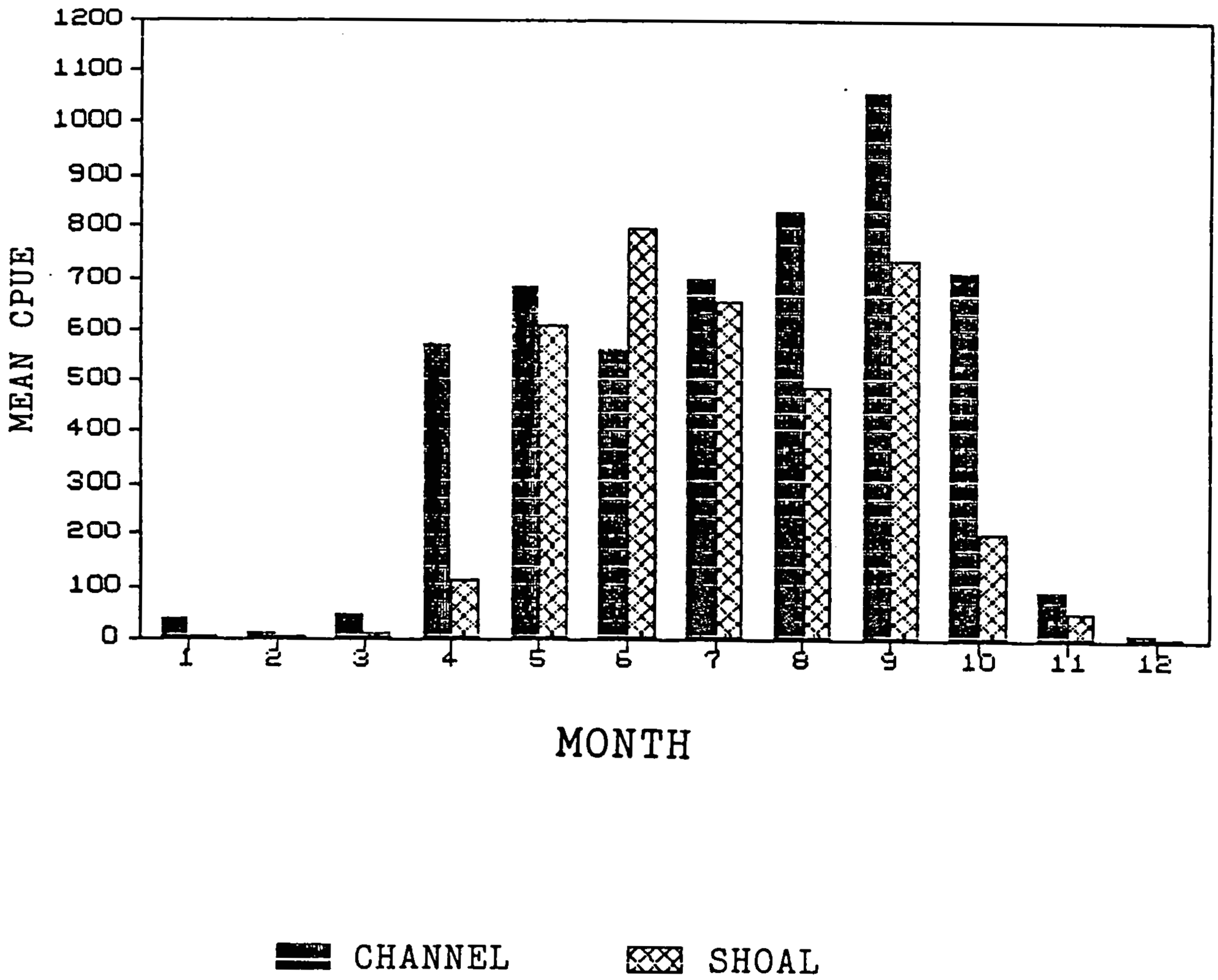


Figure 83. Seasonal distribution of YOY and adult northern anchovy, all years combined.

Table 15

ABUNDANCE INDICES* FOR NORTHERN ANCHOVY LIFE STAGES IN SAN FRANCISCO BAY-ESTUARY

Year	Eggs	Post Yolk-Sac Larvae	YOY + Adults**
1980	8.3	533.4	171.5
1981	12.0	337.3	309.5
1982	7.7	112.9	427.0
1983	11.0	816.1	255.8
1984	10.0	172.1	1,100.0
1985	13.0	403.2	454.2

* Sum of volume-weighted catch at all stations.

** Midwater trawl abundance index.

Adult and young-of-year northern anchovies were most abundant in Central Bay every year (Figure 84). In 1984, when total abundance was highest, abundance in Central Bay was also the highest for the 6-year study, exceeding total systemwide abundance in all other years. The second highest abundance index was for San Pablo Bay in wet years (1982, 1983) and South Bay in dry years (1981, 1985). In 1980, a normal water year, anchovies were more abundant in San Pablo Bay than in South Bay, whereas in 1984, a normal water year with lower winter-spring outflow than 1980, anchovies were more abundant in both South Bay and Suisun Bay than in San Pablo Bay. Anchovies were relatively more abundant in San Pablo Bay in normal and dry years than in wet years and were found upstream of Carquinez Strait only in dry years.

Abundance measured by the midwater trawl index fluctuated from month to month in all embayments within the estuary. Monthly abundance fluctuated more widely in Central Bay than in South Bay or in San Pablo Bay, probably because of movement of anchovies between Central Bay and the Pacific Ocean as well as between the adjacent bays. Systemwide seasonality in abundance (Figure 85) was the net result of large changes in anchovy abundance in Central Bay, modified or buffered by less dramatic fluctuations in the rest of the system.

Adult and young-of-year anchovies occur together in the study area. Length frequency data showed increased abundance in April and May was a combination of young-of-year and adult anchovies (Figure 86). Adults (>90 mm) enter the study area in April or May, spawn through the summer, and usually return to the ocean by September.

Young-of-year anchovies caught in the spring were probably a combination of immigrants to the study area from ocean spawning during winter and anchovies produced during late spawning in the estuarine system the previous year. Length frequency histograms reveal growth of these YOY through the summer, as well as recruitment of the current year's production within the study area to the size class vulnerable to capture in the midwater trawl (>35 mm).

Cohorts were not conspicuous in length frequency distributions because of multiple spawning by individuals through the summer and fall and the contribution of young to the study area from winter spawning in the ocean.

Adult anchovies were caught later in the fall in dry years than in wet years. The few anchovies remaining in the Bay during winter are probably young-of-year from late fall spawning.

Abundance and Distribution of Eggs and Larvae

Annual Bay anchovy egg abundance, indicating the amount of spawning taking

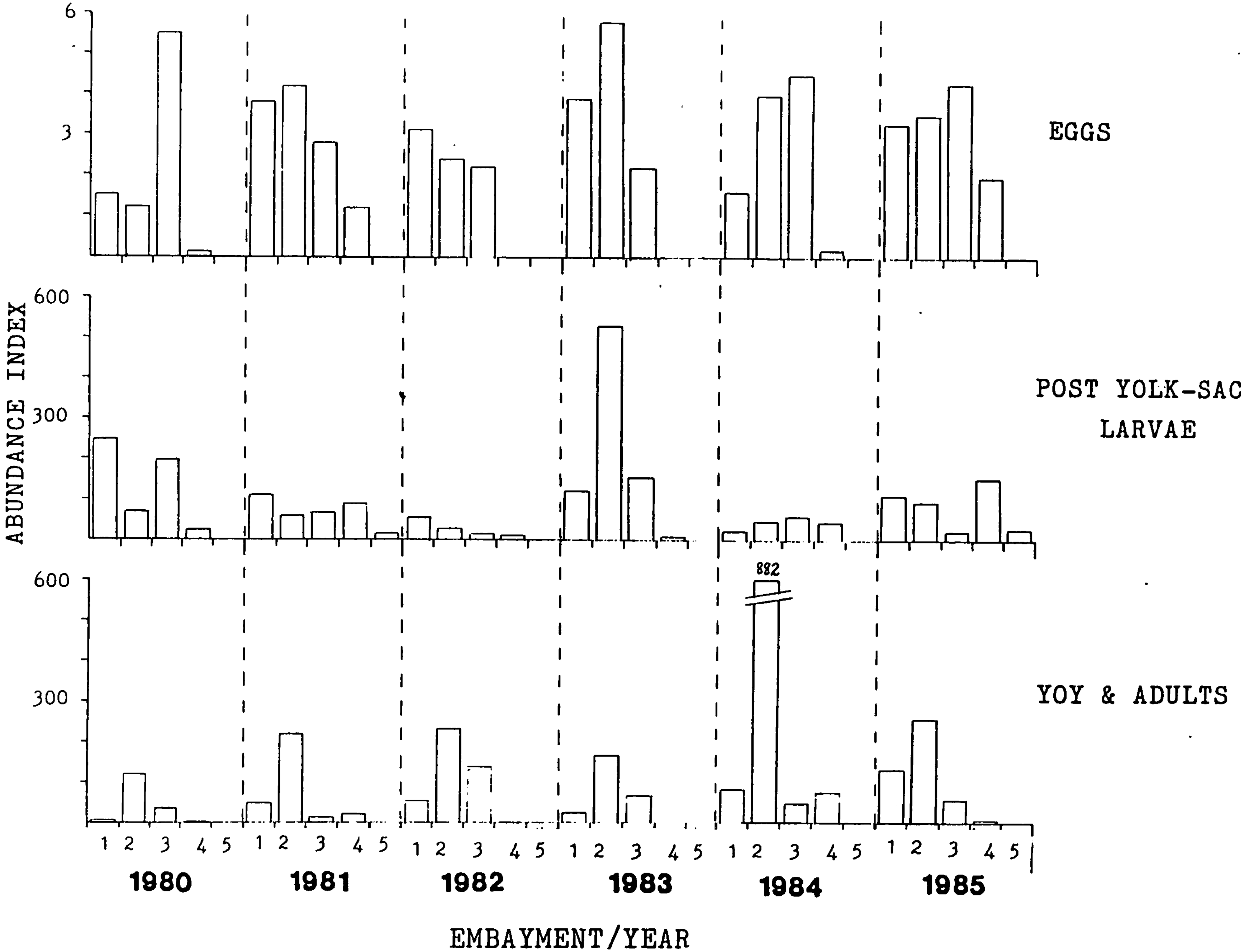


Figure 84. Annual abundance indices for northern anchovies by embayment, 1980-1985. Embayments are labeled: 1-South Bay, 2-Central Bay, 3-San Pablo Bay, 4-Suisun Bay, and 5-West Delta.

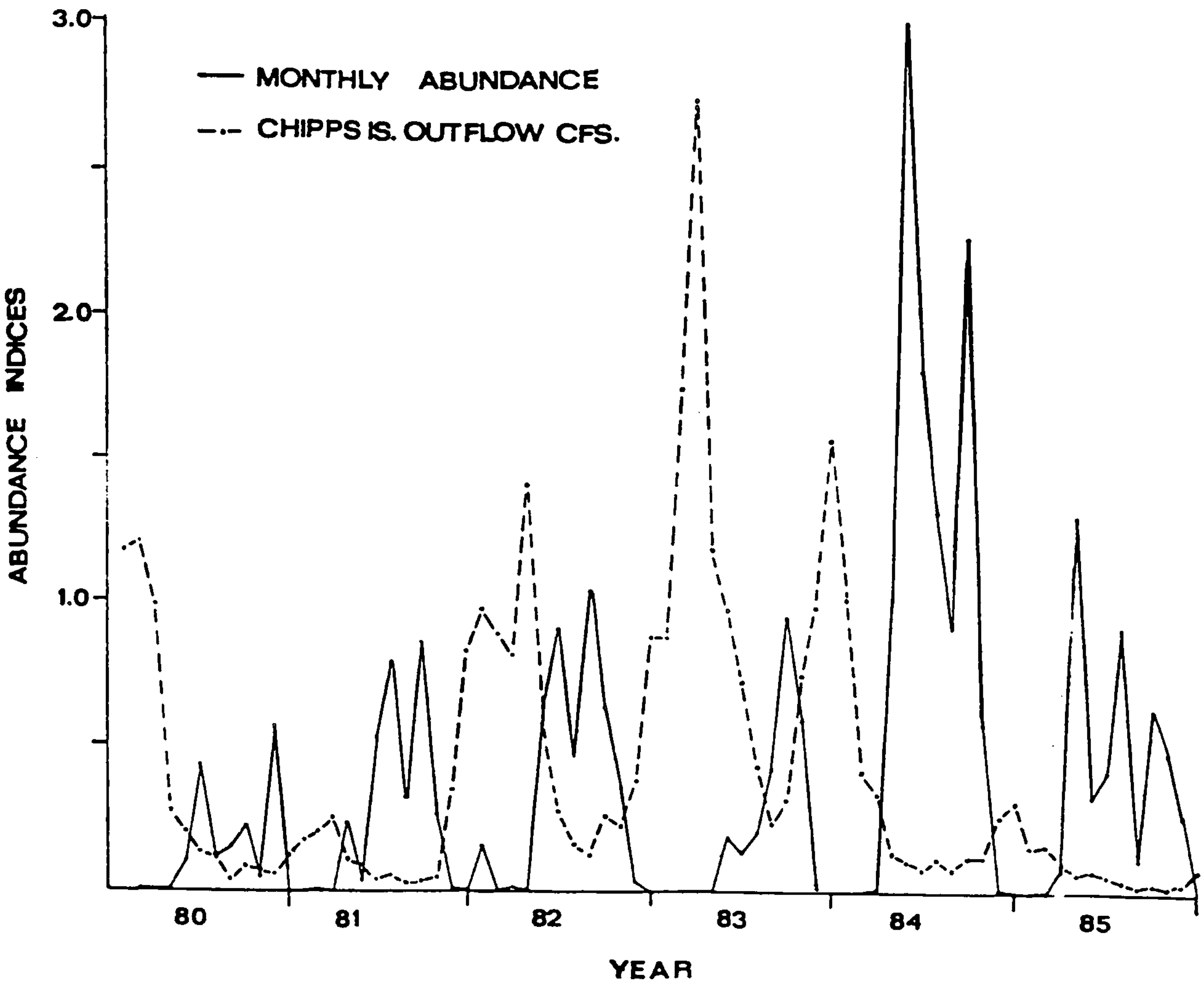


Figure 85. Abundance of YOY and adult northern anchovy vs. average monthly Delta outflow.

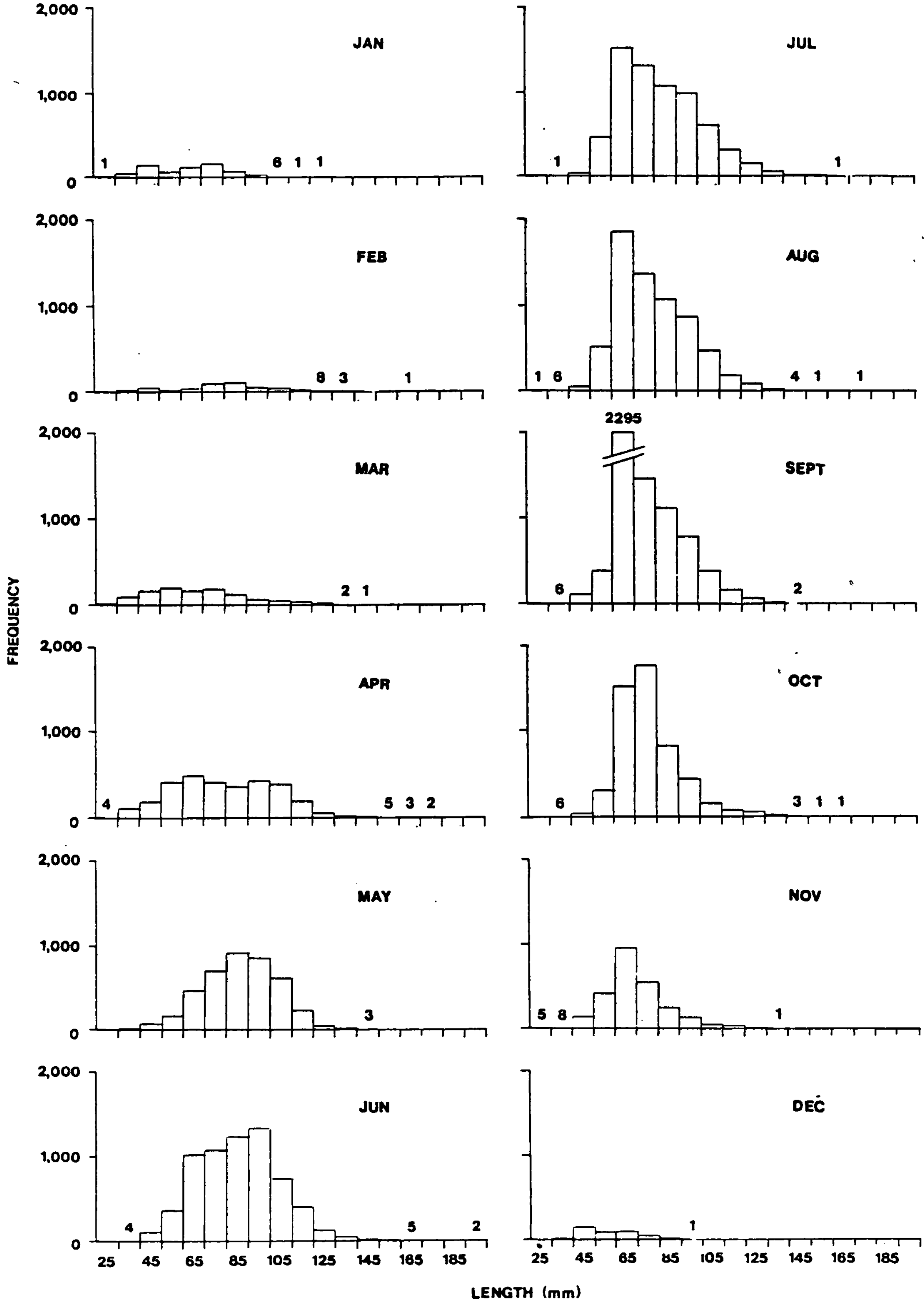


Figure 86. Length frequency distribution of northern anchovies caught in the midwater trawl, 1980 through 1985.

place in the Bay, was less variable than abundance of adults and young-of-year; the lowest index was 62 percent of the highest (Table 15). The two highest egg abundance indices from 1980 through 1985 were in dry years, 1981 and 1985. The lowest index was in 1982, a wet year. However, in 1983, an even wetter year than 1982, the egg abundance index was above the 6-year average.

On an annual basis, anchovy egg abundance was highest in San Pablo Bay in normal water years (1980, 1984) and in South Bay or Central Bay in wet years (1982, 1983) (Figure 84). Although young-of-year and adults were always most abundant in Central Bay, egg abundance was more often higher elsewhere, although eggs were relatively abundant in Central Bay in most years. Significant numbers of eggs were collected upstream of Carquinez Strait (Suisun Bay) only in dry years (1981 and 1985); egg distribution was most uniform among the bays downstream from Carquinez Strait in dry years.

Abundance of post-yolk-sac larval anchovies fluctuated annually more than abundance of eggs or young-of-year and adults (Table 15). Larvae were most abundant in the estuarine system in 1983, a wet year, but were least abundant (17 percent of 1983 abundance) in 1982, the second wettest year during the study. Larval abundance was relatively high in one normal water year (1980) but was low in another (1984). Abundance of larvae was about 50 percent of peak levels in both dry years, 1981 and 1985.

There were no consistent spatial or seasonal patterns in larval abundance. Larvae were five times as abundant in Central Bay than in the other bays in 1983, whereas in other years larvae were more abundant in at least one and usually two other bays (Figure 84). Larvae were twice as abundant in South Bay in 1980 as in any other year and were relatively abundant in South Bay in all years except 1984. Larval anchovies were abundant in San Pablo Bay in 1980 and 1983 and, although bay-wide abundance was low in 1984, abundance was highest in San Pablo Bay relative to the other bays. Anchovy larvae were present in substantial number upstream of Carquinez Strait only in 1981, 1984, and 1985, and were more abundant in Suisun Bay and upstream in 1985 than in any other bay.

In most years there was a minor peak in larval abundance in winter or spring, followed by a larger peak during summer and fall. Larval abundance decreased to very low levels for 1 or 2 months between successive peaks. High annual larval abundance in 1980 resulted from much above average abundance during summer and fall, whereas high abundance in 1983 was due mostly to extraordinary abundance throughout winter and spring. Annual larval abundance was low in 1982 and 1984, when summer-fall increases in abundance were small.

No statistically significant correlation was found between annual egg abundance and either larval abundance ($r=0.34$) or YOY-adult abundance ($r=-0.18$) or between larval abundance and abundance of YOY-adults ($r=-0.71$).

Cross Sectional Distribution

Shoals appear to be important for all life stages of anchovies, particularly for spawning and larval rearing. Egg CPUE was the same in channels and shoals in dry years, higher in the shoals in normal years, and slightly higher in the channels in wet years (Figure 87). Average egg CPUE was higher in channels in March and April when catches were low, was slightly higher in shoals as catches increased from May through July, and remained high in shoals during August and September, whereas egg CPUE in the channels declined (Figure 88).

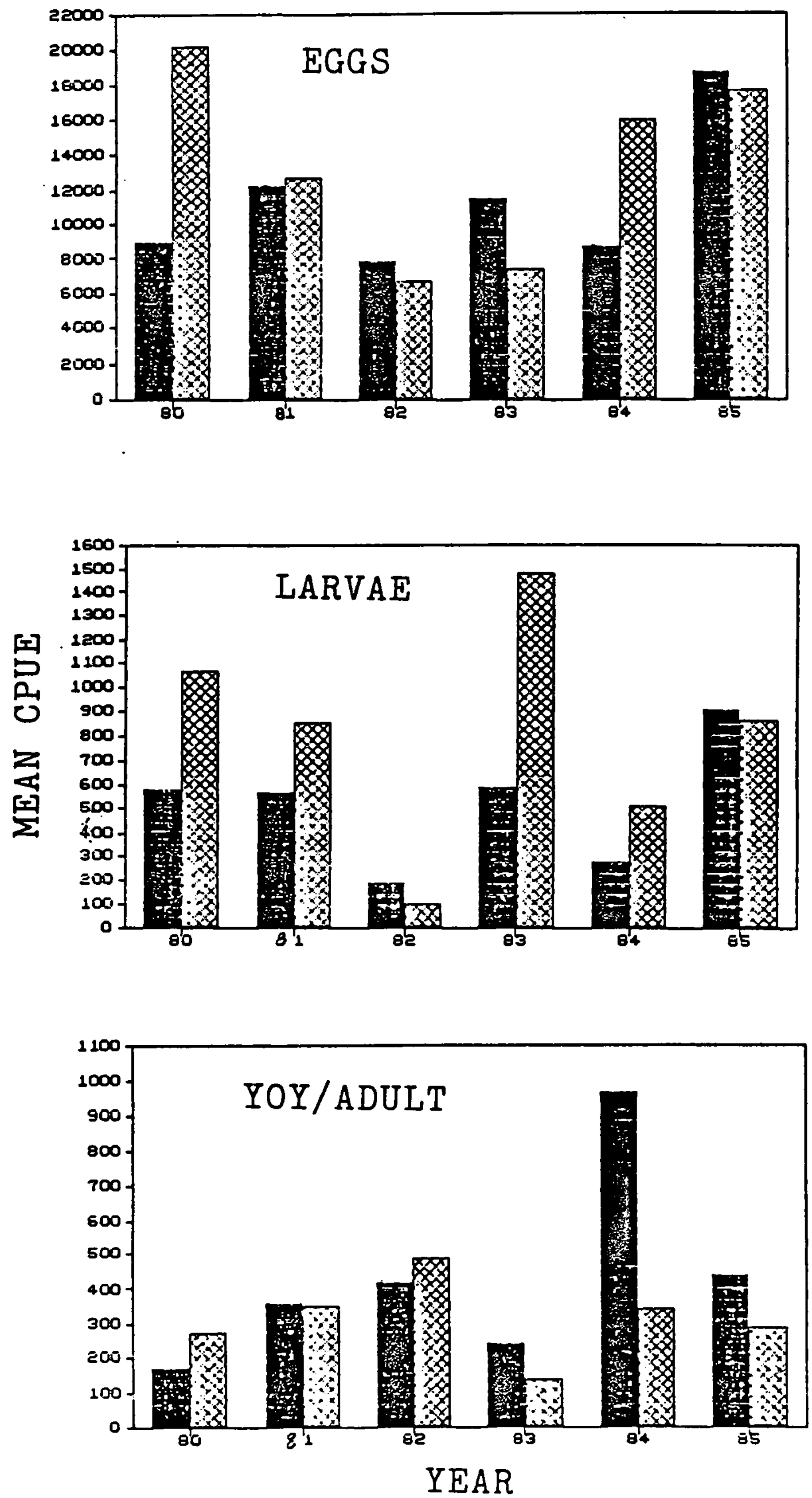


Figure 87. Cross-sectional distribution of anchovy lifestages each year. Solid bars are for channel stations and hached bars for shoal stations.

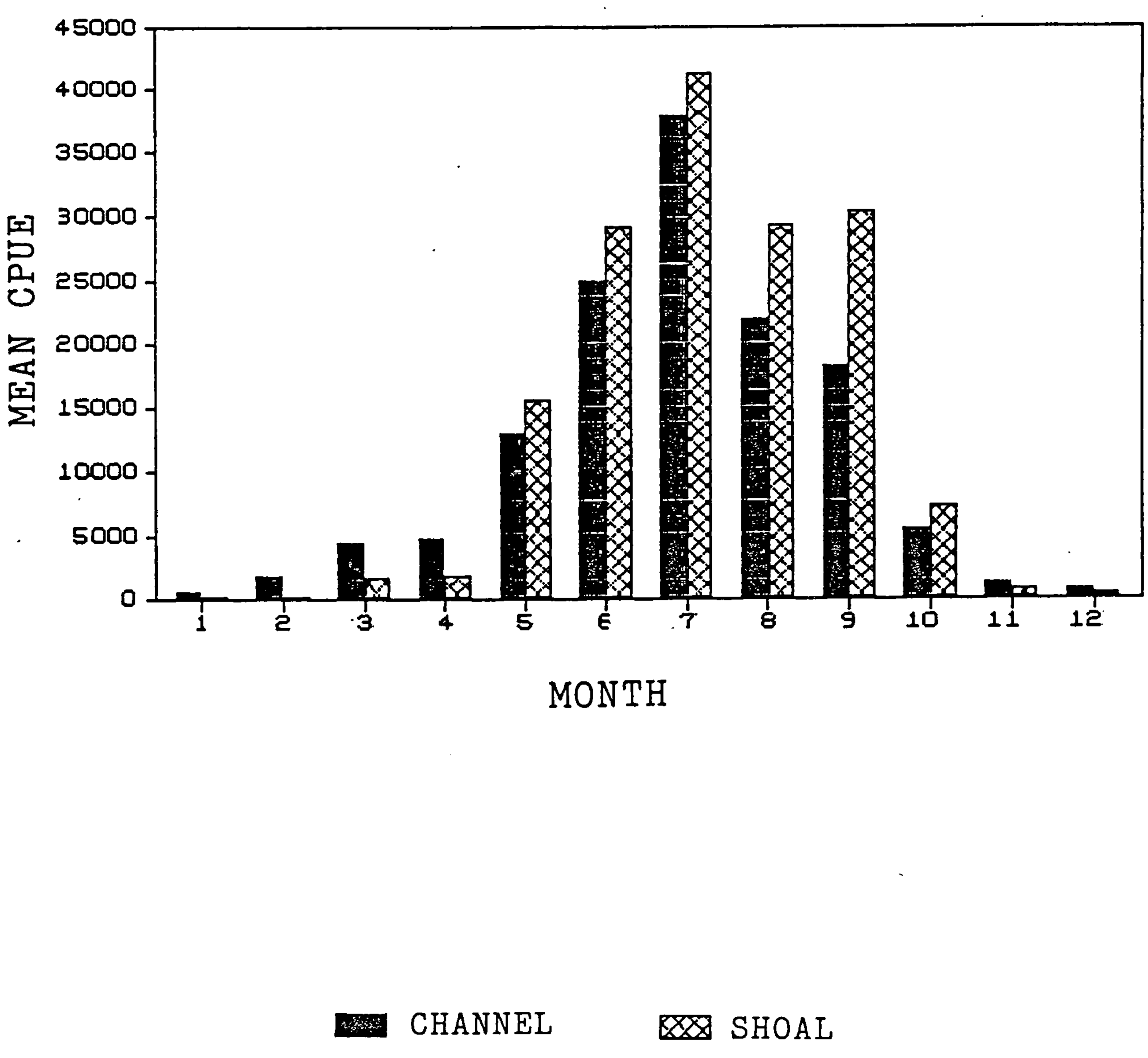


Figure 88. Seasonal occurance and cross-sectional distribution of northern anchovy eggs, 1980-1985.

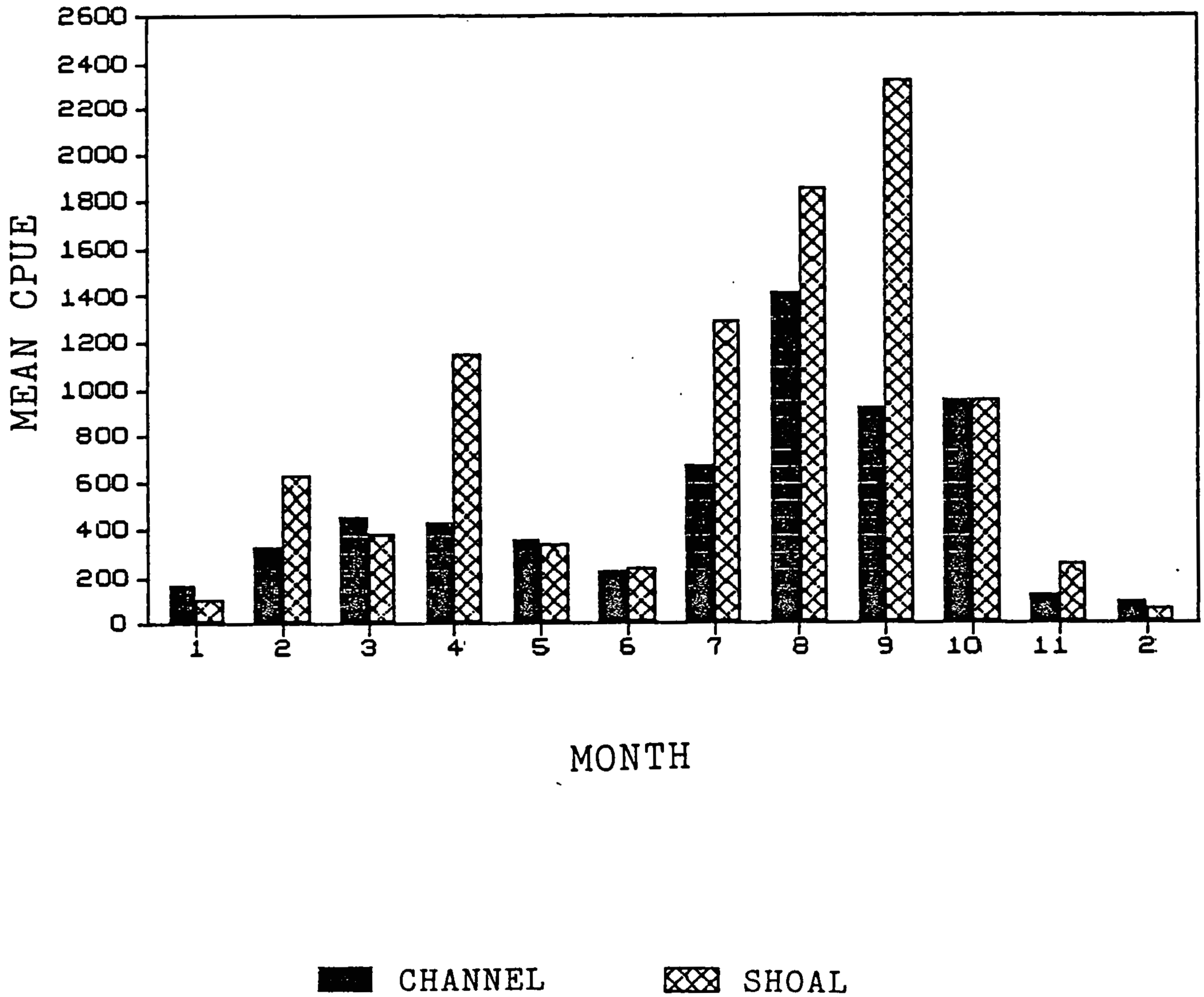


Figure 89. Seasonal occurance and cross-sectional distribution of northern anchovy larvae, 1980-1985.

The relative CPUE of anchovy larvae in channels and shoals was similar to that for eggs, except in 1983 when larvae utilized shoals more extensively (Figure 87). Monthly CPUE, averaged over 6 years, indicated greater use of shoal areas by larvae in most months when larvae were abundant (Figure 89). CPUE of adults and young-of-year anchovies in the midwater trawl indicates greater use of channels by these life stages than by larvae (Figure 87). Anchovy CPUE was higher in channels than in shoals every month except June (Figure 83). Relatively large numbers of anchovies were caught in the midwater trawl from May through September at shoal stations and from April through October at channel stations. High catches in channels during one month before and one month after the period of high catches in the shoals suggests movements into and out of the study area occur in the channels, but after migrating into the estuarine system anchovies disperse and occupy shoal areas as well.

The relative importance of channel areas for young-of-year and shoal areas for adult anchovies is not clear and would require a comparison of separate length frequency distributions for channel and shoal catches. Better survival for channel or shoal areas by any life stage would be difficult to demonstrate, since environmental variables such as salinity or temperature probably control their distribution among and within the individual bays, which have very different proportions of channel and shoal habitat.

Effects of Delta Outflow

No relationship was found between annual abundance of anchovies in the estuarine system and Delta outflow (r=-0.28) (Figure 90). For example, anchovies were most abundant in 1984 and 1985 when flows to the Bay were low, but they were much less abundant in 1981 when flows also were low.

Northern anchovies occurred in the study area in a predictable seasonal pattern each year. They entered the estuarine system in spring as outflow decreased and salinity increased. This migration usually began in April, but was delayed until May in years of high spring outflow (Figure 91). Offshore abundance may influence the number of anchovies entering the Bay more than any other factor.

Outflow influences the distribution of anchovies in the Bay primarily by its effect on salinity. Anchovies are effectively excluded from areas in the estuarine system when salinity becomes too low. Few adults and young-of-year were found in areas where surface salinity was below 10 ppt (bottom salinity may have been several parts higher) (Figure 92). Low salinity apparently restricted the upstream extent of anchovy distribution to San Pablo Bay in normal and wet years; they occurred upstream of Carquinez Strait only in low outflow years, when salinity in Suisun Bay was relatively high (Figure 91).

Most adult and larger young-of-year anchovies leave the study area in the fall. In normal or wet years they migrate to the ocean in September and October; in dry years they may remain longer. In any case, few anchovies overwinter in the estuarine system.

The annual index of anchovy egg abundance was negatively correlated with most measures of Delta outflow, including annual average monthly flow (r=-0.94) (Figure 90), winter-spring flow (December-May, r=-0.97), and summer flow (June-August, r=-0.86) when 1983 was excluded from the analysis. This relationship probably results from the salinity-mediated effect of outflow on the distribution of anchovies in the system. Anchovies enter the estuarine system and become widely distributed if outflow is low and salinity is relatively high, whereas in high outflow conditions their distribution is

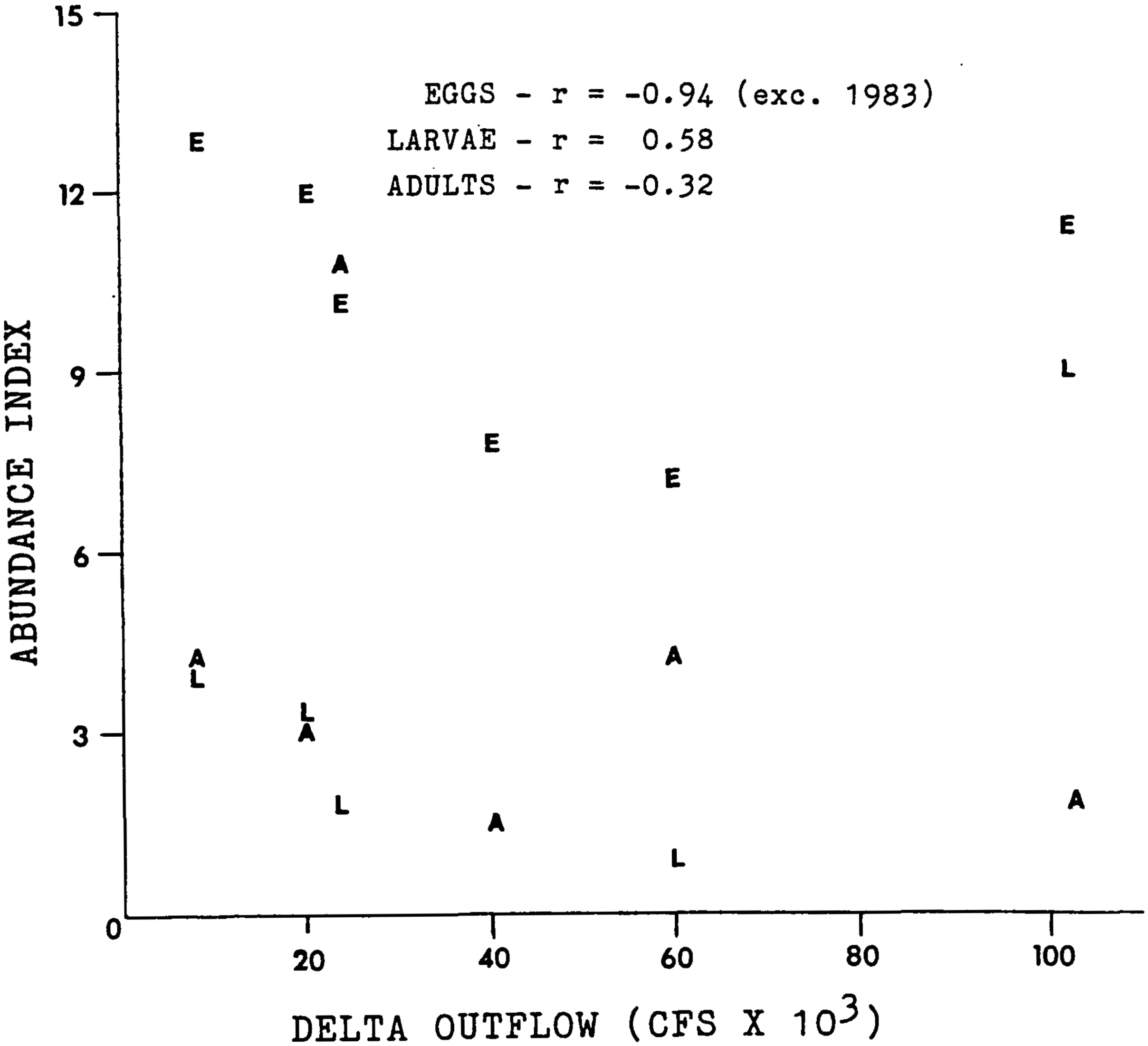


Figure 90. Relationship between northern anchovy abundance and Delta outflow, 1980-1985. Egg abundance is indicated by an "E", larval abundance by an "L", and YOY/adult abundance by an "A". Correlation coefficients are given for each lifestage.

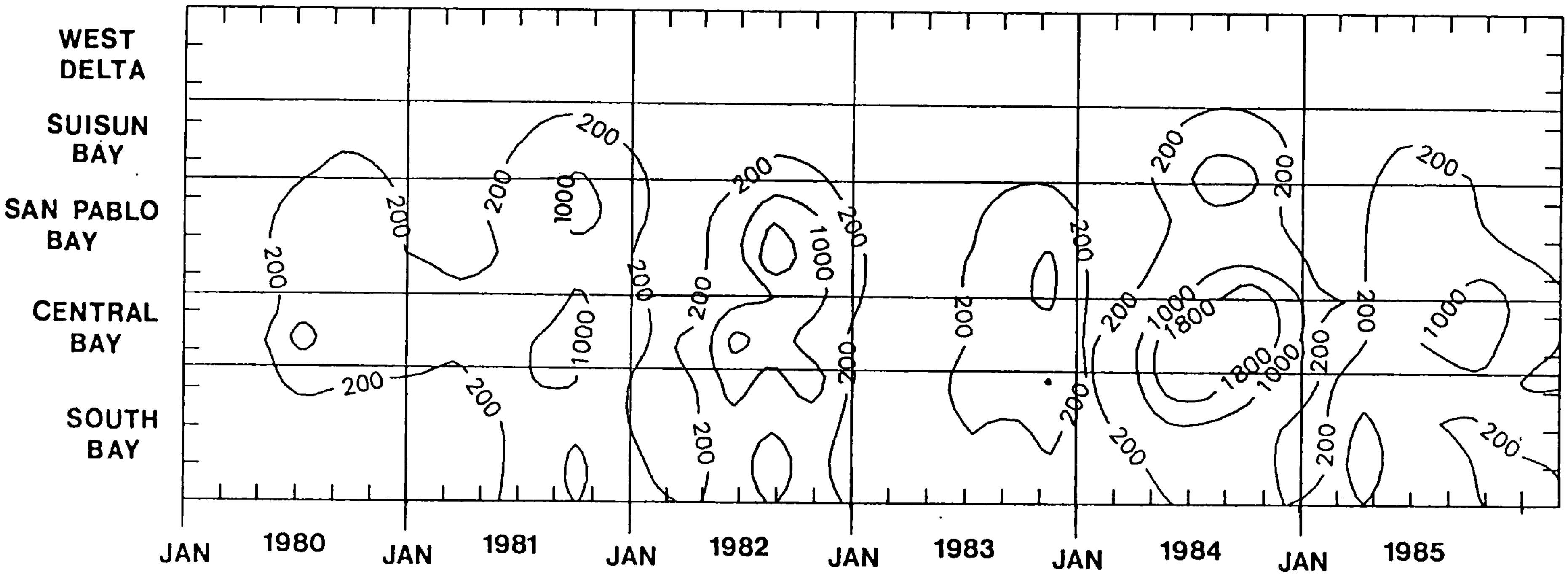


Figure 91. Temporal and spatial distribution of YOY and adult northern anchovies, 1980 through 1985. Abundance is represented by catch contours of 200, 1000, and 1800 fish per 10000 m^3 sampled by the midwater trawl.

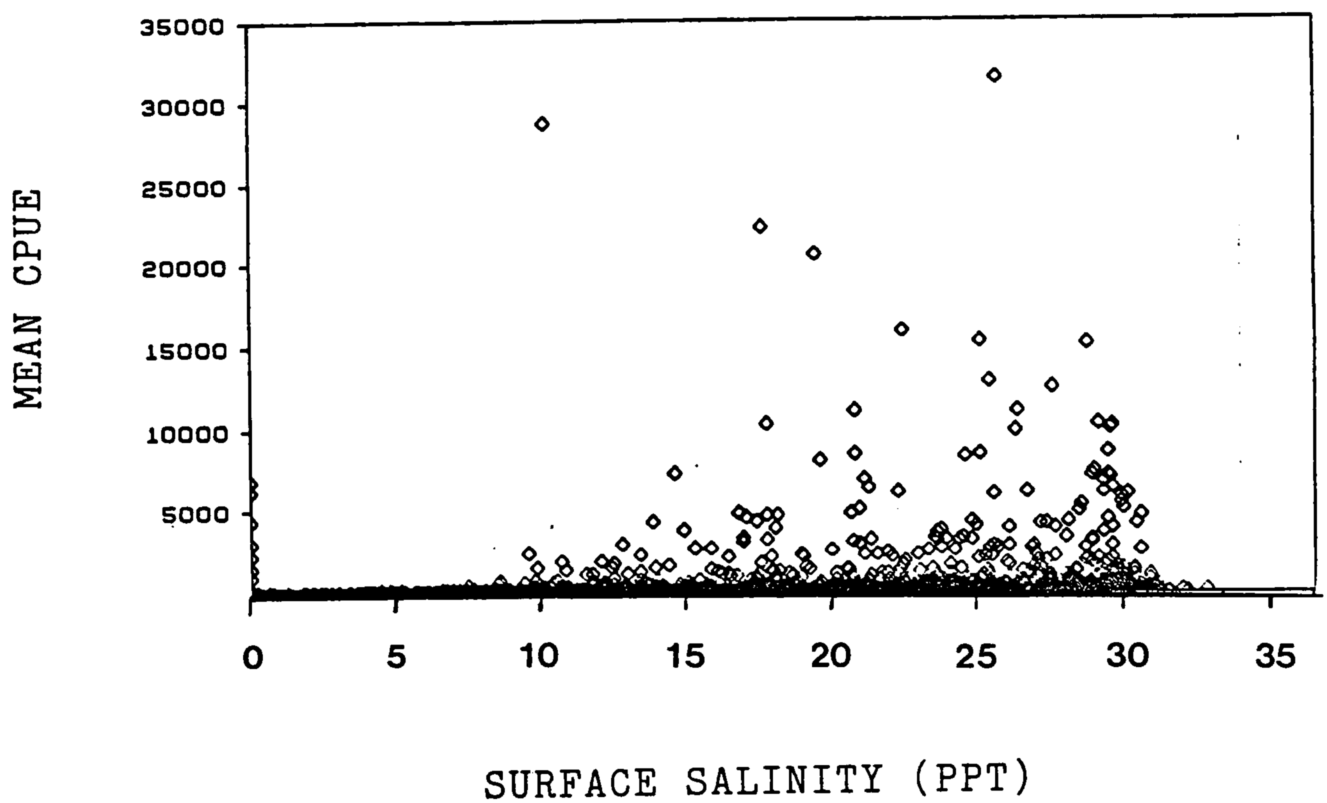


Figure 92. Relationship of northern anchovy abundance and surface salinity, 1980-1985.

restricted to downstream areas and essentially no anchovies are found upstream of Carquinez Strait.

The number of adults moving into the Bay each spring may depend mostly on their abundance in the Pacific Ocean near the Golden Gate, but may also be differentially affected by outflow-related environmental conditions outside the Gate that stimulate them to migrate into the study area.

Peak spawning occurs later in the year in wet and normal years (August-September) than in dry years (May-July) (Figure 93). Average monthly temperature in each Bay ranged from about 11 to 22 degrees C during the spawning period and was in the preferred range (13 to 18 degrees C) in all bays during some of the peak spawning months (May-September).

Thus, outflow determines the proportion of the estuarine system that is suitable for anchovies and may influence the number of anchovies entering the study area. Another hypothesis is that outflow influences annual egg abundance through a temperature effect on the onset, frequency, and duration of spawning.

The validity of this egg abundance index as an indicator of annual egg production is uncertain. Egg sample data may be reasonably reliable, since anchovies are multiple spawners and the probability of missing the spawning period with monthly sampling is less than with a species that spawns once annually. On the other hand, eggs hatch in a few days, and peaks in spawning could be missed.

The 1983 egg abundance index was excluded from the outflow relationship. Abundance of eggs in 1983 was much higher than in 1982, and should have been lower than it was based on our hypotheses of factors controlling spawning in the estuarine system. Our data indicate spawning in the study area was delayed, and peaked in September, later than in any other year. Anchovies moved into the Bay during summer in spite of high flows and relatively low salinity. Egg abundance was highest in South Bay and Central Bay, suggesting conditions there were most favorable for spawning.

Annual abundance of post-yolk-sac larvae was not related to outflow (r=0.58) (Figure 90). The abundance index for larvae was lowest in 1982 and highest in 1983, both wet years. Larval abundance usually was highest in late summer and early fall, when outflow was generally low. Although annual larval indices were not correlated with egg indices, summer-fall peaks in larval catch coincided with or closely followed peaks in egg catch.

A minor peak in larval abundance occurred in the spring in most years. This peak was not preceded by a similar peak for eggs and presumably results from transport or migration of ocean-produced larvae into the study area. The magnitude of this spring influx was greatest in 1983 when winter-spring outflow was very high.

Anchovies spawned mostly in Central Bay and South Bay in 1983, however, low larval abundance in 1983 suggests conditions for larval survival were poor or larvae were carried out of the study area. Survival may have been low in South Bay, and larvae in Central Bay may have been carried out. Spawning continued in late summer, and catches of both eggs and larvae reached peaks in September, this time in Central Bay and San Pablo Bay. In 1982, with generally similar outflow conditions, eggs and larvae followed a temporal pattern similar to 1983; however, densities were much lower.

<u>Summary</u>

The northern anchovy is found in the study area all year but in significant

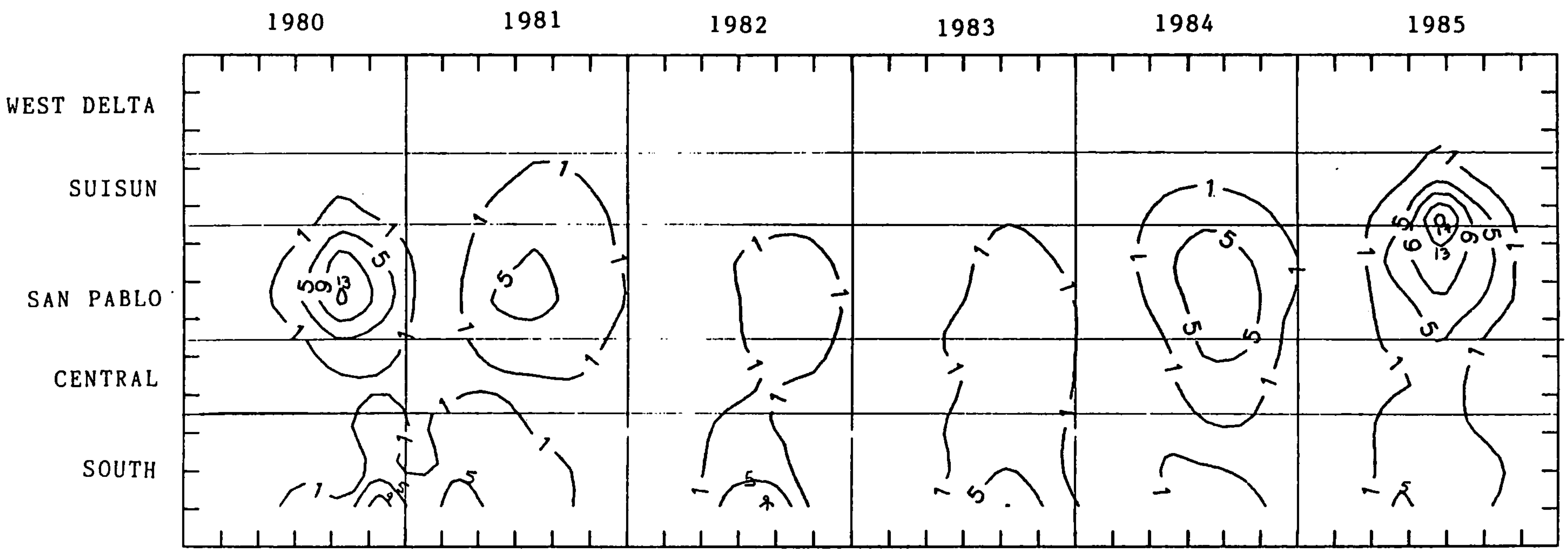


Figure 93. Spatial and temporal distribution of northern anchovy eggs, 1980 through 1985. Abundance is represented by catch contours of 1, 5, 9, 13, and 17 fish per m? sampled.

numbers only in the spring through fall. Outflow has some effect on the timing of anchovy migration into the study area, but the numbers that migrate in are probably influenced more by their abundance in the Pacific Ocean than by outflow. Outflow also determines what portion of the estuarine system is suitable for anchovies; they avoid areas where the water is too fresh. Anchovies spawn in the Bay, and larval and young-of-year survival is undoubtedly influenced by food availability and other environmental factors that may be related to outflow.

The viability of northern anchovy populations in California probably does not hinge on successful spawning and rearing in San Francisco Bay. Nevertheless, anchovies have a significant ecological role as the most important forage fish in the estuarine system. Many resident and anadromous species, both native and introduced, include anchovies in their diet. In addition, anchovies have economic importance, supporting a local fishery that supplies live and frozen bait for sport fisheries in the Bay and in the Pacific Ocean.

Northern anchovies which migrate seasonally into the study area are an adjunct to a large mobile offshore population; hence, they are not likely a sensitive indicator of changing environmental conditions within the estuarine system. Populations of other species with a more direct dependence on the Bay will reveal more about changes in the quality of the estuarine environment.

Pacific Herring

Pacific herring is a member of the family Clupeidae, which is represented by four species in San Francisco Bay (Table 16). The four species have very different life cycles. Threadfin shad (Dorosoma petenense) are a small freshwater species introduced into California waters for its perceived value as a forage species for predatory freshwater game fish (Moyle, 1976). Threadfin shad are established in the Delta, and we caught them in relatively low numbers primarily during periods of high flow in the upper part of the study area. The Pacific sardine (sardinops sagax caeruleus) is strictly a marine, pelagic species, centered off the Southern California coast (Clemens and Wilby, 1967). We caught only one sardine between 1980 and 1985. American shad (Alosa sapidissima) is an introduced, anadromous species that uses the Bay primarily as a migration corridor between the ocean and its spawning and nursery grounds in the major rivers of the Sacramento-San Joaquin drainage. Because these three species make such limited use of the Bay, this report does not discuss their abundance or distribution, but focuses on the Pacific herring.

The Pacific herring, which made up 6.79 percent, of our midwater trawl, 17.19 percent of our seine, and 50.70 percent of our larval catch, ranges from central Japan northward into the Bering Sea and south along the Pacific coast of North America to northern Baja California.

In California, herring spawn in estuaries and bays. Herring mature at 3 to 5 years, and spawners begin entering bays and estuaries in late November and December. Large herring enter at the earliest dates, with smaller spawners following. Miller and Schmidtke (1956) reported herring schools spawn between December and June. The spawning season begins and ends earliest at the most southern regions of the Pacific herring's range and latest in the more northerly portions. Several spawnings usually occur at each locality during the spawning season, although individual herring spawn only once (Hardwick, 1973).

Table 16

CATCH AND PERCENT OF ALL FISH CAUGHT OF THE FAMILY CLUPEIDAE, 1980 THROUGH 1985

	Gear							
	Midwater Trawl		Otter Trawl		Beach Seine		E&L Net	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
American shad	2,638	0.43	130	0.09	72	0.06	37	*
Pacific herring	42,146	6.79	2,355	1.63	21,576	17.19	390,098	50.70
Sardine	1	*	0	0.00	0	0.00	0	0.00
Threadfin shad	366	0.06	73	0.05	667	0.53	1,994	0.26
Total	45,151		2,558		22,315		392,129	
Percent of all fish		7.28		1.77		17.74		50.96

San Francisco Bay is sheltered from the ocean, and influenced by fresh water. Spawning areas are primarily the intertidal zone and immediately adjacent subtidal areas to a depth of 4.5 meters. Herring literally cover the rock and sandy shoreline and its associated vegetation with spawn. The only areas not utilized are mud flats with no vegetation. The shoreline areas most often utilized are just inside the Golden Gate Bridge along the Marin Peninsula, the Tiburon Peninsula, Angel Island, and across the bay between Richmond and Oakland. Herring have been known to spawn at the northern terminus of San Pablo Bay (Croker, 1930), and limited spawning has been observed in south San Francisco Bay.

The major subtidal spawning areas are Richardson Bay and the large shallow area between Richmond and Oakland. Vegetation in both of these areas is predominantly _Gracilaria_ spp., with small patches of _Zostera marina_ found in localized areas. The subtidal spawning areas, discovered in 1978, have proven to be the major spawning areas for herring in the Bay (Spratt, 1981).

Herring may spend up to 2 months in the Bay before spawning. During this time they school in the deepest areas until 1 or 2 days before spawning. They then swim into shallow areas, where they spawn on whatever substrate is available. In spawning, the female swims parallel to and directs eggs toward the substrate upon which eggs are to be deposited (Maxwell B. Eldridge, National Marine Fisheries Service, personal communication). The eggs readily adhere to any surface they contact. It is common to find eggs more than one layer thick on vegetation.

Spawning occurs during the day as well as at night (Maxwell B. Eldridge, National Marine Fisheries Service, personal communication), and in a single locality may last from a few hours to several days. In San Francisco Bay, over 88 percent of all spawnings take place when the highest daily tide occurs during darkness (Spratt, 1981). Herring return to the sea immediately after spawning. The eggs hatch in 6 to 11 days in water 8 to 10 degrees C (Hardwick, 1973).

Newly hatched herring larvae average about 7.5 mm long, usually with a yolk sac that persists for a variable length of time, depending on temperature, but not usually exceeding 2 weeks. Within a couple of months a length of 2.5-4.0 cm is reached. By this stage, the young herring begin to resemble adults, and they form schools. Through summer, herring continue to grow and congregate, and reach a length of 7-10 cm. They disappear into deeper water in fall, after which they are seldom evident on usual fishing grounds for 2 or 3 years (Hart, 1973).

Pacific herring are the object of a large commercial fishery in San Francisco Bay for their roe, much of which is exported to Japan. The spawn also offers a substantial seasonal food supply for fish and other wildlife of San Francisco Bay.

Gear Effectiveness and Effort Correction

Adult Pacific herring enter San Francisco Bay only to spawn. Virtually all of the herring caught in the trawls and seine are YOY fish, so our analysis of data from these years will be limited to YOY. The midwater trawl and beach seine were the most effective in catching YOY herring, so data from these gear were used in characterizing their abundance and distribution. Because young herring are generally pelagic, we calculated CPUE based on the volume of water sampled by each net.

Larval Abundance and Distribution

Significant presence of larval Pacific herring during the 6-year study occurred only during November through April (Figure 94). The peak month was January in three of the seasons (1980-1981, 1981-1982, 1982-1983) for which we have complete data and February in the other two seasons (1983-1984 and 1984-1985). February had the highest mean CPUE for the 6-year period. In every season except 1984, there was a significant larval presence for at least 3 months. The protracted presence of larvae probably resulted from multiple spawns, which occur during most seasons.

Pacific herring larvae had a wide distribution within the Bay during the study (Figure 95). They occurred in every embayment and were abundant at one time or another in every area but upper Suisun Bay and the West Delta. Area of peak abundance ranged from upper South Bay in 1980 and 1985 to upper San Pablo Bay in 1981. Only once, in 1983, was the area of highest abundance in Central Bay.

Young-of-Year Abundance and Distribution

March was the earliest that YOY fish appeared in our midwater trawl samples, and they were not abundant in any of the 6 years until April (Figure 96). The peak month of abundance ranged from May, in 1984, to August, in 1980. Relatively few fish remained in the Bay after October in any year.

YOY herring were widely dispersed in the estuary. They differed from the larvae, in that peak abundance tended to be in Central Bay rather than San Pablo Bay or upper South Bay (Figure 97).

We characterized the abundance of YOY herring each year by calculating the

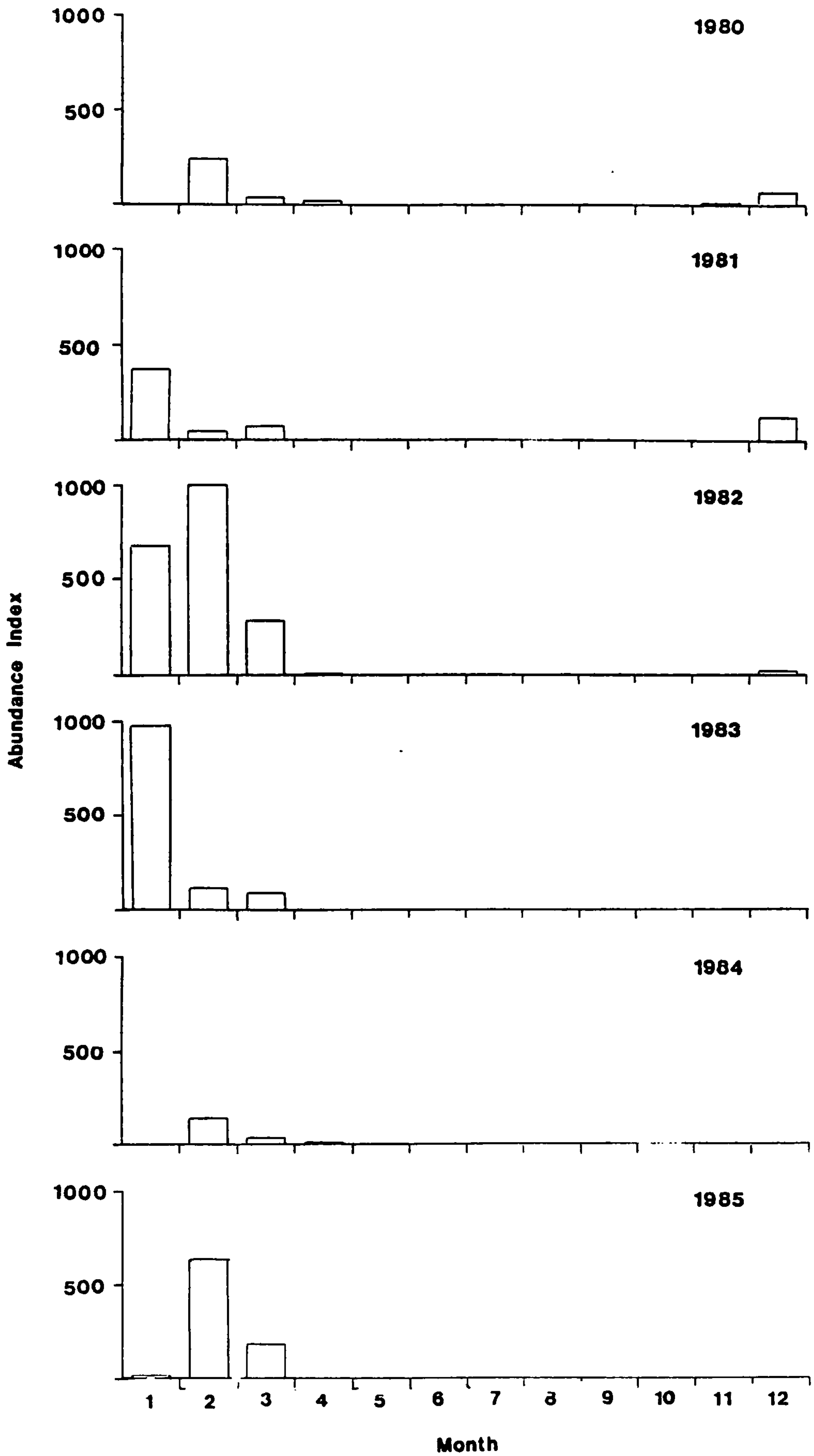


Figure 94. Seasonal distribution of larval Pacific herring, 1980-1985.

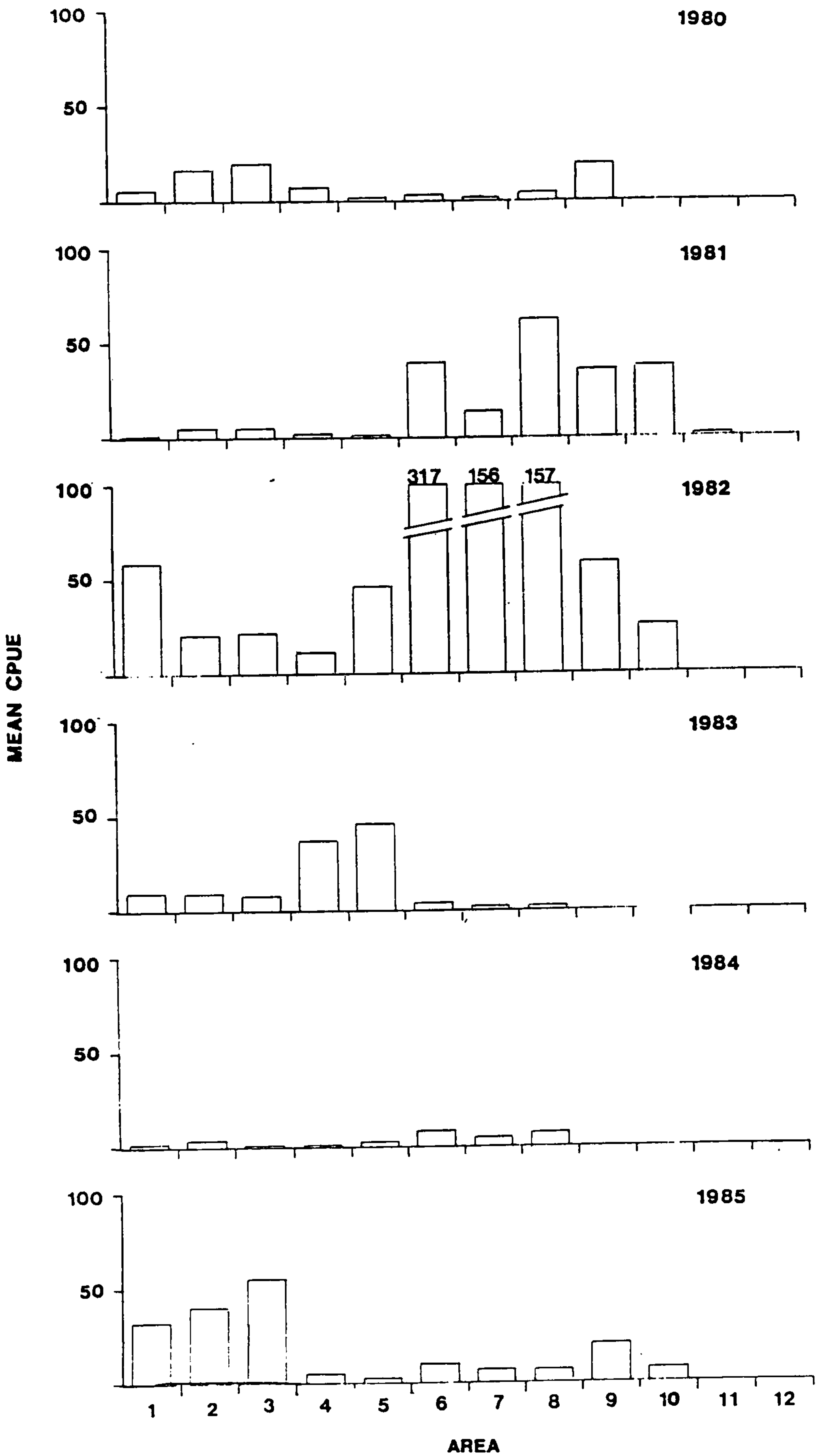


Figure 95. Spatial distribution of larval Pacific Herring during the period January through March, 1980-1985.

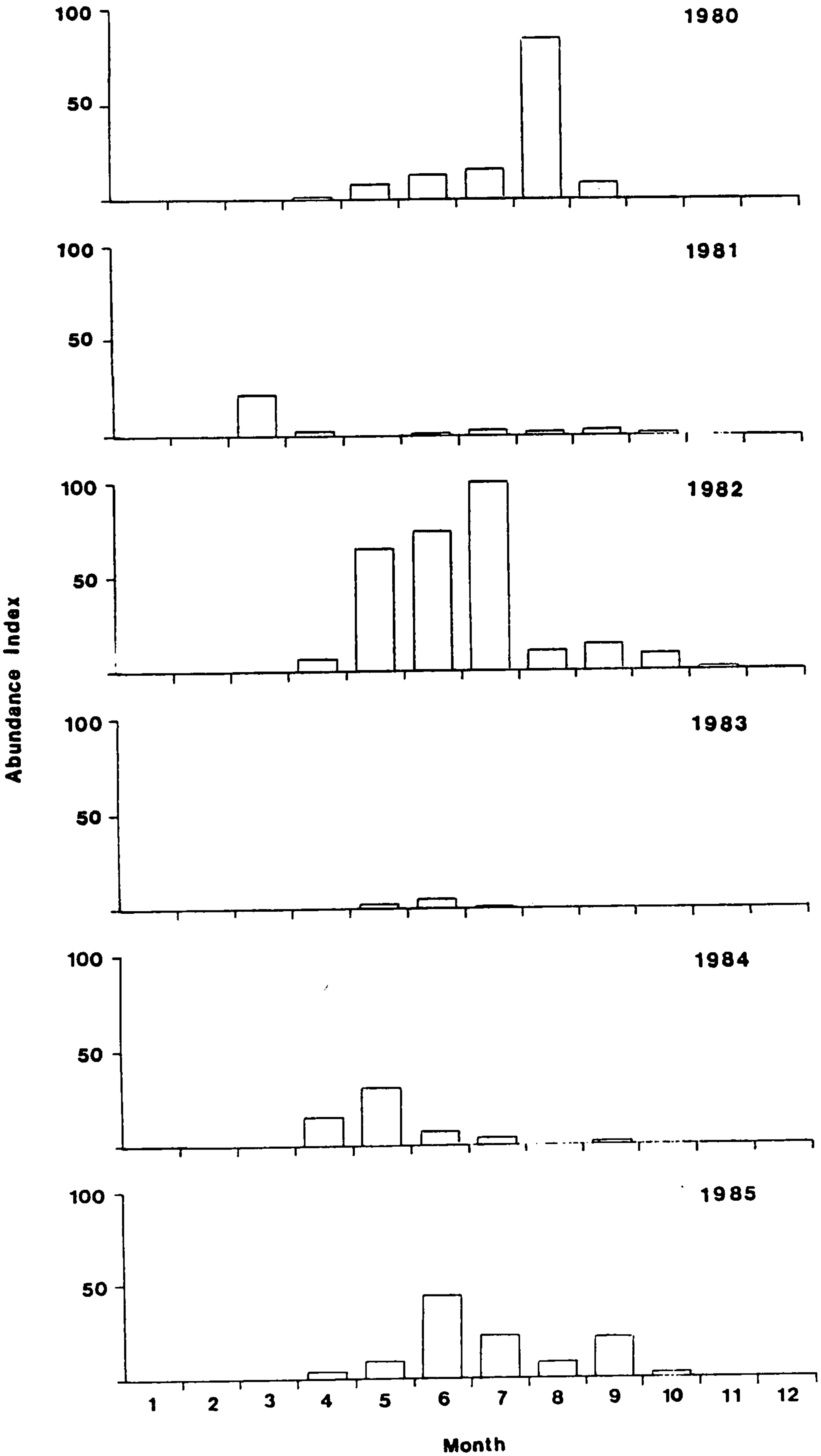


Figure 96. Seasonal distribution of YOY Pacific Herring, 1980-1985.

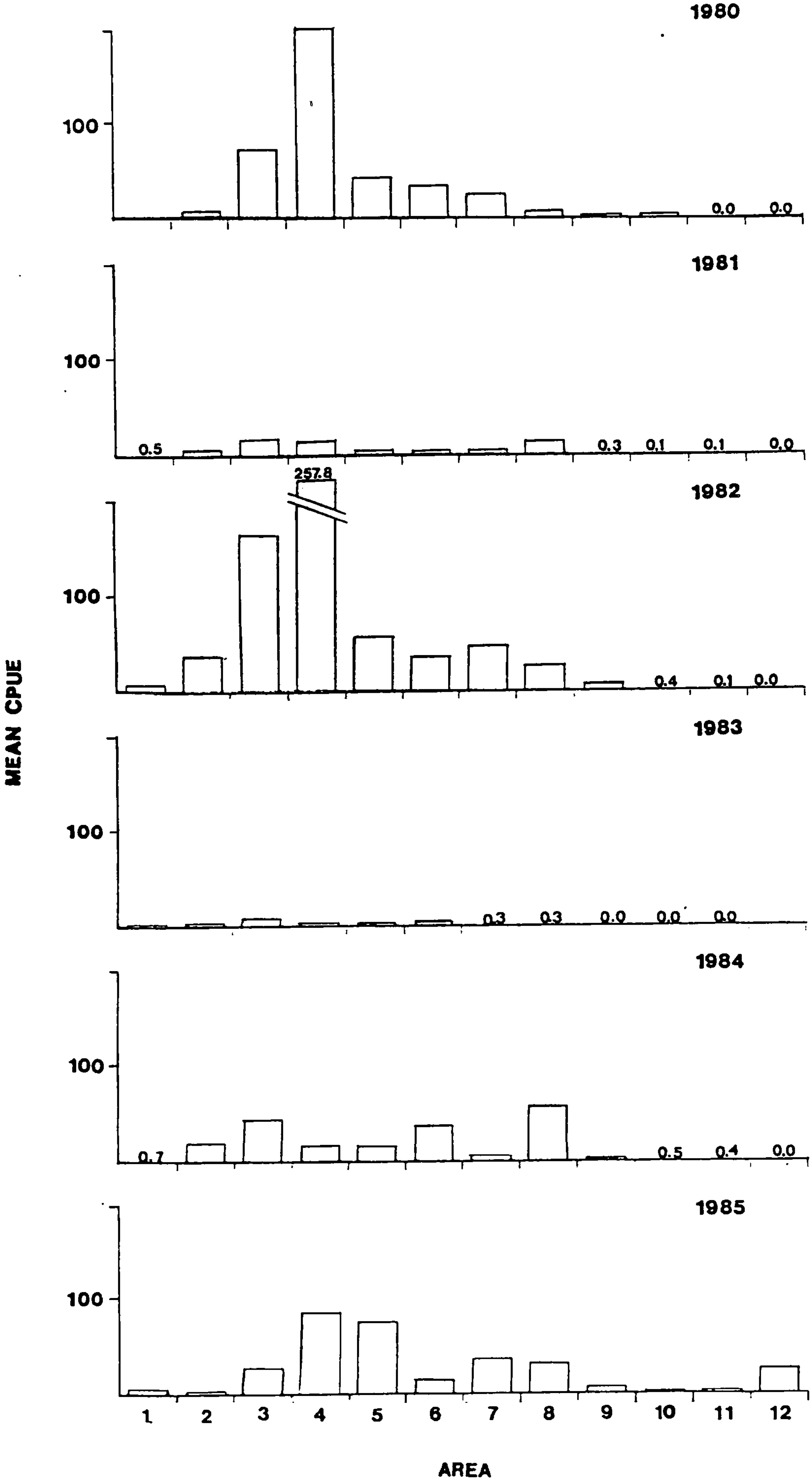


Figure 97. Spatial distribution of YOY Pacific herring,1980-1985.

mean volume weighted CPUE for April through September. There was a 28-fold difference in index between the highest year (1982) and lowest year (1983). Variation in YOY abundance was greater than that in larval abundance, suggesting estuary conditions may influence survival or residence time of young herring in the Bay.

The annual abundance of YOY herring was weakly associated with spawning stock size (Figure 98) and better associated with larval abundance (r=0.86, n.s., n=5). Using the ratio of the YOY abundance index to larval abundance index as a rough measure of survival of herring while in the Bay, we found survival to have a weak negative association with January through June levels of Delta outflow. In combination, these observations on YOY abundance and survival suggest they were primarily controlled by spawning stock or the abundance of newly hatch fish size rather than factors associated with the magnitude of Delta outflow.

Jacksmelt
(Atherinopsis californiensis)

Jacksmelt are members of the family Atherinidae, commonly called silversides. They are not true smelts, which are in the family Osmeridae. Jacksmelt are a pelagic, schooling, marine species ranging from Yaquina, Oregon, to Santa Maria Bay, Baja California (Miller and Lea, 1972; Baxter, 1980). They are generally found within a few miles of shore and commonly enter bays (Baxter, 1980).

Few life history studies have been conducted on jacksmelt. Clark (1929) studied the population off Southern California and found that jacksmelt reach an average length of 110 mm at the end of their first year, 180-190 mm after 2 years, and a maximum length of about 350 mm. They live a maximum of 9 or 10 years.

Clark found that jacksmelt become sexually mature at 2-years. She determined that individuals spawn more than once during a spawning season, October to March, and that spawning occurred at all times throughout the season. Jacksmelt eggs hatch in about 7 days at 10 to 12 degrees C and in salinities as low as 5 ppt (Wang, 1986). The larvae rise to the surface, where they are active swimmers.

Major food items of young jacksmelt include algae, detritus, and small crustaceans; they are fed upon by other fish and by birds (Wang, 1986).

