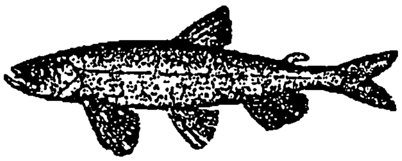
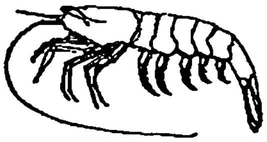
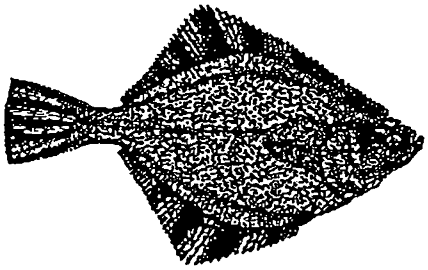
WRINT-DFG-Exhibit # 6

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





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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 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.

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 <u>C. franciscorum</u>. 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

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 <u>C</u>. <u>franciscorum</u> 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.

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

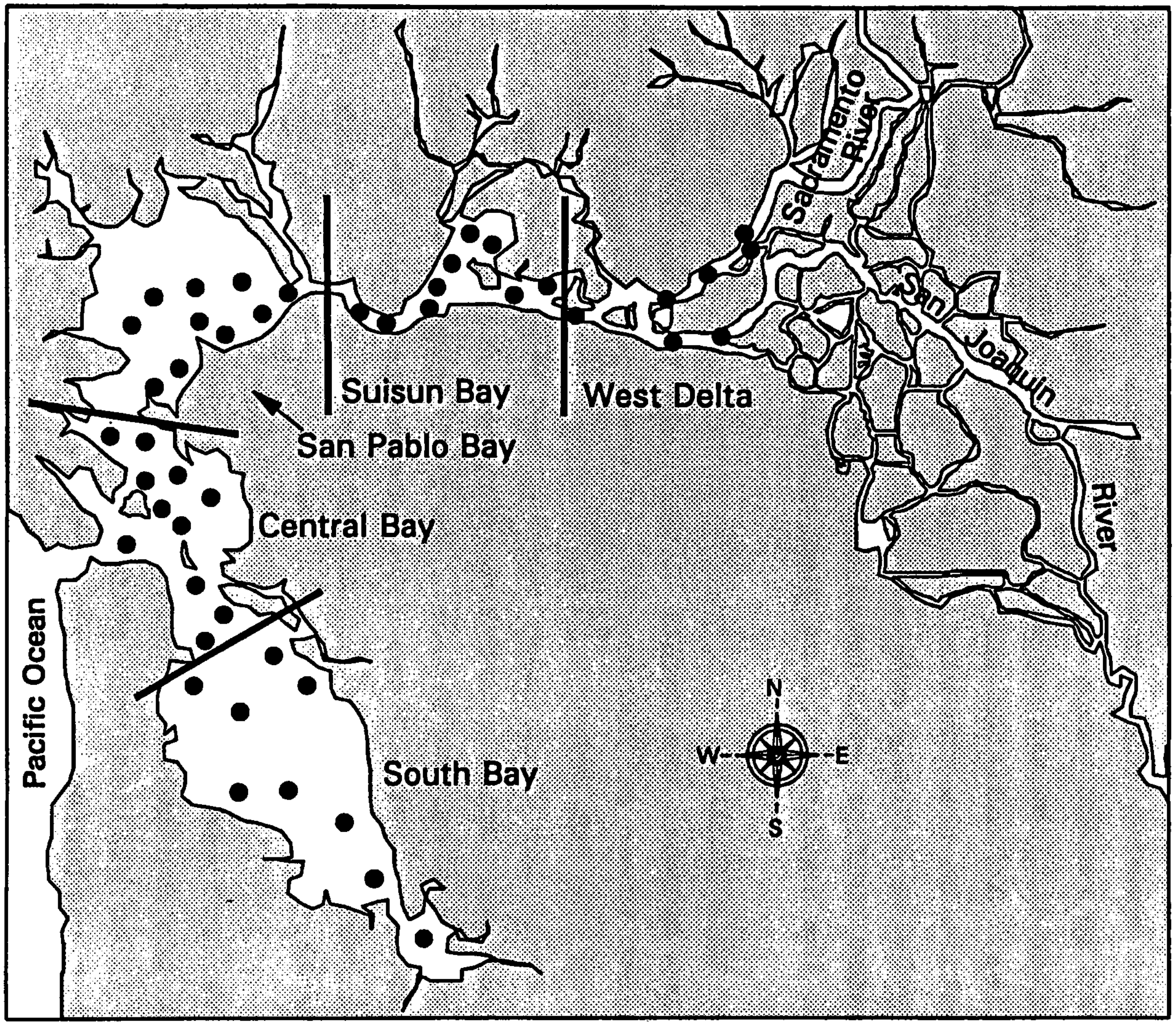


Figure 1. Study area and embayments.

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

Spawning area:

Ocean → Bay

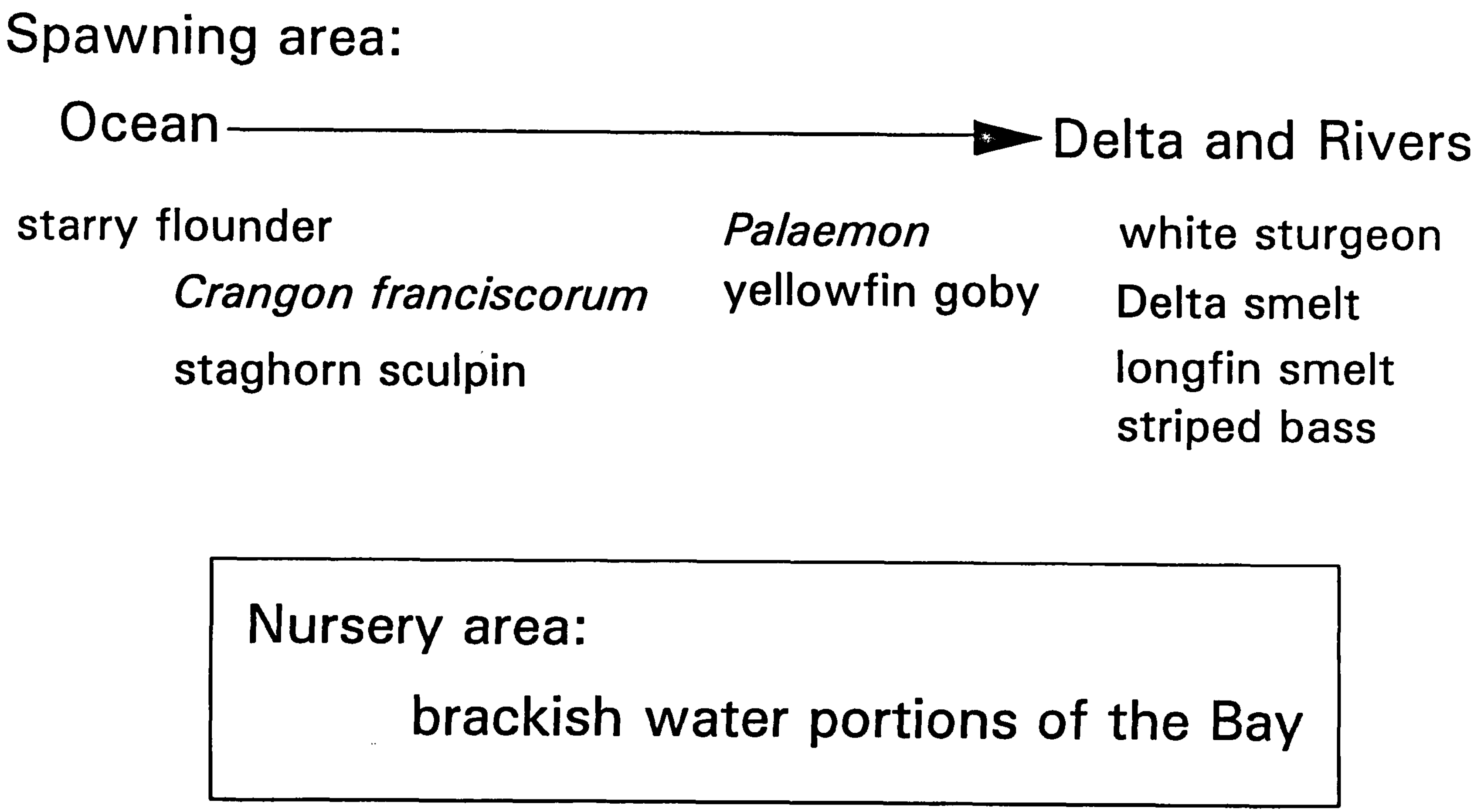
Crangon nigromaculata
Cancer magister
brown rockfish
California tonquefish
California halibut
English sole
speckled sanddab

Crangon nigricauda
Cancer gracilis
Elasomobranchs
northern anchovy
white croaker

Pacific herring
arrow goby
bay goby
plainfin midshipman
shiner perch
jacksmelt

Nursery area:
Marine portions of the Bay

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



Spawning area:

Ocean → Delta and Rivers

starry flounder

Crangon franciscorum

staghorn sculpin

Palaemon

yellowfin goby

white sturgeon

Delta smelt

longfin smelt

striped bass

Nursery area:

brackish water portions of the Bay

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 0.001	0.01	0.05	0.1	No Difference >0.1	0.1	0.05	0.01	Dry 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.

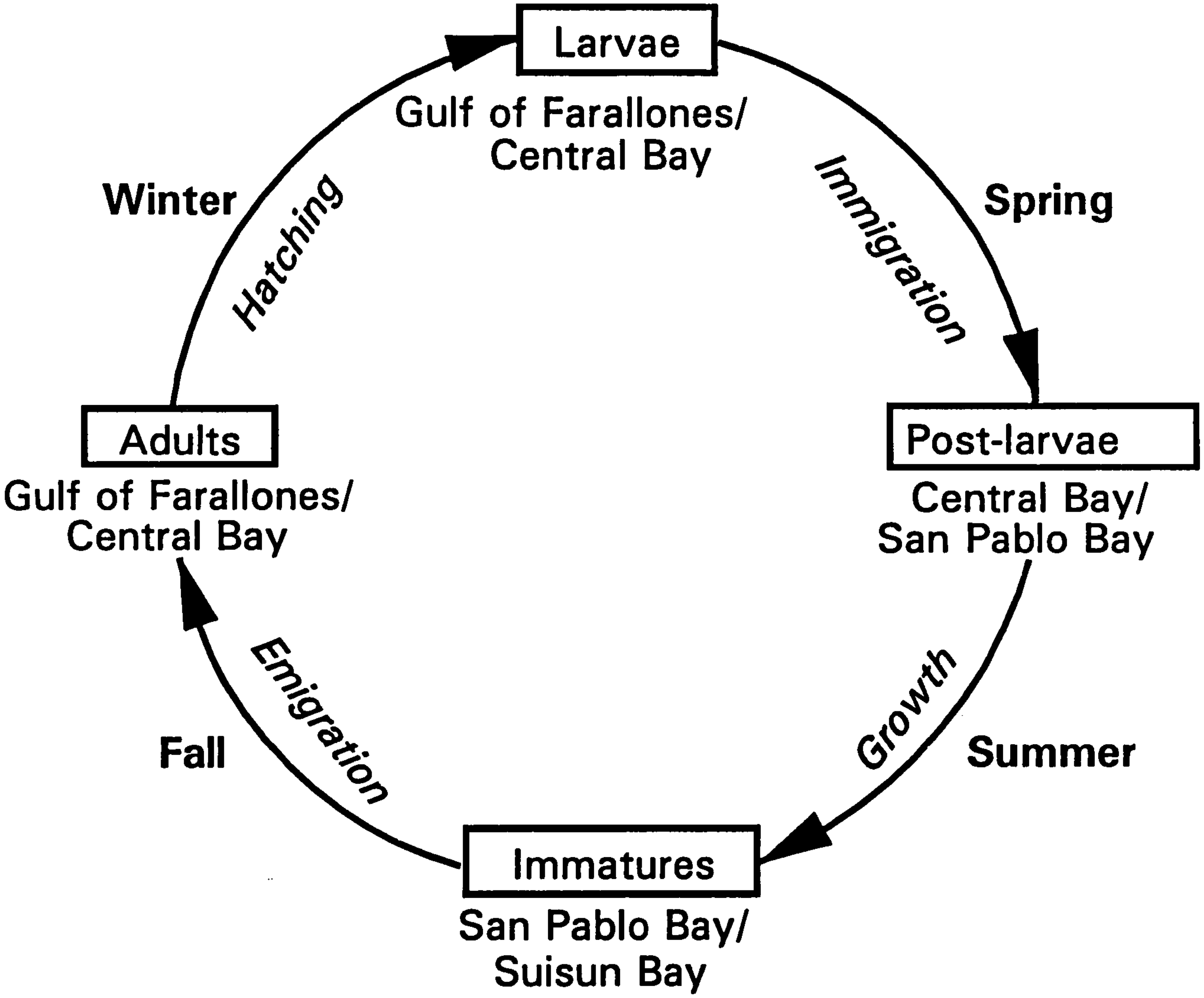


Figure 4. Life cycle of Crangon franciscorum in the San Francisco Bay-Estuary.

