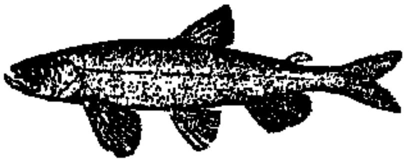
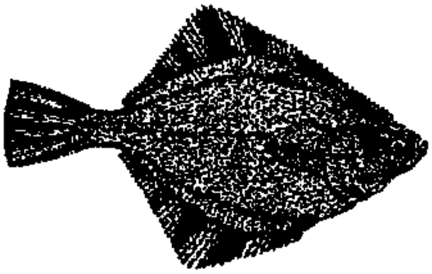
WRINT-DFG-Exhibit # 6

Exhibit WRINT-DFG-Exhibit # 6 entered by the
California Department of Fish and Game for the
State Water Resources Control Board
1992 Water Quality/Water Rights Proceedings on the
San Francisco Bay/Sacramento - San Joaquin Delta



Estuary Dependent Species



Estuary Dependent Species

Summary

The abundances of 70 species of fish, shrimp and crabs were analyzed for the years 1980-1988. A majority of the species in this study (55.5%) showed no difference in their abundance between wet years (1980, 1982, 1983, 1984, 1986) and dry years (1981, 1985, 1987, 1988). Most of the species that showed no significant difference in abundance between wet or dry years were marine. In contrast, over two thirds of the species in this study considered to be estuarine, anadromous, or freshwater were significantly more abundant in wet years. Fourteen marine species exhibited significant differences in abundance when wet and dry years were compared. Of these, six were more abundant in wet years and eight were more abundant in dry years. However, no significant relationship between outflow and abundance was found for any of the marine species. There was a highly significant difference between wet and dry years for six of the seven estuarine species. Of these, five species were found to be significantly more abundant in wet years. One recently introduced estuarine species was found to be significantly more abundant during dry years. Significant positive relationships between outflow and abundance were found for three of these estuarine species. This analysis was used to select species for a more detailed analysis of the mechanisms controlling the observed outflow-abundance relationships. The mechanistic models developed for these species are detailed in this exhibit.

The model developed for the shrimp Crangon franciscorum relates the abundance of juveniles with March through May freshwater outflow. Strong positive relationships were found between March through May outflow and both juvenile and the subsequent years mature shrimp. The March through

May period was chosen as the critical period for juvenile shrimp since this is the period of time in which the juveniles are recruited into the estuarine nursery areas and grow rapidly. Selection of this time period was based on biology rather than the best statistical fit between the data and outflow. Freshwater outflow affects *C. franciscorum* throughout their life cycle. The amount of available habitat for *C. franciscorum*, as determined by depth and the range of salinities in which they were collected, had a significant positive relationship with outflow and abundance. This supports our hypothesis that the abundance of *C. franciscorum* is related to the amount of available habitat and that the amount of available habitat is related to freshwater outflow. Freshwater outflow also affects the downstream dispersal of ovigerous females and early stage larvae, assists the late stage larvae and post-larvae in identifying the mouth the estuary and direction of the brackish water nursery areas, and aids the upstream migration of the post-larvae by enhancing the landward flowing bottom currents. No other species of shrimp had a significant relationship between abundance and outflow. The other species of *Crangon* and *Heptacarpus* are much less estuarine dependent than *C. franciscorum* and their abundance is affected more by ocean conditions. The other major shrimp species, *Palaemon macrodactylus*, is fully adapted to life in the estuary, but based on our data, there was not a positive linear relationship between abundance and outflow.

The model developed for longfin smelt is based upon a significant positive relationship between abundance and February through May freshwater outflow. The February through May period is critical to the success of the longfin smelt year class because larval dispersal, first feeding, and establishment of the brackish nursery habitat all occur during this time. Longfin smelt developed stronger year classes in years with high freshwater outflows when the larvae were dispersed downstream into the broader brackish water nursery areas of Suisun and San Pablo bays. Increased dispersal associated with increased freshwater outflow acts to reduce intra-specific competition and provides larvae access to a greater food source. The amount of brackish water nursery area for longfin smelt had a significant positive relationship to freshwater outflow.

The model developed for starry flounder was based upon the significant positive relationship between starry flounder abundance and freshwater outflow from March to June. During this critical time period, transforming larval and juvenile starry flounder in the coastal marine area immigrated to the Bay and the shallow brackish water nursery areas. Outflow is believed to create salinity gradients and currents that assist in the location of the Bay mouth and subsequent immigration to the nursery areas. There was a positive significant relationship between the amount of shallow, brackish nursery habitat and freshwater outflow during the critical period.

Fish and shrimp abundance during the recent California drought are discussed and compared to earlier years. During the period 1987-1991, successive years of low outflow resulted in increased salinities in the estuary. However, temperatures did not increase in a similar manner over the same period.

In South Bay the abundance of demersal fish and shrimp increased during the drought. The increase in shrimp was due to the increased abundance of species other than *C. franciscorum*. Pelagic fish species increased in abundance in South Bay during the drought when compared to high outflow years but was less than the low outflow years prior to the drought.

In Central Bay the abundance of shrimp increased during the drought while the abundance of pelagic and demersal fish decreased when compared to the high and previous low outflow years. As in South Bay, the increase in shrimp abundance in Central Bay was due to increased abundances of *C. nigricauda*, *C. nigromaculata* and *Heptacarpus*.

In San Pablo Bay the abundance of shrimp, demersal fish and pelagic fish decreased when compared to the wet years. The abundance of pelagic fishes in San Pablo Bay during the 1988-1990 period was 30% of that during the high flow years and 44% of that in the low flow years. The more marine species of fish and shrimp increased their abundance in San Pablo Bay during the drought, but this wasn't enough to offset the observed decline of the estuarine species that normally inhabited the area.

In Suisun Bay the decrease in abundance of shrimp and fish was greater than that for any other embayment during the 1988-1990 drought period. During the drought, demersal fish abundance was 66% of that seen in the high outflow years, pelagic species abundance was 5%, and shrimp abundance was 34%.

To the east of Suisun Bay, in the West Delta, the abundance of shrimp, primarily *C. franciscorum*, increased while demersal and pelagic fish abundance decreased.

Overall the numerical abundance index of shrimp was highest in the high outflow years, followed by the drought years, and lowest in low outflow years prior to the drought. However, the shrimp biomass index during the drought was 20% less than the index in the low outflow years prior to the drought and 55% less than the index in high outflow years. This is because the species and size groups of shrimp that increased in abundance during the drought were not as large as those that dominated the catch previous to 1987, when *C. franciscorum* was the most abundant species.

The hypothesis that the abundance of marine species in the estuary increase and estuarine species decrease as the estuary becomes more saline due to decreased freshwater outflow is only partially supported by our data. Most estuarine species decreased in abundance as the estuary became more saline. However, most marine species did not increase in abundance when salinities increased. Overall during the drought years, abundances increased in South Bay, showed mixed results in Central Bay, and decreased in all other embayments. Increases in marine species abundance did not offset the decreases in abundance of estuarine species normally found in the area encompassing San Pablo Bay through the West Delta. Many important prey species, including northern anchovy, Pacific herring, longfin smelt, and *C. franciscorum* decreased in abundance, especially upstream of Central Bay. This, along with the decrease in shrimp biomass, indicates the amount of food available to larger organisms (i.e., commercially and recreationally important fishes, marine birds, and marine mammals) decreases during successive years of low freshwater outflow.

Table of Contents

Caridean Shrimp

Longfin smelt

Starry flounder

Appendices

Figures

Tables

Estuary Dependent Species

Introduction

The Department of Fish and Game will offer evidence in this exhibit that populations of three major estuary dependent species found in the Bay-Delta Estuary have declined in recent years because of the decrease in freshwater outflow during critical periods in their life histories. In addition the Department will provide information on how the marine and estuarine species found in the Bay-Delta Estuary reacted to the long periods of low freshwater outflow associated with the current drought and discuss the implications of such outflows to the estuary.

In this exhibit, the Bay-Delta Estuary is defined as that area between the Golden Gate Bridge and the lower Sacramento River at Sherman Island and the Highway 160 bridge on the San Joaquin River at Antioch. This includes all of South San Francisco, Central San Francisco, San Pablo, Suisun, Grizzly and Honker bays and the brackish water portions of the rivers. To facilitate analysis this area has been divided into five embayments: South Bay, Central Bay, San Pablo Bay, Suisun Bay, and West Delta (Figure 1).

Over 200 species of fish, shrimp and crabs are known to inhabit the Bay-Delta Estuary and each is unique in how it exists in or utilizes the estuary. Some of the more important variables that affect the abundance and distribution of these species are freshwater outflow, salinity, temperature, tidal and non-tidal currents, ocean currents, ocean temperatures, ocean upwelling, habitat types, pollution, introduction of exotic species, dredging and filling, and commercial and recreational fishing. The fish found in the estuary can be categorized or grouped in a number of ways to facilitate understanding how they use the

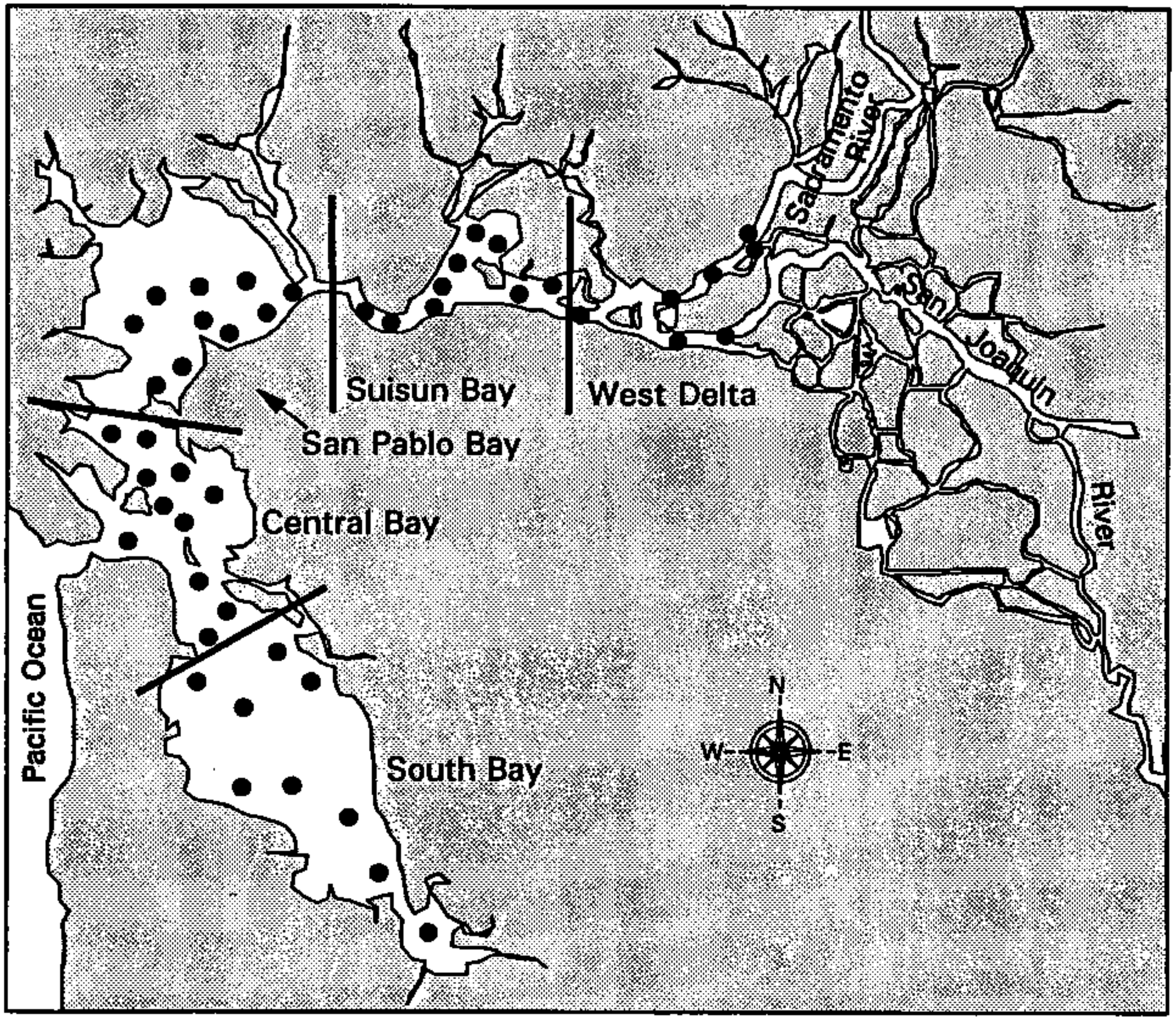


Figure 1. Study area and embayments.

estuary. The categories used in this exhibit are pelagic for those fish normally found in the water column and demersal for those normally associated with the bottom. Additionally, the fish fauna is divided into the general ecological groups of marine, anadromous, estuarine and freshwater.

Marine species are those typically found in the higher salinity portions of the estuary (Figure 2). They spawn in both the ocean and the Bay and many use the higher salinity areas of the Bay as a nursery area. Estuarine species are those that use the brackish water portions of the estuary as a nursery (Figure 3). Depending on the species, spawning can occur in marine or freshwater, but brackish water habitats are critical nursery areas.

All organisms in the estuary can be categorized based on whether they are a predator or prey species and at any given time an individual can be either. There are five general ways fish use the estuary. Many use it as a residence such as shiner perch. Some, such as Pacific pompano, use the Bay as a feeding area. Some species use it as a spawning and nursery area e.g. Pacific herring. A number of species such as starry flounder, spawn elsewhere and use the estuary as a nursery area. Anadromous species use the estuary as a migration corridor to and from upstream spawning grounds.

Methods

The methods used in the collection of data and analysis procedures were discussed in CDFG Exhibit 60 (CDFG 1987). Where specific changes have occurred, they are discussed in that portion of the text of this exhibit. One new approach used in this exhibit that wasn't used in CDFG Exhibit 60 is the calculation of a habitat index and an analysis of its relationship to outflow and abundance. Available habitat was defined as that area where the majority of a given

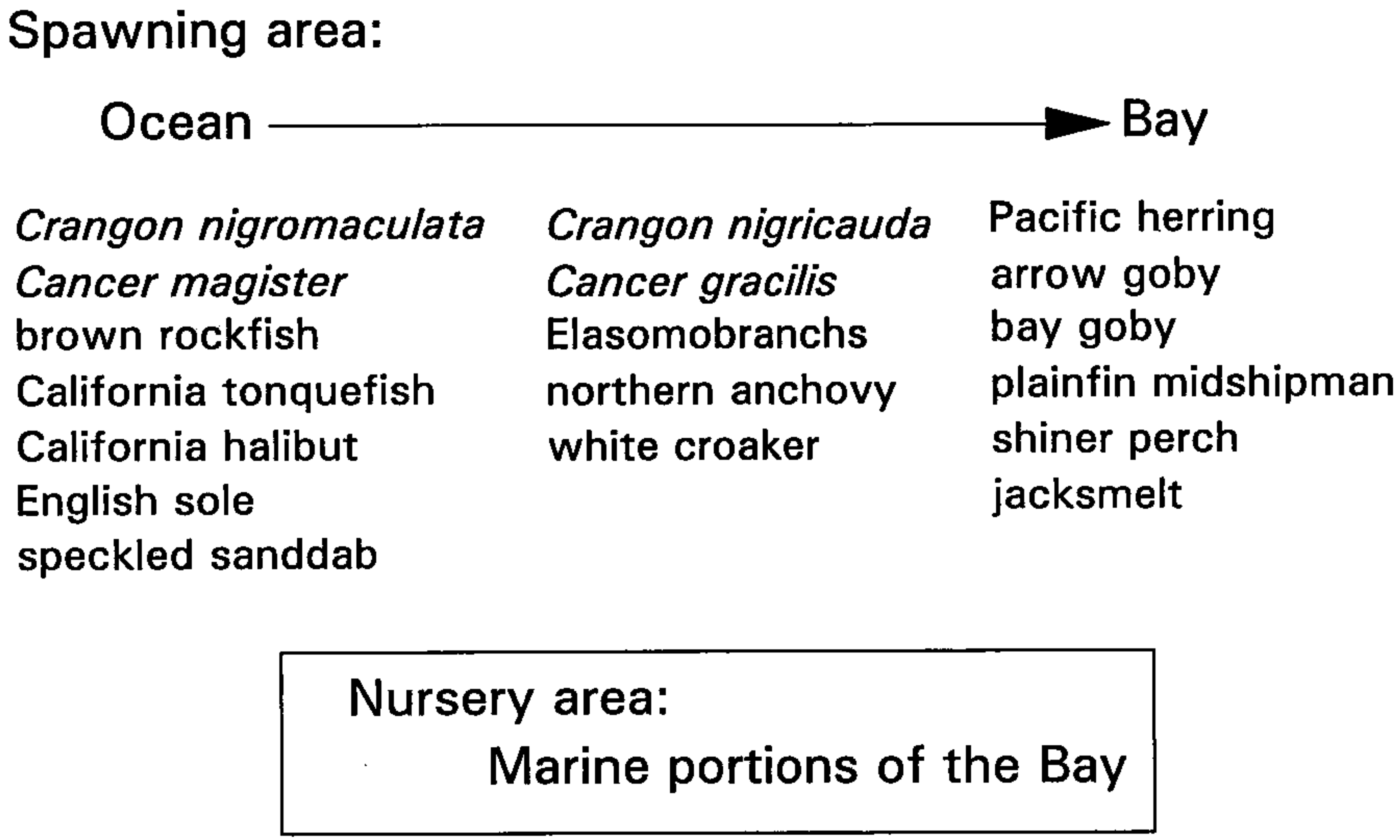


Figure 2. Summary of common Bay species that use the more marine areas of the estuary as a nursery.