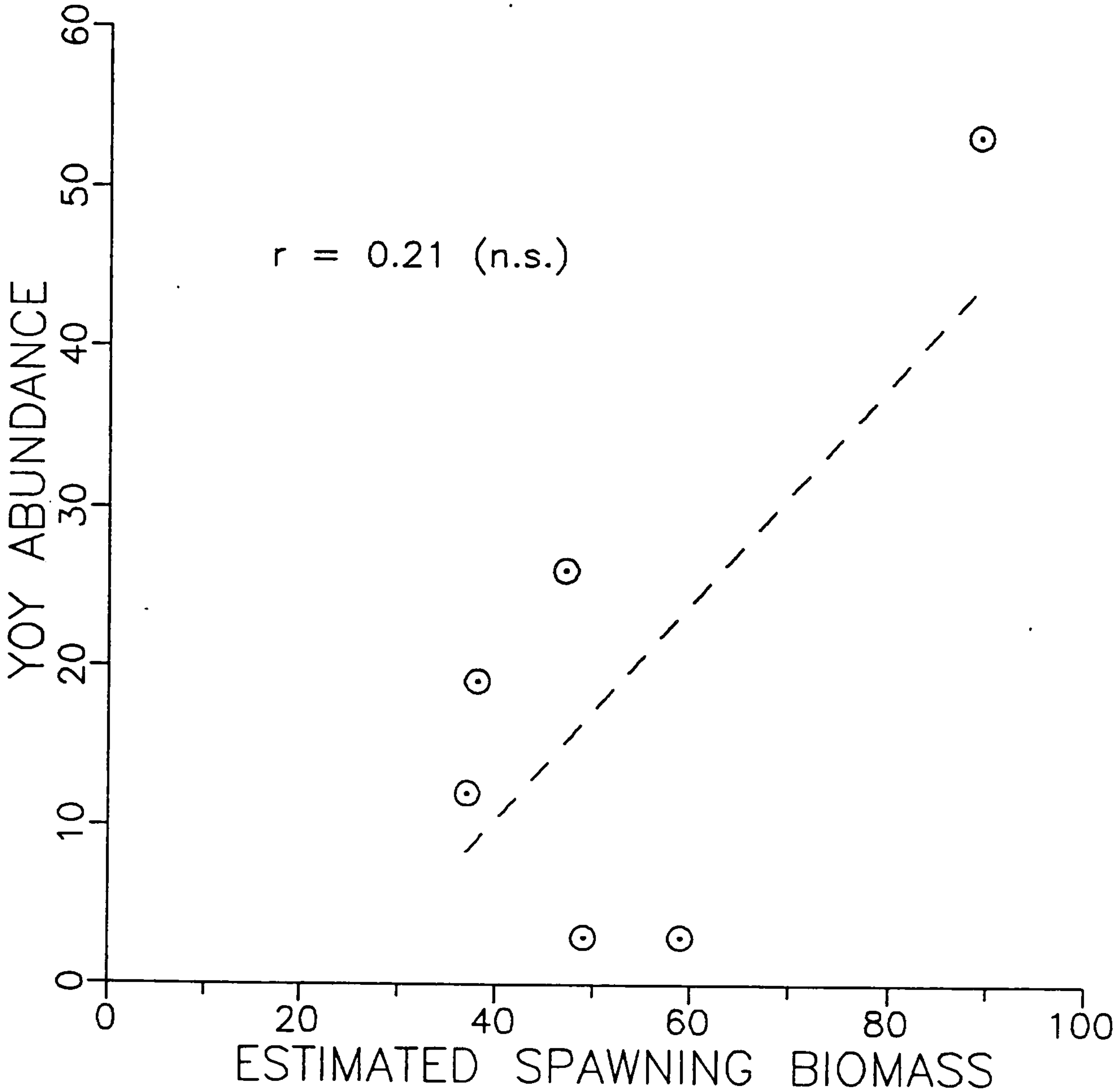
Length-frequency distributions of jacksmelt caught during the study (Figure 99) showed that individuals of fork length 99 mm or less were young-of-year, and those 100 mm or greater one-year and older. The one-year and older group are referred to here as adults. Most individuals in this group are greater than 200 mm in length and are, therefore, at least 2 years old and sexually mature (Clark, 1929).

Gear Effectiveness

Only 34 jacksmelt were caught by the otter trawl during the study period, so otter trawl catches are not included in the discussion of distribution and abundance.

The egg and larval net captured 1,822 yolk-sac larvae, 1,991 post yolk-sac larvae, and 85 juvenile jacksmelt. Larvae occurred primarily from March through August (Figure 100). Jacksmelt larvae actively swim near the surface, and since the egg and larvae net samples primarily along the bottom, the absolute abundance of jacksmelt larvae relative to other larvae may be underestimated.

The beach seine, the most effective gear for jacksmelt, caught 13,049 which represented 10.40 percent of total individuals caught with that gear. The



(X 1000 TONS)

Figure. 98. Correlation of YOY Pacific herring abundance index and spawning stock size.

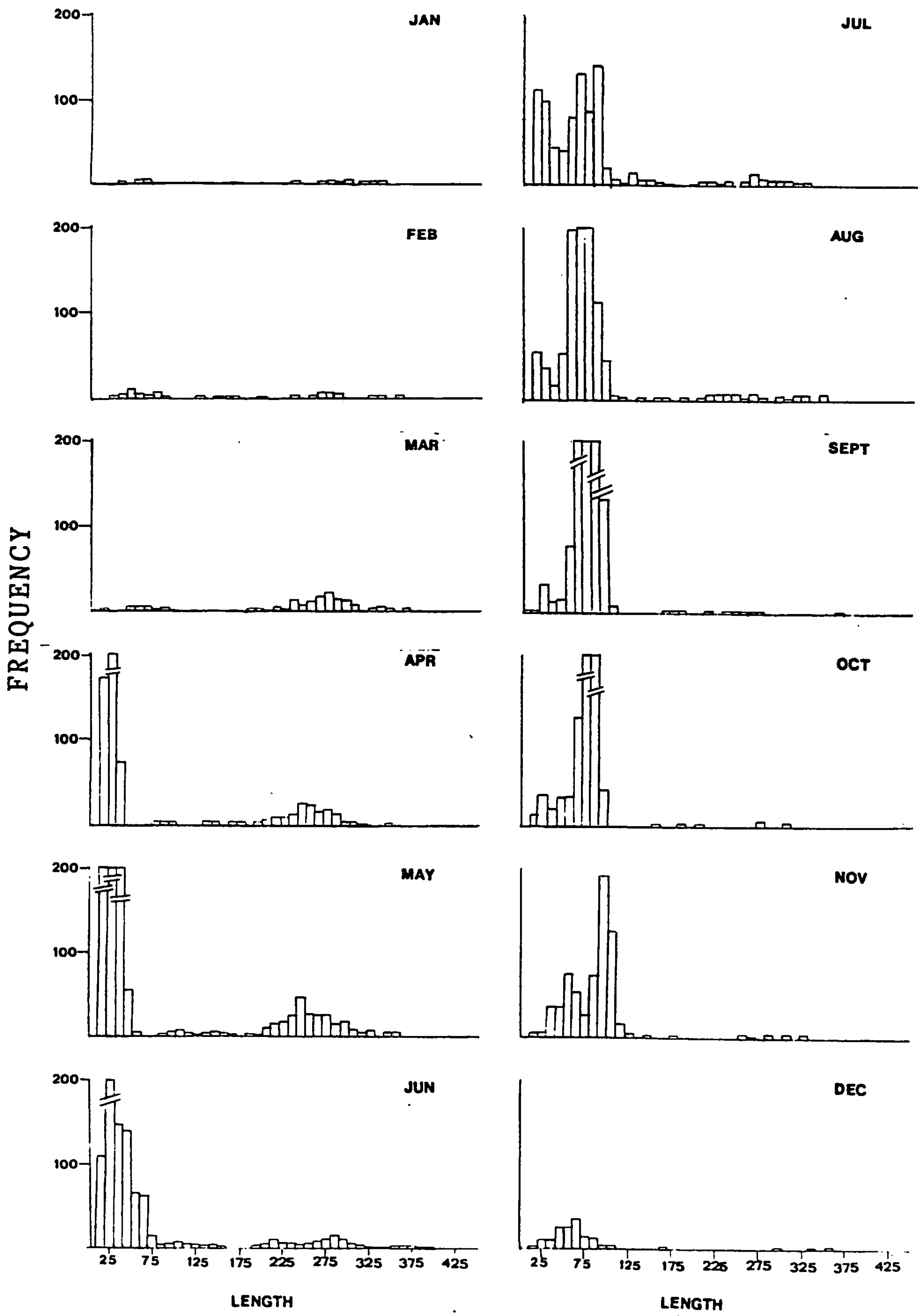


Figure 99. Length frequency distribution of jacksmelt collected in the midwater trawl, 1980-1985.

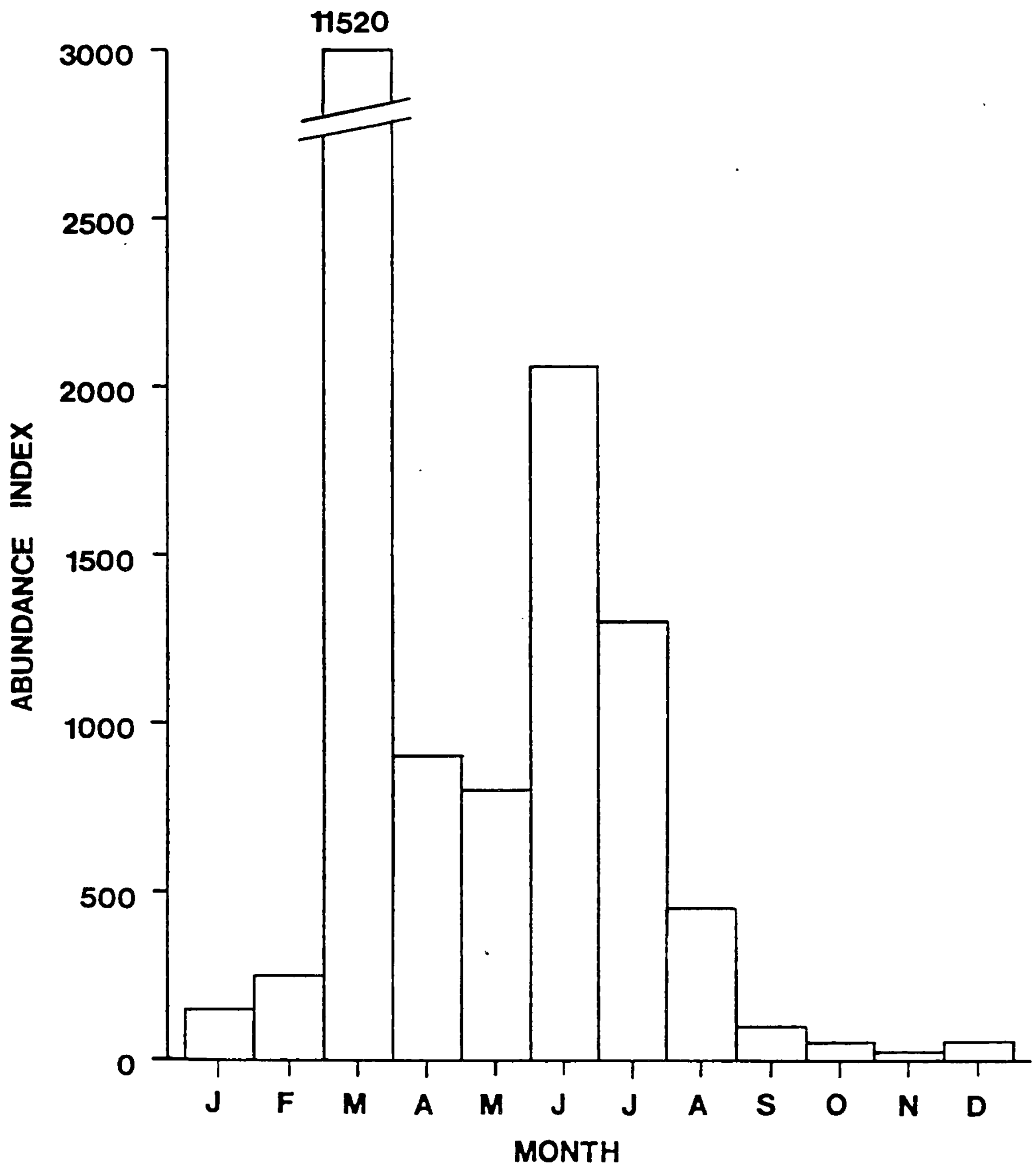


Figure 100. Seasonal distribution of larval jacksmelt, all years combined.

beach seine captured young-of-year individuals primarily from April through September (Figure 101). Adults were not efficiently sampled by the beach seine, representing only 0.5 percent of all individuals caught by it.

The midwater trawl caught 7,864 individuals, which represented 1.27 percent of the total midwater catch. Of these, 79.5 percent were young-of-year and 20.5 percent were adults. Adults were collected during most of the year, with peak abundances from February through June; young-of-year were caught from July through November (Figure 102).

Adult Distribution and Abundance

Adult jacksmelt begin increasing in numbers in January, peak in May, then gradually decline to minimum in October. Few adults are present in the study area from October through January.

In February, adults are found from South Bay to lower San Pablo Bay (Figure 103). During March they begin entering the Bay en masse, leading to an increase in distribution and abundance in Central Bay. During the next month or two they move from Central Bay into South Bay and San Pablo Bay. By May, adults are widely distributed in lower South Bay and lower San Pablo Bay. They are present in these areas in June, and by July they begin funneling back into Central Bay and presumably into the ocean. Only five adults were caught above San Pablo Bay, one in each year of the study except 1983.

Larval Distribution and Abundance

Jacksmelt larvae were most often caught from February to July, peaking around May and tapering off in August. They were present in low numbers or were absent during September through January (Figure 100).

Throughout the year, larvae were most widely distributed in South Bay, especially lower South Bay (Figure 104). Beginning about March, they were distributed throughout San Pablo Bay and were widely distributed there in June. By September, the few larvae sampled were evenly distributed from South Bay to San Pablo Bay.

Larvae are most abundant in the study area in spring, coinciding with the appearance of adults. They begin increasing noticeably in March in South Bay and Central Bay. They are most abundant throughout the study area in June, gradually declining to low abundances by October. In most years they appear in low numbers during October, November, and December. However, no larvae were sampled from September 1983 through February 1984.

Young-of-Year Distribution and Abundance

Young-of-year jacksmelt are caught in both the beach seine and the midwater trawl. They begin showing up in the beach seine samples in April, generally peak around June, decline for a month or two, and often show a second, smaller peak in September. After this second peak, they decline in numbers and are present only in reduced numbers during winter (Figure 101).

The midwater trawl begins catching young-of-year as they grow and presumably begin leaving the shallow shore areas (Figure 102), as evidenced by the decrease in beach seine catches at this time (Figure 101). This generally occurs in July or August, when they are around 70 mm in length. They are caught by the midwater trawl through December, and for the most part are absent from its catches from January through June.

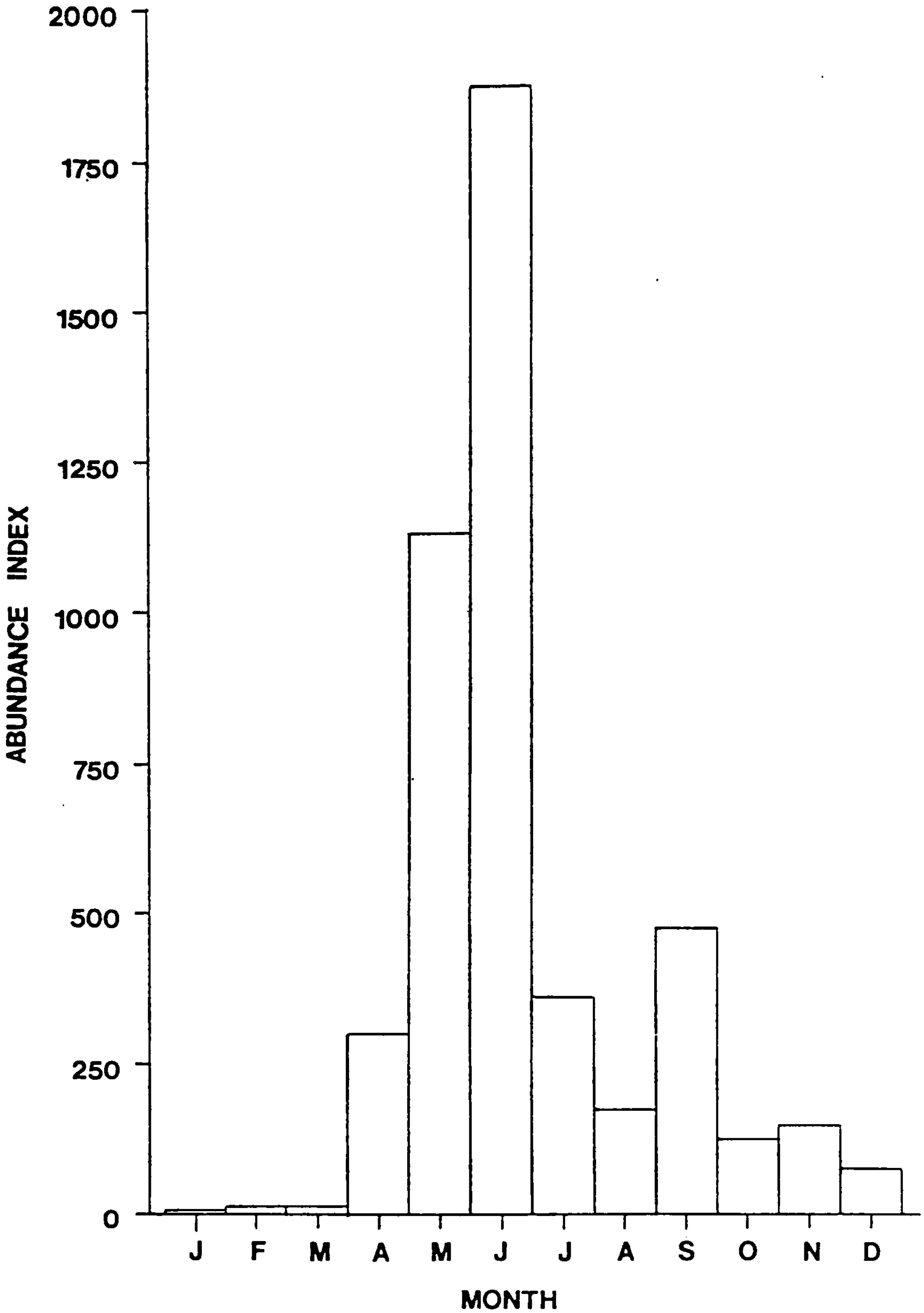


Figure 101. Seasonal distribution of YOY jacksmelt, all years combined.

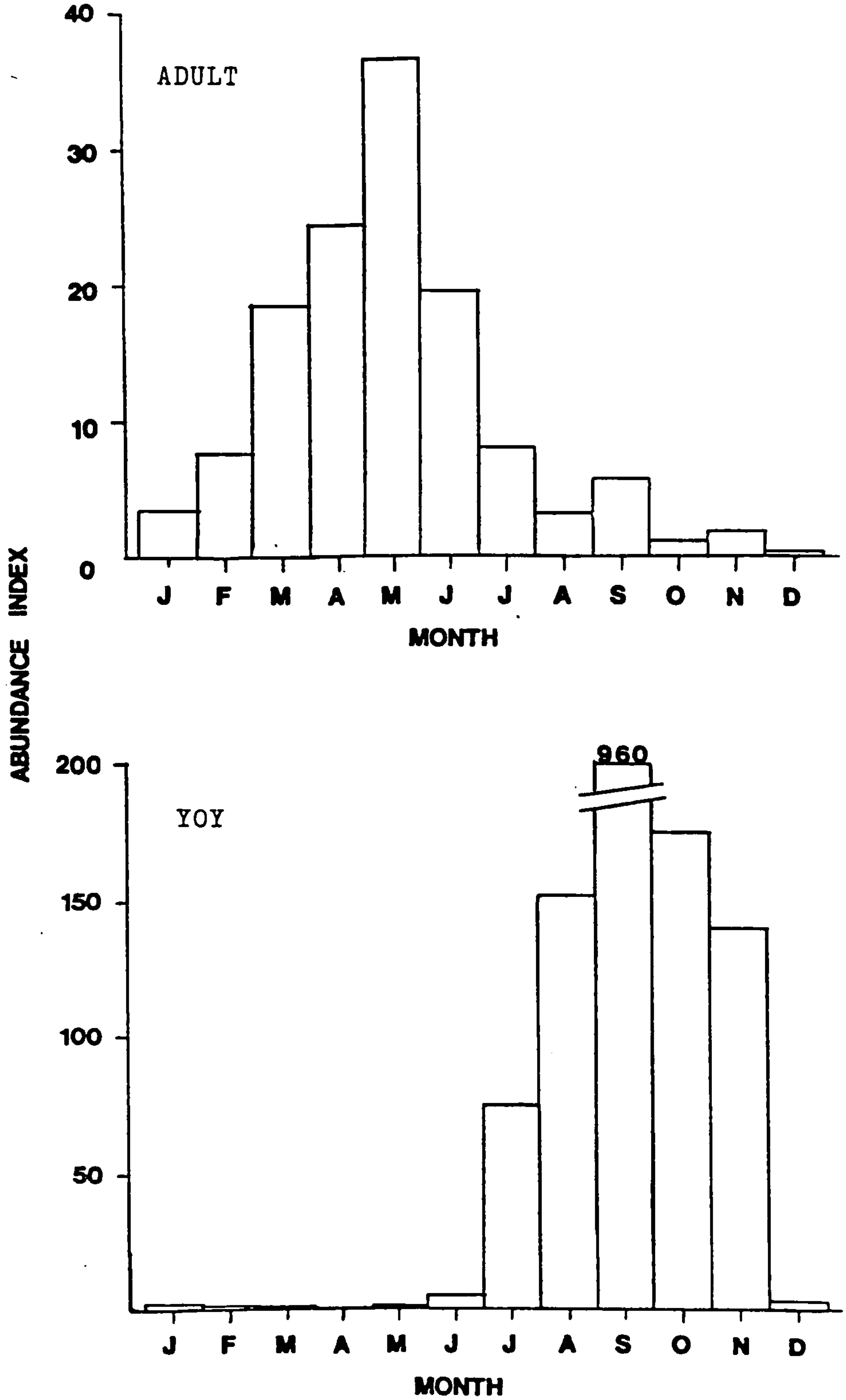


Figure 102. Seasonal distribution of YOY and adult jacksmelt, 1980 through 1985.

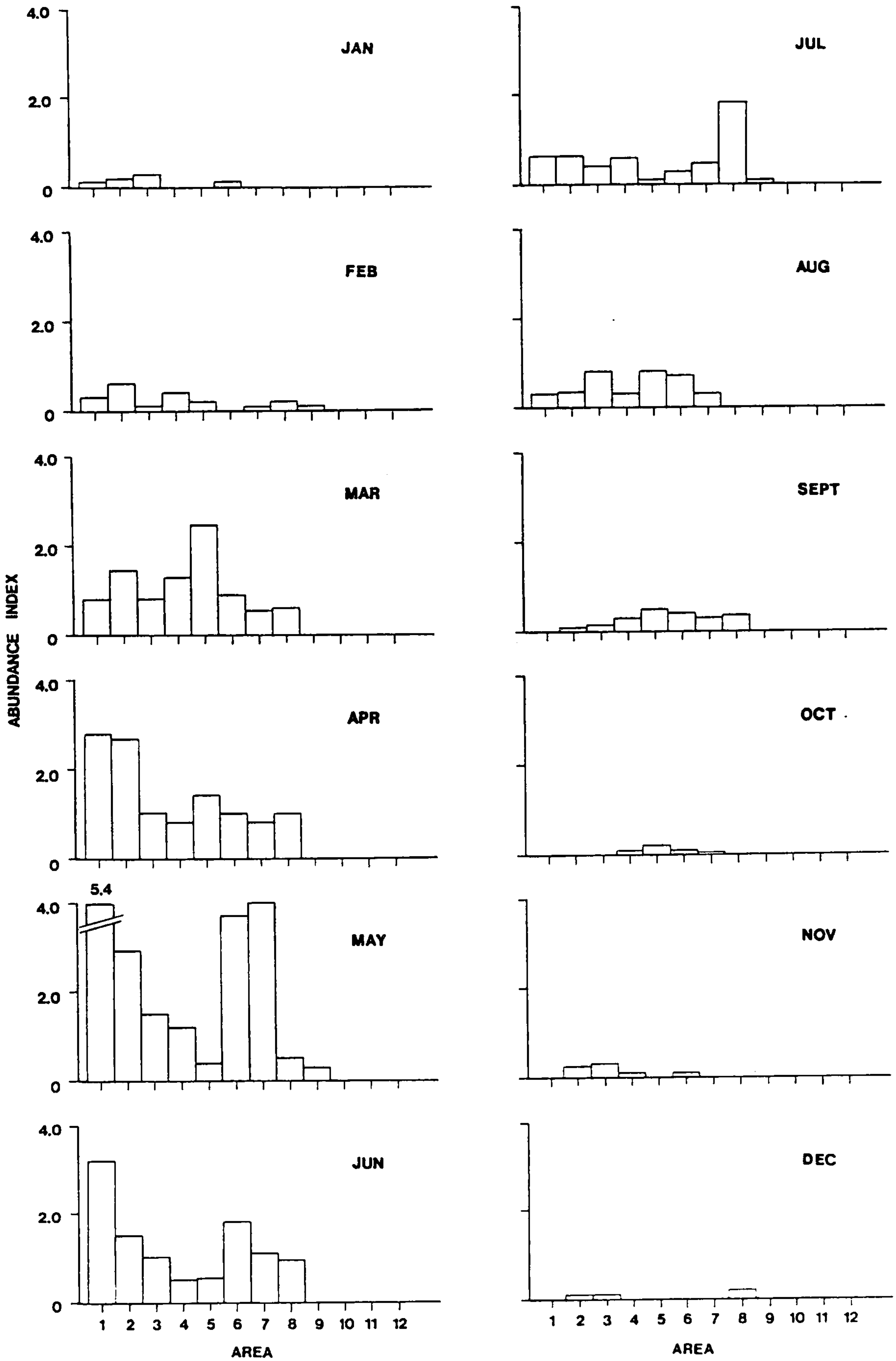


Figure 103. Seasonal distribution of adult jacksmelt, by month.

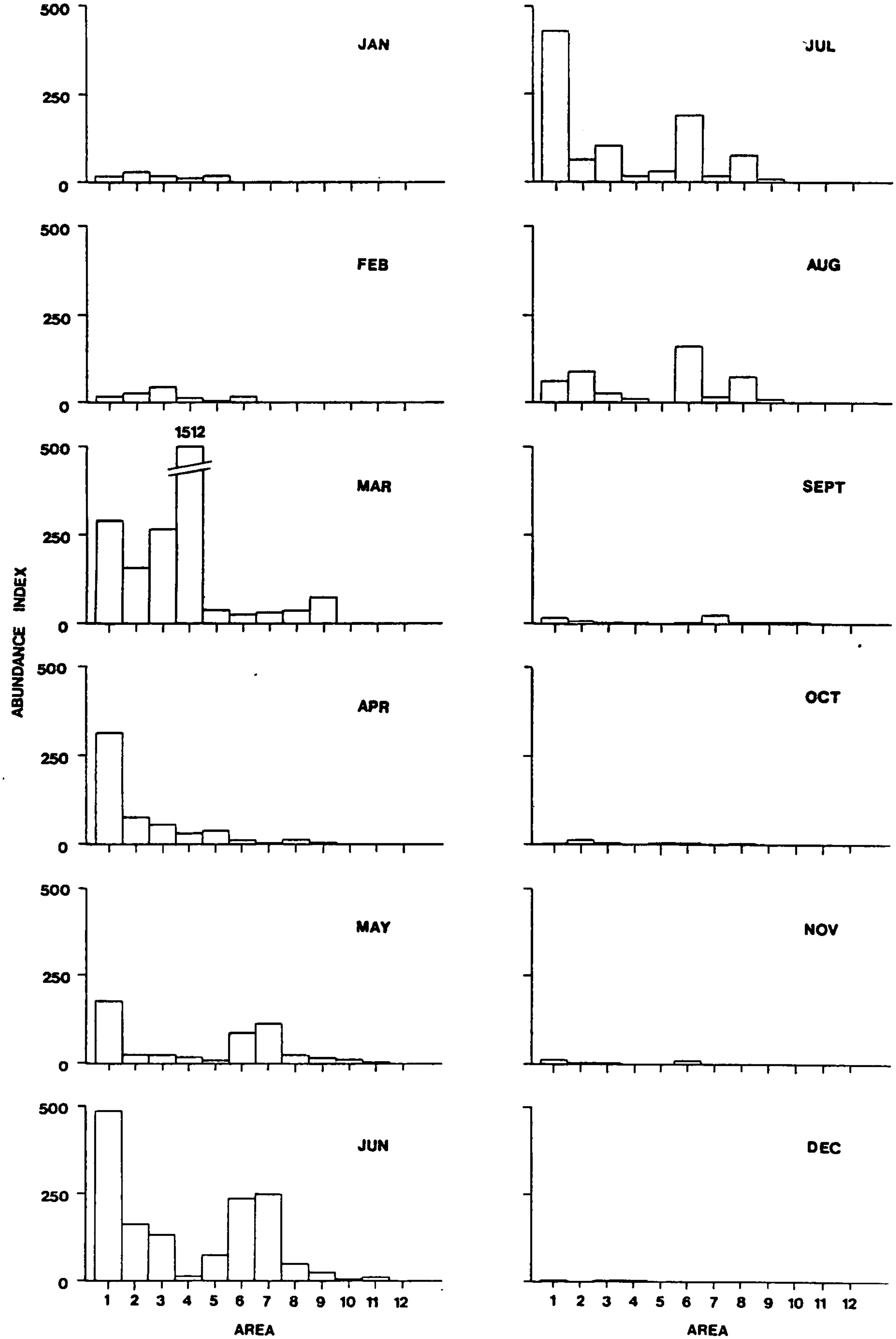


Figure 104. Spatial distribution of larval jacksmelt by month, 1980 through 1985.

Beginning in April, young-of-year jacksmelt are dispersed from South Bay to Carquinez Strait. They are most widely distributed at this time in upper South Bay and lower Central Bay. In June they are most widely distributed in lower South Bay beach seine samples, but are also present throughout San Pablo Bay and up into Carquinez Strait.

In July, as catches decrease in the beach seine, young-of-year begin showing up in the midwater trawl samples. Abundance is greatest in upper South Bay and lower Central Bay. Abundance in these two areas continues to be high through November, as young-of-year jacksmelt leave the study area (Figure 105).

Abundance indices of young-of-year jacksmelt begin increasing in April and peak in May or June for the beach seine. Young-of-year are generally most abundant in beach seine samples from South Bay, although they occur in good numbers in Central Bay and San Pablo Bay. The midwater trawl begins sampling young-of-year in July, primarily in upper South Bay and lower Central Bay. Abundance indices for these areas remain high through November. Young-of-year jacksmelt are present in reduced numbers from December to April, when they again show up again in the beach seine samples.

Effects of Delta Outflow

Correlation techniques were used to assess the degree of association between jacksmelt abundance and distribution and Delta outflow. Analysis was conducted on each life stage, by embayment, and for periods of flow expected to affect jacksmelt abundance or distribution. Table 17 gives the correlation coefficient values for annual abundance and average monthly January through December outflow. While only one value was significant ($p<0.05$, $n=6$), the trends in the magnitude and sign of correlation coefficients suggest possible influences of flow on jacksmelt abundance and distribution.

Table 17

CORRELATION COEFFICIENTS FOR ANNUAL ABUNDANCE INDICES OF JACKSMELT AND AVERAGE MONTHLY OUTFLOW (JANUARY-DECEMBER) (n=6)

Life Stage	Total Study Area	South Bay	Central Bay	San Pablo Bay	Upstream
Larvae	-0.29	0.35	-0.33	-0.45	-0.36
Young-of-Year (Beach Seine)	0.70	0.84*	0.55	-0.52	-0.55
Young-of-Year (Midwater Trawl)	-0.59	-0.69	-0.58	-0.63	-0.50
Adult (Midwater Trawl)	0.05	-0.33	0.67	-0.42	-0.40

* p<0.05.

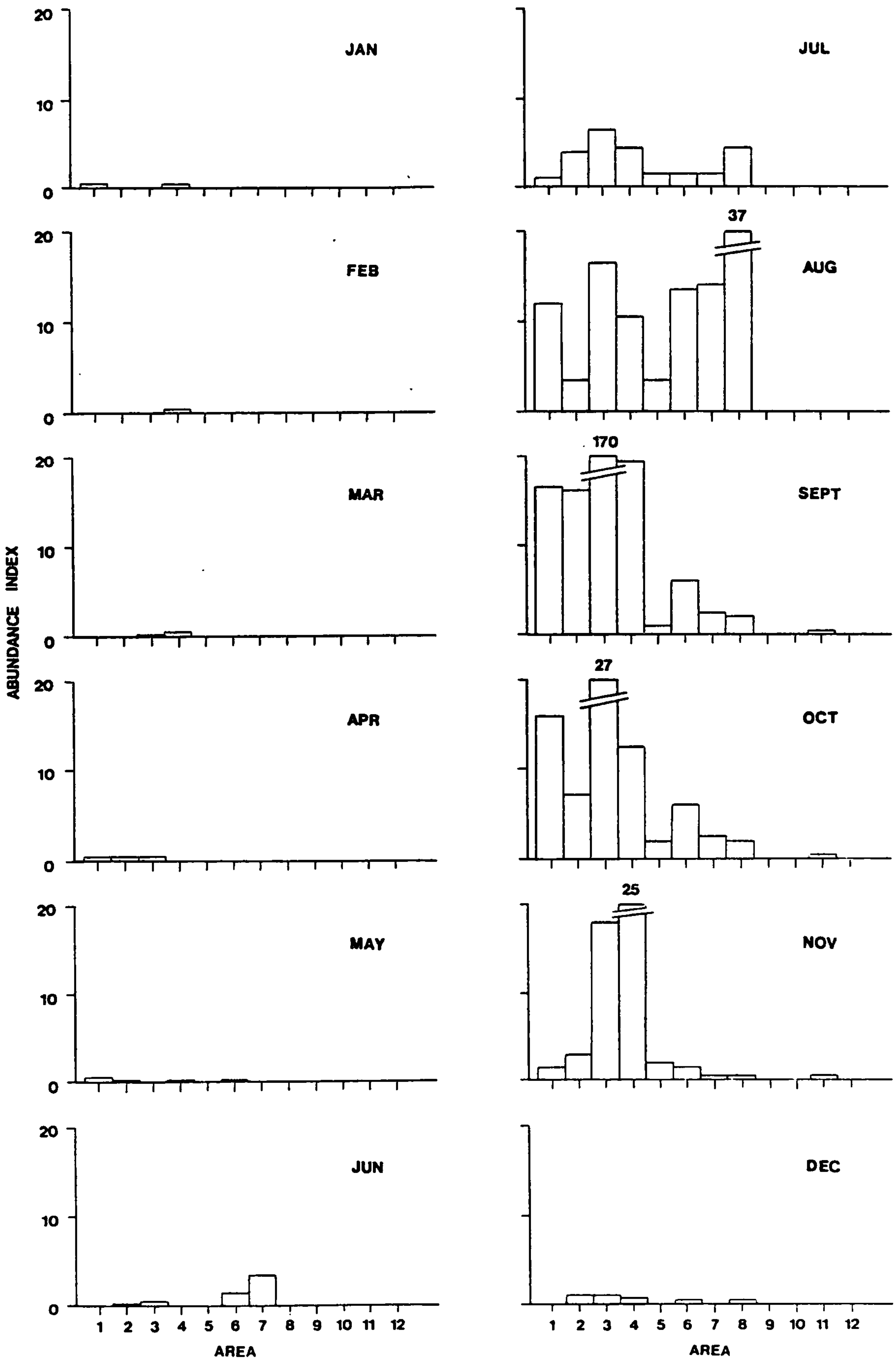


Figure 105. Spatial distribution of YOY jacksmelt, by month, 1980 through 1985.

Adults. Except for a peak in May 1982, the average monthly abundance index of adult jacksmelt caught in the midwater trawl for February through May has been fairly constant. This indicates a relatively constant recruitment of adult, spawning jacksmelt into the study area each year. In addition, this recruitment of adult jacksmelt is relatively constant over a wide range of flows (Figure 106).

For incoming adults, the monthly abundance indices do not show a strong correlation with either the previous month's average daily outflow or with 15-day or 7-day previous average flows. Flow also does not seem to influence when adults come into the study area. In 1980, 1981, 1982, and 1984 they appeared in February. In 1983 and 1985 they appeared in March.

Although flow does not appear to affect the number of adult jacksmelt entering the study area, it does influence their distribution within embayments. In general, when flows increase, they concentrate in Central Bay. As flows diminish, they disperse into South Bay and throughout the northern arm of the estuary.

Larvae. Annual abundance indices of larvae, by embayment, were correlated against average monthly flow (Table 17). None of the correlation coefficients was significant. Negative coefficients were obtained for Central Bay, San Pablo Bay, and upstream areas. The only positive coefficient was for South Bay. Jacksmelt larvae are pelagic and occur at the surface. They are, therefore, distributed by movement of the upper layer of the water column. It makes sense, then, to expect a decrease in abundance in the upper portions of the study area with higher flows and an increase in abundance in South Bay. This was observed in 1982 and 1983 (Figure 107).

In 1984, larvae were most abundant in San Pablo Bay, followed by South Bay. This is not surprising, considering that with a dry spring more adults were able to move into San Pablo Bay. What is surprising is that in 1985, the driest year and the year when adult jacksmelt were widely distributed in San Pablo Bay, larvae were most abundant in South Bay, followed by Central Bay, and then San Pablo Bay. Larvae were also less abundant in San Pablo Bay in 1985 than in 1984.

Young-of-Year. Young-of-year jacksmelt are sampled by both the beach seine and midwater trawl. Abundance indices based on beach seine catches show an inverse relationship to flow for San Pablo Bay and upstream areas and a positive relationship for South Bay and Central Bay (Table 17).

The midwater trawl catches of young-of-year show inverse relationships to flow in all bays. Central Bay always shows the greatest abundance of young-of-year jacksmelt caught in the midwater trawl, followed by South Bay (Figure 108). This would seem to indicate that the midwater trawl is sampling young-of-year individuals as they leave the study area and head out the gate; rates of emmigration are greatest when flows are highest, causing a negative relationship between flow and abundance.

It seems reasonable that higher flows are either pushing the YOY out of the study area or signaling them to leave. The three wettest years are also those with the smallest annual abundance indices for young-of-year in the midwater trawl catches. The higher flows may cause a greater percentage of the young-of-year to leave the study area earlier than normal, thereby reducing the number of individuals available to the trawl and subsequently reducing their abundance indices.

Summary

Delta outflow does not appear to influence the number of spawning adult

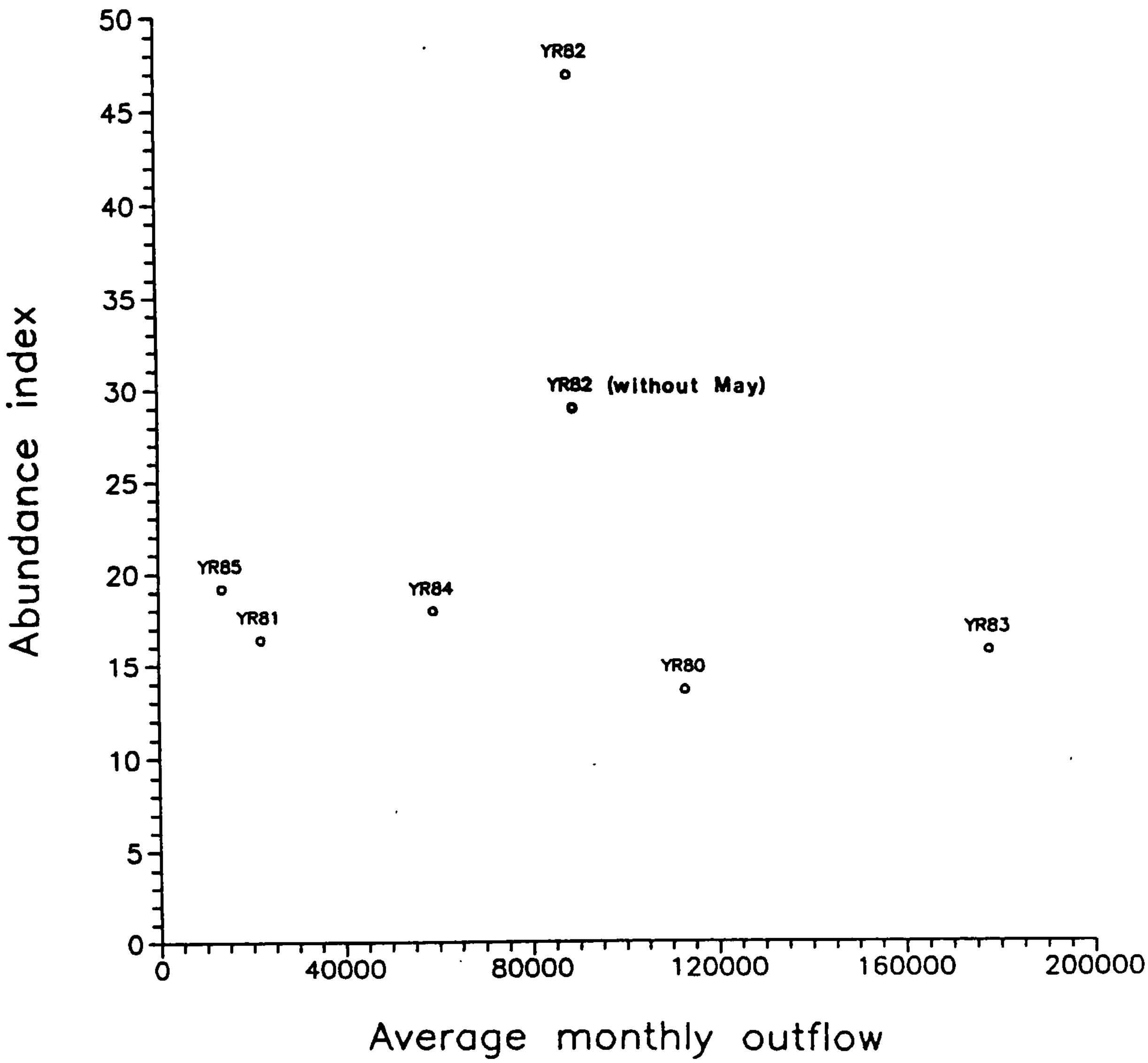


Figure 106. Relationship of February-May jacksmelt abundance and Delta outflow for the period January through March.

1 - SOUTH BAY   2 - CENTRAL BAY   3 - SAN PABLO BAY   4 - UPPER BAYS

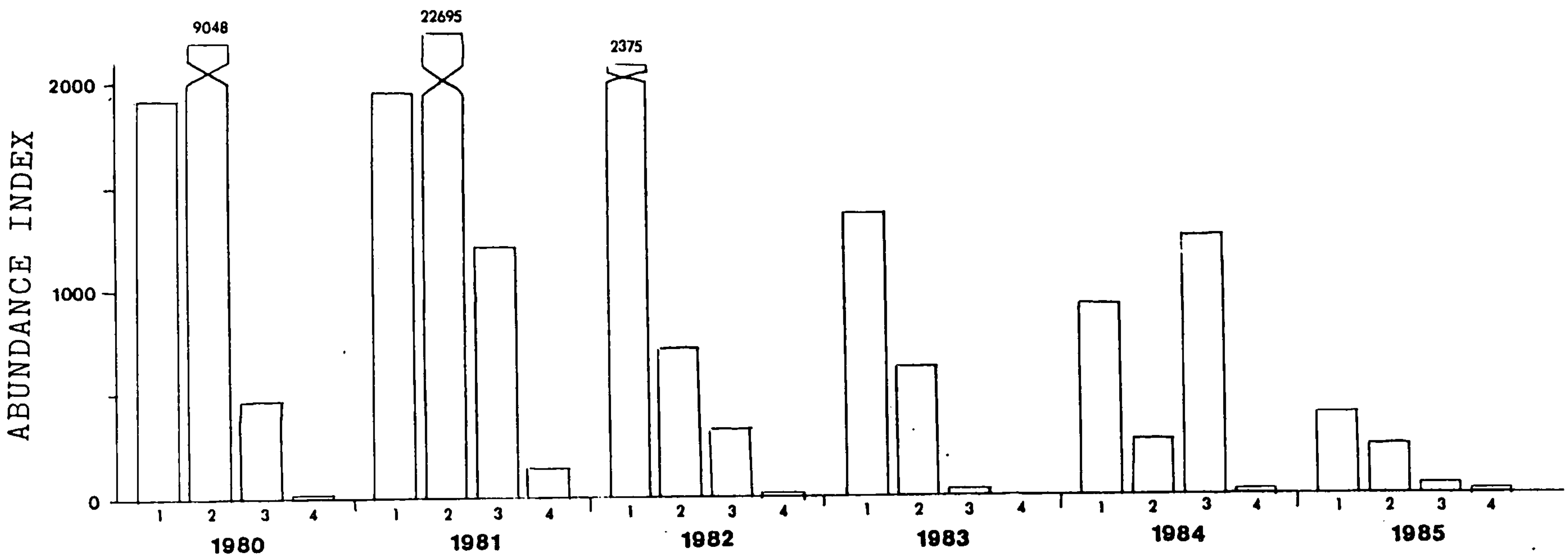


Figure 107. Annual abundance indices for larval jacksmelt, by embayment.

1 - SOUTH BAY 2 - CENTRAL BAY 3 - SAN PABLO BAY 4 - UPPER BAYS

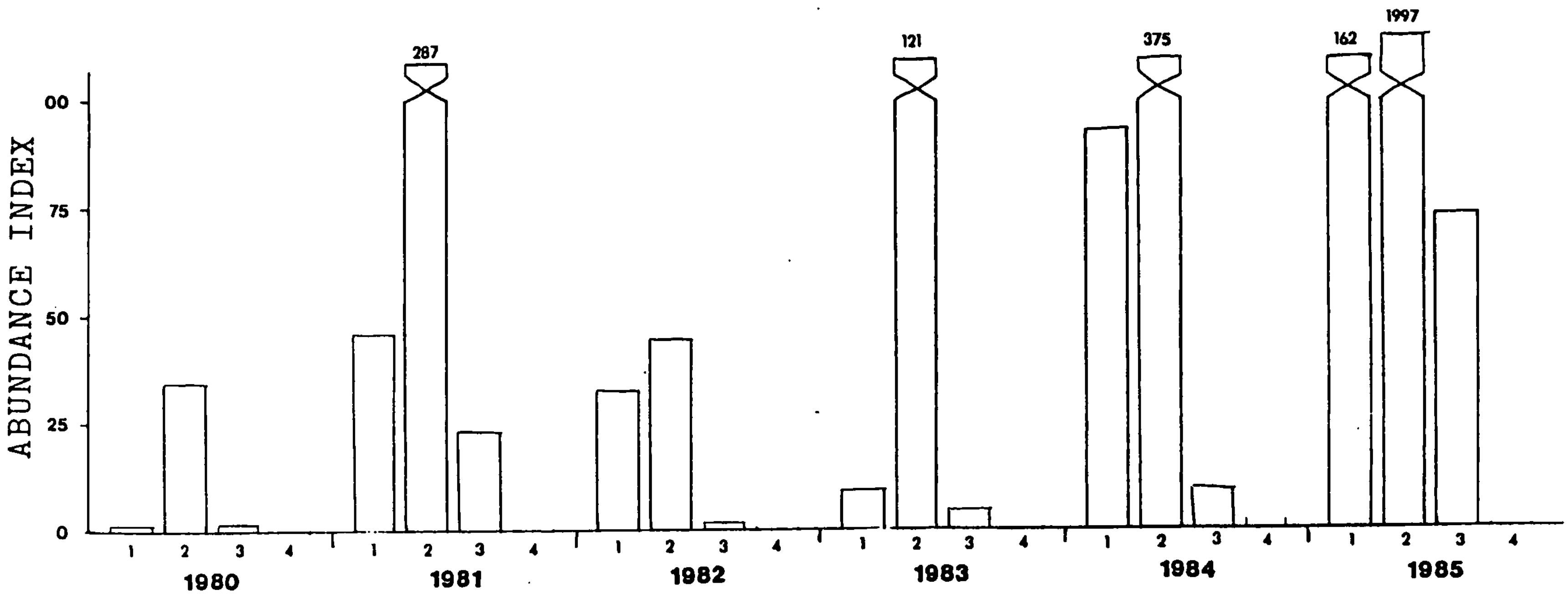


Figure 108. Annual abundance indices for YOY jacksmelt, by embayment.

jacksmelt entering the bay. However, flows do influence the distribution and abundance in each embayment for each life stage. In high flow years all life stages become more widely distributed and more abundant in South Bay and Central Bay, at the expense of San Pablo Bay and upstream areas. In low flow years, jacksmelt make use of San Pablo Bay and Carquinez Strait, although it is not possible to predict to what degree.

Topsmelt (Atherinops affinis)

Topsmelt (*Atherinops affinis*), like jacksmelt, belong to the family Atherinidae, commonly called silversides. Topsmelt are a pelagic, marine, schooling species most commonly found in bays, sloughs, and kelp beds. They range from the Gulf of California to Vancouver Island, British Columbia (Miller and Lea, 1972). They generally school near the surface, in shallow waters, over sandy or muddy bottoms (Feder, et al., 1974).

Schultz (1933) recognized three subspecies of topsmelt along the Pacific Coast. *Atherinops affinis affinis* is the subspecies inhabiting San Francisco Bay. Aside from Schultz's study on age and growth and Carpelan's (1951) study on spawning and salinity tolerance in the Alviso salt ponds, no comprehensive life history studies have been conducted on topsmelt in San Francisco Bay. Carpelan found that adult topsmelt could tolerate salinities as high as 80 ppt and that their eggs successfully hatched and larvae survived in water with a salinity level of 72 ppt.

Using length-frequency distributions, it was determined that young-of-year topsmelt were 89 mm or less in fork length, while one-year and older individuals were 90 mm or greater. The one-year and older group are referred to here as adults. Carpelan (1951) found that topsmelt became sexually mature as one year olds when they reached a total length of 100-110 mm (about 90-100 mm fork length).

Gear Effectiveness

Only 39 topsmelt were captured by the otter trawl during the study period, so otter trawl data were not used in determining distribution and abundance.

The egg and larval net captured 209 yolk-sac larvae and 37 post yolk-sac larvae. The small numbers of larvae captured indicate that adults spawn in littoral habitats and the young rear there.

The beach seine captured 42,860 topsmelt, which accounted for 34.16 percent of all fish caught in it. Topsmelt was the most abundant species in the beach seine samples. Young-of-year accounted for 94.6 percent of the topsmelt caught in the beach seine.

A total of 2,448 topsmelt were caught by the midwater trawl during the study. Of these, 64.8 percent were young-of-year. Adult topsmelt were caught nearly year-round, but young-of-year were generally caught in summer and fall, coinciding with peak catches in the beach seine.

Adult Distribution and Abundance

Adult topsmelt were caught in every month (Figures 109 and 110). Peak catches were generally in the fall and were highly variable in other months. Adults often began showing up in March in the seine samples from upper South Bay. These are most likely individuals ending their second year (Figure 111). In May and June, abundance indices increase in upper South Bay as the previous year class is recruited into the adult category. Beginning around September, adults are found not only in

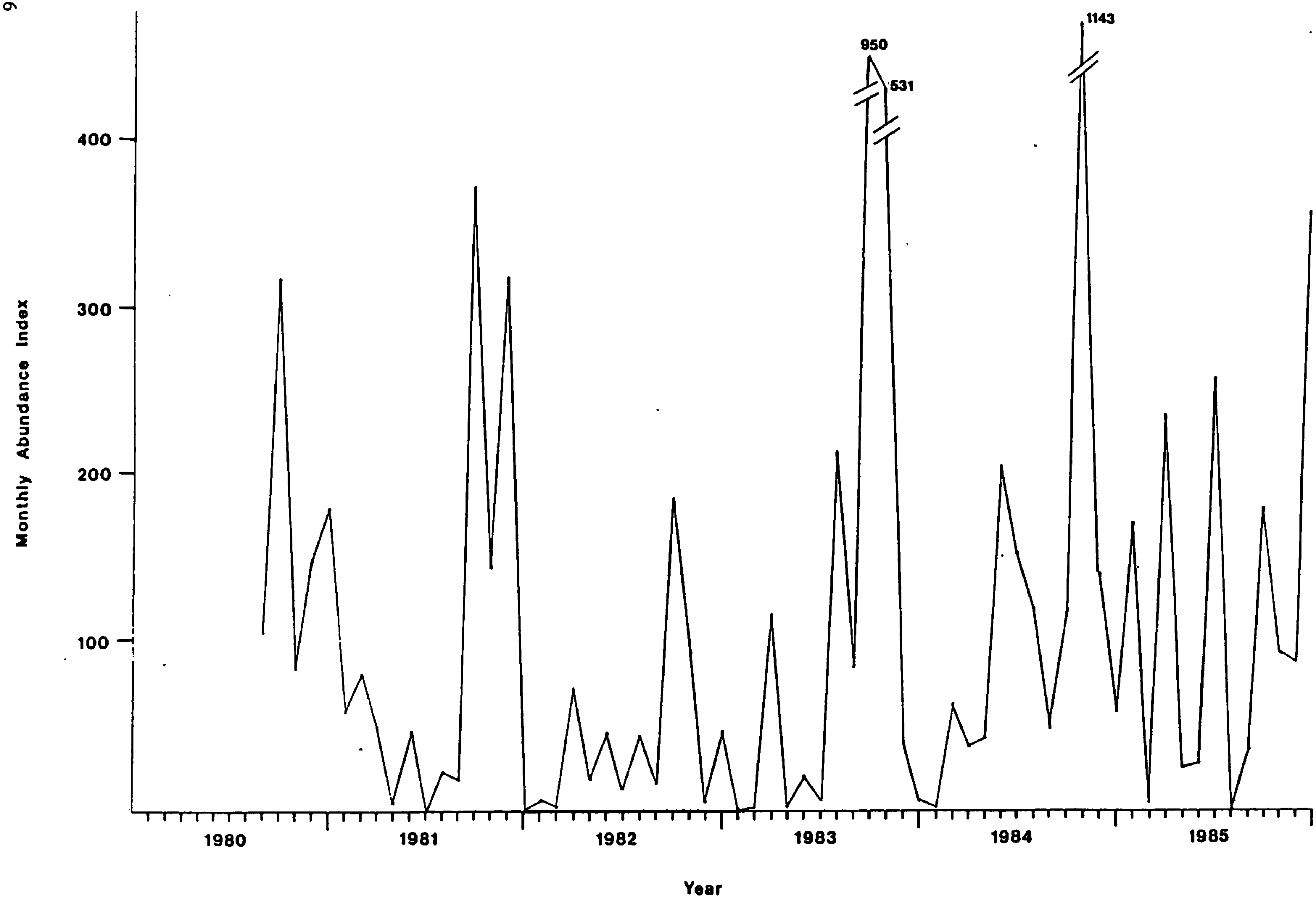


Figure 109. Monthly abundance indices for adult topsmelt collected in the beach seine.

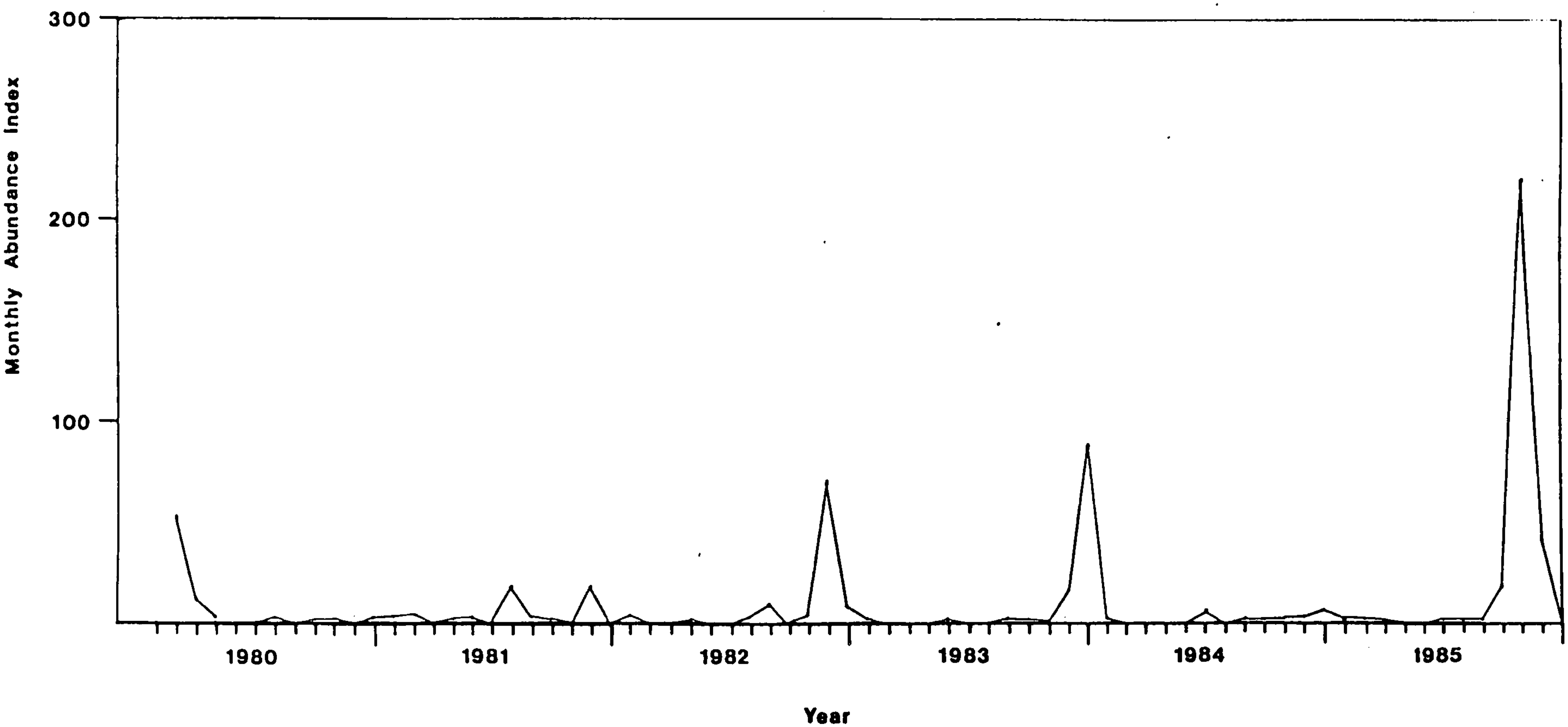
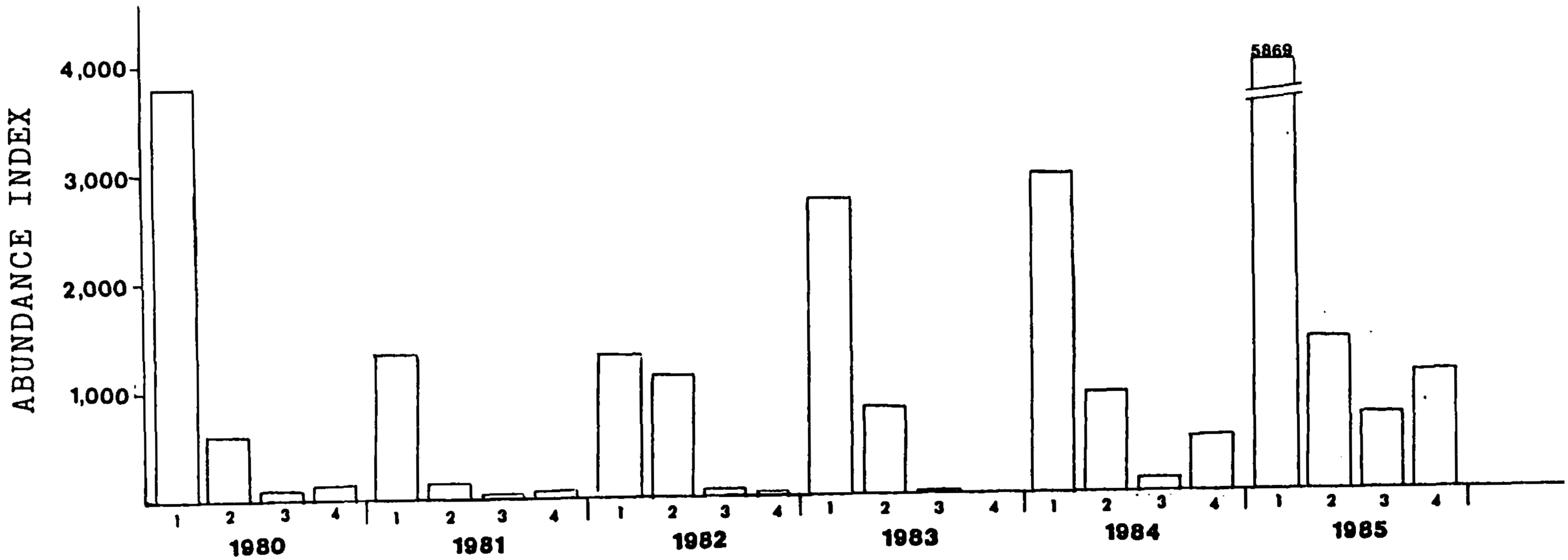


Figure 110. Monthly abundance indices for adult topsmelt caught in the midwater trawl.



1 - SOUTH BAY 2 - CENTRAL BAY 3 - SAN PABLO BAY 4 - UPPER BAYS

Figure 111. Annual abundance indices for YOY topsmelt collected in the beach seine.

South Bay, but up to and including Carquinez Strait. By January the majority of adults are back in South Bay. Adults are generally absent in February, but reappear in March.

Adults and young-of-year were always most abundant in South Bay, followed by Central Bay. Adults were also more abundant in Carquinez Strait than in San Pablo Bay in all years but 1982 and 1983, when none were found in Carquinez Strait.

Larval Abundance and Distribution

Larval topsmelt first appeared in the egg and larvae samples from May to August, with the greatest numbers in June and July (Figure 112). They were absent from our samples the rest of the year. Larvae were generally most abundant and most widely distributed in South Bay, but were common in Central Bay and to a lesser extent in San Pablo Bay. The relatively short period in which larvae are caught indicates a short spawning season.

Larvae were most abundant in South Bay in all years except 1984, when they were slightly more abundant in Central Bay (Figure 113). In 1982 larvae were found only in South Bay, but in 1983, another wet year, they were also found in Central Bay and in San Pablo Bay. Of the three drier years, larvae were found in San Pablo Bay only in 1981; they were not caught there in 1984 or 1985, the other dry years, even though Central Bay abundance was greatest in those two years.

Young-of-Year Abundance and Distribution

Young-of-year topsmelt began showing up in the seine catches about May; they quickly peaked in July and generally were abundant through October and into November (Figure 114). There was often a second, smaller peak in February or March, indicating an extended spawning season.

Young-of-year began showing up in upper South Bay and lower Central Bay about May or June. By July they were abundant throughout the South Bay and lower Central Bay, and were present in San Pablo Bay and Carquinez Strait. This distribution, which is stair-stepped from South Bay (highest) to upper San Pablo Bay (lowest), retains the same form through November (Figure 115). By December, young-of-year are found primarily in South Bay and lower Central Bay, where they remain through the spring.

No young-of-year topsmelt were caught above Carquinez Strait, possibly because of the lack of seine sites within Suisun Bay. The midwater trawls, used in Suisun Bay, are relatively inefficient for topsmelt since they do not sample the shallower, nearshore areas.

Young-of-year topsmelt were always most abundant in South Bay, followed by Central Bay (Figure 115). They were more abundant in Carquinez Strait than in San Pablo Bay in all years except 1982 and 1983, the two wettest years. No young-of-year individuals were found in Carquinez Strait in 1983. In 1984 and 1985, abundances were elevated in San Pablo Bay and Carquinez Strait.

Effects of Delta Outflow

Annual abundance indices were derived from catches from May of one year to April of the following year (i.e., 1983's index is based on catches from May 1983 through April 1984). This period best approximates the first year of topsmelt life. Indices based on this period may be low for 1980 (May-July are missing) and high for 1985 (January-April 1986 are missing).

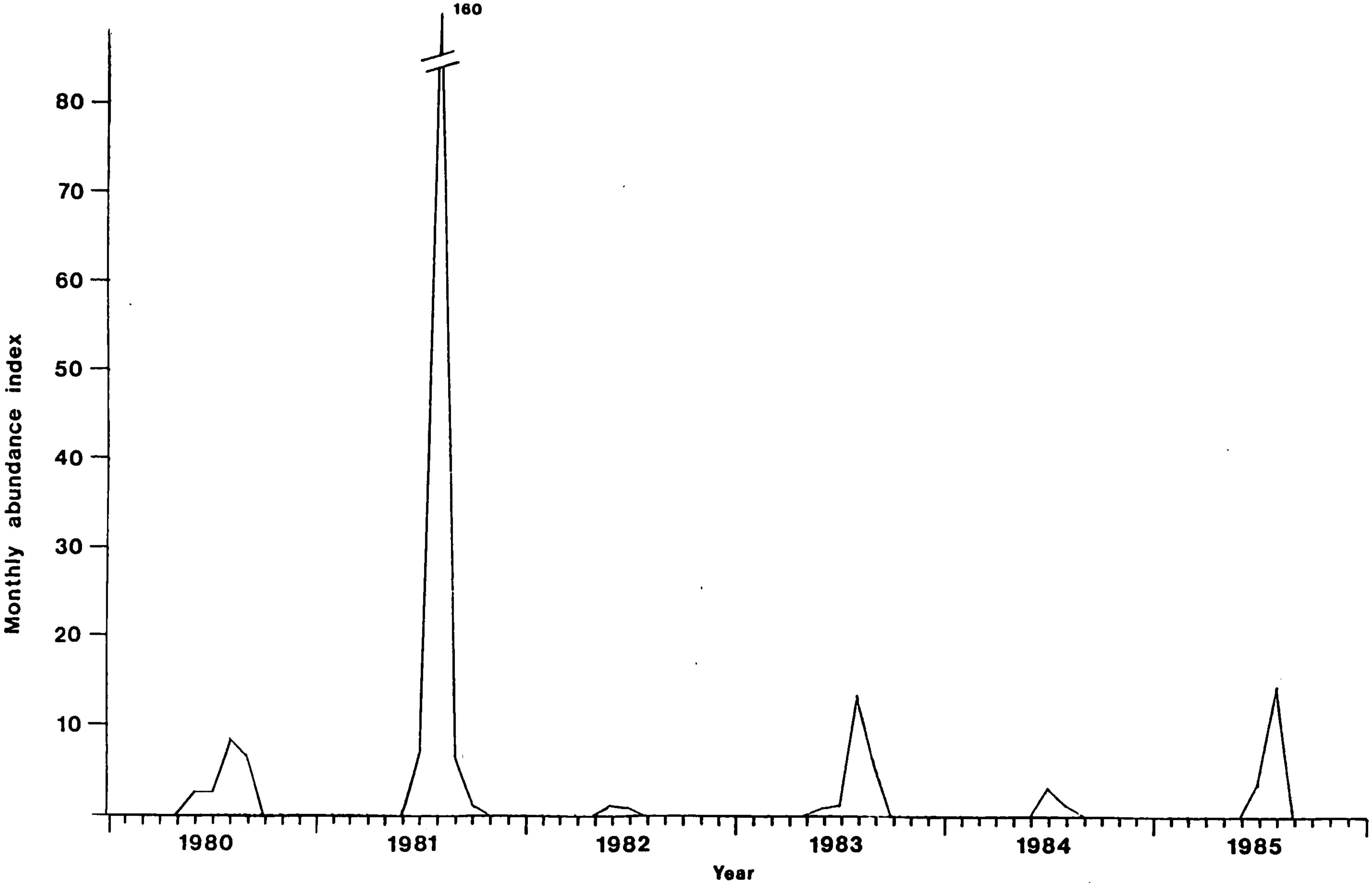


Figure 112. Monthly abundance indices for larval topsmelt.

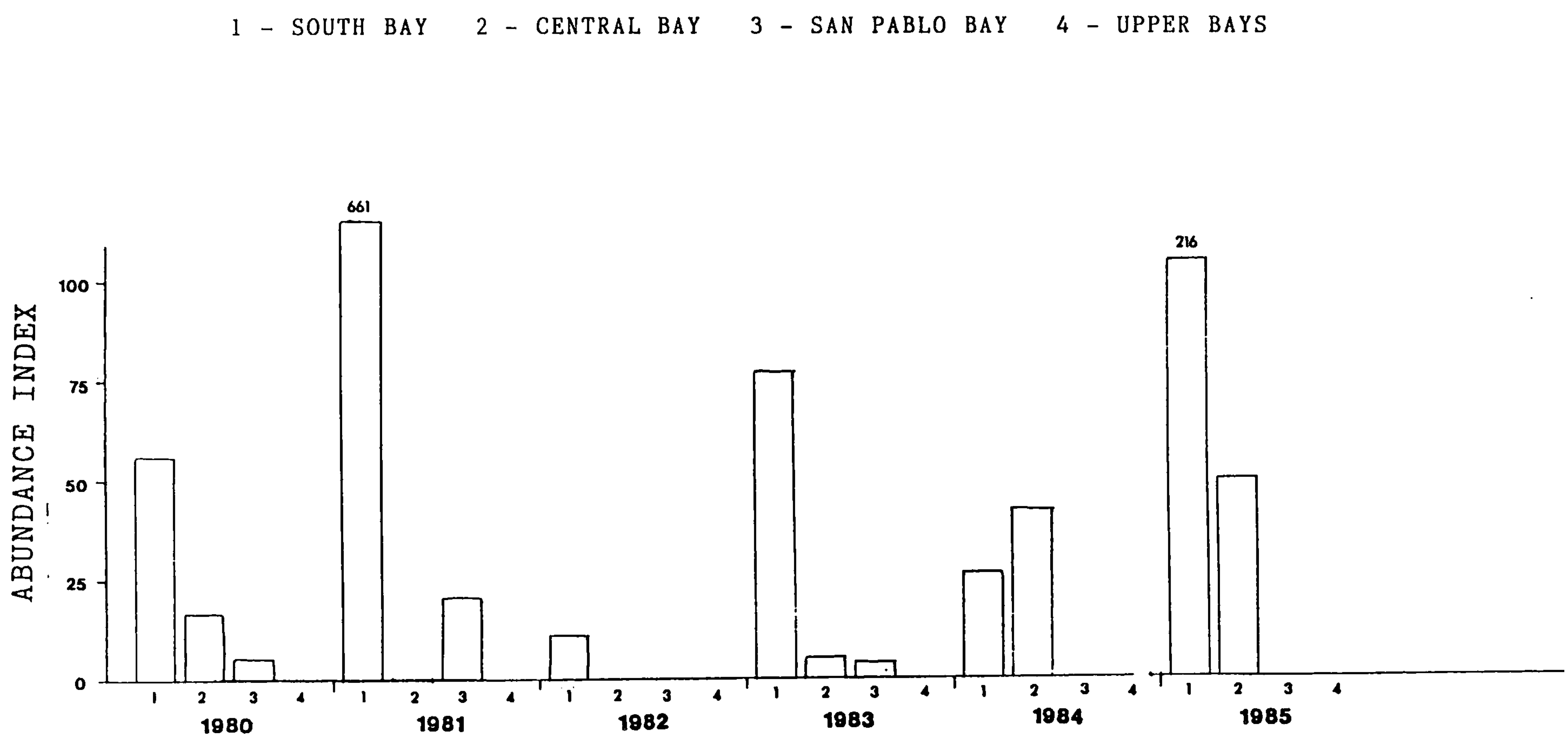


Figure 113. Annual abundance indices for larval topsmelt, by embayment.

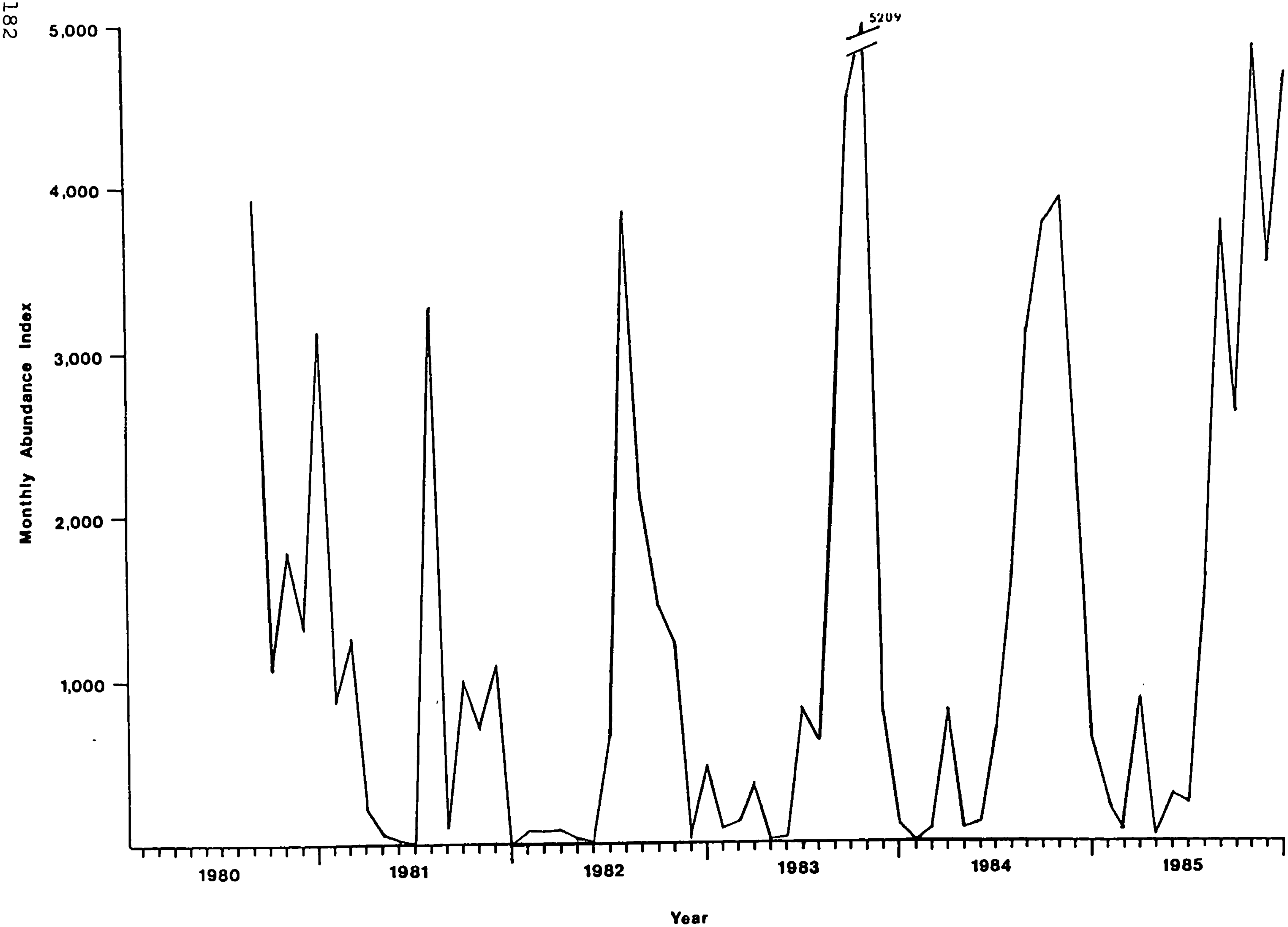


Figure 114. Monthly abundance index for YOY topsmelt caught in the beach seine, 1980-1985.