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

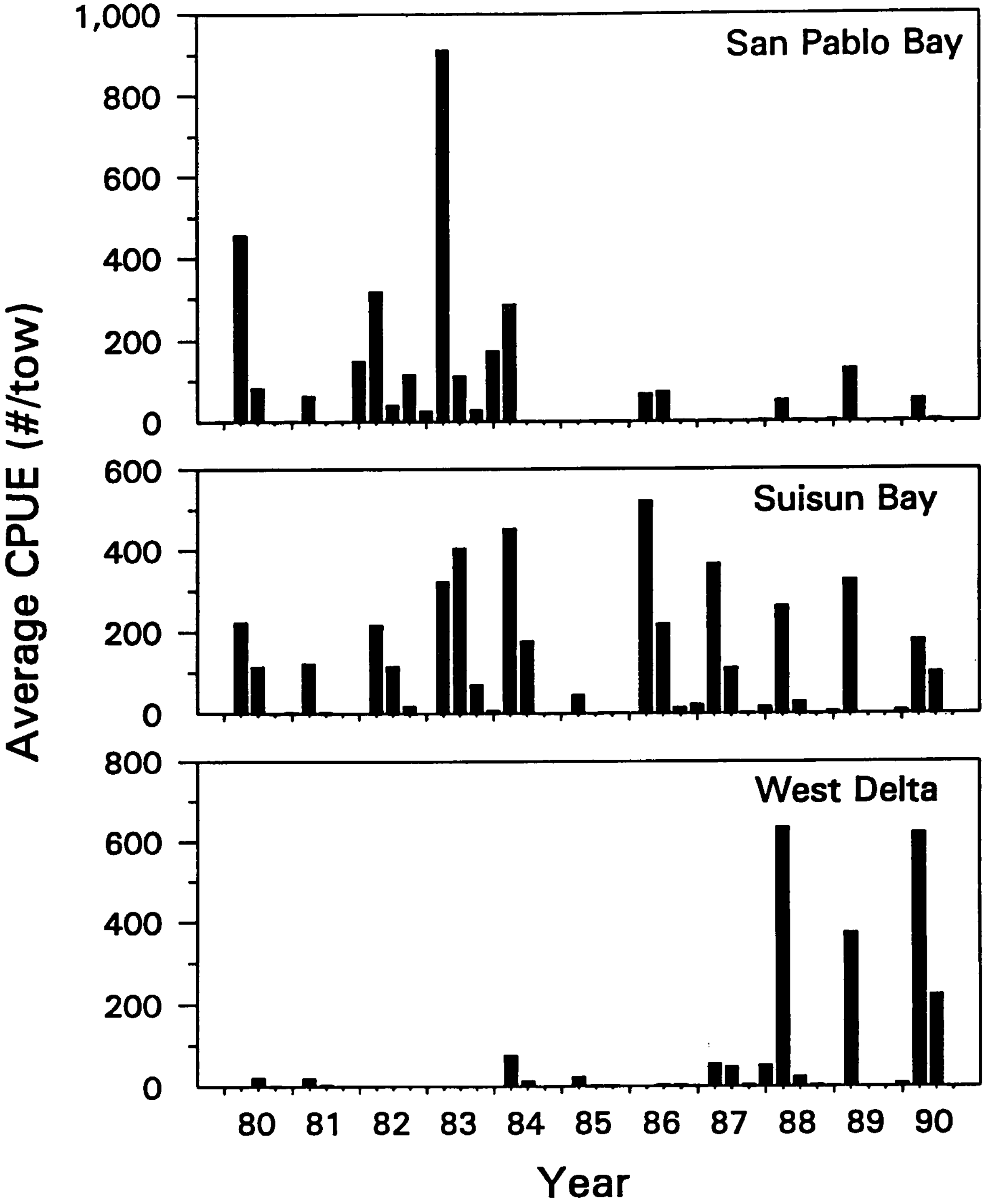


Figure 5. Distribution of small (11-25 mm) juvenile <u>Crangon franciscorum</u>, 1980-90 by quarters. Quarters begin in February (February- April, May-July, August-October, November-January). There is no data for the third and fourth quarters of 1989 and the fourth quarter of 1990.

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

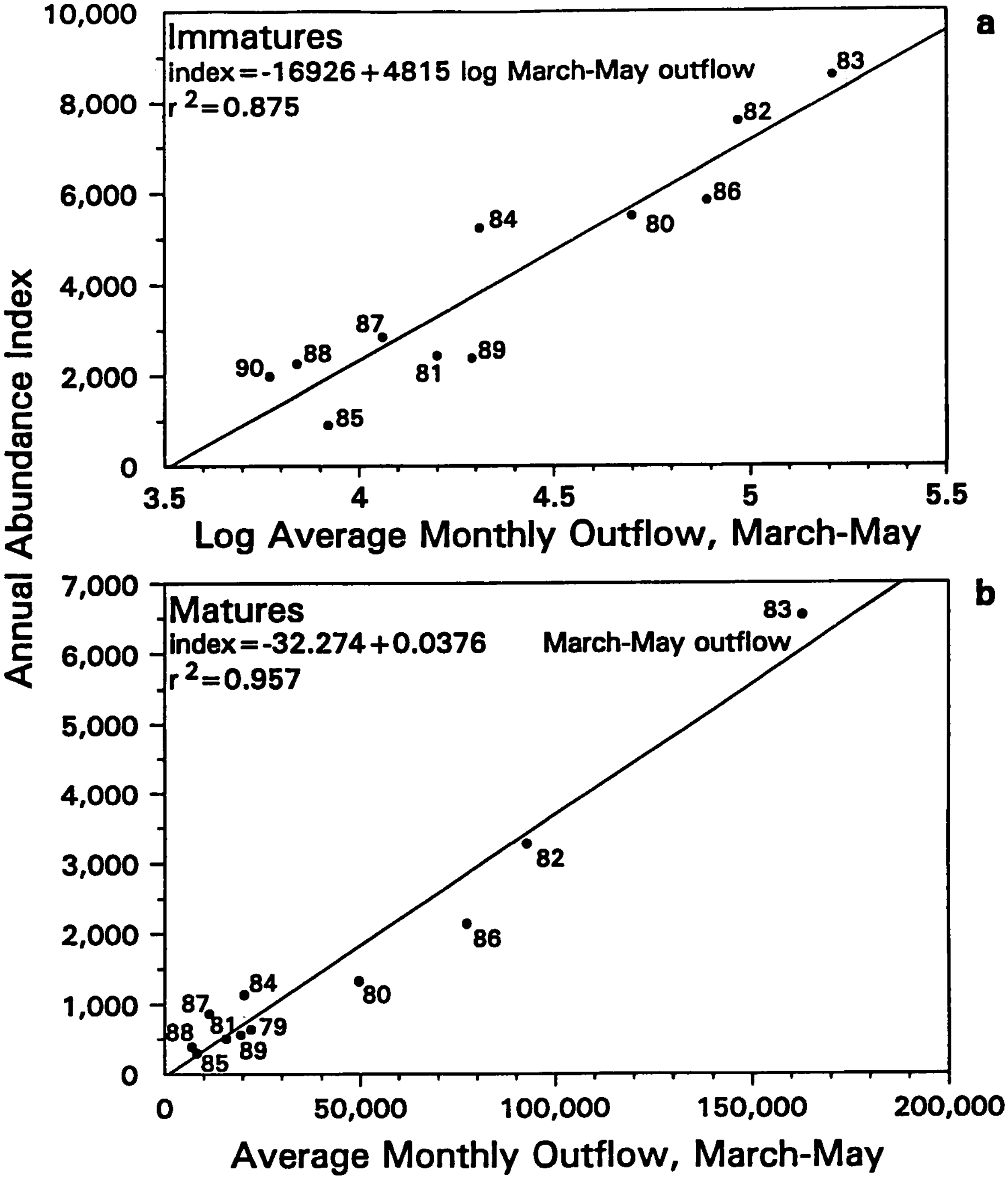


Figure 6. a. Relationship between the annual abundance index of immature *Crangon franciscorum* (May-October) and $\log_{10}$ average monthly outflow at Chipps Island, March-May. 1980-1990.

b. Relationship between the annual abundance index of mature *Crangon franciscorum* (January-April) and 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

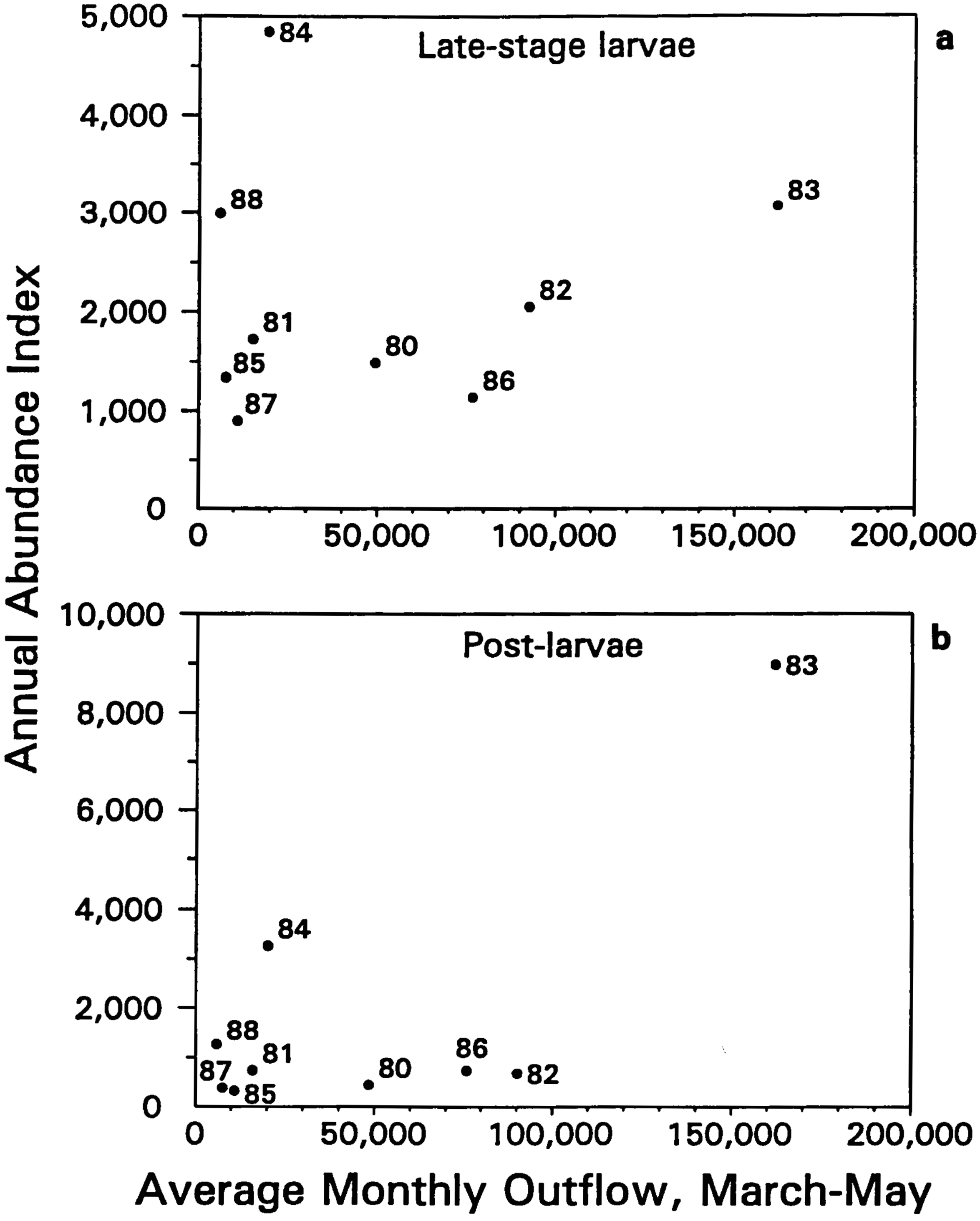


Figure 7. Relationship between the annual abundance index of Crangon early life stages and average March to May outflow at Chipps Island.

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

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

downstream transport is minimized. The strength of landward moving bottom currents could be an important factor in determining the length of time that it takes for these life stages to migrate to the nursery area. A longer time period would result in higher mortality rates due to increased predation or starvation. The amount of freshwater outflow is related to the magnitude of gravitational circulation, which is an important component of these bottom currents. With increased gravitational circulation, recruits could migrate to the nursery area faster and may have a lower mortality rate.

In years with low freshwater outflow, juvenile C. franciscorum are concentrated in Suisun Bay or the West Delta (Figure 5), where there is much less shallow water habitat than in San Pablo Bay. The importance of the size of the nursery area to year class success is in part confirmed by the positive relationship between the annual abundance index of immature shrimp and the annual habitat index (Figure 8a). The size of the nursery area is important to juvenile C. franciscorum for several reasons, including increased food and space, reduced inter- and intra-specific competition, and reduced predation. For C. franciscorum, the habitat index is the sum of the shallow (less than 10 feet), brackish (1.6-21.6 ppt) water area from April to June. This index is positively related to the amount of freshwater outflow from March to May (Figure 8b).

Freshwater outflow prior to March is probably also important to the recruitment success of C. franciscorum in the Bay. In winters with low outflow, when Bay salinities area relatively high, most ovigerous C. franciscorum remain in the Bay and hatch their larvae. As a result, early stage larvae, which are in the upper portions of the water column and subject to downstream transport by surface currents (IESP 1991), are more abundant in the Bay during low outflow years (CDFG 1987 and unpublished data). But these are not

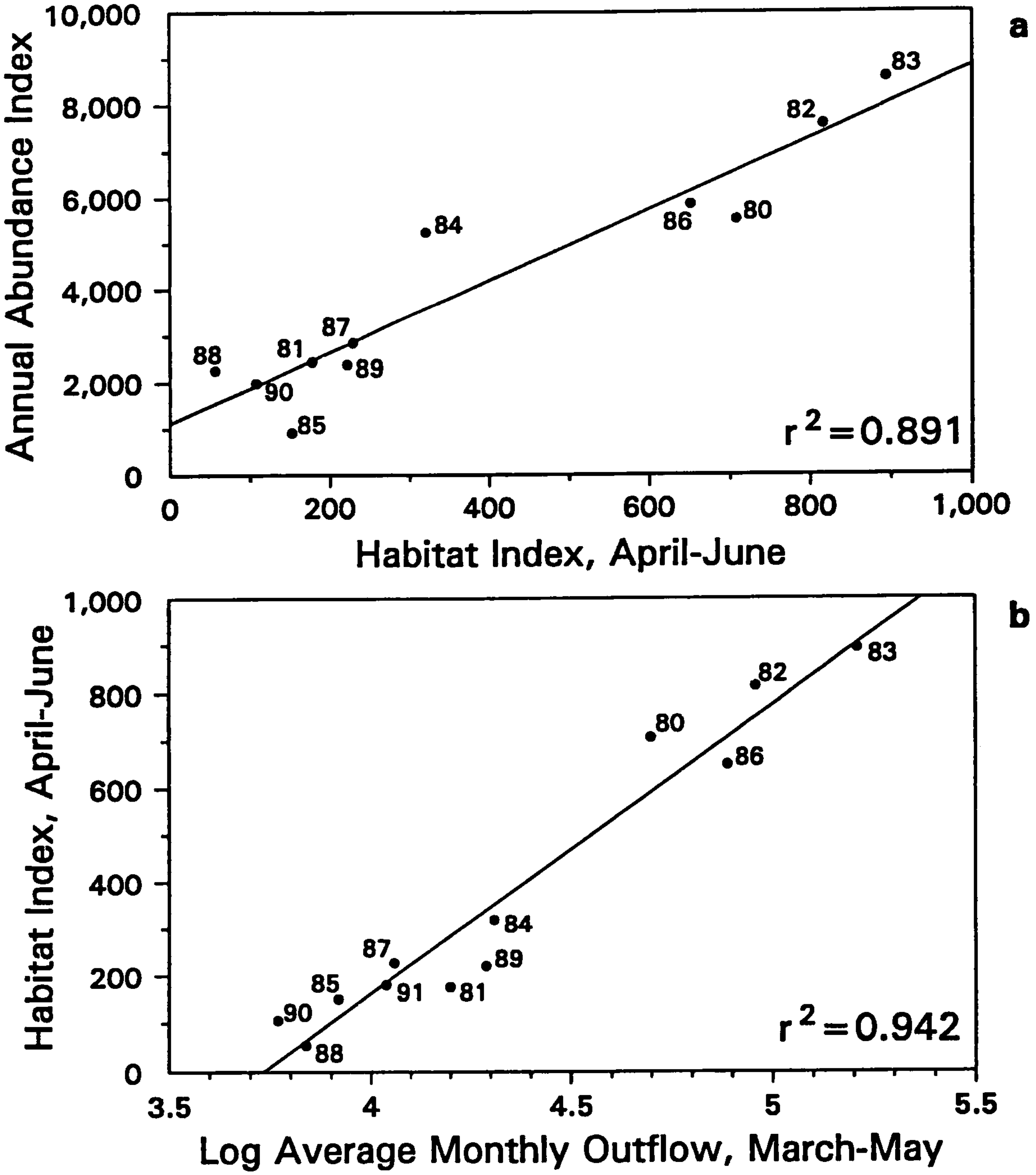


Figure 8. a. Relationship between the annual abundance index of immature <u>Crangon</u> <u>franciscorum</u> (May-October) and the annual habitat index (April-June, 1.6 - 21.6 ppt, shoals only). 1980-1990.