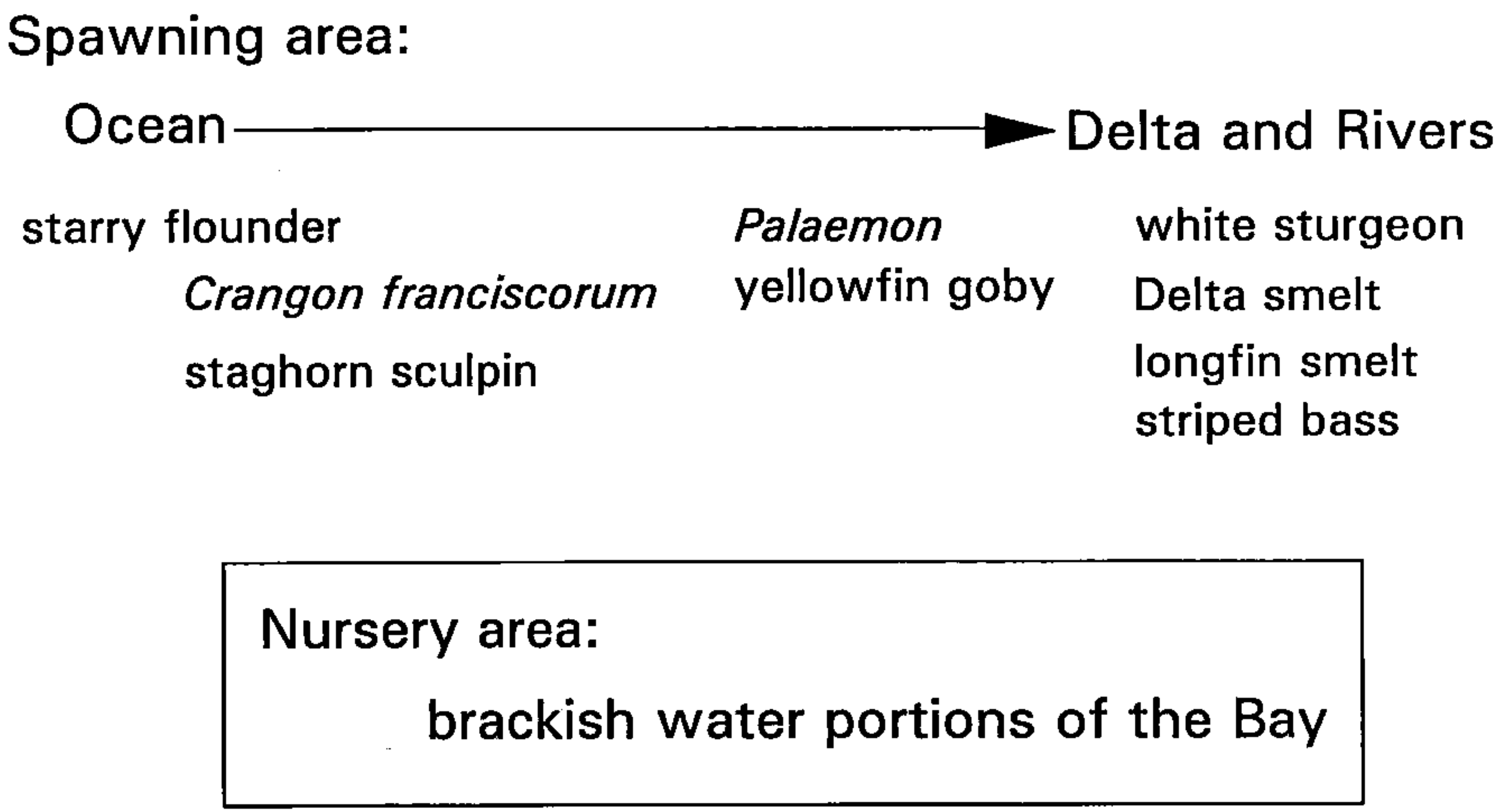


Figure 3. Summary of common Bay species that use the brackish water areas of the estuary as a nursery.

species could exist based on range of preferred salinities. Our hypothesis is that species abundance is in part determined by available habitat and that habitat is determined by outflow. In general, the procedure consisted of calculating a range of salinities in which most individuals were collected, using that range to calculate the amount (either area or volume) of available habitat and then relating habitat to outflow and abundance. In specific cases, an additional depth factor was added when a species showed a distinct tendency to use shallow water areas. The range of salinities selected by a species was calculated by weighting the salinities measured at each station during the time of collection with the catch of that species at the same time and location. Estimates of area or volume for each station whose measured salinity was within the range were summed for a defined period of months each year to determine the amount of available habitat for that species.

Species Association With Water Year Type

During the 1987 phase of this water right hearing DFG presented evidence on the responses of various species of fish and invertebrates to wet (wet and above normal) and/or dry (below normal, dry and critical) water year types (CDFG 1987). During 1990, this evidence was re-evaluated using a longer time period and effort corrected data (Tables 1 and 2). This recent evaluation of the most abundant 70 species of fish shrimp and crabs didn't change the conclusions of the earlier analysis appreciably and it validated the fact that a majority, 55.6%, of these species demonstrated no clear abundance trends related to wet or dry water year types. However, when those species with abundances that did vary consistently between wet and dry years were reviewed, it was found that species were more abundant during wet years than dry by factor of 2 to 1 (Table 1). A majority of the species showing no difference between the wet and dry years were both common and rare marine species. This was

Table 1. Summary of Contrasts Between Wet and Dry Years

	Wet				No Difference				Dry
	0.001	0.01	0.05	0.1	>0.1	0.1	0.05	0.01	0.001
Freshwater	2		3	1	4				
Anadromous		4	1		3				
Estuarine	5				1				1
Marine		2	3	1	31	1	2	2	3
Total	7	6	7	2	39	1	2	2	4
Percent	10	8.6	10	2.9	55.6	1.4	2.9	2.9	5.7
	31.5%				55.6%	12.9%			

Note: Wet years = 1980, 1982, 1983, 1984, and 1986
Dry years = 1981, 1985, 1987, and 1988

Table 2. Contrast in Catches Between Wet Years and Dry Years

Wet p<=0.001	0.001>p<=0.01	0.01>p<=0.05	0.05>p<=0.1	No Difference p>0.1	0.05>p<=0.1	0.01>p<0.05	0.001>p<0.01	Dry p<=0.001
				Freshwater Species				
Prickly sculpin		Threadfin shad	Delta smelt	Bigscale logperch				
Splittail		3-spine stickleback		Carp				
		White catfish		Channel catfish				
				Tule perch				
				Anadromous Species				
	Chinook salmon	American shad		Pacific lamprey				
	Green sturgeon			River lamprey				
	Striped bass			Steelhead trout				
	White sturgeon							
				Estuarine Species				
Crangon franciscorum				Palaemon macrodactylus				Chameleon goby
Longfin smelt								
Staghorn sculpin								
Starry flounder								
Yellowfin goby								
				Marine Species				
	California tonguefish	Leopard shark	Dwarf perch	Arrow goby	Walleye surfperch	California halibut	Bat ray	Crangon nigricauda
	Pacific herring	Pacific tomcod		Barred surfperch		Spotted cusk-eel	Pacific pompano	Heptacarpus cristatus
		Surf smelt		Bay goby				Jacksmelt
				Bay pipefish				
				Big skate				
				Black perch				
				Bonehead sculpin				
				Brown rockfish				
				Brown smoothhound				
				California lizardfish				
				Cheekspot goby				
				Crangon nigromaculata				
				Curlfin sole				
				Diamond turbot				
				English sole				
				Lingcod				
				Lissocrangon stylirostris				
				Northern anchovy				
				Pacific sanddab				
				Pile perch				
				Plainfin midshipman				
				Rubberlip seaperch				
				Sand sole				
				Shiner perch				
				Showy snailfish				
				speckled sanddab				
				Spiny dogfish				
				Topsmelt				
				White croaker				
				White seaperch				
				Whitebait smelt				

Wet Years = 1980, 1982, 1983, 1984, and 1986
Dry Years = 1981, 1985, 1987, and 1988

expected; however, what wasn't expected was that some marine species were more abundant in the wet years. A majority of the estuarine species were strongly more abundant in the wet years. The exception to this was chameleon goby which was found to be more abundant in the dry years. This is due to this recently introduced species expanding its distribution into Suisun Bay during in 1986 and subsequently increasing its abundance there during 1987 and 1988. The results for California halibut and California tonguefish are examples of were ocean conditions rather than the amount of freshwater outflow are thought to be responsible for these marine species response.

This information was then used to direct detailed analysis on those species found to be either strongly associated with wet or dry years. No significant negative relationships between outflow and abundance could be found for those species that were more abundant in the dry years. For those species which were more abundant in the wet years, additional analysis found significant positive relationships between delta outflow and abundance for Crangon franciscorum, longfin smelt, and starry flounder. Analyses and supporting biological information describing the relationship between outflow and the abundance of these species are presented in this exhibit.

Caridean Shrimp

Introduction

Five species of Caridean shrimp are relatively abundant in the Bay: *Crangon franciscorum*, *C. nigricauda*, *C. nigromaculata*, *Heptacarpus cristatus*, and *Palaemon macrodactylus*. *Heptacarpus* and the three species of *Crangon* are native while *Palaemon* was accidently introduced to the Bay from the Orient in the 1950's. For a more detailed review of the ecological value, life histories, salinity and temperature preferences, food habits, etc. of *Crangon* and *Palaemon* the reader is referred to CDFG 1987. This report also presented analyses of abundance and distribution data from 1980 to 1985. Recent publications of interest include IESP Annual Reports (1990, 1991) for study updates, the final South Bay Dischargers Authority Report (Kinnetic Laboratories 1987), and a life history review of West Coast *Crangon* (Siegfried 1989).

Crangon spp. are commonly referred to as "Bay shrimp" and *Palaemon* as "pile shrimp"; collectively they are often referred to as "grass shrimp". These species are fished commercially by trawl fishermen in the Bay and are primarily sold as bait for sport fishermen. Earlier in this century, when there was a large market for dried shrimp, over three million pounds per year were landed (CDFG 1987). Since 1980 this fishery has landed between 100,000 and 200,000 pounds of shrimp per year. During the recent drought the fishery has concentrated in the Alviso Slough and Redwood Creek areas of South Bay. Shrimp are presumed to be abundant in these areas because of the lower salinity water present year-round in the vicinity of the sewage treatment plant discharges. Since 1985 shrimp fishermen have been restricted from the area upstream of Carquinez Strait to protect juvenile striped bass. Occasionally commercial fishermen are not able to meet demand because of a scarcity of large shrimp suitable for bait (P. Reilly, per. comm.).

The general life cycle of *Crangon* and *Palaemon* is that larvae hatch in relatively high salinity waters, post-larvae and juveniles migrate upstream to a lower salinity nursery area where they grow for four to six months, and mature shrimp migrate downstream to higher salinity waters to complete the life cycle (Figure 4). All of these shrimp species mature when they are one year old. They have a short life span, with males living 1 to 1.5 years and females 1.5 to 2 years. Some females hatch more than one brood of eggs during a breeding season. Little is known about the life cycle of *Heptacarpus*. It is assumed that *Heptacarpus* juveniles prefer lower salinity water than the adults, as this study has observed juveniles distributed further upstream than adults.

Each of these species utilize the Bay as a nursery area to a varying degree. Timing of larval hatching and juvenile recruitment to the Bay is slightly different for each species. *C. franciscorum* is estuary dependent and its juveniles are found in brackish, relatively warm waters (Tables 3 and 4). Peak abundance of small juvenile *C. franciscorum* consistently occurs in late spring or early summer (April to June). This peak is usually followed by one or two smaller abundance peaks, with another peak occasionally in the fall. Juvenile *C. franciscorum* were most common in San Pablo and Suisun Bays during years with high freshwater outflow, as 1980, 1982, and 1983 (Figure 5). Their center of distribution moved upstream to Honker Bay and the lower portions of the Sacramento and San Joaquin rivers during low outflow years, especially from 1988 through 1990. *C. franciscorum* reaches the largest size of the shrimp species commonly collected in the Bay, with some females attaining a total length of 85 mm and males 70 mm.

C. nigricauda are found in higher salinity, cooler waters than *C. franciscorum* (Tables 3 and 4) but still are an important component of the Bay's shrimp population.