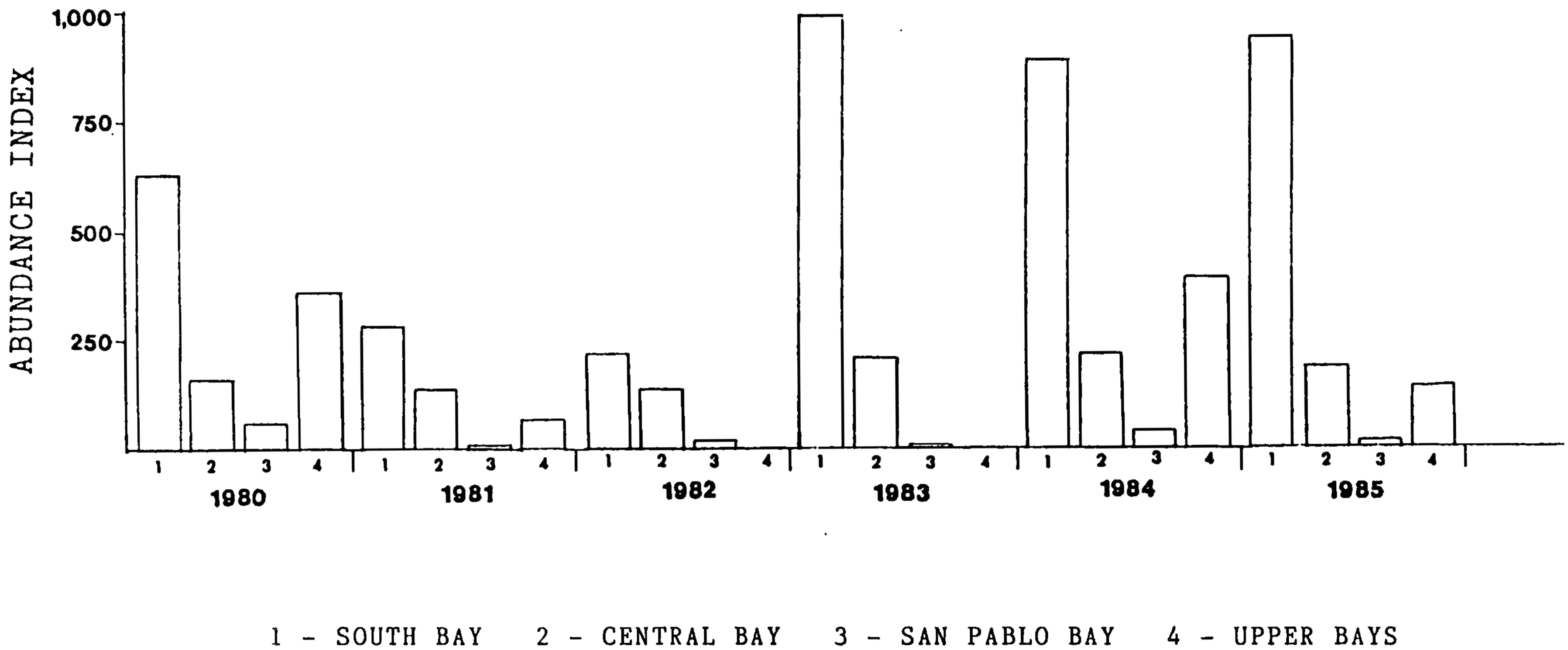


Figure 115. Annual abundance indices for adult topsmelt collected in the beach seine.

Topsmelt are residents of South Bay, so South Bay always had the highest annual abundance index, followed by Central Bay. Annual abundance indices were calculated for each life stage by embayment, and then correlated with various defined periods of outflow (annual, seasonal, monthly, and weekly) (Table 18). None of the correlations was significant, but a few observed trends may show some possible effects of outflow on topsmelt distribution.

Adults. Annual adult abundance indices show negative correlations with annual outflow (May-April) in all four embayments. The best correlation occurs in Carquinez Strait (r=-0.87, n=5), where no adults were found during the wet years 1982 and 1983, but none of these correlations are significant.

Annual systemwide abundance also does not show any significant associations with flow, although most are negative. For example, the 1983 abundance index of 173 is closer to the 1984 index of 179 than it is to the 1982 index of 47. In general, high flows prevent adults from using Carquinez Strait but do not affect their overall abundance.

Larvae. Correlations of annual larval abundance, by bay, with outflow show negative relationships for all bays, but there are some inconsistencies. In 1984 and 1985, no larvae were found in San Pablo Bay even though they were quite abundant in Central Bay. In 1983, larvae were fairly abundant in San Pablo Bay, when they would not have been expected to be there. In essence, flow is not a reliable predictor of distribution or abundance of larvae.

Young-of-Year. The results of correlations between YOY abundance and flow are similar to the results obtained for adults, except that young-of-year showed a positive relationship to flow in Central Bay. This is most likely due to a flushing effect that pushes young-of-year into Central Bay from San Pablo Bay and Carquinez Strait.

South Bay abundances for 1981 (1483) and 1982 (1459) are very similar, as were those for 1983 (3296) and 1984 (3254). Average monthly flow for May 1982 to April 1983 is twice that for 1981-1982 (78,500 to 38,700), and the difference is even greater when 1983 and 1984 are compared (64,400 and 14,200, respectively). It seems reasonable that if flow affected topsmelt abundance to any appreciable degree, these pairs of years would not have such similar abundance indices.

Table 18

CORRELATION COEFFICIENTS FOR ANNUAL ABUNDANCE OF TOPSMELT AND ANNUAL OUTFLOW (MAY-APRIL)

Life Stage	Total Study Area	South Bay	Central Bay	San Pablo Bay	Carquinez Strait Area
Larvae	-0.48	-0.43	-0.57	-0.73*	-
Young-of-Year**		-0.60	+0.30	-0.71	-0.79
Adult**		-0.37	-0.07	-0.58	-0.87
Midwater Trawl		-0.32	-0.43	-0.05	-

* n=3.
** From Seine, n=5.

Chapter 8. SCULPINS (COTTIDAE)

Cottidae is a diverse family of primarily small, inshore marine fish species. Miller and Lea (1972) listed 42 species of cottids reported along the California coast. In addition to the marine species, eight cottid species inhabit the fresh, inland waters of California (Moyle, 1976). The only euryhaline species among the California cottids is the Pacific staghorn sculpin. Most cottid species are highly adapted for bottom dwelling, having (among other characteristics) a flattened head and no swim bladder.

During this study, nine sculpin species were collected in the Bay (Table 19). Seven of the nine were marine species, all of which occurred in very small numbers in all gear types. Prickly sculpin, a freshwater form, was caught in greatest numbers as larvae, which probably washed into the bay from surrounding tributary streams. The most abundant juvenile and adult sculpin is the Pacific staghorn sculpin, the only species discussed in detail in this report.

Table 19

CATCH AND PERCENT OF ALL FISH CAUGHT IN EACH GEAR TYPE OF SCULPIN SPECIES, 1980 THROUGH 1985
AN * INDICATES A PERCENTAGE ROUNDING TO LESS THAN 0.01

	Gear							
	Otter Trawl		Midwater Trawl		Beach Seine		E&L	
	Number	Percent	Number	Percent	Number	Percent	Number	Percent
Boneyhead Sculpin	20	0.01	1	*	1	*	33	*
Brown Irish Lord	3	*	0	0.00	0	0.00	9	*
Cabezon	0	0.00	0	0.00	2	*	97	0.01
Fluffy sculpin	0	0.00	0	0.00	1	*	0	0.00
Prickly sculipn	4	0.03	1	*	1	*	8,041	1.04
Red Irish lord	1	*	0	0.00	0	0.00	0	0.00
Scaleyhead sculpin	1	8	0	0.00	0	0.00	0	0.00
Pacific staghorn	5,329	4.04	166	0.03	4,553	3.63	3,206	0.42
Tidepool sculpin	0	0.00	0	0.00	0	0.00	3	*
Total	5,858		168		4,558		11,389	
Percent of all fish		4.06		0.03		3.63		1.48

The overall range of Pacific staghorn sculpin consists of the coastal marine waters, estuaries, and the lower reaches of coastal rivers from Kodiak Island, Alaska, south to San Quintin Bay, Baja California (Wang, 1986; Miller and Lea, 1972). Throughout most of its range, it is one of the most numerous fish species in coastal embayments and estuaries (Jones, 1962; Tasto, 1975; Pearcy and Myers, 1974). In this study Pacific staghorn sculpin were found in all parts of the Bay at one lifestage or another. They were the seventh most abundant fish species in the otter trawl samples, making up over 4 percent of the overall catch for the 6 years of collections (Table 19).

For a species with little direct sport or commercial value, the life history of the Pacific staghorn sculpin has been relatively well documented (Jones, 1962; Boothe, 1967; Tasto, 1975). They are generally reported as being euryhaline, but individual lifestages have restricted salinity tolerances. Maturing and adult sculpin are found primarily in high salinity waters, spawning in fall and winter. Demersal eggs hatch most successfully at salinities of about 26 ppt (Jones, 1962), and the larvae survive best at salinities of about 10-17 ppt. Young juveniles apparently seek shallow water and are concentrated in the upper parts of estuaries and even tributary streams. During their first year, they become less tolerant of low salinity and shallow water and move into coastal water and higher salinity portions of estuaries.

The trophic position of the staghorn sculpin is as a demersal predator. They are opportunistic feeders on a wide variety of shrimp, crabs, small fish, and other animals living on or just above the bottom (Jones, 1962; Boothe, 1967; Kinnetic Laboratories, 1985). It is not clear how staghorn sculpin are utilized by other organisms. Tasto (1975) found no evidence that they were heavily preyed upon by other fish, but suggested that they may be an important food for aquatic birds. There is no significant commercial or sport fishery for staghorn sculpin, but they are used as bait.

Gear Effectiveness and Effort Correction

Juvenile and adult staghorn sculpins are demersal and are rarely caught in the midwater trawl (Table 19), which samples primarily in the upper portions of the water column. Therefore, analysis of juvenile and adult abundance and distribution is limited to data from the beach seine and otter trawl, where juveniles made up about 4 percent and 3.6 percent of the overall catch. Both the yolk-sac and post-larval forms of staghorn sculpin were abundant in the egg and larval net but juvenile forms were absent.

Beach seine and otter trawl catches were corrected to reflect the area swept by the net during each haul or tow. These CPUE values were used to represent the density of organisms at each station. CPUE values were weighted according to the total area represented by each station. These weighted CPUE values were used in calculating indices for comparison of seasonal and annual abundance. The larval fish catches were treated similarly, except that effort correction was based on the volume of water filtered during each tow. These volume-corrected CPUE values were used to represent the density of organisms at each station.

Larval Distribution and Abundance

During the study, yolk-sac and post-larval forms of Pacific staghorn sculpin were caught in every month but July, August, and September (Table 20). The primary period of abundance in all

Table 20

MEAN CPUE OF LARVAL PACIFIC STAGHORN SCULPIN BY MONTH, 1980-1986. ALL STATIONS WERE AVERAGED IN CALCULATING MEAN CPUE VALUES (catch per 10,000M^3)

	Year						
Month	1980	1981	1982	1983	1984	1985	All Years
January		307	45	86	53	459	190
February	133	167	273	87	156	485	218
March	54	89	65	10	32	260	85
April	22	16	23	2	4	47	19
May	6	0	0	0	0	0	1
June	0	1	0	0	0	0	0
July	0	0	0	0	0	0	0
August	0	0	0	0	0	0	0
September	0	0	0	0	0	0	0
October	0	2	29	0	0	0	5
November	2	3	3	1	23	1	6
December	44	12	34	7	86	71	42
All Months	24	50	39	16	30	110	45

years was from December through March, with the peak in February during 4 of the 5 seasons for which data are complete. Our observations on presence of larvae agree closely with Jones' (1962) observations on the timing of San Francisco Bay spawning, which he based on ovarian condition in females caught in the shrimp fishery just south of Treasure Island.

Whereas the timing of larval presence was quite consistent from year to year, their spatial distribution and general abundance was not. The general location of peak abundance varied from upper San Pablo Bay in 1981 to mid-South Bay in 1985 (Figure 116). At no time during this study were larval staghorn sculpin abundant upstream of Carquinez Strait. Most widespread distribution and greatest abundance was during the two years of lowest Delta outflow, 1981 and 1985. Conversely, in the year of highest outflow, 1983, abundance was lowest and distribution most restricted.

Young-of-Year Distribution and Abundance

Pacific staghorn sculpin mature toward the end of their first year, so we have defined juvenile fish as those less than 1 year, assuming a January 1 hatch. Because no specific age and growth studies were conducted, age

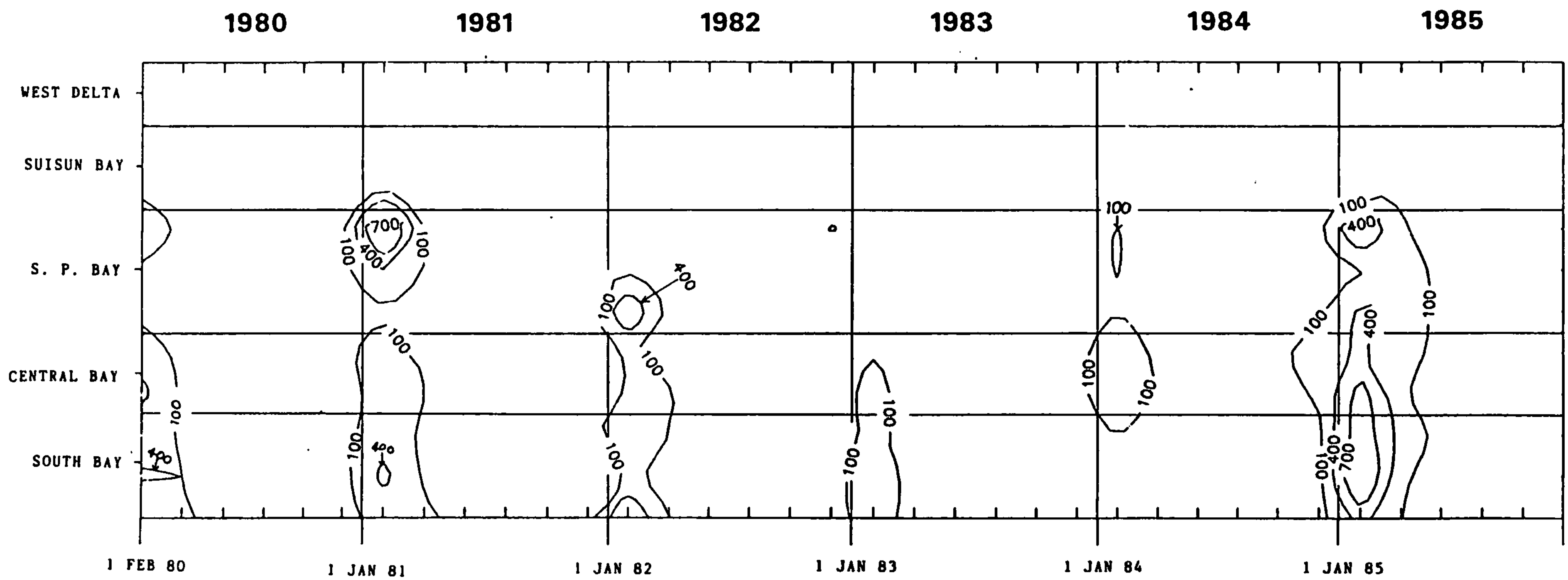


Figure 116. Distribution of larval Pacific staghorn sculpin, 1980 through 1985. Relative abundance is represented by three contours corresponding to sample densities of 100, 400, and 700 larvae per 10000 m^3. Data has been smoothed using the Inverse Distance Weighting technique described by Ripley (1975).

class assignments were made based on examination of length frequency data and review of growth studies by others (Jones 1962). For each month, a cut-off length was established that best separated fish less than 1 year old from older fish. Our data and that of Jones (1962) show a considerable overlap in the length distribution of 0+ and 1+ fish (particularly in summer and fall), which leads to some misassignment of individual fish to age groups. Cut-off lengths used to determine the proportion of overall CPUE for each tow attributable to each age group are:

Month	Length
January	90
February	90
March	105
April	115
May	130
June	140
July	140
August	145
September	145
October	150
November	155
December	155

YOY Pacific staghorn sculpin were numerous in the beach seine samples even before the larval season was complete (Figure 117). The highest sample densities of juveniles were in the seine samples, on the average, in March, one month after the usual peak of larval abundance. Catches in the seine gradually decreased through spring, while catches by the otter trawl at shallow water stations gradually increased and peaked in June. While otter trawl catches at shallow stations were decreasing through the summer, catches at deep-water stations were increasing until September and October, when highest fish densities were in the deep channels of the bay. The pattern of catches suggests that small juveniles just past the larval stage migrate inshore, then gradually migrate to deeper water as they grow through their first year.

Figure 118 illustrates the general distribution of small YOY staghorn sculpin caught in the seine during the March, April, and May surveys. During the five years for which data are complete, abundance and distribution varied considerably. Peak abundances for the March-May period were always downstream of Carquinez Strait, and occurred in San Pablo Bay, Central Bay, or South Bay in at least one of the years of study. Peak abundances occurred in South Bay in 1983 and 1985, Central Bay in 1982 and 1984, and San Pablo Bay in 1980. Overall highest abundance was in 1982, 1984, and 1985. Neither the spatial nor temporal pattern of abundance illustrated in Figure 118 suggests any consistent response to the magnitude of Delta outflow.

Spatial and temporal patterns of abundance of YOY staghorn sculpin caught in the otter trawl were, for the most part, consistent with those caught in the seine (Figure 119). Otter trawl catches generally peaked in late summer, abundances were relatively high in 1982, 1984, and 1985 and relatively low in 1981 and 1983, with the March-May seine catches. Early spring seine catches and late summer otter trawl catches were highly correlated ($r=0.94$; $p<0.05$).

In a broad sense the distribution of juvenile staghorn sculpin caught in late summer in the otter trawl is similar to those caught in the seine in march, April, and May; that is, they occur primarily below Carquinez Strait, and they are farther downstream in years when peaks in seine abundance are downstream, and farther upstream when peaks in seine abundance are upstream. However, there is a general upstream shift each year from the point at which seine abundances were highest.

Adult Distribution and Abundance

Figure 120 shows the mean otter trawl CPUE of adult Pacific staghorn sculpin

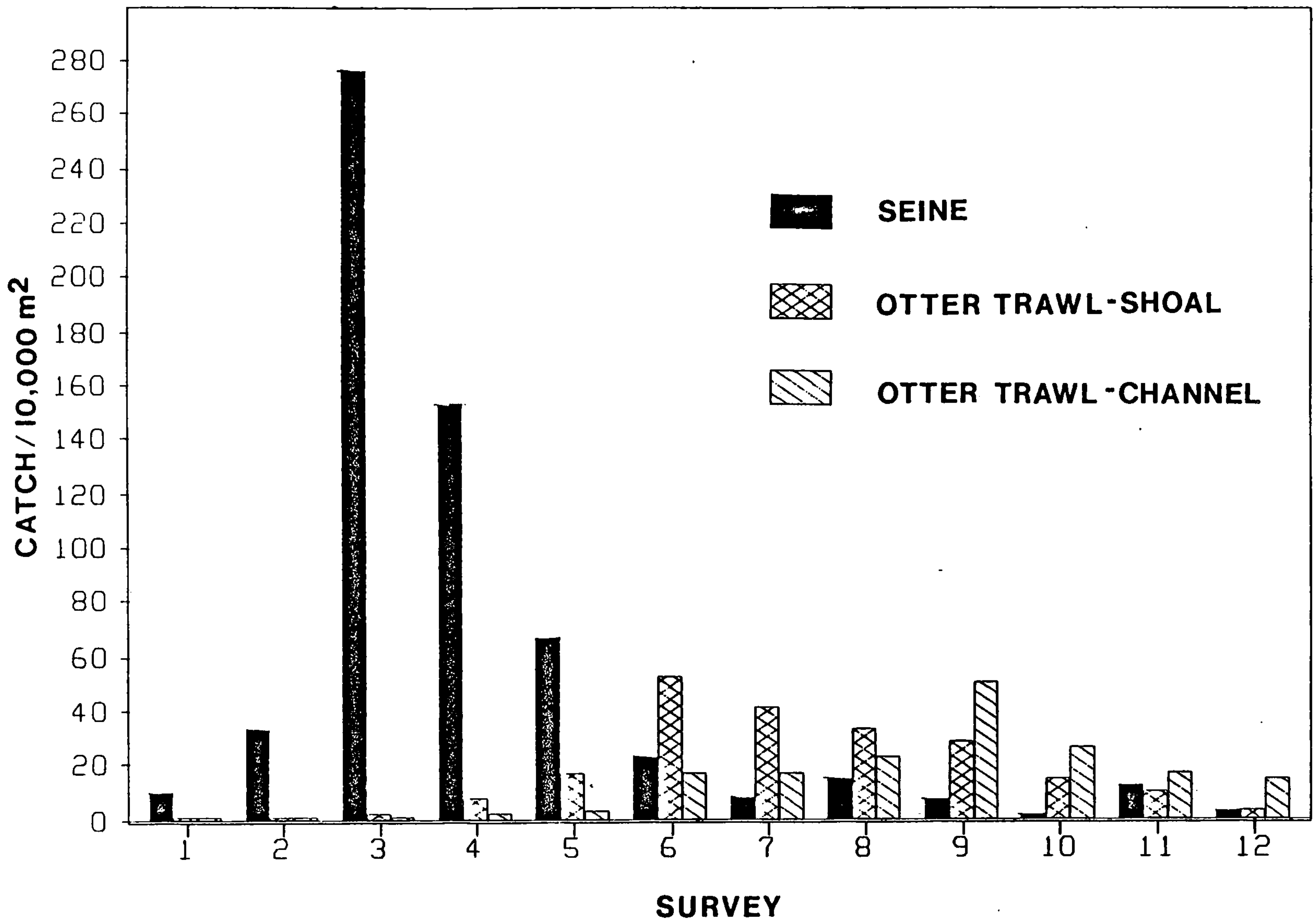


Figure 117. Seasonal abundance of YOY Pacific staghorn sculpin in the seine and otter trawl.

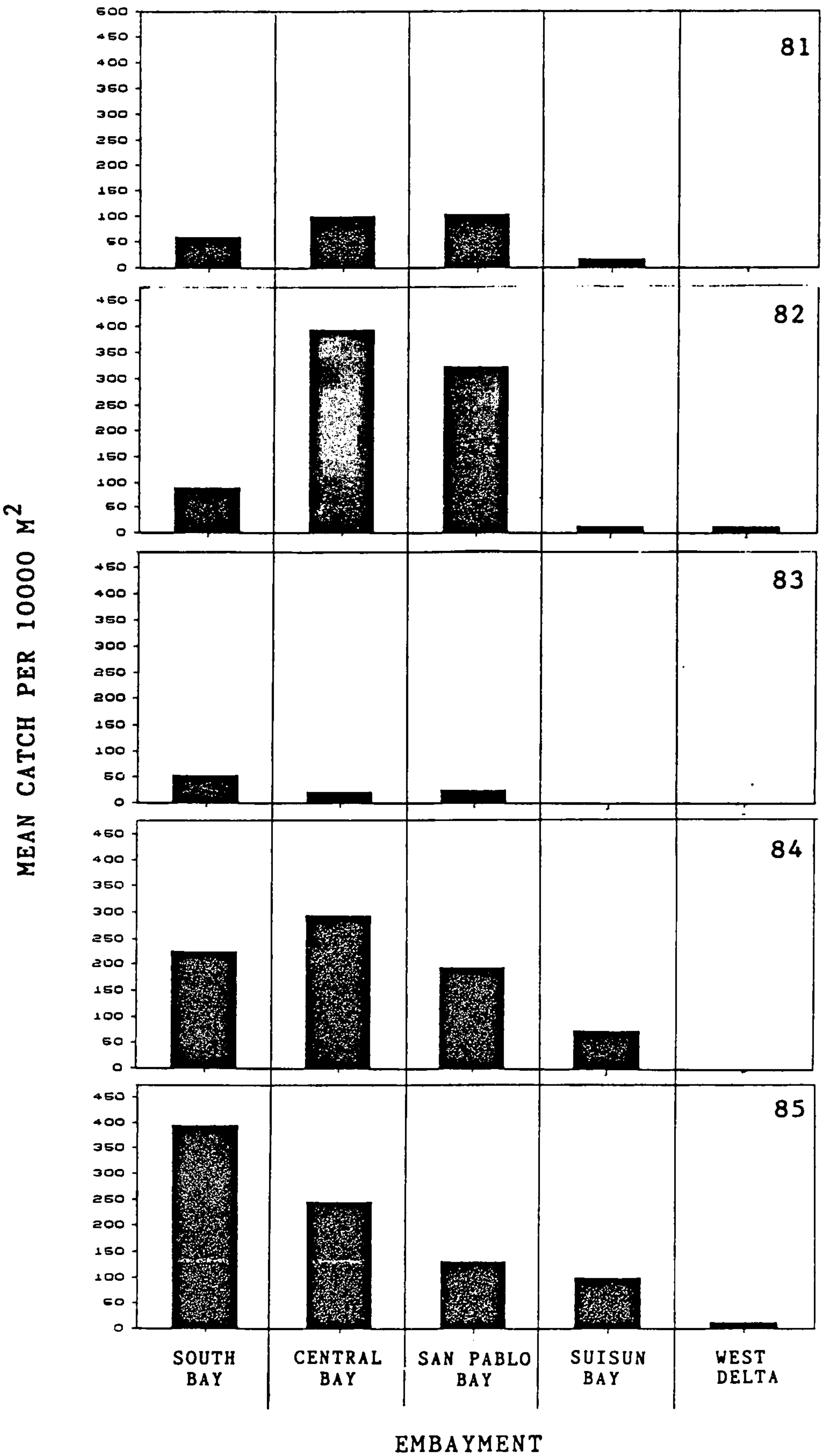


Figure 118. Distribution of YOY Pacific staghorn sculpin during March through May, 1981 through 1985.

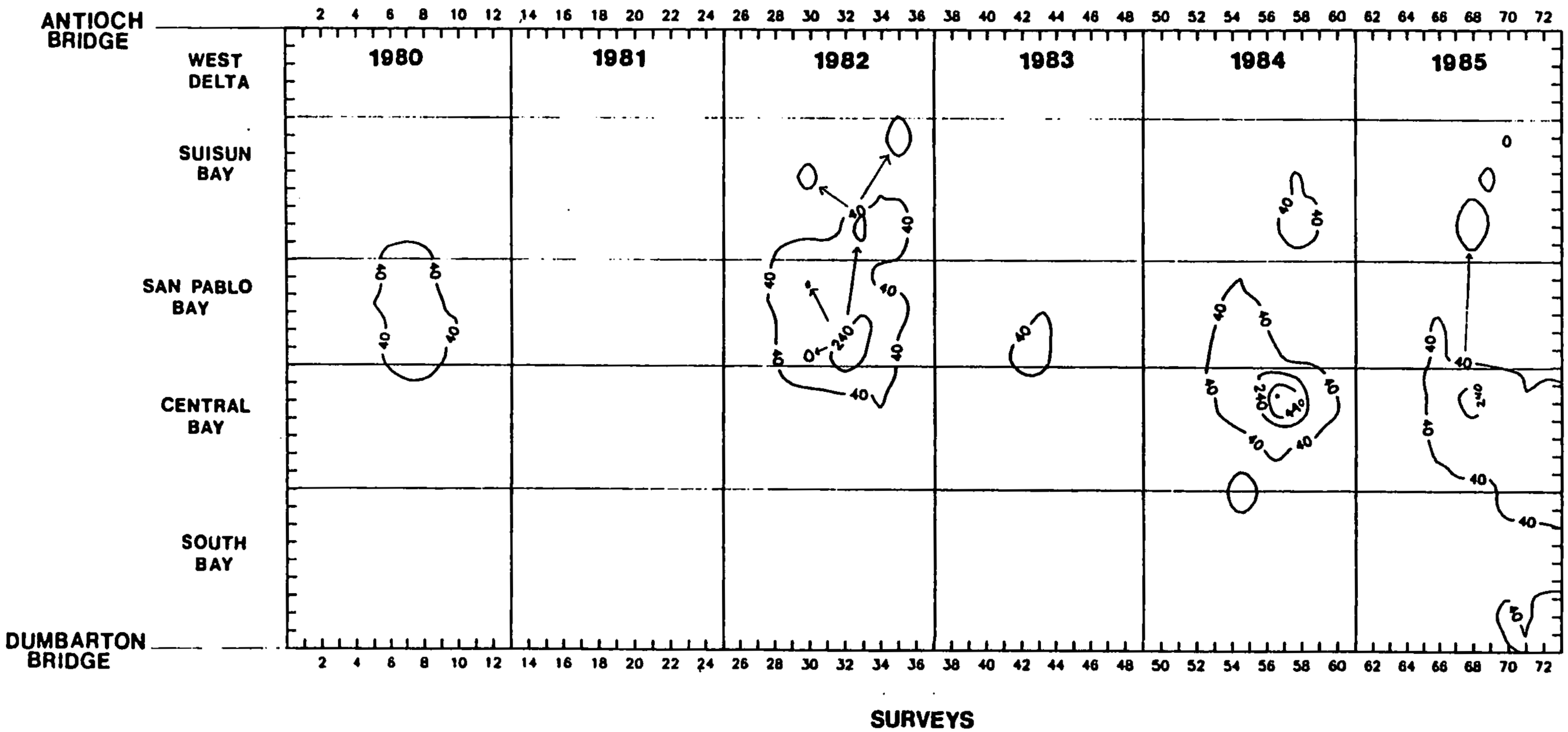


Figure 119. Spatial and temporal distribution of YOY Pacific staghorn sculpin. Abundance is represented by catch contours of 40, 240, 440, and 640 fish per 10000 m^2 swept by the otter trawl. Data has been smoothed before plotting using the Inverse Distance Weighting technique (ripley 1975).

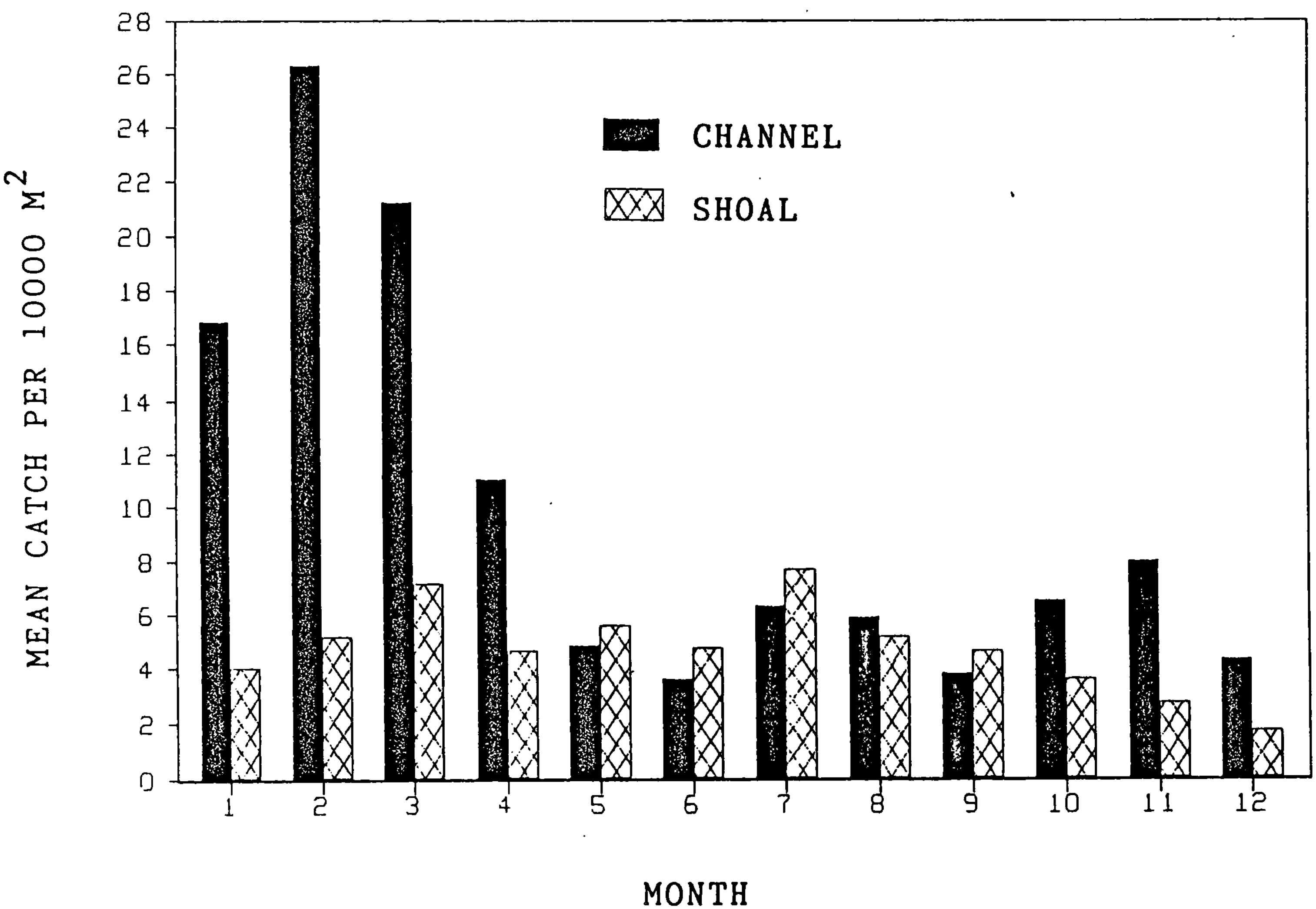


Figure 120. Seasonal distribution of adult Pacific staghorn sculpin based on otter trawl collections. All years are included.

by month. On the average, the abundance of adult staghorn peaks in midwinter, drops sharply through early spring, then fluctuates mildly through the end of the year. We do not know whether the decline through late spring is due to change in gear efficiency, migration out of the system, or mortality. However, since this pattern of abundance is roughly the inverse of that observed in the Gulf of the Farallones, migration from the Bay to the Gulf seems to offer the best explanation (City of San Francisco, unpublished data).

Figure 120 also illustrates a seasonal pattern of occupation of channel and shoal areas by adult staghorn sculpin. During winter (October through April) the fish are more abundant in channels than in shoal areas, but they appear to slightly favor the shoals during late spring and summer.

Adult Pacific staghorn sculpin were generally confined to Central Bay and San Pablo Bay (Figure 121), although they were common at one time or another in portions of all embayments but the West Delta. Substantial differences in distribution of fish from year to year appear to be related to the magnitude of Delta outflow. Staghorn sculpins were most widely distributed in the winter and spring of 1980 and 1983 and generally less widely distributed in the drier periods.

Periods of highest abundance were the winter and spring of 1980, 1982, and 1983, all of which were periods of high outflow.

Effects of Salinity

Salinity preferences or tolerances seem to play a role in determining distribution of larval Pacific staghorn sculpin in the estuary (Figure 116). The work of Jones (1962) seemed to demonstrate that successful spawning occurred only in highly saline waters and that larvae survived best in salinities of 10-17 ppt. Surface salinities where larval sculpins were captured during this study covered the full range of those available in the estuary (Figure 122). On the average, greatest catches were at points with surface salinities of 18-30 ppt. It is not certain whether this represents a divergence from Jones' (1962) results, because we do not know where in the water column our larvae were collected or how well the larvae taken from different salinity levels survived to the juvenile stage.

Previous studies (Tasto, 1975; Jones, 1962) have shown that juvenile staghorn sculpin can occupy a full range of salinities, and our work would appear to confirm the euryhaline nature of this life stage (Figure 123). Examined seasonally, juvenile sculpins appeared to have no consistent preference for any particular range of salinity.

Our sampling also suggests that adult staghorn sculpin will inhabit a wide range of salinities. They were found in virtually the full range of Bay salinities and showed no consistent preference within any season (Figure 124).

Effects of Delta Outflow

Figure 116 indicates that in years when there are relatively high Delta outflows during staghorn sculpin peak larval abundance (winters of 1982, 1983, and 1984) abundances were lower and distribution more confined than in years of low Delta outflow. We further examined this apparent association of outflow and larval abundance by correlating the abundance of larvae during the month of peak abundance each year with estimated mean Delta outflow in the previous month. Although the two variables appeared to be negatively correlated ($r=-0.67$), the association was not significant ($n=5$, d.f.=3).

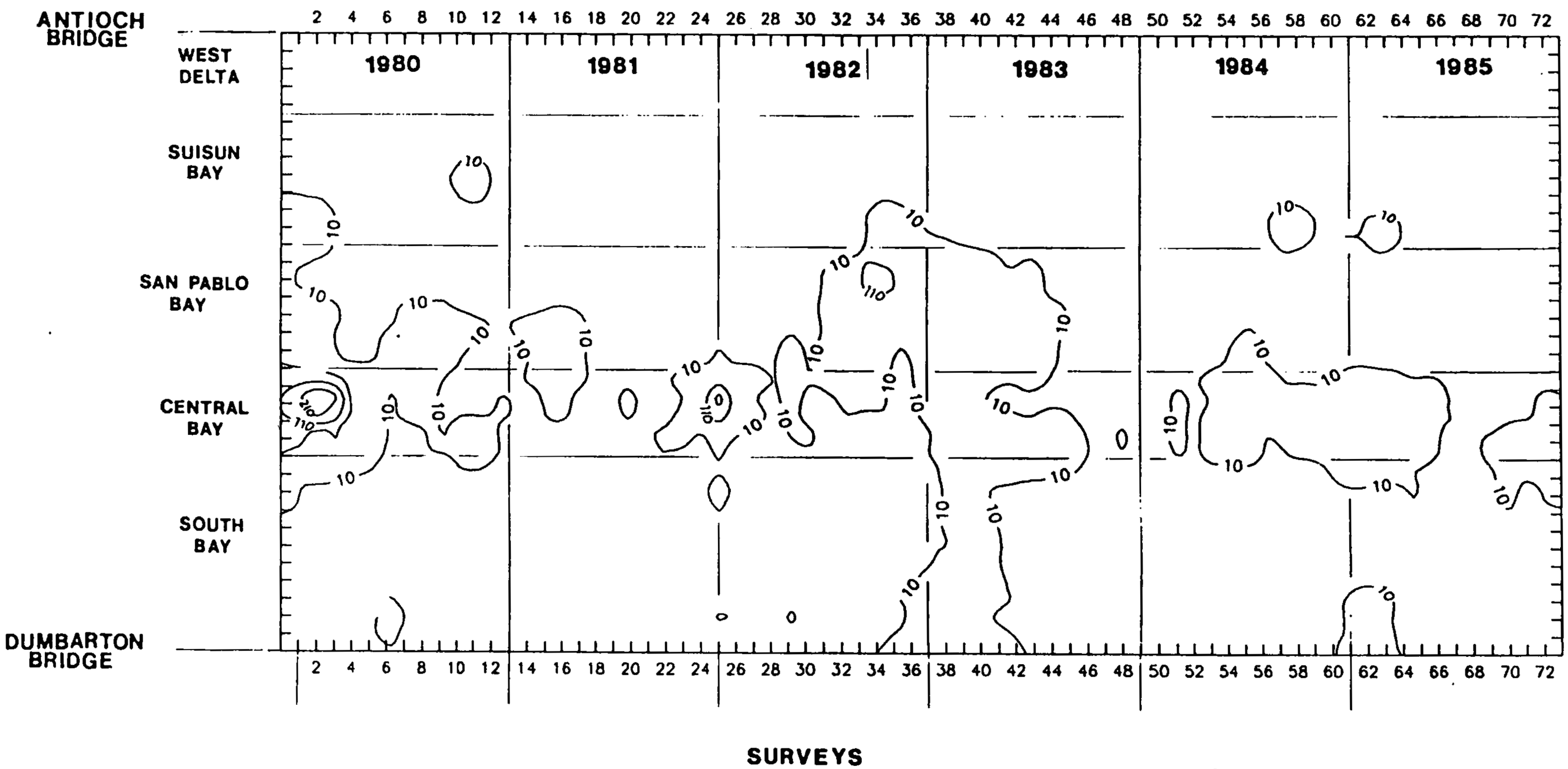


Figure 121. Spatial and temporal distribution of adult Pacific staghorn sculpin. Abundance is represented by catch contours of 10, 110, 210, and 310 fish per 10000 m^2 swept by the otter trawl. Data has been smoothed before plotting using the Inverse Distance Weighting technique described by Ripley (1975).

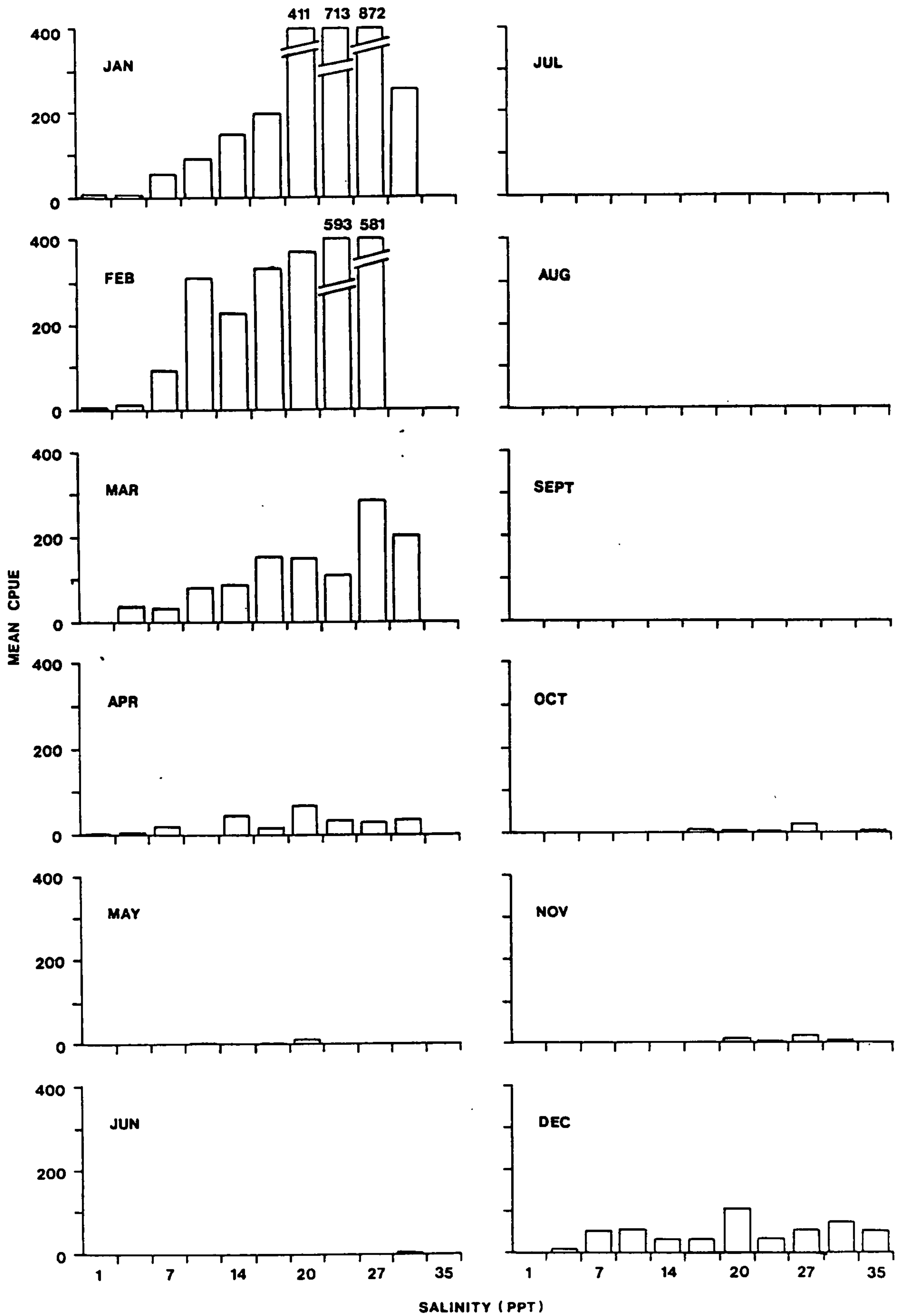


Figure 122. Mean CPUE of larval Pacific staghorn sculpin vs. surface salinity by month. All years are included.

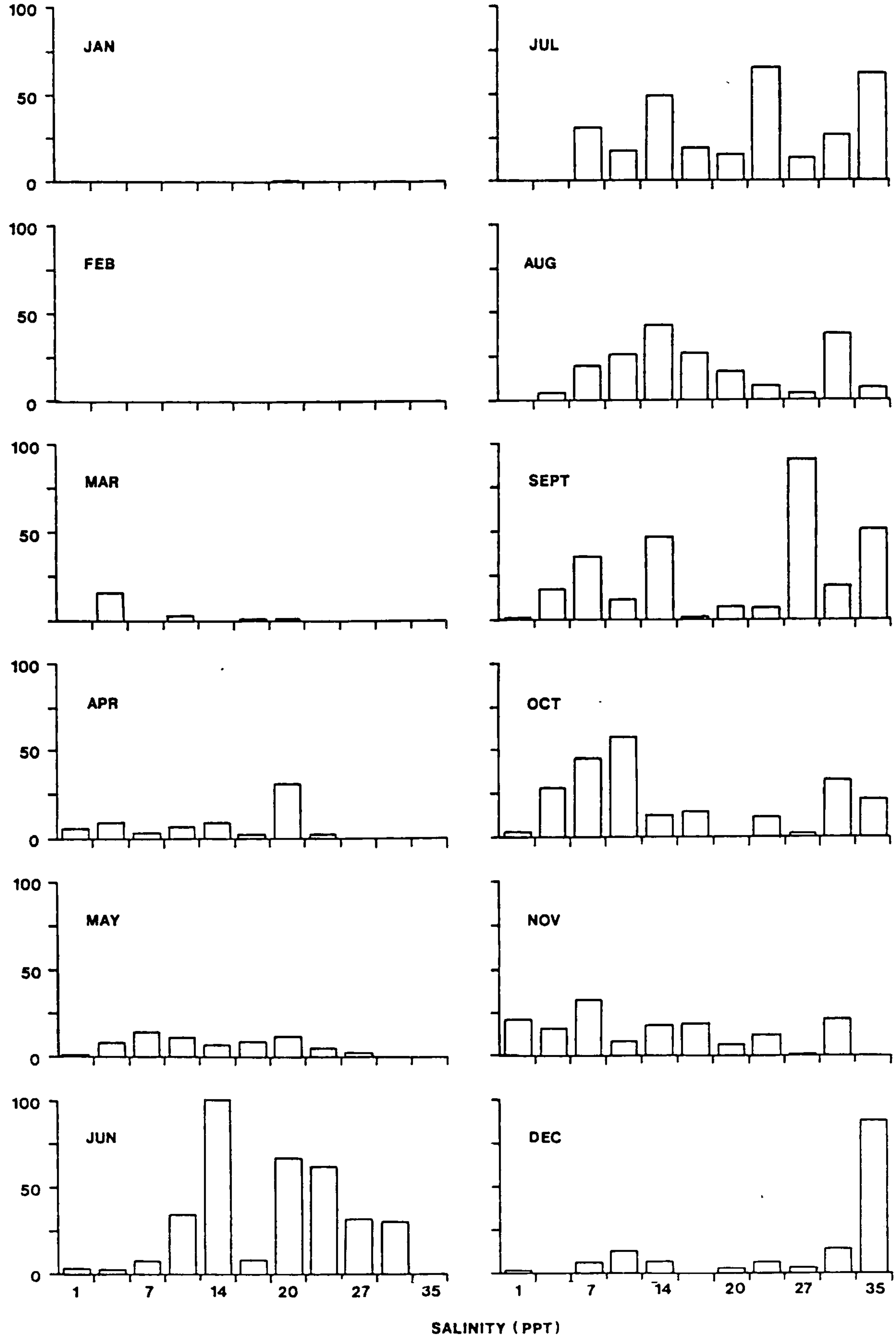


Figure 123. Mean CPUE of YOY Pacific staghorn sculpin vs. bottom salinity by month, 1981 through 1985.

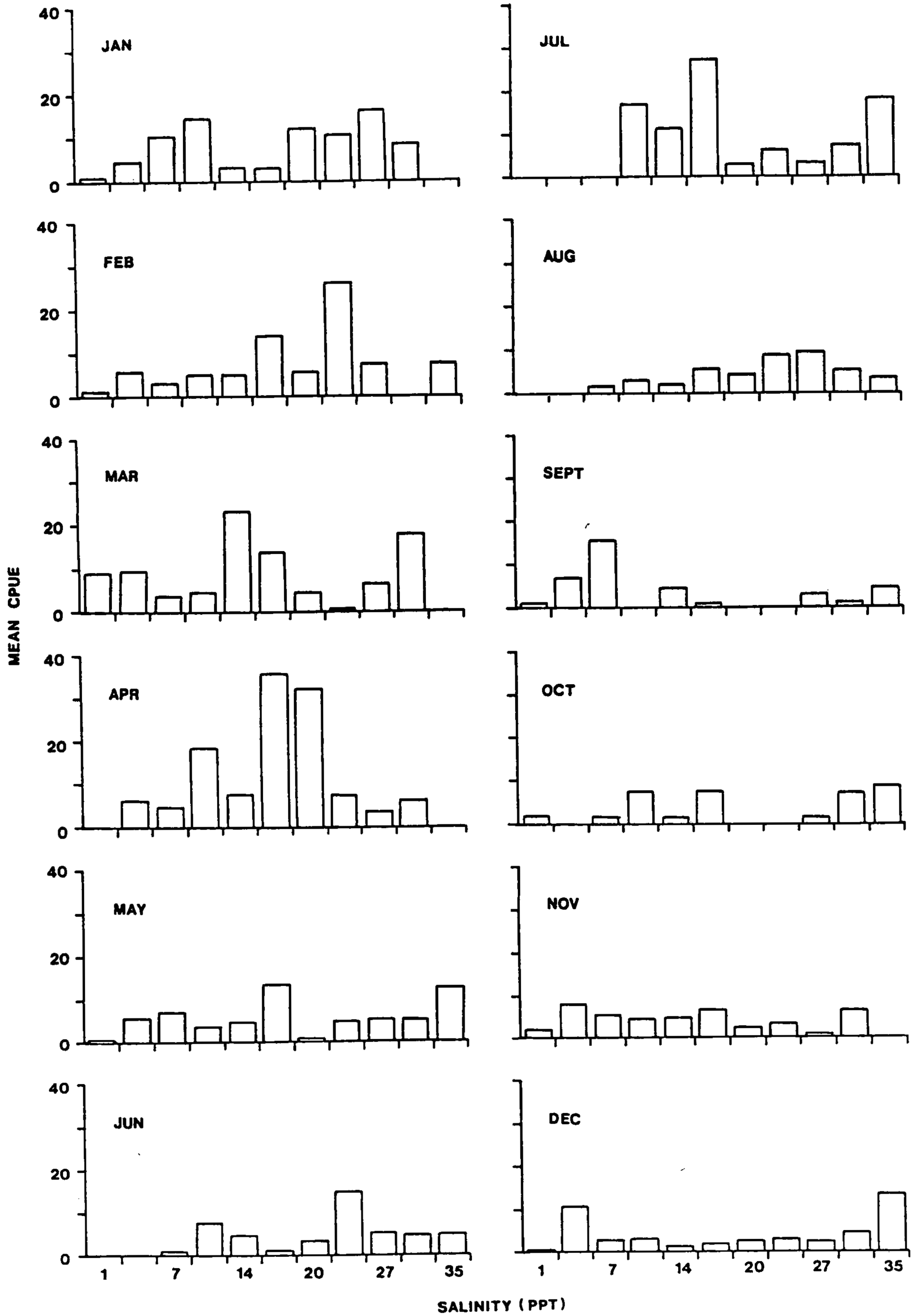


Figure 124. Mean CPUE of adult Pacific staghorn sculpin vs. bottom salinity by month, 1981 through 1985.

Abundance and distribution of YOY Pacific staghorn sculpin did not respond consistently to the magnitude of Delta outflow (Figures 118 and 119). This inconsistency was also evident from a series of correlations to compare mean monthly Delta outflow with abundance of YOY sculpin (Table 21). None of the correlations was statistically significant, but a negative association between spring and summer outflow and spring and summer abundance was suggested.

Adult Pacific staghorn sculpin appeared to respond positively to high Delta outflow in the sense that during most of these periods they had a wider distribution within the estuary (Figure 121). Correlations between abundance and mean monthly outflow (Table 21), also seemed to show a positive association. The strongest associations were between winter and early spring flows and abundance in late summer.

Summary

The abundance and distribution of larvae in the estuary appears to be negatively associated with the magnitude of Delta outflow during the 6 years of study. This would be consistent with the fact that it is a pelagic, lower motility, form that survives best in mid- to high salinity waters.

The apparent negative response or non-response of juvenile sculpin to Delta outflow is somewhat surprising given the findings of Jones (1962) from Tomales Bay, where young juveniles were found to congregate in creek mouths. However, as Jones pointed out, low salinity is not essential for juvenile fish survival. Perhaps because of the size of San Francisco Bay, if the sculpin are not present in the bay as larvae, they cannot migrate far enough to establish themselves in the bay as juveniles.

Adults did seem to respond favorably to the magnitude of Delta outflow in the sense that late summer abundance was strongly associated with winter and spring outflow levels. Their abundance in spring, however, was not strongly associated with spring outflow, which is consistent with the fact that this lifestage favors moderate salinities. On the whole, these facts suggest that although high flows may repel adult sculpin during the time the flows occur, the same flows may establish conditions (e.g. food supply or general water quality) later in the year that are more favorable than those following a dry winter and spring.

Table 21

RESULTS OF CORRELATIONS BETWEEN INDICES OF PACIFIC STAGHORN SCULPIN ABUNDANCE AND ESTIMATED MEAN MONTHLY DELTA OUTFLOW

	Abundance Index			
	Juveniles		Adults	
Flow Period	April-June	July-September	April-June	July-September
October-November	0.43	0.71	0.18	0.61
December-January	0.53	0.58	0.10	0.82*
February-March	-0.21	-0.41	0.80	0.81*
April-May		-0.27		0.62
June-July		-0.37		0.78

* $p<0.05$.

Abundance and distribution of YOY Pacific staghorn sculpin did not respond consistently to the magnitude of Delta outflow (Figures 118 and 119). This inconsistency was also evident from a series of correlations to compare mean monthly Delta outflow with abundance of YOY sculpin (Table 21). None of the correlations was statistically significant, but a negative association between spring and summer outflow and spring and summer abundance was suggested.

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Adults migrate to more saline water in fall and winter to spawn (Wang, 1986).

Because of their relatively high abundance, yellowfin gobies are probably an important food item for larger fish, including striped bass. There is no evidence of this from the literature, but anglers often use them as bait for striped bass. They are also consumed by wading shorebirds; several great blue herons were reported to have eaten yellowfin gobies, including one fish 8 inches long (Brittan et al., 1970). There is a commercial bait fishery for yellowfin gobies; some anglers also fish for them directly. In Japan, they are a desired food and game fish; in California, some Asians catch yellowfin gobies for human consumption.

Methods

Few fish older than one year were collected during this study (Figure 125), which supports the hypothesis that yellowfin gobies spawn at one year and then the majority die. A "cut-off" length of 100 mm was designated to separate juveniles from adults. A juvenile annual abundance index from the otter trawl was determined by averaging the weighted CPUE of fish less than 100 mm from June to October, the period of peak juvenile abundance. An adult annual index was computed using fish greater than 99 mm from November to April, the period of peak adult abundance. Juvenile data are also available from the plankton net. The annual index of juveniles from this net is the mean area weighted CPUE for all months.

No larval data were available for 1980, as yellowfin gobies were combined with arrow and cheekspot gobies. These three species were also combined for part of 1981, but we separated yellowfin goby larvae from arrow and cheekspot goby larvae based on differences in peak spawning periods and size.

Relative Abundance

Yellowfin gobies comprised about 1.7 percent of all fishes and 24.2 percent of all gobies collected in the otter trawl (Table 22). They also accounted for 1.9 percent of all fish and 39.7 percent of all gobies collected in the beach seine. They ranked tenth in abundance in both nets. Larvae accounted for 15.6 percent of all fish larvae (they ranked second to Pacific herring larvae) and 71.2 percnt of all goby larvae collected. Because of the high larval numbers and their burrowing habits, yellowfin gobies are probably more abundant in the Bay in relation to other fish than the trawl and seine catches indicate.

Larval Abundance and Distribution

Yellowfin goby larvae were collected from December to July by this study (Figure 126a). Peak abundance was from February to April. The peak did not occur later in high outflow years (1982 and 1983), as happens with some other species. Highest annual abundance (of the 5 years available) was in 1985, lowest was in 1983 (Table 23). There is no significant relationship between larval abundance and adult abundance for the same year (r=0.105).

Larvae were concentrated in San Pablo Bay every year except 1983 (Figure 127), when the greatest catches were in Central Bay. Because the larvae are pelagic, they would be expected to occur farther downstream in higher outflow years. There were relatively high catches of larvae in South Bay in 1985 (also the year of highest larval abundance). Although we did not collect a significant number of juveniles or adults in South Bay, they were ranked seventh in abundance in 1985 by a study by Kinnetics Laboratory (1986) in South Bay. All of their stations except one were south of the Dumbarton Bridge, including several slough stations.

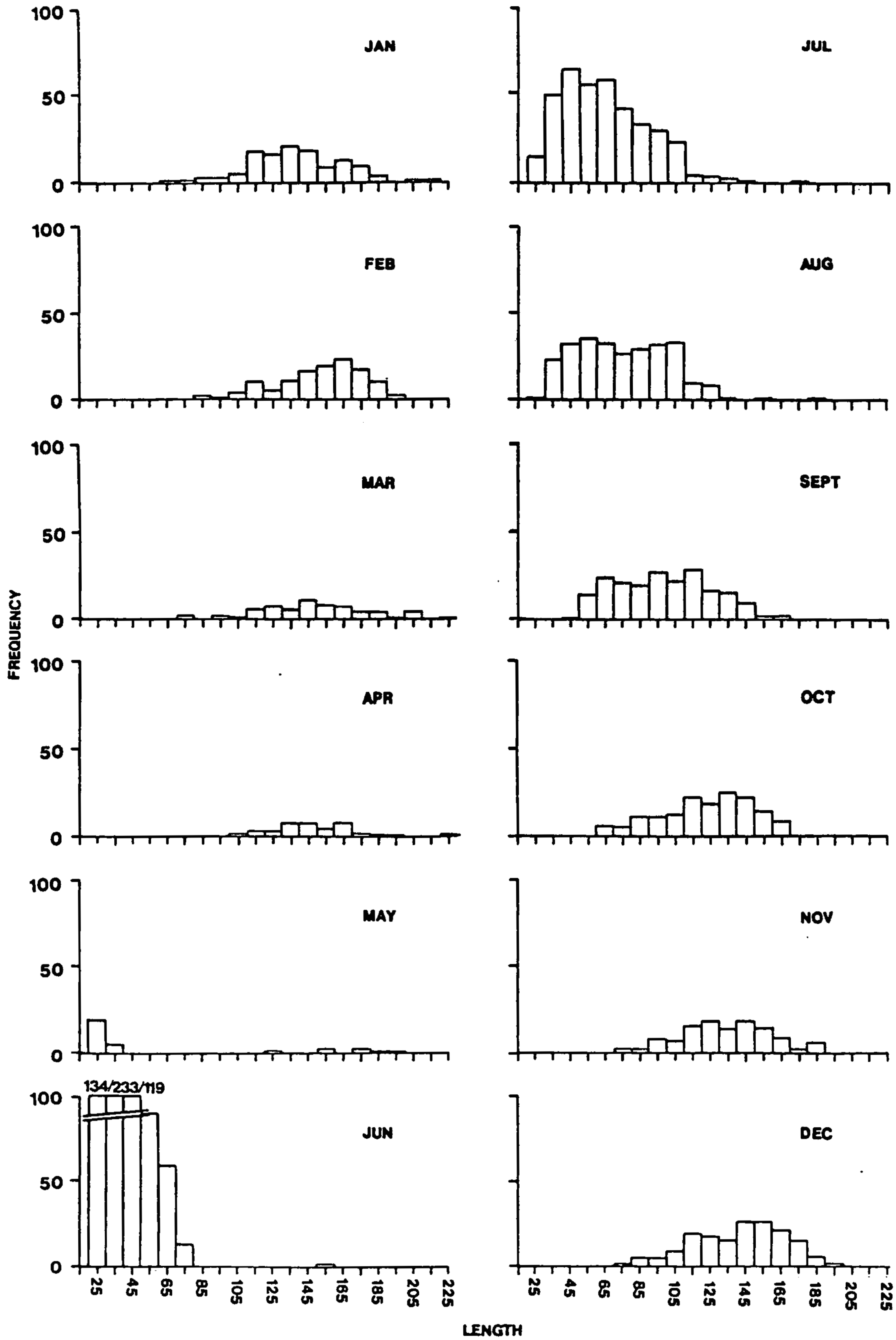


Figure 125. Length frequencies of yellowfin gobies.

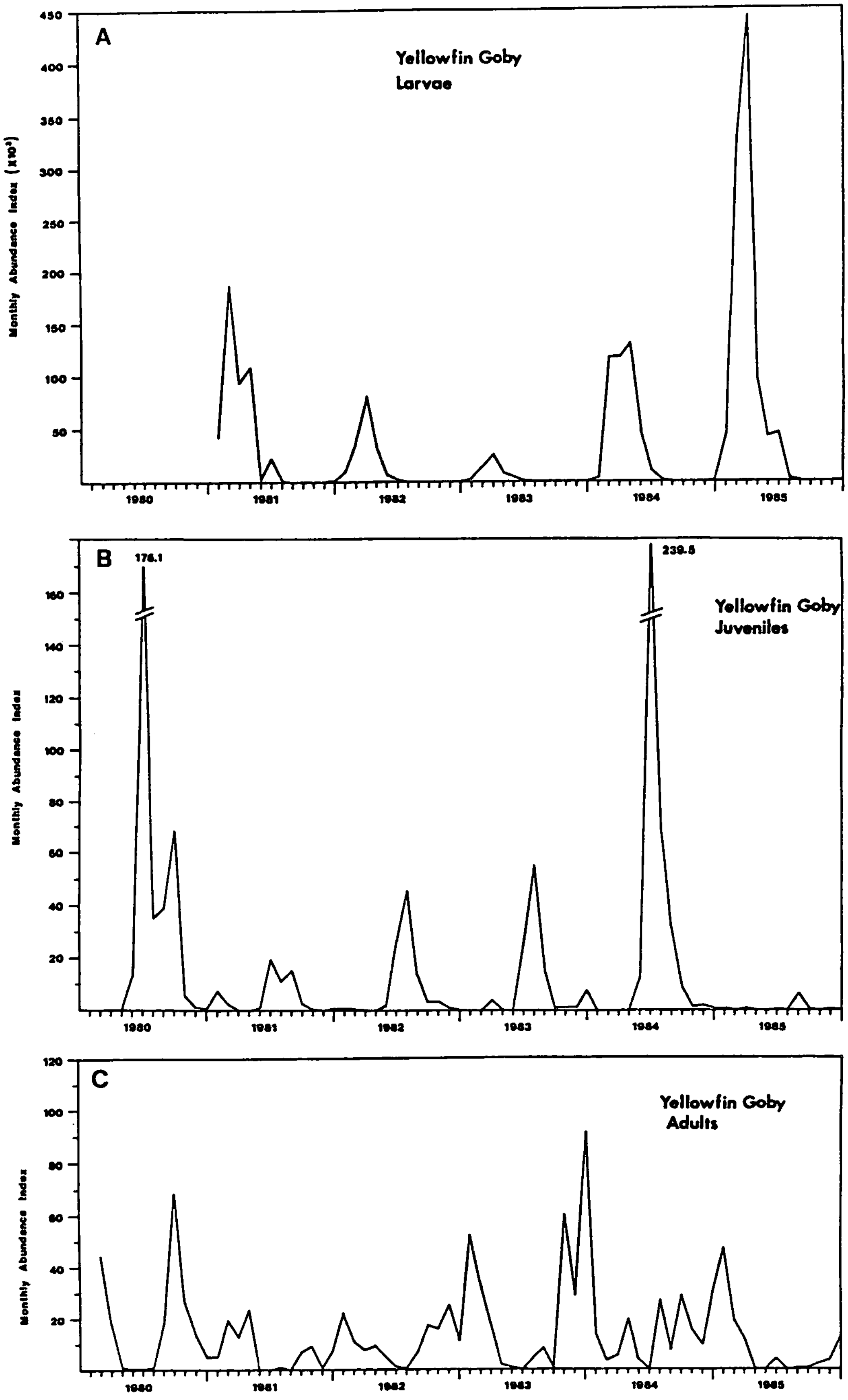


Figure 126. Monthly abundance indices of yellowfin goby larvae, juveniles, and adults, 1980-195.

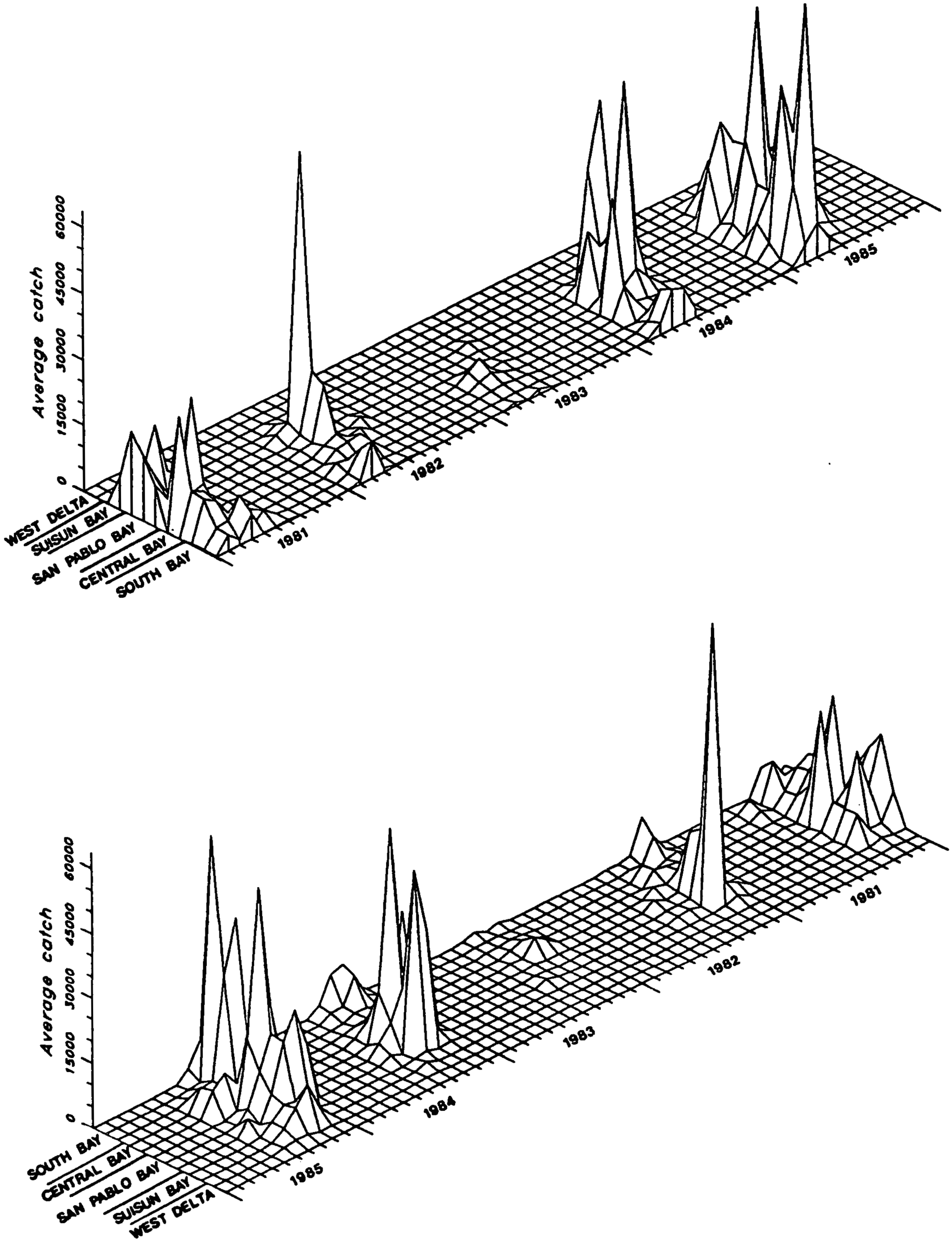


Figure 127. Distribution of yellowfin goby larvae.

Table 23

ABUNDANCE INDICES FOR YELLOWFIN GOBY

	1980	1981	1982	1983	1984	1985
Larvae	--	37,973	14,578	5,024	35,888	83,636
Juveniles (plankton net)	51.8	0	4.2	4.8	238.1	0
Juveniles (June-October)	65.2	9.5	18.5	19.0	70.1	1.4
Adults (November-April)	13.2	9.5	23.4	27.1	19.8	--
$\bar{x}$ Number salvaged (May-August)	12,434	5,314	25,857	377	352,413	8,450

Juvenile Abundance and Distribution

Peak abundance of juvenile yellowfin gobies from the otter trawl was from June to October (Figure 126b). In the plankton net, we collected juveniles only in April and May. Years with lowest juvenile abundance indices were 1981 and 1985 (Table 23). No juvenile yellowfin gobies were collected in the plankton net these years. The highest juvenile index from the otter trawl was in 1984, followed closely by 1980. Juvenile abundance from the plankton net was also greatest in 1984. There is no significant relationship between larval abundance and subsequent juvenile abundance from the otter trawl ($r=-0.256$) or the plankton net ($r=-0.003$).

One explanation for the low abundance of juvenile yellowfin gobies in 1981 and 1985 may be that they moved upstream of the study area during these low outflow years. Counts of fish salvaged from the State and Federal pumping plants are a source of upstream data. The mean of May-August salvage data shows that the lowest numbers salvaged were in 1983, followed by 1981 and 1985 (Table 23). The low numbers would be expected in 1983, as juveniles would not move upstream in an extremely high outflow year. But the low numbers in 1981 and 1985 indicate the population may not have shifted upstream of our study area these two low outflow years. Our data probably represent accurately the relative abundance in the estuary.

Juveniles primarily utilized San Pablo Bay, Suisun Bay, and the west Delta (Figure 128). No juveniles were collected in San Pablo Bay in the summers of 1981 and 1985; they apparently shifted to the areas upstream of Carquinez Strait these years. Juveniles also prefer shallow areas (Figure 129a), as would be expected from their concentration in Suisun Bay and the west Delta.

Adult Abundance and Distribution

The peak abundance of adults was usually in January or February (Figure 126c). In 1984, the peak abundance of adults was actually in December 1983. This shift may have

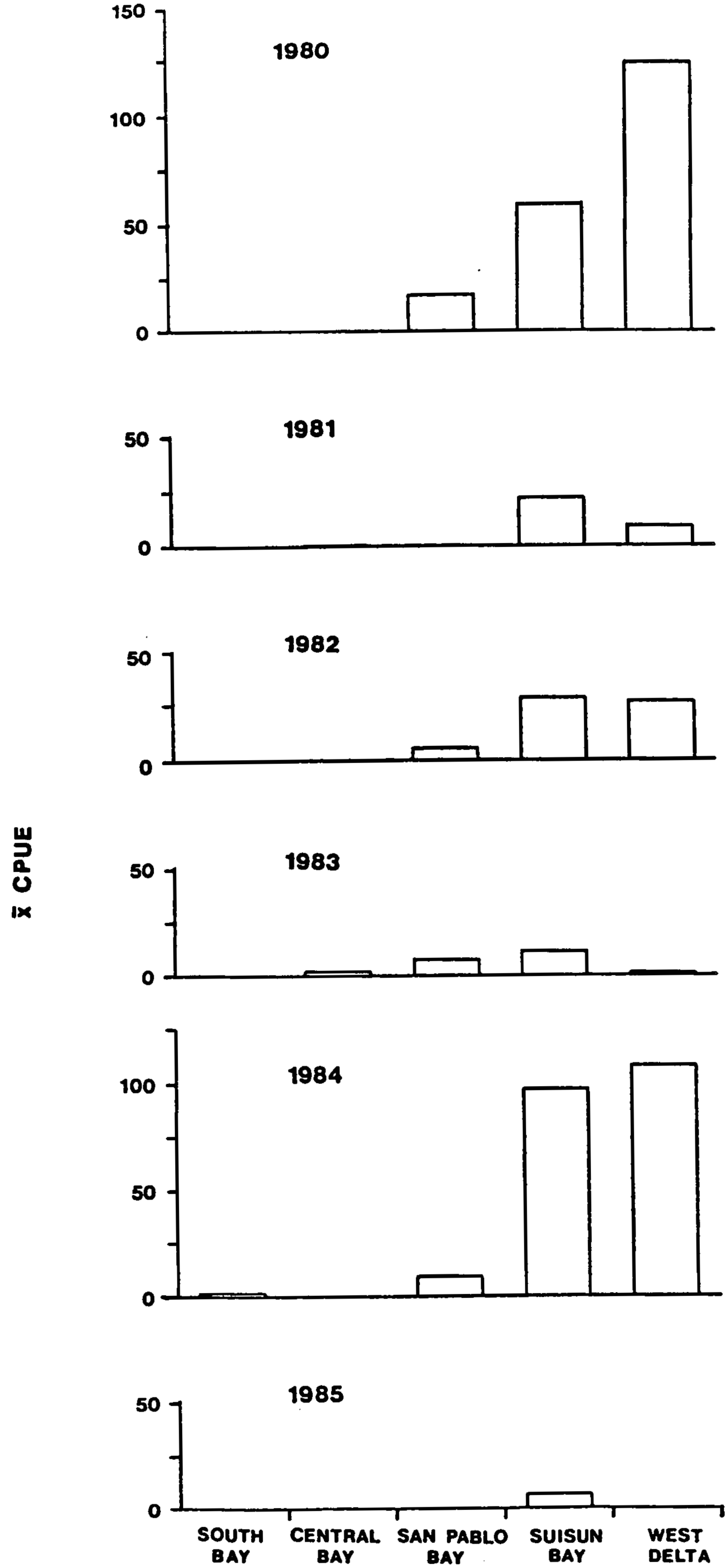


Figure 128. Distribution of juvenile yellowfin gobies, June-October.