b. Relationship between the annual habitat index for <u>Crangon</u> <u>franciscorum</u> (April-June, 1.6 - 21.6 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

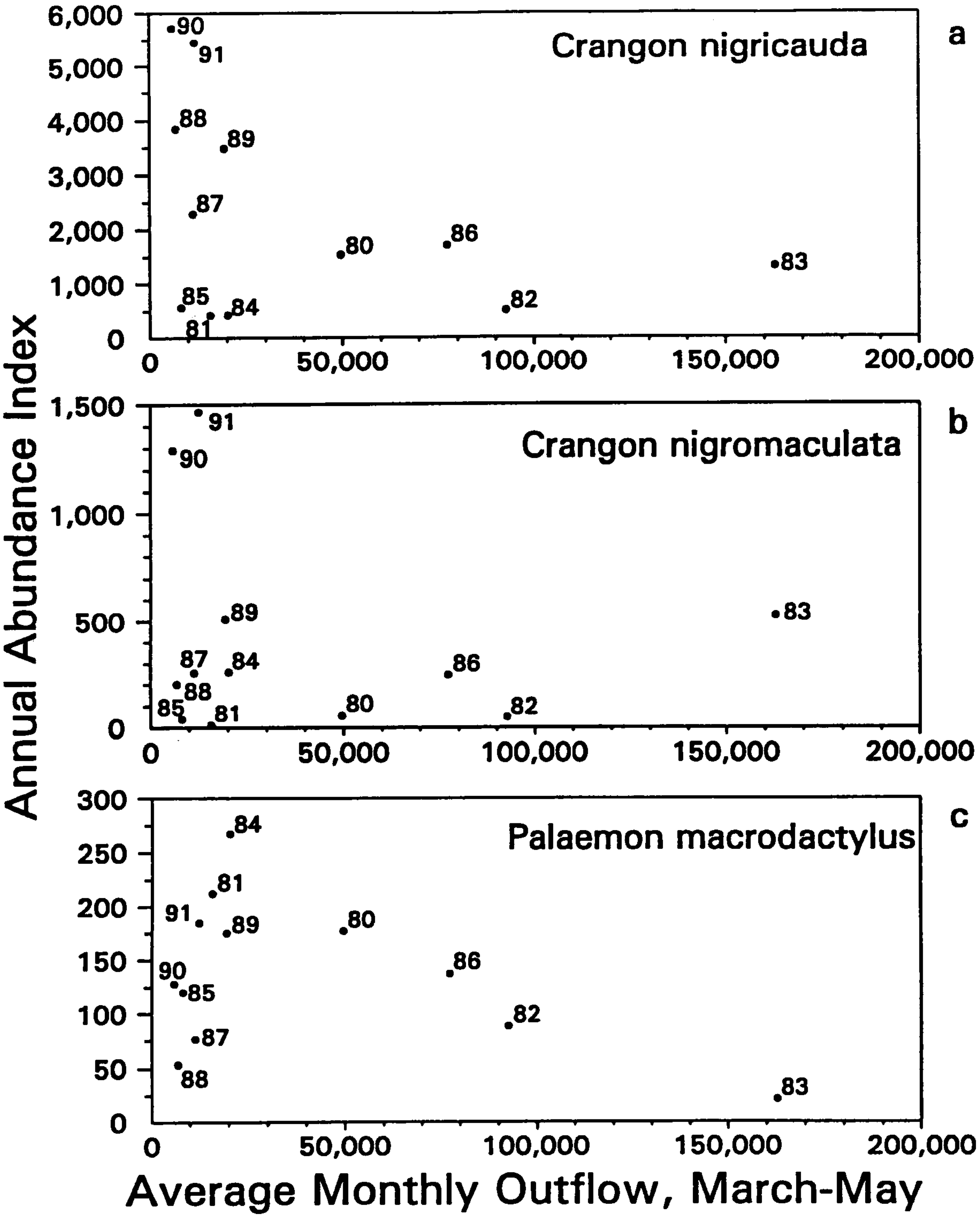


Figure 9. Relationship between the annual abundance index of several species of shrimp (May-October) and the average monthly outflow at Chipps Island, March-March. 1980-1990.

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.

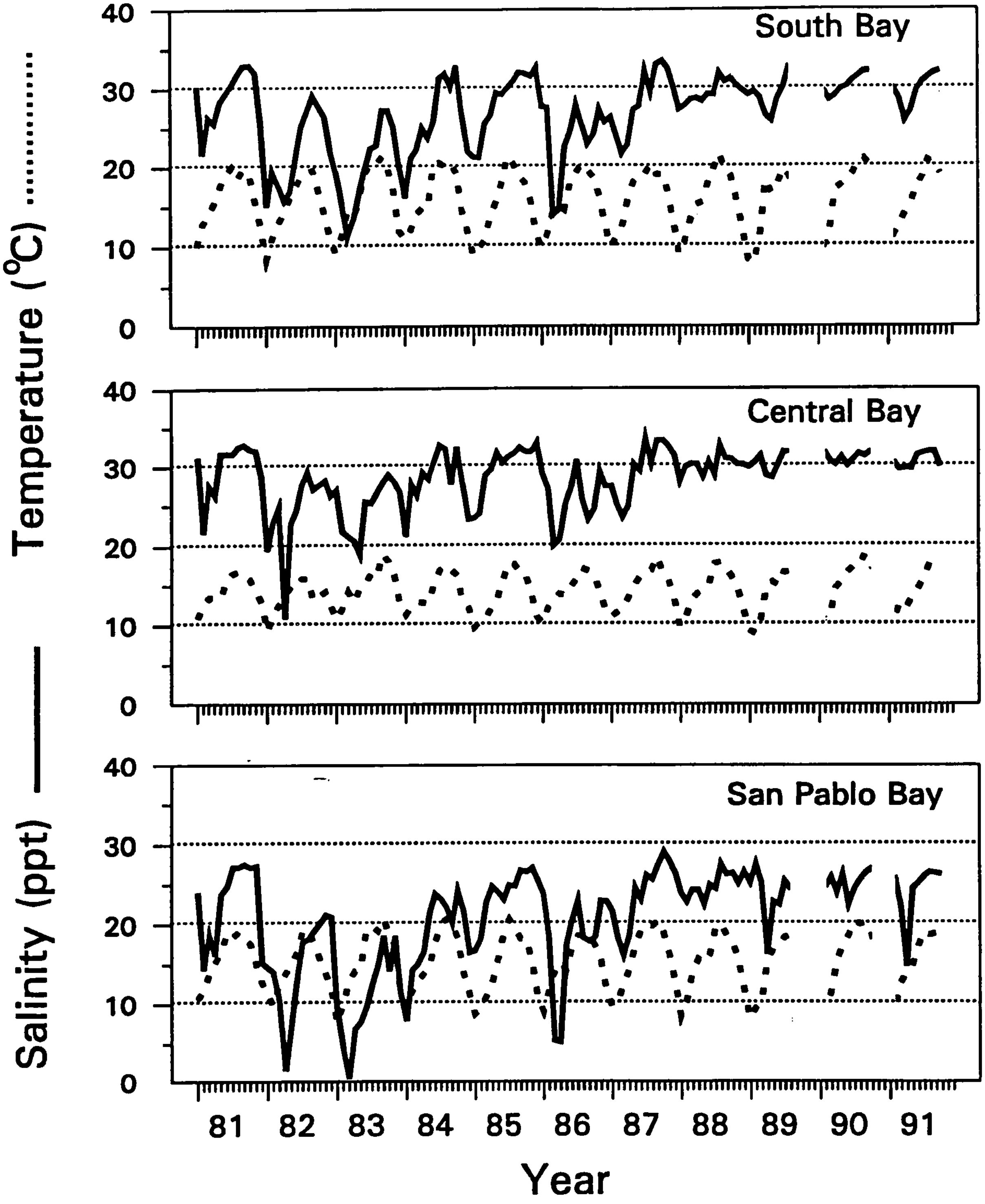


Figure 10. Average bottom salinities and temperatures for South, Central, and San Pablo bays, 1981-91. No data were collected from September 1989 to January 1990, November 1990 to January 1991, and in November and December 1991.

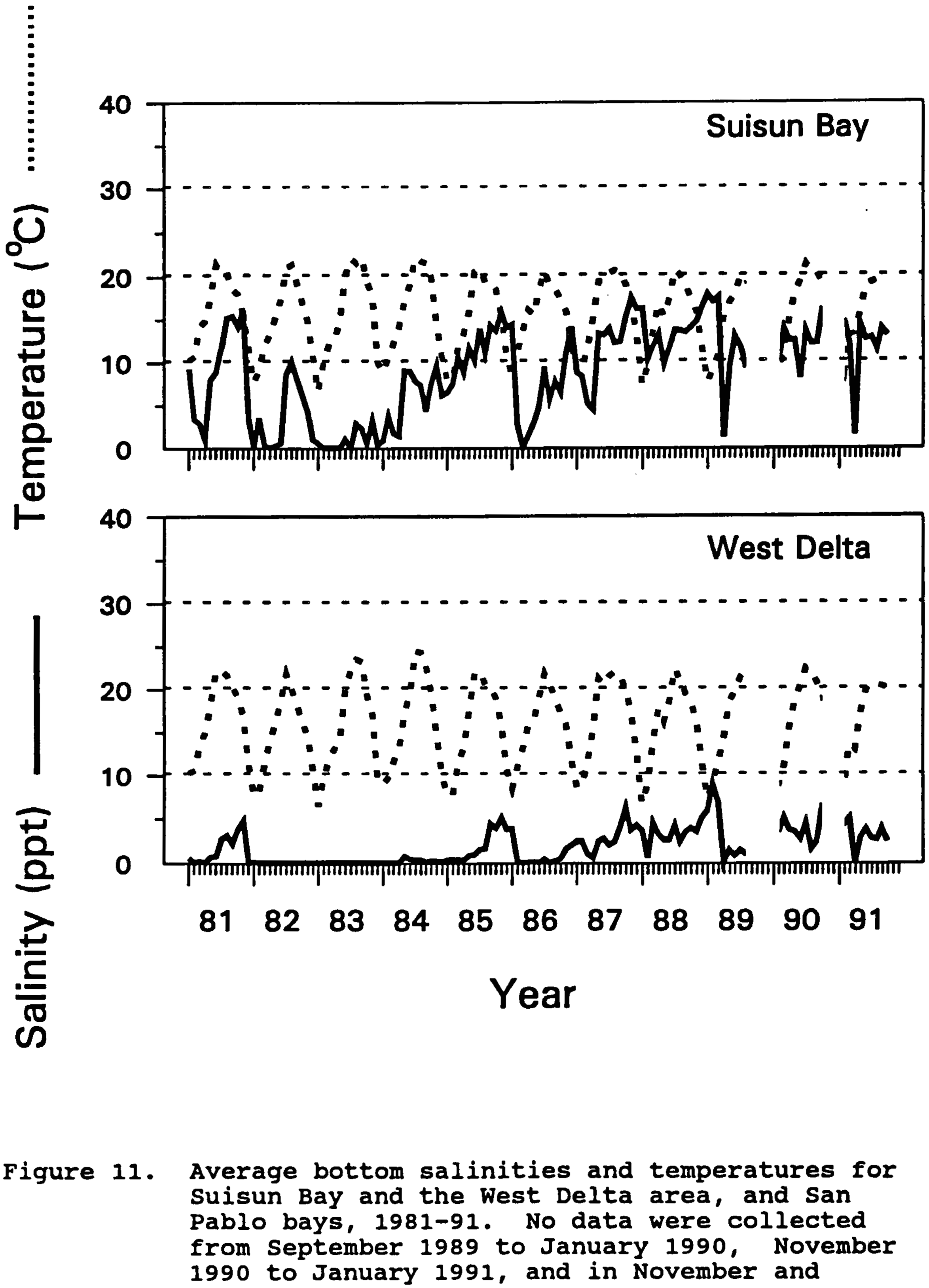


Figure 11. Average bottom salinities and temperatures for Suisun Bay and the West Delta area, and San Pablo bays, 1981-91. No data were collected from September 1989 to January 1990, November 1990 to January 1991, and in November and December 1991.

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

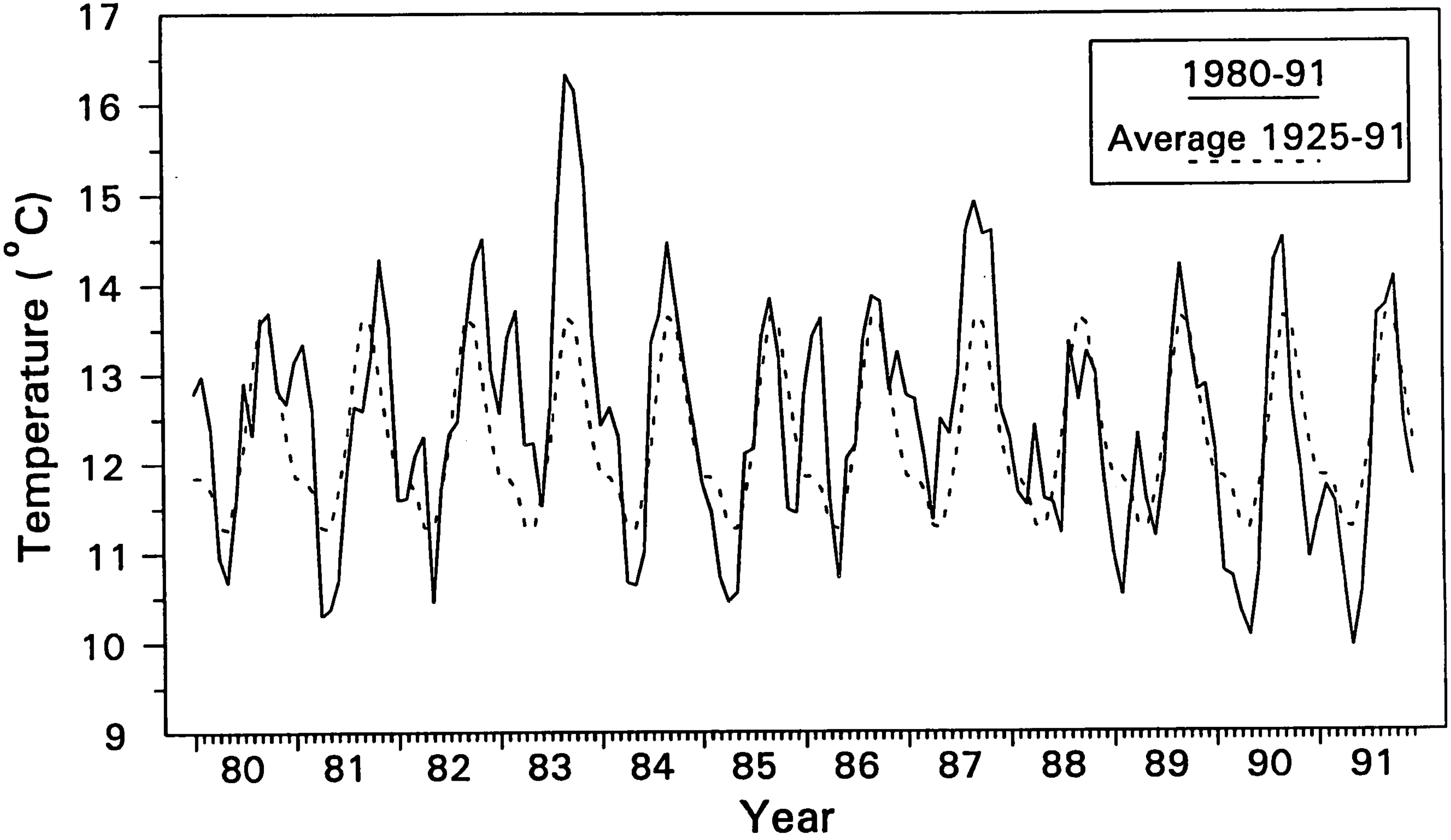


Figure 12. Average monthly sea surface temperature in the Gulf of the Farallones (SE Farallone Island), 1980-91. The dashed line is the average monthly temperature for the period 1925-91.