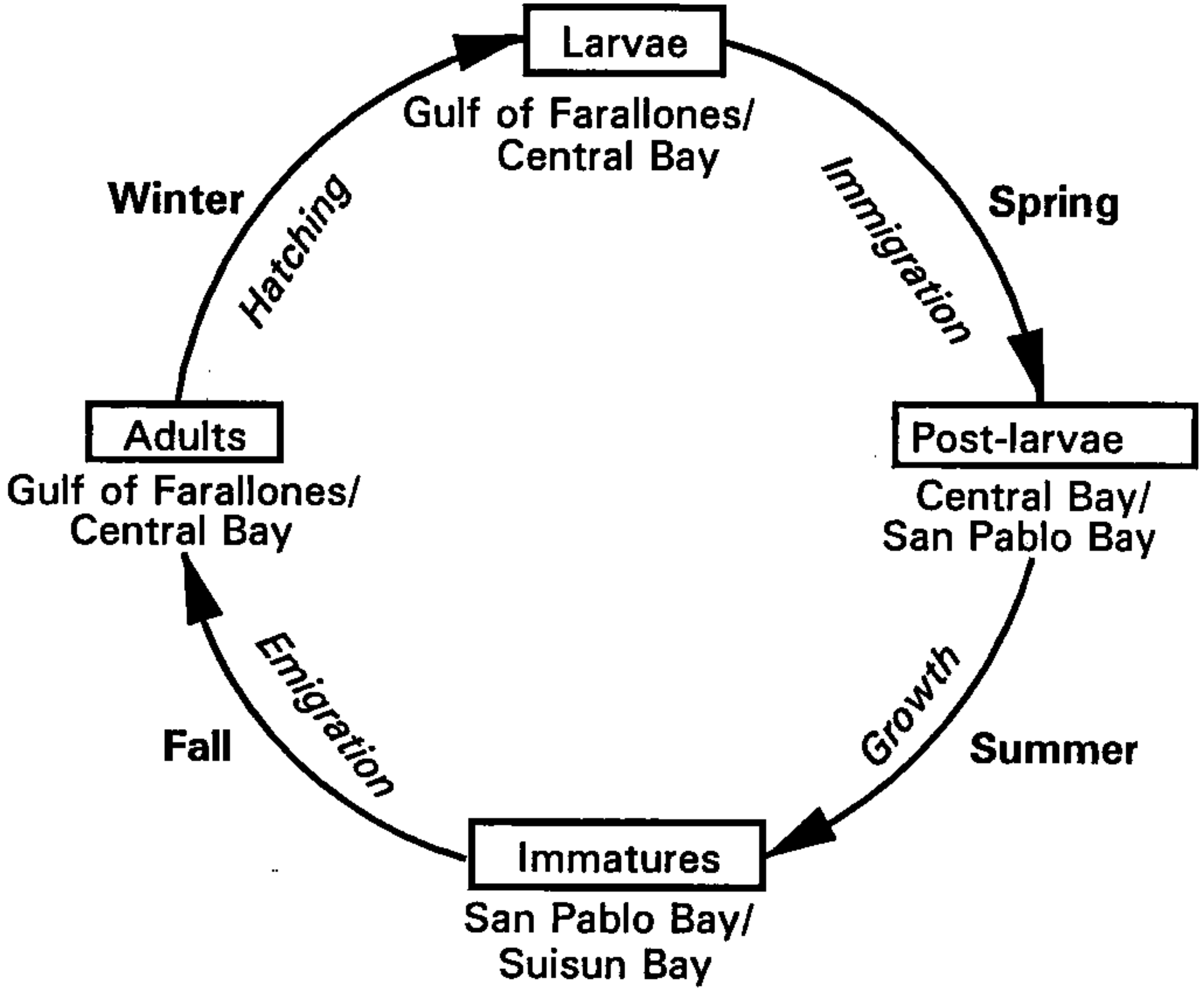


Figure 4. Life cycle of Crangon franciscorum in the San Francisco Bay-Estuary.

Table 3. Salinity statistics for shrimp. Only data with bottom salinity values were used in the calculations. All values are ppt. Juveniles refers to the smallest sized shrimp that were not sexed; immatures includes larger males and females.

Species/life stage	Median	10th percentile	90th percentile
C. franciscorum			
juveniles (<26 mm)	9.5	1.6	21.6
immatures	10.9	2.5	20.9
all sizes	13.0	3.7	24.5
ovigerous females	20.9	13.9	29.5
C. nigricauda			
juveniles (<21 mm)	25.9	17.8	32.1
immatures	26.4	17.8	32.1
all sizes	27.4	18.5	32.2
ovigerous females	29.2	23.2	33.4
C. nigromaculata			
juveniles (<21 mm)	31.0	26.4	32.4
all sizes	30.9	26.4	32.7
ovigerous females	29.9	24.3	32.4
Palaemon macrodactylus			
all sizes	9.5	0.9	19.5
ovigerous females	7.8	1.6	19.4
Heptacarpus cristatus			
all sizes	30.0	25.4	32.7
ovigerous females	30.0	25.1	32.7

Table 4. Temperature statistics for shrimp. Only data with bottom temperature values were used in the calculations. All values are °C. Juveniles refers to the smallest sized shrimp that were not sexed; immatures includes larger males and females.

Species/life stage	Median	10th percentile	90th percentile
C. franciscorum juveniles (<26 mm)	19.1	15.5	21.5
immatures	19.6	15.9	21.6
all sizes	19.0	12.7	21.4
ovigerous females	14.4	10.4	19.3
C. nigricauda juveniles (<21 mm)	16.8	11.9	19.5
immatures	16.5	11.1	19.4
all sizes	15.8	10.3	19.0
ovigerous females	15.2	10.3	18.3
C. nigromaculata juveniles (<21 mm)	16.6	13.5	17.6
all sizes	16.0	10.9	17.8
ovigerous females	12.6	10.3	17.7
Palaemon macrodactylus all sizes	19.4	11.8	21.8
ovigerous females	20.5	17.6	22.1
Heptacarpus cristatus all sizes	14.9	10.7	17.8
ovigerous females	14.6	10.4	17.5

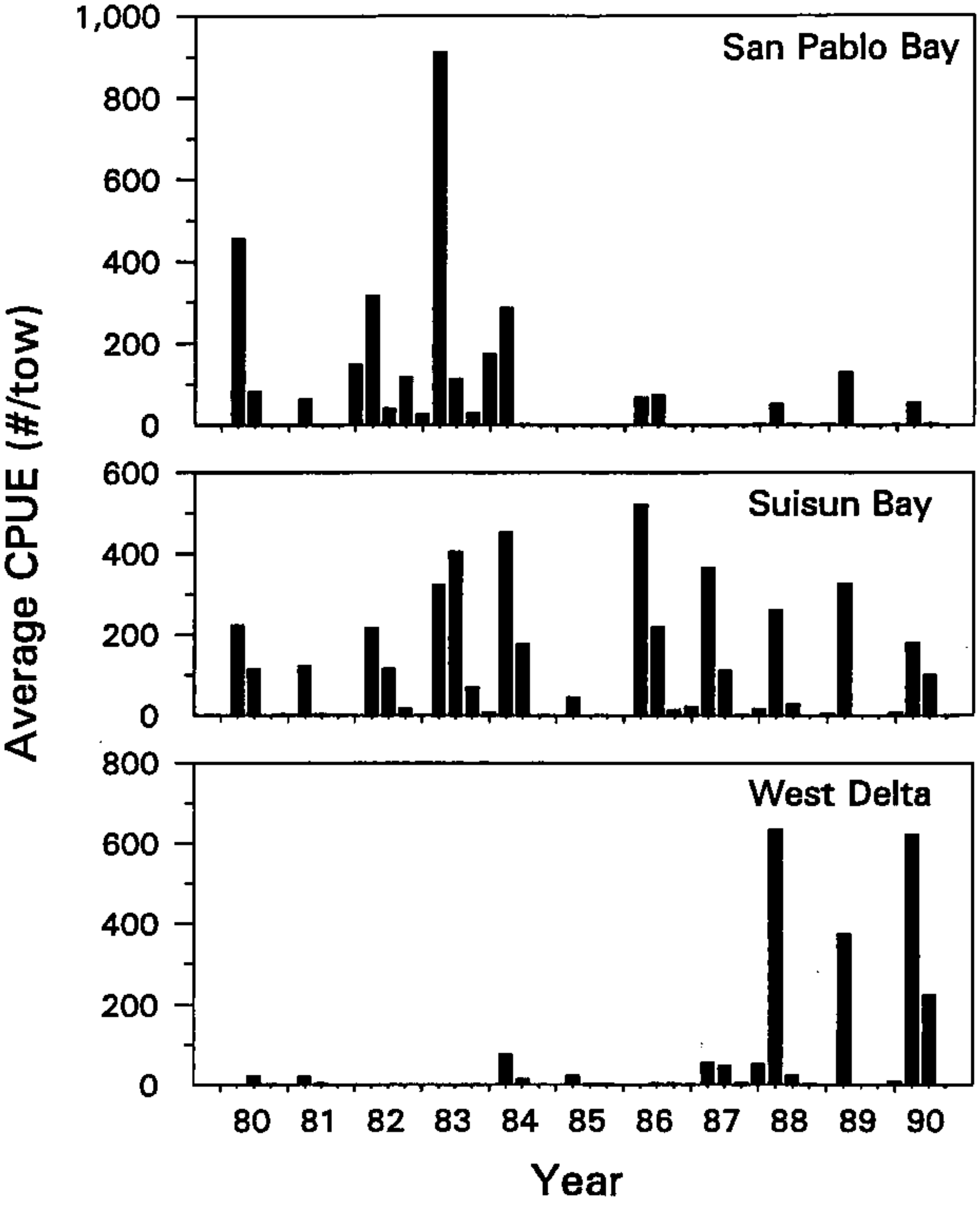


Figure 5. Distribution of small (11-25 mm) juvenile <u>Crangon franciscorum</u>, 1980-90 by quarters. Quarters begin in February (February- April, May-July, August-October, November-January). There is no data for the third and fourth quarters of 1989 and the fourth quarter of 1990.

Abundance of small juvenile *C. nigricauda* peaks in late spring or early summer, similar to *C. franciscorum*. Fall and winter cohorts have been relatively large, especially during 1986-87 and 1987-88. In high outflow years, the distribution of *C. nigricauda* was restricted by low salinities and they were common only as far upstream as lower San Pablo Bay. In low outflow years, and most notably the recent drought years, their distribution expanded to upper San Pablo Bay and lower Suisun Bay. *C. nigricauda* is smaller than *C. franciscorum*, with females reaching a maximum length of 65 mm and males 60 mm.

C. nigromaculata is primarily a coastal shallow water species and is the most common crangonid in the nearshore ocean area adjacent to San Francisco Bay. Juvenile *C. nigromaculata* were collected at higher salinities and lower temperatures (Tables 3 and 4) than either *C. franciscorum* or *C. nigricauda*. Recruitment of *C. nigromaculata* to the Bay also appears to occur later in the year and is more unpredictable than for *C. franciscorum* or *C. nigricauda*. From 1980 to 1988, abundance peaks of small juvenile *C. nigromaculata* occurred from May to November, with six of the eight peaks occurring after July. During years with high freshwater outflow, *C. nigromaculata* were limited to South and Central Bays. Their distribution expanded upstream to upper San Pablo Bay and occasionally Carquinez Strait during years with low freshwater outflow. *C. nigromaculata* collected by this study were intermediate in size between *C. franciscorum* and *C. nigricauda*; females had a maximum size of 70 mm and males 60 mm.

Heptacarpus cristatus was found in high salinity, cool waters, very similar to *C. nigromaculata* (Tables 3 and 4). This genus is considered to be coastal (Butler 1980), although *H. cristatus* is locally abundant in the Bay (Schmitt 1921). There appears to be a spring and fall peak in abundance of small *Heptacarpus* in the Bay. Its distribution is very similar to that for C. nigromaculata, with shrimp concentrated in South and Central Bays most years. Their distribution expanded upstream to upper San Pablo Bay and Carquinez Strait during the recent drought. This is a small species, with shrimp larger than 30 mm rarely collected in the Bay.

Palaemon macrodactylus is an estuarine species that remains in the Bay through out its life cycle. No life stages are known to occur in the ocean. Adults are most common in Suisun Bay, the west Delta, and areas adjacent to freshwater sources such as the mouths of creeks in South and San Pablo Bays. Juveniles prefer brackish, almost fresh water and are most common upstream of our study area in the rivers and tidal sloughs. Palaemon larvae hatch from April to August and juveniles are most abundant from June to September. Palaemon are highly adapted to estuarine conditions and, based on the behavior of closely related species (Sandifer 1975), larvae are hypothesized to use tidal vertical migrations to minimize downstream transport. Females reach a maximum length of 70 mm and males 65 mm.

Freshwater Outflow Needs

Freshwater outflow to the Bay affects shrimp at every life stage. It affects the distribution of mature shrimp and transports early stage larvae hatched in the Bay downstream and to the nearshore coastal area. Freshwater outflow creates salinity gradients that are hypothesized to be used by late-stage larvae and post-larvae to identify the mouth of the Bay and the upstream direction in their migration from the nearshore coastal area to the in-bay nursery area. This migration to the nursery area is aided by landward bottom currents (tidal and non-tidal). One of the non-tidal components, gravitational circulation, increases with increased freshwater outflow (Smith 1987). Freshwater outflow also affects the size and location of the nursery area, the abundance of predators and food organisms, and the timing of the downstream movement of mature shrimp.

Model and Biological Support - *Crangon franciscorum*

CDFG (1987) reported that a strong positive relationship existed between the annual abundance of *C. franciscorum* and freshwater outflow. In this report, the relationship between abundance and outflow is updated with data from five additional years (1987-90) and a mechanistic based model is proposed to explain this relationship. The period from March to May was selected as the time when freshwater outflow is most critical in the establishment of a strong year class of C. *franciscorum* in the Bay. Most late-stage larval and post-larval (5-10 mm total length) *C. franciscorum* migrate into the Bay and upstream to the nursery area between April and June (affected by March to May outflow) and then begin a period of rapid growth. Freshwater outflow probably affects the number of *C. franciscorum* that recruit to the Bay and, based on the size and location of the nursery area, their subsequent survival and growth. *C. franciscorum* have evolved to use the Bay as a nursery area in the spring and early summer when freshwater outflow results in a salinity gradient that helps immigrating late-stage larvae and post-larvae identify the mouth of the Bay and the upstream direction, produces strong landward bottom (gravitational) currents that aid their upstream migration, and creates a large area of brackish water in the shallows of San Pablo and Suisun bays.

There is a strong positive relationship between the annual abundance of immature *C. franciscorum* and freshwater outflow from March to May (Figure 6a). There is also a strong positive relationship between the annual abundance of mature *C. franciscorum* in the winter and early spring (February through April) and freshwater outflow the previous spring, when they recruited to the Bay (Figure 6b). Note that the abundance of mature shrimp in the Bay during the

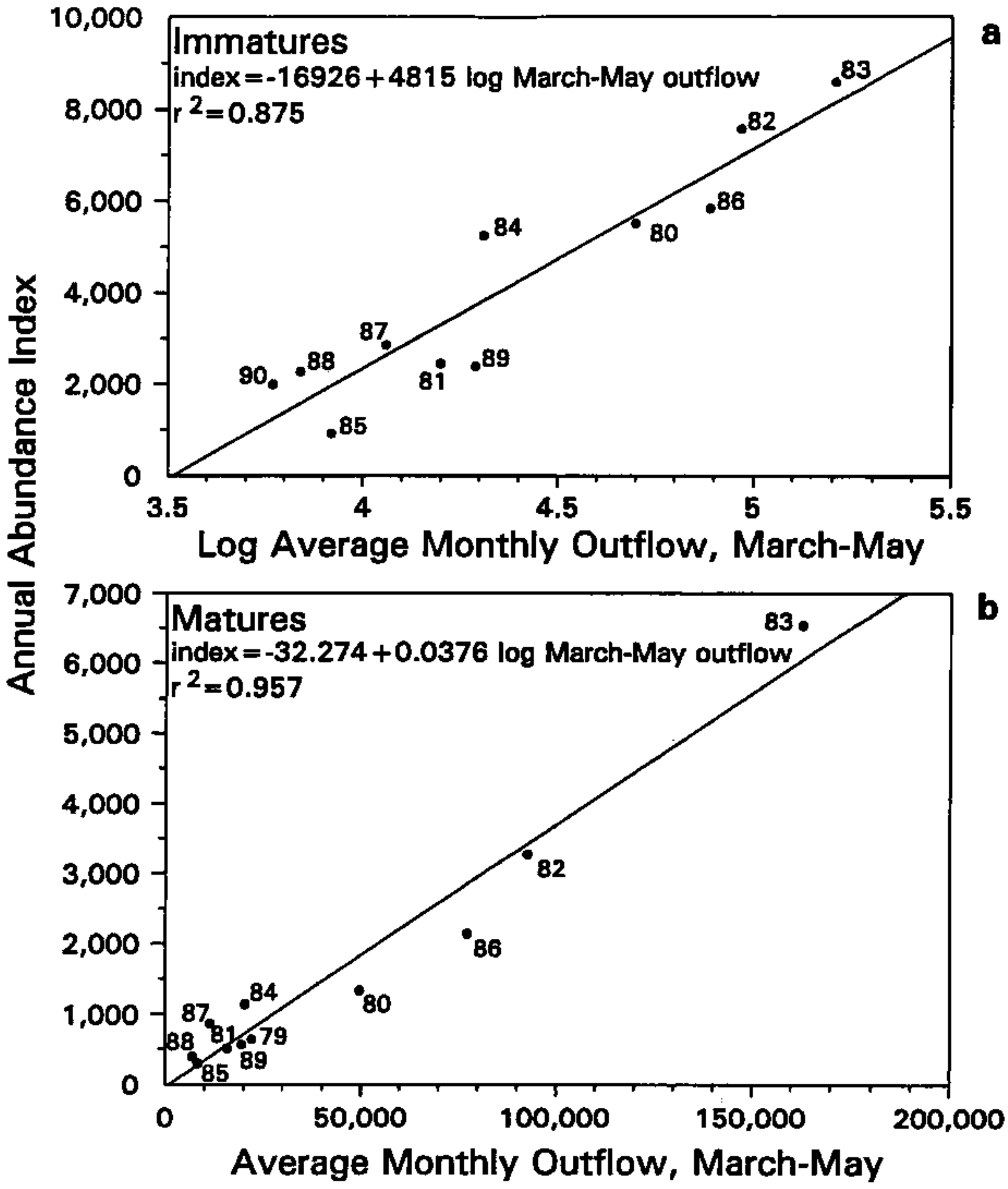


Figure 6. a. Relationship between the annual abundance index of immature *Crangon franciscorum* (May-October) and $\log_{10}$ average monthly outflow at Chipps Island, March-May. 1980-1990.

b. Relationship between the annual abundance index of mature *Crangon franciscorum* (January-April) and $\log_{10}$ average monthly outflow at Chipps Island, March-May the previous year. 1979-1989.

winter and early spring is affected not only by the freshwater outflow the previous spring, when they were juveniles, but also the outflow that winter. Low freshwater outflow in the winter results in a larger portion of the population of mature *C. franciscorum* located inside the Bay than during years with high outflow.