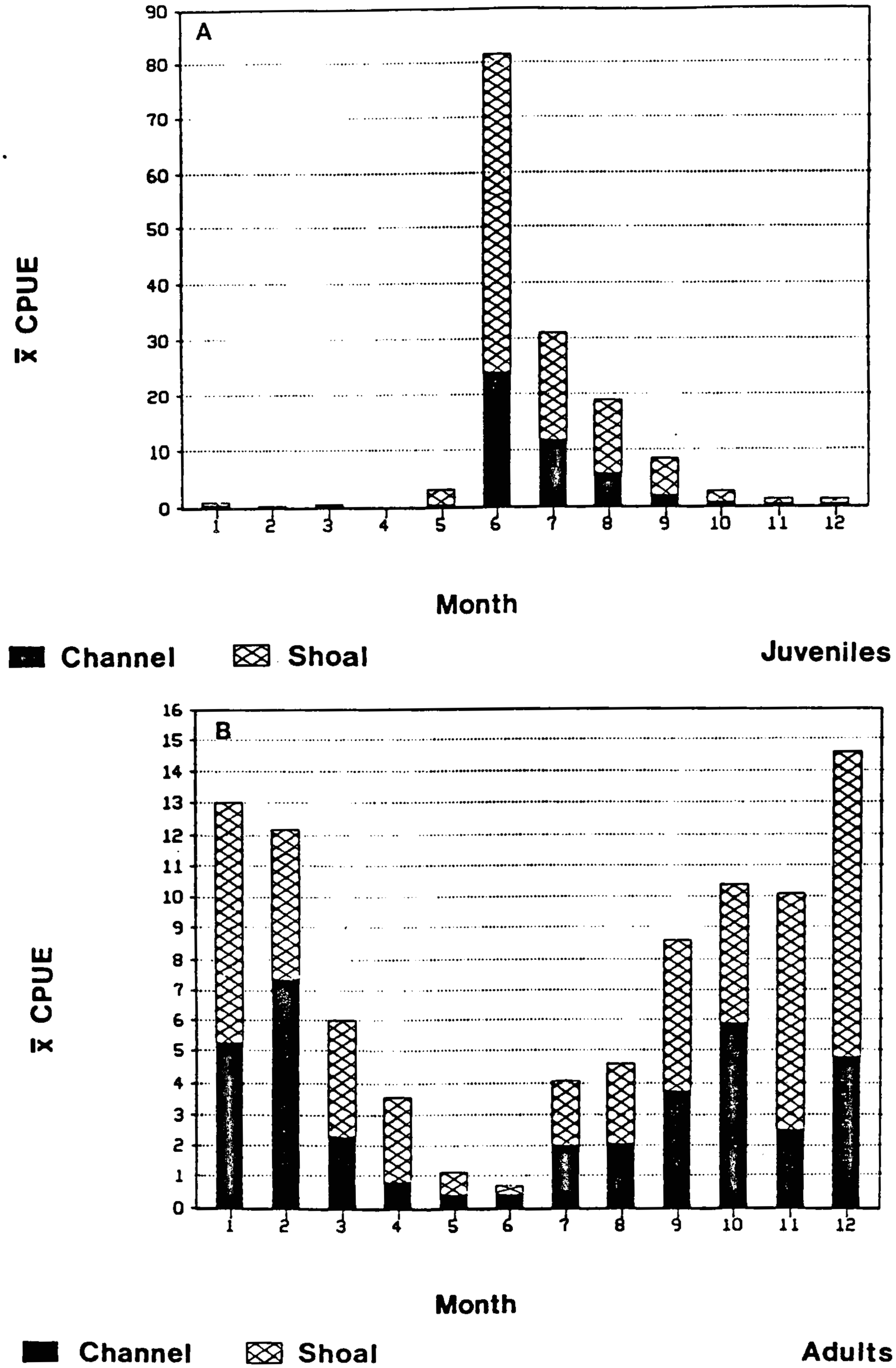


Figure 129. Mean CPUE of juvenile and adult yellowfin gobies at channel and shoal stations.

been due to a relatively high outflow in November and December, which is earlier than other years. Consequently, adult yellowfin gobies moved downstream earlier. The highest annual abundance of adults was in 1983-1984 (the 1983 year class) and the lowest in 1981-1982 (the 1981 year class) (Table 23). There is no significant relationship between juvenile abundance and subsequent adult abundance (r=-0.125, otter trawl juveniles; r=0.023, plankton net juveniles).

Adult yellowfin gobies were concentrated in San Pablo and Suisun bays (Figure 130). In 1983 and 1984, adults appeared to utilize San Pablo Bay to a greater extent than other years. The large pulse of fresh water that moved through the Bay in November-December 1983 may be why a larger proportion of adult yellowfin gobies were collected in San Pablo Bay in 1984. Adults utilized channel areas more than juveniles did (Figure 129b); this can be explained in part by the downstream migration of adults to embayments with more channel area than Suisun Bay and the west Delta.

Effects of Salinity and Temperature

This species has been classified as euryhaline and was collected at a wide range of salinities and temperatures by this study. The greatest concentration of yellowfin gobies was at salinities less than 15 ppt and temperatures greater than 18 degrees C (Figure 131). Juveniles were found at lower salinities (1-12 ppt) than were adults (4-22 ppt) (Figure 132).

Effects of Delta Outflow

Various life stages of yellowfin gobies respond differently to Delta outflow. There is a negative relationship between larval abundance and January-March outflow (r=-0.807) (Figure 133). Larvae may be swept from the Bay during high outflow periods. No strong relationship was found between juvenile abundance and outflow. Juvenile abundance was relatively low in both high (1982 and 1983) and low (1981 and 1985) outflow years and was high in moderate outflow years (1980 and 1984). Fall-winter adult abundance is significantly correlated with the previous spring-summer outflow ($r=0.883$, $p<0.05$) (Figure 134). Outflow may affect the survival of juveniles to adults.

Although this species can tolerate a wide range of salinities and temperatures, its distribution is affected by outflow. Juveniles were more affected than adults, as they did not utilize San Pablo Bay in 1981 and 1985. Larvae were shifted downstream by high outflow.

Summary

The yellowfin goby, an introduced species, is an important component of the Bay fish community. It ranked tenth among fishes from the otter trawl and tenth among fishes from the beach seine. The larval data indicate its relative abundance is even greater, as this was the second most common species collected in the plankton net. Yellowfin gobies are preyed upon by larger fishes, including striped bass, and by wading shorebirds. They have some commercial importance as bait for sport fishermen.

Peak spawning is from February to April. The pelagic larvae may be swept from the Bay during high outflow years. There is a strong negative correlation between larval abundance and outflow, but the larval abundance is not correlated with the subsequent abundance of juveniles. There is not a linear relationship between juvenile abundance and outflow as both high and low outflow resulted in low abundance. The highest

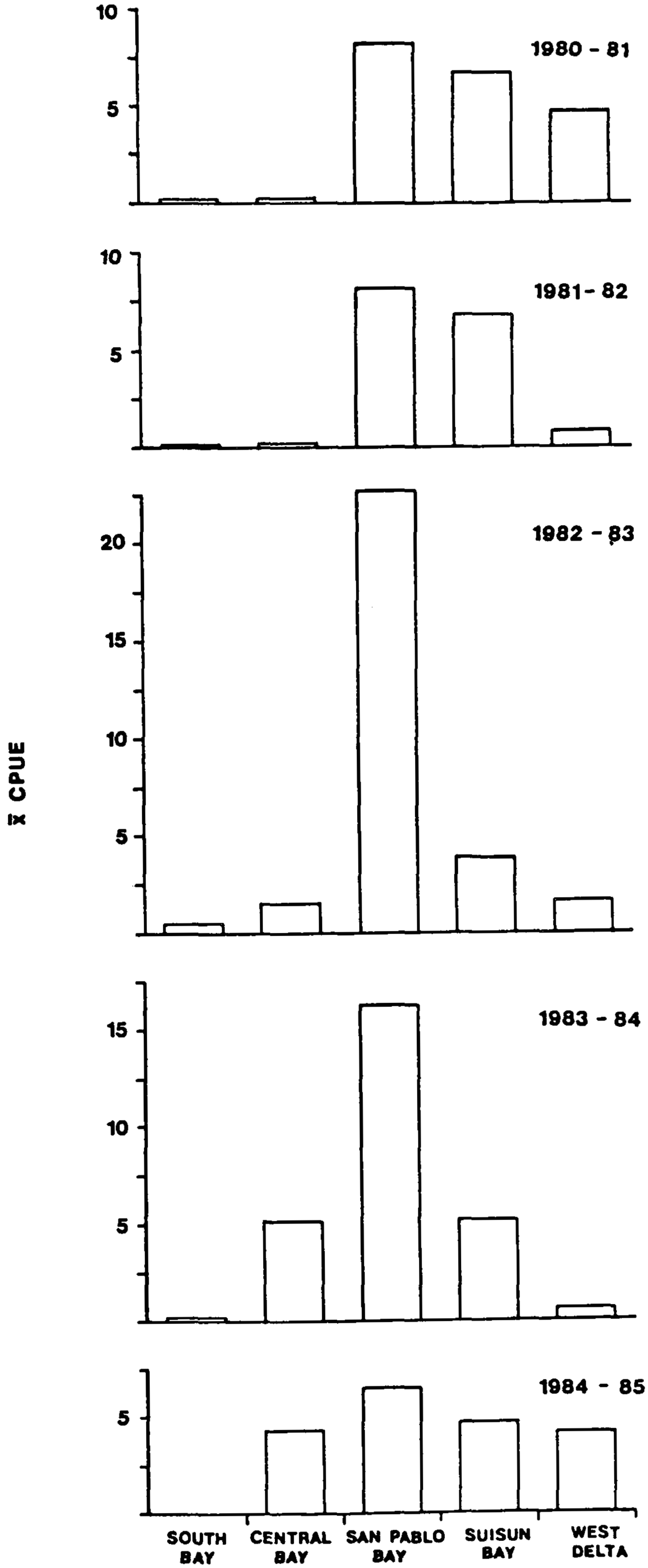


Figure 130. Distribution of yellowfin goby adults, November-April.

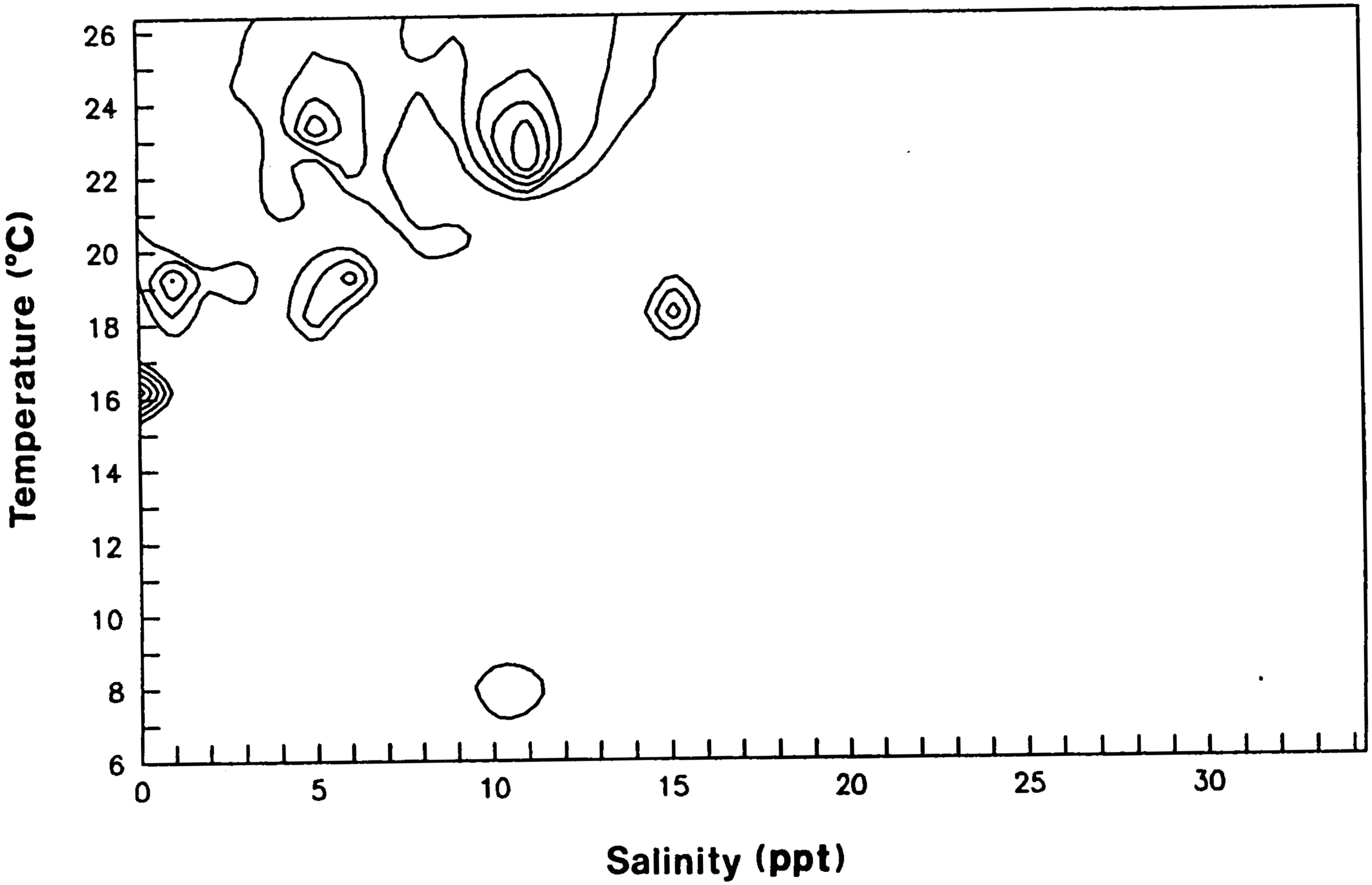


Figure 131. Mean CPUE of yellowfin gobies vs. salinity and temperature (contours from 50 to 300, every 50).

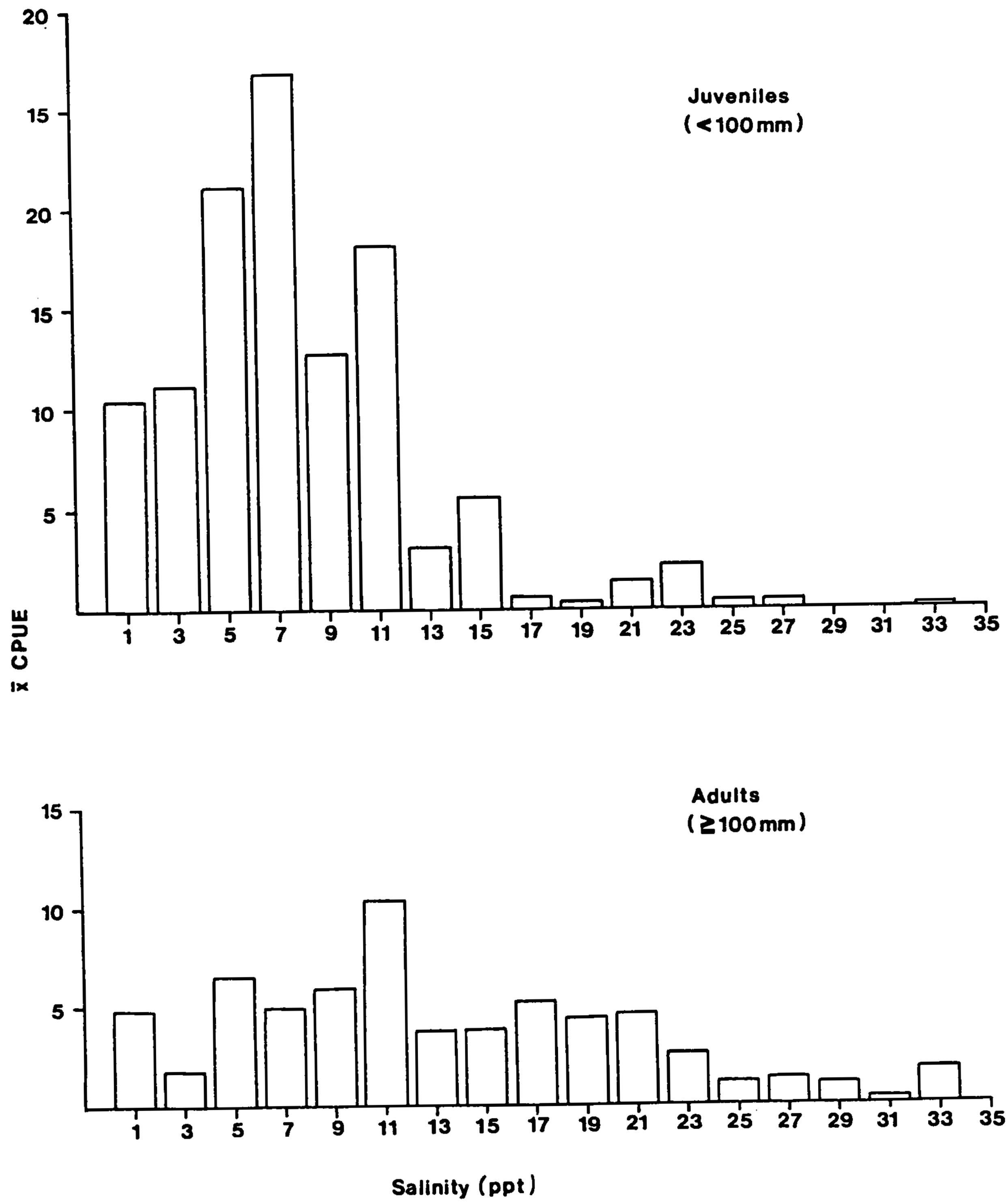


Figure 132. Mean CPUE of juvenile and adult yellowfin gobies vs. salinity.

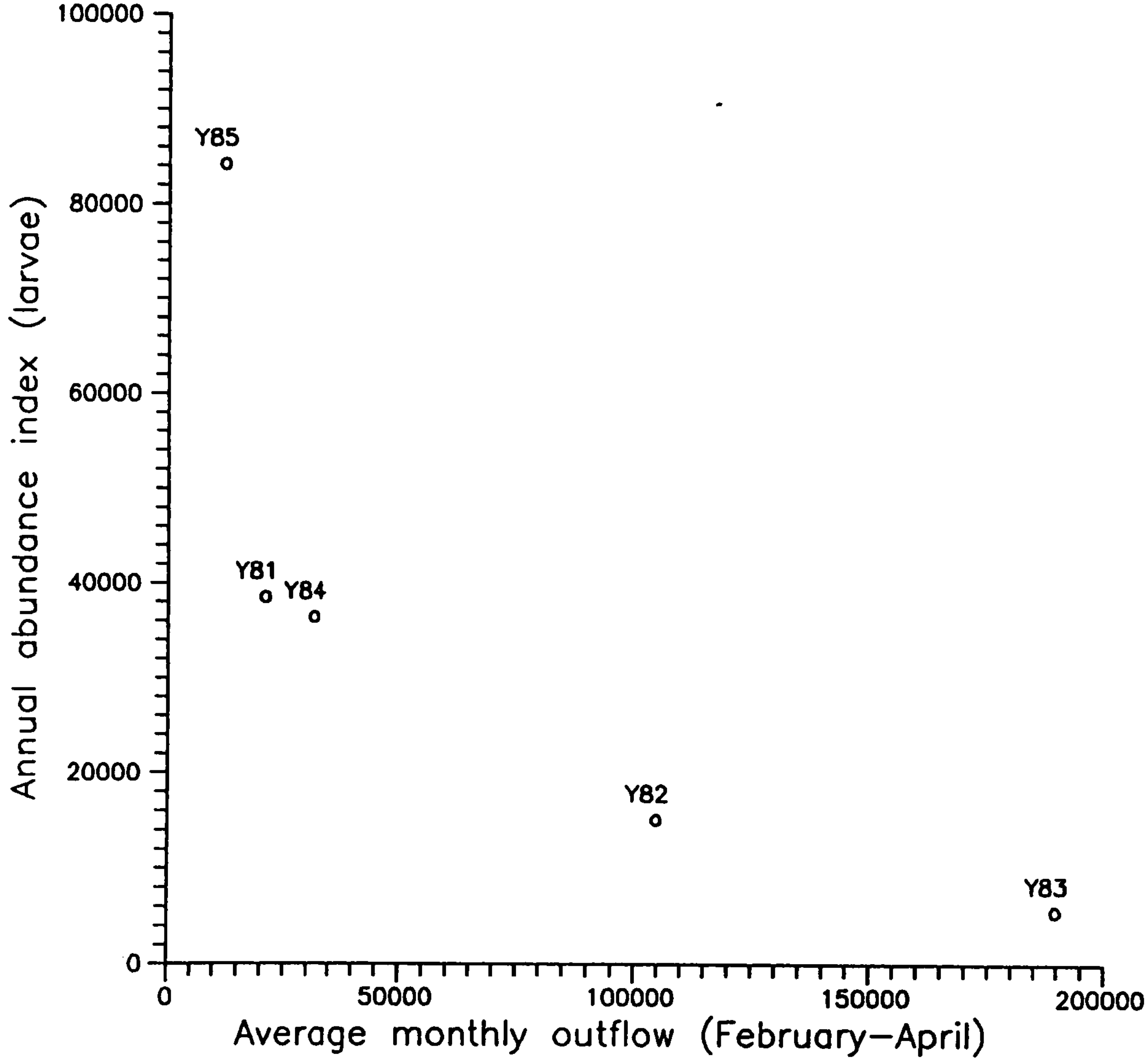


Figure 133. Annual abundance of yellowfin goby larvae vs. outflow (r=-0.807).

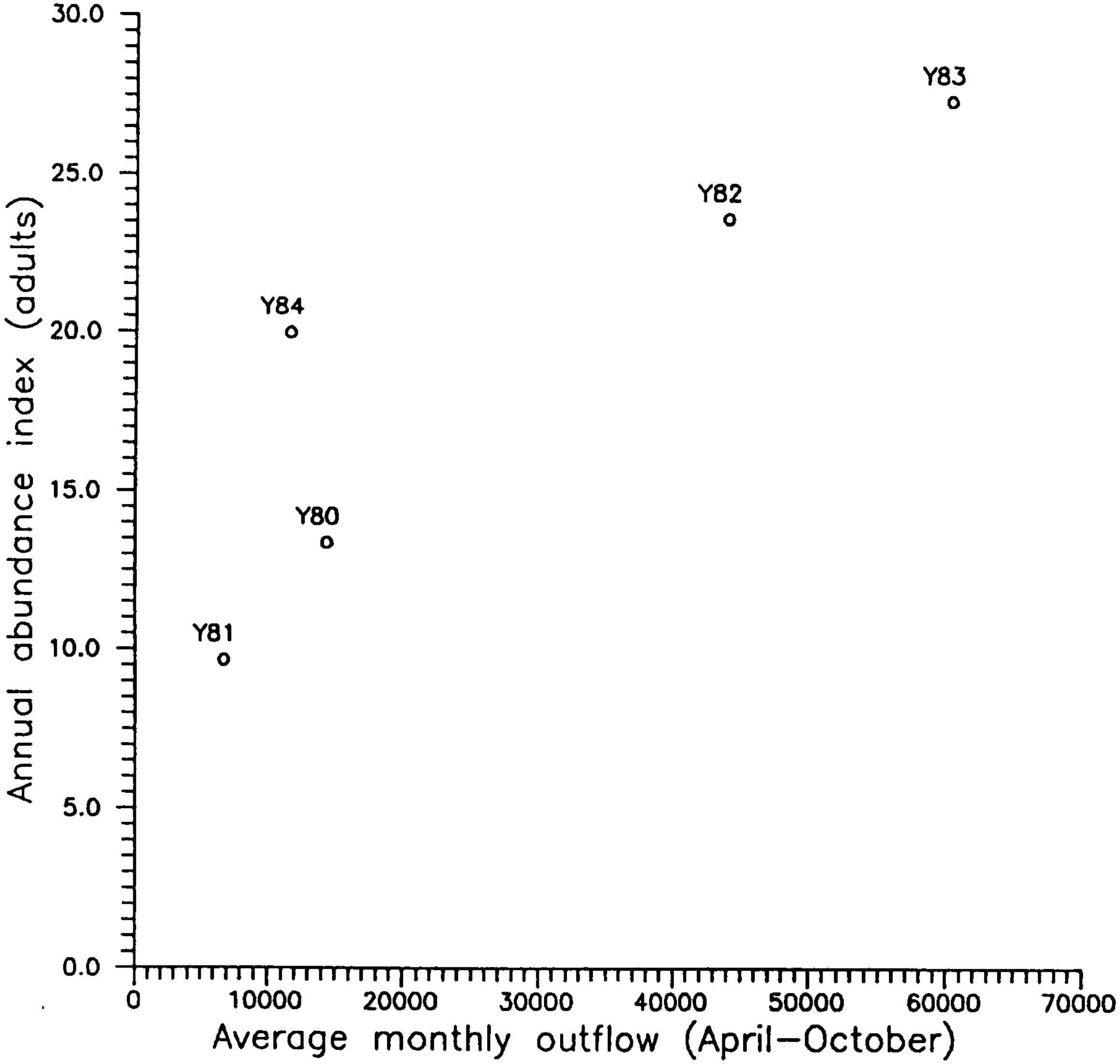


Figure 134. Annual abundance of yellowfin goby adults vs. outflow (r=0.883).

juvenile abundance indices were in 1980 and 1984, years of moderate outflow. There is a positive correlation between spring-summer outflow and subsequent fall-winter adult abundance.

Yellowfin gobies are classified as euryhaline, with most juveniles being caught in areas where salinities were less then 15 ppt, upstream of Carquinez Strait. Adults and larvae were usually concentrated in San Pablo Bay. There may be a separate South Bay population, but we collected few adults or juveniles in this embayment.

Bay Goby

The bay goby (Lepidogobius lepidus) ranges from Baja California to British Columbia (Miller and Lea, 1972). It is common in bays and estuaries and is often commensal with burrowing invertebrates. Bay gobies were collected from burrows of the mud shrimp (Upogebia pugettensis), fat inkeeper worm (Urechis caupo), and geoduck clam (Panope generosa) in Morro Bay (Grossman, 1979a). This is an intermediate size goby, reaching a total length about 100 mm. Peak spawning is from April to September in Yaquina Bay, Oregon (Pearcy and Myers, 1974), and in April and May in Humboldt Bay (Eldridge and Bryan, 1972) and San Francisco Bay (Wang, 1986). There is possibly a fall migration of adults from shallow to deeper water; temperature may be an important factor associated with this migration (Grossman, 1979b).

As with other members of the goby family, the bay goby is not effectively sampled by trawls or seines. In Yaquina Bay, this was the second most abundant species as larvae, but juveniles were rarely collected in trawl samples (Pearcy and Myers, 1974). Using quinaldine (an anesthetic) to collect fish from mudflat tidepools, Grossman (1979a) concluded that the bay goby is numerically one of the dominant fish in the lower intertidal zone of Morro Bay. In a larval survey of Humboldt Bay, bay gobies comprised 43.2 percent of all larvae, but only 5.67 percent of juvenile fishes collected by plankton nets (Eldridge and Bryan, 1972).

Because of their relatively small size and high abundance, bay gobies are probably preyed upon by a variety of fishes. There is some evidence of this in the literature; they are a major component of the diet of staghorn sculpins in San Francisco Bay (Boothe, 1967). Major prey items of bay gobies include polychaetes, harpacticoid copepods, gammarid amphipods, molluscs, and other crustaceans (Grossman, 1980).

Methods

Using length frequency data by survey (Figure 135), it was estimated that a "cut-off" length of 60 mm would reliably separate juveniles (fish less than one year) from adults. Using this length, few individuals would be classified as juveniles from July to October, the period of peak spawning every year of this study. Our length frequency data give little evidence that bay gobies live more than 2 years. This conflicts with Grossman (1979b), who concluded that they lived as long as 7 years.

Juvenile indices were calculated from the otter trawl and plankton net data. The mean weighted CPUE for January-June (the peak period of juvenile abundance) for fish less than 60 mm is used for the otter trawl; only fish less than 50 mm are included in the plankton net data base. The adult annual index is the mean weighted CPUE of fish greater than 60 mm for June to October, the period of peak adult abundance.

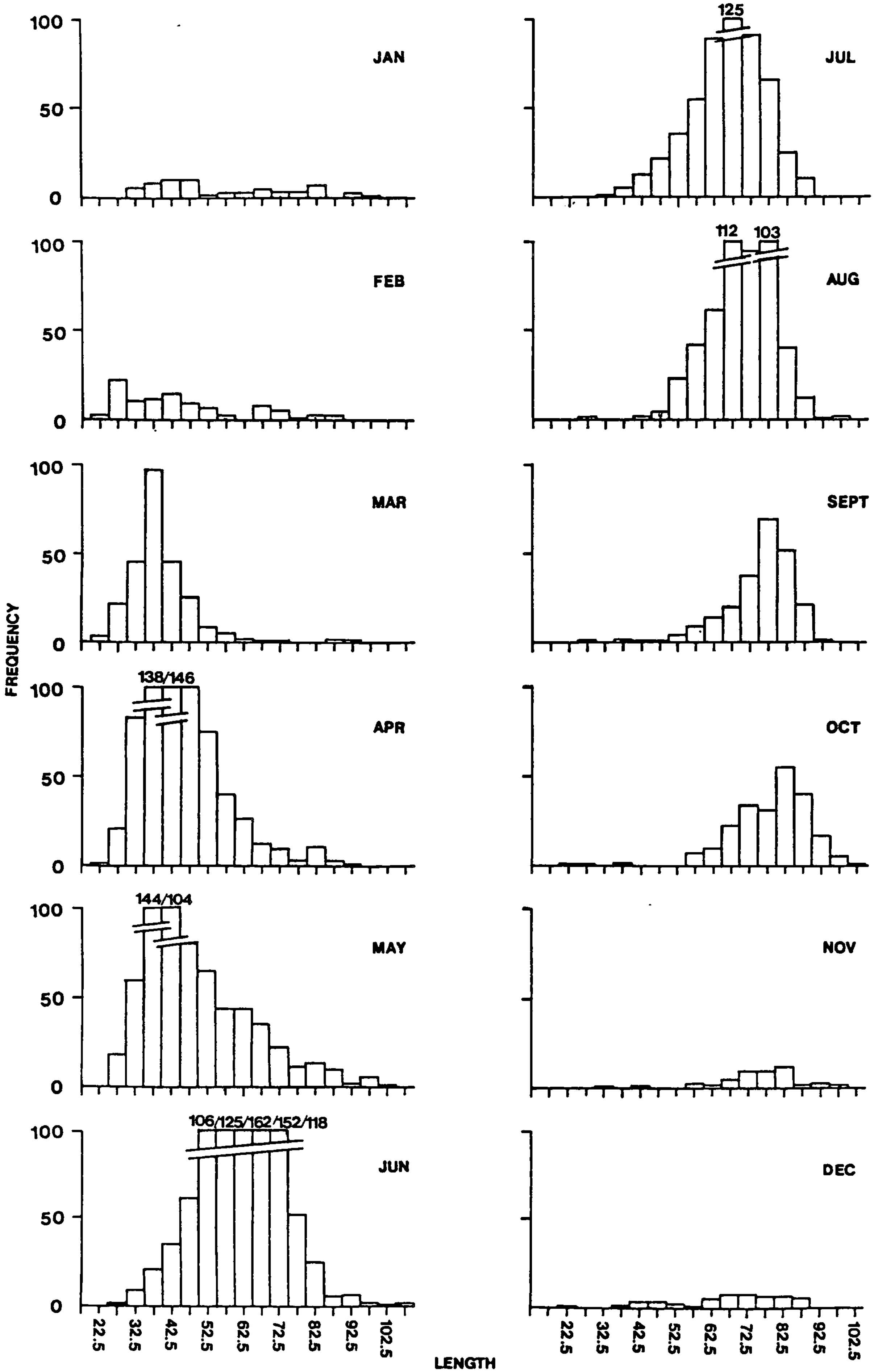


Figure 135. Length frequencies of bay gobies.

Relative Abundance

The bay goby was the most numerous goby and the eighth most abundant fish collected by this study in the otter trawl. This species comprised 5.1 percent of all fishes and 53.9 percent of all gobies collected by this net (Table 22). In the beach seine it accounted for less than 0.2 percent of all fishes and only 3.5 percent of all gobies collected. Bay goby larvae comprised 0.7 percent of all larvae and 3.0 percent of all goby larvae collected by the plankton net. The juveniles comprised 9.4 percent of all juvenile fishes and 45.3 percent of all juvenile gobies collected by the plankton net.

Larval Abundance and Distribution

Bay goby larvae peaked in abundance from July to October (Figure 136a). This is later than previously reported for this species in the Bay. Few larvae were collected in the winter and early spring. The only months that we did not collect larvae were March and April 1983, a period of extremely high outflow. The highest annual abundance index of larvae was in 1981, the lowest in 1983 (Table 24). The trend is for higher larval indices in 1980-1982 than in 1983-1985. There appears to be little relationship between annual abundance of larvae and annual abundance of adults from the same year (r=-0.656) or the subsequent abundance of juveniles (r=0.520, plankton net juveniles; r=0.641 otter trawl juveniles).

Greatest catches of larvae were usually in Central Bay (Figure 137). In 1982 larvae were concentrated in the northern area of South Bay. Very few larvae were collected upstream of Carquinez Strait or in the southernmost portion of South Bay.

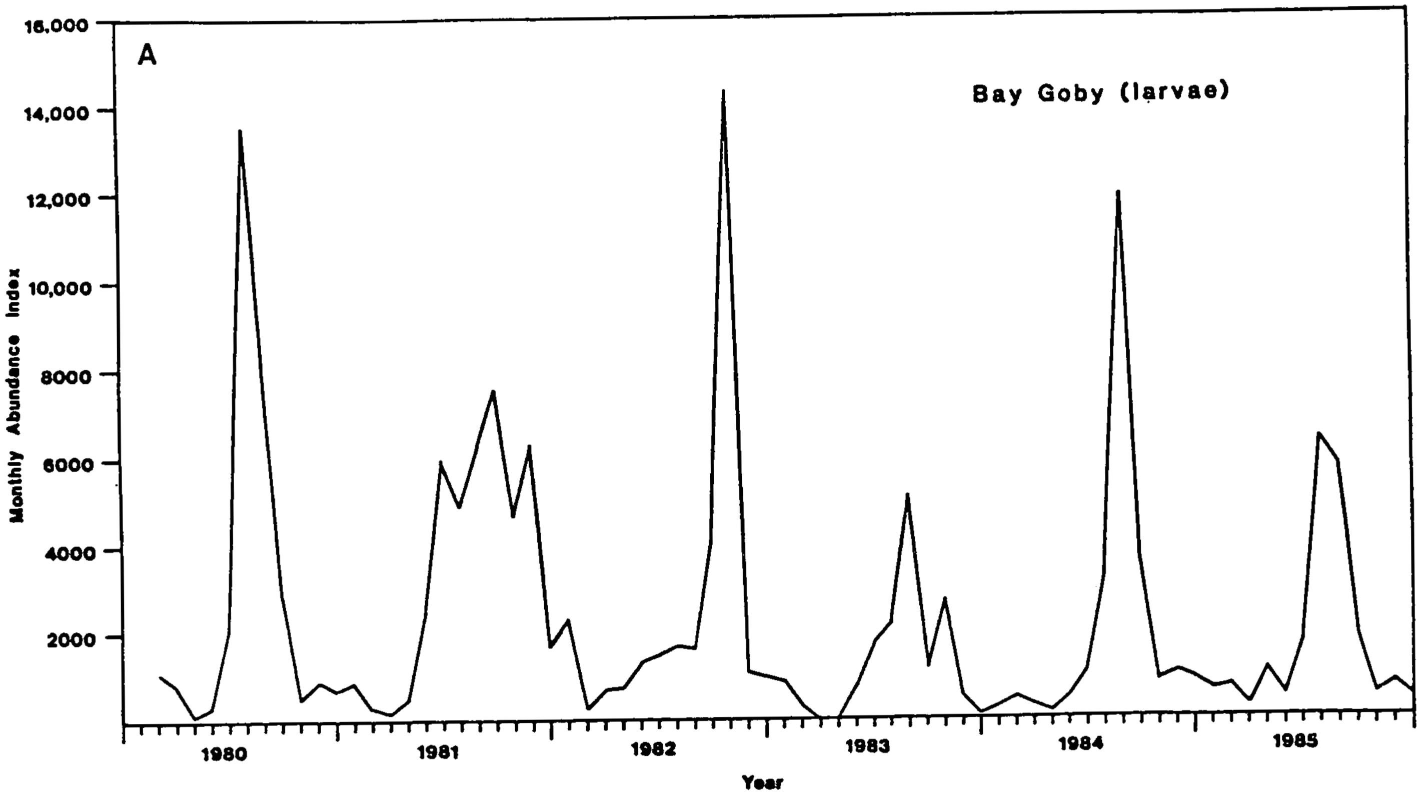
Juvenile Abundance and Distribution

We usually began to collect a significant number of bay goby juveniles in the plankton net by December and continued to collect them through June (Figure 138a). Juveniles were not collected by the otter trawl in significant numbers until March (Figure 138b), as this net selects larger fish than does the plankton net. Highest annual abundance indices of juveniles from the plankton net were in 1980 and 1982 (the 1979 and 1981 year classes) (Table 24). Lowest abundance was in 1981 (the 1980

Table 24

ABUNDANCE INDICES FOR BAY GOBY

	1980	1981	1982	1983	1984	1985
Larvae	2,881	3,503	2,551	1,341	2,023	1,700
Juveniles (plankton net)	687.5	74.6	544.8	169.4	149.0	105.9
Juveniles (January-June)	137.9	36.4	241.7	168.1	64.2	4.5
Adults (June-October)	72.7	96.6	84.1	489.7	228.0	75.6
All sizes	104.0	68.8	167.2	347.7	137.7	39.2



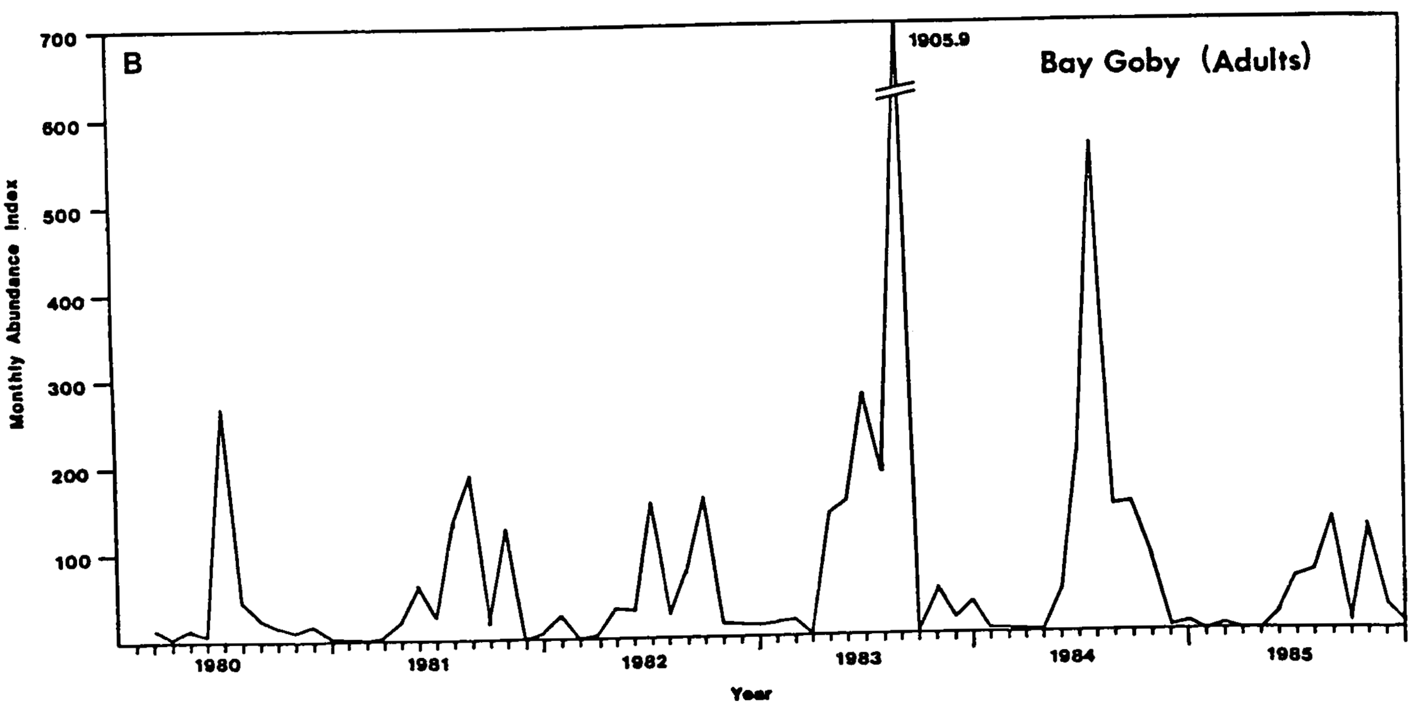
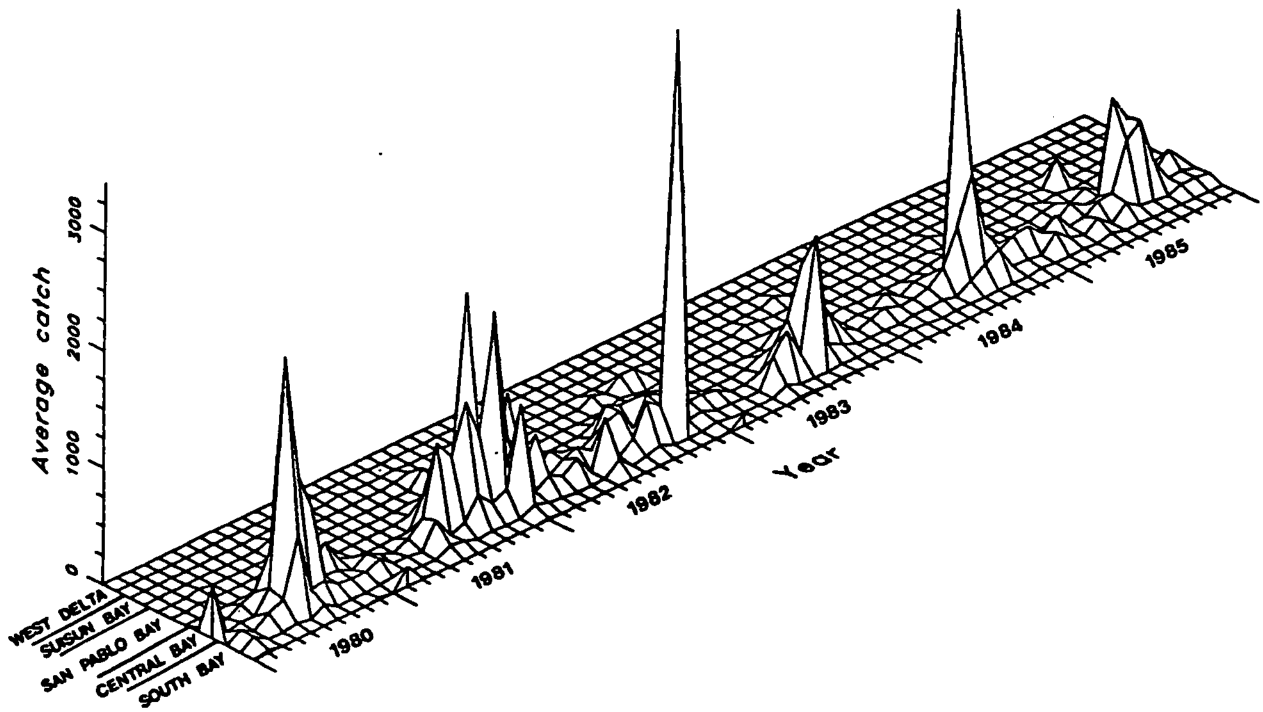


Figure 136. Monthly abundance indices of bay goby larvae and adults, 1980-1985.



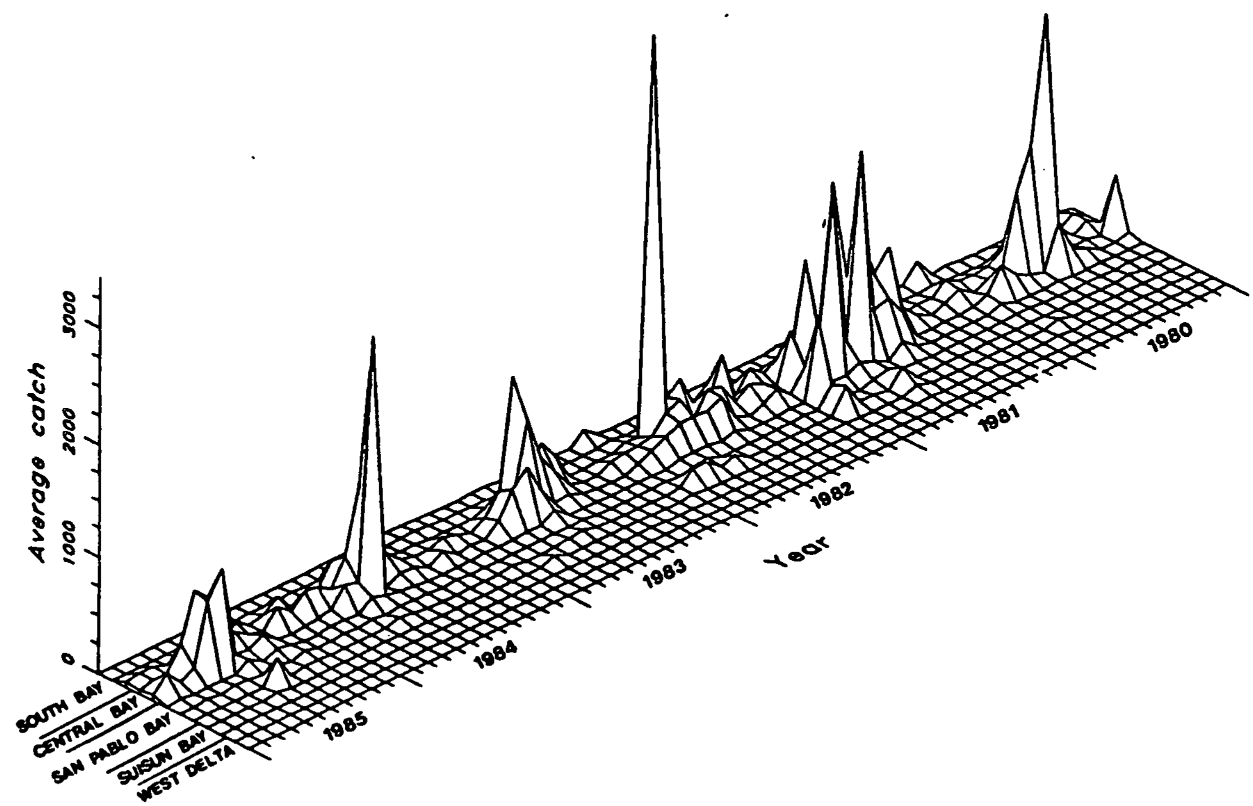
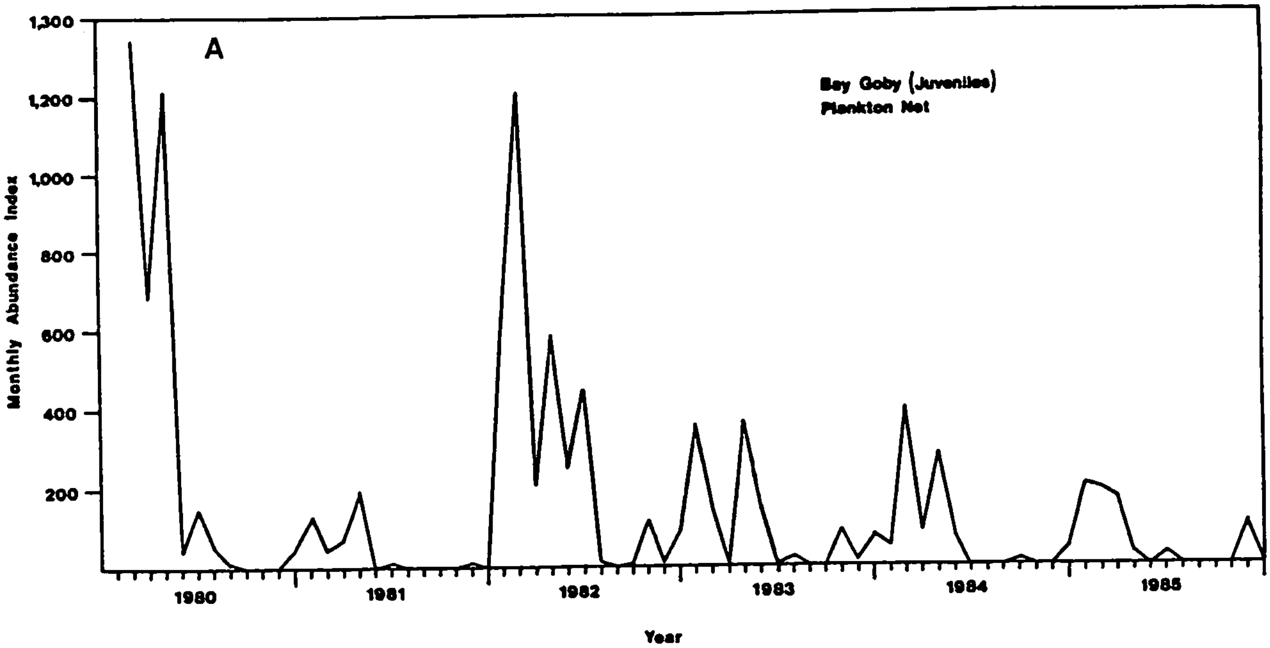


Figure 137. Distribution of bay goby larvae.



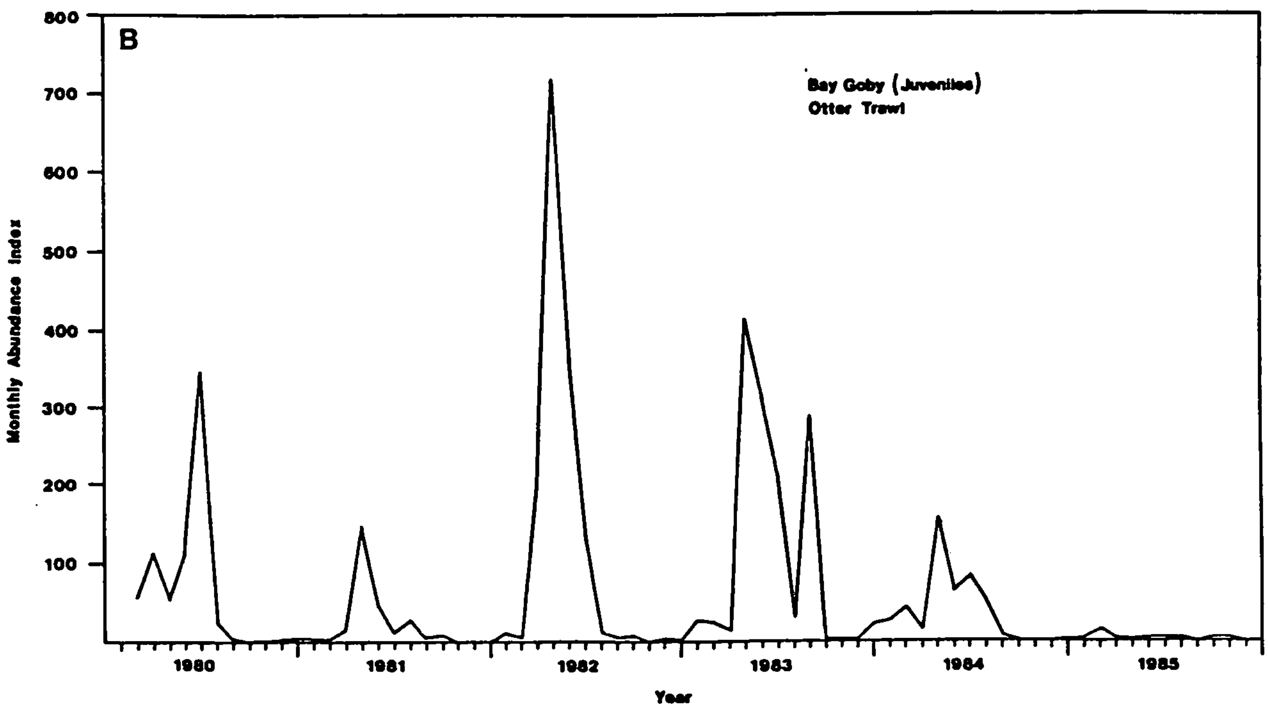


Figure 138. Monthly abundance indices of bay goby juveniles, 1980-1985.

year class). Juveniles from the otter trawl for the same period (January-June) had the highest abundance in 1982 and the lowest in 1985 (Table 24). Although there are some discrepancies between these two nets, the lowest indices were in 1981 and 1985 for both data sets.

Juvenile bay gobies were usually concentrated in San Pablo Bay (Figure 139). In 1983 the greatest catches were in South Bay; catches were also relatively high in South Bay in 1980 and 1982, years of high abundance. Catches were never highest in Suisun Bay, as for yellowfin gobies. More juveniles were collected at the shoal stations than at the channel stations (Figure 140a).

Adult Abundance and Distribution

Peak abundance of adult bay gobies was usually from April through October (Figure 136b); they were not collected in significant numbers other months. There may be a migration of adults out of the Bay in the fall and winter, similar to the migration of adults to deeper water found by Grossman (1979b) in Morro Bay. Another explanation for this "disappearance" is that few bay gobies live past one year, which would be similar to the findings for the yellowfin goby.

Highest annual abundance of adult bay gobies was in 1983, the lowest abundance in 1980 (Table 24). There is little relationship between juvenile abundance and subsequent adult abundance (r=-0.346, plankton net juveniles; r=0.233, otter trawl juveniles).

Adult bay gobies were concentrated in South, Central, and San Pablo bays and were rarely collected upstream of Carquinez Strait (Figure 141). The area with the highest adult catch varies by year, but adults did not move downstream in years of high outflow. More adults were collected at shoal stations than at channel stations during spring and summer (Figure 140b). By September catches at the shoal stations dropped significantly; this is also the period that adult abundance decreased overall in the Bay.

Effects of Salinity and Temperature

The greatest catches of bay gobies were at salinities greater than 10 ppt and temperatures from 12 to 20 degrees C (Figure 142). We collected bay gobies only at salinities less than 10 ppt in 1982 and 1983, the highest outflow years. In 1985, the lowest outflow year, bay gobies were collected only at salinities greater than 20 ppt. Juveniles apparently can tolerate lower salinities (<20 ppt) than adults can (Figure 143). This is reflected in part by the concentration of juveniles in San Pablo Bay rather than in Central Bay or South Bay in most years.

Effects of Delta Outflow

Delta outflow effects on abundance of bay gobies varied by life stage. Although the highest abundance of adults was in 1983, this was the year of lowest larval abundance. The pelagic larvae may be carried out of the Bay during high outflow years, even though peak spawning is during late summer and early fall. A correlation between larval abundance and June-September outflow (the period believed to most affect larval abundance) is negative, but not significant (r=-0.555).

There is a positive correlation between juvenile abundance and December-May outflow (r=0.801, otter trawl juveniles; r=0.316, plankton net juveniles) (Figure 144). This outflow period was chosen because juvenile bay gobies were most abundant from January to June.

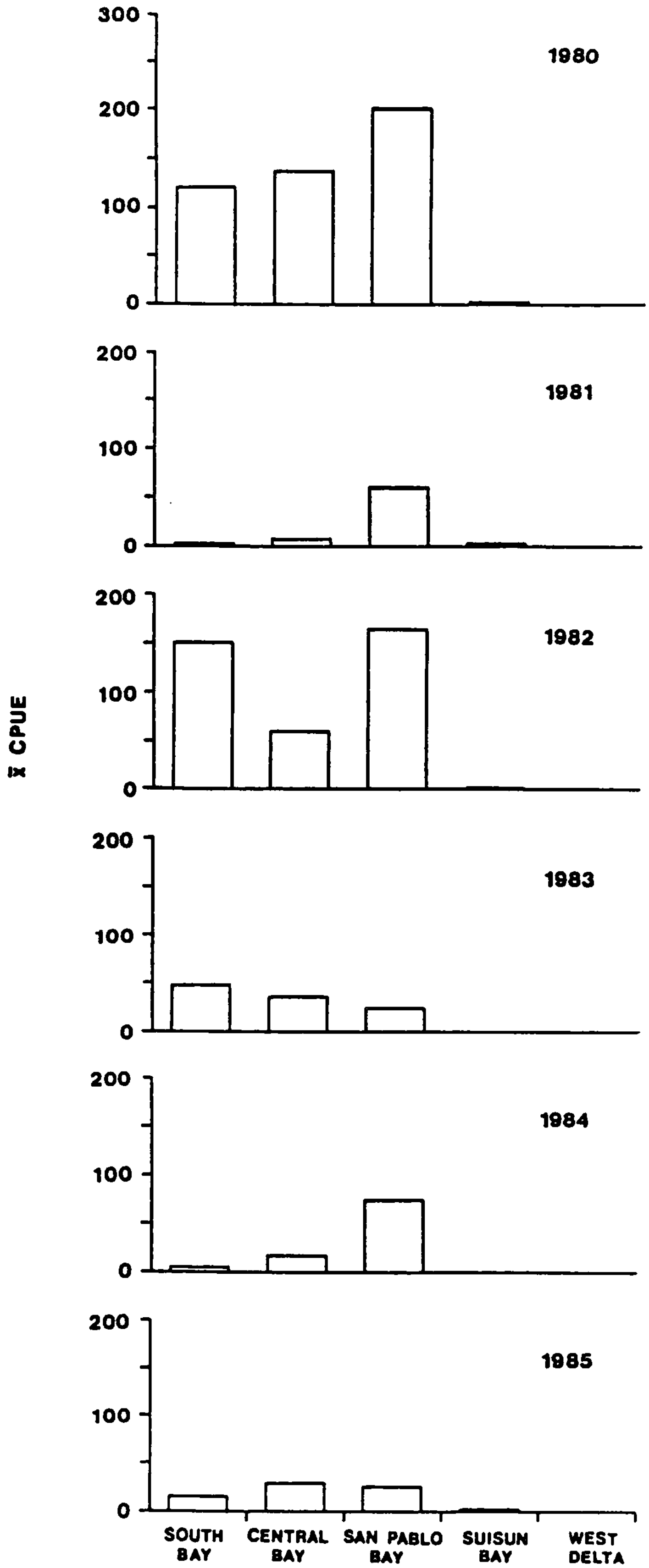


Figure 139. Distribution of juvenile bay gobies, January-June.

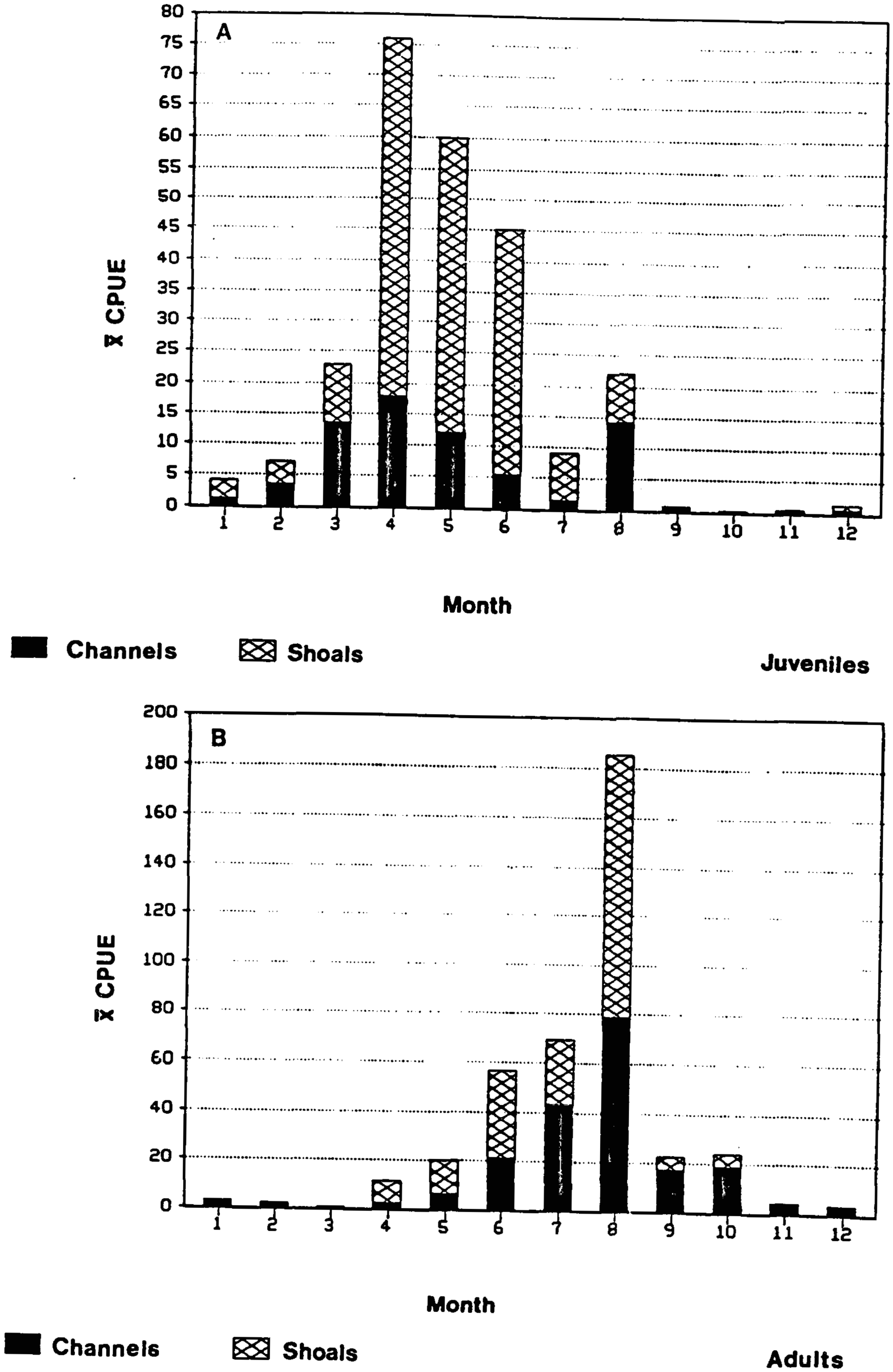


Figure 140. Mean CPUE of juvenile and adult bay gobies at channel and shoal stations.

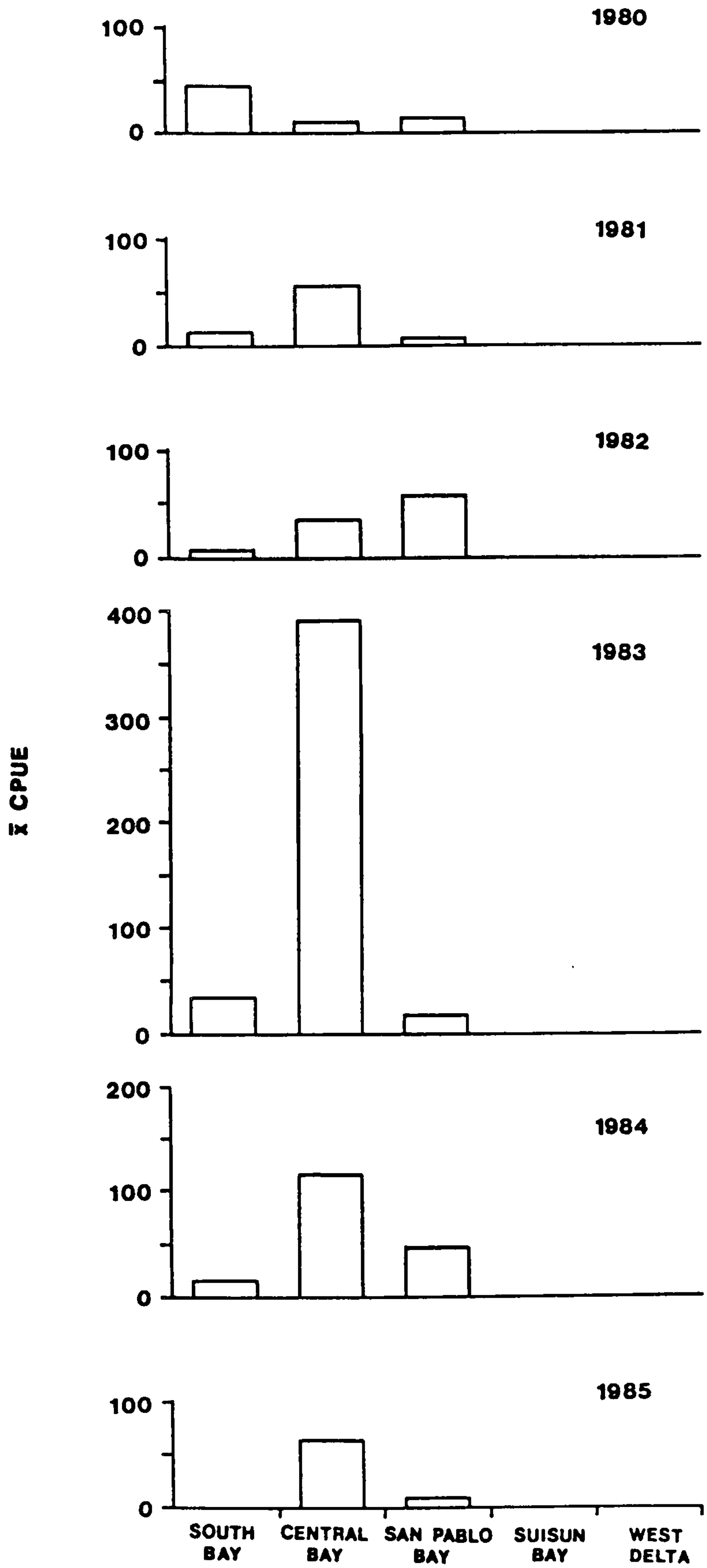


Figure 141. Distribution of adult bay gobies, June-October.

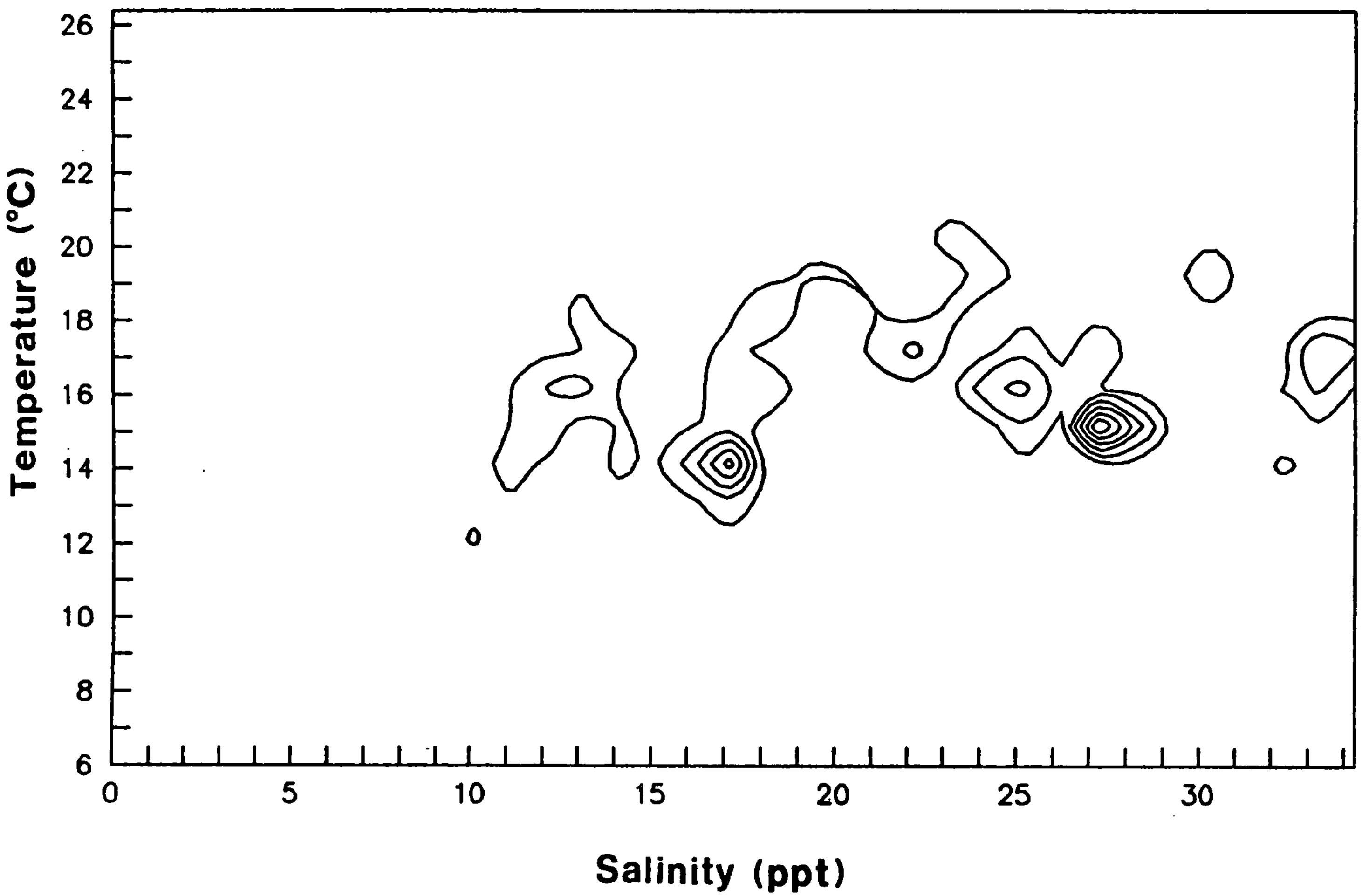


Figure 142. Mean CPUE of bay gobies vs. salinity and temperature (contours from 50 to 950, every 150).

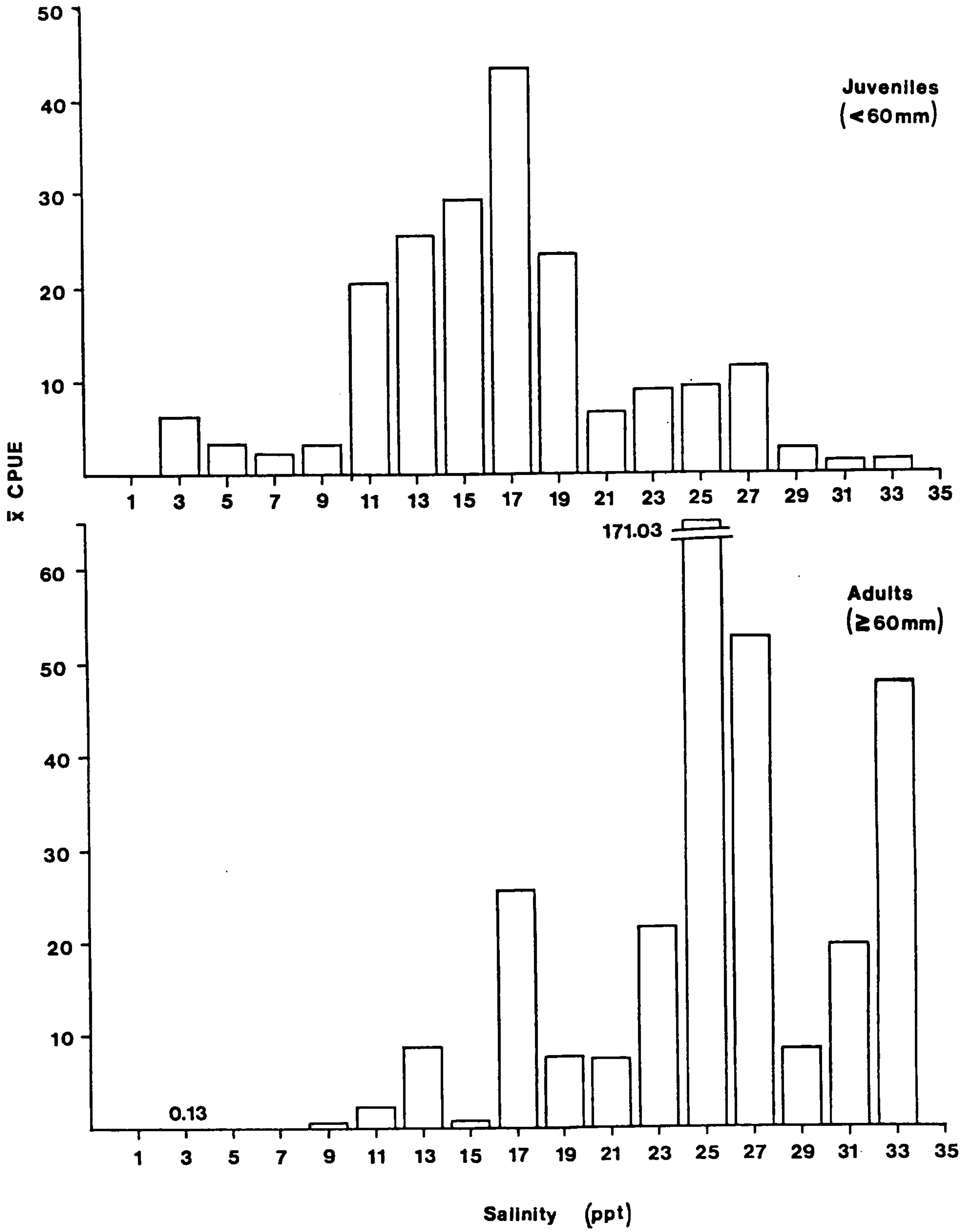


Figure 143. Mean CPUE of juvenile and adult bay gobies vs. salinity.

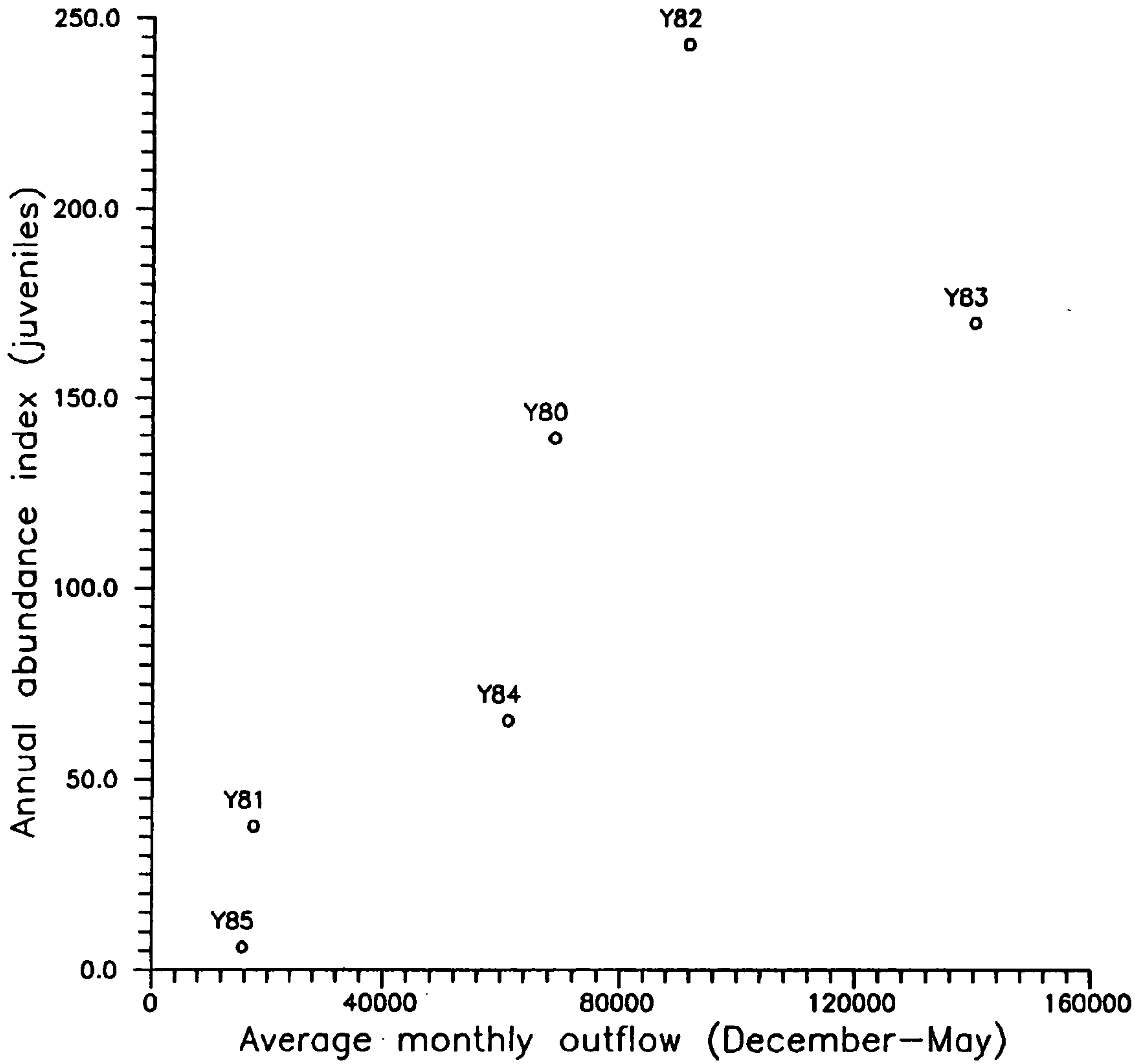


Figure 144. Annual abundance of juvenile bay gobies vs. outflow (r=0.801).

This may be the period that year class strength is determined, but there is no significant relationship between juvenile abundance and subsequent adult abundance. There is also a positive correlation between adult abundance (June-October) and December-May outflow ($r=0.751$). There is a significant correlation between the annual abundance index of all sizes of bay gobies (otter trawl) and December-May outflow ($r=0.949$, $p<0.01$) (Figure 145). Because the life history of this species in the Bay is not well documented, the mechanism for such a relationship is speculative at this time. Juveniles may be more abundant in high outflow years because they move to more suitable habitat, food supply is increased, predators are less abundant, or some other factor or combination of factors.