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

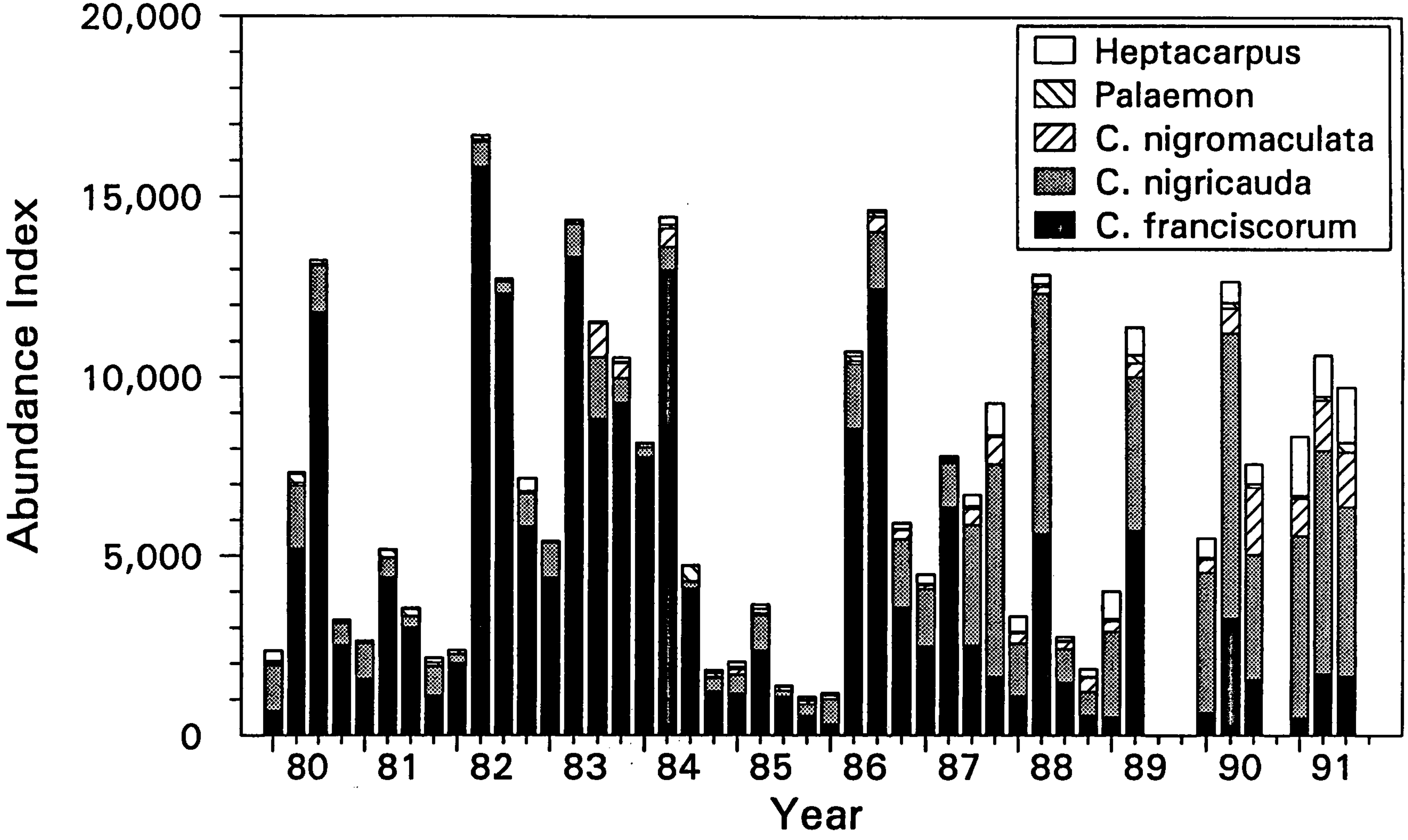


Figure 13. **Quarterly abundance indices for the five major species of shrimp in the Bay, 1980-1991. Quarters begin in February (February-April, May-July, August-October, November-January). There is no data for the third and fourth quarters of 1989 and the fourth quarter of 1990 and 1991.**

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

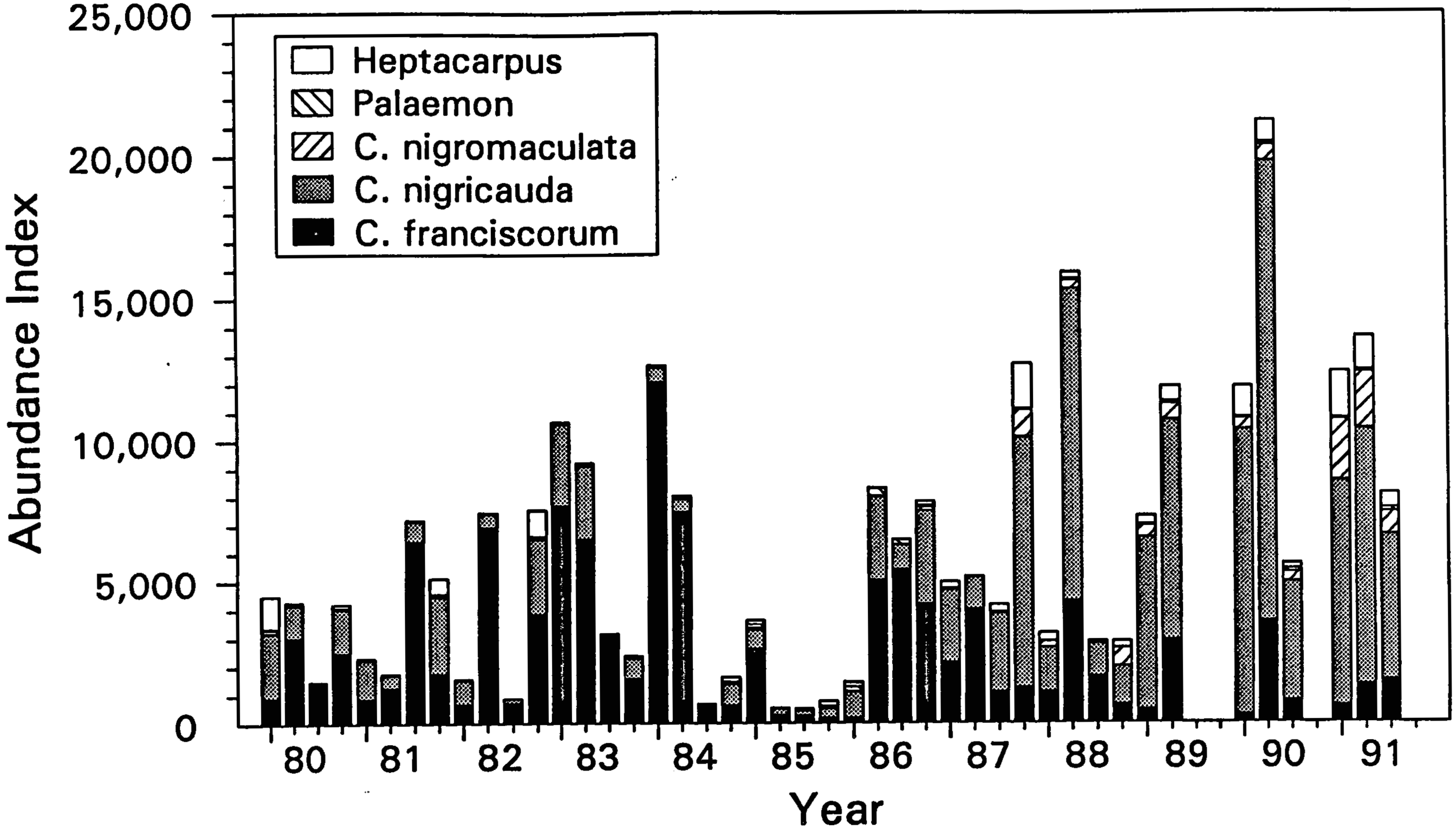


Figure 14. Quarterly abundance indices for the major species of shrimp in South Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

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

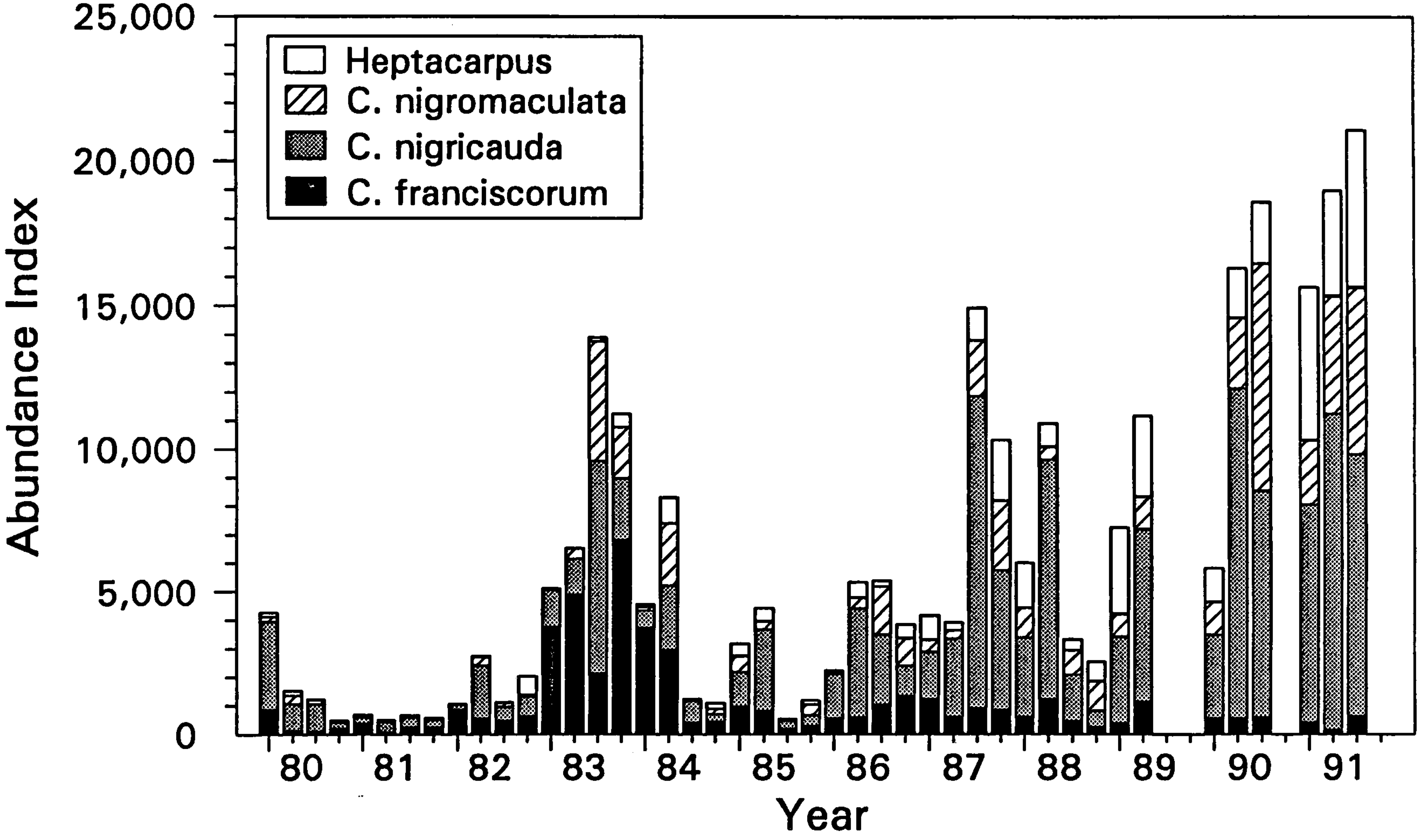


Figure 15. Quarterly abundance indices for the major species of shrimp in Central Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

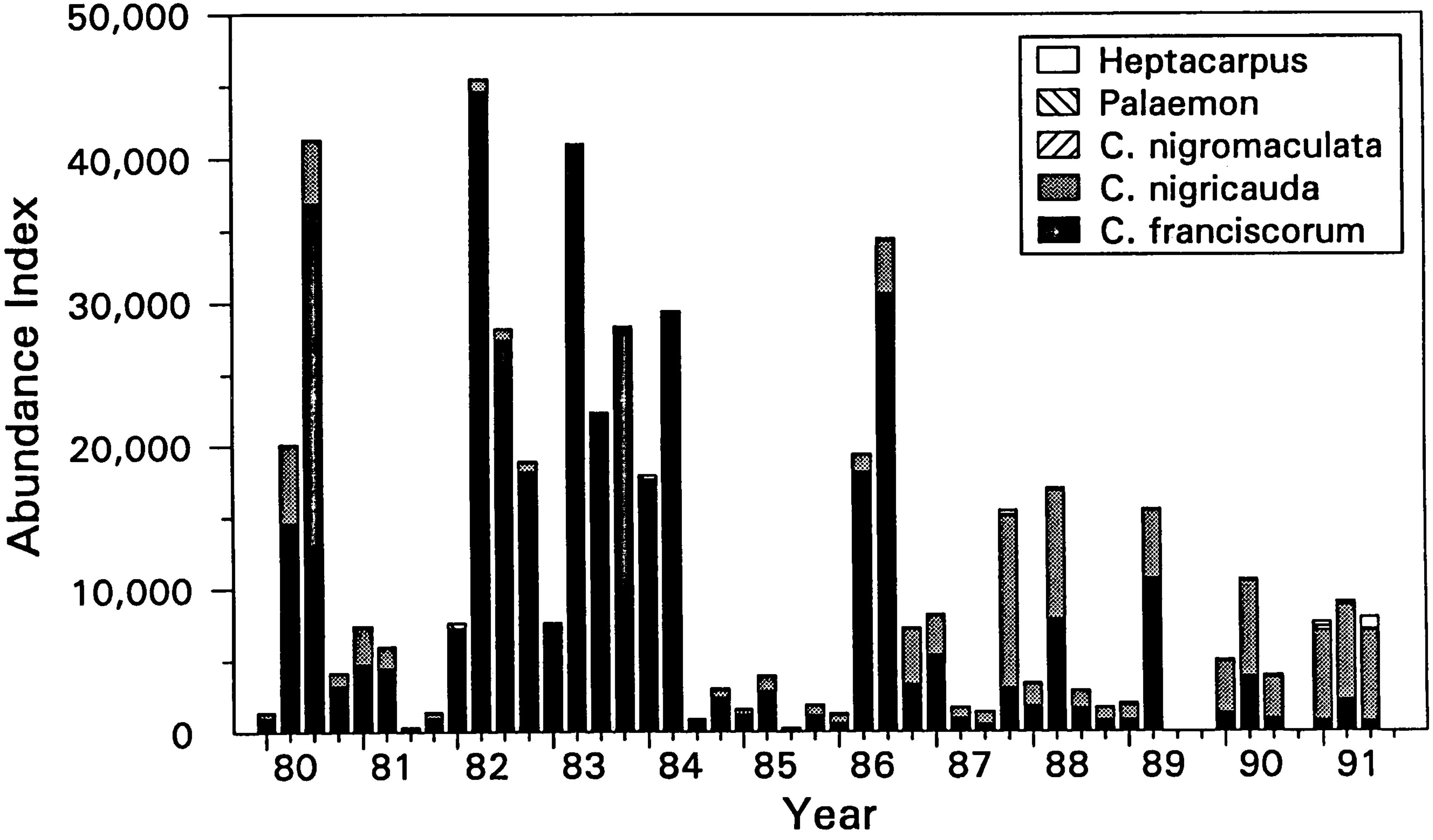


Figure 16. Quarterly abundance indices for the major species of shrimp in San Pablo Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