We have some data to support that freshwater outflow is an important factor in determining how many late-stage larval and post-larval *C. franciscorum* recruit to the Bay from the nearshore area. There is a no significant relationship between the annual abundance of *Crangon* late-stage larvae and post-larvae and March through May outflow (Figures 7a and 7b), although the relationship between post-larvae and outflow is weakly positive. These life stages can not be speciated and the abundance indices include *C. nigricauda* and *C. nigromaculata* in addition to *C. franciscorum*. We hypothesize that the salinity gradients created by freshwater outflow help late-stage larvae and post-larvae identify the mouth of the Bay and the upstream direction. The importance of salinity gradients in the recruitment of penaeid shrimp to estuaries was reported by Hughes (1969). Other physical factors that may serve as cues for immigrating larvae include temperature gradients, water chemistry (olfactants), and currents (Boehlert and Mundy 1988), all of which are affected by freshwater outflow.

We believe that *Crangon* late-stage larvae and post-larvae use tidally induced vertical migration in their recruitment to estuaries. Late-stage larvae and post-larvae were present only in near bottom and mid-depth flood tide plankton samples collected over a tidal cycle in Central Bay (IESP 1991), indicating that these stages vertically migrate and use the bottom currents to aid their upstream migration. It is assumed that during the ebb tide late-stage larvae and post-larvae are closely associated with the substrate and

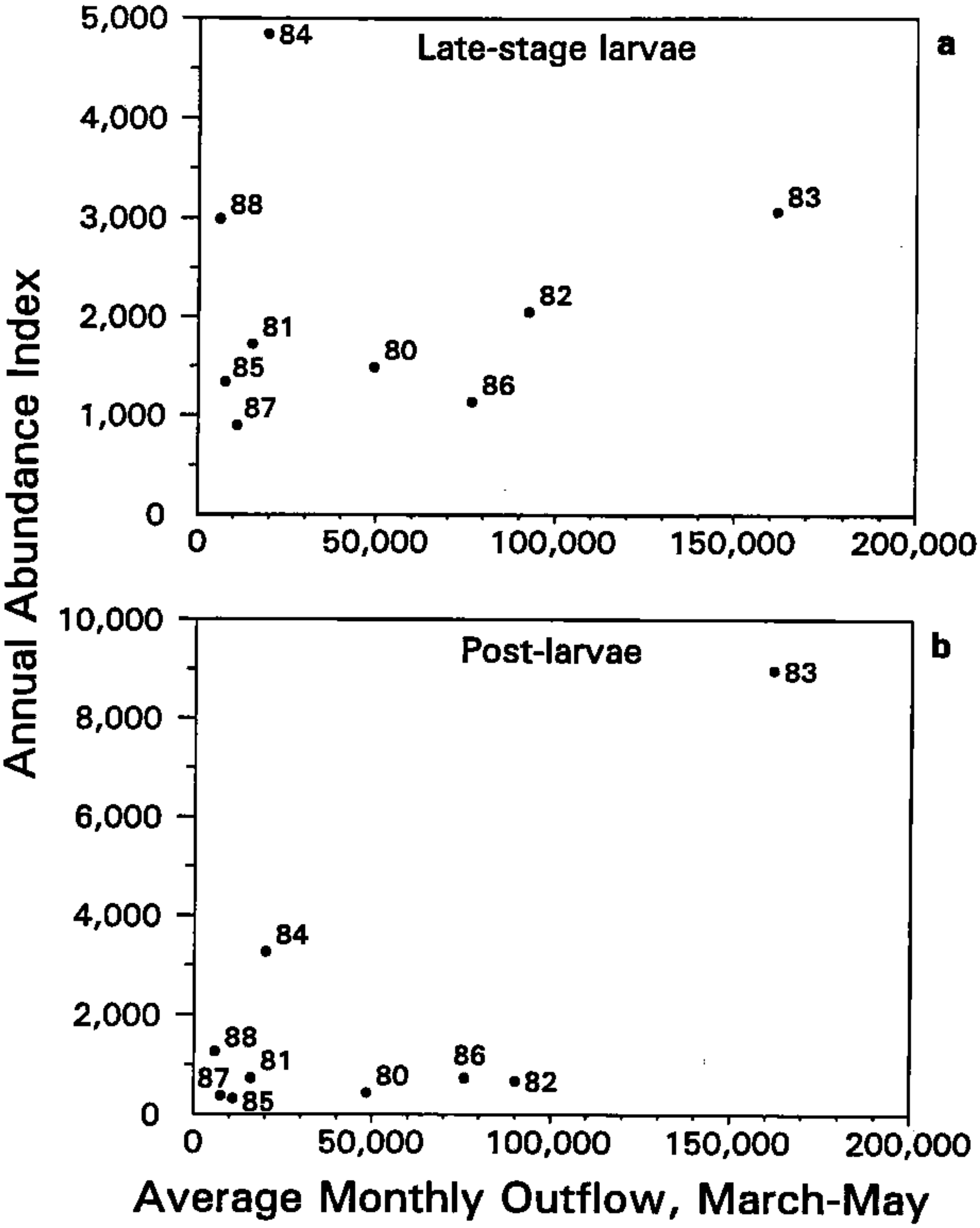


Figure 7. Relationship between the annual abundance index of <u>Crangon</u> early life stages and average March to May outflow at Chipps Island.

a. Late-stage larvae (stages VI and VII), 1980-88.

b. Post-larvae, 5-10 mm total length, 1980-88.

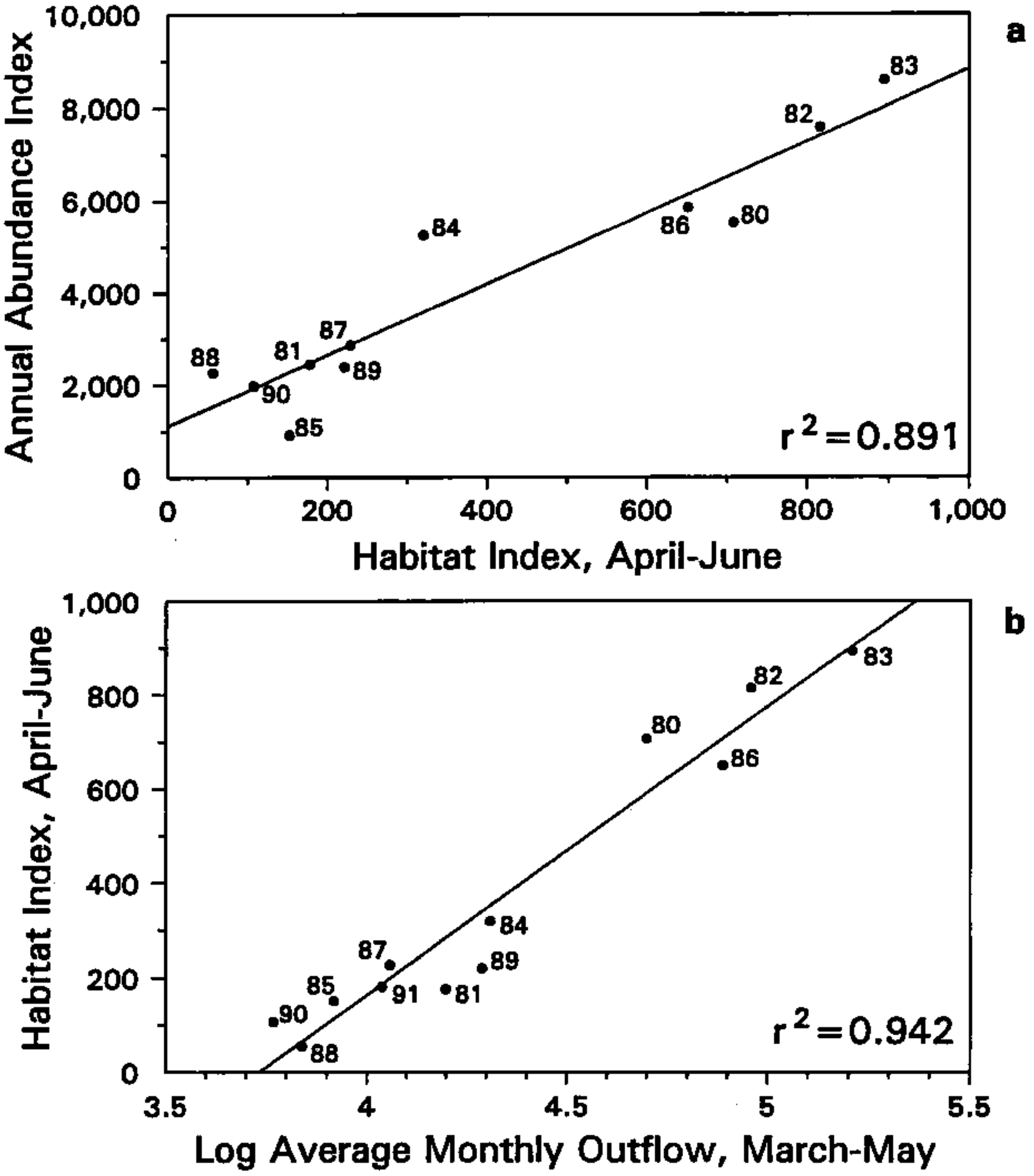


Figure 8. a. Relationship between the annual abundance index of immature Crangon franciscorum (May-October) and the annual habitat index (April-June, 3.0-18.1 ppt, shoals only). 1980-1990.

b. Relationship between the annual habitat index for Crangon franciscorum (April-June, 3.0-18.1 ppt, shoals only) and the average monthly outflow at Chipps Island, March-May. 1980-1991.

consistently the years with the highest abundance of late stage *Crangon* larvae (Figure 7a), *Crangon* post-larvae (Figure 7b), or juvenile *C. franciscorum*. Other researchers have speculated that estuarine-reared larvae of some decapod crustaceans have a higher mortality rate than ocean-reared larvae (Strathmann 1982, McConaugha 1988). If this were true for *C. franciscorum*, high freshwater outflow during the winter would result in higher larval survival. During years with high outflow, mature shrimp are located in Central Bay and the nearshore ocean area and larvae are transported from the Bay to the nearshore area. Winter outflow is also important in determining the size and location of the nursery area later that spring. Possibly because of these reasons, there is a slightly better relationship between the abundance of immature *C. franciscorum* and outflow for periods including December and January than the March to May period (Table 5). But based on our current understanding of the life cycle of *C. franciscorum*, outflow during the March to May period is most critical in determining the year class success of *C. franciscorum* in the Bay.

Table 5. Coefficient of determination (r^2) values for *Crangon franciscorum* abundance indices and outflow from various periods.

Outflow period	Immatures vs. log outflow	Matures vs. outflow
December-June	0.886	0.886
December-May	0.877	0.866
January-June	0.910	0.891
January-May	0.903	0.869
February-June	0.867	0.900
February-May	0.856	0.875
March-June	0.887	0.970
March-May	0.875	0.957

Other Shrimp Species

The annual abundance of C. *nigricauda* does not have a linear relationship with freshwater outflow (Figure 9a). Previous to 1987, the years with the highest abundance occurred during years with high spring freshwater outflow (1980, 1983, 1986). Since 1986 the annual abundance has increased each year (Table 6). This can be in part attributed to the recent drought that has resulted in relatively high salinities year-round in the Bay, especially in South, Central, and San Pablo Bays (Figures 10 and 11). In addition to increased abundance during the spring and summer, there is evidence that fall and/or winter cohorts of *C. nigricauda* have been relatively large during these years. The occurrence of fall or winter cohorts is not as consistent as the occurrence of the spring-summer cohort. The first large fall-winter cohort appeared during the winter of 1986-87 and again in 1987-88, but a fall or winter cohort did not appear during 1988-89. It is difficult to estimate the abundance of *C. nigricauda* juveniles in the Bay during the winters of 1989-90, 1990-91, and 1991-92 because of data gaps these years. Because the increase in abundance of *C. nigricauda* started in 1986 and 1987, before a regime of stable salinities was established, it is possible that other factors, including ocean conditions, affected the abundance of *C. nigricauda* in the Bay. We could not find any consistent relationship between ocean conditions, including sea surface temperature and upwelling, and the abundance of *C. nigricauda* in the Bay.