Delta outflow effects on the distribution of bay gobies appears to be minimal, due in part to their use of South, Central, and lower San Pablo bays. There was a shift of juveniles from San Pablo Bay to South Bay in 1983, the highest outflow year. Adults, which may use burrows to a greater extent than juveniles, did not move downstream during high outflow years.

Summary

The bay goby was the eighth most abundant fish collected by the otter trawl by this study. Because of their abundance and relatively small size, bay gobies are presumed to be preyed upon by many fishes. Their benthic existence and preferred food items would lead to the conclusion that they are an important link in the food web in the Bay.

The peak spawning period was July to October, which is later than previously reported. There is some indication that larvae are carried from the Bay during high outflow years as 1983.

There is a negative relationship between annual larval abundance and Delta outflow. There is a positive relationship between juvenile and adult abundance and winter-spring outflow. The mechanism for this relationship is not known at this time.

This species is not tolerant of low salinities (we rarely collected fish at salinities less than 10 ppt), but juveniles were collected at lower salinities than adults. Bay gobies were most common in South, Central, and San Pablo bays. There was little effect of Delta outflow on distribution.

Arrow Goby

The arrow goby (*Clevelandia ios*) is probably the most abundant native goby in the San Francisco Bay and estuary. Its geographic range extends from Gulf of California to Vancouver Island, B.C. (Miller and Lea, 1972). This species is found mostly in shallow areas with soft substrates and is common in bays, estuaries, and tidal sloughs. It is often commensal with burrowing invertebrates, especially the ghost shrimp (*Callianassa califoriensis*), mud shrimp (*Upogebia pugettensis*), and fat-inn keeper worm (*Urechis caupo*). The male arrow goby constructs a burrow for the female to deposit her eggs.

The arrow goby reaches a maximum size of 45-50 mm and matures at one year (30-40 mm). The majority die after spawning and few live long than two years (MacDonald, 1972; Brothers, 1975). Larvae have been collected year-round; the period of peak spawning varies with geographic location (southern populations peak earlier than northern populations). In Mission Bay (San Diego) and Anaheim Bay (Orange County), peak spawning is from February to May (MacDonald, 1972; Brothers, 1975). In Elkhorn Slough (Monterey County), peak spawning occurs 2 months

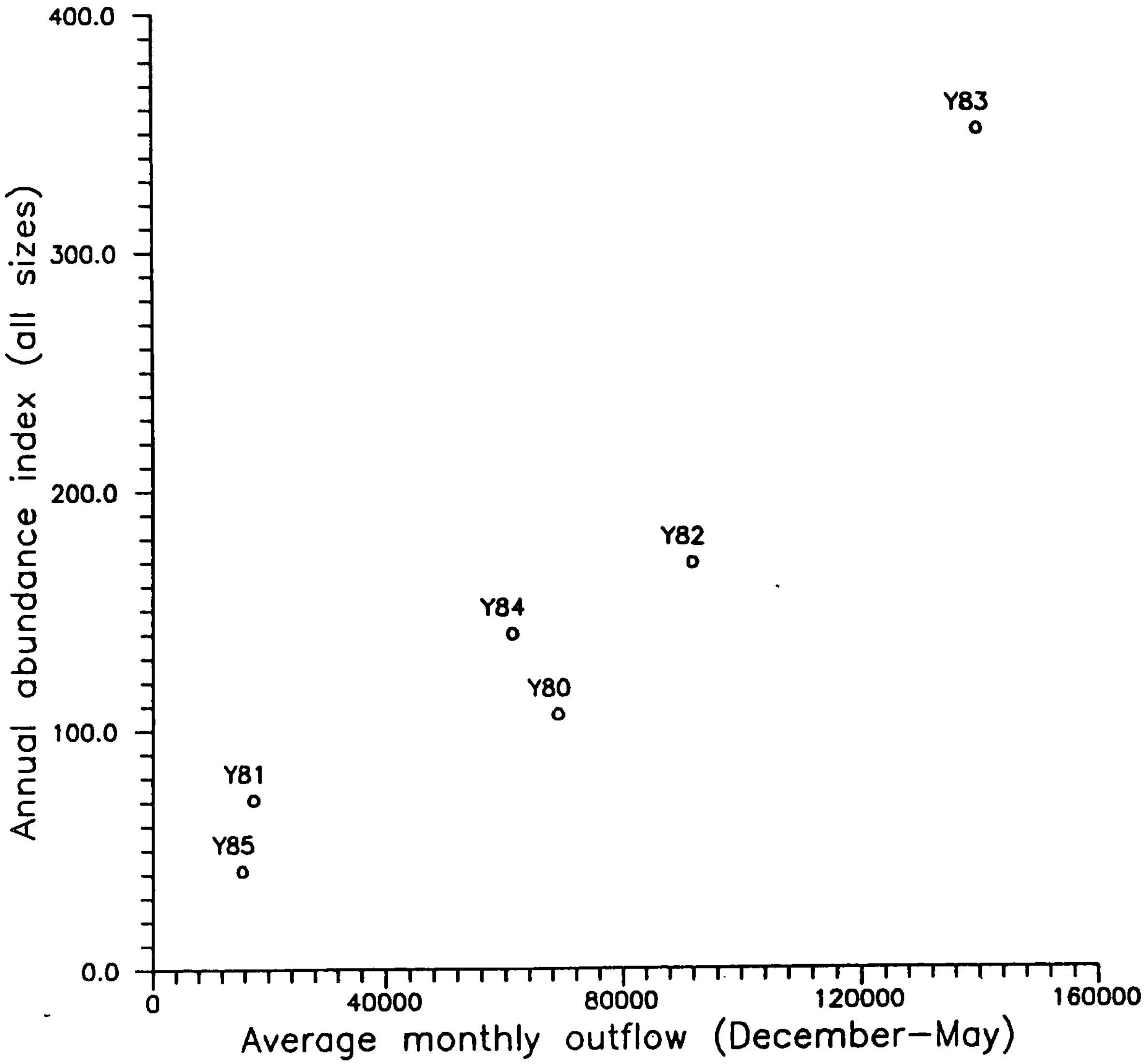


Figure 145. Annual abundance of bay gobies (all sizes) vs. outflow (r=0.949).

later (Brothers, 1975). Arrow goby larvae were collected from August to December in Humboldt Bay (Eldridge and Byran, 1972).

Arrow gobies prey upon a variety of organisms, including copepods, amphipods, ostracods, nematodes, tanacians, and mollusc siphon tips (MacDonald, 1972; Brothers, 1975). They are consumed by many fishes, including California halibut and staghorn sculpin (MacGinitie and MacGinitie, 1949; Brothers, 1975; Haaker, 1975). They are also preyed upon by wading shorebirds including willets, godwits, curlews, short-billed dowitchers, and greater yellowlegs (MacGinitie and MacGinitie, 1949; Reeder, 1951). Because of their abundance, small size, and position in the food web, arrow gobies are an important component of California estuaries.

Relative Abundance

Very few arrow gobies were collected in the otter trawl, so this data set was not used for this analysis. They comprised 2.6 percent of all fishes collected in the beach seine. The larvae (which are combined with larvae of the less abundant cheekspot goby) accounted for 5.5 percent of all larval fish collected (Table 22). As with other species of gobies, the relative abundance of juvenile and adult arrow gobies is probably underestimated by trawls and seines due to their burrowing habits. The larval data are probably more indicative of their relative abundance (larvae ranked fifth in abundance in the plankton net; juveniles and adults ranked eighth in abundance in the beach seine). In Yaquina Bay, Oregon, arrow goby larvae ranked fourth in abundance (Pearcy and Myers, 1974). A complex of goby larvae (the major component was the arrow goby) ranked first in abundance in two surveys of Newport Bay (White, 1977; M. Horn, personal communication).

Larval Abundance and Distribution

Arrow goby larvae were collected throughout the year (Figure 146a), but the peak abundance was from April to July. The peak abundance of larvae did not occur later during years of high outflow. Annual abundance of arrow goby larvae was highest in 1981 and lowest in 1983 (Table 25). Annual abundance remained low in 1984 and 1985. Most arrow goby larvae were collected in South and San Pablo bays (Figure 147). More were collected upstream of Carquinez Strait in 1981 and 1985 than in other years.

Table 25

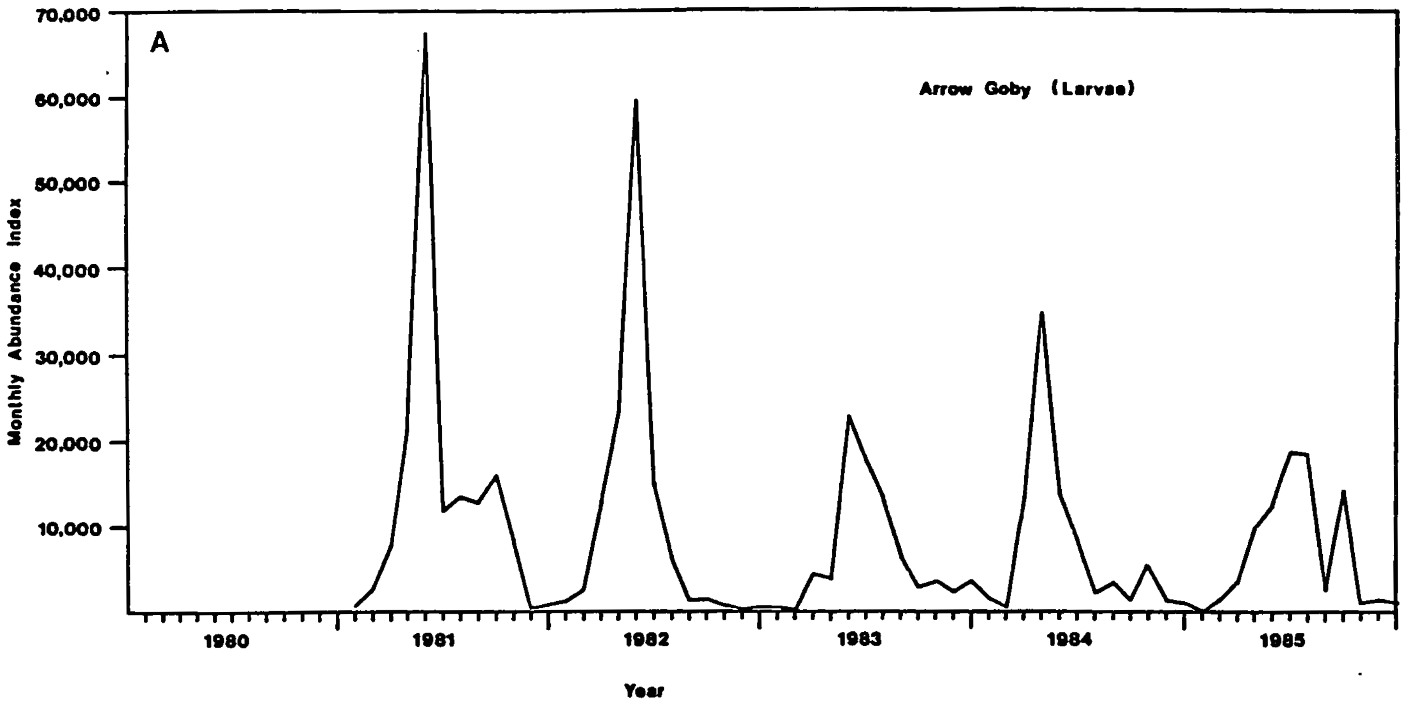
ABUNDANCE INDICES FOR ARROW GOBY

Year	Larvae	Juveniles/adults
1981	13,239	138
1982	10,433	15
1983	6,794	56
1984	7,169	24
1985	7,007	10

Juvenile and Adult Abundance and Distribution

Peak abundance of arrow gobies collected in the seine net was from March to August (Figure 146b). It is assumed that the majority of these fish were juveniles, as the timing of this peak was generally one month after the peak abundance of larvae. The highest annual index was in 1981, the lowest in 1985 (Table 25). There is a positive, but not significant relationship between larval abundance and annual abundance of juveniles and adults from the seine (r=0.723).

Most arrow goby juveniles and adults were collected in South, Central, and San Pablo bays (Figure 148). We did not collect more arrow gobies in Suisun Bay during years of low outflow, as with yellowfin gobies.



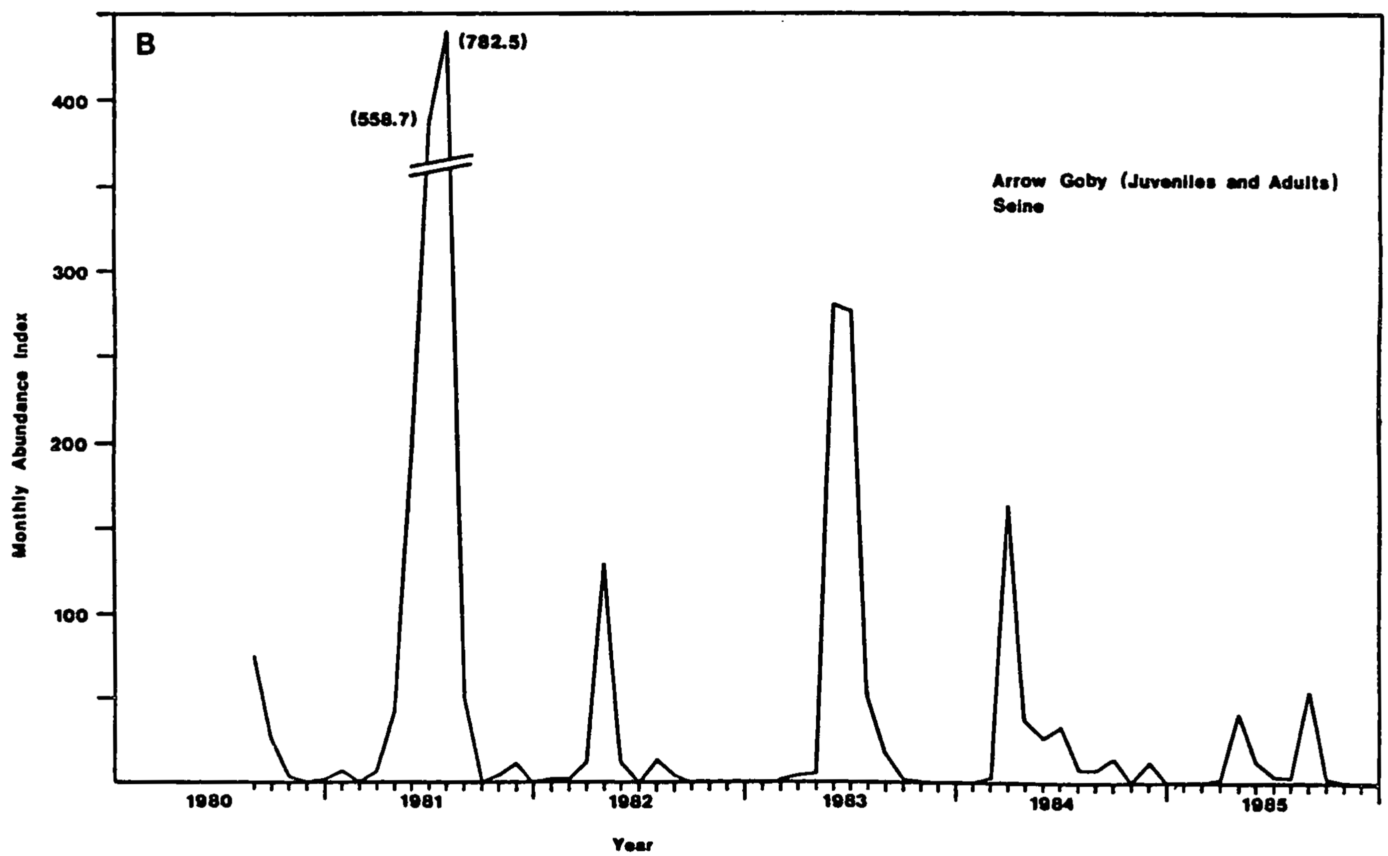
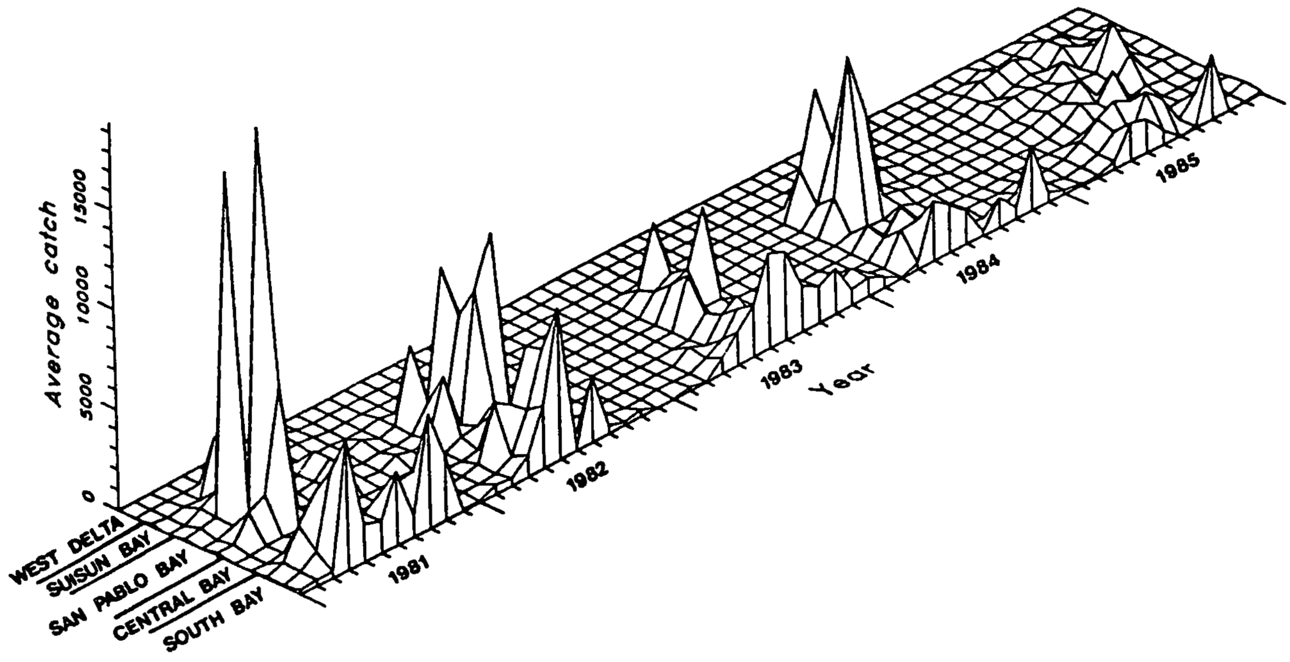


Figure 146. Monthly abundance indices of larval, juvenile, and adult arrow gobies, 1980-1985.



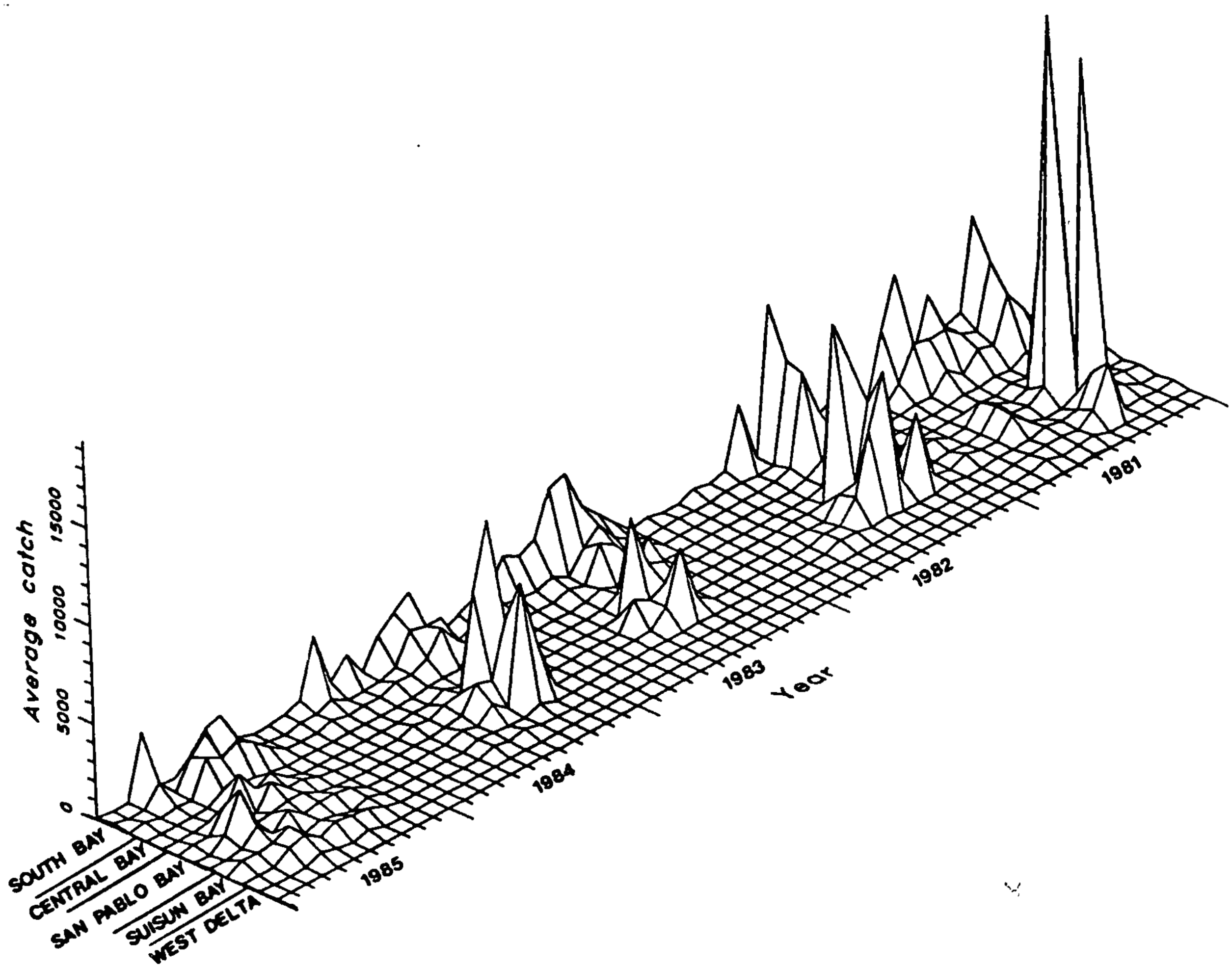


Figure 147. Distribution of arrow and cheekspot goby larvae.

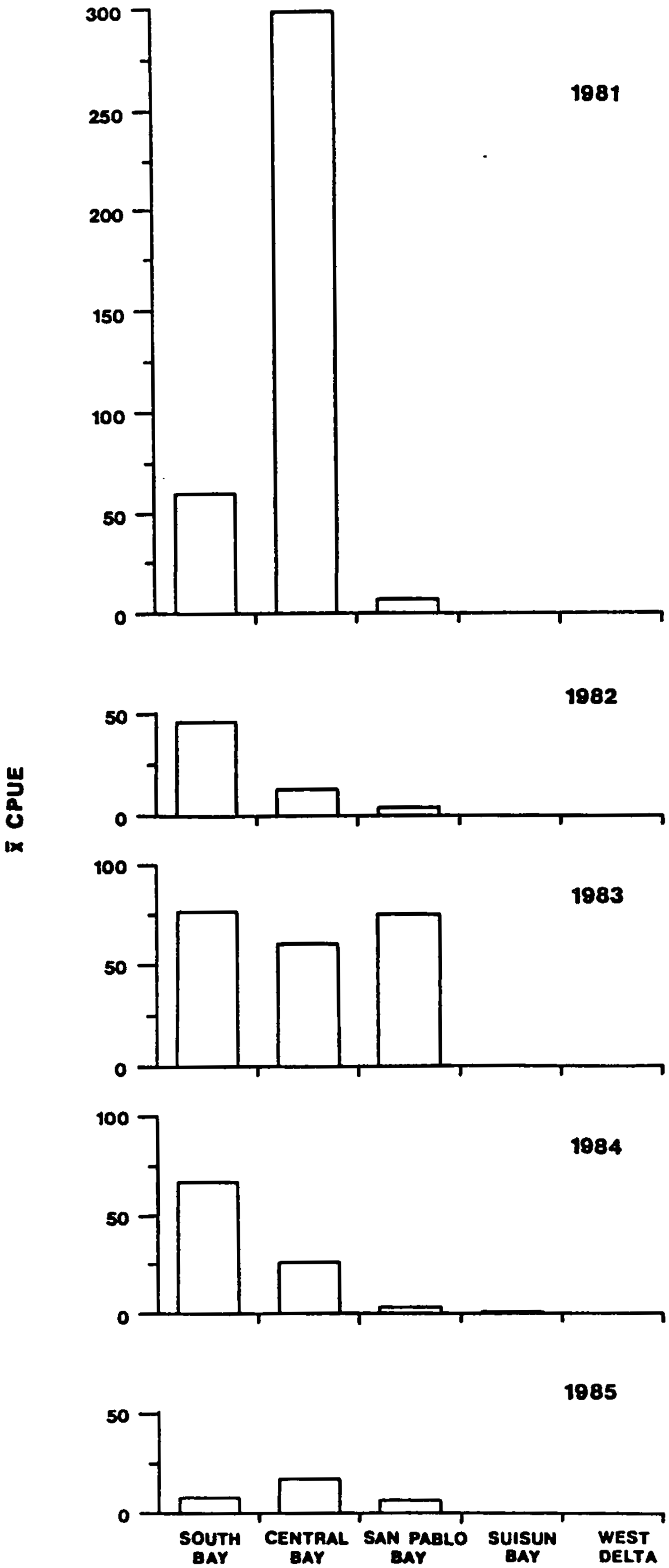


Figure 148. Distribution of arrow goby juveniles and adults.

Effects of Salinity and Temperature

Arrow gobies were collected over a wide range of salinities (3.6-33.9 ppt) and temperatures (7.5-30.5 degrees C). Highest catches were at salinities greater than 11 ppt and temperatures from 15 to 26 degrees C (Figure 149). During 1982 and 1983, arrow gobies were collected at lower salinities than in other years (Figure 150). This is consistent with the distributional data, which indicated that they did not shift upstream or downstream in response to outflow. Salinities in Suisun Bay may be within their tolerance range these years, but their preferred habitat may not be available.

Effects of Delta Outflow

There appears to be little effect of Delta outflow on abundance or distribution of arrow gobies. Both larvae and juveniles had highest and lowest abundance during low outflow years (1981 and 1985). There is no strong relationship between arrow goby annual abundance and the magnitude of Delta outflow (r=-0.254, March-May outflow). Although we collected more larvae upstream of Carquinez Strait in low outflow years, we did not collect more juveniles or adults in this area during these years. Arrow gobies can tolerate a wide range of salinities, but did not expand their range to Suisun Bay during low outflow years.

Summary

The arrow goby is a small fish which prefers intertidal mudflats. It is often commensal with burrowing invertebrates, resulting in an underestimation of its relative abundance in trawl and seine samples. This was the eighth most abundant fish collected by the beach seine, but the fifth most abundant larvae in the plankton net. Arrow gobies spawn all year with a peak spawning period from April to July. Spawning did not occur later during high outflow years.

Arrow gobies were collected in South, Central, and San Pablo bays. Their distribution did not expand upstream during low outflow years, possibly because of lack of suitable habitat. They were most abundant at salinities greater than 11 ppt, but their salinity range varies widely by year. There is no strong relationship between the annual abundances of arrow gobies and Delta outflow.

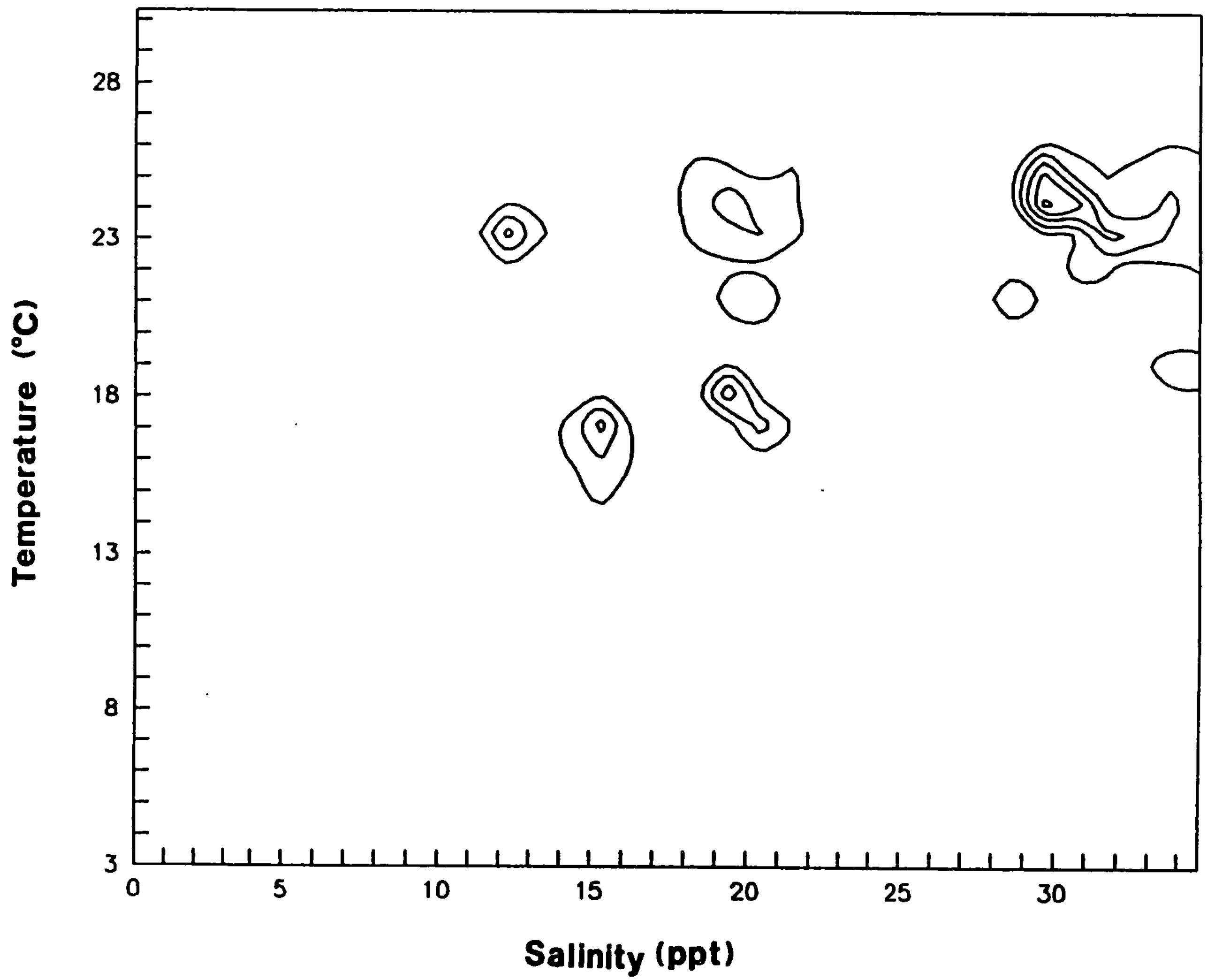


Figure 149. Mean CPUE of arrow gobies vs. salinity and temperature (contours from 200 to 2200, every 400).

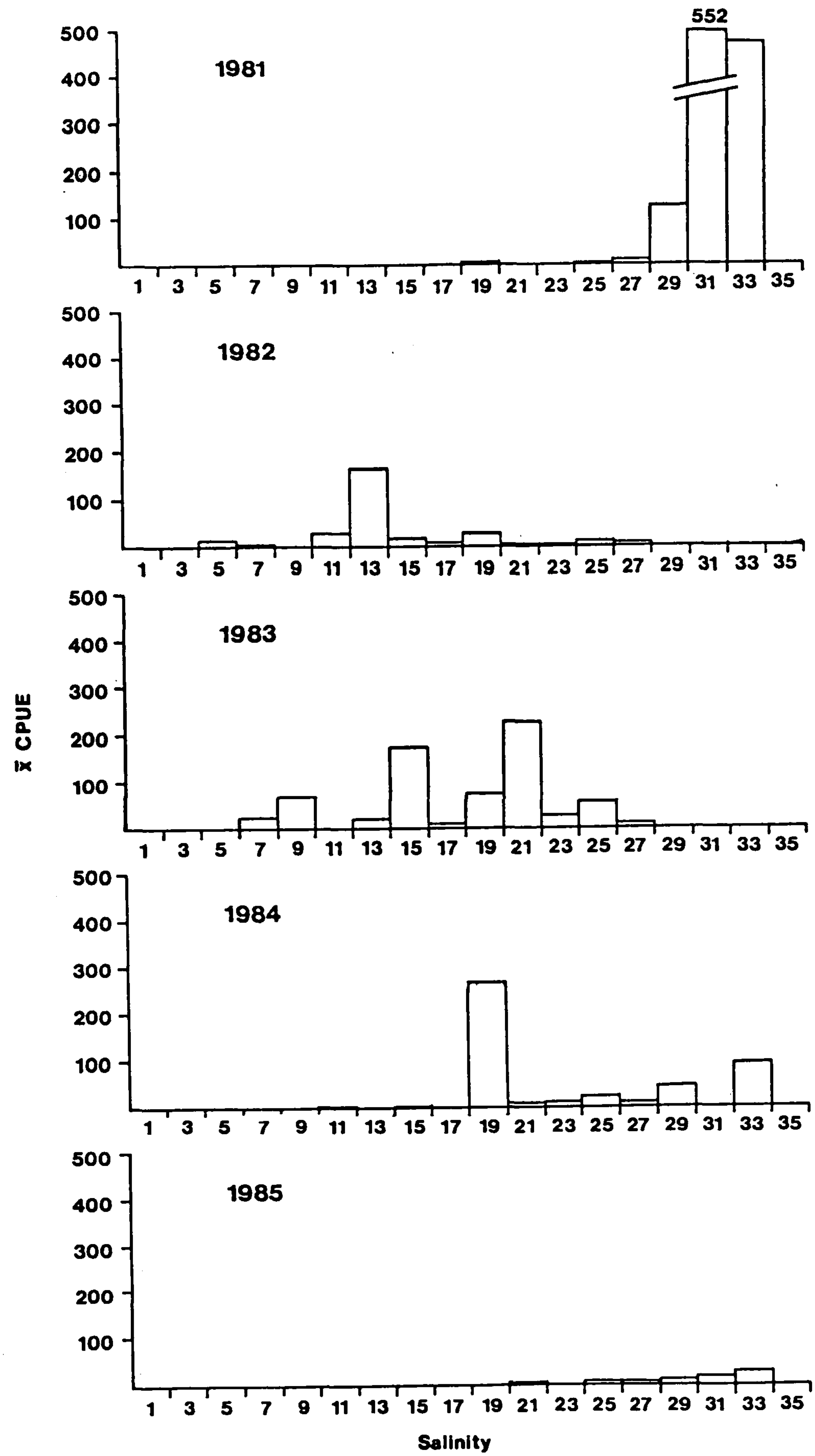


Figure 150. Mean CPUE of arrow gobies vs. salinity, by year.

Chapter 10. FLATFISH

Flatfish, fish of the order Heterosomata, are a large and important group containing many valuable food species, including the halibuts, soles, flounders, and sanddabs.

Anatomically speaking, flatfish are most notable for their adaptions for bottom dwelling. As juveniles and adults, they are severely dorso-ventrally flattened, have both eyes on the top of the head, and are generally pigmented only on the top side.

Flatfish are not born with the bottom dwelling characteristics exhibited by juveniles and adults. The larvae of most flatfish are pelagic, near-surface dwelling forms that are anatomically similar to other fish. The metamorphosis from pelagic to bottom dwelling form takes place early in life, so that generally by the time they are 8-15 mm in length (depending on the species) they have adopted the sterotypical flatfish form and way of life.

Three of the four flatfish families found worldwide, Bothidae, Pleuronectidae, and Cynoglossidae, are represented by species found along the California coast (Herald, 1961; Miller and Lea, 1972). In all, about 30 species of flatfish have been recorded from the coast of California, and 9 of these were captured during our sampling in 1980 through 1986 (Table 26).

The species listed in Table 26 are ranked by their abundance in the otter trawl. The list includes some of the most important game and commercial fish found along the Central California Coast, including English sole (Parophrys vetulus), starry flounder (Platichthys stellatus), California halibut(Paralichthys californicus), and Pacific sanddab (Citharichthys sordidus). Absent from the list are such important commercial flatfish species as Dover sole (Microstomus pacificus), petrale sole (Eopsetta jordani), and rex sole (Glyptocephalus zachirus), which are not generally found at any life stage in shallow, inshore waters like those of San Francisco Bay.

This report discusses only the four most abundant species from otter trawl sampling. The other five, California halibut, diamond turbot (Hypsopsetta guttulata), sand sole (Psettichthys melanostictus), curlfin turbot (Pleuronichthys decurrens), and Pacific sanddab, were not caught in large enough numbers to allow meaningful analysis of their distribution or abundance patterns in the Bay. Also, the Bay is in some geographical or physical sense at the edge of the range of the four least abundant species, suggesting that: (1) conditions in the Bay are not critical to the success of the species, and (2) they are not a major element of the Bay fish community.

Since juvenile and adult flatfish are generally offshore bottom dwellers, they are most efficiently sampled by the otter trawl. Sampling effort associated with each trawl was measured as the area of bottom swept by the net for the purposes of determining flatfish CPUE.

Flatfish larvae are pelagic. We therefore measured the effort associated with individual egg and larval net tows as the volume of water filtered for determining larval flatfish CPUE.

Table 26

FLATFISH SPECIES CAPTURED DURING SAN FRANCISCO BAY-DELTA OUTFLOW STUDY SAMPLING, 1980-1986
(Total number caught and percentage of the number of all fish species caught is listed, by gear type)

		Sampling Gear					
		Egg and Larva		Seine		Otter Trawl	
Rank	Species	Number	Percent	Number	Percent	Number	Percent
1	English sole	394	0.05	218	0.17	10,415	7.21
2	Speckled Sanddab	0	0.00	5	<0.01	4,744	3.29
3	Starry flounder	162	0.02	114	0.09	3,301	2.29
4	California tonguefish	0	0.00	0	0.00	827	0.57
5	California halibut	63	<0.01	25	0.02	84	0.06
6	Diamond turbot	194	0.03	37	0.03	66	0.05
7	Sand sole	16	<0.01	7	0.01	24	0.02
8	Curlfin turbot	0	0.01	0	0.00	21	0.01
9	Pacific sanddab	0	0.00	0	0.00	14	0.01
	Total Number	829		406		19,496	
	Percent all fish		0.11		0.32		13.50

California Tonguefish

California tonguefish (Symphurus atricauda) is the only member of the family Cynoglossidae found along the Pacific coast of North America (Wang, 1986; Miller and Lea, 1972). The reported range of the California tonguefish extends from Cape San Lucas, Baja California, to Big Lagoon in Humboldt County, California (Miller and Lea, 1972). Within its range, the preferred habitat of California tonguefish appears to be shallow, coastal waters (Horn, 1980), but they do commonly occur in the lower, more saline parts of coastal embayments (Aplin, 1967; Lane and Hill, 1975).

California tonguefish grow to a maximum length of only about 200 mm (Miller and Lea, 1972), too small to be valuable as a sport or commercial species. However, their small size and great abundance suggest they could be an important forage species for larger coastal fish.

The life history and habits of the California tonguefish are poorly understood. Larvae have been collected in offshore areas during summer and fall (Ahlstrom 1965), but not inside San Francisco Bay or Moss Landing Harbor (this study; Wang, 1986; Eldridge, 1977) suggesting they are coastal marine, not estuarine spawners.

However, the precise location of spawning, age of maturity, environmental conditions associated with spawning, and factors determining larval survival have not been documented (Wang, 1986; Fitch and Lavenburg, 1975).

Distribution and Abundance

We did not collect any larvae of California tonguefish in our egg and larval net samples (Table 26). Larvae were also not collected by Eldridge (1977) in his Richardson Bay sampling nor in recent extensive fish entrainment sampling at electrical power generating stations on San Francisco Bay. Results of these three studies strongly suggest that California tonguefish do not utilize the Bay extensively as a spawning ground or as nursery area for very young (premetamorphis) fish.

During our study, we caught California tonguefish ranging from 45 to 186 mm (total length) in our otter trawl samples (Table 27). Based on examination of the length-frequency distribution of captured fish, it appears that essentially only two age classes (0+ and 1+) inhabit the bay.

YOY (0+) fish first appeared in our samples in the late spring when they are 45 to 90 mm in length; they were abundant generally until September or October. During November and December, few fish of either age class were captured. By January or February, 1+ fish were abundant in some years, but remained so only until May or June.

California tonguefish were found primarily in Central Bay, but were also in South Bay during the years of high Delta outflow, 1980, 1982, 1983, and 1984 (Figure 151). Both age classes were found in greater densities at channel stations than at shoal stations, with 1+ fish showing the greatest difference in density between station types (Figure 152). California tonguefish were not captured in littoral areas sampled by the beach seine.

Effects of Delta Outflow

Figure 153 displays the monthly abundance of each year class of California tonguefish during this study and the estimated Delta outflow during the same period. Examination of the figure suggests:

* Overall abundance of California tonguefish is generally higher in years of high Delta outflow than in years of relatively low Delta outflow, and

* The peak abundance of 1+ age class fish precedes the peak abundance of 0+ age class fish by several months in most years.

To further examine the general association of annual abundance of each age class with preceding flow conditions, we correlated the mean area weighted CPUE for the typical period of peak abundance for each age class with the mean monthly Delta outflow during an earlier set of months. Figure 154 illustrates a similar positive association between abundance and Delta outflow for both age classes. Neither correlation was significant at $p=0.05$, but both were at $p=0.1$. The similarity in the general flow response of the two age classes is illustrated by Figure 155 which shows a strong correlation between the annual abundance variables of each age class.

It is difficult to evaluate these apparent associations between California tonguefish abundance and Delta outflow because so little is known about this species. We did examine whether abundance in the Bay is associated with abundance outside the bay rather than Delta outflow. We correlated our indices of total abundance with the City of San Francisco's catch during its June otter trawl survey south and

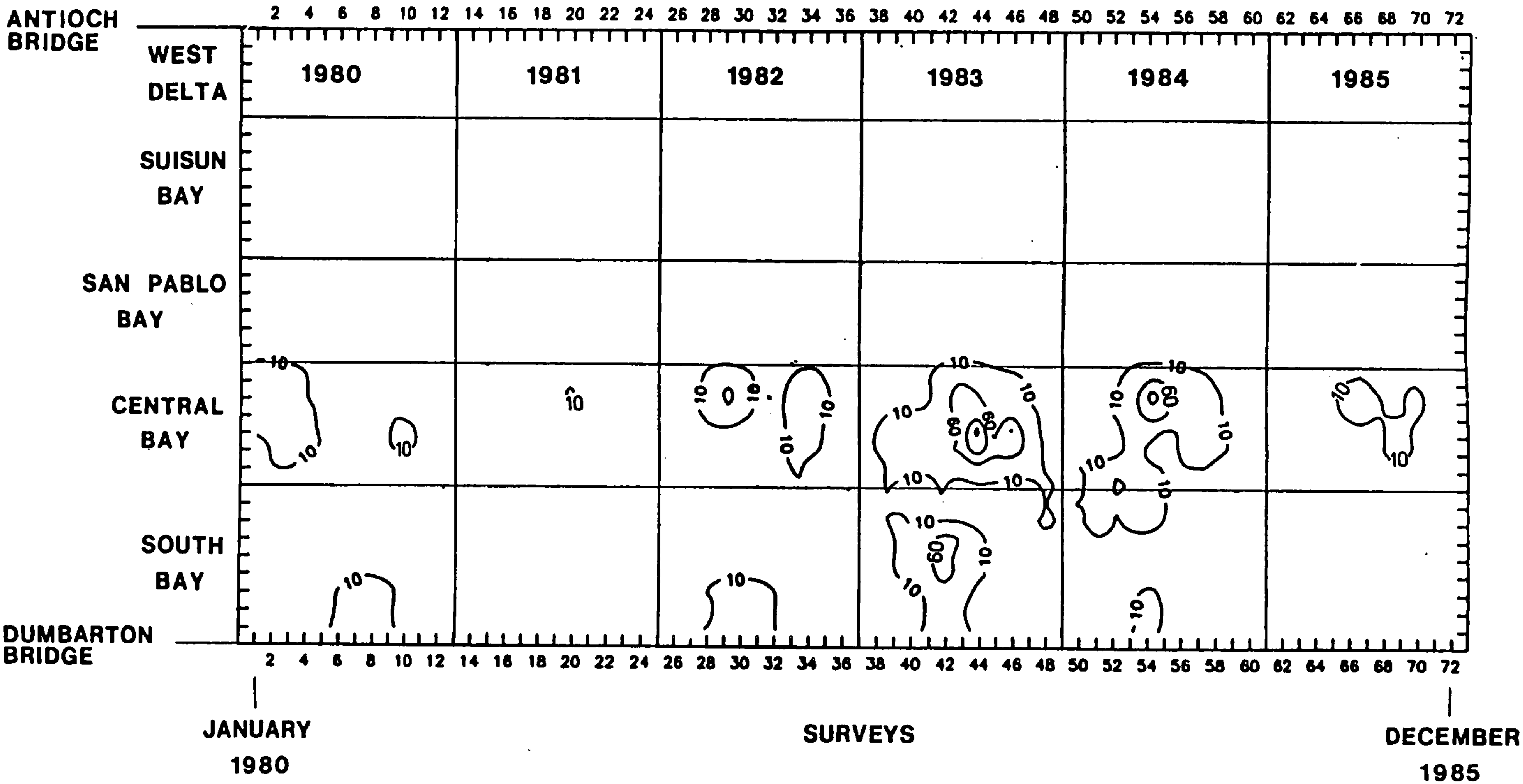


Figure 151. Abundance of California tonguefish in San Francisco Bay during the period 1980 through 1985. Abundance is represented by CPUE contours of 10, 60, 110, and 160 fish per 10000 m^2 swept by the otter trawl. Data has been smoothed before plotting using the Inverse Distance weighting technique (Ripley 1975).

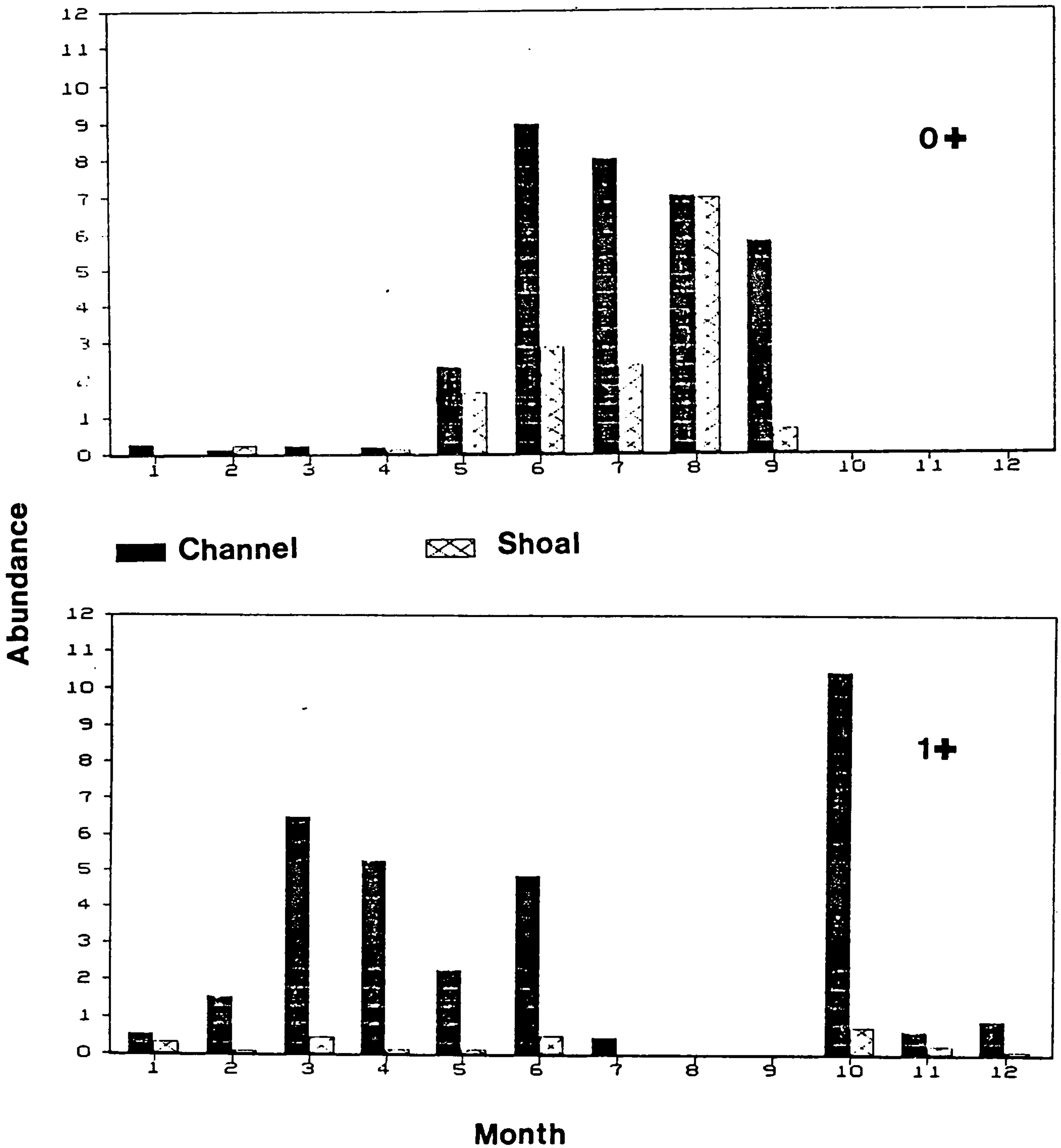


Figure 152. Seasonal distribution of YOY (0+) and adult (1+) California tonguefish at channel and shoal stations, 1980 through 1985. Abundance is calculated as the mean CPUE for each station type.

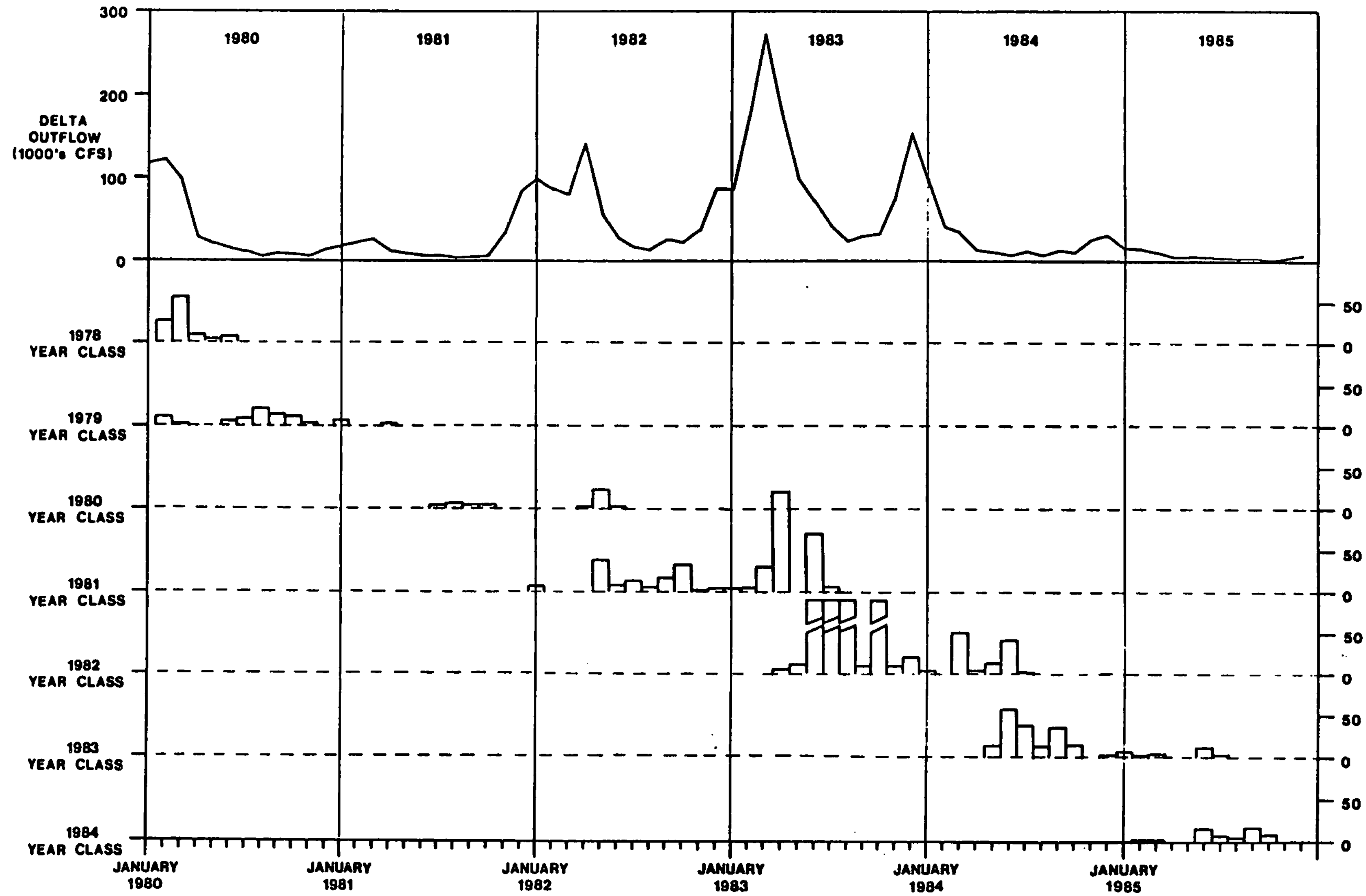


Figure 153. The monthly index of abundance of the 1978 through 1984 year classes of California tonguefish in San Francisco Bay during the years 1980 through 1985 and estimated mean estimated daily outflow at Chipps Island during the same period. The indices of abundance are calculated as the mean area weighted otter trawl CPUE for each survey.

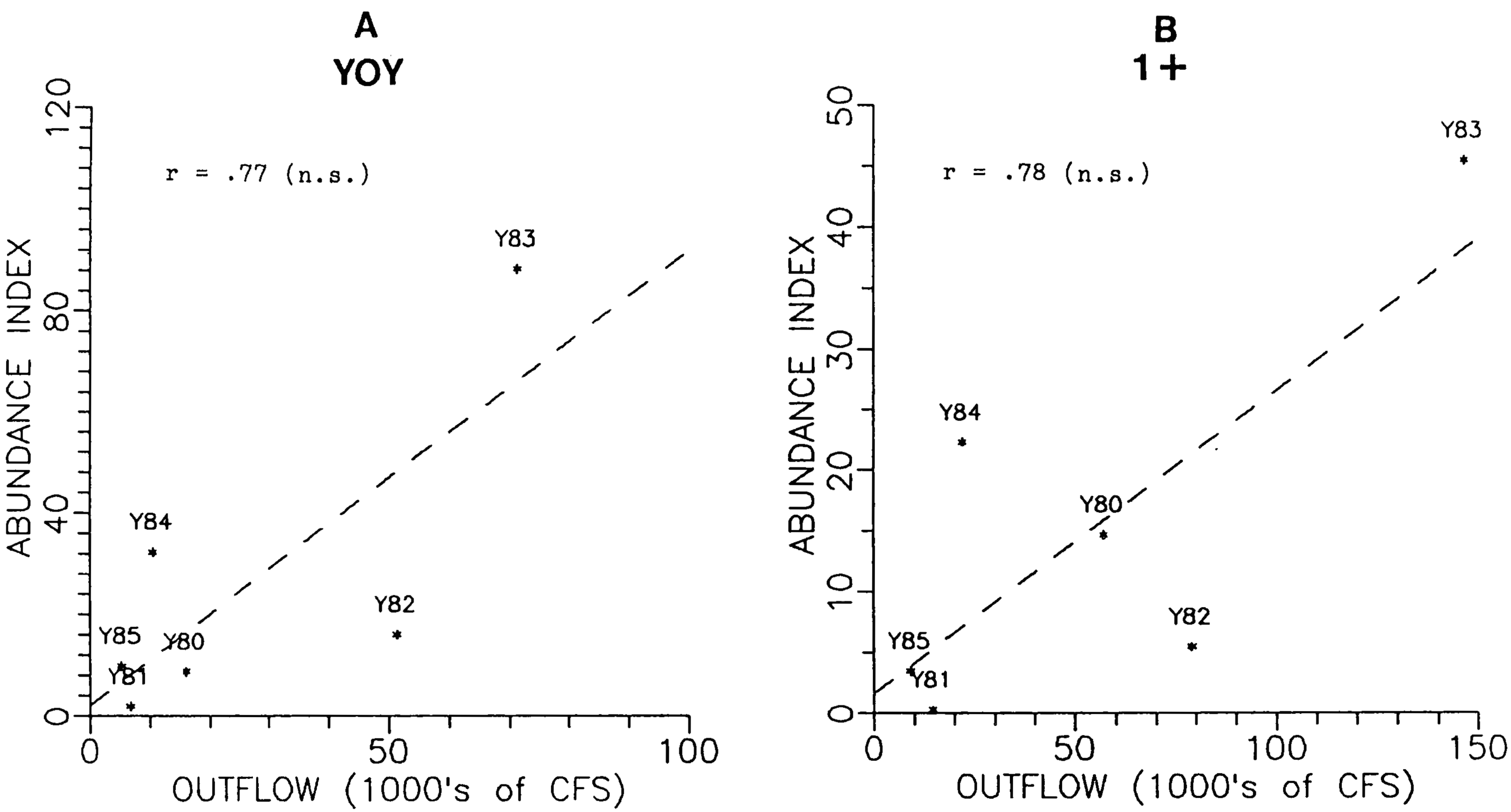


Figure 154. Two plots of California tonguefish abundance versus Delta outflow. Plot A shows the relationship between the mean area weighted otter trawl CPUE of YOY fish for the months May through September and mean monthly Delta outflow for the months April through August. Plot B shows the relationship between the mean area weighted otter trawl CPUE of 1+ age fish for the months March through July and mean monthly Delta outflow during the months February through June.

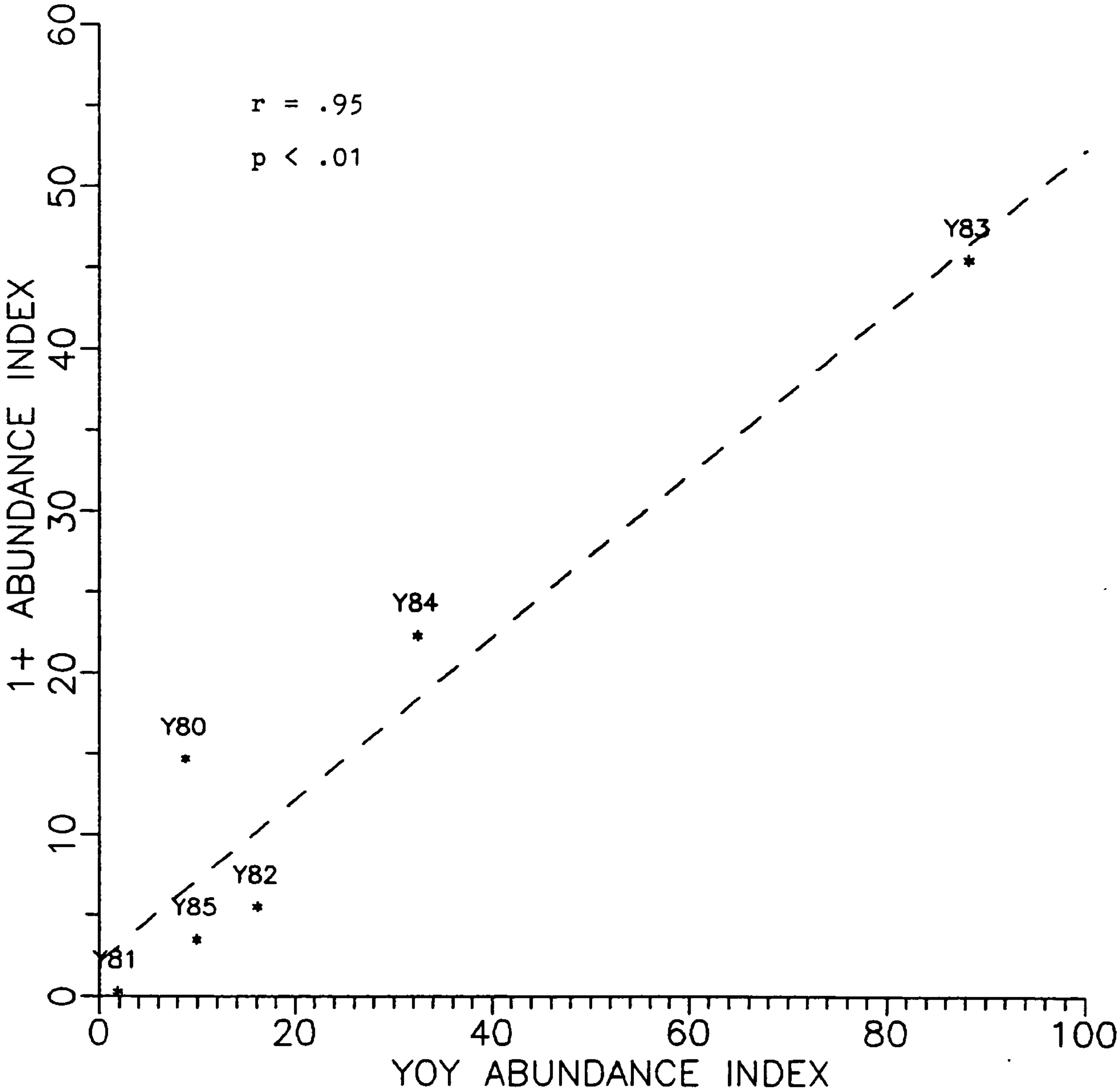


Figure 155. Relationship between the annual indices of abundance for YOY and 1+ age California tonguefish. The YOY index each year is calculated as the mean area weighted otter trawl CPUE for the months May through September, while the 1+ index is the mean area weighted CPUE for the months March through July.

Table 27

LENGTH-FREQUENCY DISTRIBUTION OF CALIFORNIA TONGUEFISH CAUGHT IN THE OTTER TRAWL, 1980 THROUGH 1986

	Month											
Length	1	2	3	4	5	6	7	8	9	10	11	12
0												
10												
20												
30												
40	1			2	8	2						
50	2	1			11	28	3	1				
60			1		16	45	36	40		1		
70		1			7	23	27	48	4	9	1	
80	4				5	8	23	25	14	24	2	
90	4	8	3	3		95	17	5	30	31	2	
100	8	15	12	9	5	4	2	3	19	24	1	1
110	3	10	9	14	7	8	1		5	13		4
120	1	1	6	16	6	11	2			2		4
130			6	6	7	10	1			1		2
140				1	1	2						
150			1		1	1	1					
160					1							
170					1							
180			1									
190												
200												
210												
220												
230												
240												
Total	23	36	39	51	76	144	113	122	72	105	6	11

west of the Golden Gate. Although there was not a strong association between the two abundance variables (p=0.28, n.s., n=4), having only 4 years of data for comparison prevents drawing a conclusion about this potential relationship.

We addressed the question of whether YOY abundance was related to 1+ fish abundance in the previous year, because 1+ fish could represent, at least in part, the parental generation for the YOY fish. No positive association was apparent (r=-0.17, n.s., n=5). Likewise, there was no apparent association (r=0.21, n.s., n=5) between the YOY abundance in one year and 1+ abundance in the next year.

Assuming the apparent positive association between Delta outflow and California tonguefish abundance is real and that Delta outflow is causitive, mechanisms related to Delta outflow that result in the abundance changes are still unknown. Again, the paucity of fundamental life history information available for this species makes discussion of flow effects speculative.

The fact that 1+ age fish tend to be present during periods of high flow suggests that they may be carried into the Bay by landward flowing bottom currents. YOY fish are not generally present in the Bay during periods of high flow; rather, they occur after flows have receded, suggesting a response to some residual effect of high flows such as increased food supply.

English Sole

Of flatfish making extensive use of the Bay, English sole is the species of greatest economic importance. The species is a high quality food fish and a major component of the groundfish fishery off the California coast. In 1986, 844 metric tons of English sole were landed in California, making up about 3 percent of the total California groundfish landings (Henry, 1987). The life history of English sole has been well studied, including the factors influencing its abundance.

English sole have a protracted spawning season, but spawning occurs primarily during January through March (Richardson and Pearcy, 1977). Before settling, the eggs and larvae go through a 5-month development period during which they drift in coastal waters, 2 to 28 km from shore (Hayman and Taylor, 1980; Pearcy and Myers, 1974). Upon settling, the juvenile fish migrate into quiet near-shore waters or embayments where they live until the fall of their first year (Olson and Pratt, 1973). Young English sole then begin to migrate back into open coastal waters where they live out their lives, entering the fishery at 3 or 4 years of age.

The time spent by English sole in estuaries and embayments is short, however, this habitat type can be an important component of their life cycle. Olson and Pratt (1973) showed that Yaquina Bay, Oregon, was essentially the exclusive nursery area for English sole in that area of the Oregon coast, possibly because the exposed coastline does not offer suitable habitat. A similar situation may exist for California English sole, because of the exposed, open coastline with strong surf and currents.

Our data show that English sole use San Francisco Bay primarily as a nursery area. Table 26 shows relatively few larvae were taken during the our study, and virtually all of the 10,415 fish caught in the otter trawl were 4 to 16 months old. Therefore, this section discusses the use of San Francisco Bay by juvenile English sole and the influence of Delta outflow on that use.

Distribution and Abundance

On the average the numbers of larval English sole were quite low. The greatest number of larvae caught at any one station was about $150/m^3*10^3$ with more common monthly catches ranging between $15\text{-}30/m^3*10^3$. January and February were generally the months of highest abundance (Figure 156).

Greater numbers of larvae were present in the higher flow years 1980, 1982, and 1983 and lower abundances occurred in the low flow flow years 1981, 1984, and 1985 (Figure 156). Larvae were also more broadly distributed throughout the Bay during the wet years.

The protracted and variably timed spawning period reported for English sole was reflected in the occurrence of YOY fish in our otter trawl samples in the Bay (Figure 157). Peak abundance of YOY English sole was in May three times (1981, 1982, and 1985), once in August (1983), and once each in June (1984) and July (1980). The timing of first significant occurrence was also quite variable, ranging from March in 1981 to July in 1983. Neither the timing of peak occurrence or first significant occurrence appeared to be

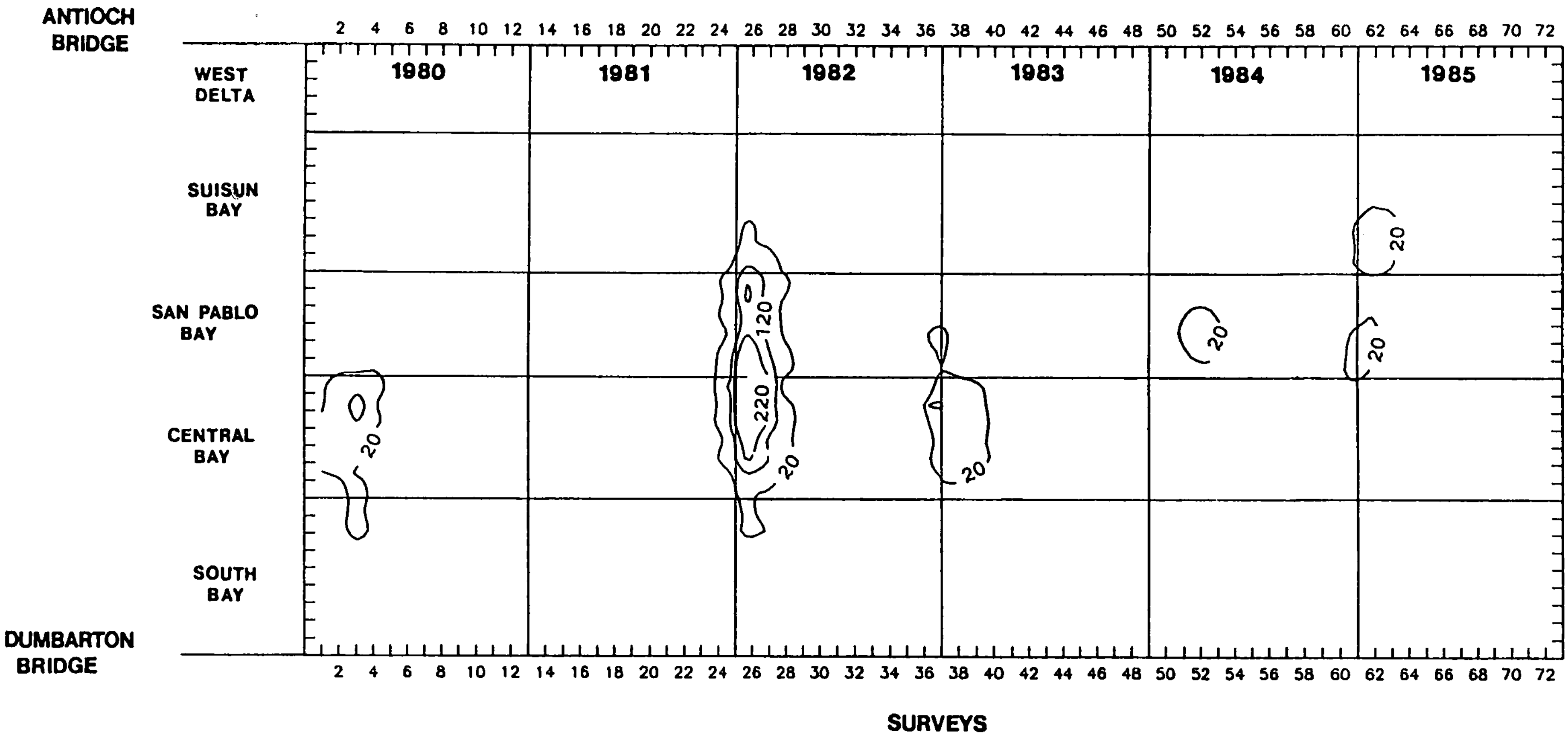


Figure 156. Distribution of larval English sole in San Francisco Bay, 1980 through 1985. Abundance is represented by catch contours of 20, 120, and 220 fish per 10000 m^3 sampled by the Egg and Larval net. Data were smoothed before plotting using the Inverse Distance Weighting technique described by Ripley (1975).

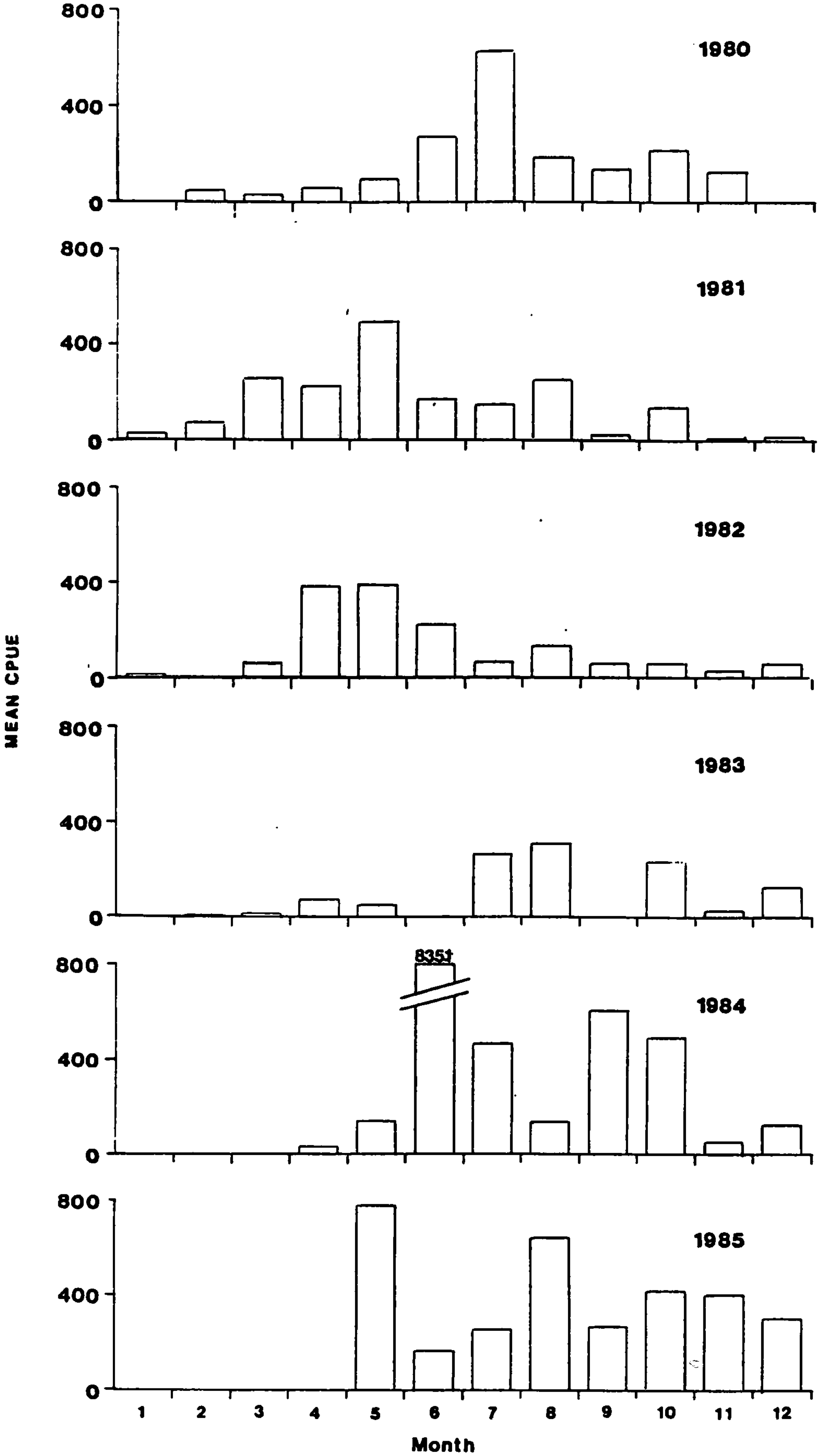


Figure 157. Seasonal distribution of YOY English sole, 1980-1985.

related to the magnitude of Delta outflow.

In general, the abundance of YOY English sole has a broad peak in late spring, summer, and early fall, followed by a decline in November and December (Figure 156). Sometime during their second year, the majority of English sole apparently leave the bay, as indicated by a precipitous drop in catches (Figure 157). This out movement of 1+ age fish occurred by February in 1981 and 1982, and by April in 1985, May in 1983, June in 1984, and not until August in 1980 (Figure 158). Again, timing of this out-migration did not appear related to the winter-spring magnitude of Delta outflow.

During their first year, English sole inhabiting the Bay were found mostly downstream of Carquinez Strait, and principally in Central Bay (Figure 159). Years of greatest upstream penetration were 1981, 1984, and 1985, all dry years. In each of these years the highest upstream penetration was early in the season, with a subsequent movement into Central Bay as the year progressed.

For fish older than one year, upper Central Bay was the area of highest catch in five of the six years of our study (Figure 160). The exception was in 1983, a very wet year, when the fish were centered in upper South Bay and Central Bay.

Effects of Delta Outflow

Intuitively, one would expect that higher flows would "flush" non-motile larvae downstream and out of the Bay. Further, if only tidal action was responsible for carrying larvae into the Bay, one would expect near equal abundances and distributions throughout the Bay each year (assuming a constant spawn offshore). However, greater numbers and broader distributions were observed in the Bay during years of high inflows (Figure 156) suggesting the influence of some operating mechanism such as circulation associated with flow related stratification. The operating mechanism affecting larval sole abundance and distribution appears to be increased upstream bottom flows that occur during periods of greater delta outflow and stratification. These stronger bottom flows subsequently carry more larvae from the ocean greater distances upstream during high flow years.