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

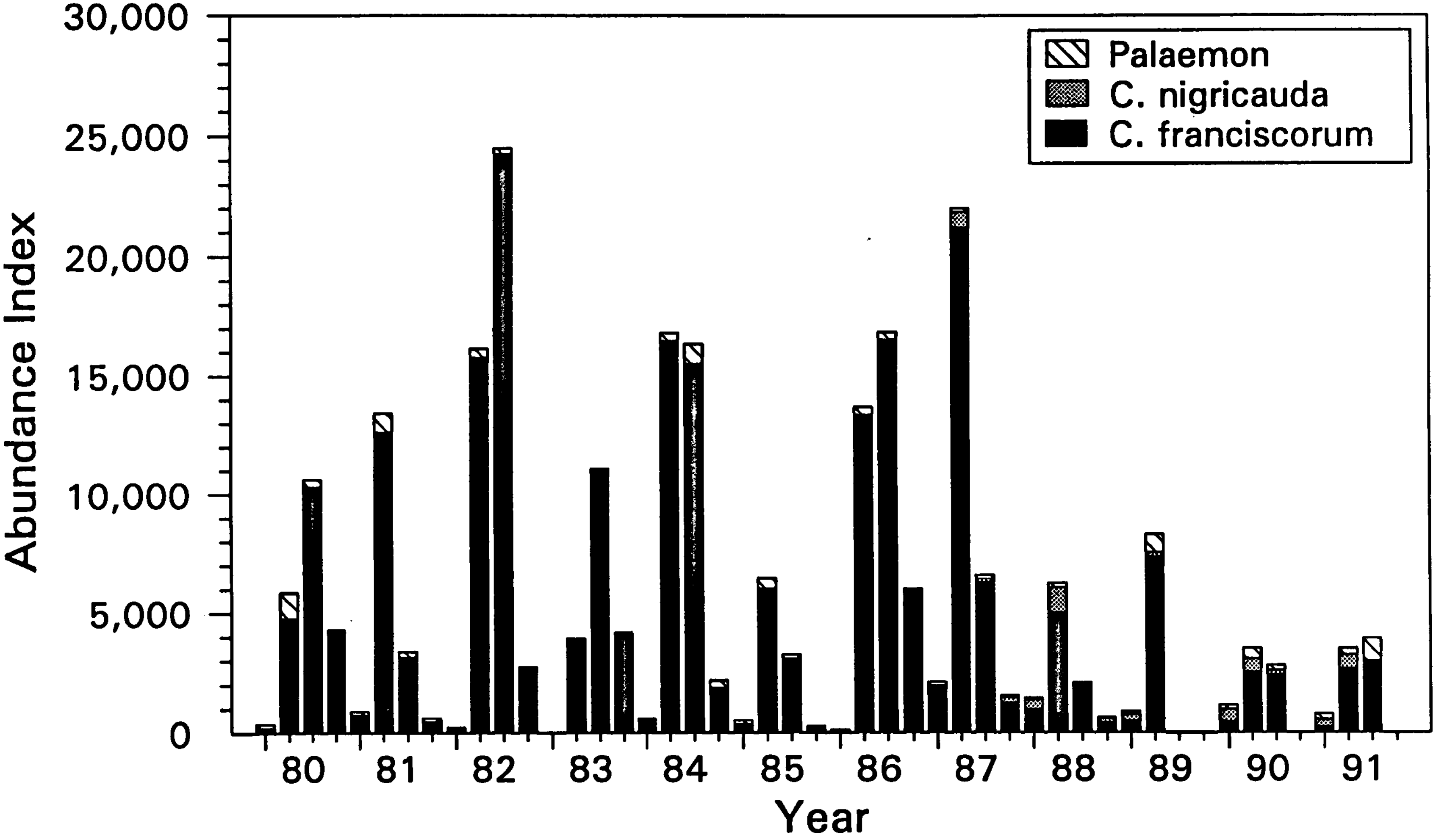


Figure 17. Quarterly abundance indices for the major species of shrimp in Suisun Bay, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

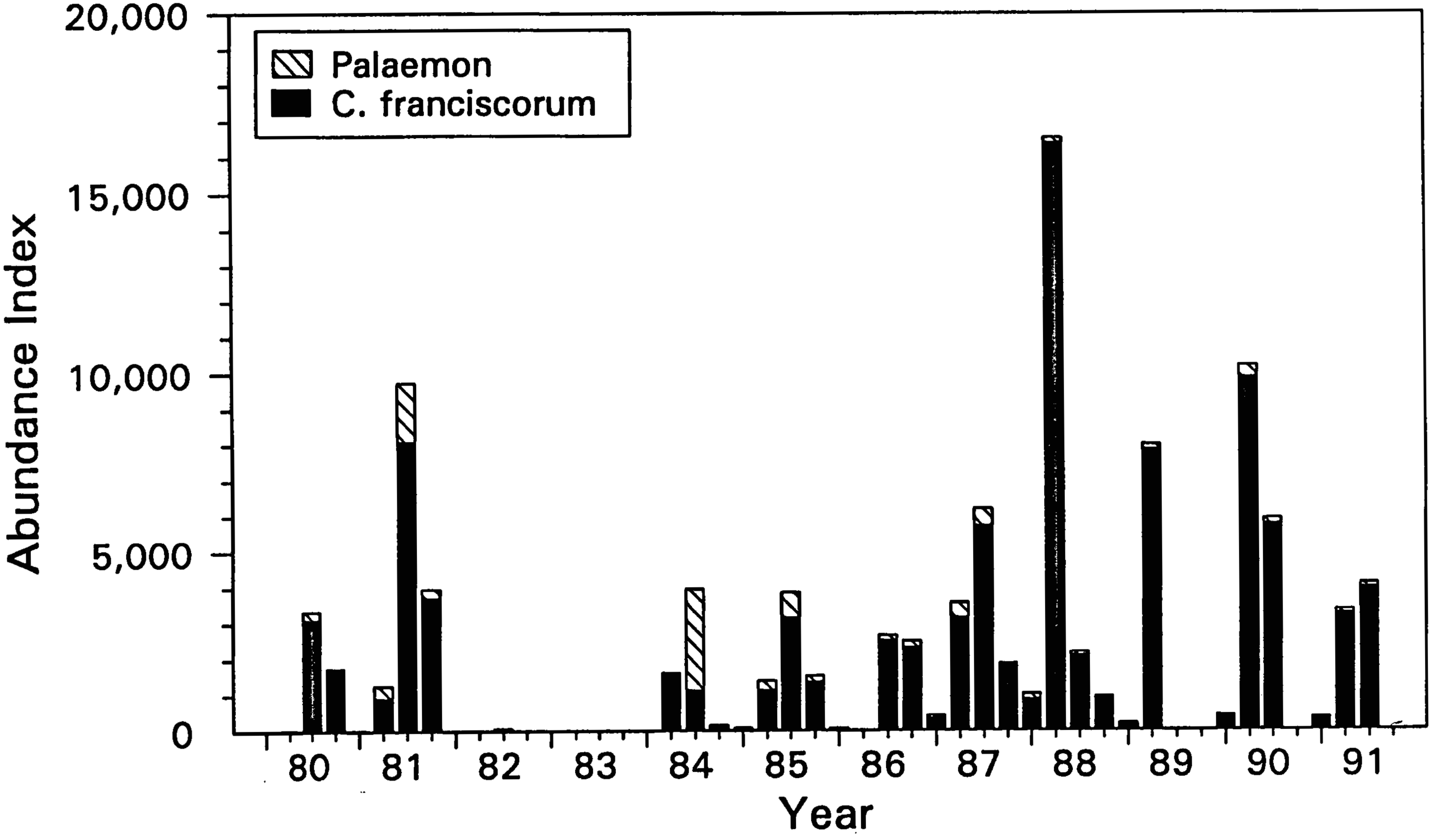


Figure 18. Quarterly abundance indices for the major species of shrimp in the West Delta area, 1980-1991. See Figure 13 for definition of quarters and data gaps. Note that this type of plot is not appropriate for comparison of total shrimp abundance between embayments.

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.

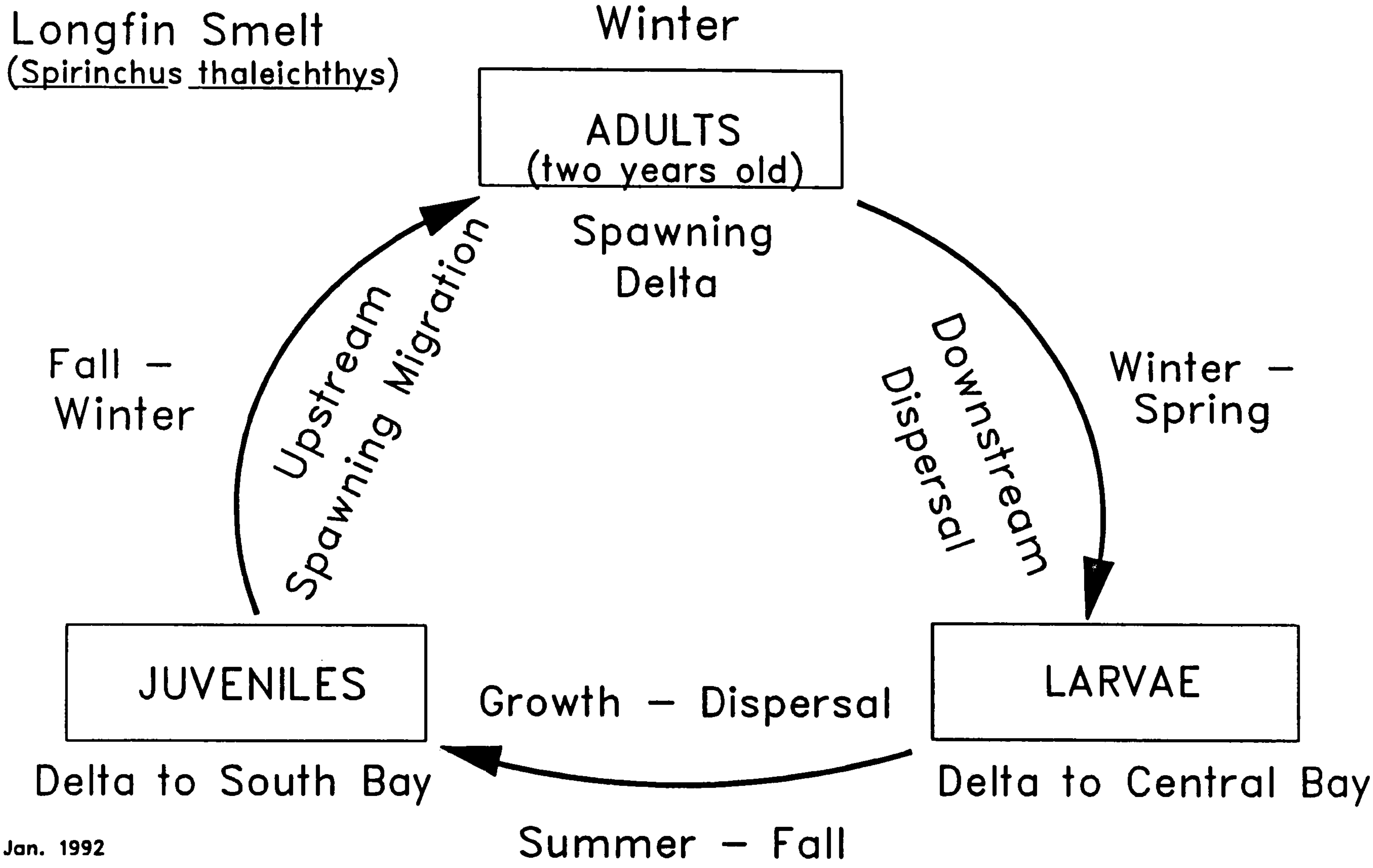


Figure 19. Longfin Smelt Life Cycle.