The affect of freshwater outflow on the abundance of *C. nigromaculata* in the Bay was also not consistent (Figure 9b). Previous to 1989, the highest annual abundance index was in 1983 (Table 6). Abundance has been relatively high since 1987 and the highest annual abundance indices were in 1990 and 1991. As for *C. nigricauda*, this increase in abundance is hypothesized to be in part attributed to the regime of relatively high stable salinities present in the

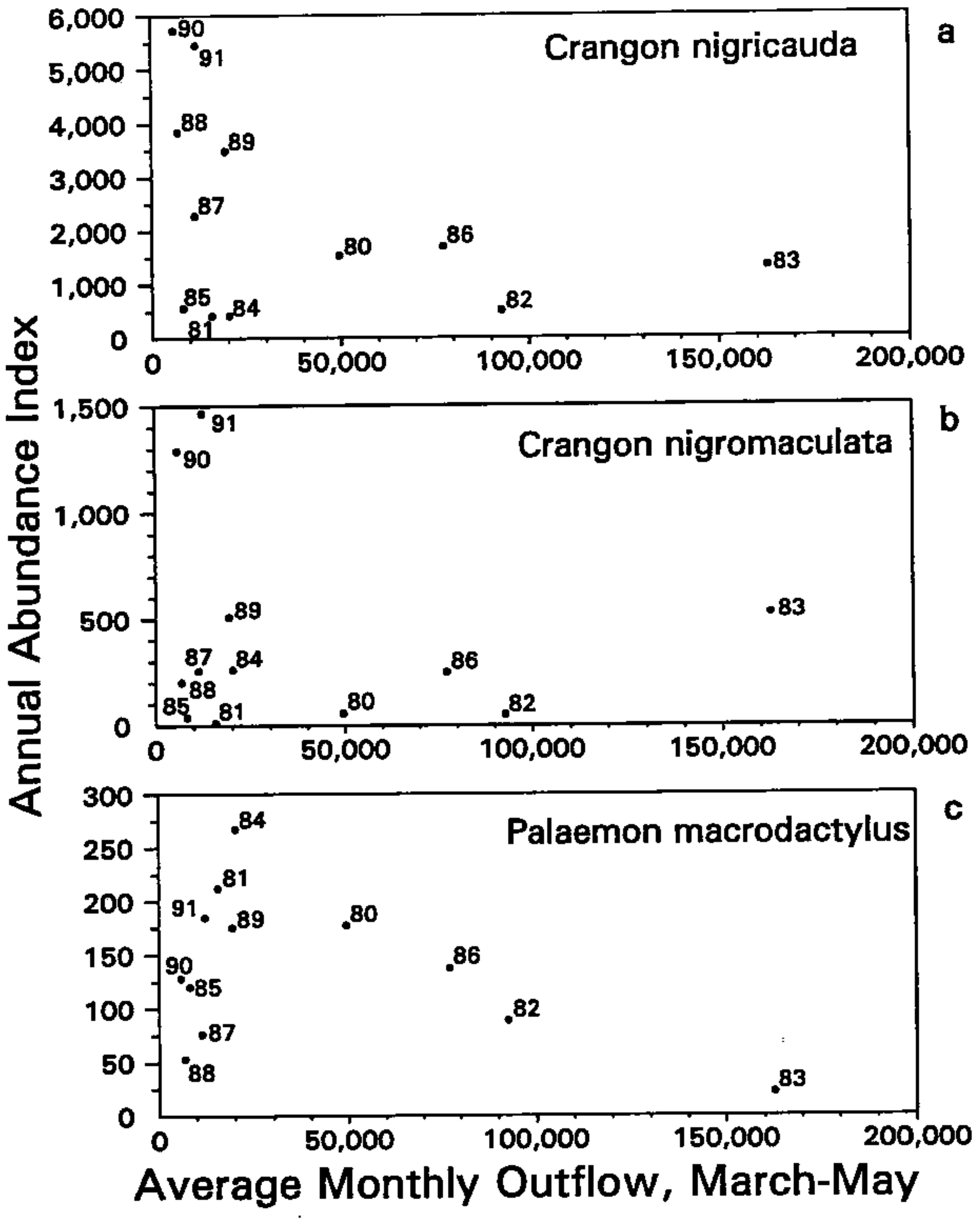


Figure 9. Relationship between the annual abundance index of several species of shrimp (May-October) and the average monthly outflow at Chipps Island, March-March. 1980-1990.
a. *Crangon nigricauda*, all sizes
b. *Crangon nigromaculata*, all sizes
c. *Palaemon macrodactylus*, all sizes

Table 6. Shrimp annual abundance indices used in correlations and other analyses. For 1989, the May-October indices were estimated using the May-August indices and percentages from other low outflow years.

Year	*C. franciscorum* immatures (May-October)	*C. franciscorum* matures* (Feb-April)	*C. nigricauda* (May-October)	*C. nigromaculata* (May-October)	*Palaemon* (May-October)	*Heptacarpus* (May-October)
1980	5523	649	1534	55	177	26
1981	2444	1399	413	11	212	12
1982	7579	519	501	49	88	4
1983	8584	3291	1317	525	21	17
1984	5253	6550	418	260	267	106
1985	910	1147	561	38	120	60
1986	5850	311	1696	246	136	88
1987	2856	2150	2285	257	76	193
1988	2265	876	3840	201	52	170
1989	2387	401	3441	525	173	667
1990	1985	574	5727	1289	128	572
1991			5485	1465	185	1344

*Previous year's year class.

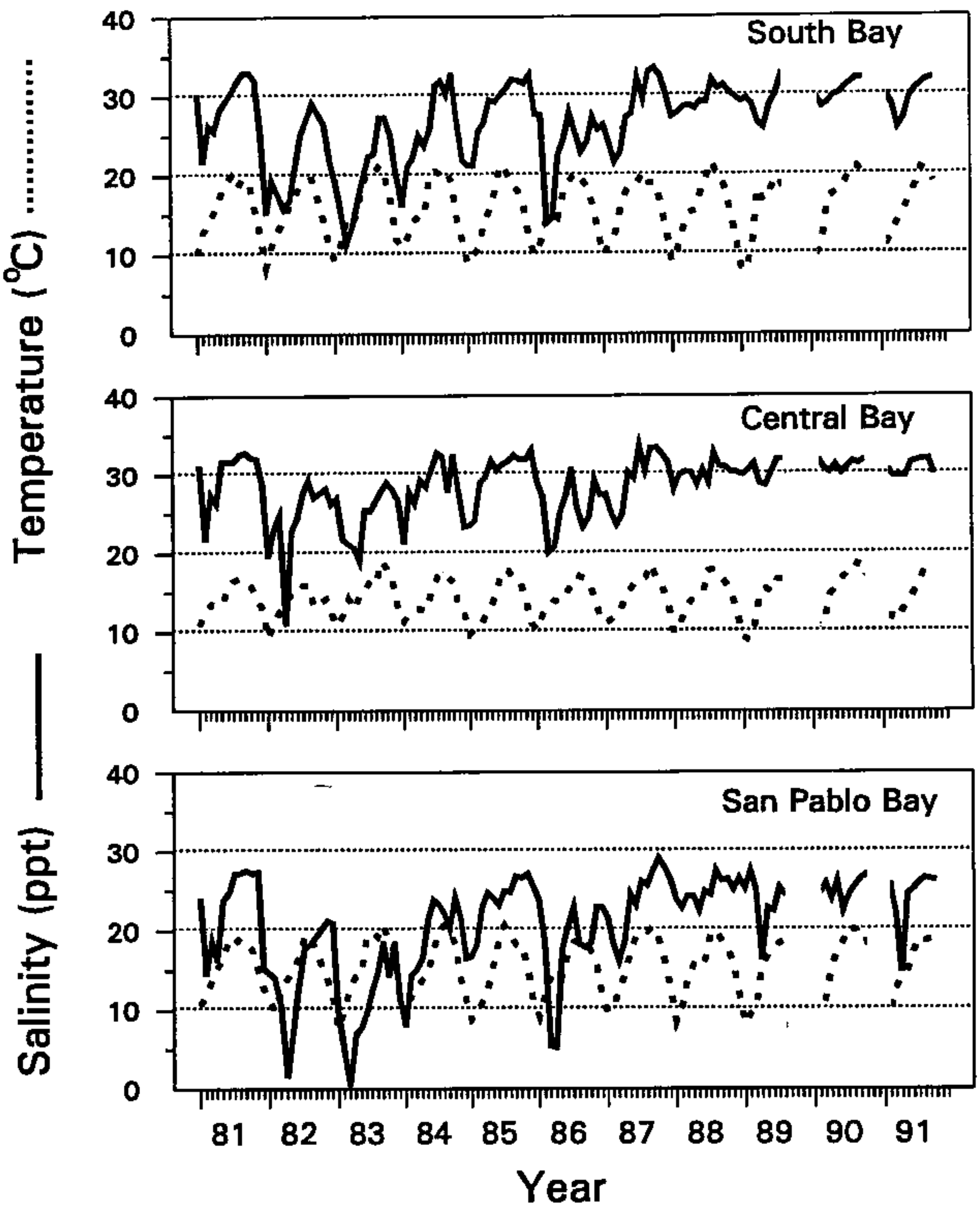


Figure 10. Average bottom salinities and temperatures for South, Central, and San Pablo bays, 1981-91. No data were collected from September 1989 to January 1990, November 1990 to January 1991, and in November and December 1991.

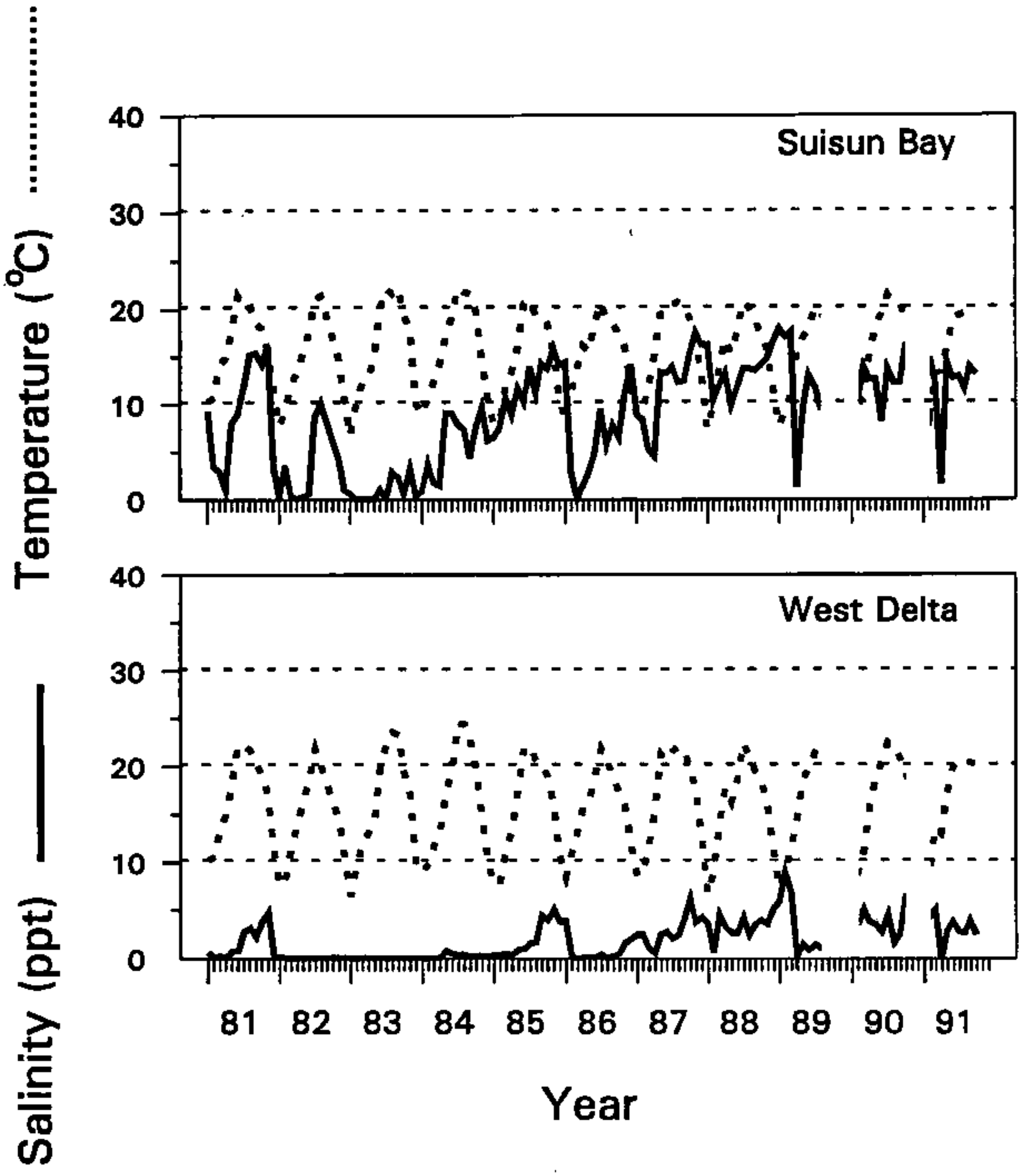


Figure 11. Average bottom salinities and temperatures for Suisun Bay and the West Delta area, and San Pablo bays, 1981-91. No data were collected from September 1989 to January 1990, November 1990 to January 1991, and in November and December 1991.

Bay since 1987. Since 1987-88 the highest monthly abundance indices occurred during the fall and winter periods. This trend could not be confirmed for 1989-90 and 1990-91 because of data gaps during the winter months. As *C. nigromaculata* is primarily a coastal species and prefers relatively cool, high salinity waters, this seasonal trend is not unexpected. It would also be expected that in-Bay abundance of *C. nigromaculata* would be affected by ocean conditions to a greater extent than *C. franciscorum* or *C. nigricauda*. As the Bay is close to the northern limit of the range of *C. nigromaculata*, the abundance of this species may increase in the Bay during or as a result of warm-water ocean events. There were large increases in the abundance of *C. nigromaculata* in 1983, 1987, and 1990 and these years all had above average sea surface temperatures in the Gulf of the Farallones (Figure 12). Yet not all warm-water ocean events resulted in increased abundance of *C. nigromaculata* in the Bay, as ocean temperatures were also above average during 1982 and 1984.

The abundance of *Palaemon* has been low during years with extremely high and low outflow; generally years with more moderate outflow have had the highest abundance in our study area (Figure 9c). It is believed that most juvenile *Palaemon* are distributed upstream of our study area during years with low outflow, resulting in an underestimation of the abundance index these years.

Heptacarpus abundance indices have increased since 1987, but not steadily (Table 6). In 1991, the annual index was very high relative to previous years.

Trends in Shrimp Abundance and Biomass

The average abundance of all shrimp species combined was slightly greater during the high outflow years (1980, 82, 83, 86) than for the drought years (1988-91). But total shrimp abundance was one and a half times greater during the

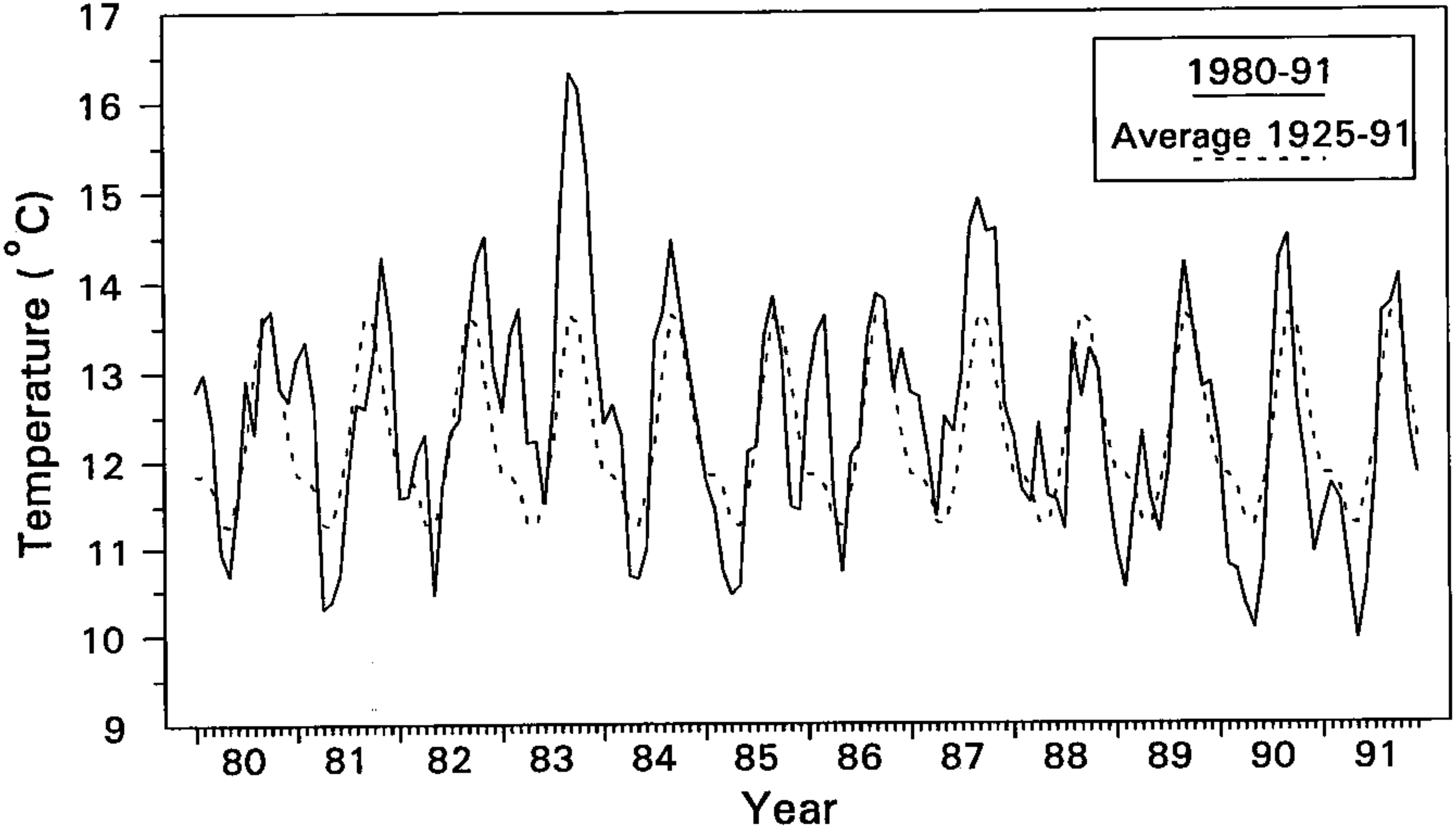


Figure 12. Average monthly sea surface temperature in the Gulf of the Farallones (SE Farallone Island), 1980-91. The dashed line is the average monthly temperature for the period 1925-91.

drought years than the other low outflow years (Table 7). This is due primarily to an increase in abundance of C. nigricauda, C. nigromaculata, and Heptacarpus, especially in 1990 and 1991 (Figure 13 and Table 6). Based on their preference for higher salinities, the increase in abundance of these three "marine" species in the Bay during a drought is predictable. What is not predictable is the approximate abundance index of each species during any given year. This is in part because ocean conditions may affect Bay abundance of C. nigricauda, C. nigromaculata, and Heptacarpus to a greater extent than C. franciscorum or Palaemon.