Distribution of YOY English sole using San Francisco Bay did appear to be influenced by the magnitude of Delta outflow. Figure 159 shows that only in the three years with low spring flows (1981, 1984, and 1985) did YOY English sole make extensive use of San Pablo Bay. In the wetter years they were confined to Central Bay and, to a lesser extent, South Bay. The 1+ age fish had a sporadic distribution within the lower part of the Bay from year to year, which did not seem consistently related to the magnitude of Delta outflow. However, in 1983, the year of highest outflow during our study, there did seem to be a downstream shift in the distribution of juvenile sole (Figure 160).

The distribution characteristics of juvenile sole suggest they are repelled to some extent by high levels of Delta outflow. This is further supported by the fact that they were found primarily in high salinity waters (Figure 161).

The timing of the influx of YOY sole to the Bay and their subsequent out-migration varied considerably from year to year. Therefore we established indices of annual abundance not based on set groups of months, but rather by using groups of months representing the peak of abundance each year for each age group (Table 28). We correlated these abundance indices with the mean monthly outflow for 3-month periods offset 1 month earlier than the 3-month

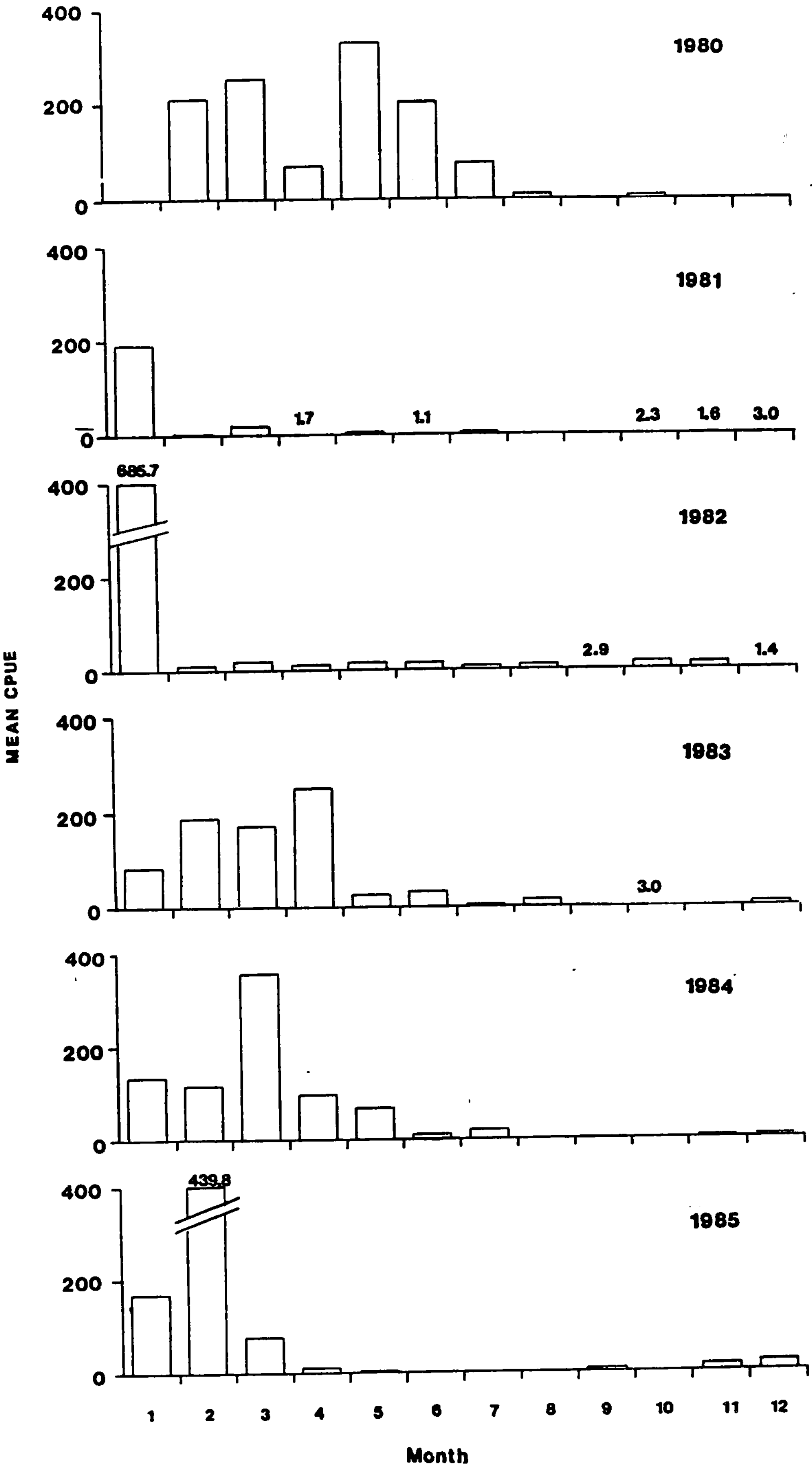


Figure 158. Seasonal distribution of 1+ age English sole, 1980-1985.

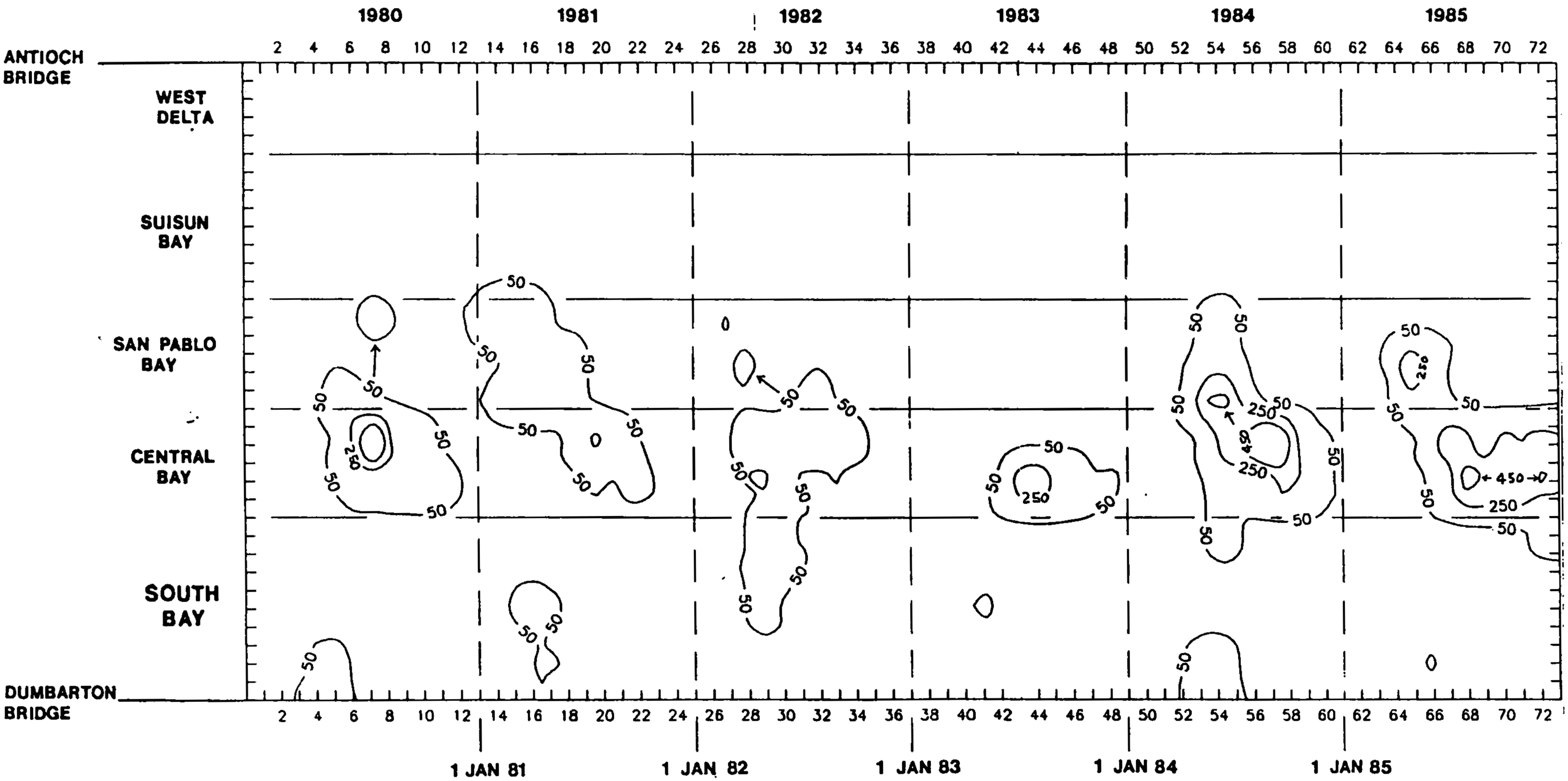


Figure 159. Distribution of YOY English sole in San Francisco Bay, 1980 through 1985. Abundance is represented by catch contours of 50, 250, and 450 fish per 10000 m^2 swept by the otter trawl. Data has been smoothed before plotting using the Inverse Distance Weighting technique described by Ripley (1975).

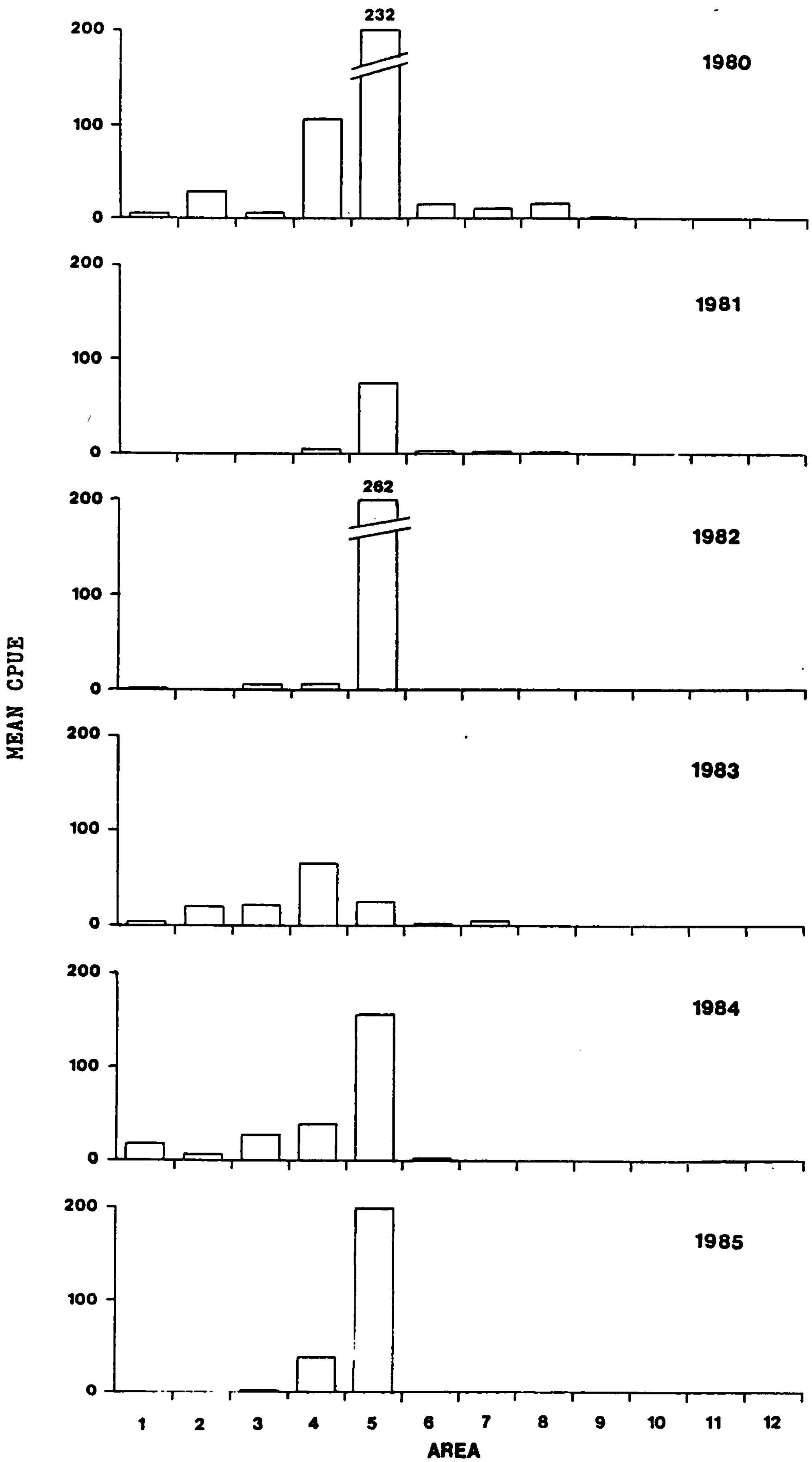


Figure 160. Spatial distribution of 1+ age English sole, January through August.

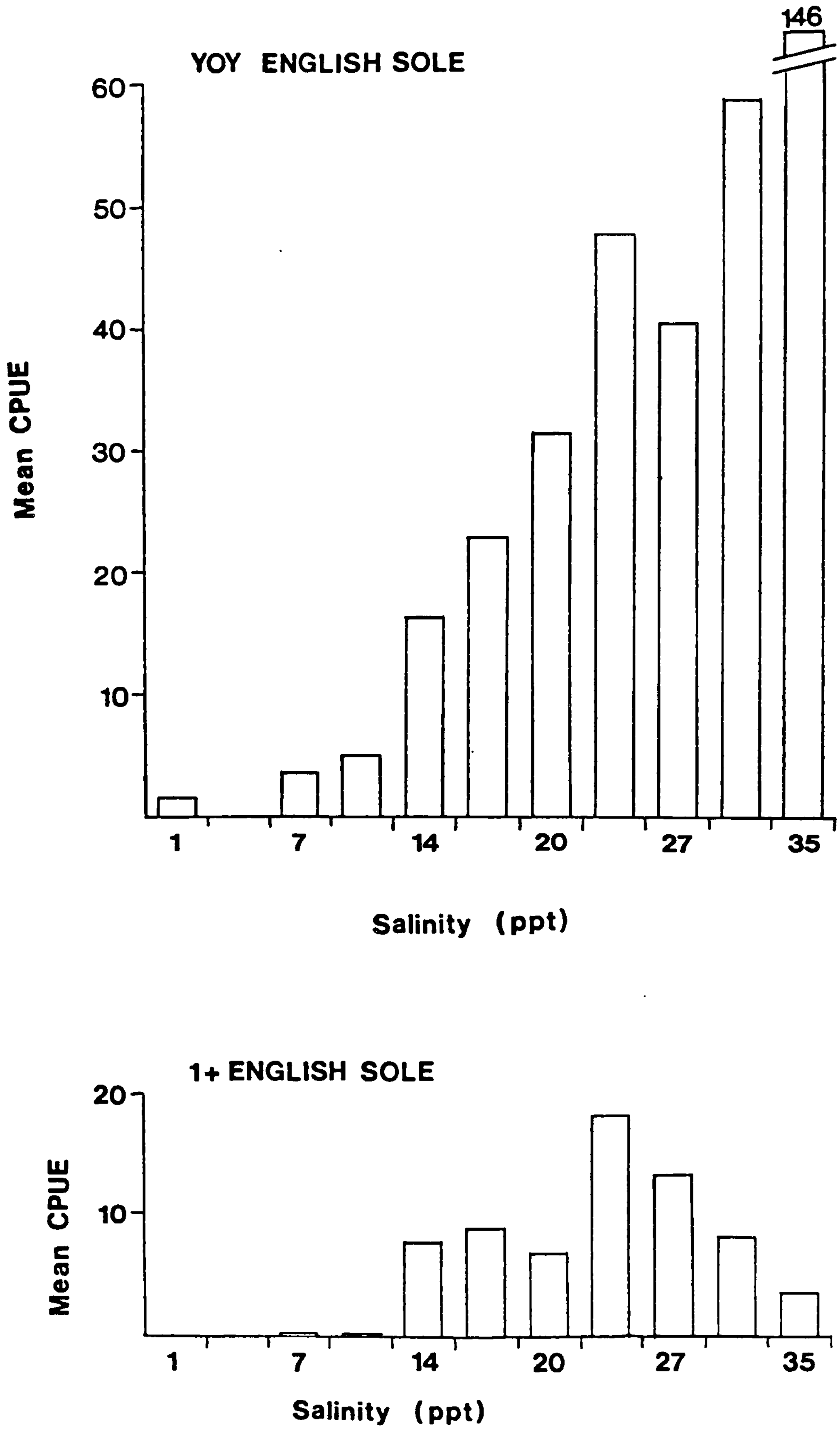


Figure 161. Mean CPUE of YOY and 1+ age English sole vs. bottom salinity.

period used for the corresponding abundance index.

Table 28

MONTHS USED IN ESTABLISHING ABUNDANCE INDICES AND ASSOCIATED FLOW INDICES FOR 0+ AND 1+ ENGLISH SOLE

Year	Abundance	Flow	Abundance	Flow
1980	5,6,7	4,5,6	4,5,6	3,4,5
1981	4,5,6	3,4,5	1,2,3	12,1,2
1982	4,5,6	3,4,5	1,2,3	12,1,2
1983	7,8,9	6,7,8	3,4,5	2,3,4
1984	5,6,7	4,5,6	2,3,4	1,2,3
1985	4,5,6	3,4,5	1,2,3	12,1,2

Flow and abundance were very weakly correlated for both age groups, indicating a lack of association between the two factors. Compared to most other species we have studied, there was relatively little variation from year to year in the abundance of either age group. The overall difference was only about threefold for both age groups.

Summary

We found high densities of juvenile (0+ and 1+ age groups) English sole in San Francisco during every year of our study. This fact, coupled with observations by others that estuaries can be the primary nursery area for some stocks of English sole, suggests the possibility that San Francisco Bay is of critical importance in the life cycle of central California sole stocks. However, we do not know to what extent English sole use other Central California sites, such as Tomales Bay, Bodega Bay, and the lagoons around Pt. Reyes.

The year-to-year variation in abundance of juvenile English sole in San Francisco Bay is relatively small and appears to be unrelated to the magnitude of Delta outflow.

When the abundance index of YOY fish in one year is correlated with that of 1+ age fish the following year, no association is apparent. This suggests that conditions in the Bay might be affecting the survival of young fish during their first year. We then correlated mean monthly flow during the time between the two indices with the ratio of the two indices and found a positive (0.69) but not significant correlation between flow and this rough measure of survival.

A major problem with this analysis is that our measure of survival may, in fact, be simply an indication of the timing and extent of out-migration from the Bay. Without data from juvenile abundance outside the gate, we cannot assess this possibility.

Flow was found to affect the distribution of juvenile English sole within the Bay. Most notably, high levels of Delta outflow appeared to limit the upstream distribution of young fish.

Speckled Sanddab

Speckled sanddab (Citharichthys stigmaeus) are a small member of the Bothidae, or lefteye flounder family, which includes the Pacific sanddab, California halibut, and other important flatfish (Miller and Lea, 1972). Speckled sanddab grow to only about 170 mm total length (Miller and Lea, 1972), making them too small to be pursued by either commercial or recreational fishermen. Therefore, relatively little information is available on the distribution and habits of this species.

Speckled sanddab have been reported along the Pacific Coast from Magdalene Bay, Baja California, to Montague Island, Alaska. They frequent bays and estuaries within their range, including San Francisco Bay (Aplin, 1967; Ganssle, 1966), Yaquina Bay (Pearcy and Myers, 1974), Tomales Bay (Bane and Bane, 1971), Elkhorn Slough (Wang, 1986), and LaJolla Bay (Ford, 1965).

The life history of speckled sanddab has not been well documented. The generally low numbers of larvae reported from estuaries (this study, Richardson, 1977; Pearcy and Myers, 1974) suggest that spawning occurs almost exclusively in open coastal waters. There appears to be a peak in spawning activity in June and July (Ahlstrom and Moser, 1975), but they may spawn year-round; our study found very small juveniles in the estuary throughout the year. Speckled sanddab apparently mature during their second year and can live up to about 4 years (Wong, 1986).

During this study, speckled sanddab were caught in significant numbers only in the otter trawl (Table 26). No larvae were caught in the egg and larval net, only 5 fish were caught in the seine and 14 in the midwater trawls. The otter trawl samples contained 4,744 speckled sanddab, comprising about 3 percent of the total catch for that gear. We used only the catches from the otter trawl in our analysis. Based on length frequencies, it appears the net is almost completely ineffective in catching speckled sanddab less than 25 mm. We assume that since speckled sanddab do not grow very large, the otter trawl gives good information on speckled sanddab through adulthood.

Larval Distribution and Abundance

We did not catch any larval speckled sanddab. Since we sampled in all seasons, at several locations in each embayment, and at all strata in the water column (although biased toward the bottom), this seems strong evidence that the Bay is not an important spawning ground for speckled sanddab. Others have caught larval sanddab (presumably speckled sanddab) in the estuary (Wang, 1986; Eldridge, 1977), but in small numbers. Pearcy and Myers (1974) found a few larval *Citharichthys spp*. in Yaquina, Oregon, but described them as occurring primarily offshore. Richardson and Pearcy (1977) found speckled sanddab larvae at Newport, Oregon, to be concentrated 2 to 28 km offshore.

YOY Distribution and Abundance

Fish less than 75 mm (fork length) were presumed to be less than 1 year of age. We found no Northern California age and growth studies of speckled sanddab to establish their typical length at 1 year or the variation in length at any age. We based our assignment of the fish to year classes on examination of length-frequency distributions from our catches and the work of Ford (1965). Because of variations in hatch time, growth rates, and other factors, this approach may lead to some incorrect assignment of fish to year classes.

Figure 162 shows the length frequency distribution of speckled sanddab in each survey for all years combined. Small juveniles (<50 mm) were present in every period, but were most abundant in the April, May, and June surveys. This seasonal abundance pattern supports conclusions by Ahlstrom and Moser (1975) that speckled sanddab have an extended spawning season, but our data suggest an earlier peak spawn than the June and July period they reported.

There were similarities and differences between years in the seasonal abundance of YOY speckled sanddab (Figure 163). The most striking similarity was a peak in abundance around May or June in every year but 1985. However, among the six years there were noticeable

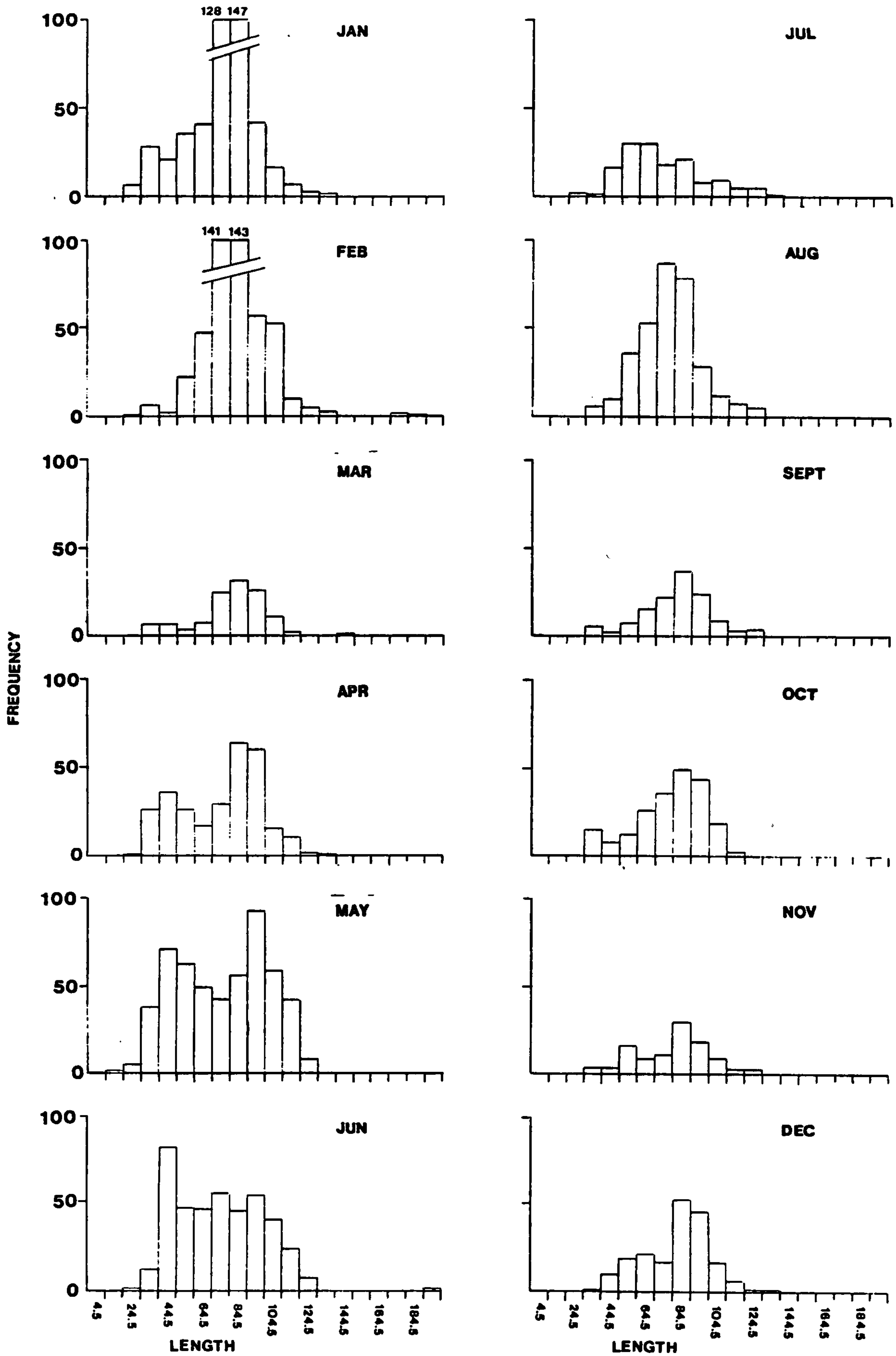


Figure 162. Length frequency distribution of speckled sanddab caught in the otter trawl, 1980 through 1985. Length axis labels are midpoints of 10mm length classes.

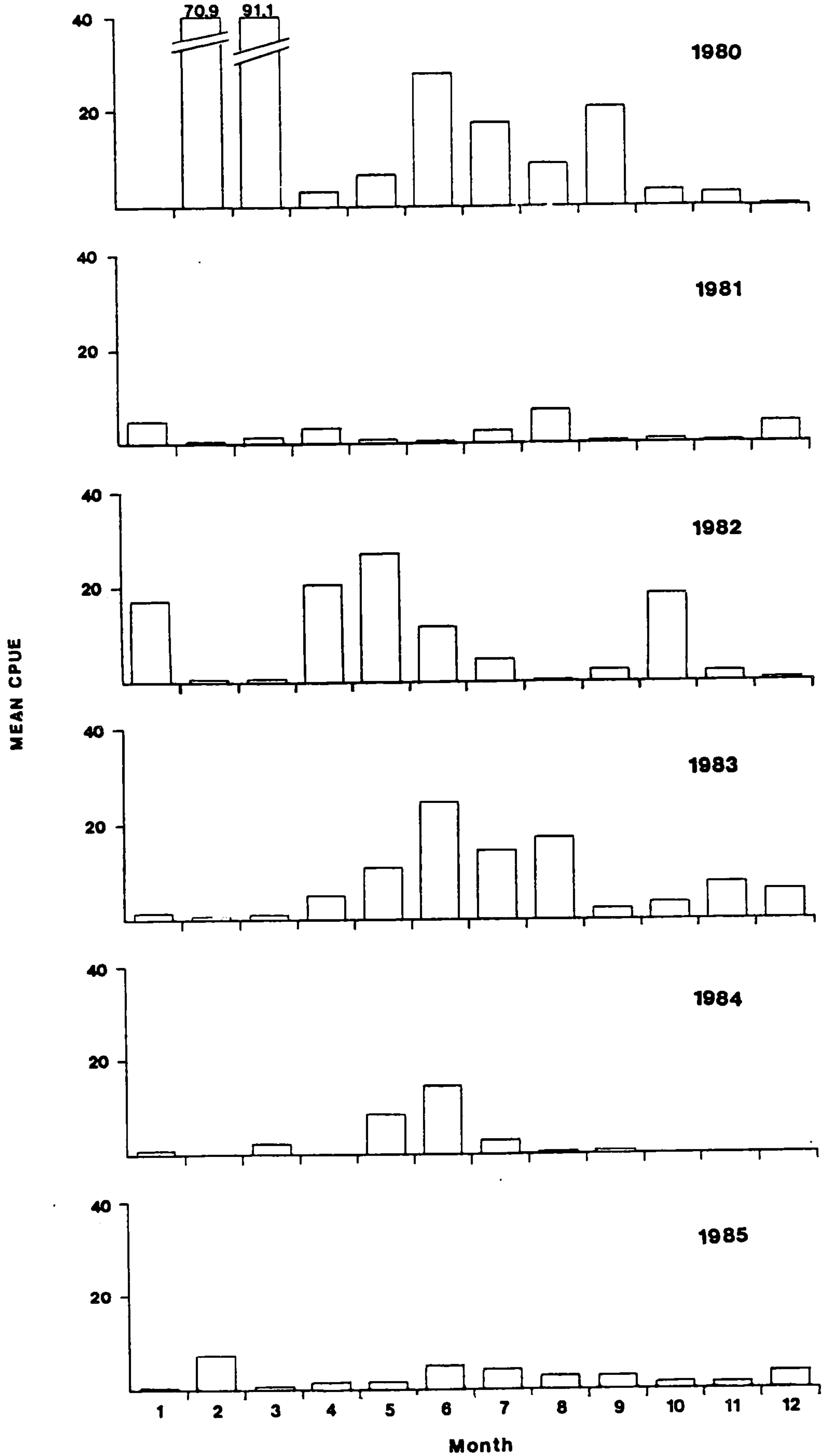


Figure 163. Seasonal distrubution of YOY speckled sanddab, 1980 through 1985.

spikes in abundance at many other times of the year. The May through June peak apparently corresponds to the first significant occurrence of YOY in our net each year.

Figure 164 shows that YOY speckled sanddab are for the most part confined to the lower part of the estuary. In every month but November highest catch was in Central Bay. YOY speckled sanddab were never abundant in San Pablo Bay and were rarely upstream of Carquinez Strait. They were found regularly in South Bay, particularly in April through May.

Adult Distribution and Abundance

We defined adults as speckled sanddab greater than 75 mm, which is their approximate length at one year, when they begin to mature (Fitch and Lavenburg, 1975).

The seasonal distribution of adult speckled sanddab during this study was similar to that of the juveniles (Figure 165). In all years except 1981 and 1985, there was a pronounced peak in abundance in May, June, or July, a pattern similar to that of juvenile fish. Also, the less consistent peaks (February-March 1980, January 1982, December 1983) corresponded roughly with periods of high YOY abundance.

We tested this apparent association of YOY and adult speckled sanddab abundance by correlating systemwide mean YOY area weighted CPUE with mean adult area weighted CPUE and found the association to be intense ($r=0.91$) and significant ($p<0.001$).

As with YOY speckled sanddab, adults tended to be most abundant in Central Bay (Figure 166), to occur regularly but in lower densities in South Bay, and to be caught rarely above lower San Pablo Bay.

Effects of Salinity and Temperature

YOY and adult speckled sanddab both occurred in a wide range of salinities (Figures 167 and 168), but tended to be more abundant in the more saline parts of the Bay. The lowest salinities at which they were found were about 5.5 ppt for YOY and 7.2 ppt for adults; neither were common in salinities less than about 12.0 ppt. During the drier months, when fresh water does not intrude into the lower part of the estuary, both life stages were found almost exclusively in salinities greater than 19 ppt. There was a small difference in the average bottom salinity at which the two life stages occurred, 26.0 ppt for adults and 24.4 ppt for YOY. Figure 169 shows the abundance of speckled sanddab (all sizes) for combinations of bottom temperature and salinity. Greatest concentrations were at salinities greater than 20 ppt and at temperatures from 9 to 18 degrees C.

Effects of Delta Outflow

Figures 170 and 171 show the spatial distribution of YOY and adult speckled sanddab at various levels of Delta outflow from 1980 through 1985. Both life stages are found in greatest concentrations in central and upper Central Bays at all but the highest outflow levels. Only at outflows of 200,000 cfs is overall abundance reduced, and within this flow range the area of highest concentration in the Bay moves to mid- or upper South Bay. Apparently, most fish are moved out of the Bay.

Figures 170 and 171 suggest that abundance of both YOY and adults in the Bay is, to a point, positively associated with the magnitude of freshwater outflow. Figure 172 shows the association of monthly abundance indices for adults and juveniles with mean monthly Delta outflow in the previous month.

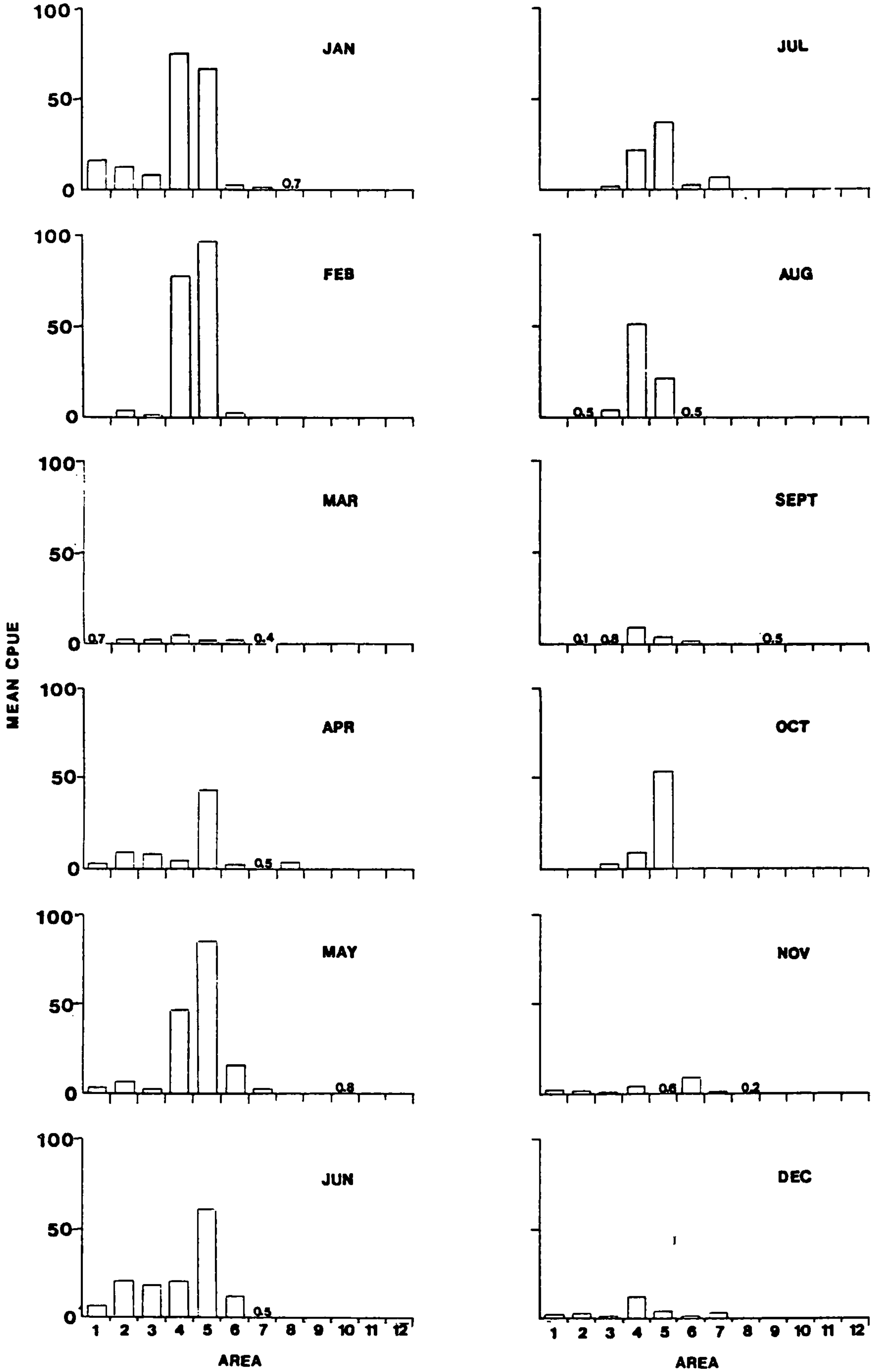


Figure 164. Spatial distribution of YOY speckled sanddab, by month, 1980 through 1985.

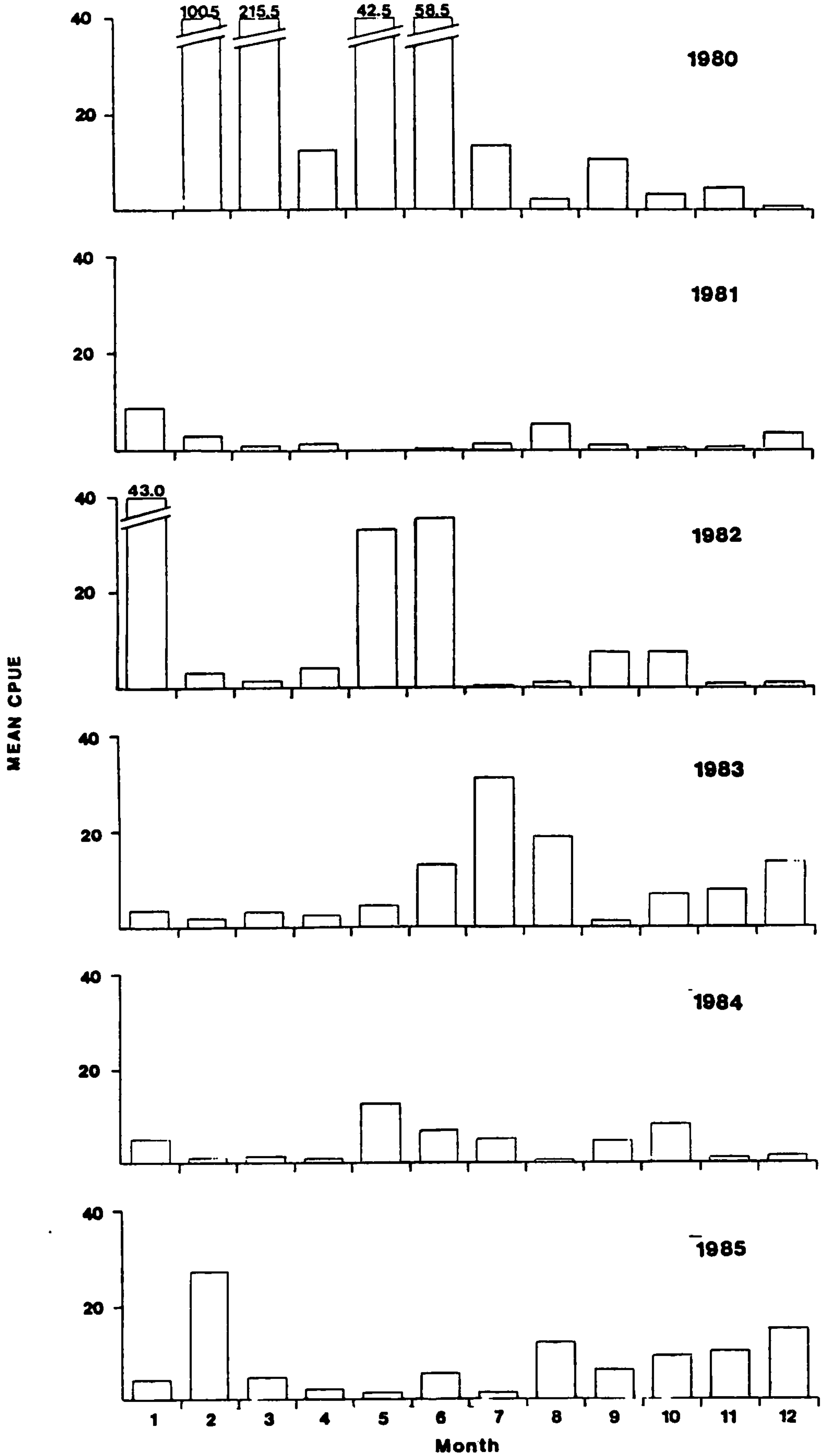


Figure 165. Seasonal distribution of adult speckled sanddab, 1980 through 1985.

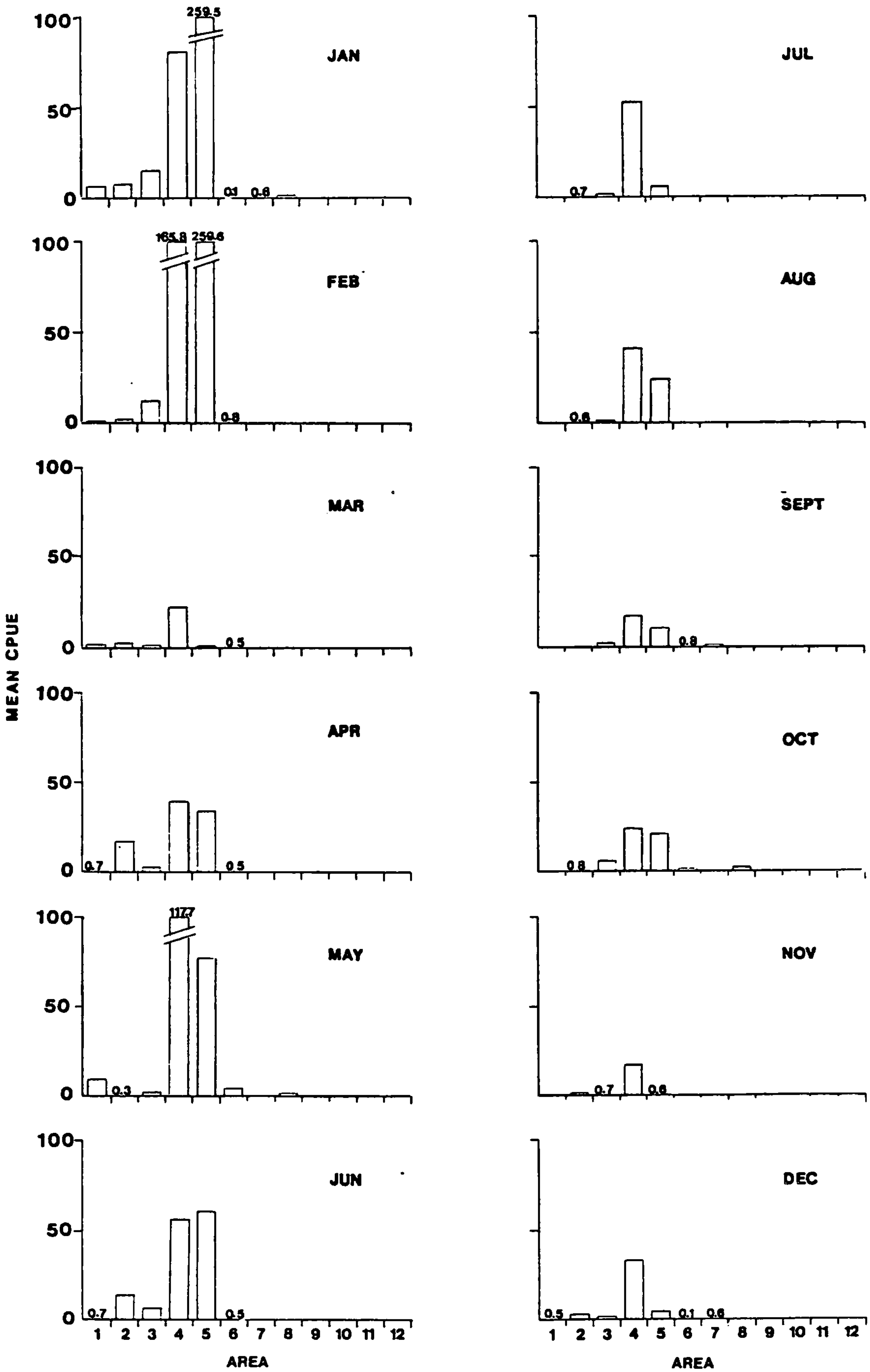


Figure 166. Spatial distribution of adult speckled sanddab, by month, 1980 through 1985.

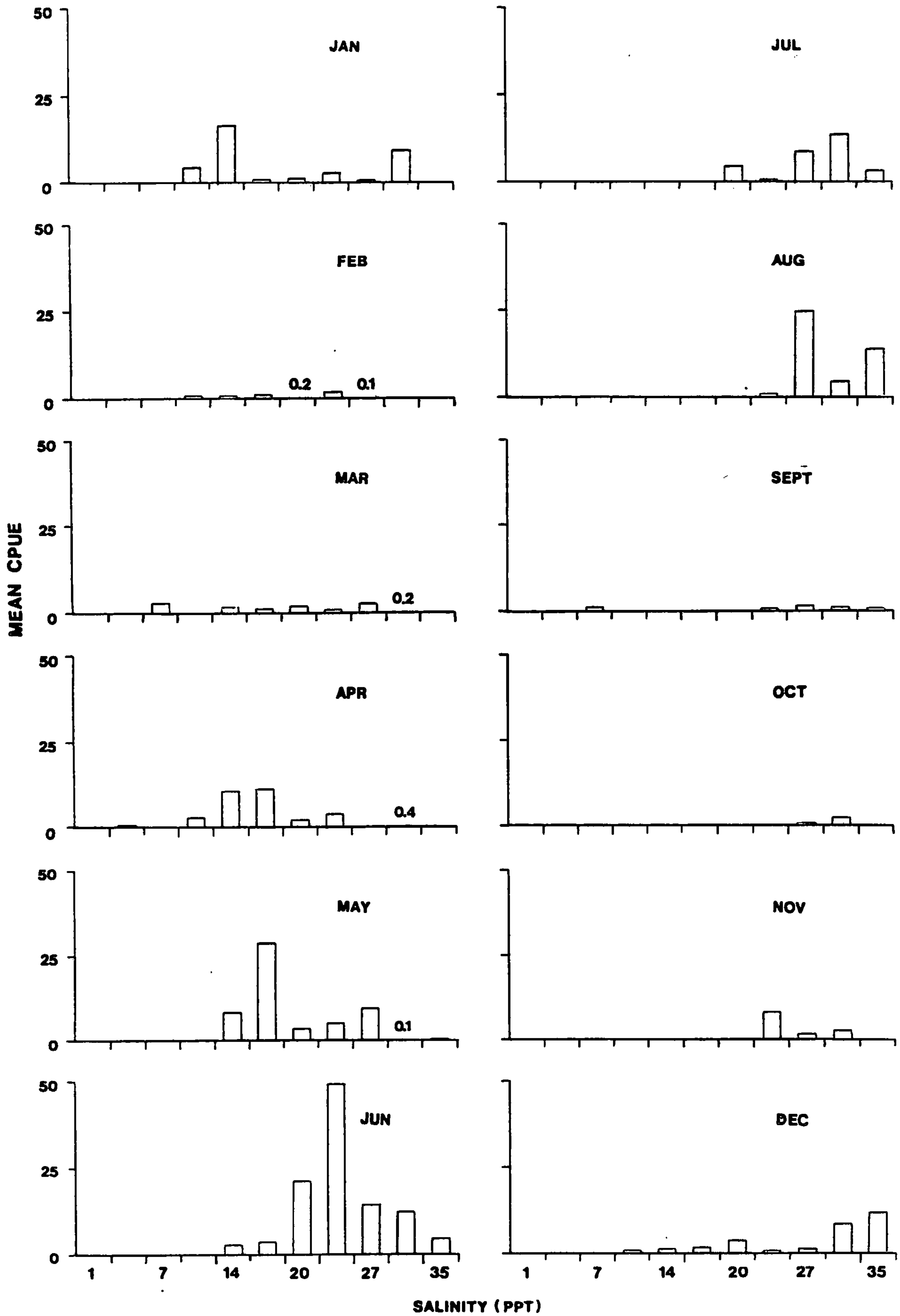


Figure 167. Mean CPUE of YOY speckled sanddab vs. bottom salinity, by month, 1980 through 1985.

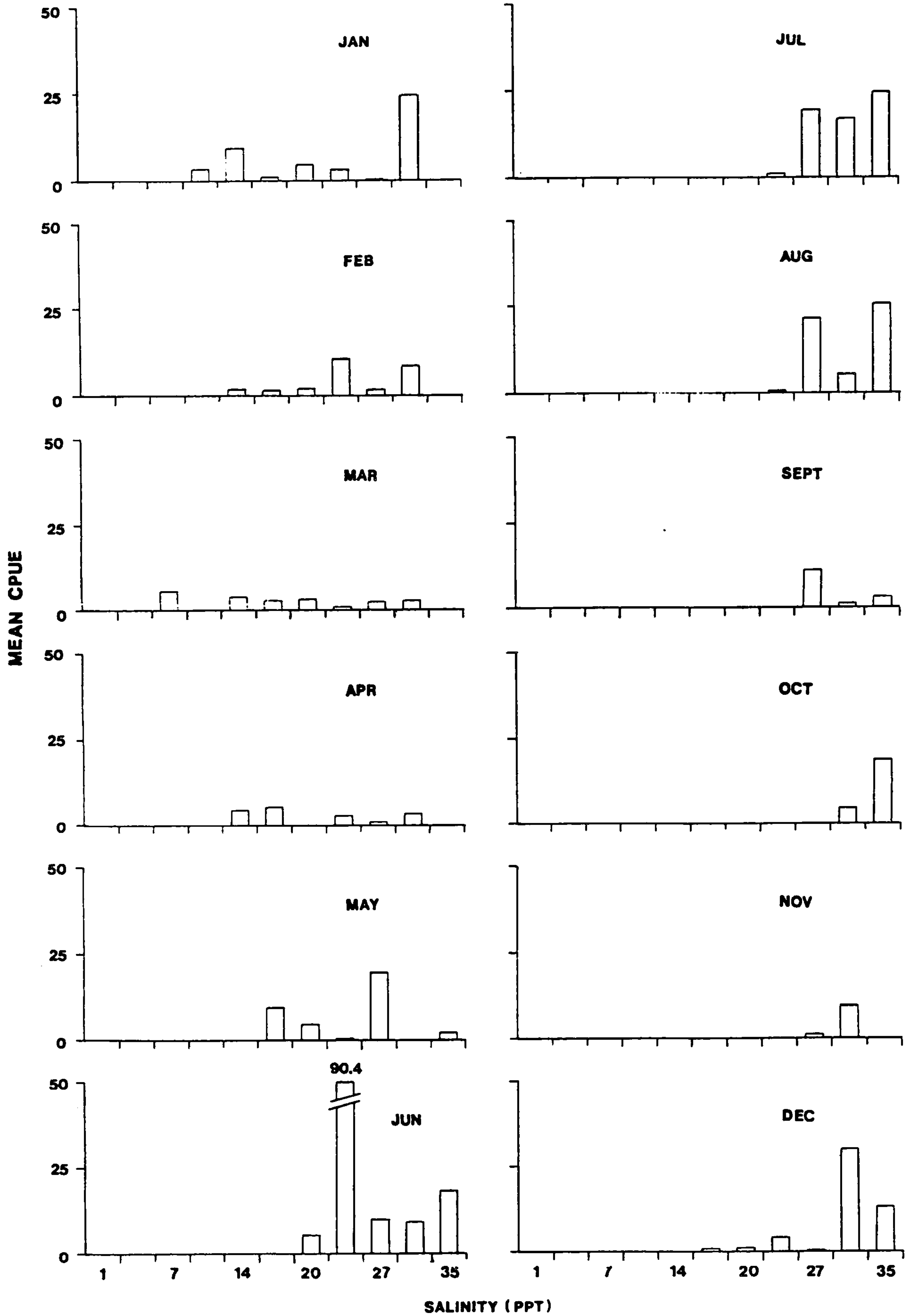


Figure 168. Mean CPUE of adult speckled sanddab vs. bottom salinity, by month, 1980 through 1985.

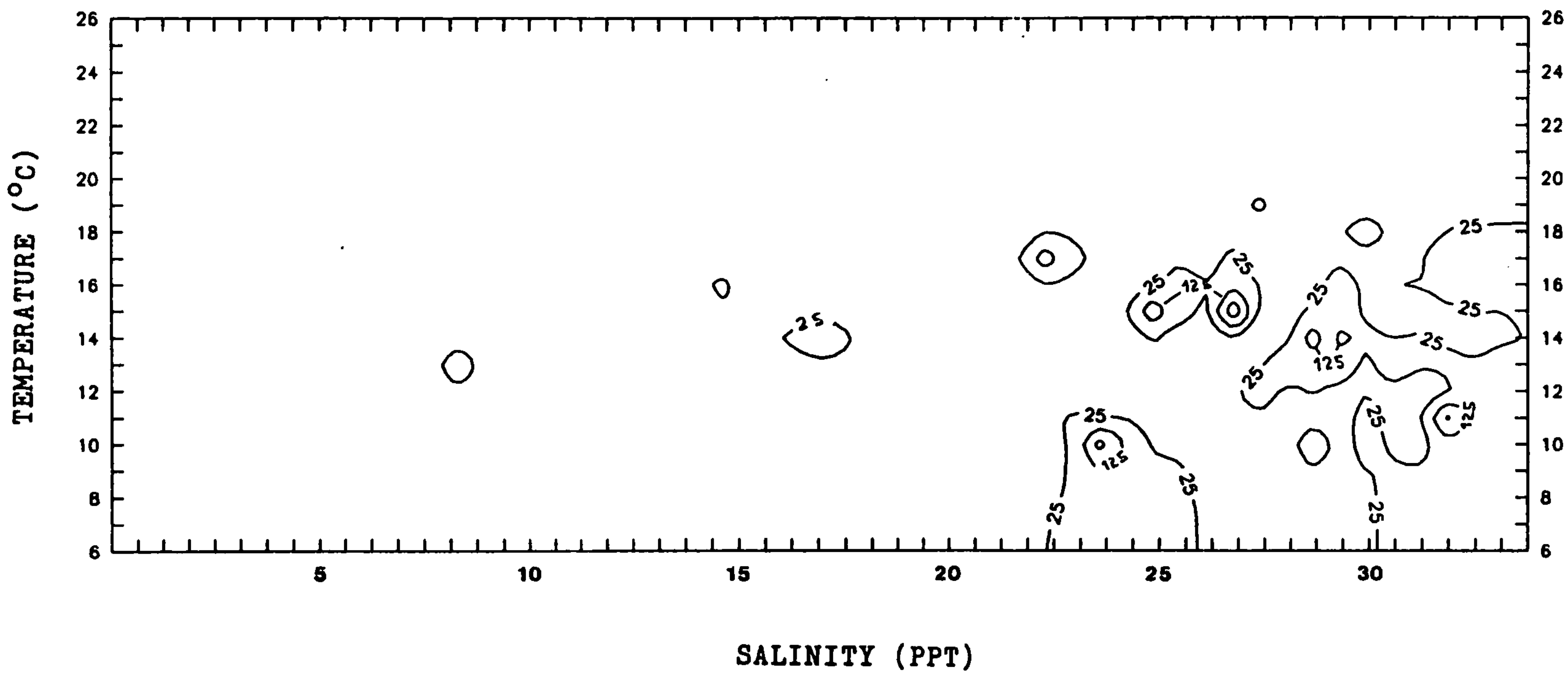


Figure 169. Abundance of YOY and adult speckled sanddab vs. salinity and temperature. Abundance is represented by catch contours of 25, 125, and 225 fish per 10000 m^2 swept by the otter trawl.

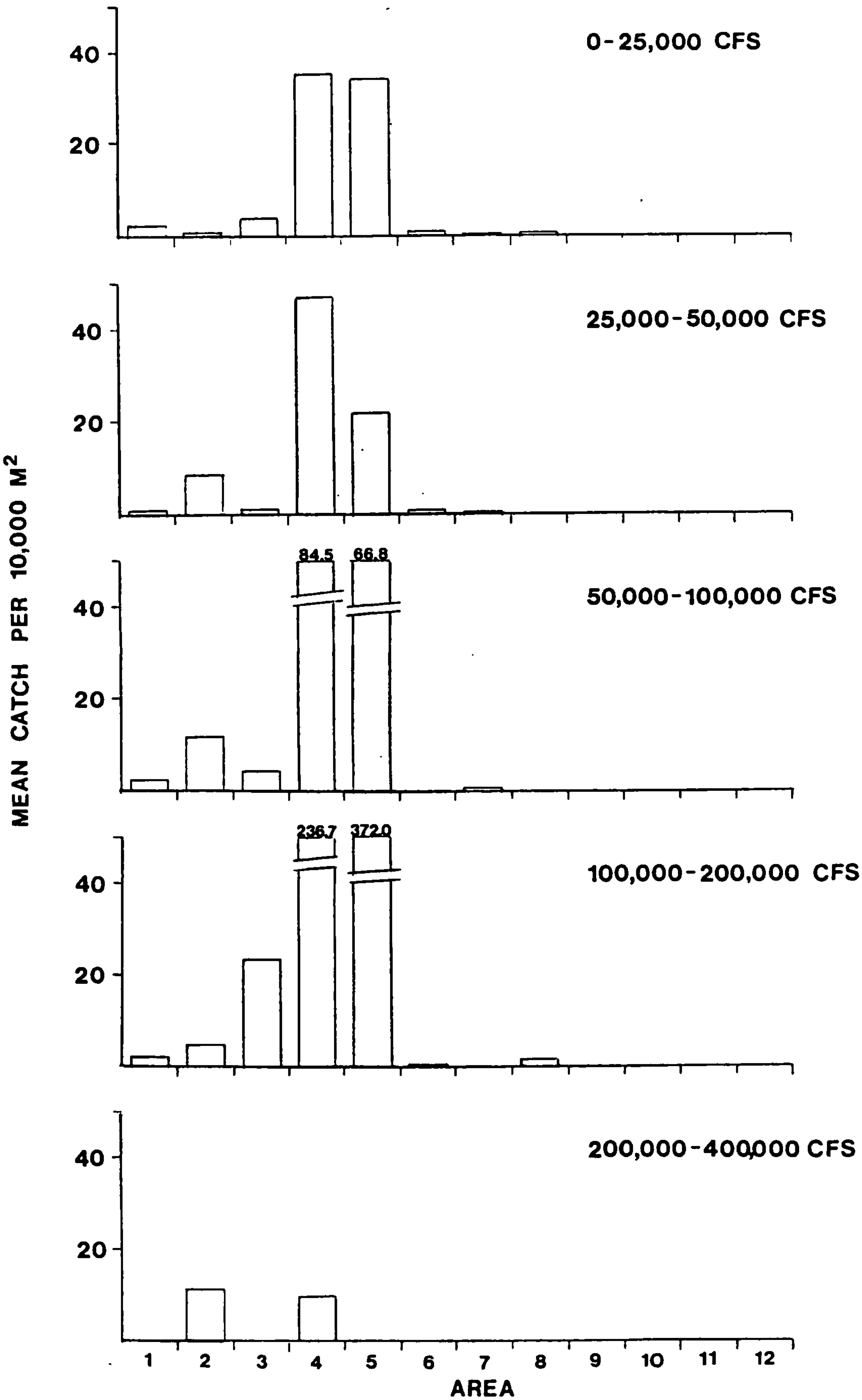


Figure 170. Spatial distribution of adult speckled sanddab at various ranges of Delta outflow.

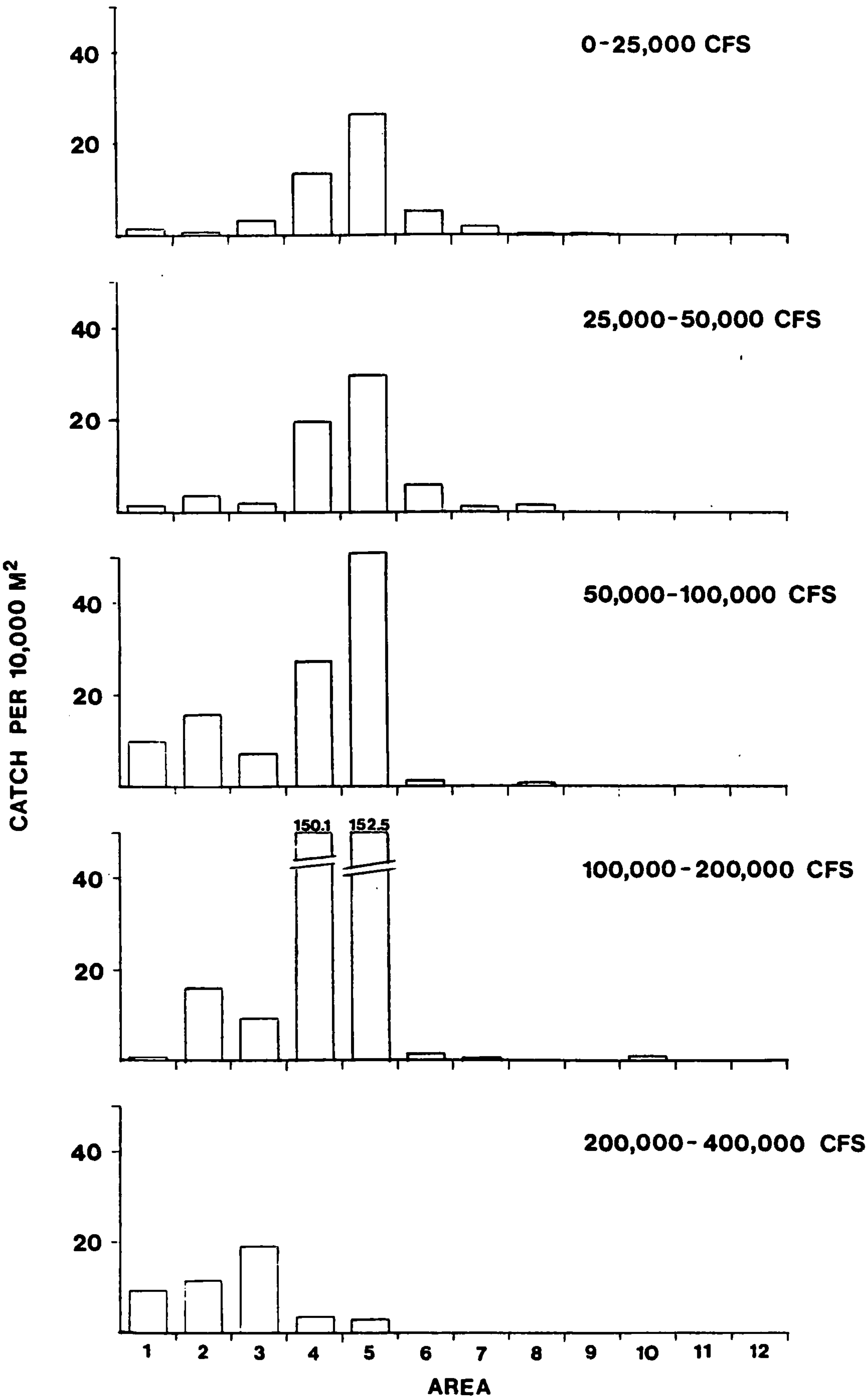


Figure 171. Spatial distribution of YOY speckled sanddab at various ranges of Delta outflow.

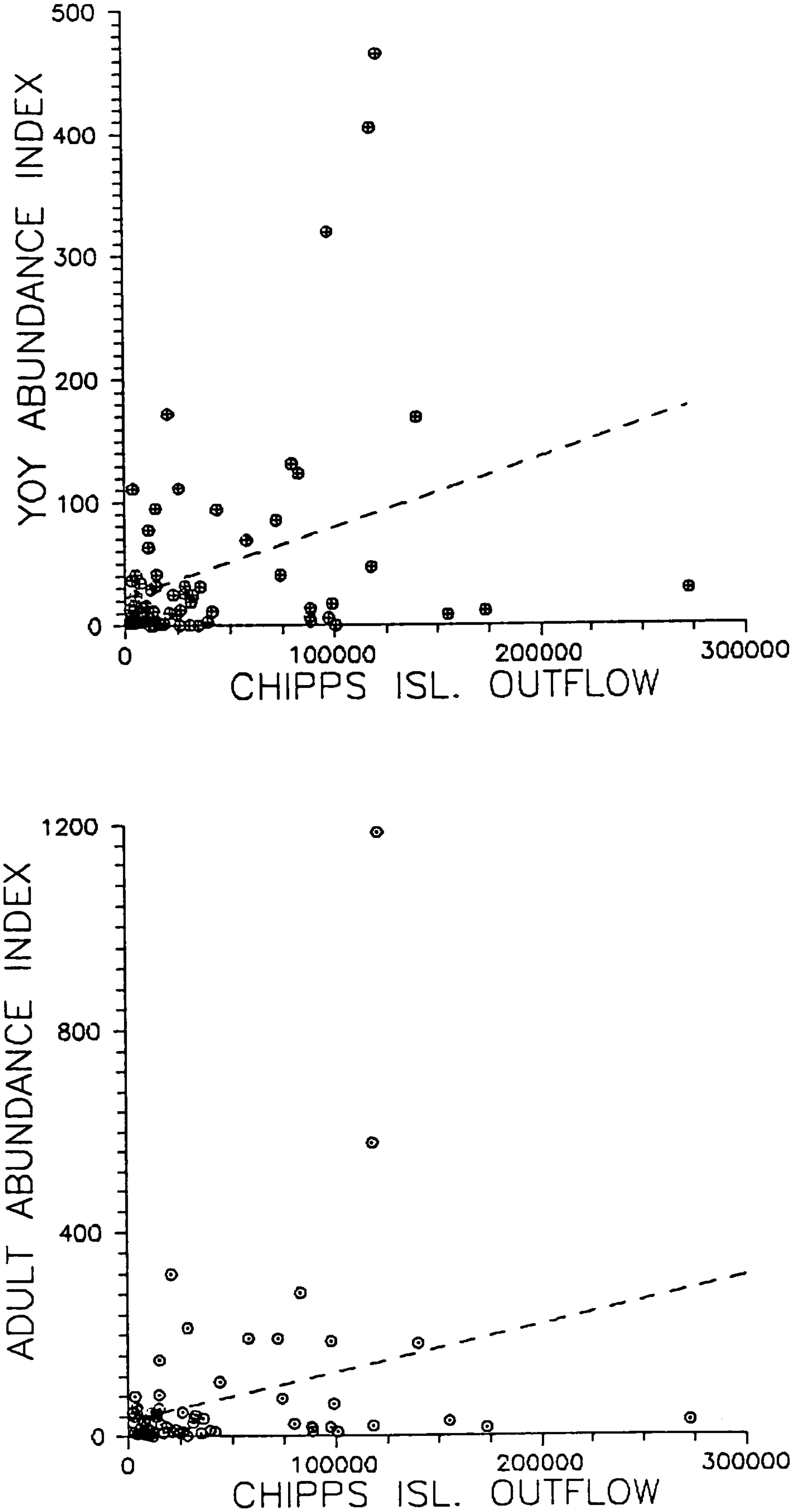


Figure 172. Monthly abundance index vs. Delta outflow in previous month, YOY and adult speckled sanddab.

Plotted this way, the data show an increasing abundance with increasing Delta outflow up to about 125,000 cfs. Figure 172 also suggests that above about 125,000 cfs the positive association between flow and abundance breaks down.

This interpretation of Figure 172 assumes that speckled sanddab abundance in the Bay can respond to changes in freshwater outflow on about a monthly time scale. Obviously, this cannot occur as the result of enhanced spawning success or larval survival, which happens on an annual time scale. The abundance of speckled sanddab in Central Bay could respond on a monthly time scale if there were a "reservoir" of sanddab in the ocean near the Golden Gate that could be carried in by landward flowing gravitational currents intensified by increasing Delta outflow.

Table 29 contains results of a series of correlations intended to examine the association of an annual abundance index for each life stage with mean Delta outflow for various periods during the spring and summer. YOY speckled sanddab abundance was strongly associated with outflows for all periods examined. Adult abundance was also well correlated with outflows, but the associations were significant only for the January through April and February through May periods of abundance.

Summary

Speckled sanddab as YOY and adults are one of the most numerous demersal fishes in San Francisco Bay (Aplin, 1967; Ganssle, 1966; this study), they are also abundant in the Gulf of the Farallones (City of San Francisco, unpublished data). They do not seem to spawn in the Bay, and juveniles and adults confine their use of the Bay to those portions that have high bottom salinities. Unlike some species (e.g. starry flounder) the adults and YOY use the Bay in a similar fashion.

Table 29

RESULTS OF CORRELATIONS BETWEEN MEAN OUTFLOW DURING VARIOUS COMBINATIONS OF MONTHS AND THE ANNUAL ABUNDANCE INDEX FOR YOY AND ADULT SPECKLED SANDDAB. (The Juvenile Index of Abundance is the Mean Area Weighted CPUE for the Period April through August. The Adult Index is the Mean Area Weighted CPUE for the Period May through December)

Months (surveys)	Juveniles	Adults
January - April	0.96**	0.91**
February - May	0.92**	0.86*
March - June	0.87*	0.80
April - July	0.82*	0.78
May - August	0.81*	0.75
All Year	0.88*	0.80

* a = 0.05
** a = 0.01
n = 6 (years)
df = 4 for all correlations

Although they occupy the more saline parts of the Bay, speckled sanddab appear to respond positively to the magnitude of Delta outflow. Associations between speckled sanddab abundance and Delta outflow suggest that, to a point, a flow-related mechanisms "draws" more fish into the Bay as flows increase. The point at which increased flows do not increase abundance of speckled sanddab in the bay, appears to be about 125,000 cfs.

The increased abundance of a marine fish with increased freshwater outflow might be because the bottom, landward moving gravitational currents are intensified during periods of high Delta outflow. Based on the positive association of annual abundance indices with flows in earlier months (Table 29), it seems that fish brought into the Bay by these landward flowing currents remain even as flows drop, providing greater numbers of fish in the Bay in wetter years.

Starry Flounder

Starry flounder belong to the Pleuronectidae (right-eye flounder) family, along with English sole, Pacific halibut, and many other important species of flatfish (Wang, 1986).

Starry flounder occur in coastal waters, estuaries, and lower rivers of the eastern and western Pacific Ocean north of parallel 33. They also occur in coastal Arctic Ocean waters of Alaska and northwestern Canada (Orcutt, 1950). The central and northern coast of California is near the southern limit of their range, but they are nevertheless abundant in this region.

Starry flounder are a major component of the fish community in San Francisco Bay (Aplin, 1967; Ganssle, 1966). During this study they were the eleventh most abundant of 86 species caught in the bottom sampling otter trawl, annually making up from 1.2 to 3.9 percent of numbers caught and a much greater percentage in terms of biomass.

Starry flounder tolerate an unusually wide range of salinities for a flatfish species and, as a result, occur in all parts of the San Francisco Bay and Delta system, including the rivers and sloughs of the eastern Delta (Turner and Kelley, 1966).

Mature starry flounder are generally found in marine water and appear to move into shallow marine water for spawning. The eggs and larvae are pelagic, drifting in the water column. As they grow beyond about 8 mm, they metamorphose into the typical flatfish form and adopt bottom dwelling habits. At this point in their life cycle they begin to be abundant in the low salinity waters of estuaries. As they grow during their first year, they are found more frequently in more saline water.

Starry flounder are not the largest or most palatable of the flatfish, but they are still a significant element of the commercial and recreational fisheries within their range (Orcutt, 1950). Starry flounder are usually taken commercially during pursuit of other "groundfish". It was estimated (Holiday et al., 1984) that in 1980, about 244,000 starry flounder were caught by marine recreational fishermen in the western United States. Most of these were taken in inland marine and near-shore coastal waters of Northern California and Oregon, where they made up about 0.8 percent of the total non-salmonid marine recreational fisheries catch and about 3 percent of those caught in inland marine waters.

Gear Limitations and Effort Correction

The number of starry flounder larvae caught in each egg and larval net sample was converted to catch per cubic meter of water filtered.

For the most part starry flounder rest, feed, and move about on or near the bottom. This fact is reflected in our midwater and otter trawl catches, where starry flounder were 10 times more abundant in the otter trawl than the midwater trawl. The fact that starry flounder are caught regularly in the midwater trawl is more an indication of the closeness of the net to the bottom at shallow stations than evidence of starry flounder swimming above the bottom. The otter trawl data were, therefore, used for analysis of juvenile and adult starry flounder abundance and distribution.

The number of starry flounder caught in each otter trawl sample was converted to catch per area of the bottom swept during that tow, based on width of the net while sampling and distance traveled during the tow.

The beach seine used in this study is a relatively short (50-foot) small mesh (1/8-inch woven mesh) net. This type net is most effective for catching small or sedentary littoral species, and is probably only effective in catching YOY starry flounder. The number of starry flounder caught was converted to catch per area of bottom swept by the net (net width times distance towed).

Larval Distribution and Abundance

During this study, 50 yolk-sac larvae and 112 post-yolk-sac larvae were collected, together comprising less than 1/10 of 1 percent of the overall larval fish catch. Figure 173 shows the length frequencies of the collected larvae by survey, all years combined. About 22 percent of the larval starry flounders collected during this study were collected in Central Bay during the May 1980 survey (Figure 174).

The occurrence of larvae in the Bay was sporadic in both space and time. They were collected in all segments except the lower Sacramento and San Joaquin rivers and in all months but January. Averaged over all years and surveys, it appears that larval densities are greatest in Central Bay and decrease moving upstream into South Bay and into the northern embayments (Figure 175). Removal of the May 1980 data results in a similar geographical catch pattern, except that San Pablo Bay and Central Bay densities become more similar.

The seasonal distribution of starry flounder larvae, when averaged over all areas and years (Figure 176) appears to show a major peak in May, with significant densities in every other month but January, June, and December. Removing the May 1980 data (Figure 176) produces a more general late spring, early summer peak of abundance, with the exception of low June values.

There were large differences between years in the overall abundance of larvae, the seasonal timing of their presence, and their seasonal geographic distribution (Figure 177). The years 1980 and 1985 had the overall highest densities of the six years of study, but in both of these years the annual high abundance is the result of a "spike" in abundance in one month -- May in 1980 and July in 1985. April was the month of peak abundance in two years, May in two years, and July and September in one year each.

When starry flounder larvae are in the Bay, they generally occur in Central and San Pablo Bays. They occurred in significant numbers in South Bay only in the late spring of 1980. They were never abundant in Suisun Bay, but were found there in spring 1985.

Young-of-Year Distribution and Abundance

As referred to here, YOY are presumed to be less than one year, based on their length. A cut-off length for 0+ fish was established for each survey, based on examination of catch length frequencies and not on the aging of individual fish. Since there is a small amount of overlap in the length distribution of 0+ and 1+ fish in some months and year to year variations in growth, a few discrepancies are likely in assignment of fish to age classes.

YOY starry flounder are apparently not large enough to be sampled effectively by the otter trawl until they are 20-30 mm in total length. Fish of this size first appeared in significant numbers in our samples in June (Figure 178). During June and July the small YOY (20-50 mm) tended to be caught in highest densities in the shoals of the west Delta (Figure 179), decreasing rapidly in a downstream direction.