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

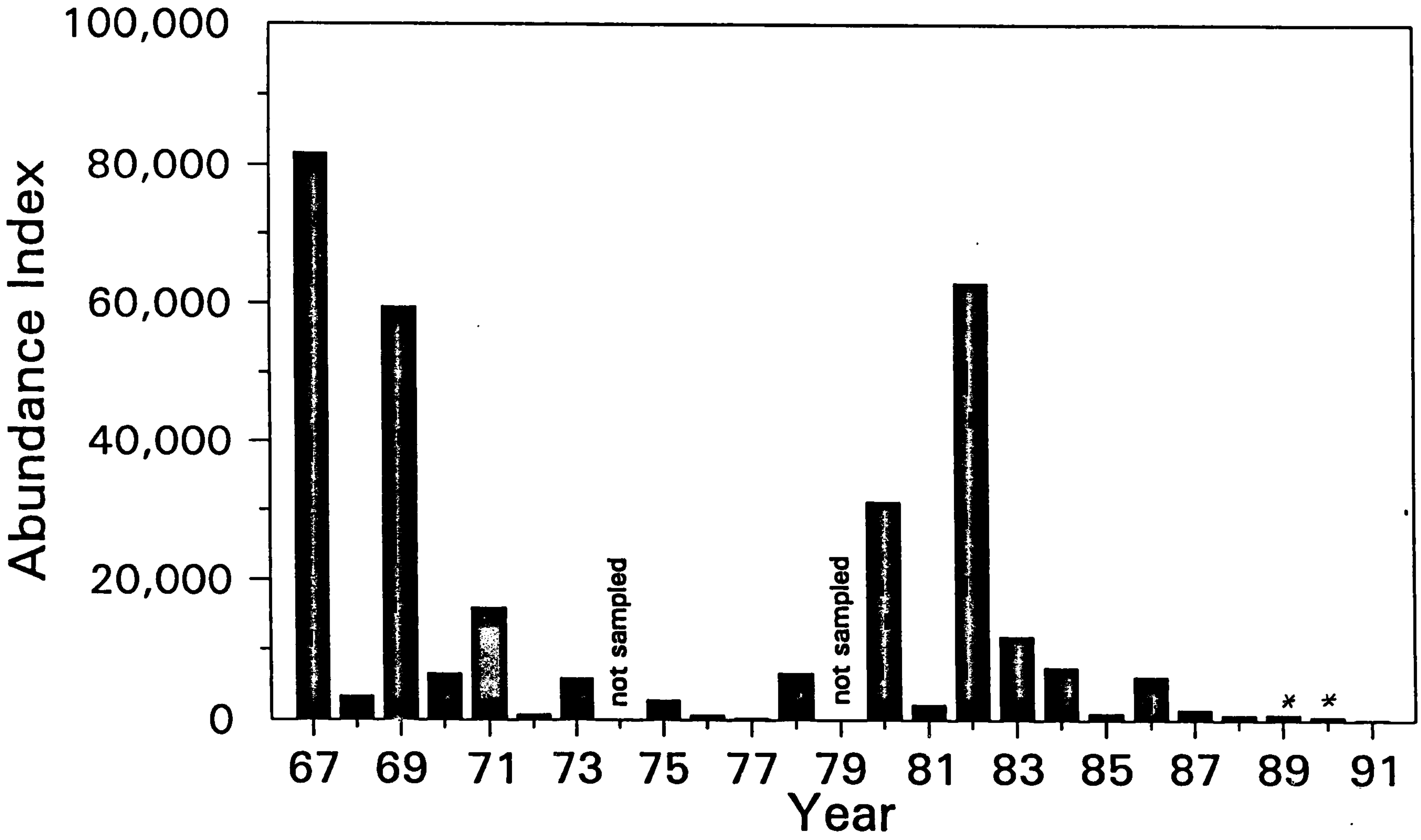


Figure 20. Longfin smelt annual abundance in CDFG Striped Bass Fall Midwater Trawl Survey sampling from 1967 to 1991. No sampling was done during 1974 or 1979. * data incorrect, see Appendix 2, page 96.

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.

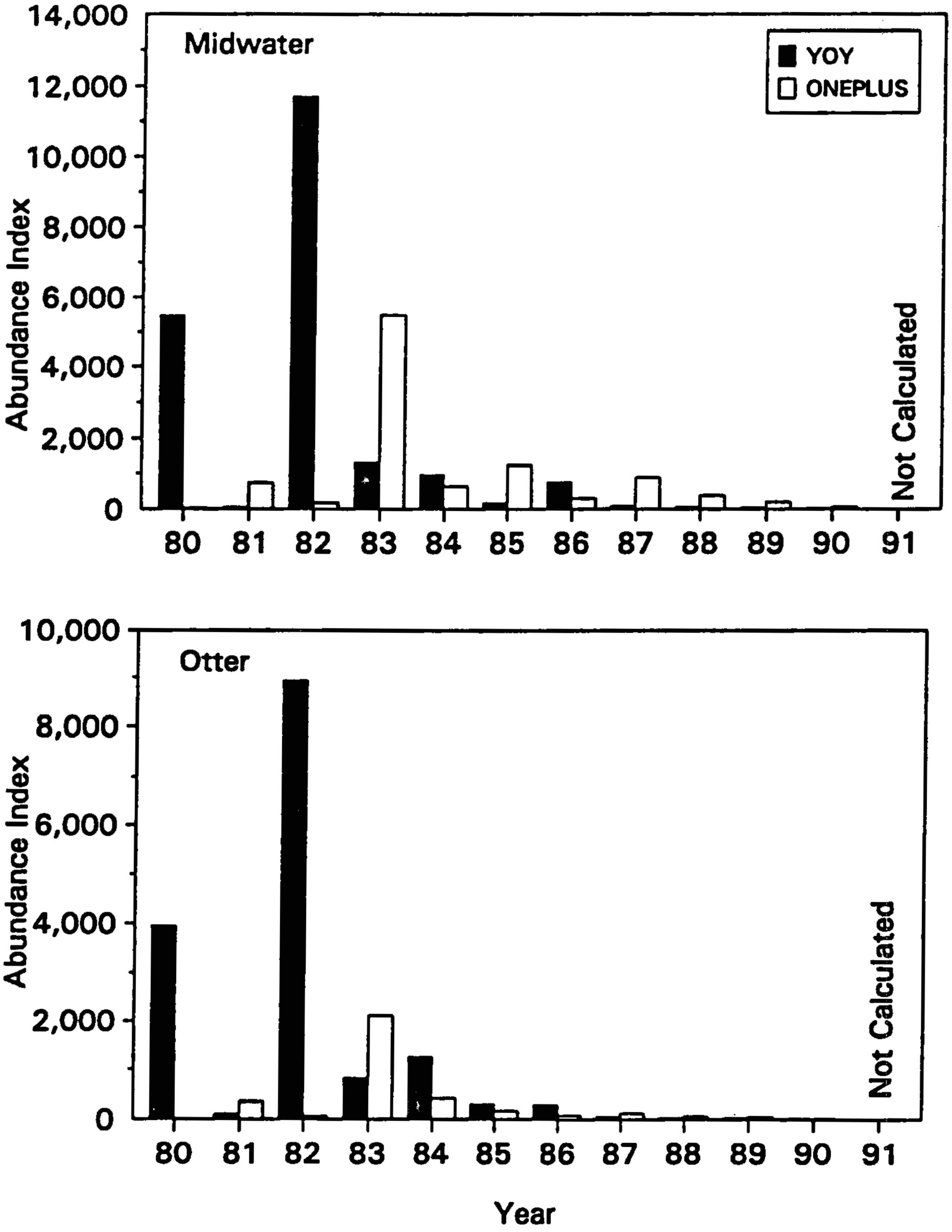


Figure 21. Longfin smelt annual abundance in CDFG Bay Study sampling. Abundance for both Midwater and Otter trawls separated into young-of-the-year (YOY) and one-year-old (ONEPLUS) individuals. Annual abundance indices were based on a May through October sampling period for YOY and February through October period for ONEPLUS fish, except in 1989 when the sampling period for both age groups ended in August.

In the present analysis a biological rationale was used to determine the most critical outflow period for longfin smelt. The February through May outflow period was selected as the most critical period, because most longfin smelt larvae begin feeding and complete fin development within this time frame. It is generally believed that for pelagic species the highest mortality occurs immediately after yolk-sac absorption during first feeding. Furthermore, until fin development is completed feeding efficiency and predator avoidance are reduced.

Table 9. Coefficient of determination values from the relationships between Log_{10} Fall MWT Longfin Smelt abundance and Log_{10} selected outflow periods.

Outflow Period	Coefficient of Determination
December-June	0.816
December-May	0.806
January-June	0.799
January-May	0.788
February-June	0.756
February-May	0.740
March-June	0.736
March-May	0.717

The present model of longfin smelt abundance uses the relationship between $\log_{10}$ of the Fall MWT Survey longfin smelt abundance index and $\log_{10}$ average February through May monthly outflow at Chipps Island ($r^2 = 0.740$, $p< 0.001$, Figure 22). It was hypothesized that this relationship resulted from increased larval dispersal and volume of nursery habitat produced by increased freshwater outflow.

Longfin smelt larvae and young juveniles are pelagic and their temporal pattern of abundance closely approximates that of the annual peak in outflow (Figure 23). Average

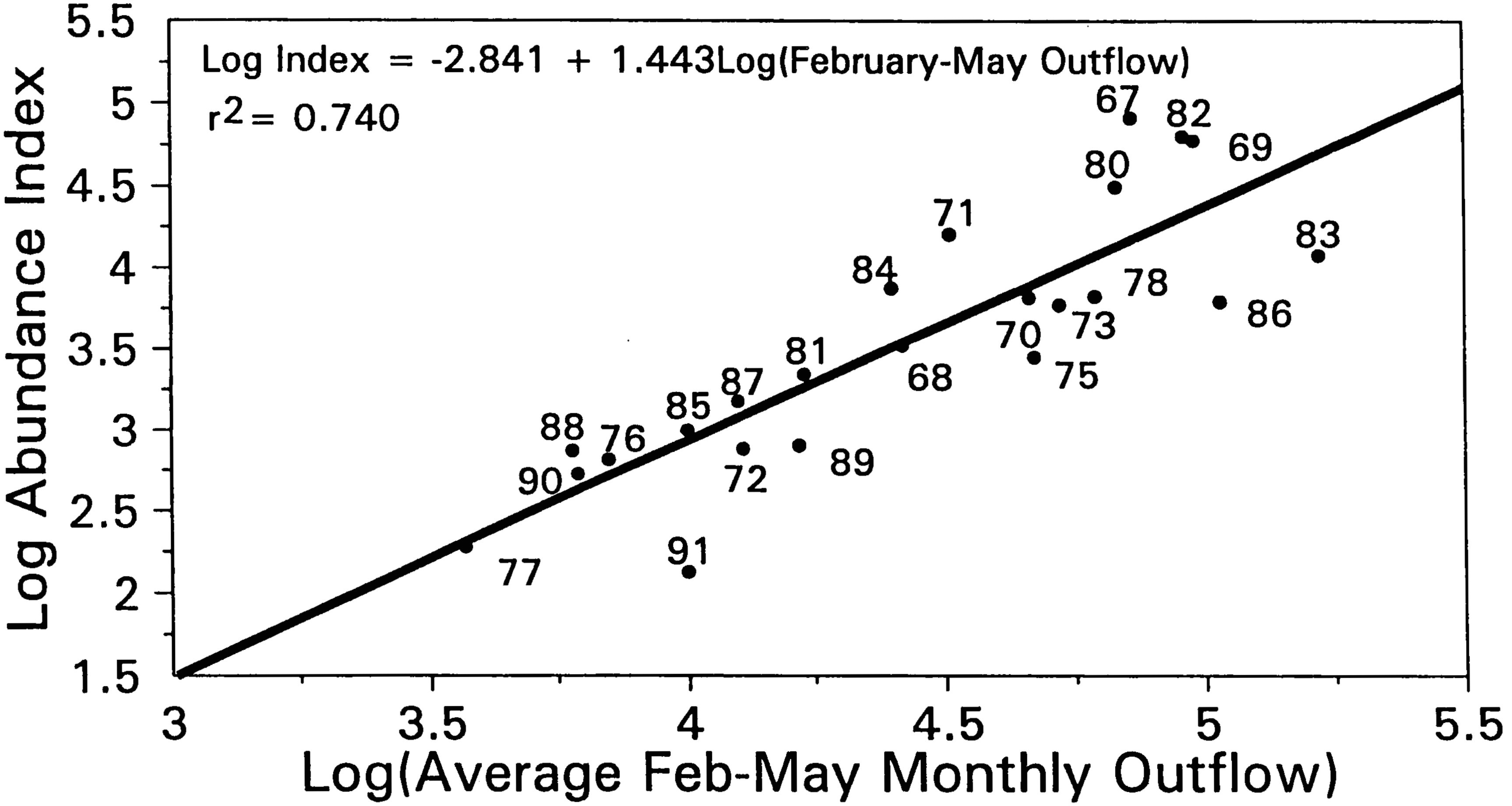


Figure 22. Relationship between the $\log_{10}$ of the average February through May outflow at Chipps Island in cubic feet per second and the $\log_{10}$ of the CDFG Striped Bass Fall Midwater Trawl longfin smelt abundance index.

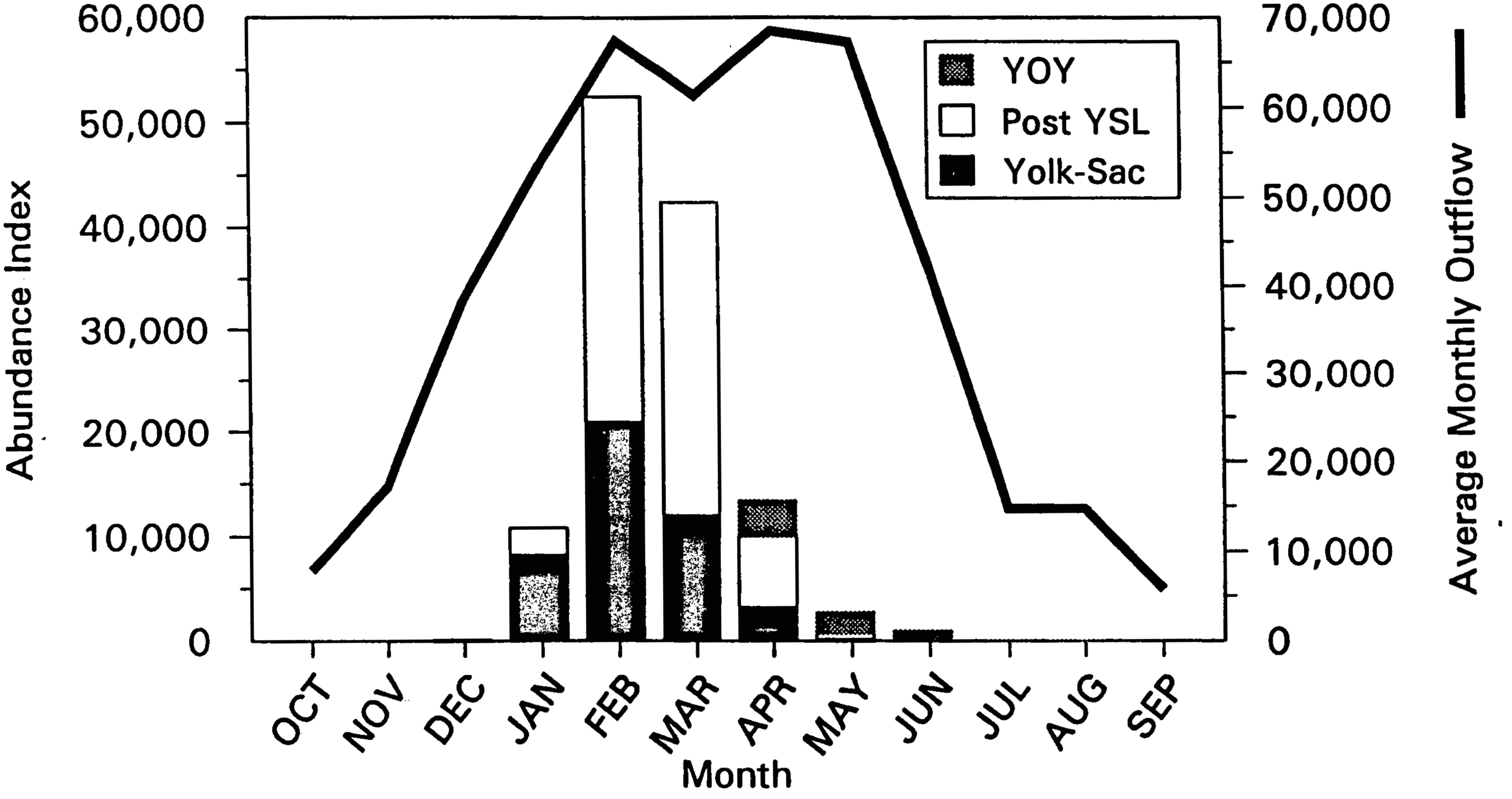


Figure 23. Average monthly abundance index of yolk-sac and post yolk-sac larval, and young-of-the-year (YOY) longfin smelt collected in the CDFG Bay Study plankton net between 1980 and 1988, plotted against the average monthly unimpaired outflow for the years between 1922 and 1978.

monthly unimpaired flows were plotted to represent the general annual pattern of outflow under which longfin smelt evolved. A limited number of depth stratified plankton samples collected with the Tucker trawl in 1990 indicated that the smallest larvae (6 - < 12 mm TL) were present in the surface layer of water, whereas larger larvae and small juveniles were located at mid-depths and toward the bottom (Figure 24). In 1992, Tucker Trawl sampling stratified by depth and tide showed that all sizes of larvae were most strongly associated with the surface layer ($p < 0.025$, ANOVA) and that this distribution did not change between flood and ebb tides ($p > 0.25$, ANOVA). Small juveniles were most often at mid- and bottom depths, but did not show a statistically significant avoidance of the surface layer ($p > 0.25$, ANOVA), and like the larvae there was no evidence of a vertical migration with the tides ($p > 0.25$, ANOVA). These data indicate that longfin smelt did not vertically migrate in the water column to maintain their position longitudinally in the river.