Biomass indices for shrimp were calculated in a manner similar to abundance indices. Wet weight was calculated using length-weight formulas derived by this study using preserved C. franciscorum; one formula was used for ovigerous shrimp and another for non-ovigerous shrimp. The same formulas were used for all species of Crangon and Palaemon. Palaemon total length was converted to a length without the rostrum to be comparable to Crangon. No weights were calculated for Heptacarpus as this species was not measured after 1986. Because it is a relatively small species, it was assumed for this analysis that Heptacarpus would be a minor component of the total biomass index.

The average shrimp biomass index during the recent drought (1988-90) was approximately 20% less than the average index for other low outflow years (Table 8) and 55% less than the average index for years with high freshwater outflow. This is because most of the increase in numerical abundance in recent years was composed of smaller, immature C. nigricauda and C. nigromaculata rather than larger individuals.

The total shrimp abundance in South Bay has increased since 1987 (Figure 14 and Table 7). The highest indices were in 1990 and 1991. For the period 1988-91, the average

Table 7. Shrimp annual abundance indices by embayment, all species. Indices are for January-December; the 1989-91 indices were estimated using the partial indices (January-August for 1989 and February-October for 1990 and 1991) and percentages from 1987 and 1988.

Year	South Bay	Central Bay	San Pablo Bay	Suisun Bay	West Delta	All
1980	3326	1951	18247	5641	1437	6862
1981	4137	567	4072	4671	3860	3415
1982	3540	1718	23537	10981	20	9182
1983	7676	8131	26629	4873	0	10932
1984	5626	5445	12894	8946	1424	7645
1985	1632	2343	1939	2664	1714	2108
1986	5734	4673	14956	8917	1017	7930
1987	5761	8251	6365	8178	3270	6804
1988	7142	6122	7342	2692	5304	5789
1989	10044	10057	7284	3515	3738	6778
1990	14189	13383	8606	2013	4804	8689
1991	12535	18228	10841	2209	2265	9677
88-91	10978	11947	8518	2607	4028	7733
81,84,85,87	4289	4152	6318	6190	2567	4993
80,82,83,86	5069	4118	20842	7603	619	8727

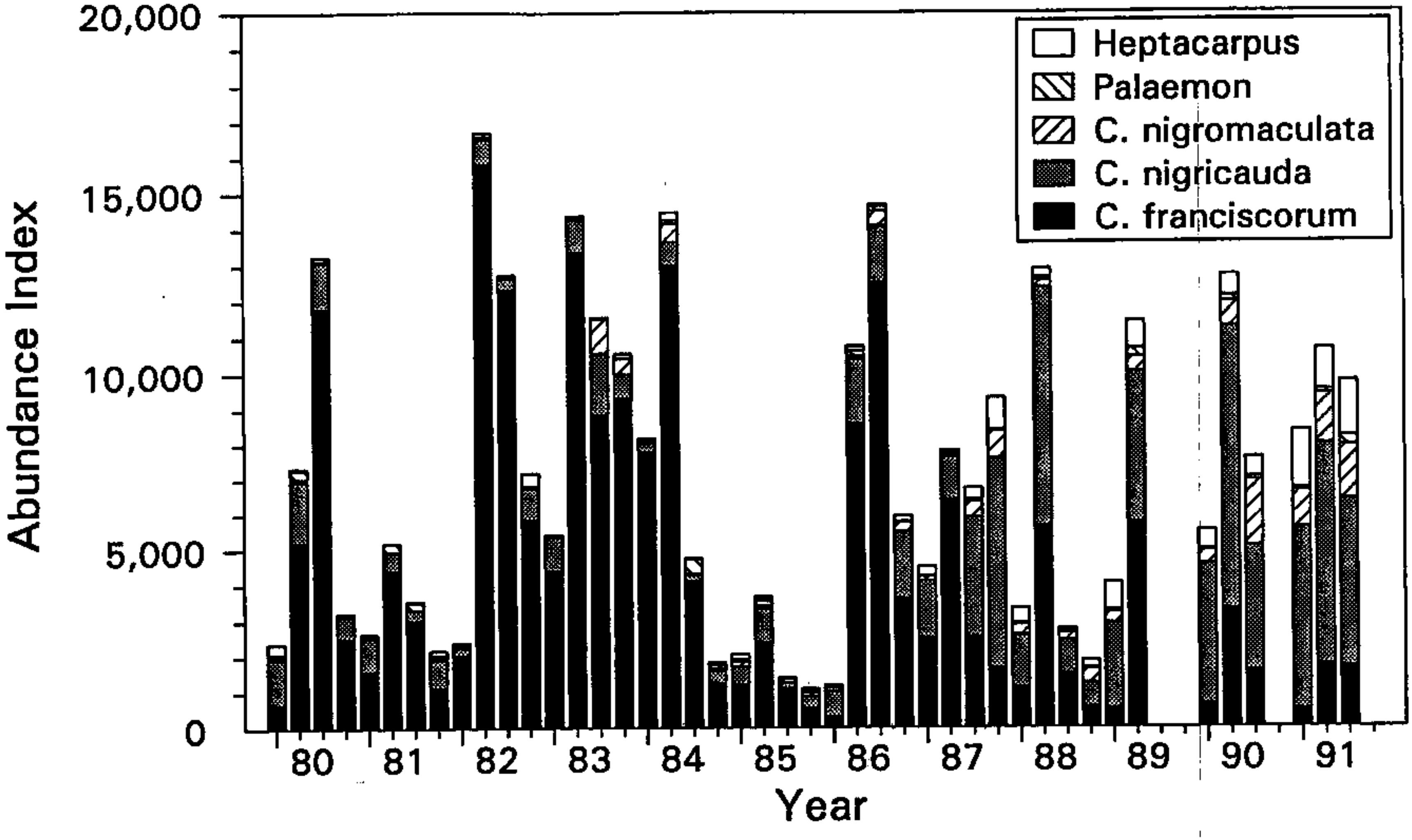


Figure 13. Quarterly abundance indices for the five major species of shrimp in the Bay, 1980-1991. Quarters begin in February (February-April, May-July, August-October, November-January). There is no data for the third and fourth quarters of 1989 and the fourth quarter of 1990 and 1991.

Table 8. Shrimp annual biomass indices by embayment, all species. Indices are for January-December; the 1989-91 indices were estimated using the partial indices (January-August for 1989 and February-October for 1990) and percentages from 1987 and 1988.

Year	South Bay	Central Bay	San Pablo Bay	Suisun Bay	West Delta	All
1980	1946	1277	13007	3864	1049	4737
1981	3580	583	3466	3504	2577	2777
1982	3239	1448	20344	8552	22	7751
1983	6379	4991	18218	1731	0	7250
1984	5172	4825	12443	5596	514	6452
1985	1885	2263	2269	2221	1326	2088
1986	3984	3051	15372	5887	701	6536
1987	4092	4859	5141	5400	1867	4615
1988	4104	3197	4573	1565	2317	3277
1989	4325	3548	3014	1908	1366	2918
1990	4680	4858	3004	988	1639	3130
88-90	4370	3868	3530	1487	1774	3092
81,84,85,87	3683	3133	5830	4180	1571	3963
80,82,83,86	3887	2692	16735	5009	443	6569

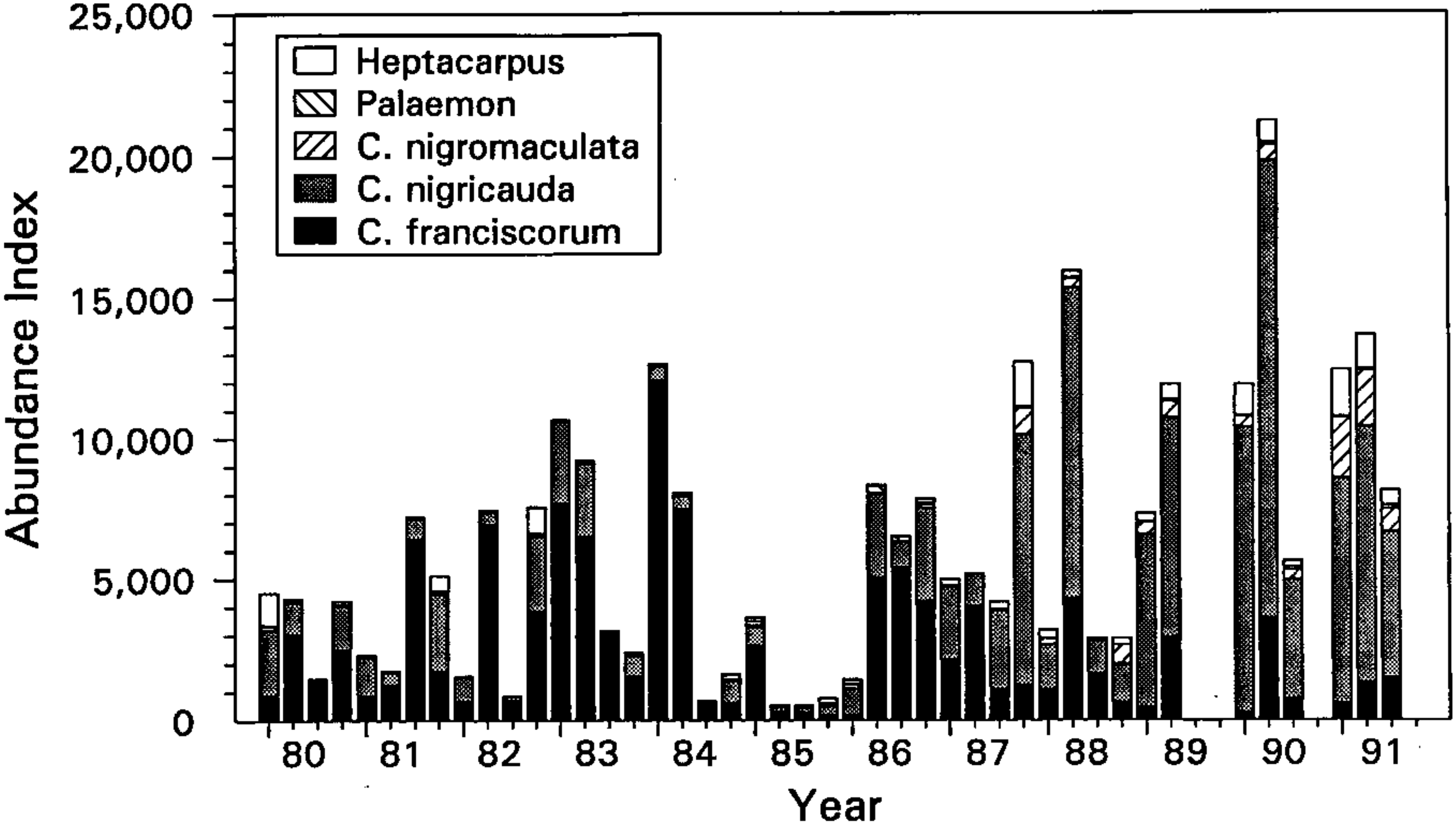


Figure 14. Quarterly abundance indices for the major species of shrimp in South Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

annual abundance index was approximately two and a half times the average index for years with low freshwater outflow and two times the average index for high freshwater outflow years. This increase in abundance in South Bay is due to an increase in C. nigricauda, C. nigromaculata, and Heptacarpus. In 1991 C. nigricauda comprised 65% of the annual index, C. nigromaculata 15%, and Heptacarpus and C. franciscorum each 10%. In 1987, C. franciscorum accounted for 51% of the total shrimp index, C. nigricauda 45%, Heptacarpus 3%, and C. nigromaculata less than 1%. Because of these changes in species composition, the biomass index for South Bay was only slightly greater during the drought than other low outflow years and high outflow years (Table 8).

The Central Bay total shrimp abundance index also increased during the drought years (Figure 15 and Table 7). For 1988-91, the average annual index was approximately three times the average for both the other low outflow years and the high outflow years. As for South Bay, this was due to an increase in abundance of C. nigricauda, C. nigromaculata, and Heptacarpus. In 1991, C. nigricauda comprised 50% of the total Central Bay index, Heptacarpus 26%, C. nigromaculata 22%, and C. franciscorum 2%. As a comparison, in 1987 C. nigricauda accounted for 65% of the total shrimp index, C. franciscorum 12%, C. nigromaculata 11%, and Heptacarpus 10%. The increase in biomass in Central Bay during the drought years was minimal, with an average biomass index that was 25% greater than the average for other low outflow years and 45% greater than the high outflow years (Table 8).