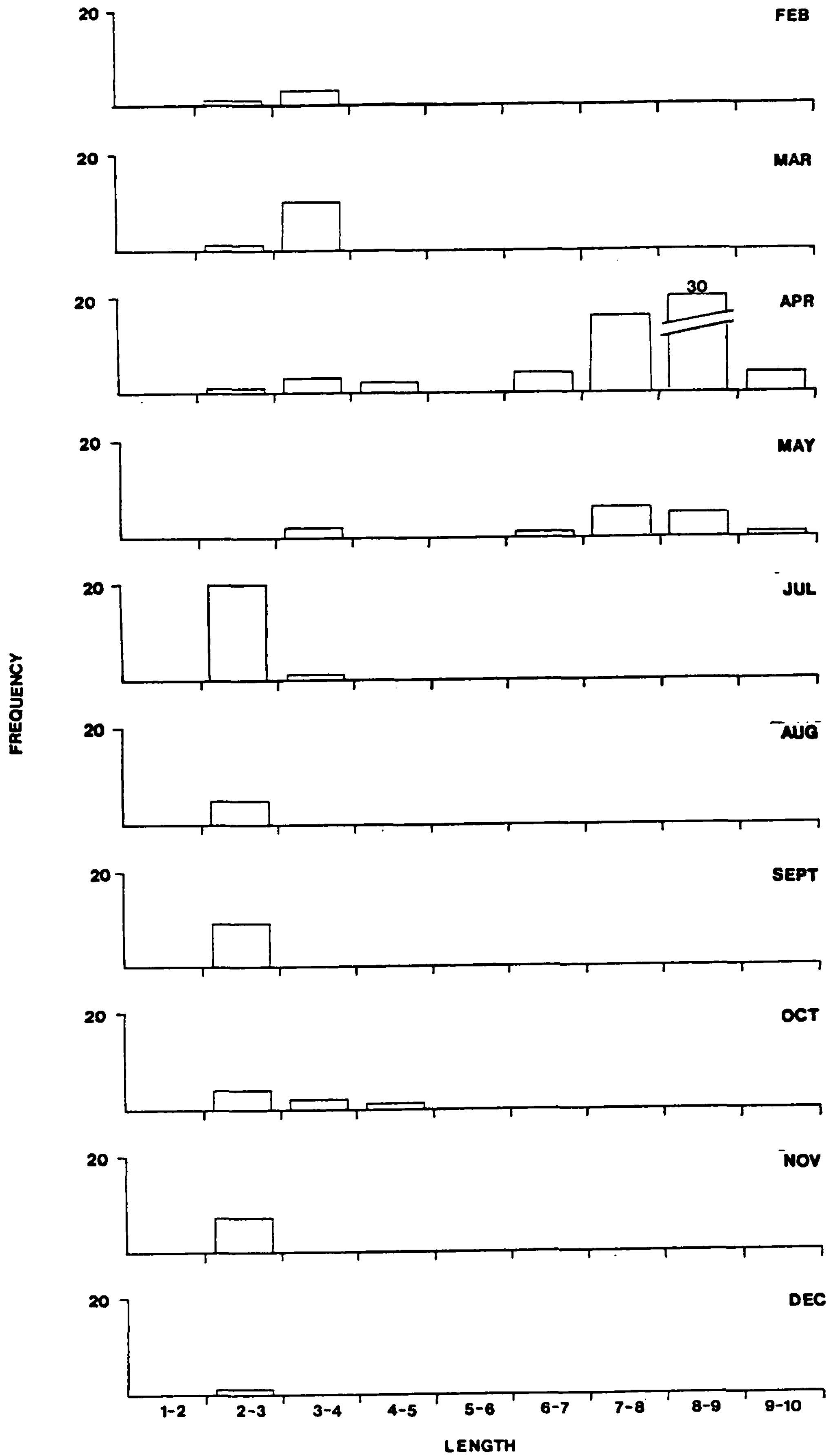


Figure 173. Length frequency distribution of larval starry flounder. Lengths are given in millimeters.

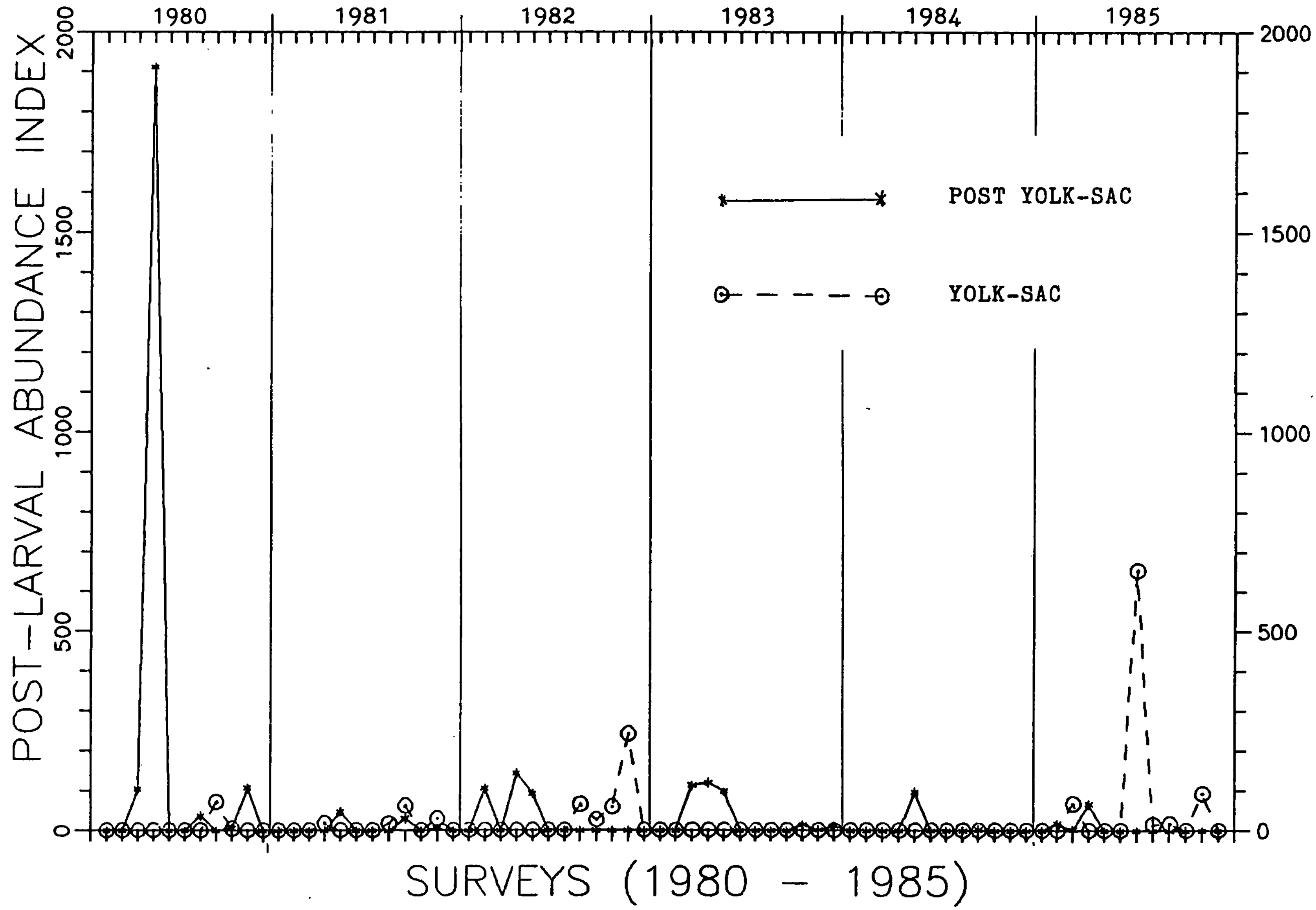


Figure 174. Monthly indices of Bay-wide larval starry flounder abundance.

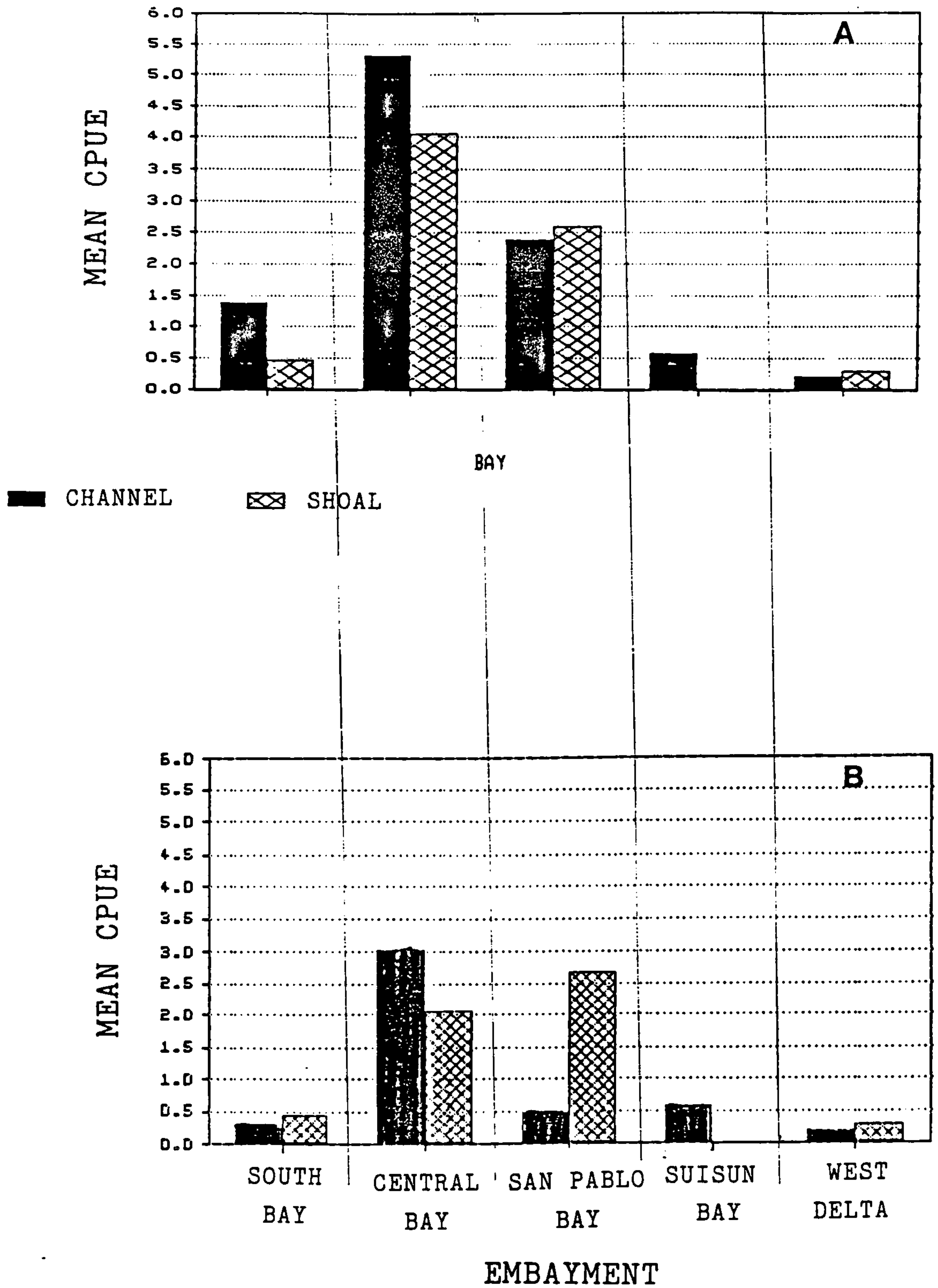
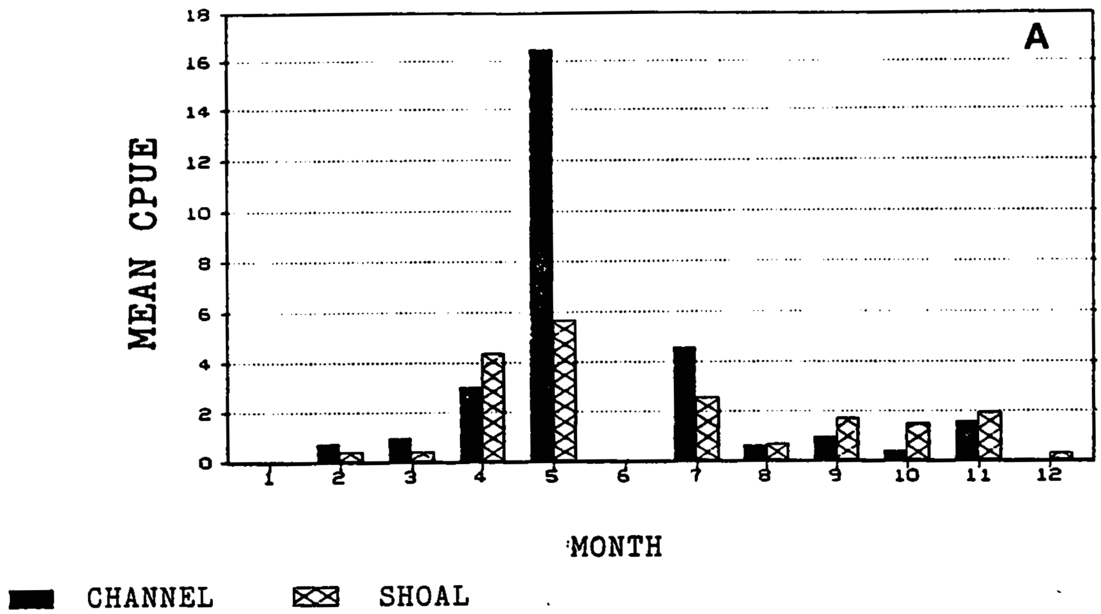


Figure 175. Mean CPUE of larval starry flonder by embayment. "A" includes data from all surveys, "B" excludes data from May 1980.



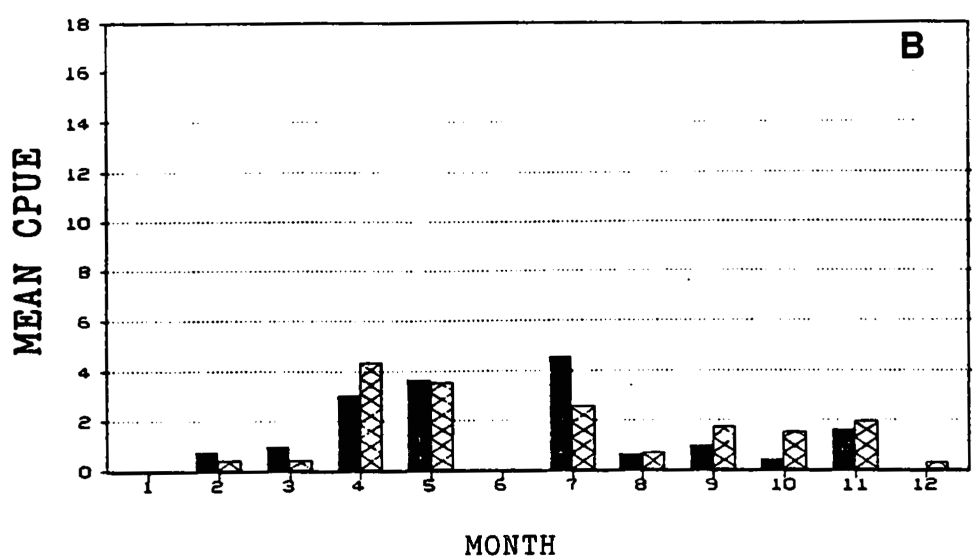


Figure 176. Mean CPUE of starry flounder larvae, by month. "A" includes data from all surveys, "B" excludes data from May, 1980. CPUE is expressed as catch per 10000 m^3 sampled.

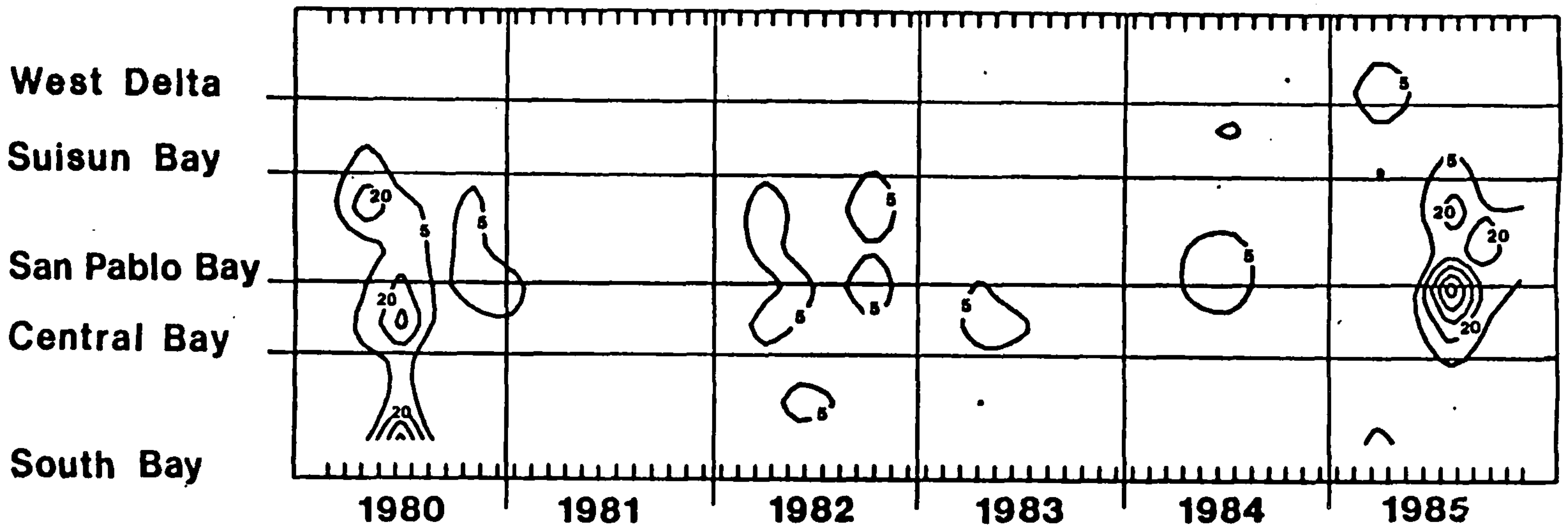


Figure 177. Distribution of larval starry flounder, 1980 through 1985. Abundance is shown by catch contours of 5, 10, and 15 fish per 10000 m^3 sampled.

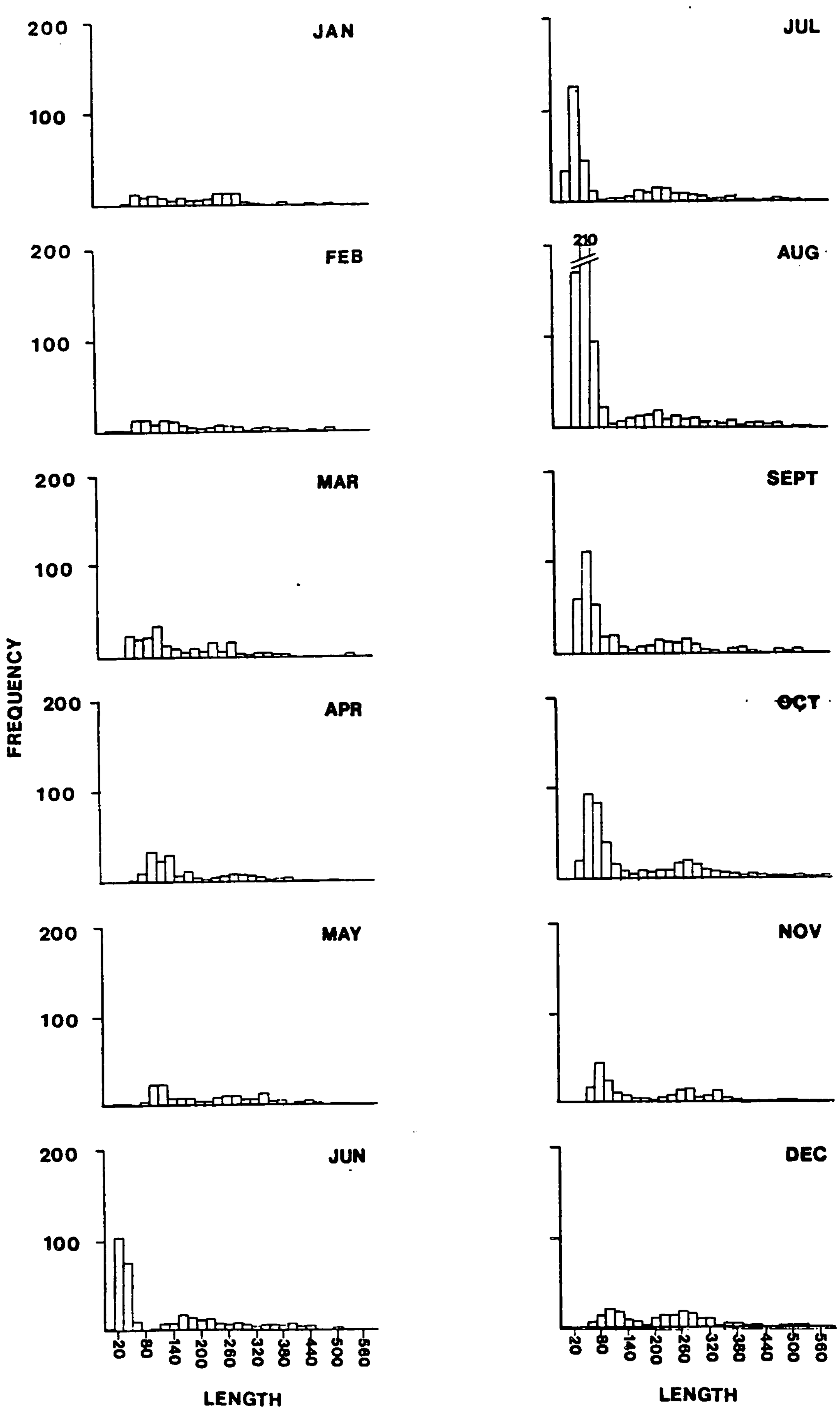


Figure 178. Length frequency distribution of starry flounder caught in the otter trawl. Length axis labels are minimum values of 20mm length groups.

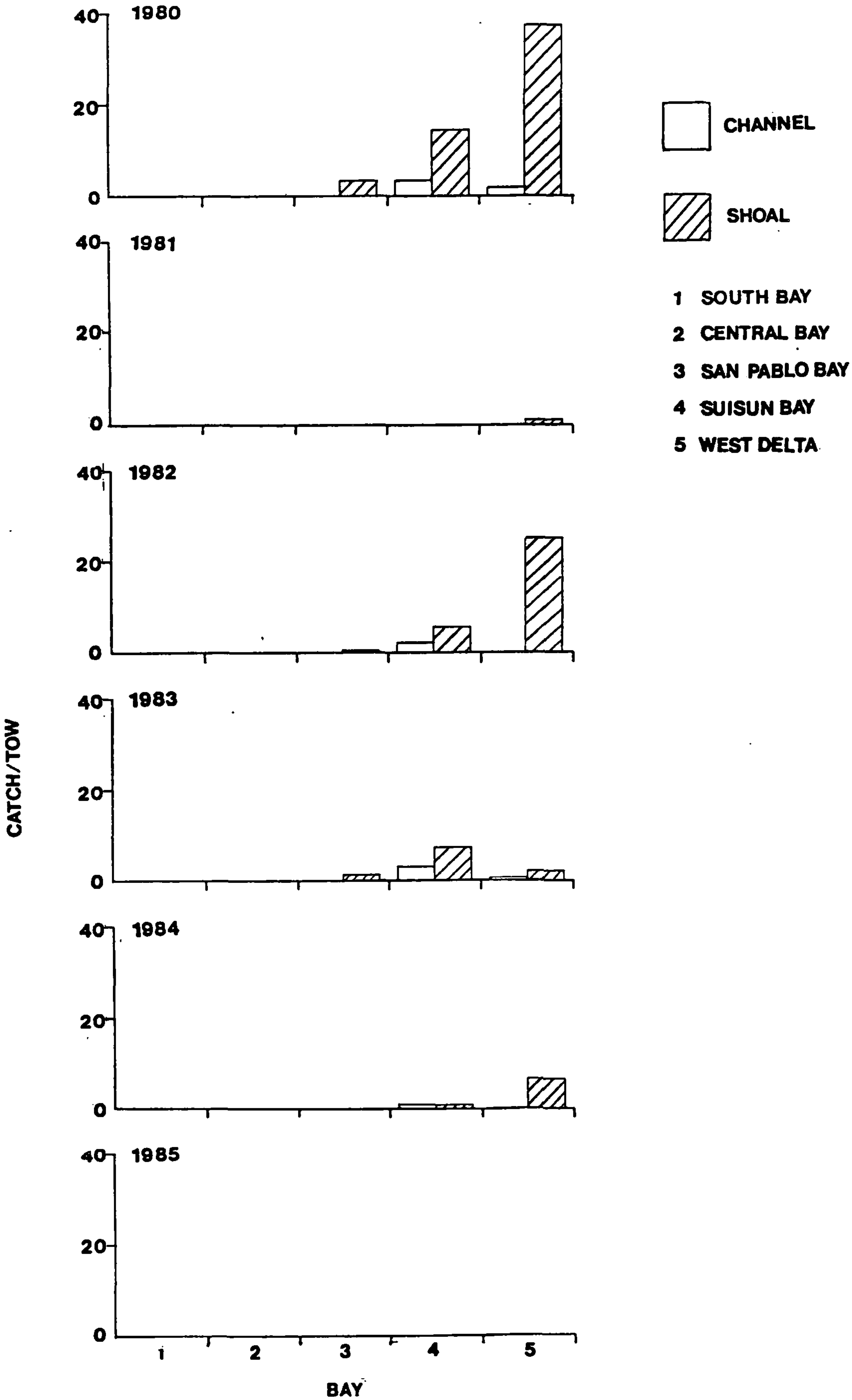


Figure 179. Distribution of starry flounder less than 50 mm in length during the months of June and July, 1980-1985.

By fall (September and October) juvenile starry flounder have grown to an average of about 80 mm and are found in greatest concentrations in the shoals of Suisun Bay and San Pablo Bay (Figure 180). As they near the end of their first year, in December and January they have grown to about 120 mm. These fish are spread more evenly among the embayments, channels, and shoals than the younger fish, but were not caught in high numbers in South Bay (Figure 181).

Juvenile and Adult Distribution and Abundance

The most obvious feature of the distribution of adult starry flounder inhabiting the Bay is that as the fish grow larger, they are more likely to be found in the lower, more saline parts of the estuary (Figure 182). San Pablo Bay was the area of peak abundance for fish between 100 and 400 mm, Central Bay for fish greater than 400 mm.

Effects of Salinity

The general distributional analysis shows that young starry flounder inhabit primarily the upper parts of the northern reach of the Bay and become increasingly more associated with the lower parts of the estuary as they grow. The strong salinity gradient through the northern reach of the estuary suggests that the observed changes in distribution represent changes in salinity preference as the fish grow older.

We performed a series of correlations to examine the possible association of the mean size of fish caught in our otter trawl sample with the surface salinity. Results of these correlations (Table 30) indicate that mean length and surface conductivity are positively associated, but that this association varies considerably with time of year. Spring and summer exhibit the strongest correlations and winter the weakest. Although there is

Table 30

COEFFICIENTS AND LEVELS OF SIGNIFICANCE FOR CORRELATIONS BETWEEN MEAN STARRY FLOUNDER LENGTH AND SURFACE SALINITY

Season	(surveys)	1980	1981	1982	1983	1984	1985	All
1	(1-3)	0.40	0.46*	-0.42	0.21	0.42*	0.42	0.19
2	(4-6)	0.70***	0.79*	0.63***	0.73***	0.83***	0.75**	0.68***
3	(7-9)	0.37*	0.67**	0.66**	0.57***	0.57**	0.73**	0.61***
4	(10-12)	0.70**	0.76**	0.68***	0.37*	0.33	0.66	0.48***

* - p<0.05
** - p<0.01
*** - p<0.001

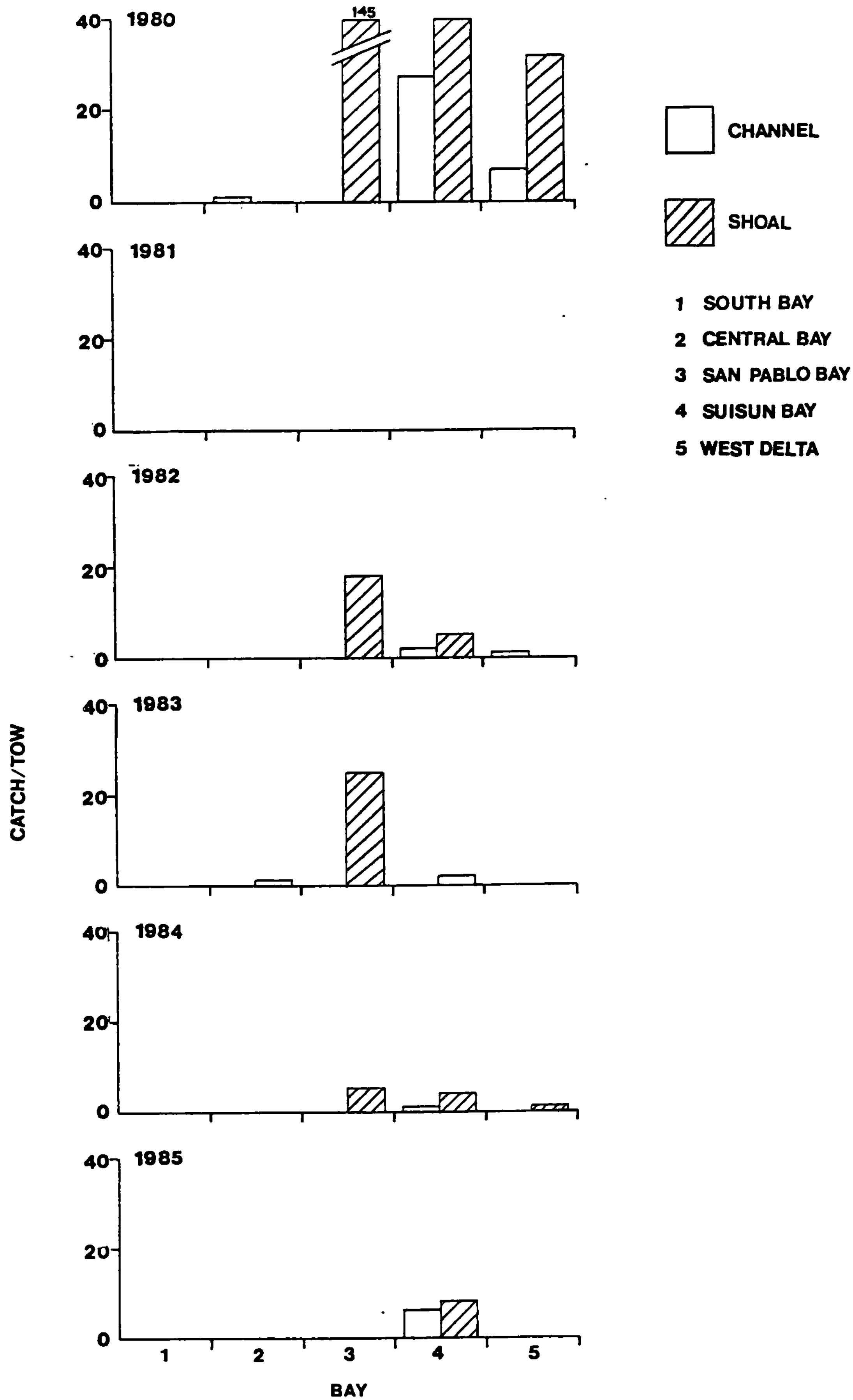


Figure 180. Distribution of 60 - 100 mm starry flounder during the months of September and October, 1980-1985.

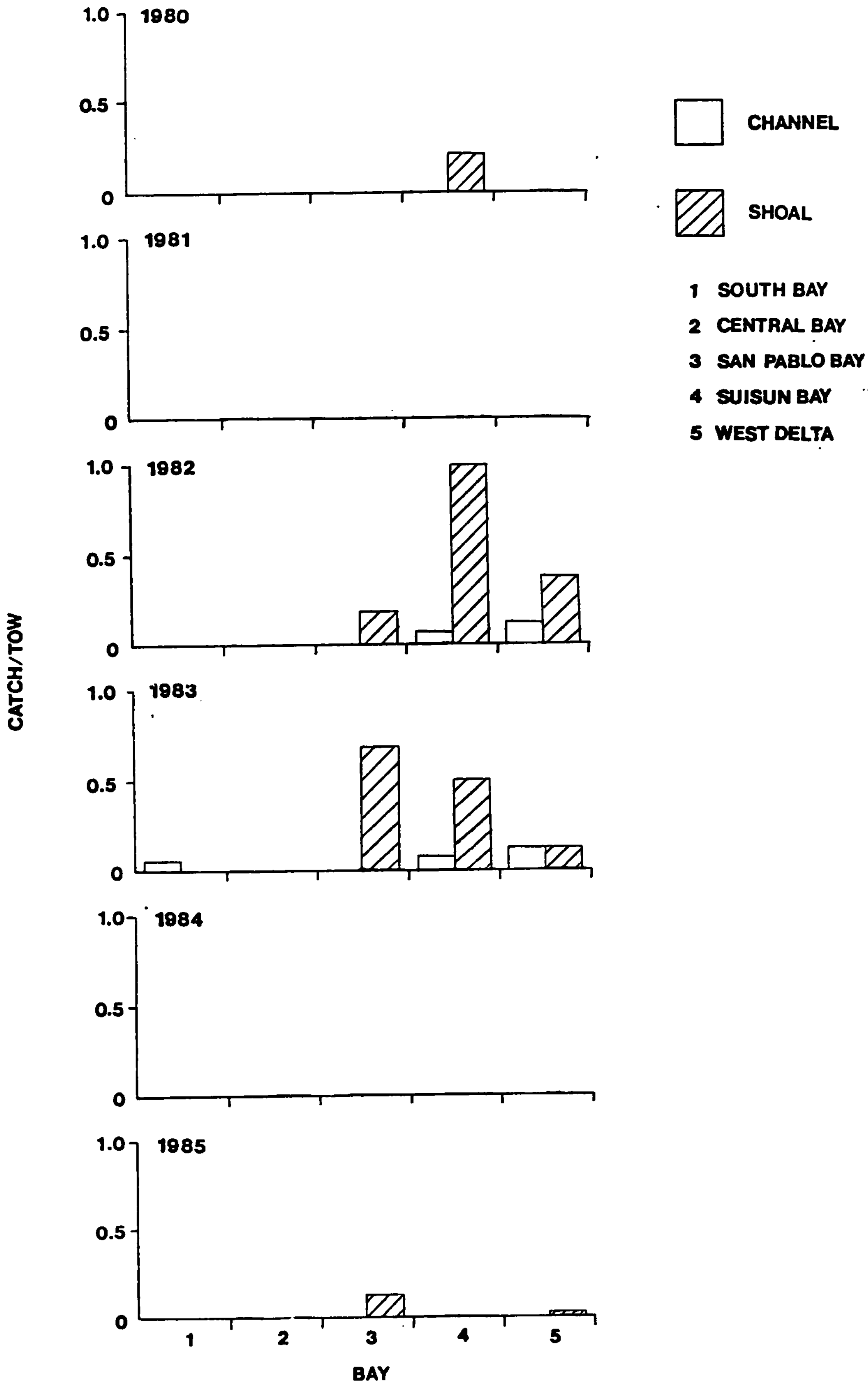


Figure 181. Distribution of 100-140 mm starry flounder during the months of December and January, 1980-1985.

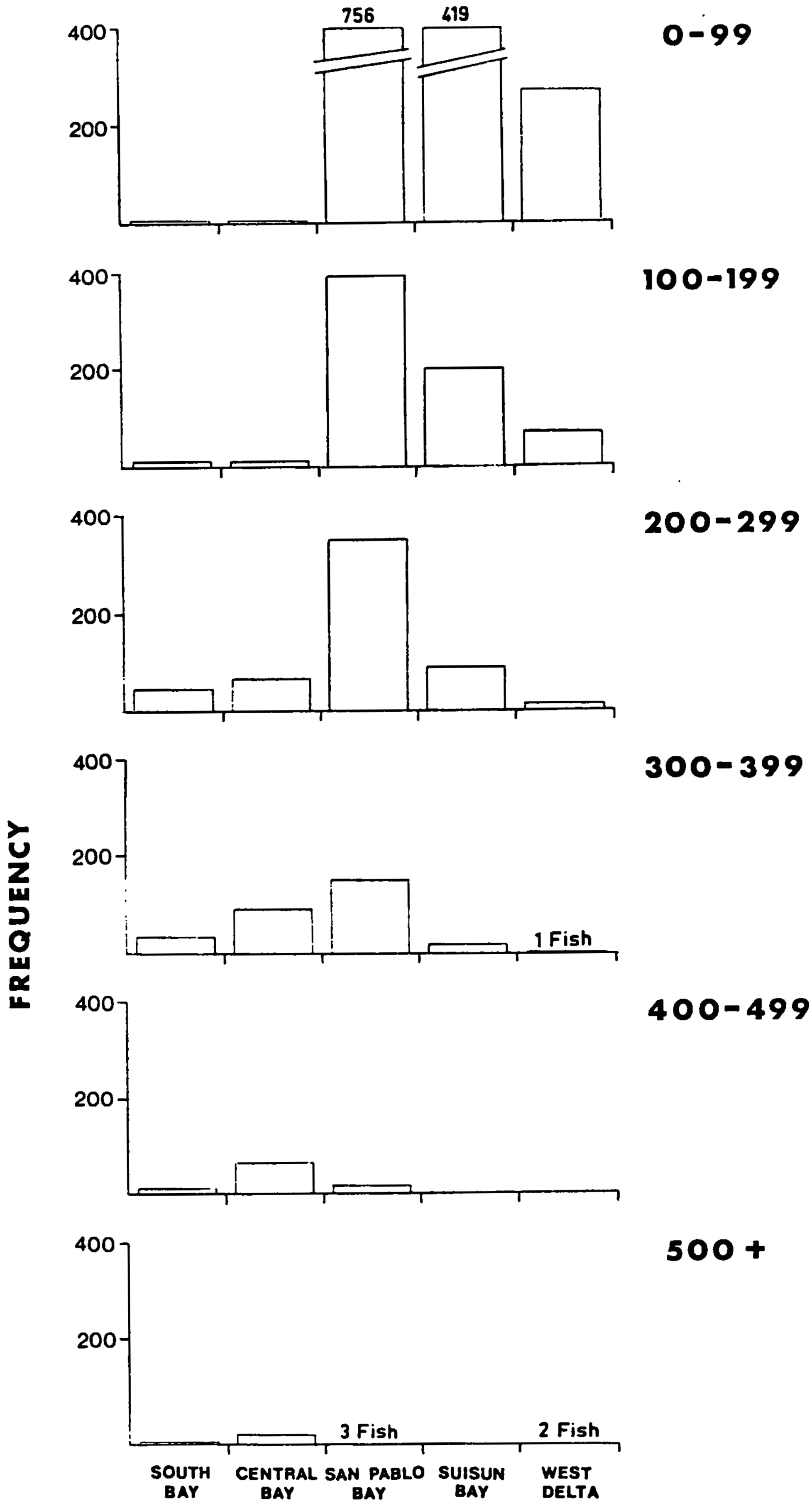


Figure 182. Distribution of various size groups of starry flounder.

on the whole a strong association between size and salinity, there is much unexplained variation in all seasons, suggesting among other things that all or some sizes can tolerate a wide salinity range.

Effects of Delta Outflow

Larvae. Delta outflow does not seem to dramatically affect either the abundance of starry flounder larvae in the Bay or their distribution within the Bay. Correlations of an April through July index of larval abundance with a series of spring and summer outflow variables resulted in weak (r=-0.20 to r=0.17), nonsignificant (n=6, a=0.05) associations of outflow and larval fish abundance.

Figure 177 shows that interannual differences in larval starry flounder distribution are hard to detect because of the low numbers in most years. In the two periods of highest abundance, 1980 (April-May) and 1985 (July) were similar despite the fact that Delta outflow differed in those two periods by a factor of 6 (24,000 cfs in 1980 and 4,000 in 1985).

Young-of-Year. It is difficult to illustrate annual differences in the distribution of YOY starry flounder that might be due to differences in freshwater outflow, because so few YOY were taken in the two dry years, 1980 and 1985. There is some evidence that in higher outflow years YOY starry flounder are found farther downstream. Figure 177 shows small juveniles (<50 mm) to have highest densities in the west Delta in all years but 1983 (the year of highest June-July outflows), when they were most abundant in Suisun Bay.

Figures 179 and 180 suggest that YOY starry flounder abundance in the Bay may vary from year to year in association with differences in outflow. In fact, the mean annual abundance index for the three wet years (1980, 1982, and 1983) was nearly 12 times that for the dry years. Even if the 1980 data (by far the strongest year class) are removed, the remaining wet years had a mean annual abundance index 6 times that of the two dry years.

Figure 183 contains plots of annual abundance index versus various outflow parameters. The plots show a positive association of flow and abundance variables; intensity of the association is greatest with the early flow variables. However, none of the associations is significant. If the 1980 data, with its exceptional high year class, are removed, the associations become much stronger and are significant (a-0.05) for the three late season flow variables.

Juveniles and Adults. As starry flounder grow, they become increasingly more associated with the lower, more saline portions of the estuary. Therefore, it might be expected that high outflows would restrict the distribution of juvenile and adult starry flounders by reducing salinities to unacceptable levels in more of the estuary and reducing their overall abundance. However, when a series of winter-spring outflow variables was correlated with a July-November abundance index for each year, strong positive associations were found between the outflow and adult abundance, particularly with late spring outflows (Figure 184).

Summary

This investigation and observations by others suggest that San Francisco Bay and the Delta are important to starry flounder as a nursery area and as habitat for adult fish. The Bay may be less important as spawning habitat.

Use of the Bay and Delta for spawning by starry flounder deserves more careful study. Our data, like that of Pearcy and Myers (1974) for Yaquina

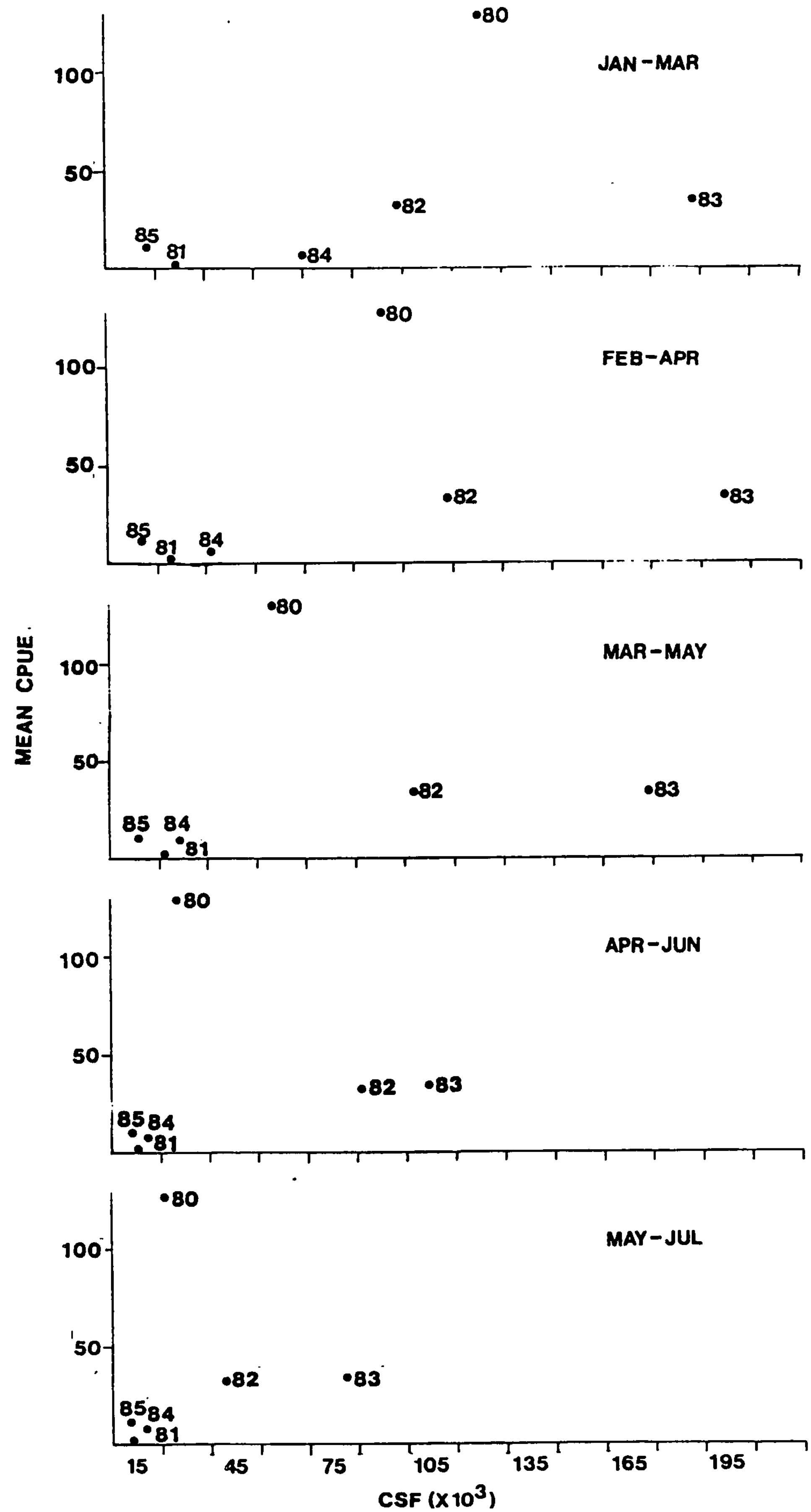


Figure 183. Mean monthly Delta outflow for various sets of months vs. annual index of YOY starry flounder abundance.

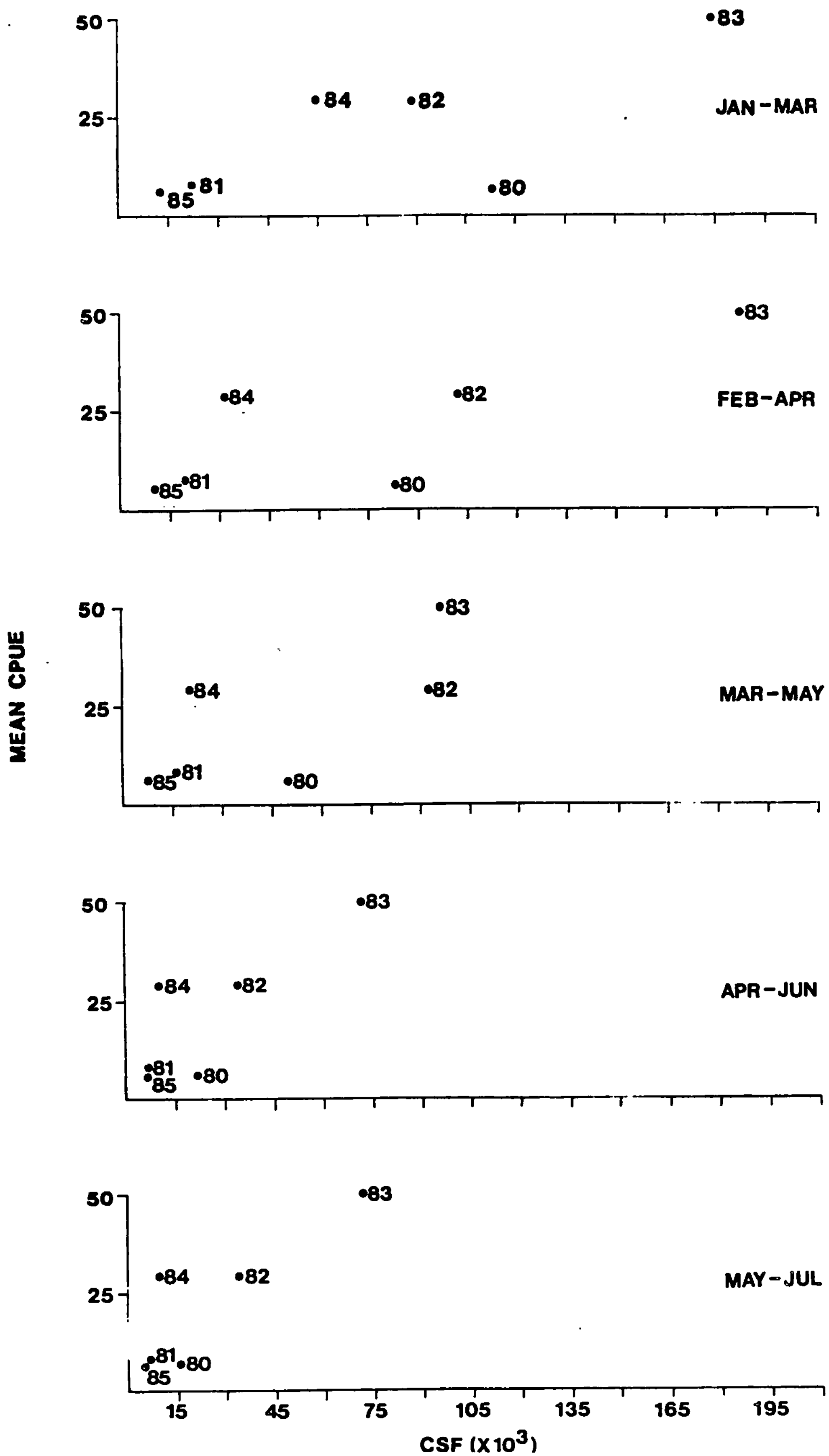


Figure 184. Mean monthly Delta outflow for various sets of months vs. an annual index of adult starry flounder abundance.

Bay, Oregon, suggest that the numbers of larvae are not adequate to explain the extensive population in the upper parts of the Bay and Delta by YOY fish. Starry flounder larvae, caught primarily in Central Bay in April and May, are large (7-10 mm) and in some cases already metamorphosing into their bottom dwelling form. These facts suggest that as larvae living offshore begin moving to the bottom, they are transported into the Bay by upstream gravitational currents. If spawning were extensive in the Bay, we would expect to see large numbers of smaller larvae, particularly in the 4 to 7 mm range.

Two things are necessary to determine whether or not the Bay and Delta are an important nursery area for starry flounder. It must be demonstrated both that young starry flounder use the estuary extensively and that their abundance there is not trivial compared to numbers outside the estuary.

Although we and others have documented the extensive use of the Bay, little information exists on abundance of young starry flounder outside the estuary. A monitoring program is being conducted by the City of San Francisco, related to a proposed sewage outfall to be located about 4 miles offshore of the San Francisco Peninsula and about 5 miles south of the Golden Gate, in 75 to 90 feet of water. Their otter trawling at 6 stations in this area from 1982 to 1986 with gear similar to ours has <u>not</u> collected any young-of-year starry flounder.

The upper parts of the estuary, San Pablo Bay and above, are the areas of greatest concentration of starry flounder until they reach 300 to 400 mm, or 3 to 4 years. Beyond this size Central Bay is the area of greatest concentration, suggesting that the larger sizes have essentially adopted a marine existence. The shoals of the estuaries are a major habitat for starry flounder up to 400 mm on the California coast, but lack of good information on their open coast occurrence prevents conclusions about the relative importance of the estuary. Nevertheless it seems likely that the large numbers of flounder growing up in the Bay contribute significantly to overall central coast starry flounder recruitment. Also, the abundance of catchable sized flounder in the estuary provides for local sport fishery value.

There are apparent associations of the magnitude of Delta outflow with the abundance of both YOY and older starry flounder found there each year. With only 6 years of monthly observations and somewhat inconsistent relationships, it would be improper to conclude that Delta outflow is predictive of subsequent starry flounder abundance in the estuary or that Delta outflows result in high starry flounder abundance.

One possible mechanism for the apparent relationships is that greater outflow results in greater transport of young fish into the estuary through intensification of the gravitational, two-layered flows. This hypothesis assumes a reservoir of larval starry flounder lies outside the gate which, when metamorphasing and settling to the bottom could use the variable upstream bottom currents to get to the upper estuary.

Another possibility is that in dry years the extensive shallows of San Pablo Bay and Suisun Bay have salinities greater than that desired by young flounder, thus forcing them into the more confined channels of the Delta where there is less total habitat and possibly greater predation and competition.

Also, overall productivity in the upper estuary may be lower in years of lower Delta outflow, causing reduced survival of young flounder. Other common upper estuary fish that do not depend on outflow-related upstream transport (longfin smelt, striped bass) do not do as well in years of low Delta outflow.

There are other possible explanations for the apparent association of Delta outflow and starry flounder abundance. It may be, for instance, that the same meteorological conditions that produce high outflow affect starry flounder spawning, survival of larvae, or location of the larvae in relation to the Golden Gate. At this time there is little basic information available on starry flounder spawning or the larval dynamics with which to evaluate these possibilities.

Chapter 11. FRESHWATER PULSE FLOWS

Freshwater flows into the Bay can increase quite dramatically after major storm systems occur. These "pulse" flows are short-term, large magnitude increases. They can be likened to flash floods of desert regions; a sudden rapid increase in flow followed by a slightly longer subsidence period.

Pulse flows investigated in this analysis were usually of 3-week duration. The average period of increase was 8 to 9 days; for example, from 100,000 to 340,000 cfs (based on Chipps Island flow as estimated by DWR) in 4 days beginning February 21, 1980. The subsidence period averaged 13 days. Sometimes flows did not subside to pre-pulse levels before runoff from another storm entered the area.

Freshwater pulse flows during 1980 to 1985 usually occurred between November and March (Figure 185). In some years pulses did not occur until January (1981) or they continued until April (1983). Studies of these pulse flows and how they affected the abundance and distribution of animals in the Bay are discussed in this chapter.

Methods

Three studies were conducted in this analysis. Study 1 used selected species of fish and shrimp whose abundance indices were available for use. The purpose of this study was to investigate abundance and distributional changes that might not be apparent from the catch data. Using catch data for Study 2 allowed a greater number and variety of fish species to be considered. Abundance indices were not available for all fish species. Study 3 concentrated on distributional changes in two planktonic organisms. Specifics of these studies are delineated below.

Study 1

Some pulse flows were selected for analysis based on the timing of the pulse in relation to sampling surveys. Only those periods with distinct pulse flows between surveys were considered. Thirteen pulse events were studied (Table 31).

Abundance indices were available for some fish species and their life stages (larvae, juveniles, adults) and two species of shrimp (Table 32). The fish species were chosen based on their habitat: benthic (bottom dwellers), pelagic (water column), marine, estuarine. Distinct pulse flows that occurred between surveys were used in the analysis. The Mann-Whitney U test and the Wilcoxon paired sample test (Zar, 1984), were used to check for significant abundance changes. A Kruskal-Wallis test was used on some of the data associated with multiple pulses (i.e. Table 31, pulses Nos. 6 through 8).

Study 2

Other pulse flows were selected for analysis because they were: (1) the first pulse of the water year, (2) the largest pulse of the water year, or (3) the first pulse in a dry year. Most of these pulses were already

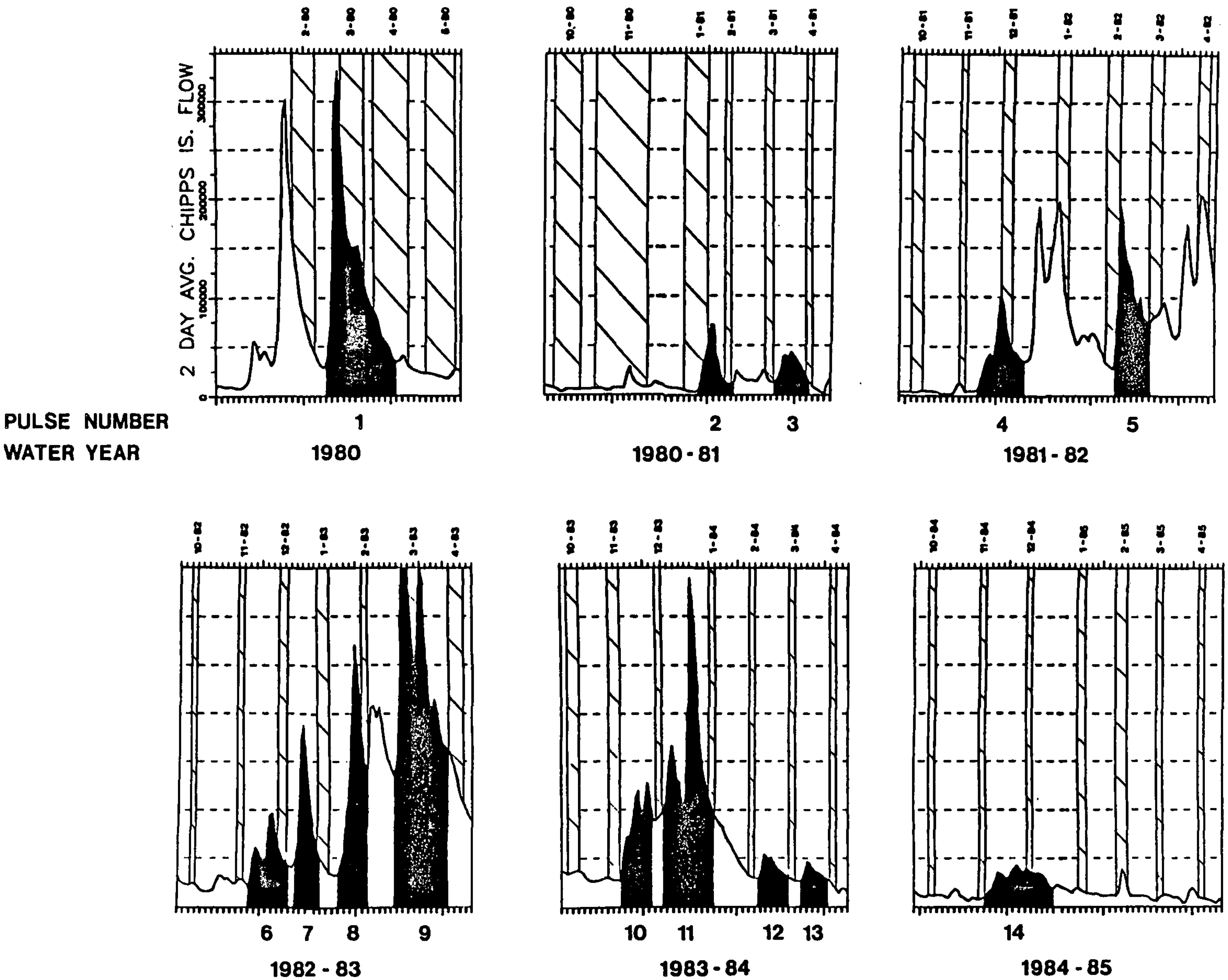


Figure 185. Hydrographs of time periods considered in analysis of freshwater pulse flows. Solid areas denote pulses considered in the analysis. Pulse numbers correspond with Table 31. Parallel lines with cross-hatching denote days during which sampling occurred. Numbers at top are month-year of sampling and correlate with Figs. 189 & 190. Ticks at bottom denote 2-day time periods. Flows are in cfs.

Table 31

FRESHWATER PULSE FLOWS INVESTIGATED AS TO THEIR EFFECT ON ABUNDANCE AND DISTRIBUTION OF ANIMALS IN THE STUDY AREA
(Flows are to the nearest 1,000 cfs)

Pulse No.	Begin/End Date of Pulse Flow	Duration (Days)	Mean Daily Flow During Period	Highest Flow During Period	Date of Maximum Flow
1	02/17/80 - 03/13/80	25	185,000	340,000	02/21/80
2	01/23/81 - 02/12/81	16	43,000	75,000	01/31/81
3	03/18/81 - 04/02/81	16	38,000	45,000	03/26/81
4	11/12/81 - 12/13/81	33	51,000	109,000	11/26/81
5	02/15/82 - 03/03/82	17	134,000	197,000	02/16/82
6	11/16/82 - 12/15/82	30	59,000	99,000	12/01/82
7	12/20/82 - 12/30/82	11	138,000	197,000	12/23/82
8	01/22/83 - 02/05/83	15	181,000	276,000	01/29/83
9	02/28/83 - 03/18/83	19	317,000	(2 Peaks) 420,000 360,000	03/03/83 03/13/83
10	11/16/83 - 12/02/83	17	106,000	128,000	11/27/83
11	12/08/83 - 01/12/84	36	165,000	(2 Peaks) 168,000 356,000	12/13/83 12/27/83
12	02/13/84 - 03/02/84	18	46,000	57,000	02/17/84
13	03/14/84 - 03/31/84	18	39,000	50,000	03/18/84
14	11/08/84 - 12/22/84	45	33,000	45,000	11/30/84

Table 32

SPECIES INVESTIGATED FOR ABUNDANCE AND DISTRIBUTION CHANGES AFTER FRESHWATER PULSE FLOWS (Study 1)

Species	Type
Starry flounder (Platichthys stellatus)	Estuarine
English sole (Parophrys vetulus)	Marine
Topsmelt (Atherinops affinis)	Marine
Jacksmelt (Atherinopsis californiensis)	Marine

Species	Type
Northern anchovy (Engraulis mordax)	Marine
Bay Crangon (Crangon franciscorum)	Estuarine
Sand Crangon (Crangon nigricauda)	Marine
Arrow-worm (Sagitta euneritica)	Marine

selected in Study 1. Pulse event No. 9 was added for this study (Table 31).

Catch data for all species of fish present in sufficient numbers for statistical analysis were used. Catches of 16 fish species were analyzed in relation to first, largest, and first in a dry year pulses (Table 33). A Wilcoxon matched-pairs signed-ranks test, available through the statistical software package "SPSS/PC" was used.

Study 3

Chaetognaths have been used in defining and tracking water mass movements in offshore areas (Gross, 1977). For this reason and because of its high abundance during the pulse flow period, November through March, distribution of *Sagitta euneritica* was used to better delineate pulse flow effects in the Bay. Initial studies had indicated some distributional response to flows.

Table 33

FISH SPECIES INVESTIGATED FOR CATCH AND DISTRIBUTION CHANGES AFTER FRESHWATER PULSE FLOWS (Study 2)

Common Name	Species Name	Type
Delta smelt	*Hypomesus transpacificus*	Fresh/upper pelagic
Northern anchovy	*Engraulis mordax*	Marine/upper pelagic
Pacific herring	*Clupea harengus*	Marine/upper pelagic
Jacksmelt	*Atherinopsis californiensis*	Marine/upper pelagic
American shad	*Alosa sapidissima*	Anadromous/upper Pelagic
Pacific tomcod	*Microgadus proximus*	Marine/pelagic
Shiner surfperch	*Cymatogaster aggregata*	Marine/pelagic
Striped bass	*Morone saxatilis*	Anadromous/pelagic
White croaker	*Genyonemus lineatus*	Marine/pelagic
Longfin smelt	*Spirinchus thaleichthys*	Estuarine/pelagic
English sole	*Parophrys vetulus*	Marine/bottom
Speckled sanddab	*Citharichthys stigmaeus*	Marine/bottom
Starry flounder	*Platichthys stellatus*	Marine/bottom
Pacific staghorn sculpin	*Leptocottus armatus*	Estuarine/bottom
Bay goby	*Lepidogobius lepidus*	Marine/bottom
Yellowfin goby	*Acanthogobius flavimanus*	Estuarine/bottom

S. euneritica is a motile planktonic animal, albeit a weak one. It is, therefore, more widely distributed in the Bay than other incoming passive marine plankton studied (Chapter 2, Euphausiid and Emerita sections). It is thought that S. euneritica is found in the same areas as larvae of many species of fish (Chapter 2). Therefore, distributional changes seen in S. euneritica could be an indicator of distributional changes in larval fish.

Distributional changes of yellowfin goby larvae were studied in conjunction with S. euneritica. The adult yellowfin goby population is centered in San Pablo Bay, with a small population at the south end of South Bay. Yellowfin goby is a demersal species. The planktonic larvae are spawned from January through April, but they can appear from December through May (Chapter 9).

Results

Similar results were obtained for Study 1 and 2. No apparent differences were found in using either catch data or abundance indices. Therefore, the results of both studies are presented together.

Abundance/Catch (Study 1 and 2)

Results of analysis of catch and abundance index changes in relation to pulse flows are shown in Tables 34 and 35. Consistent significant changes were not found that could be related to pulse flows.

The decline in abundance of northern anchovy in the Bay at first appeared to be related to the onset of pulse flows. Pulse flows and emigration of anchovy both usually began in November. Only in one year, 1980, were pulse flows delayed. The first pulse of water year 1980-1981 did not occur until January 1981 (Figure 185). Northern anchovy began their emigration in November 1980 without increased freshwater flows in the Bay. Therefore, the fall decrease of northern anchovy abundance in the Bay appears due to their normal migration pattern.

Anchovies were found in the Bay during winter, but showed no consistent abundance changes that could be related to pulse flows.

Increases in the abundance or catch of some fish species occurred in the study area during winter. Reasons for this increase vary for each species. English sole (larvae, YOY) move or are carried in from the ocean. Longfin smelt (YOY) move down from the northern reaches, thereby increasing the catch in the study area. The increase in bay goby catch was probably due to YOY becoming large enough to be collected. The increase in yellowfin goby in January and February 1981 was thought to be due to adults moving downstream to spawn. All showed no consistent change in abundance or catch in relation to pulse flows.

It was thought that spring pulse flows would most affect fish populations because many marine fish enter the Bay at this time. Adults enter to spawn; larvae and YOY enter to use the Bay as a nursery area.

Northern anchovy abundance in the Bay began to increase in February or March. Two pulses occurred during February (197,000 cfs in 1982, pulse No. 7; 57,000 cfs in 1984, pulse No. 12). Northern anchovy abundance significantly increased after both of these pulse flows, but there was a larger increase in abundance after pulse No. 12. It appears that the larger flow retarded adult entrance into the Bay.

After the two March (1981 and 1984) pulses of 45,000 cfs and 50,000 cfs (pulse Nos. 3 and 13), respectively, anchovy abundance significantly increased. No fish species were found

Table 34

CATCH CHANGES IN RELATION TO PULSE FLOWS
(* = 0.05 significant)

	First Pulse of Year				Largest Pulse of Year					First Pulse of Dry Year	
Pulse No.	2	4	6	10	1	4	5	9	11	2	14
Peak flow (x1,000 cfs)	75	109	99	128	340	109	197	420	356	75	45
Species											
Surface Pelagic											
Delta smelt											
Northern anchovy		*		*		*	*	*			*
Pacific herring											
Jacksmelt											
American shad			*						*		
Pelagic											
Pacific tomcod				..					..		
Shiner surfperch				*			*				
Striped bass		*				*	*	*	*		
White croaker											
Longfin smelt								*			
Demersal											
English sole				*			*				
Speckled Sanddab		*				*					
Starry flounder											
Pacific staghorn sculpin				*			*				
Bay goby					..		*				
Yellowfin goby				*				*	*		

Table 35

ABUNDANCE CHANGES IN RELATION TO PULSEFLOWS
(* = 0.05 significant)

Pulse No.	1	2	3	4	5	6	7	8	10	11	12	13	14
Peak flow (x1,000 cfs)	340	75	45	109	197	99	197	276	128	356	57	50	45
Northern anchovy													
Eggs	..					*	*		*	..	*		
Post-larvae					*				*	*			
Adults & YOY			*	*			*		*		*	*	
Jacksmelt													
Larvae	*		*						..	..	*		..
YOY	..				..			..			..	..	..
Adult						..	..				*		..
Topsmelt													
Adults	*			*	..						..	..	..
English sole													
Larvae				..	*				..	..			..
YOY							*		*	*		*	
Starry Flounder													
Larvae	..	..					..	..			..	..	..
YOY													
Bay Crangon				*						*	*		*
Sand Crangon				*									

to be negatively affected by these two pulses.

Striped bass, longfin smelt, and yellowfin goby were the only fish to show a significant decrease in catch between February and March 1983 (pulse No. 9, 420,000 cfs). All three are usually found in the more brackish waters of the Delta. This indicates that the brackish water species were most effected by very large pulse flows.

Distribution (Study 1 and 2)

Distributional changes were found that could be directly related to pulse flow effects. The most definitive distributional changes were for those fish that inhabited the upper water column (surface pelagic) and the brackish areas of the Bay. Distributions of demersal and pelagic marine species were least affected by pulse flows.

Figures 186 to 188 show catch distribution of fish before and after pulse events. Pulse flows generally occur within the November-April period of a water year. Three pulses were selected to represent the beginning (pulse No. 6), middle (pulse No. 2), and end (pulse No. 5) of that pulse period.

Figure 186 displays distributional changes for surface pelagic species. Distribution of the marine species, Pacific herring and jacksmelt, were little affected by pulse flows. As well as those northern anchovy found within the Bay during the pulse period. The estuarine species, Delta smelt and American shad, were found farther downstream after pulse flows.

Large changes in the range of demersal fish species were not seen (Figure 187). Some increase in catch of English sole was found upstream after a pulse, indicating some upstream movement. This was the only demersal species to indicate any movement.

Of the marine pelagic (lower water column) species, Pacific tomcod, shiner surfperch, and white croaker, no consistent distributional changes were seen that could be related to pulse flows (Figure 188). Between the estuarine species, striped bass and longfin smelt, only longfin smelt displayed a consistent distributional change. The distribution of longfin smelt (most of which were YOY) increased and became more even after pulses.

Distribution (Study 3)

Sagitta euneritica was usually present in the Bay from September through May; the population peaked in winter (December through February). Therefore care had to be taken in distinguishing between pulse flow effects and population increases and decreases. November through April was found to be the best period for use in the analysis because *S. euneritica* numbers were high and distribution was generally widespread. Catches of *S. euneritica* are shown in Figure 189.

When average flows were about 10,000 cfs and constant, the distribution of *S. eneritica* was very extensive and even (Figure 189: 12/80, 1/81, 11/81). As average flows increased above 10,000 cfs *Sagitta* was found farther downstream and its distribution was more variable. The reasons for the different distributions are discussed in more detail as embayment areas are discussed.

S. euneritica was found in the Suisun and Grizzly bay areas when average monthly flows were less than 17,000 cfs (Figure 189: 11/80, 12/80, 1/81, 11/81). When flows were larger, Carquinez Strait was the upstream limit of distribution. Exceptions to this can be seen in Figure 189: 2/80, 11/83, 3/84. The presence of *S. euneritica* in the Carquinez Strait area in higher average flow periods (above 17,000 cfs) could be the result

SURFACE PELAGIC

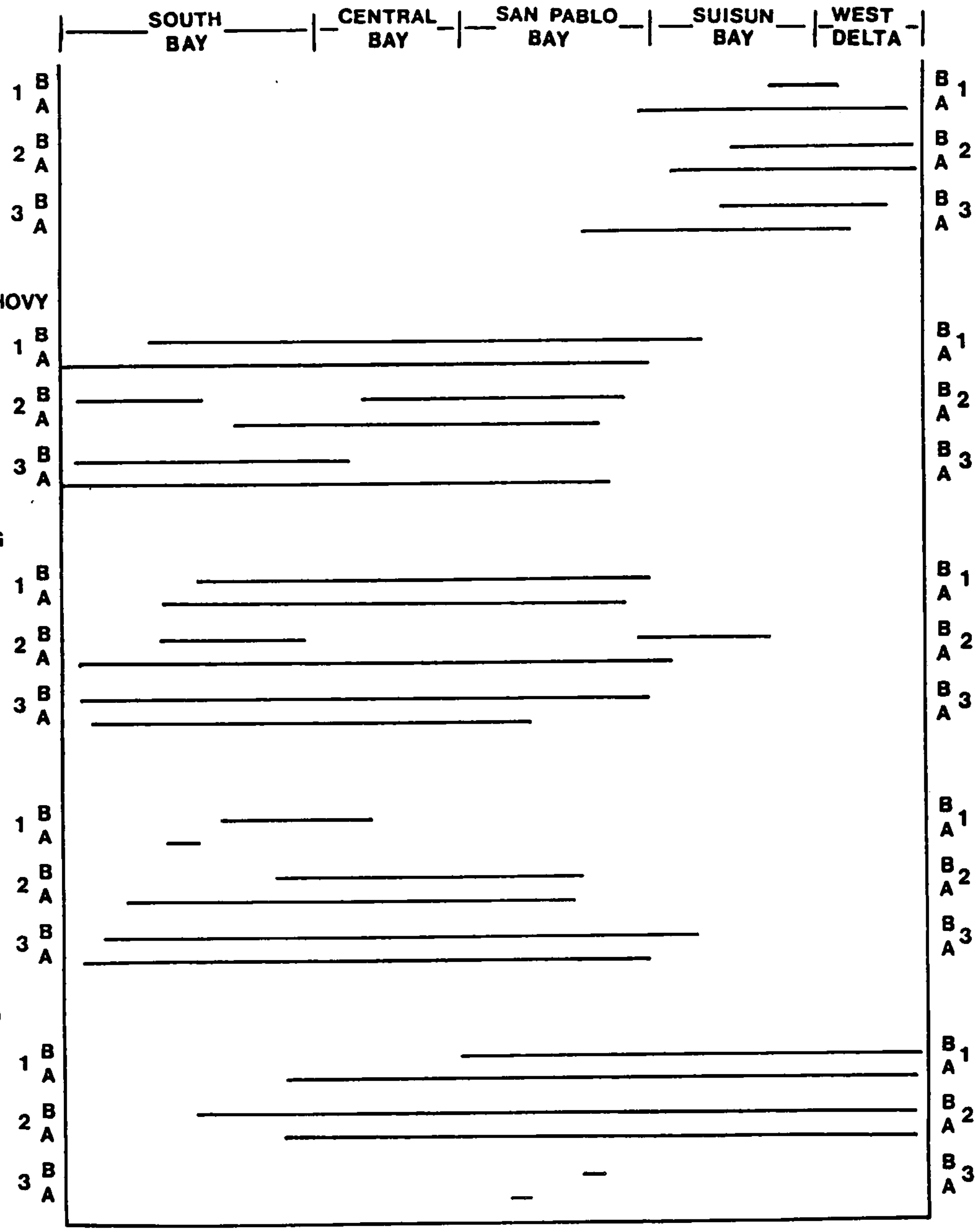


Figure 186. Distribution of surface pelagic species catch before (B) and after (A) three pulse flows. 1 = pulse No. 6, 2 = pulse No. 2, 3 = pulse No. 5 (Table 31). Southern South Bay (left) to Sacramento - San Joaquin river sampling sites (right).

DEMERSAL

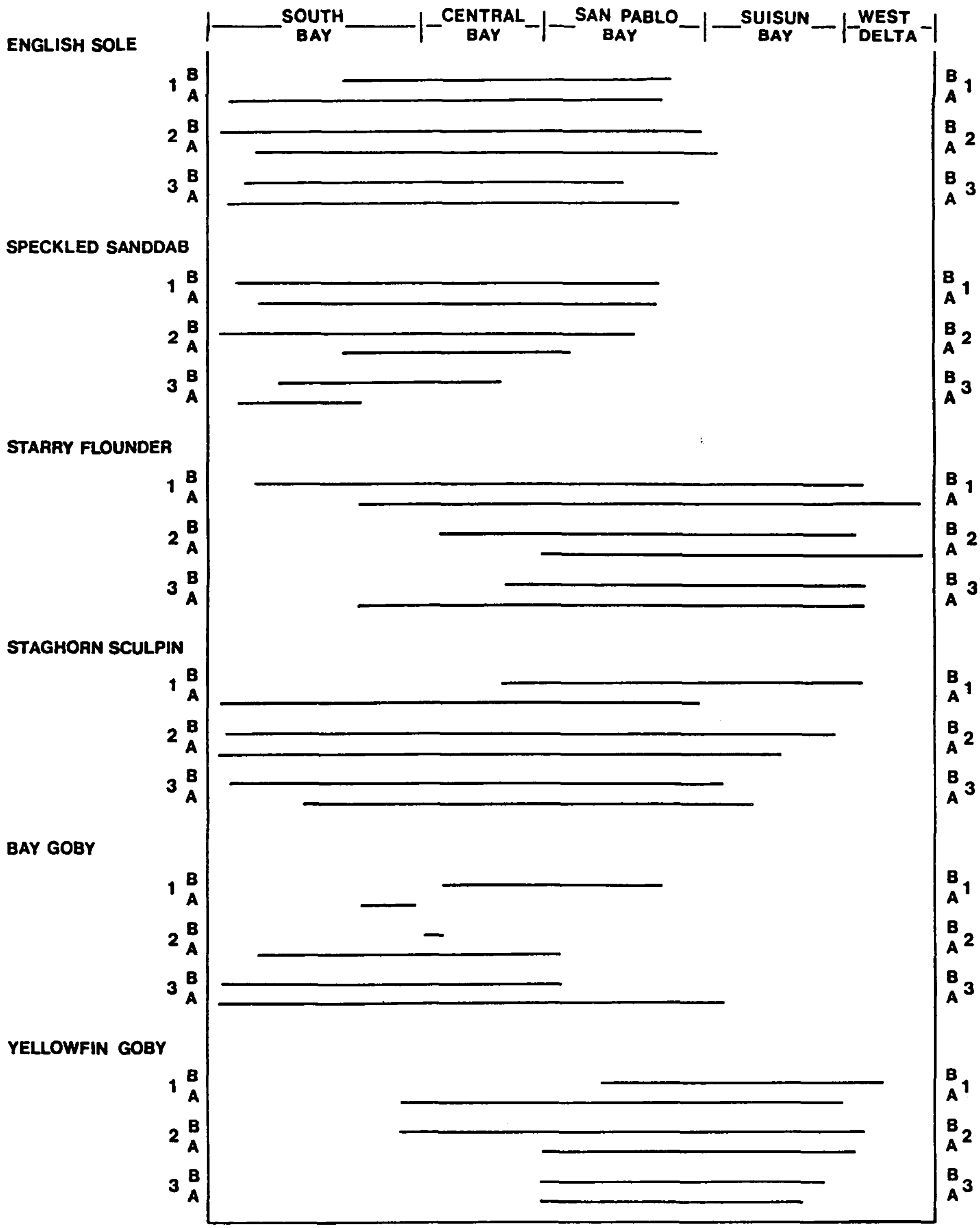


Figure 187. Distribution of demersal species catch before (B) and after (A) three pulse flows. 1 = pulse No. 6, 2 = pulse No. 2, 3 = pulse No. 5 (Table 31). Southern South Bay (left) to Sacramento - San Joaquin river sampling sites (right).