By remaining near the surface larval longfin smelt would be very susceptible to downstream transport by high outflows. Any larvae or juveniles distributed deeper in the water column would be more likely to maintain their position or be transported upstream by outflow induced gravitational currents. If larval stages are transported by outflow events, but juveniles remain in place, then successive flow events during the February through May period would tend to disperse longfin smelt throughout the Delta and into adjoining embayments. Such a dispersal mechanism would likely result in longfin smelt being distributed over a greater proportion of the estuary as outflow increased during the larval period. Greater dispersal should reduce intra-specific competition and perhaps allow larvae access to a greater food supply, which would likely increase abundance as a function of outflow.

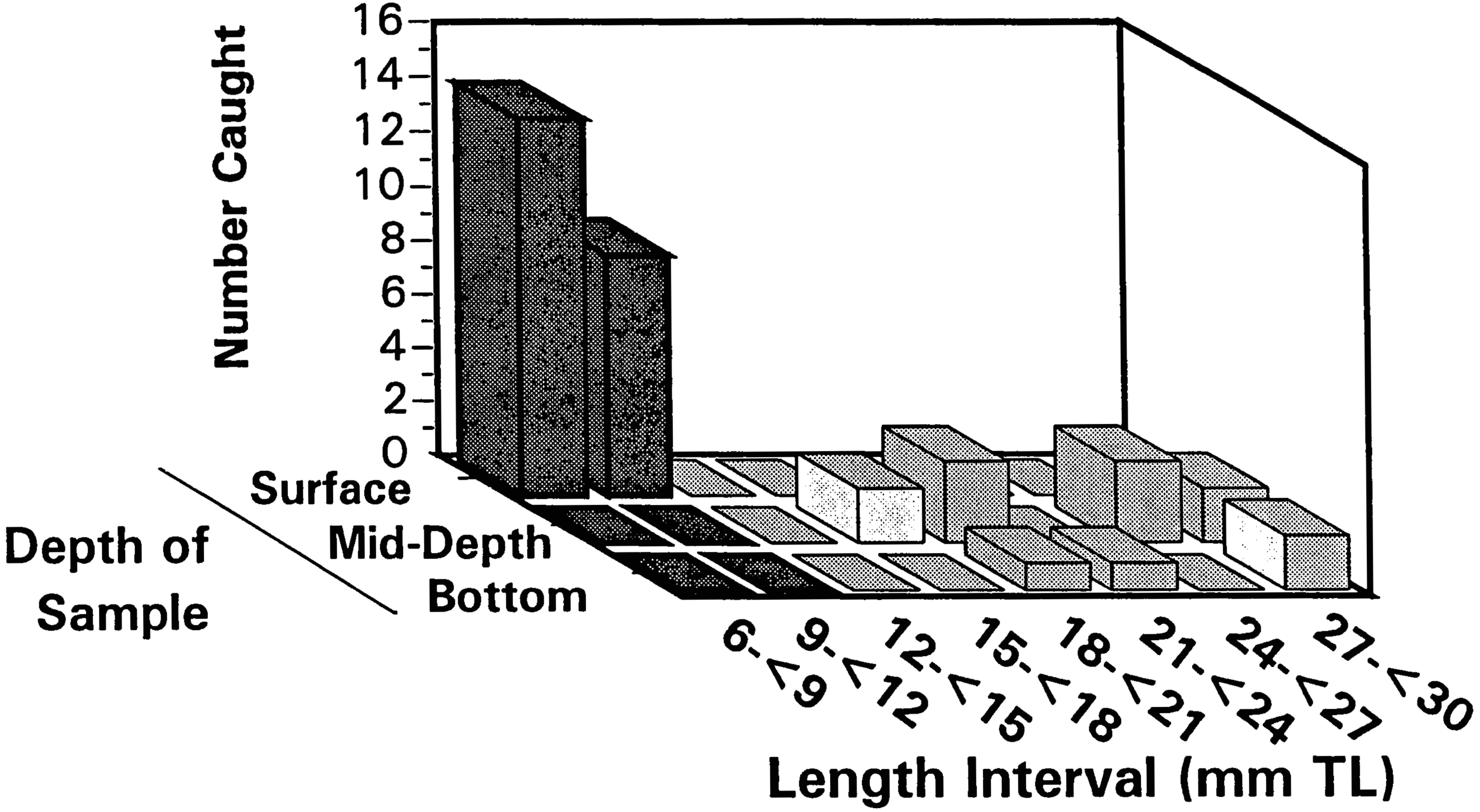


Figure 24. Depth distribution by length interval of larval and small juvenile longfin smelt collected in the Tucker Trawl during April 1990 while sampling between Carquinez Strait and the lower Sacramento River. Surface samples were collected about 2 m below the surface, mid-depth at 10 m below the surface and bottom samples at 16 m, 2 m above the bottom.

Larval longfin smelt distribution data indicated that freshwater outflow events did result in increased downstream transport of larvae (Figures 25a and 25b). High outflows of 1980, 1982, 1983, 1984, and 1986 resulted in a major portion of the larval smelt population being transported to San Pablo Bay. During the low outflow years of 1981, 1985, 1987, and 1988 most of the larvae remained upstream of San Pablo Bay (Figure 25b). Larval and juvenile longfin smelt distributions were similar in most years with juveniles present in San Pablo Bay and downstream during high outflow years, but not distributed downstream of Suisun Bay during low outflow years with the exception of 1985 (Figure 26).

Creation of brackish water habitat also may be a mechanism by which outflow influences the abundance of longfin smelt. It was assumed that most of the mortality occurred at first feeding (post-yolk sac larvae) and that by 50 mm fork length (FL) mortality had stabilized. Since these small juveniles inhabited a broader salinity range than post-yolk sac larvae, using bottom salinity data measured at the point of capture for juvenile smelt established an the upper salinity limit of critical nursery habitat that completely included the habitat of post-yolk sac larvae.

Approximately 90 percent of juvenile longfin smelt < 50 mm FL from Bay Study plankton sampling were collected over bottom salinities less than 18 ppt. Critical nursery habitat was then defined as the volume of water represented by each Bay Study sampling station for which bottom salinity measurements were less than 18 ppt during the months of March through June (produced by February-May outflow). The volumes of water with bottom salinities falling within this range during the March through June period were then summed for each year, log transformed and compared to the resulting $\log_{10}$ Fall MWT Survey longfin smelt abundance index (Figure

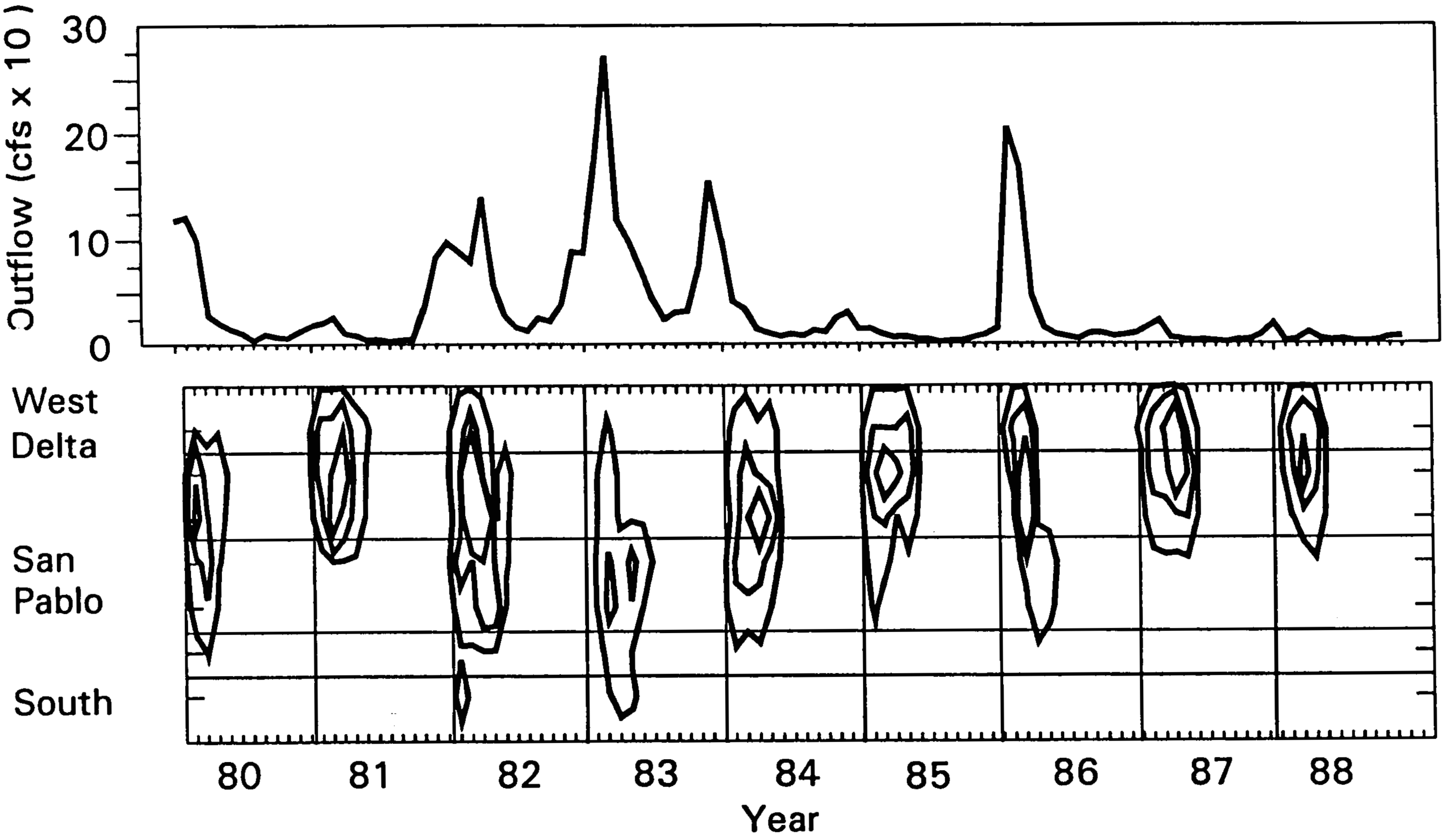


Figure 25. a. Average monthly outflow at Chipps Island (cfs x 10000) from 1980 through 1988. b. topographic representation of the geographical (vertical axis) and temporal (horizontal axis) longfin smelt larval distribution in San Francisco Bay between 1980 and 1988. Contour line represent average larval densities of 50, 150, and 500 larvae per 1000 m^3 of water filtered by the plankton net.

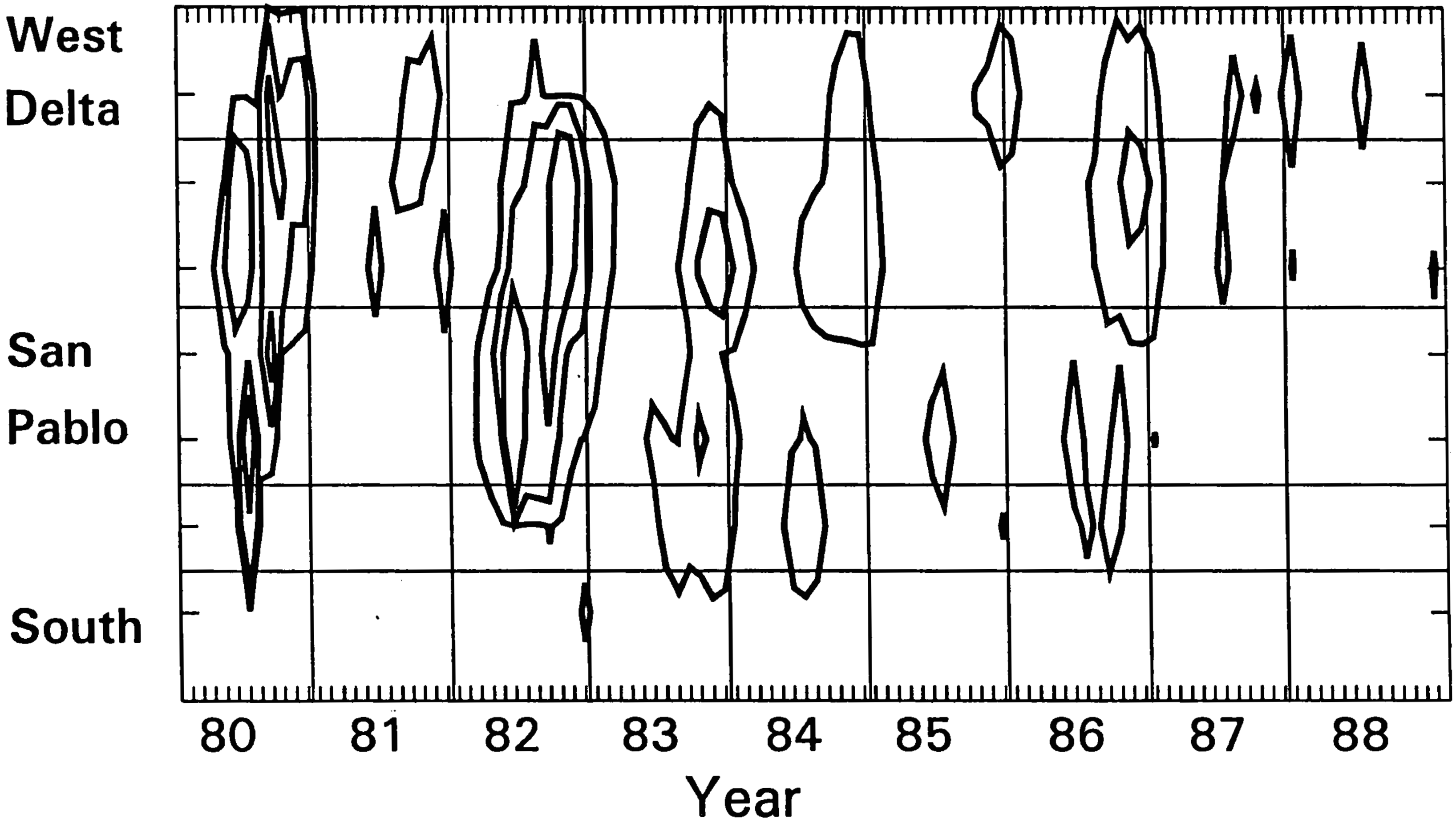


Figure 26. Topographic representation of longfin smelt young- of-the-year (juvenile) geographical (vertical axis) and temporal (horizontal axis) distribution in the Bay from 1980 to 1988. Contour lines represent 3.5, 30 and 150 young of the year longfin smelt per 10,000 m^3 of water.