Unlike South or Central Bays, total shrimp abundance in San Pablo Bay was greatest during the high outflow years (Figure 16 and Table 7). The average annual abundance index for 1988-91 was approximately 60% less than the high outflow years average index and 35% greater than the average index

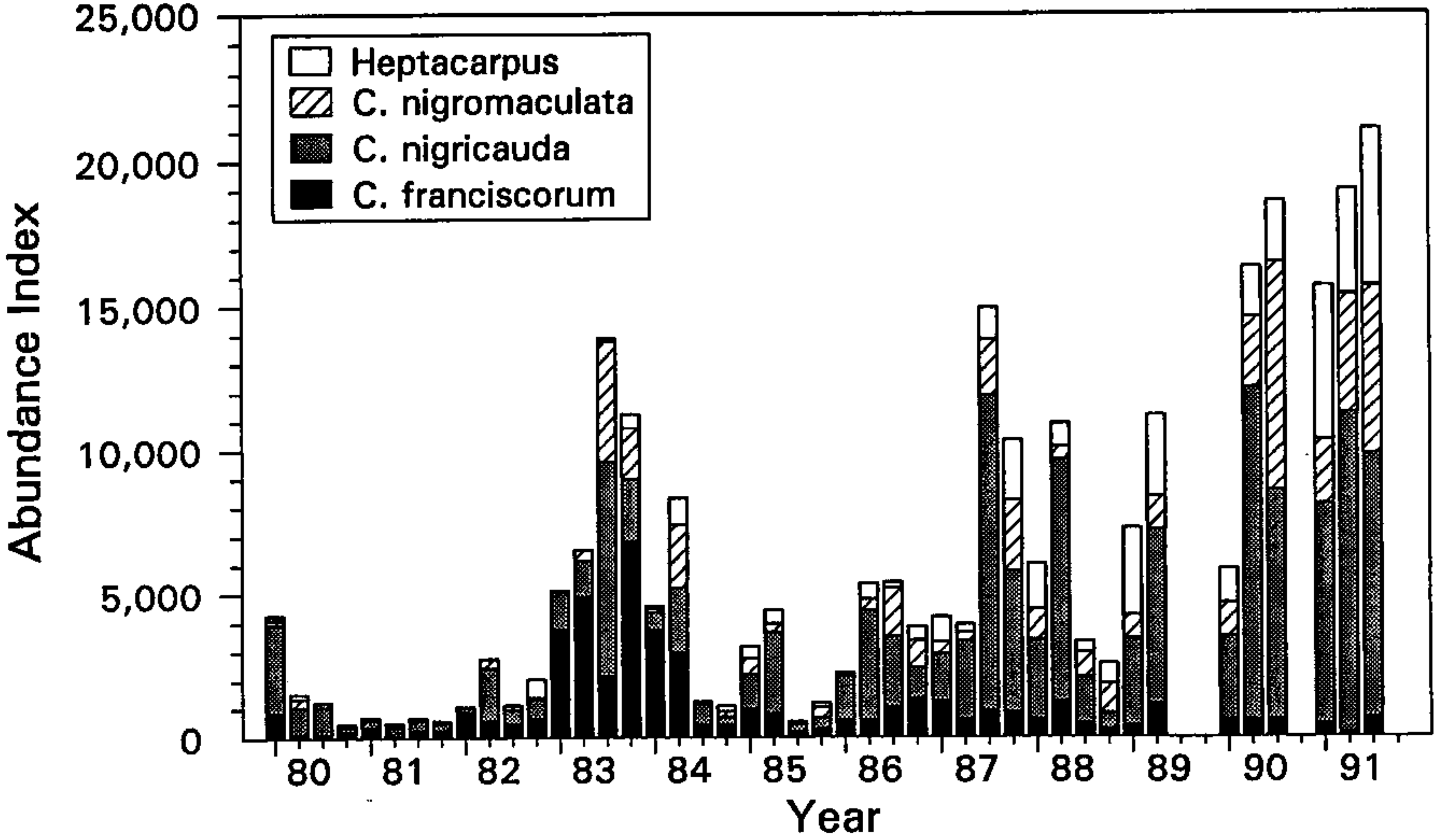


Figure 15. Quarterly abundance indices for the major species of shrimp in Central Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

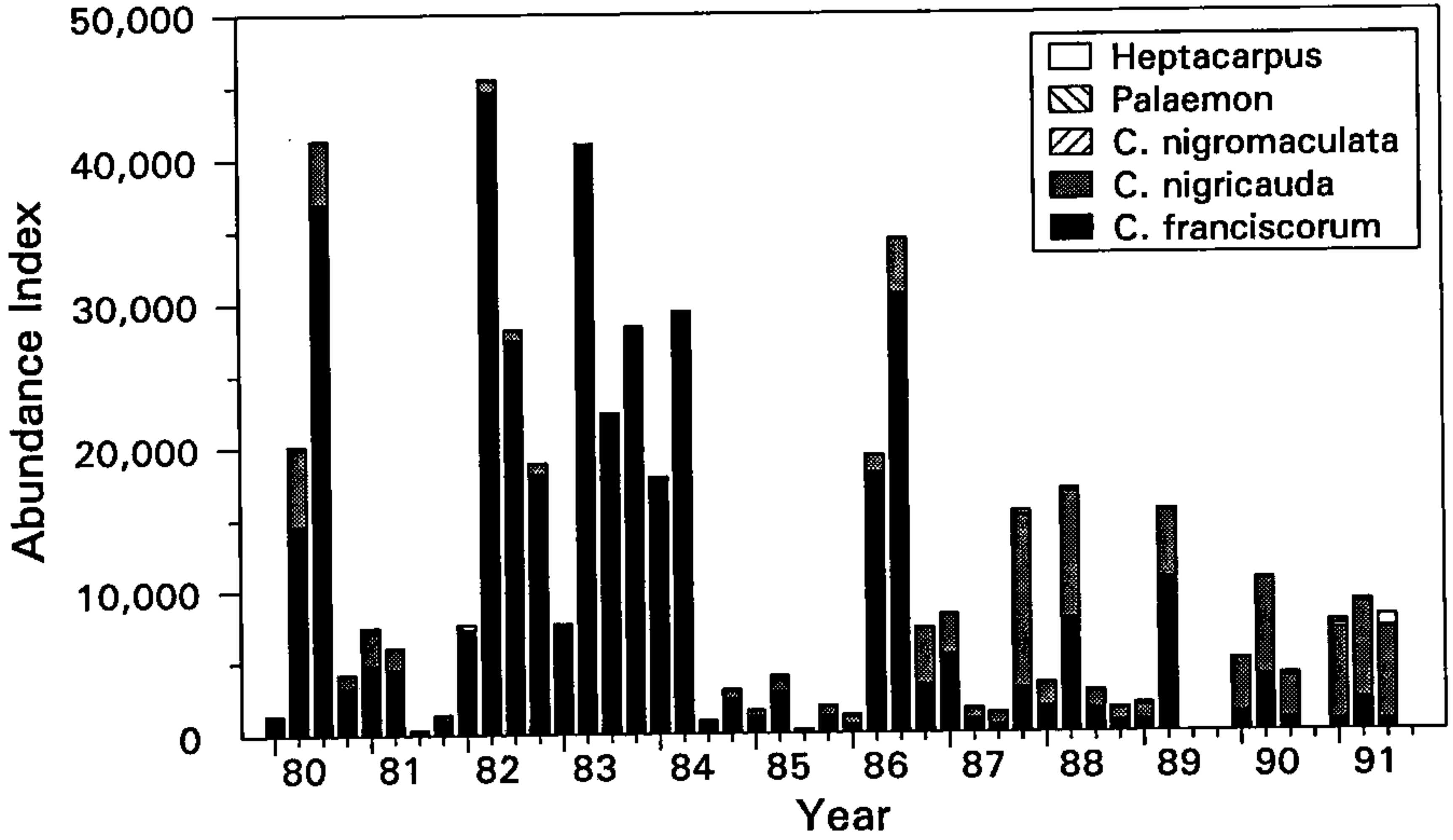


Figure 16. Quarterly abundance indices for the major species of shrimp in San Pablo Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

for the other low outflow years. The decrease in shrimp abundance in San Pablo Bay during all low outflow years was due to a decrease in the abundance of *C. franciscorum*. Although the abundance of the "marine" species increased during the drought in San Pablo Bay, the abundance of *C. franciscorum* continued to decline. In 1991, *C. franciscorum* comprised 15% of the total index, *C. nigricauda* 78%, *C. nigromaculata* 2% and *Heptacarpus* 5%. For comparison, in 1987 *C. franciscorum* accounted for 60% of the total index, *C. nigricauda* 39% and *C. nigromaculata* and *Heptacarpus* each less than 1%. The average biomass index for the drought years was 40% less than index for other low outflow years and 80% less than the average index for the high outflow years (Table 8).

In Suisun Bay the total abundance of shrimp during the drought years was lower than the other low outflow years by approximately 60% and the high outflow years by 65% (Table 7). In all years *C. franciscorum* dominated the shrimp population of Suisun Bay and its abundance declined in recent years (Figure 17). The abundance of *C. nigricauda* increased in Suisun Bay during recent years, but not to a level to compensate for the decline of *C. franciscorum*. Because *C. franciscorum* was the major component of the shrimp population in Suisun Bay, the changes in biomass indices were comparable to the changes in abundance indices. The average biomass index for the drought years was 65% less than the index for the other low outflow years and 70% less than the index for the high outflow years (Table 8).

The abundance of shrimp in the West Delta area was greater during the drought than during other years (Figure 18 and Table 7). The average annual index for 1988-91 was approximately one and a half times the annual index for other low outflow years. It was over six and a half times the average index for the high outflow years. Because of extremely high outflow during 1983, no shrimp of any species

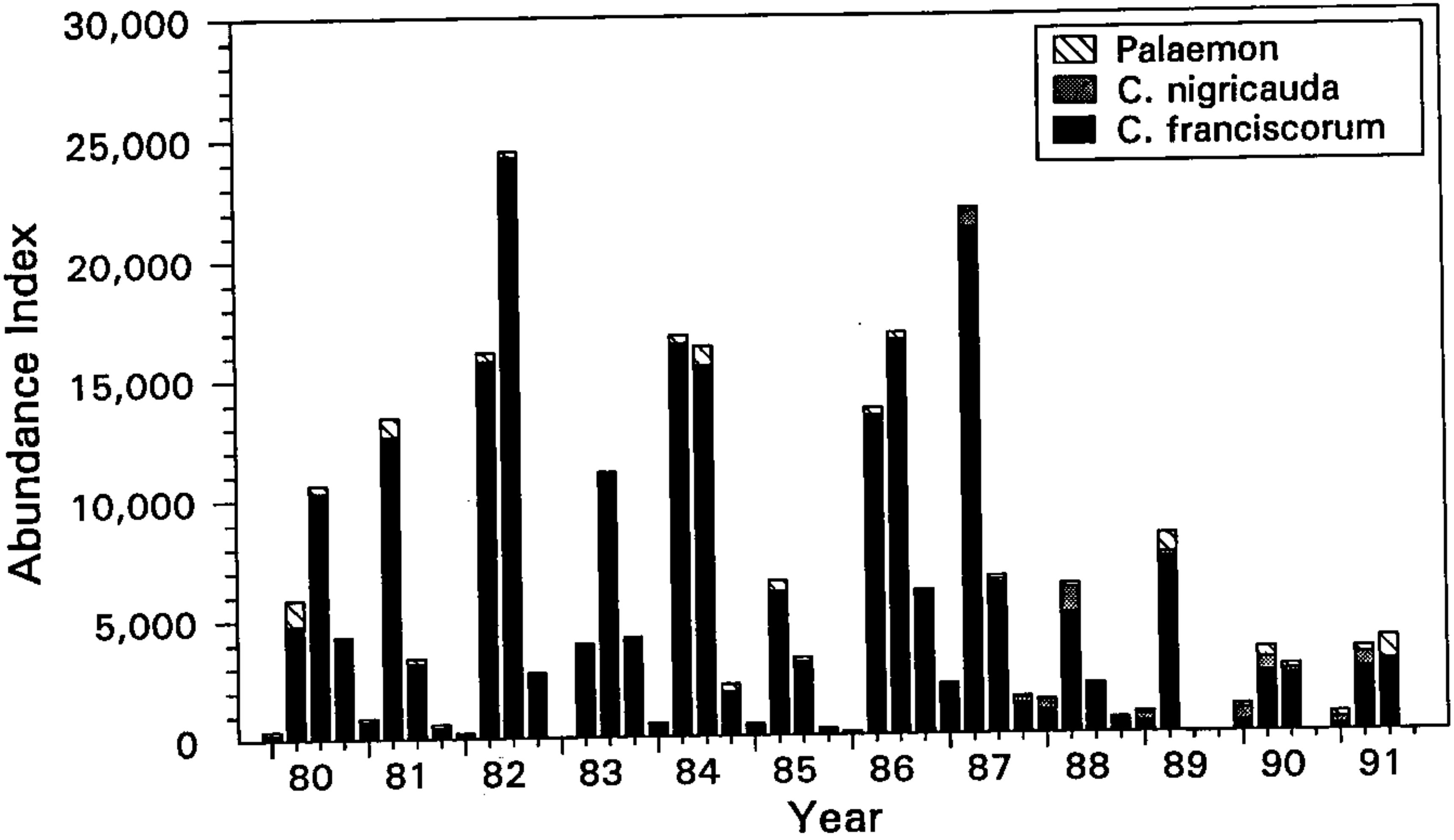


Figure 17. Quarterly abundance indices for the major species of shrimp in Suisun Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

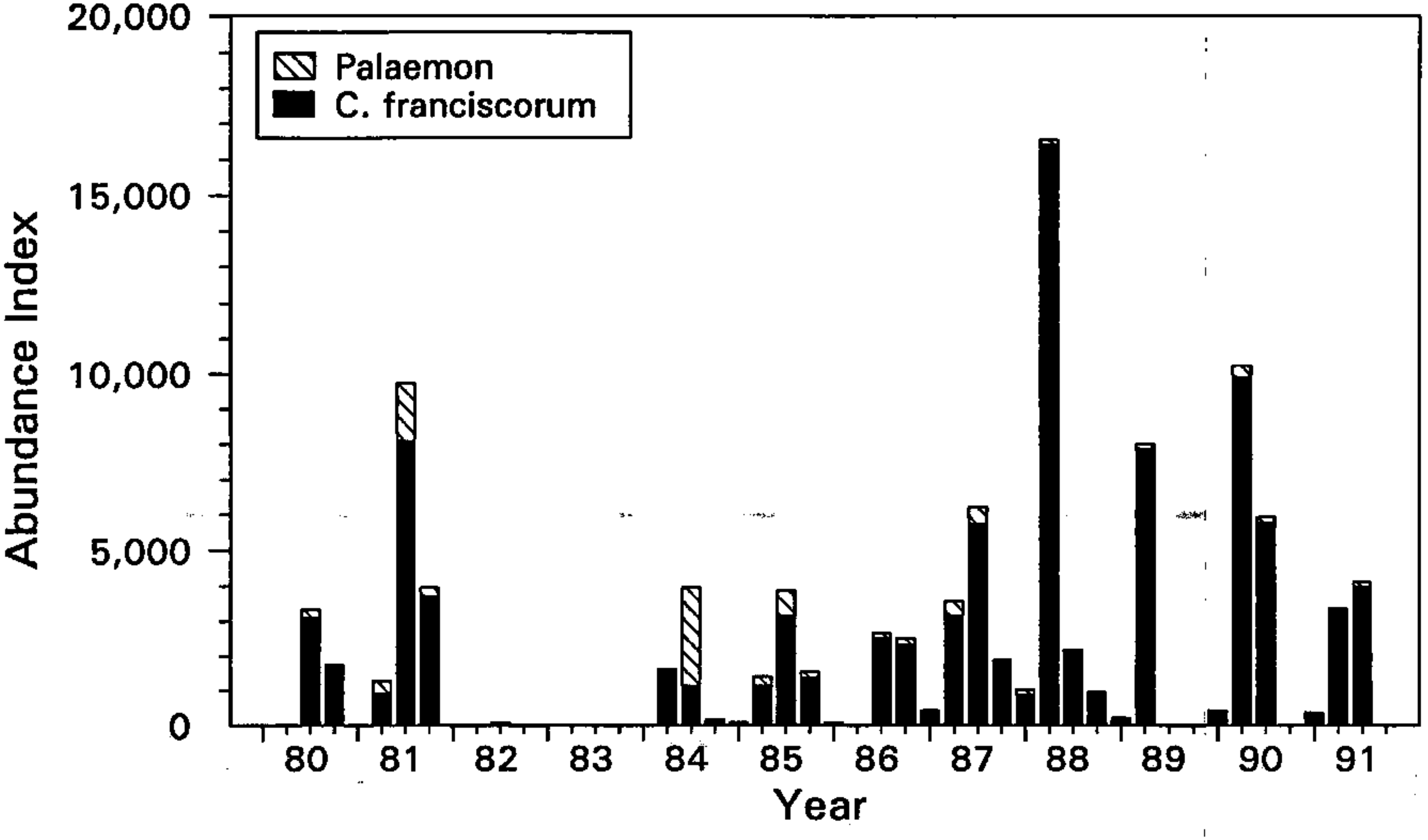


Figure 18. Quarterly abundance indices for the major species of shrimp in the West Delta area, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

were collected in this area that year. The annual index during the drought years is underestimated for this area because shrimp, especially *C. franciscorum*, were distributed upstream of our sampling area in the lower Sacramento and San Joaquin Rivers. We extended our sampling area upstream in 1991, and preliminary analysis indicates that approximately 10% of the *C. franciscorum* population may have been upstream of our original sampling area during some low outflow years. *C. franciscorum* dominated the catch in this area all years except for 1984, when *Palaemon* was slightly more abundant. The average biomass index during the drought years was slightly greater than the other low outflow years and four times the average index for the high outflow years (Table 8).