PELAGIC

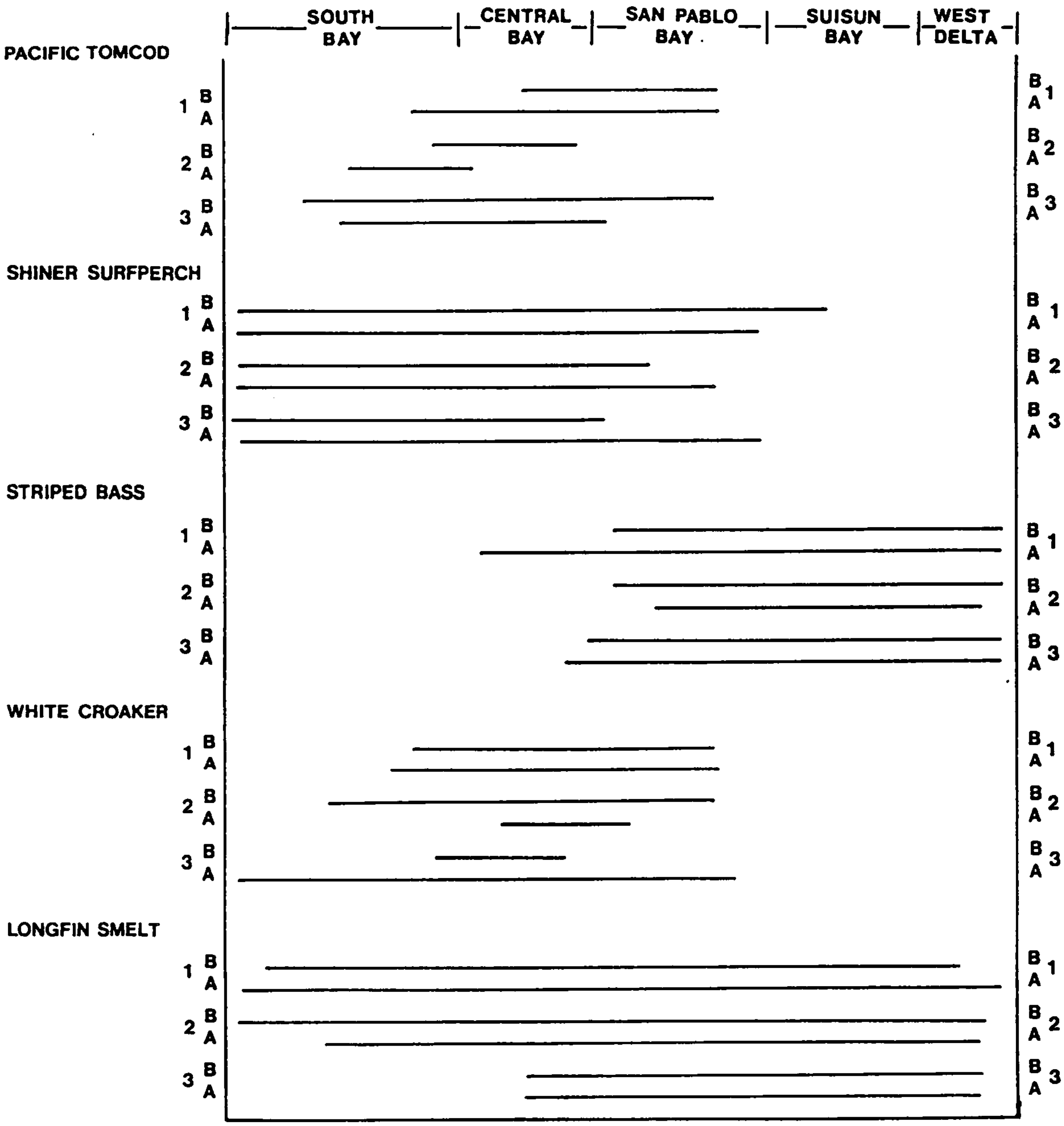
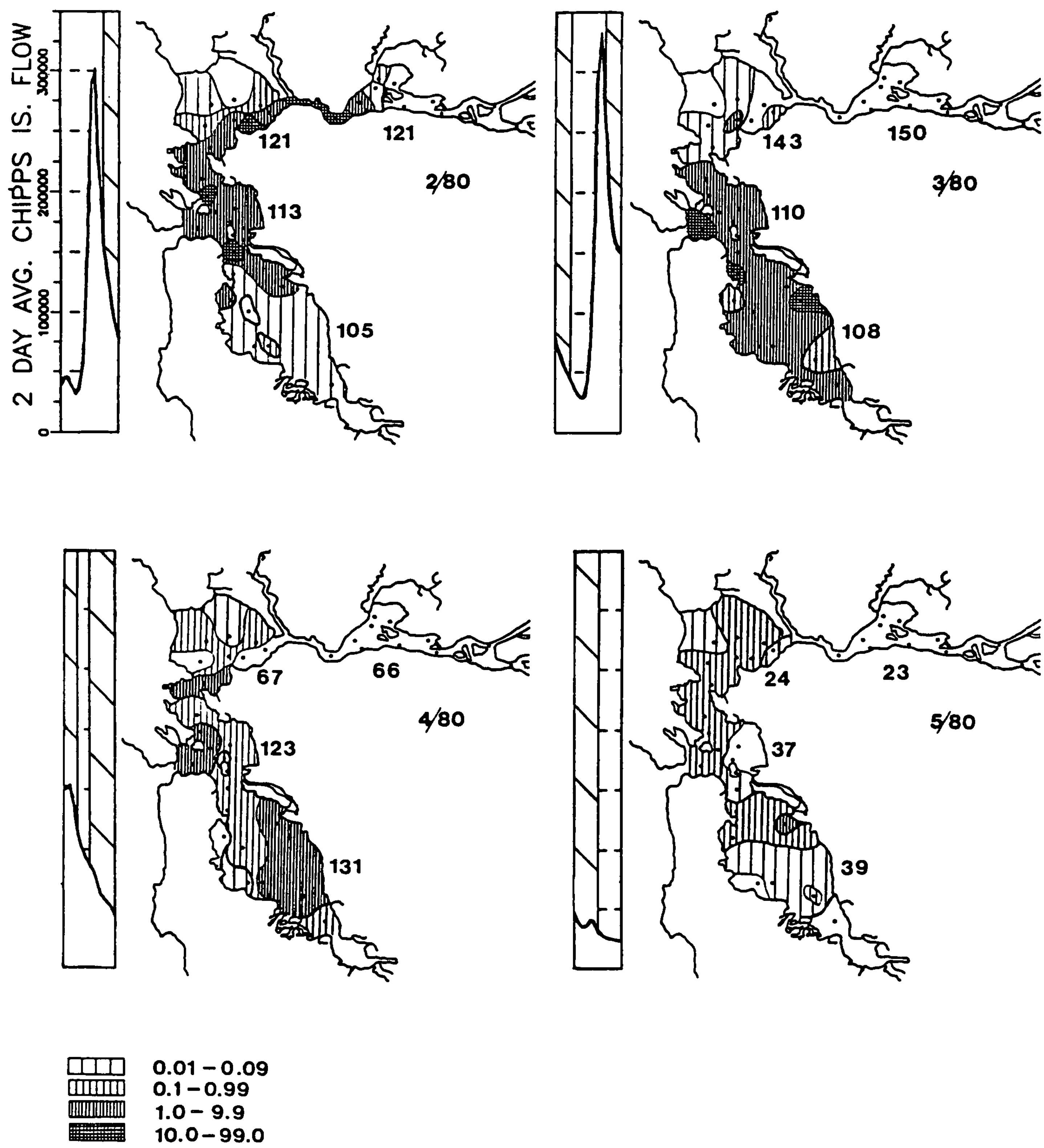


Figure 188. Distribution of pelagic species catch before (B) and after (A) three pulse flows. 1 = pulse No. 6, 2 = pulse No. 2, 3 = pulse No. 5 (Table 31). Southern South Bay (left) to Sacramento - San Joaquin river sampling sites (right).

Figure 189. Catch maps of _Sagitta euneritica_. Catch (number per cubic meter) of _S. euneritica_ at each sampling site. Contour lines are approximated by eye. Numbers to the bottom or right of the embayments are the average daily flow (x 1,000 cfs) that occurred between survey periods. Because all embayments were not sampled on the same day, average flows prior to sampling did vary especially when flows were fluctuating from pulses. Hydrographs to the left of the maps represent the two day average flow (cfs) that occurred prior to the sampling survey.


2 DAY AVG. CHIPPS IS. FLOW
0
100000
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121
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143
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67
66
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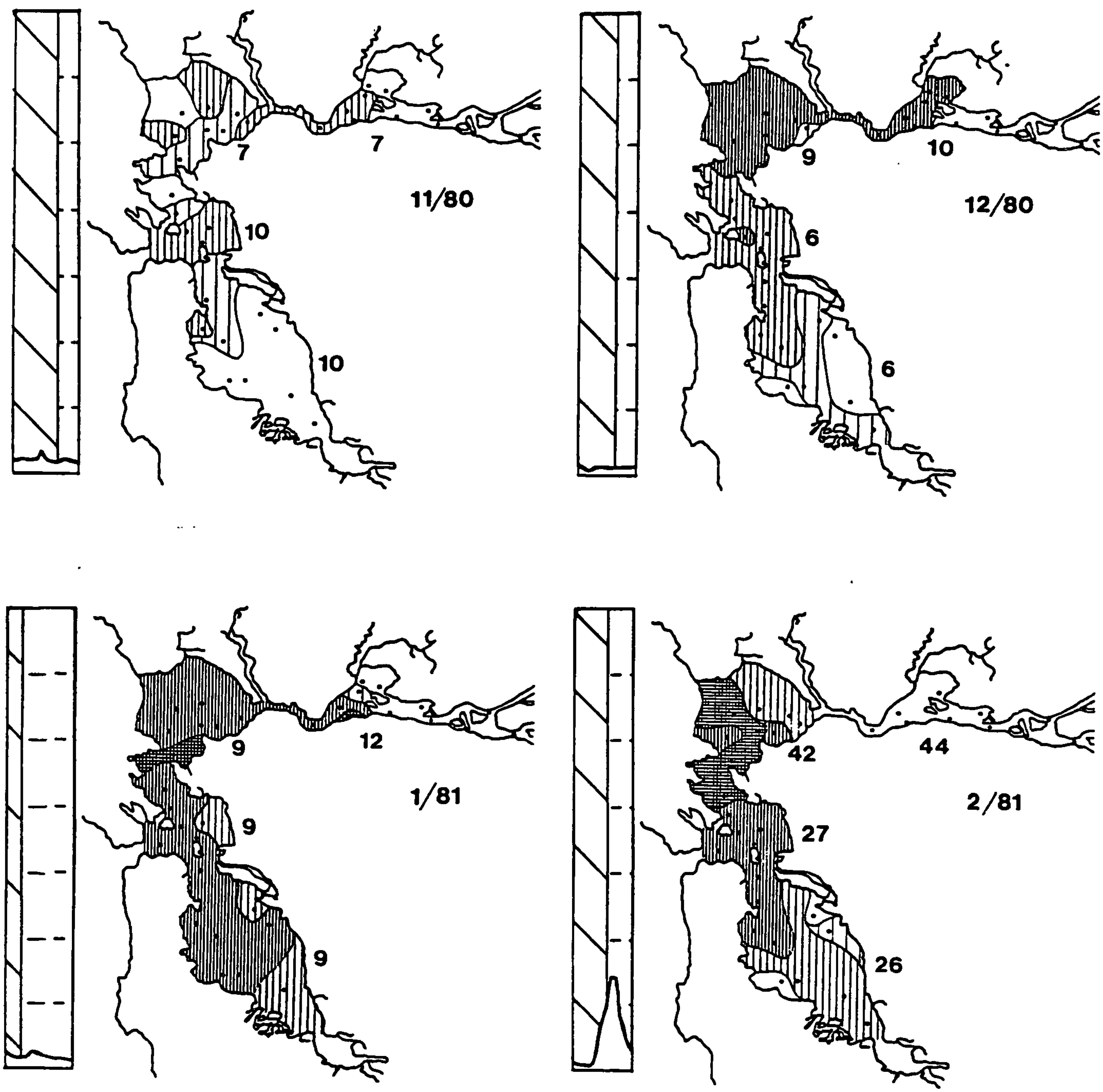
39
0.01 – 0.09
0.1 – 0.99
1.0 – 9.9
10.0 – 99.0



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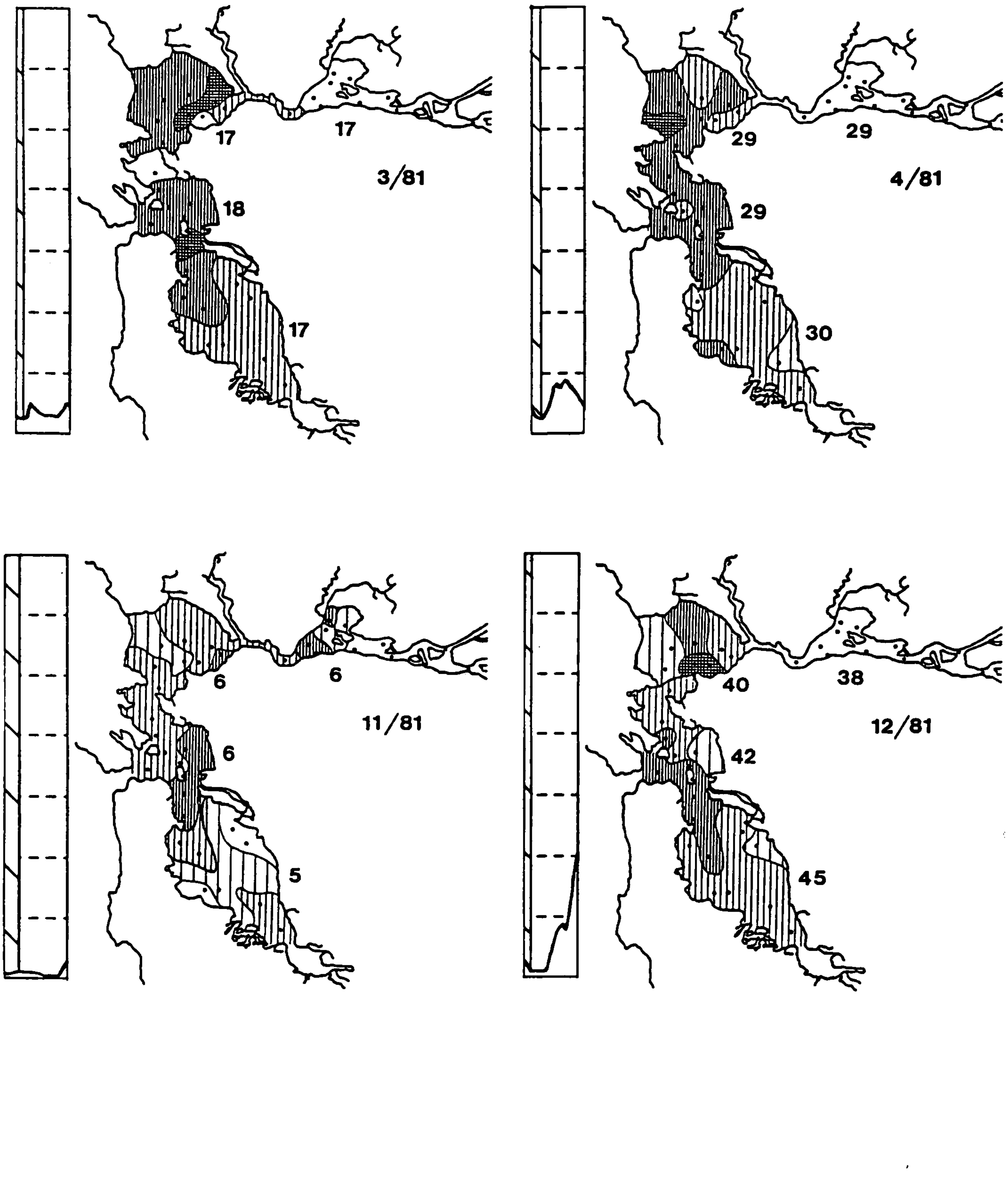
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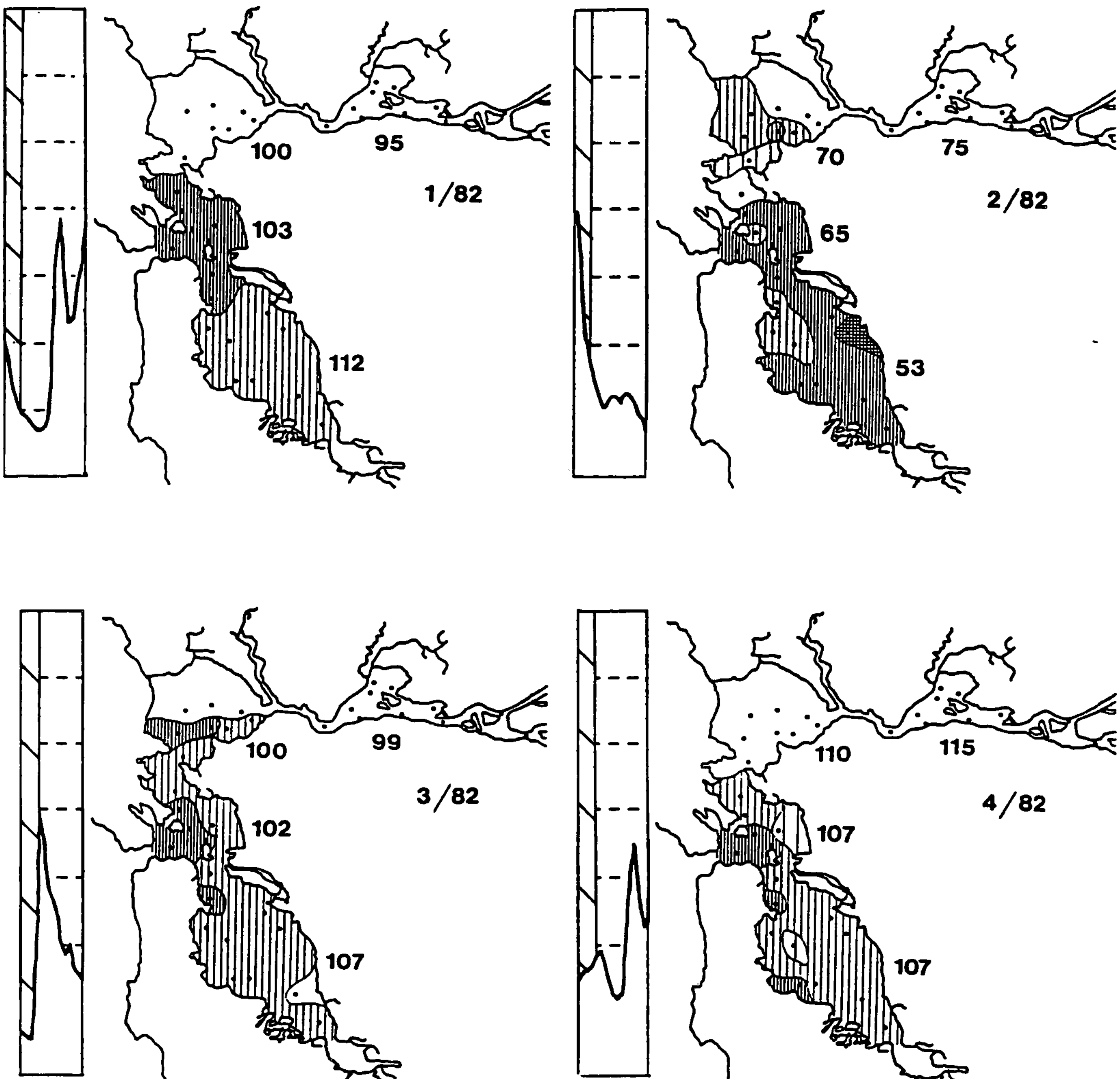
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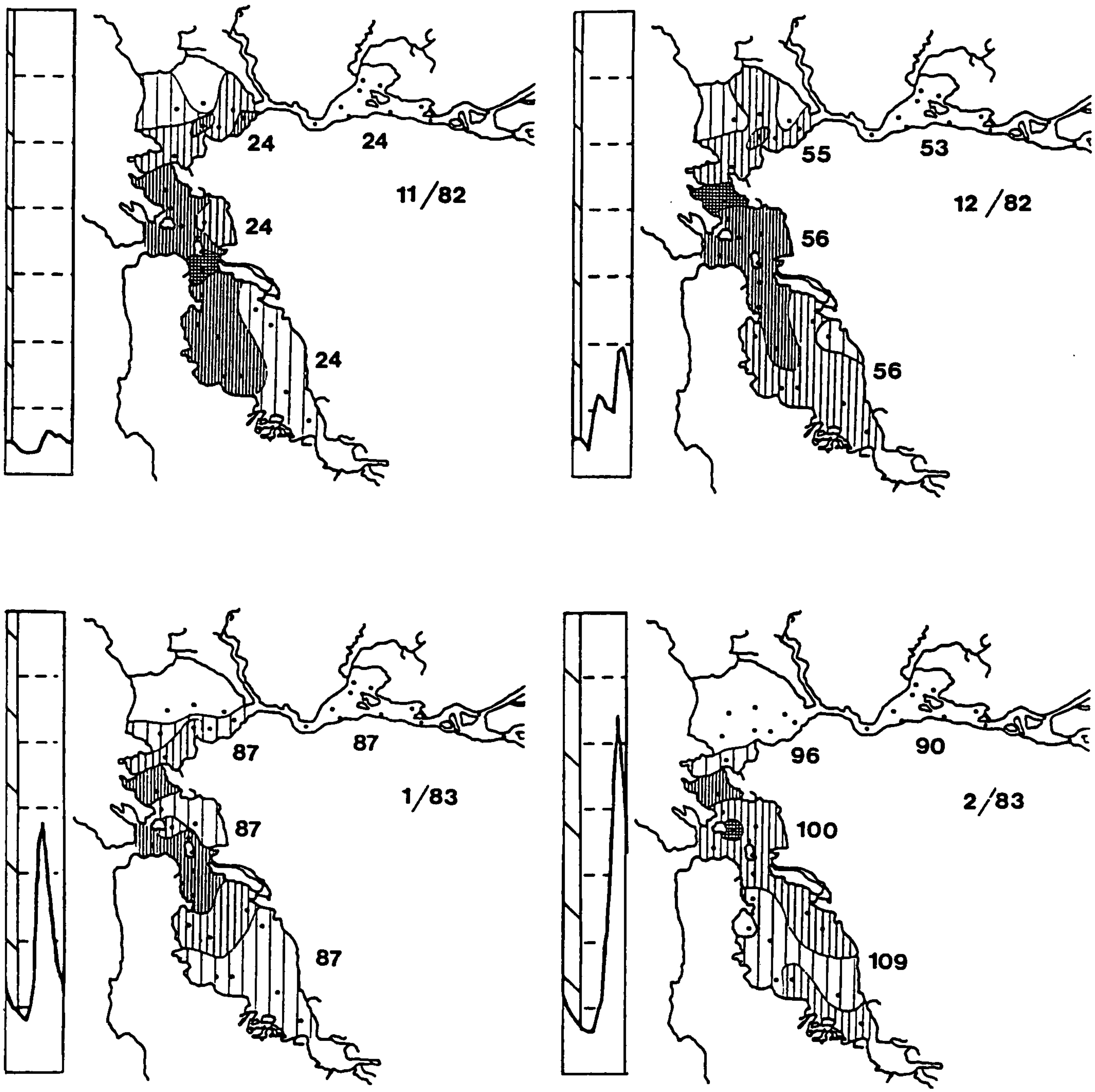
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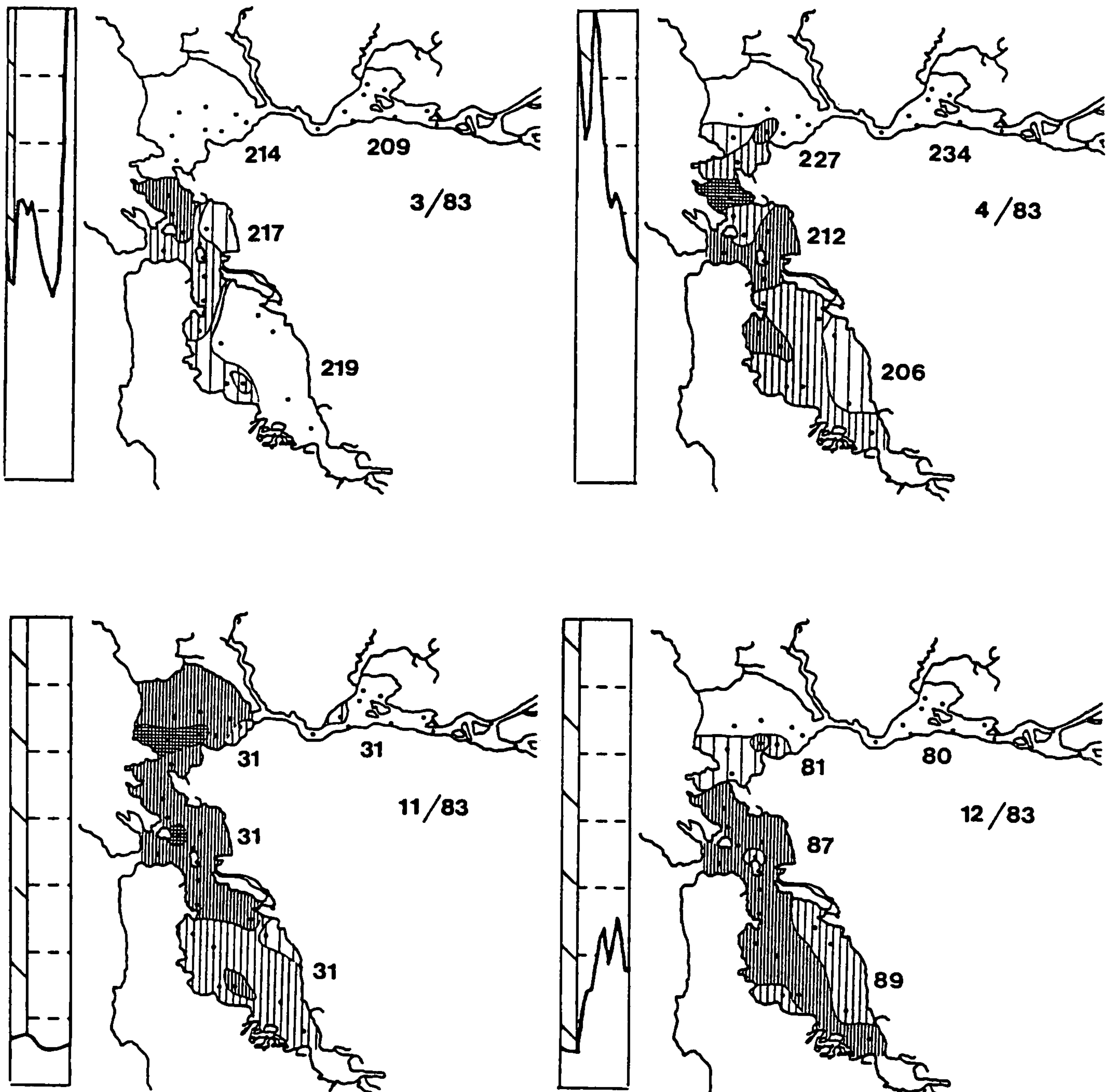
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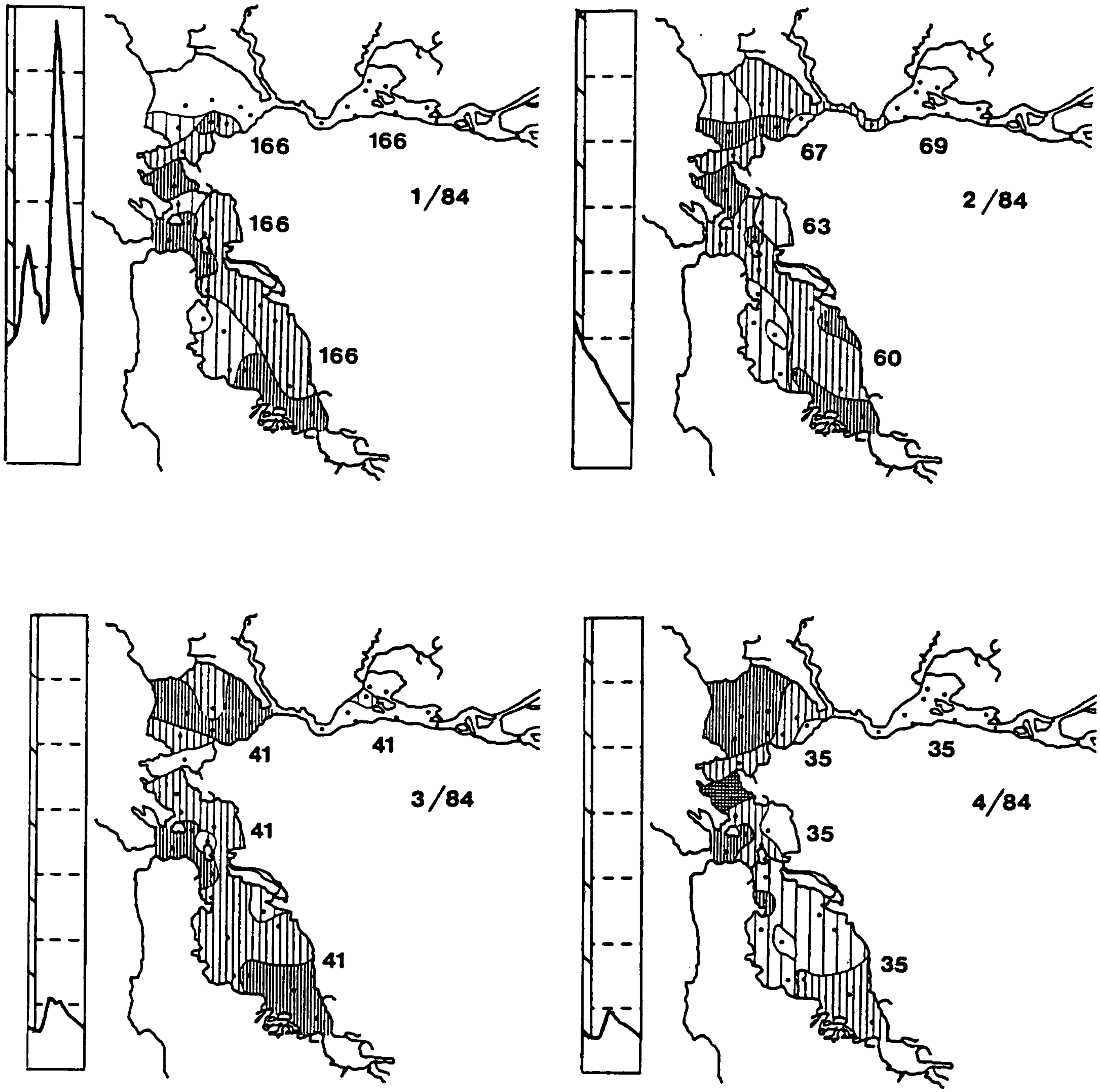
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35

of tidal excursion or gravitational currents carrying them in from San Pablo Bay.

Average monthly flows were found to be a poor indicator of S. euneritica distribution in San Pablo Bay when flows were high. The average monthly flow prior to the January and March 1982 samples was 100,000 cfs (Figure 189: 1/82, 3/82). Yet in January 1982, San Pablo Bay was devoid of S. euneritica, while they were found at half of the stations in the bay during the March survey. A similar pattern was found in the March and April 1983 surveys when average flows were over 200,000 cfs (Figure 189: 3/83, 4/83). Why was there such a significant ($p<0.05$) difference in abundance where the previous average flows were similar? A possible explanation is offered below which involves the timing of pulse flows in relation to surveys and the effects of pulses on stratification and water movement.

Before Sagitta distribution in San Pablo Bay can be explained the hydrodynamic change that occurs during a pulse event must be known. Denton (1987) found that as flow increased during a pulse event, salinities in the water column decreased at the same rate. The outflowing water acted as a moving barrier, forcing water out of San Pablo Bay, from top to bottom. As the pulse flow subsided, an increase in bottom water salinity occurred sooner than surface water salinity. This increase in bottom salinity suggested that a landward propagating bottom flow had formed, i.e. a gravitational current.

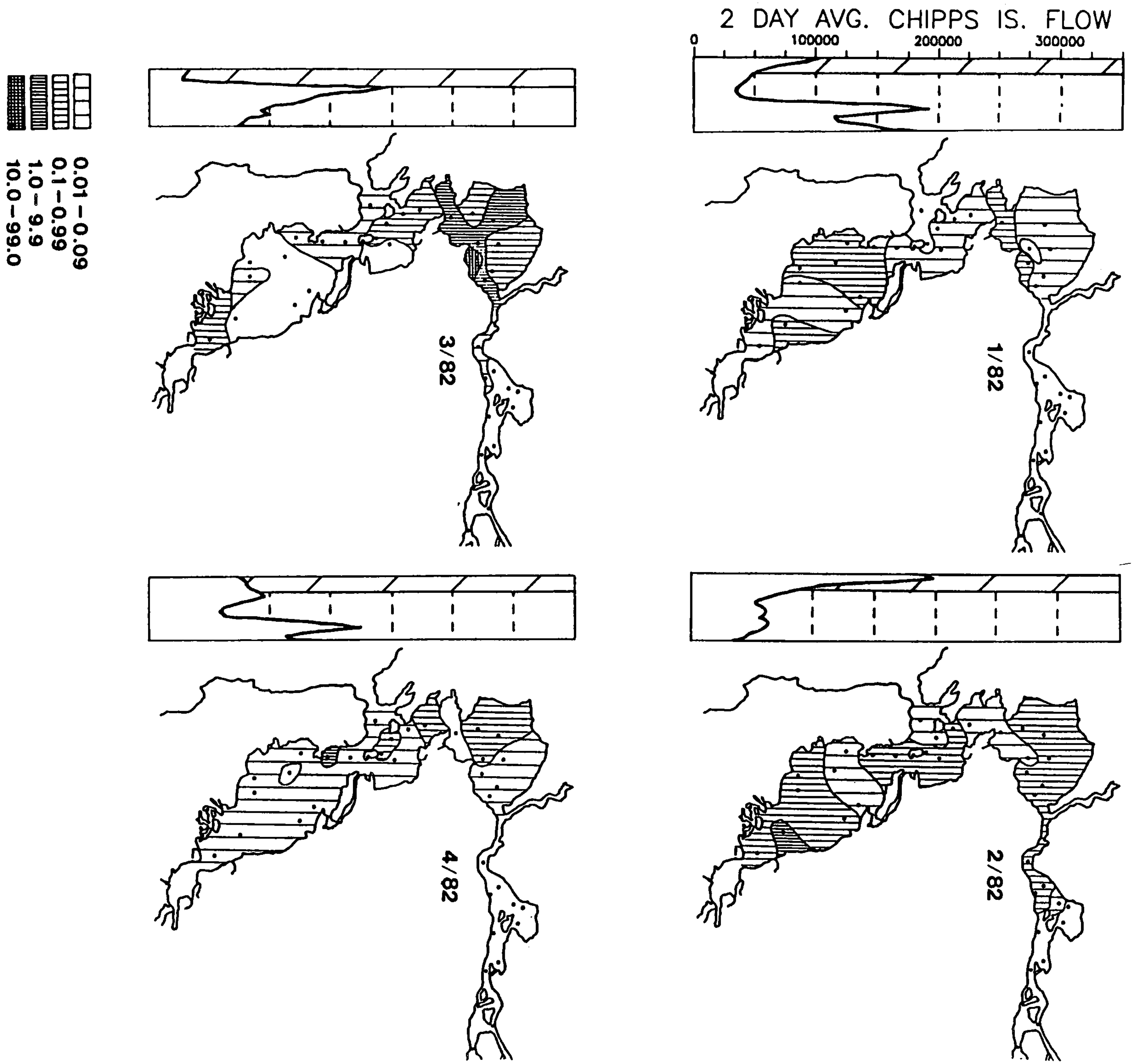
The distribution patterns of Sagitta in San Pablo Bay during high flow periods can now be understood. Although average flows prior to January/March 1982 (average about 100,000 cfs) and March/April 1983 (average about 200,000 cfs) were similar, the hydrographs of the pair members were not. The January 1982 (1/82) and March 1983 (3/83) samples were taken while the pulse flow was increasing (note rising hydrographs). Water was being forced out of San Pablo Bay enmass carrying Sagitta with it. The March 1982 (3/82) and April 1983 (4/83) samples were taken when the pulse flow was decreasing (note falling hydrographs). The Sagitta present in San Pablo Bay at this time were a result of the gravitational current carrying them in.

Distributional changes due to direct effects from pulse flows were harder to interpret or verify in Central and South bays. Immigration and emigration through the Golden Gate confused distributional effects of pulse flows in Central Bay. The wide spacing of sampling sites and the apparently rapid current changes due to wind and tidal effects masked pulse flow effects in South Bay. For these reasons and because the average length of a pulse flow was three weeks, monthly sampling was not enough to demonstrate more direct effects of pulse flows in the lower reaches of the Bay.

Yellowfin goby larval data were available for 1982 through 1985. Catch distributions are shown in Figure 190. The distributional analysis of yellowfin goby larvae was complicated by the fact that larvae were being continuously spawned in San Pablo Bay. Larvae grow to the next stage within the month, so that the next month's sample represents a different group of larvae. Therefore, the effect of pulse flows on their distribution was not as clear. The general distributional changes seen were similar to that seen in Sagitta.

In the 1982 data, decreasing catches of yellowfin goby larvae were seen in San Pablo Bay when the hydrograph was rising, and vice versa. These distributions were similar to those of S. euneritica during that same time period (Figure 189). Larvae were found in Carquinez Strait and east on a falling hydrograph (Figure 190: 2/82,

Figure 190. Catch maps of yellowfin goby larvae. Catch (number per cubic meter) of yellowfin goby larvae at each sampling site for January through April, 1982 - 1985. Contour lines were approximated by eye. Hydrographs to the left of the maps represent the two day average flow (cfs) that occurred prior to the sampling survey.


2 DAY AVG. CHIPPS IS. FLOW
0
100000
200000
300000
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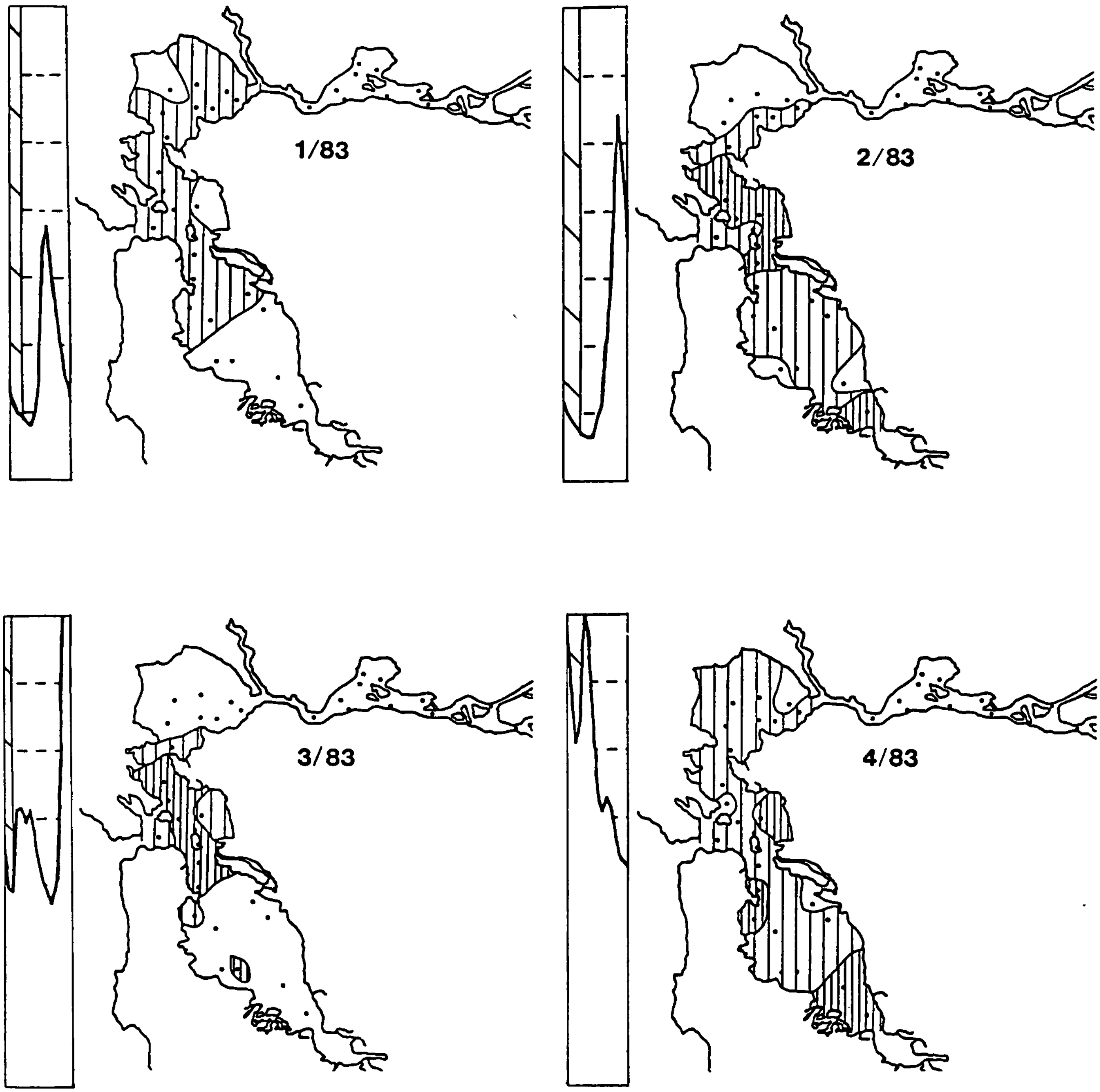
2/82
3/82
4/82
0.01-0.09
0.1-0.99
1.0-9.9
10.0-99.0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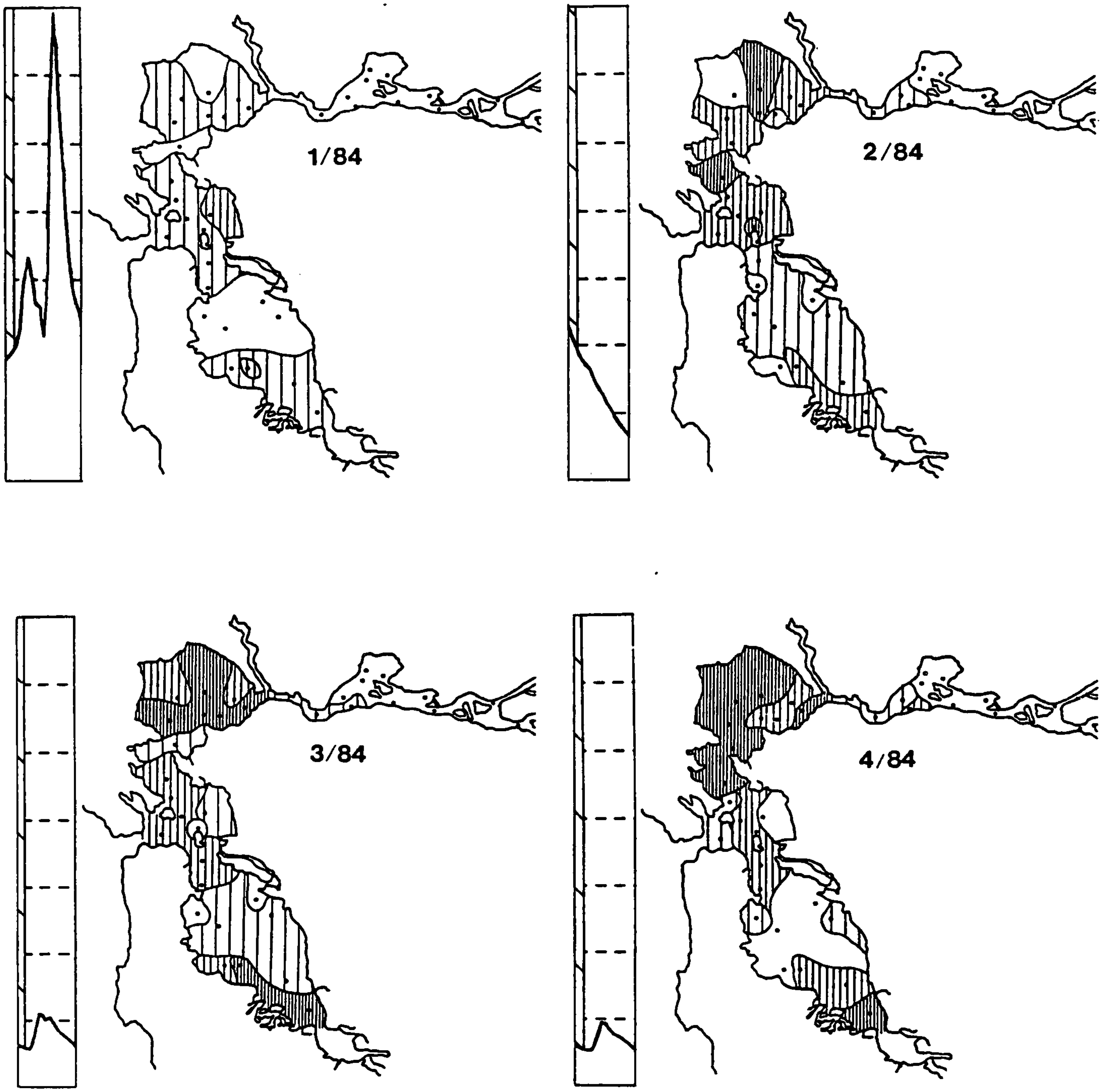
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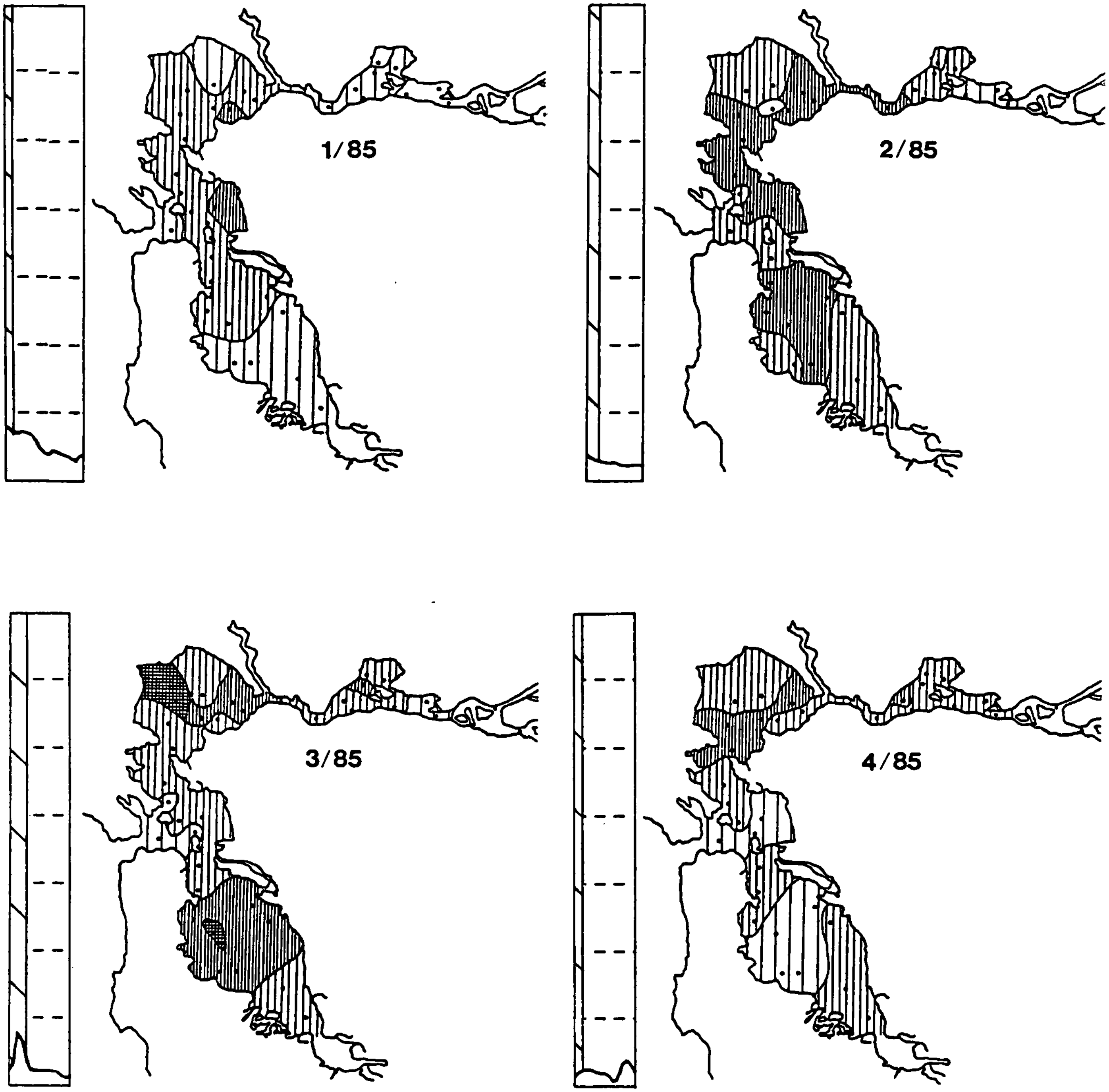
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Chapter 12. ANALYSIS OF COMMERCIAL LANDINGS AND DELTA OUTFLOW

One of the major roles of an estuary is to serve as a nursery area for marine species. Comparisons of estuarine conditions, in this case freshwater outflow, and subsequent years' commercial landings of fish and invertebrates have shown the importance of estuaries to commercial fisheries in Texas (Texas Department of Water Resources 1980a, 1980b, 1981a, 1981b, 1981c) and the Gulf of Maine (Sutcliff 1973). Efforts to determine similar relationships between commercial landings in the San Francisco Bay area and freshwater outflow into the estuary were not successful.

The data set used consisted of 1940-1984 annual landings for all commercially caught ocean species also known to inhabit the bay and 1930-1984 Chipps Island outflows. Commercial landings were based on calendar year landings in the San Francisco Bay area (all ports between Princeton and Bodega Bay) of Pacific herring, northern anchovy, white croaker, turbot, sanddab, California halibut, surfperch, flounder, and English sole. The exception was Dungeness crab, which were tabulated on a fishery year basis, November through July, since that refinement of the data was available.

Outflow variables used in the correlations were average and sum outflows for each year, successive groupings of months starting with November and ending with June, and yearly offsets of the annual and monthly groups, i.e. a 5-year offset results in 1980 catch data being correlated with 1975 flow data (Table 36). Monthly groupings consisted of each month, each month plus the next month, each month plus the next two months, and so on until the entire period was covered. This resulted in 35 monthly groupings, in addition to the annual value. Yearly offsets were run for 1 through 10 years.

Table 36

COMBINATIONS OF MONTHS USED FOR FLOW VARIABLES IN CORRELATIONS OF COMMERCIAL LANDINGS AND DELTA OUTFLOW

Nov	Nov-Dec	Nov-Jan	Nov-Feb	Nov-Mar	Nov-Apr	Nov-May	Nov-Jun
Dec	Dec-Jan	Dec-Feb	Dec-Mar	Dec-Apr	Dec-May	Dec-Jun	
Jan	Jan-Feb	Jan-Mar	Jan-Apr	Jan-May	Jan-Jun		
Feb	Feb-Mar	Feb-Apr	Feb-May	Feb-Jun			
Mar	Mar-Apr	Mar-May	Mar-Jun				
Apr	Apr-May	Apr-Jun					
May	May-Jun						
Oct-Sept(year)							

Several assumptions about the data are necessary before this type of correlation analysis can be successful:

* There has be a relationship between catch and stock abundance.

* Catch location is known.

* Fishing effort is known.

* Reporting of landings is consistent and accurate.

Those variables with a correlation coefficient of $p<0.05$ are shown in Table 37. Since there was no difference in terms of statistical significance between average and sum outflows results, only average outflow results are presented.

Results are not discussed here, because there were a number of problems with this analysis, mostly because the required assumptions were not met. During the period used, commercial fishing equipment and methods have changed dramatically. Fishermen are now more efficient and range farther than those fishing in the 1940s. The reporting of catches has not been consistent. Landings are now available for ports only, and not by ocean block number, making it difficult to establish where the catch came from. Thus, fish included in San Francisco Bay landings could be from anywhere off the California coast, especially in recent years.

The lack of effort data associated with the catch makes it difficult to determine whether higher catches are due to a greater stock abundance or to increased effort by fishermen. Economics and market demand are probably the major factors determining what species is fished and with what effort. Many of the assumptions necessary for this analysis cannot be met. In addition, any significant correlations should be interpreted using known life history and fishery data for each species. Such basic data as spawning times, ages of fish that spawn, ages of fish that contribute most to the spawn, and ages of fish that comprise the commercial landings are not available for most commercially important species. Without this information and along with the failure to meet the basic assumptions, it is not possible to determine if there is a relationship between freshwater outflows to San Francisco Bay and commercial catch of estuarine-reared species.

Table 37

COMBINATIONS OF FLOW VARIABLES AND COMMERCIAL LANDINGS WITH SIGNIFICANT CORRELATIONS ($P<0.05$)

Species	Years Offset	Type of Correlation*	Flow Variables with $p<0.05$			
Northern Anchovy	5	-	Nov-Feb	Nov-Mar	Nov-Apr	Nov-May
			Nov-Jun	Dec-Jan	Dec-Feb	Dec-Mar
			Dec-Apr	Dec-Jun	Jan-Feb	Jan-Mar
			Jan-Apr	Jan-May	Jan-Jun	Feb
			Feb-Mar	Feb-Apr	Overall	
	7	+	Nov			
	8	+	Nov			
Surfperch	1	+	Nov-Jan	Dec-Jan	Jan	
			Apr			
White croaker	1	+	Nov-Mar	Nov-Apr	Nov-May	Nov-Jun
			Dec-Mar	Dec-Apr	Dec-May	Dec-Jun
			Jan-Mar	Jan-Apr	Jan-May	Jan-Jun
			Feb	Feb-Mar	Feb-Apr	Feb-May
			Feb-Jun	Mar	Mar-Apr	Mar-May
			Mar-Jun	Apr-May	Apr-Jun	May
			May-Jun	Jun	Overall	
	2	+	Apr			
	10	+	Nov	Nov-Dec	Nov-Jan	
Sanddab	3	+	May	May-Jun		
			Nov	Nov-Dec	Dec	
Turbot	8	+	Mar	Mar-Apr		
	9	+	Nov-Mar	Nov-Apr	Nov-May	Nov-Jun
			Dec-Mar	Dec-Apr	Dec-May	Dec-Jun
			Jan-Feb	Jan-Mar	Jan-Apr	Jan-May
			Jan-Jun	Feb	Feb-Mar	Feb-Apr
			Feb-May	Feb-Jun	Mar	Mar-Apr
			Mar-May	Mar-Jun	Apr	Apr-May
			Apr-Jun	May	May-Jun	Jun
			Overall			
	10	+	Nov-Feb	Nov-Mar	Nov-Apr	Nov-May
			Nov-Jun	Dec-Feb	Dec-Mar	Dec-Apr
			Dec-May	Dec-Jun	Jan-Feb	Jan-Mar
			Jan-Apr	Jan-May	Jan-Jun	Feb
			Feb-Mar	Feb-Apr	Feb-May	Feb-Jun
			Mar	Mar-Apr	Mar-May	Mar-Jun
			Apr	Apr-May	Apr-Jun	May
			May-Jun	Jun	Overall	

Table 37 (Continued)

COMBINATIONS OF FLOW VARIABLES AND COMMERCIAL LANDINGS WITH SIGNIFICANT CORRELATIONS ($P<0.05$)

Species	Years Offset	Type of Correlation*	Flow Variables with $p<0.05$			
English sole	4	-	Nov-Dec	Nov-Jan	Nov-Feb	Nov-Mar
			Nov-Apr	Dec	Dec-Jan	Dec-Feb
			Dec-Mar			
	8	+	Feb-Mar	Feb-Apr	Mar	Mar-Apr
	9	+	Dec-Apr	Dec-May	Dec-Jun	Jan-Mar
			Jan-Apr	Jan-May	Jan-Jun	Feb
			Feb-Mar	Feb-Apr	Feb-May	Feb-Jun
			Mar	Mar-Apr	Mar-May	Mar-Jun
			Apr	Overall		
	10	+	Nov-Apr	Nov-May	Nov-Jun	
			Dec-Mar	Dec-Apr	Dec-May	Dec-Jun
			Jan-Mar	Jan-Apr	Jan-May	Jan-Jun
			Feb-Mar	Feb-Apr	Feb-May	Feb-Jun
			May	Mar-Apr	Mar-May	Mar-Jun
			Apr	Apr-May	Apr-Jun	Overall
California halibut	1	+	Mar			
	4	-	Nov-Dec			
	5	-	Nov-Feb	Nov-Mar	Nov-Apr	Nov-May
			Nov-Jun	Dec-Feb	Dec-Mar	Dec-Apr
			Dec-Jun	Jan-Apr	Jan-May	Jan-Jun
			May-Jun	Jun	Overall	
	6	-	Nov-Feb	Nov-Apr	Nov-May	Nov-Jun
			Dec-Feb	Dec-Apr	Dec-May	Dec-Jun
			Overall			
	8	+	Nov			
	10	+	Nov			
Pacific herring	4	+	May	May-Jun	Jun	
	5	+	May			
	8	+	Nov			
	9	+	Nov			
	10	+	Nov	Nov-Feb	Nov-Mar	Dec-Jun
			Jan			
Flounder	3	-	Nov-Feb	Dec-Feb	Feb	
	4	-	May	May-Jun	Jun	
Dungeness crab	3	+	May			
	5	+	Apr-Jun	May	May-Jun	Jun
	6	+	May	May-Jun		
	8	+	May			

* Years offset refers to the number of years offset or the lag between flow and landing data. Type of correlation refers to positive (+) or negative (-).

Chapter 13. SPECIES ASSOCIATION WITH WATER YEAR TYPE

Time did not allow detailed analysis of data for all species collected in our survey. In an effort to provide an overview of the changes in abundance and distribution of fish and shrimp community including those species not analyzed in detail, a more cursory analysis was undertaken to assess the relationship between the fish and shrimp catches and water year type. For this general overview, wet and dry year catches and distributions were compared. The analysis assumed three possible results. Organisms can react positively to flow by becoming more numerous in wet years, react negatively by becoming more numerous in dry years, or have no response to either wet or dry conditions.

The data base used for this analysis was the 1980-1985 raw catches at each station of adult and juvenile fish and shrimp. Data from the net that most effectively sampled a given species on a annual basis was used. Rare species (those collected in only 2 of the 6 years and with catches less than five) were not used. If no organisms were collected in a specific embayment during the 6 years, data from that embayment were removed from the analysis.

Annual catch differences were determined with a one-way ANOVA, using a general linear model. A contrasting of means from the ANOVA was used to determine if the catch in the wet years (1980, 1982, 1983, 1984), was different from that in the dry years (1981, 1985).

Species were separated into five groups based on results of the contrasting of the wet and dry year catches. Those species whose p value for the contrast was 0.05 or less were classified as wet if the mean catch was greater in the wet years and dry if the mean catch was greater in the dry years. If the p value was between 0.06 and 0.10, the species was classified as limited wet or limited dry, depending on whether the mean catch was greater in wet or dry years. All species with a p value greater than 0.10 were classified as having no preference.

Range extensions were determined for the marine species by comparing on a station by station basis, average wet year catches with average dry year catches. Species were categorized as extending their range in the wet years, extending it in the dry years or no change in range between water year types.

We used 69 species of fish and 3 species of shrimp in this analysis. A significant difference ($p<0.05$) was found between the annual catches for all of the shrimp species and 42 of the fish species (Table 38). The majority of the species with no difference in abundance between years were the less abundant or rarer species. The exceptions were topsmelt, inland silverside, and plainfin midshipman.

Catches of most species, and especially of the most abundant ones, were different between years. This leads to the conclusion that there is considerable interannual variability in the majority of more common species. If a difference in abundance between years exists, the next step is to determine what factor or factors are responsible. In this case freshwater outflow as represented by water year type was considered since it is known to be a major factor that changes between years and

Table 38. Classification of fish and shrimp based on association with water year type. The catch of those species followed by an asterisk (*) had a significant (p<0.05) difference between years.

Species Type	Association Class				
	Wet	Limited Wet	No Preference	Limited Dry	Dry
Freshwater	Prickly sculpin * Splittail *	White catfish *	Sacramento squawfish* Bigscale logperch Channel catfish * Common carp Delta smelt * Inland silverside Mosquitofish Threadfin shad *	Tule perch	
Anadromous	Green sturgeon White sturgeon *	American shad * Striped bass *	Chinook salmon * Steelhead River lamprey *	Pacific lamprey *	
Estuarine	Crangon franciscorum * Longfin smelt * Starry flounder * Threespine stickleback * Yellowfin goby *	Pacific staghorn sculpin *	Palaemon macrodactylus * Rainwater killifish		
Marine	California tonguefish * Pacific tomcod * Bay goby * Leopard shark * Speckled sanddab *	California lizardfish * Pacific herring * Pacific sandlance	Crangon nigricauda * English sole * Pacific pompano * Pacific sanddab * Arrow goby * Barred surfperch * Bat ray Big skate Black perch Bonehead sculpin Brown rockfish * Brown smoothhound Chameleon goby Cheekspot goby Curlfin sole Diamond turbot * Lingcod * Northern anchovy * Pile perch Plainfin midshipman Rubberlip seaperch Sand sole Shiner perch * Showy snailfish Spiny dogfish Spotted cusk-eel Surf smelt * Topsmelt White croaker * White seaperch Whitebait smelt		California halibut * Bay pipefish * Dwarf perch * Jacksmelt * Walleye surfperch *

29% 61% 10%

has a major impact on many fish and shrimp species.

Of the species tested, 61 percent (44 species) had no preference as to water year type. Not surprising, 31 of these were marine species. This result is expected because the amount of fresh water flowing into the bay should not affect the annual catches of species that have not evolved a mechanism to use it or whose main habitat exists outside the bay. Chinook salmon and steelhead trout are in the group showing no preference, because of the number of hatchery fish planted directly into the Bay.

The principal finding of this analysis is that 29 percent of the species tested were more abundant in the wet years than in the dry years, 10 percent were more abundant in the dry years and 61 percent were unaffected by water year type. Only marine species were more abundant in dry years; marine, estuarine, anadromous, and freshwater species were more abundant in wet years. Nearly all the more common estuarine species were more abundant in the wet years. If the data were subdivided into juvenile or young-of-year and adult individuals for each species, a number of the limited wet and no preference species would be elevated to wet or limited wet status. Pacific staghorn sculpin is a good example of this. It should be noted that the classification of California halibut as a dry species is due to the large catches in 1985 and that catches of California halibut have been increasing since 1983.

Of the marine species, 22 expanded their range in the wet years, 9 expanded their range in the dry years and 13 showed no change in range in relation to wet and dry years (Table 39). Only jacksmelt and California halibut had increased abundances and ramge in the dry years. Northern anchovy and Pacific herring increased their range the greatest by expanding into study area sections 11 and 12 in the dry years. In general, most marine species did not move any further upstream than study area section 9.

The significant finding of this analysis is that of the species showing a difference between wet and dry years, a greater number of species were more abundant and widespread in the wet years than the dry years. The increased catch of marine species in the dry years was limited to five species. In our study plan it was postulated that abundances and distributions of marine species would be greater in dry years due to more marine conditions being available over a greater portion of the Bay and for a longer period of time. This was not the case; in fact the opposite was found. If conditions in the Bay were allowed to become similar to those found during dry years, this analysis suggests that the abundance and distribution would increase for only a few marine species and decrease for nearly all estuarine species. In addition, many of the major forage species would be negatively impacted under these conditions and this would have a negative effect on the recreationally important species.

Table 39

MARINE FISH AND SHRIMP RANGE EXTENSIONS
IN RELATION TO WATER YEAR TYPE

Range Extended During Wet Years	Range Extended During Dry Years	No Change in Range
California tonguefish	Pacific herring	Bay goby
Pacific tomcod	*Crangon nigricauda*	Pacific sandlance
Leopard shark	Pacific pompano	English sole
Speckled sanddab	Bonehead sculpin	Big skate
California lizardfish	Cheekspot goby	Black perch
Pacific sanddab	Surf smelt	Lingcod
Brown smoothhound	California halibut	Showy snailfish
Barred surfperch	Jacksmelt	Spotted cusk-eel
Bat ray	Northern anchovy	Topsmelt
Brown rockfish		White croaker
Chameleon goby		Whitebait smelt
Curlfin sole		Dwarf perch
Diamond turbot		Arrow goby
Pile perch		
Plainfin midshipman		
Rubberlip seaperch		
Sand sole		
Shiner perch		
Spiny dogfish		
White seaperch		
Bay pipefish		
Walleye surfperch		

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Appendix A

SPECIES OF FISH AND SHRIMP COLLECTED

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Appendix A

SPECIES OF FISH AND SHRIMP COLLECTED

Appendix A. Species of Fish and Shrimp Collected

Common Name	Scientific Name
river lamprey	Lampetra ayresi (Gunther)
Pacific lamprey	Lampetra tridentata (Gairdner)
brown smoothhound	Mustelus henlei (Gill)
leopard shark	Triakis semifasciata (Girard)
spiny dogfish	Squalus acanthias (Linnaeus)
Pacific electric ray	Torpedo californica (Ayres)
big skate	Raja binoculata (Girard)
bat ray	Myliobatis californica (Gill)
green sturgeon	Acipenser medirostris (Ayres)
white sturgeon	Acipenser transmontanus (Richardson)
American shad	Alosa sapidissima (Wilson)
Pacific herring	Clupea harengus pallasi (Valenciennes)
threadfin shad	Dorosoma petenense (Gunther)
Pacific sardine	Sardinops sagax (Jenyns)
northern anchovy	Engraulis mordax (Girard)
coho salmon	Oncorhynchus kisutch (Walbaum)
chinook salmon	Oncorhynchus tshawytscha (Walbaum)
rainbow trout	Salmo gairdneri (Richardson)
smelts	Osmeridae (smelts)
whitebait smelt	Allosmerus elongatus (Ayres)
wakasagi	Hypomesus nipponensis (McAllister)
surf smelt	Hypomesus pretiosus (Girard)
delta smelt	Hypomesus transpacificus (McAllister)
night smelt	Spirinchus starksi (Fisk)
longfin smelt	Spirinchus thaleichthys (Ayres)
Pacific argentine	Argentina sialis (Gilbert)
Pacific blacksmelt	Bathylagus pacificus (Gilbert)
California lizardfish	Synodus lucioceps (Ayres)
northern lampfish	Stenobrachius leucopsarus (Eigenmann)
blue lanternfish	Tarletonbeania crenularis (Jordan and Gilbert)
unidentified minnows	Cyprinidae (carps and minnows)
goldfish	Carassius auratus (Linneaus)
common carp	Cyprinus carpio (Linneaus)
hitch	Lavinia exilicauda (Baird and Girard)
Sacramento blackfish	Orthodon microlepidotus (Ayres)
splittail	Pogonichthys macrolepidotus (Ayres)
Sacramento squawfish	Ptychocheilus grandis (Ayres)
Sacramento sucker	Catostomus occidentalis (Ayres)
white catfish	Ictalurus catus (Linneaus)

Appendix A. Species of Fish and Shrimp Collected

Common Name	Scientific Name
brown bullhead	Ictalurus nebulosus (Lesueur)
channel catfish	Ictalurus punctatus (Rafinesque)
plainfin midshipman	Porichthys notatus (Girard)
northern clingfish	Gobiesox maeandricus (Girard)
unidentified cod	Gadidae (codfishes)
Pacific hake	Merluccius Productus (Ayres)
Pacific tomcod	Microgadus proximus (Girard)
spotted cusk-eel	Chilara tayolri (Girard)
red brotula	Brosomophycis marginata (Ayres)
Pacific saury	Cololabis saira (Brevoort)
rainwater killifish	Lucania parva (Baird)
mosquitofish	Gambusia affinis (Baird and Girard)
topsmelt	Atherinops affinis (Ayres)
jacksmelt	Atherinopsis californiensis (Girard)
inland silverside	Menidia beryllina (Cope)
threespine stickleback	Gasterosteus aculeatus (Linneaus)
bay pipefish	Syngnathus leptorhynchus (Girarad)
striped bass	Morone saxatilis (Walbaum)
unidentified sunfishes	Centrarchidae (sunfishes)
bluegill	Lepomis macrochirus (Rafinesque)
largemouth bass	Micropterus salmoides (Lacepede)
bigscale logperch	Percina macrolepida (Stevenson)
white croaker	Genyonemus lineatas (Ayres)
queenfish	Seriphus politus (Ayres)
halfmoon	Medialuna californiensis(Steindachner)
barred surfperch	Amphistichus argenteus (Agassiz)
calico surfperch	Amphistichus koelzi (Hubbs)
shiner perch	Cymatogaster aggregata (Gibbons)
black perch	Embiotoca jacksoni (Agassiz)
spotfin surfperch	Hyperprosopon anale (Agassiz)
walleye surfperch	Hyperprosopon argenteum (Gibbons)
silver surfperch	Hyperprosopon ellipticum (Gibbons)
rainbow seaperch	Hypsurus caryi (Agassiz)
tule perch	Hysterocarpus traski (Gibbons)
dwarf perch	Micrometrus minimus (Gibbons)
white seaperch	Phanerodon furcatus (Girard)
rubberlip seaperch	Rhacochilus toxotes (Agassiz)

Appendix A. Species of Fish and Shrimp Collected

Common Name	Scientific Name
pile perch	Rhacochilus vacca (Girard)
striped mullet	Mugil cephalus (Linnaeus)
Pacific barracuda	Sphyraena argentea (Girard)
senorita	Oxyjulis californica (Gunther)
smooth ronquil	Rathbunella hypoplecta (Gilbert)
rockpool blenny	Hypsoblennius gilberti (Jordan)
unidentified clinids	Clinidae (clinids)
striped kelpfish	Gibbonsia metzi (Hubbs)
onespot fringehead	Neoclinus uninotatus (Hubbs)
monkeyface prickleback	Cebidichthys violaceus (Girard)
unidentified pricklebacks	Xiphister spp.
penpoint gunnel	Apodichthys flavidus (Girard)
saddleback gunnel	Pholis ornata (Girard)
Pacific sandlance	Ammodytes hexapterus (Pallas)
unidentified gobies	Gobiidae (Gobies)
yellowfin goby	Acanthogobius flavimanus (Temminck and Schlegel)
arrow goby	Clevelandia ios (Jordan and Gilbert)
blackeye goby	Coryphopterus nicholsii (Bean)
longjaw mudsucker	Gillichthys mirabilis (Cooper)
cheekspot goby	Ilypnus gilberti (Eigenmann and Eig.)
bay goby	Lepidogobius lepidus (Girard)
chameleon goby	Tridentiger trigonocephalus (Gill)
goby complex	
arrow/cheekspot goby	
chub mackerel	Scomber japonicus (Houttuyn)
medusafish	Icichthys lockingtoni (Jordan and Gilbert)
Pacific pompano	Peprilus simillimus (Ayres)
brown rockfish	Sebastes auriculatus (Girard)
black rockfish	Sebastes melanops (Girard)
unidentified rockfish	Sebastes spp.
kelp greenling	Hexagrammos decagrammus (Pallus)
lingcod	Ophiodon elongatus (Girard)
painted greenling	Oxylebius pictus (Gill)
unidentified sculpins	Cottidae (sculpins)
scalyhead sculpin	Artedius harringtoni (Starks)
bonehead sculpin	Artedius notospilotus (Girard)
prickly sculpin	Cottus asper (Richardson)
brown Irish lord	Hemilepidotus spinosus (Ayres)
Pacific staghorn sculpin	Leptocottus armatus (Girard)
tidepool sculpin	Oligocottus maculosus (Girard)
fluffy sculpin	Oligocottus snyderi (Greeley)
cabezon	Scorpaenichthys marmoratus (Ayres)

Appendix A. Species of Fish and Shrimp Collected

Common Name	Scientific Name
unidentified poachers	Agonidae (poachers)
pygmy poacher	Odontopyxis trispinosa (Lockington)
unidentified snailfishes	Cyclopteridae (snailfishes)
showy snailfish	Liparis pulchllus (Ayres)
Pacific sanddab	Citharichthys sordidus (Girard)
speckled sanddab	Citharichthys stigmaeus (Jordan and Gilbert)
California halibut	Paralichthys californicus (Ayres)
unidentified flounders	Pleuronectidae (righteye flounders)
diamond turbot	Hypsopsetta guttulata (Girard)
English sole	Parophrys vetulus (Girard)
starry flounder	Platichthys stellatus (Pallas)
curlfin sole	Pleuronichthys decurrens (Jordan and Gilbert)
hornyhead turbot	Pleuronichthys verticalis (Jordan and Gilbert)
sand sole	Psettichthys melanostictus (Girard)
California tonguefish	Symphurus atricauda (Jordan & Gilbert)
ocean sunfish	Mola mola (Linnaeus)
unidentified fish	Unidentified osteichthyes
	Crangon franciscorum
	Crangon nigricauda
	Crangon nigromaculata
	Palaemon macrodactylus
red Irish lord	Hemilepidotus hemilepidotus (Tilesius)
black bullhead	Ictalurus melas (Rafinesque)
unidentified clupeidae	Clupeidae (herring)
unidentified pricklebacks	Stichaeidae (pricklebacks)
	Crangon munitella
	Beteaus harrimani
	Heptacarpus brevirostris
	Heptacarpus cristatus
	Heptacarpus palpator
	Heptacarpus pictus
	Heptacarpus taylori
	Lissocrangon stylirostris
	Lysmata californica
	Pandalus danae
unidentified Alpheidae	Alpheidae
unidentified Beteaus	Beteaus sp.
unidentified Majidae	Majidae
Dungeness crab	Cancer magister
red rock crab	Cancer productus
brown rock crab	Cancer antennarius

Appendix A. Species of Fish and Shrimp Collected

Common Name	Scientific Name
slender crab	Cancer gracilis
	Cancer oregonensis
mud crab	Rhithropanopeus harrisii
unidentified Xanthidae	Xanthidae
sand crab	Emerita analoga
spiny sand crab	Blepharidoda occidentalis
mud shrimp	Upogebia pugettensis
unidentified Callianassa	Callianassa ssp.
	Nematoscelis difficilis
	Nytiphanes simplex
	Thysanoëssa gregaria
	Sagitta euneritica