In summary, the recent drought resulted in an increase in the numerical abundance of several species of shrimp that prefer higher salinity waters. This increase was most dramatic in South and Central Bays, where the average abundance index for 1988-91 was estimated to be at least twice that for years with high freshwater outflow. But the abundance of shrimp in San Pablo and Suisun Bays during the drought was less than half that of years with high freshwater outflow. In Suisun Bay the average abundance index during the drought years was also about half of the index for the previous low outflow years. The decrease in total shrimp abundance in San Pablo and Suisun bays during the recent drought was due to the decrease in abundance of *C. franciscorum*. As documented in this and previous reports, the abundance of *C. franciscorum* is strongly related to the amount of freshwater outflow in the spring. Not only did the abundance of *C. franciscorum* decrease during years with low freshwater outflow, but their distribution shifted upstream. The increased abundance during the drought in the West Delta area was because *C. franciscorum* were concentrated in the lower Sacramento and San Joaquin rivers.

During the recent drought years the average biomass index for all embayments combined was less than the average index for the other low outflow years and years with high freshwater outflow. This is because the species and sizes of shrimp that increased in abundance during recent years were not as large as *C. franciscorum*, which dominated the catch in most embayments previous to the drought. The biomass index is important because it is a more realistic indicator of the amount of energy (organic carbon) that shrimp contribute to the food chain than the numerical index.

Longfin Smelt

Introduction

Longfin smelt (Spirinchus thaleichthys) are found in fresh, brackish, and marine waters from San Francisco Bay, California to Prince William Sound, Alaska (Miller and Lea 1972). In California, longfin smelt have been collected from numerous river estuaries and bays between the Oregon boarder and San Francisco Bay (Moyle 1976, DeWitt and Welch 1977), but the largest reproductive population inhabits San Francisco Bay.

The longfin smelt life cycle (Figure 19) begins with spawning in the lower Sacramento and San Joaquin Rivers, the Delta and the freshwater portions of Suisun Bay from December through April (Simonsen 1977, Moyle 1976). Longfin smelt spawn adhesive eggs (Dryfoos 1965) which are probably released over rock, vegetation or some other firm substrate (Moyle 1976). In Lake Washington, Washington state, longfin smelt eggs hatched in 37 to 47 days at 7°C (Dryfoos 1965). After hatching, pelagic larvae are carried downstream by freshwater outflow to nursery areas in the lower Delta, Suisun and San Pablo Bays (CDFG 1987).

In their second year of life, prior to sexual maturity, longfin smelt inhabit most of San Francisco Bay (CDFG 1987) and occasionally venture into the Gulf of the Farallones (BWPC 1984). During the fall of their second year of life, rarely at age 1 (Dryfoos 1965, CDFG unpub. data), maturing fish migrate back to the Delta to spawn. It is believed that most longfin smelt die after spawning (Dryfoos 1965, Moyle 1976), but some females may live to reproduce a second time (Moyle 1976). In most years the entire life cycle of longfin smelt is carried out in the Bay.

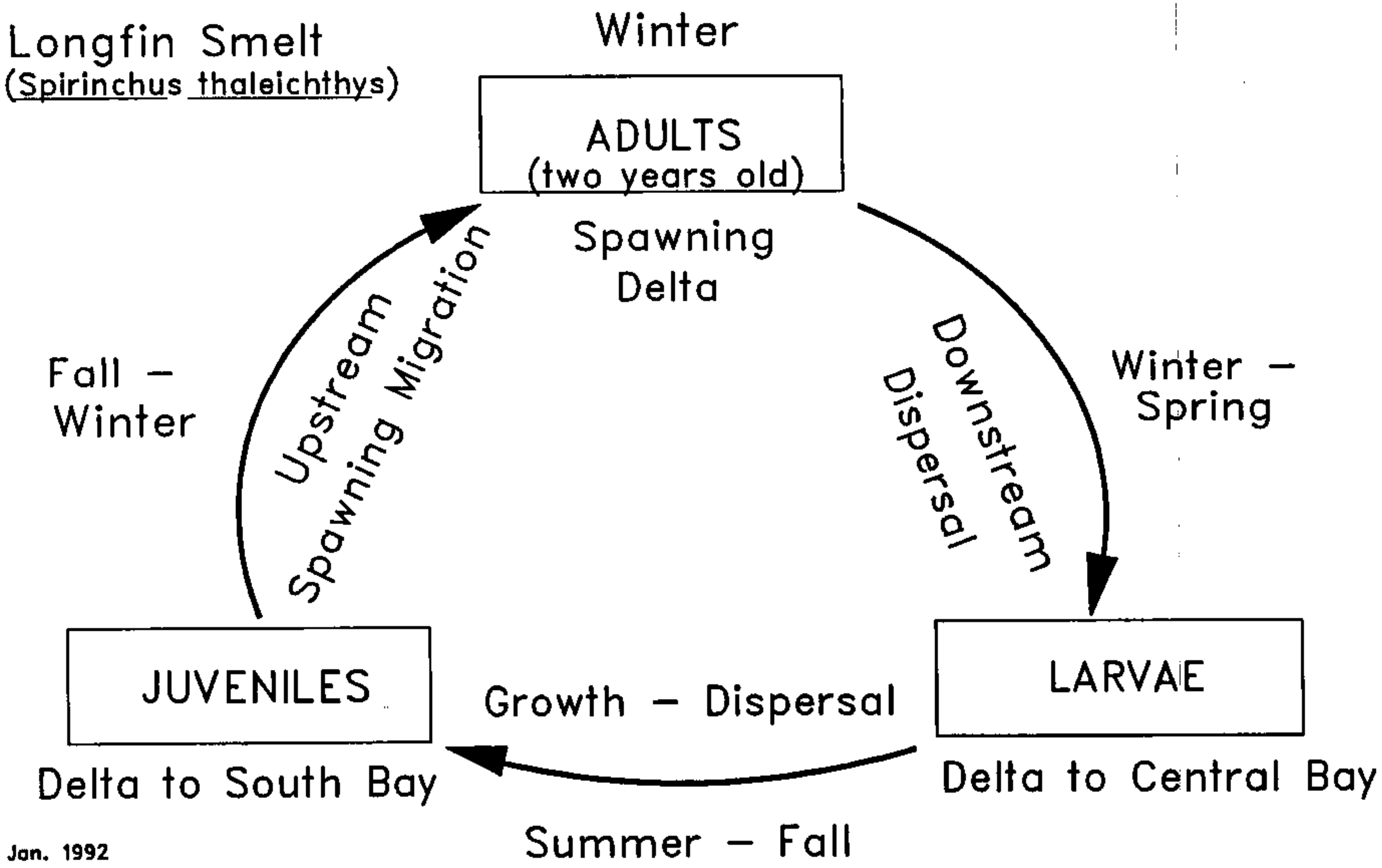


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Figure 19. Longfin Smelt Life Cycle.

Historically, longfin smelt in San Francisco Bay were harvested commercially as part of the "whitebait" fishery which included night smelt (*S. starski*) and surf smelt (*Hypomesus pretiosus*) (Skinner 1962). The longfin smelt contribution to this fishery was not quantified. Both night smelt and surf smelt continue to be harvested commercially in and near San Francisco Bay along with other unidentified smelt species, including longfin smelt. Between 1985 and 1988, the smelt (all species) catch landed in the Bay area totalled between 20 and 40 thousand pounds annually (CDFG Marine Res. unpub. data).

Longfin smelt larvae, juveniles and adults are eaten by predatory fishes, birds and marine mammals (Emmett et al. 1991). Longfin smelt were uncommon in the winter and spring diets of striped bass (*Morone saxatilis*) collected from the Carquinez Strait to the Martinez area by Thomas (1967) in the late 1950's and early 1960's, and were not found in a subsequent, more intensive study of striped bass from the Delta (Stevens 1966). Longfin smelt were also found in the diet of striped bass from South San Francisco Bay during the extremely high outflow year of 1983 (Kinnetic Laboratories Inc./Larry Walker Associates 1987). Considering that longfin smelt were the most abundant of all species collected in the otter trawl and ranked third in midwater trawl sampling by the CDFG Bay Study between 1980 and 1988 (IESP 1990), it seems likely that more species prey on longfin smelt. Longfin smelt form an important part of the diet of harbor seals (*Phoca vitulina*) year-round in the Colombia River estuary (Jeffries 1984).

Patterns of Abundance

The California Department of Fish and Game Striped Bass Fall Midwater Trawl Survey (Fall MWT Survey) provides the longest, most accurate index of longfin smelt abundance for San Francisco Bay. The Fall MWT Survey samples most of the range of longfin smelt in the Bay (Stevens and Miller 1983, CDFG 1987). This survey was initiated in the fall of 1967 and has been conducted annually to the present, with the exceptions of 1974 and 1979. Sampling takes place from September through at least December at locations throughout San Pablo Bay and upstream to approximately Cache Slough on the Sacramento River and to the Port of Stockton on the San Joaquin River (Stevens and Miller 1983). The longfin smelt from this survey were not separated into year classes, so the index from each year represents at least two year classes. During most years young-of-the-year predominate in the fall catch of longfin smelt.

The Fall MWT Survey longfin smelt abundance index showed that the population fluctuated widely from year to year (Figure 20, Appendix 2). No real trend was evident over the entire period of record, yet in the past five drought years longfin smelt abundance has remained at very low levels ending in 1991 with the lowest index recorded.

The California Department of Fish and Game's Delta Outflow/San Francisco Bay Study (Bay Study) began sampling in 1980 and continues to the present. The Bay Study collects fish and invertebrates from locations throughout San Francisco Bay into the lower portions of the Sacramento and San Joaquin Rivers (Figure 1). Longfin smelt were collected in both the otter trawl (OT) and midwater trawl (MWT).

Analysis of length frequency data was used to separate the Bay Study longfin smelt catch into year classes (CDFG 1987). Annual abundance indices were calculated for young-of-the-year (YOY) and one-year-old (ONEPLUS) longfin smelt based upon May-October and February-October sampling periods, respectively. Indices for both ages were calculated for each net (Appendix 2). The YOY indices for both nets were positively correlated with the Fall MWT Survey longfin smelt index; r = 0.997 for Bay Study MWT vs

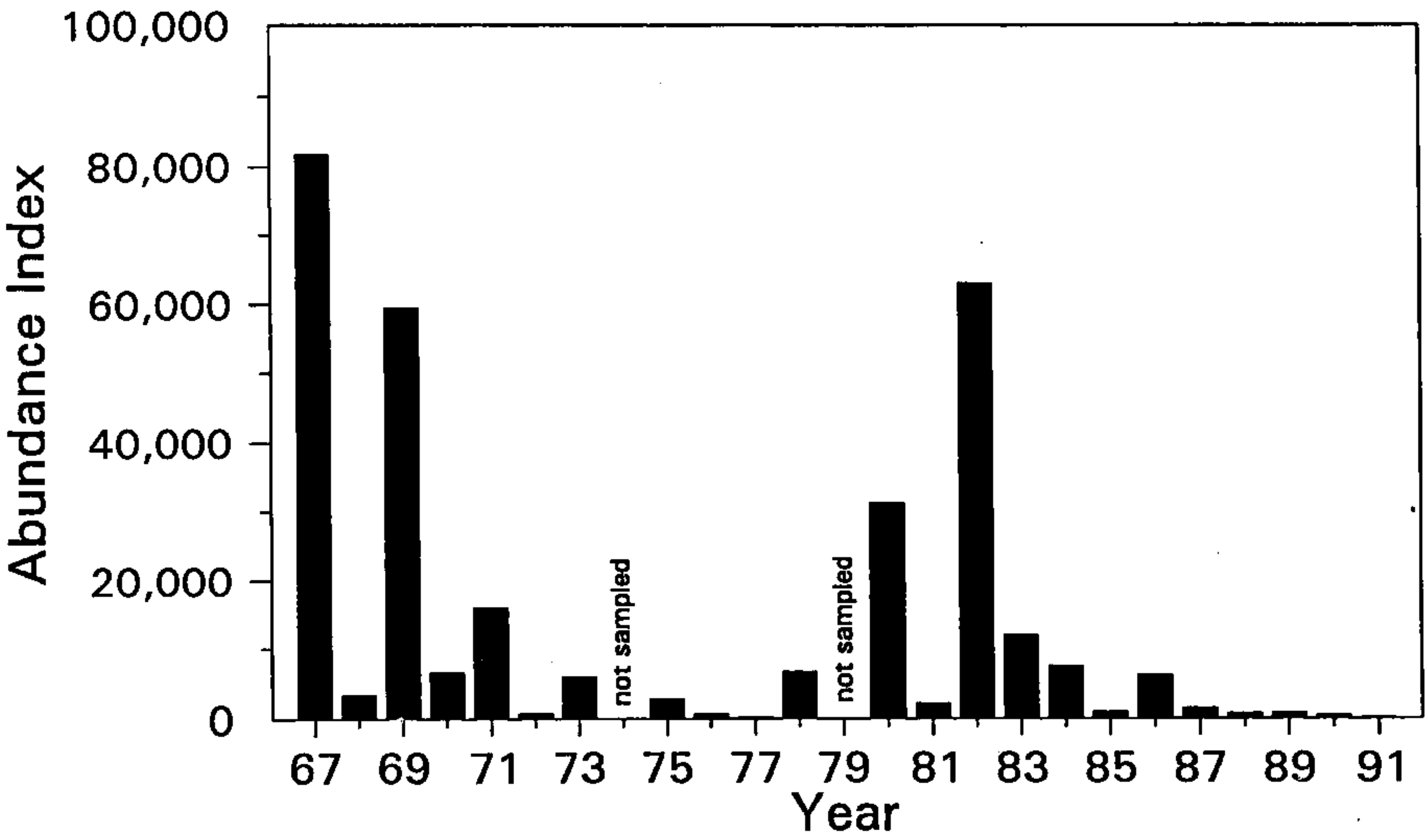

Figure 20. Longfin smelt annual abundance in CDFG Striped Bass Fall Midwater Trawl Survey sampling from 1967 to 1991. No sampling was done during 1974 or 1979.

Fall MWT, and $r = 0.993$ for Bay Study OT vs Fall MWT indices. This indicated that although neither study sampled the entire range of longfin smelt within San Francisco Bay, each detected virtually identical trends in abundance between 1980 and 1991. Both the midwater and otter trawl longfin smelt abundance indices showed a decline in longfin smelt abundance during the latter half of the 1980s (Figure 21).

Longfin Smelt Abundance Model and Biological Support

The Department of Fish and Game has been aware of a relationship between freshwater outflow and longfin smelt abundance since at least the early 1980's (Stevens and Miller 1983). Correlation analyses using all combinations of months between December and August run by Stevens and Miller (1983) indicated significant positive relationships between average monthly flow into the Sacramento-San Joaquin Delta and longfin smelt abundance in the Fall MWT Survey (1967-1979) for almost every combination of months tested. The highest correlation coefficients ($r = 0.93$) were for flow periods of December-July and December-August.

In more recent analyses prepared for SWRCB workshops in 1991, the relationship between $\log_{10}$ average monthly outflow for January-June and $\log_{10}$ Fall MWT Survey longfin smelt abundance index ($r^2 = 0.799$, $p < 0.001$, Table 9) was presented and used to quantify freshwater outflow needs for longfin smelt. Although the January through June period was originally selected for use because it had the highest coefficient of determination (r^2) for the flow periods analyzed, it does have some biological relevance. The January to June period includes most of the longfin smelt spawning and larval periods; by the end of June most longfin smelt have recruited to the juvenile stage.