27a). This relationship was positive and significant ($r^2 = 0.750$, $p < 0.05$), suggesting that increasing habitat volume does have a positive effect on longfin smelt abundance. Log transformed habitat volume was directly related to log transformed freshwater outflow ($r^2 = 0.917$, p<0,05, Figure 27b).

Strong positive outflow-abundance relationships that included December and January outflow (during the start of spawning, Table 9) suggest that freshwater flow may have a positive influence on spawning success. Improved spawning success with increased outflow could result if outflow improved spawning conditions, increased the size or quality of the spawning area, synchronized spawning migrations allowing easier mate location, or improved the chances that larvae would hatch under favorable conditions.

Other factors associated with outflow that may affect longfin smelt abundance during a broader time period include: 1) "predation on young fish may increase during low flow years because the water tends to be clearer and the young are more concentrated in smaller volumes" (Stevens and Miller 1983); 2) outflow may increase nutrients that form the base of the food chain (Sutcliffe 1972) as well as the abundance of <u>Neomysis</u> <u>mercedis</u> (J. Orsi, pers. comm.), a major food item of longfin smelt (Moyle 1976); 3) as flows decrease, losses of fish increase at CVP and SWP facilities and other irrigation diversions (Stevens and Miller 1983).

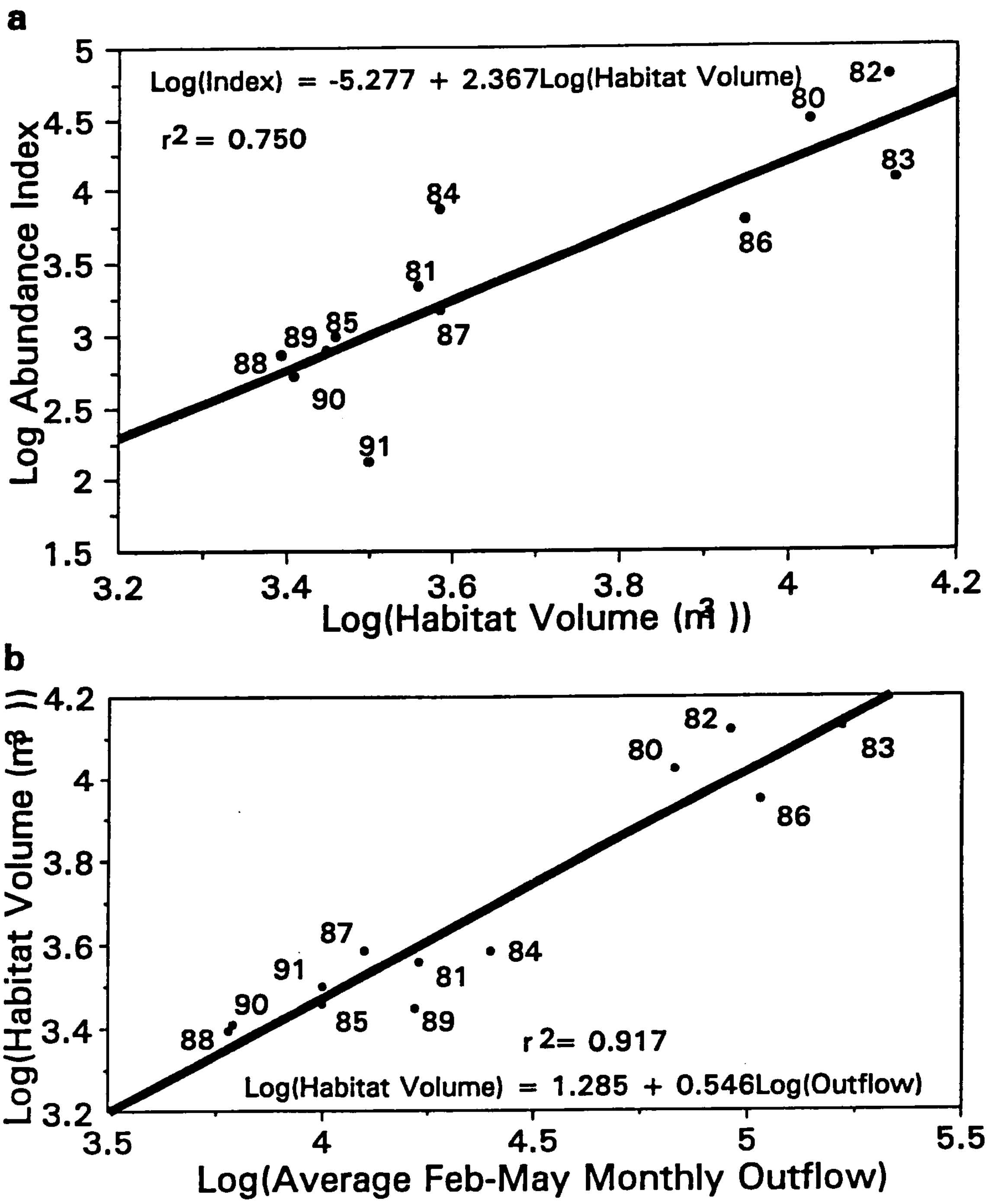


Figure 27. a. Longfin smelt abundance-habitat relationship. CDFG fall midwater trawl longfin smelt abundance index plotted against the volume of water represented by Bay Study sampling stations with bottom salinity < 18 ppt during the months of March through June. b. Relationship between longfin smelt habitat index and February-May average monthly outflow at Chipps Island.

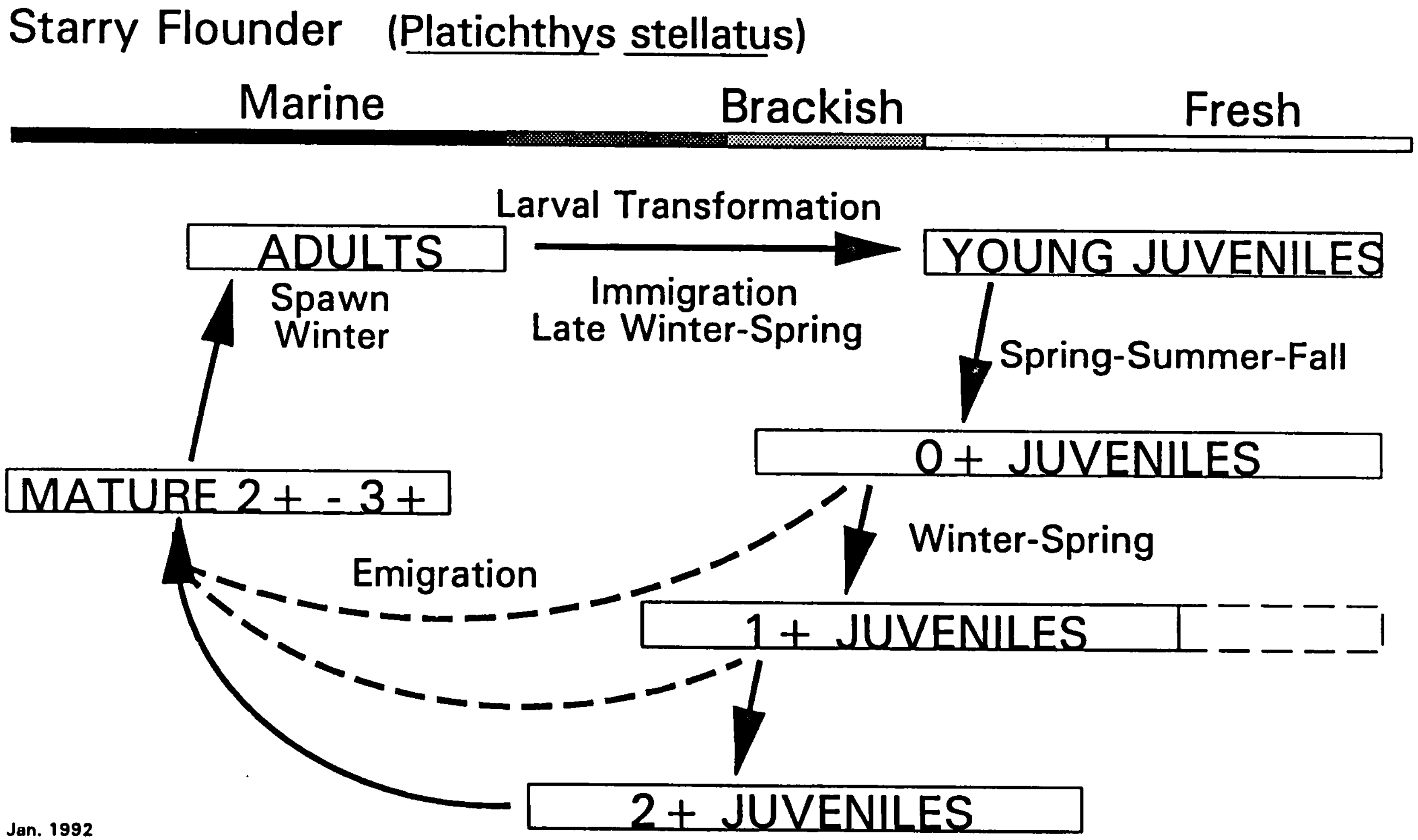
Starry Flounder

Introduction

Starry flounder (Platichthys stellatus) are native to San Francisco Bay. They range from Santa Barbara, California northward to Arctic Alaska, then southwest to the Sea of Japan (Miller and Lea 1972). Starry flounder adults inhabit shallow coastal marine water, whereas juveniles seek out fresh to brackish water areas of bays and estuaries for nursery areas (Orcutt 1950, Moyle 1976, Wang 1986). Emmett et al. (1991) state that juvenile starry flounder appear to be estuarine-dependent. Then, by virtue of its size, San Francisco Bay should be the most important nursery area for starry flounder in California.

The starry flounder life cycle (Figure 28) begins with spawning which occurs between November and February based upon data collected from Monterey Bay by Orcutt (1950). Spawning appears to take place in shallow coastal marine areas near the mouths of rivers and sloughs (Orcutt 1950, Garrison and Miller 1982, Wang 1986), but some researchers have suggested that spawning may have occurred in the San Francisco Bay (Radtke 1966, Moyle 1976). No ripe female starry flounder were collected in San Francisco Bay during winter surveys in the mid-1980s (B. Spies pers. comm.), nor were any mature flounder, eggs or yolk-sac larvae collected by Wang (1986) from San Francisco Bay between 1978 and 1982.

Eggs and larvae are pelagic and found mostly in the upper water column (Orcutt 1950, Wang 1986). Starry flounder larvae are approximately 2 mm long at hatching and settle to the bottom about two months after hatching at approximately 7 mm standard length (SL) (Policansky and Sieswerda 1979, Policansky 1982). Larvae depend upon favorable ocean currents to keep them near or transport them to their estuarine nursery areas prior to settlement. Transforming larvae and the smallest juveniles migrate from the coast to shallow brackish or freshwater where they rear


Starry Flounder (*Platichthys stellatus*)

Jan. 1992

Figure 28. Starry flounder life cycle.

for one or more years (Haertel and Osterberg 1967, Wang 1986, IESP 1991).

As they grow, juvenile starry flounder move to water of higher salinity, but appear to remain in the Bay through at least their second year of life (IESP 1991) as was found in the Columbia River Estuary (Haertel and Osterberg 1967). Most male starry flounder mature by the end of their second year of life (220-276 mm SL), whereas females mature at age 3 or 4 (239-405 mm SL) (Orcutt 1950). During the late fall and winter, mature starry flounder probably migrate to coastal waters to spawn. Some adult starry flounder returned to the Bay for feeding and were most common from late spring through early fall (Ganssle 1966).

Starry flounder were once the most common flatfish species found in San Pablo Bay and were reported to have provided excellent fishing there prior to 1900 (Skinner 1962). As recently as the early 1970s starry flounder were very common in San Pablo Bay (D. Kohlhorst, pers. comm., CDFG Marine Res. unpub. data). Starry flounder are still an important component of the recreational fishery in and near San Francisco Bay (Baxter 1980, CDFG Marine Res. unpub. data). Baxter (1980) states that starry flounder are the most common flatfish taken by sportsmen in northern California and that they are excellent eating. Starry flounder were the second most common flatfish and one of the most commonly caught fish in general reported for the Berkeley and San Francisco Muni piers between 1957 and 1961 (Miller and Gotshall 1965).

Starry flounder are a moderately important part of the commercial fisheries from California to the Bearing Sea (Emmett et al. 1991). Commercial landings of starry flounder in the San Francisco Bay Area between 1960 and 1991 have varied between a maximum of 486 thousand pounds in 1980 to a minimum of 40 thousand pounds in 1990 (D. Thomas, pers.

comm.). Although they are a small component of the flatfish catch (2 percent by weight) they are second only to California halibut in price per pound at the dock (CDFG Marine Res. unpub. data).

Starry flounder are part of the prey of marine mammals (Jeffries et al. 1984) and piscivorous birds (Emmett et al 1991)). They are also occasional prey of striped bass in both fresh and marine waters of the San Francisco Bay/Estuary (Stevens 1966, Thomas 1967).

The longest historical record of starry flounder numbers in San Francisco Bay comes from the Commercial Passenger Fishing Vessel (CPFV) logs. CPFV log data from 1964 to 1990 with the exception of 1979 and 1981-1983 were reviewed for starry flounder catch. Most of the starry flounder catch occurred in San Pablo and Suisun Bays. Only the catch data for San Pablo Bay was analyzed for long-term trends due to gaps in the Suisun Bay data available. Catch was converted to average catch per angler hour during the months of January through May and multiplied by 10,000 to create whole numbers (Figures 29a and 29b, Appendix 3).

The increase in average catch per hour and total fishing hours between 1964 and 1966 (Figure 29a) appeared to be a response to the successful use of shrimps Crangon spp. and Palaemon macrodactylus as sturgeon bait beginning in 1964 (Kohlhorst et al. 1991). Fishing effort (i.e. total hours) dropped off before the peak in average catch per hour of starry flounder suggesting that much of the effort was for sturgeon or another species (Figure 29a). Beginning with 1976, the total starry flounder catch and catch per hour dropped rapidly and, except for a brief period in the mid-1980s, has not recovered to anywhere near previous levels (Figure 29b). Although effort through the 1980s returned to levels near those of the mid-1970s (Figure 29a), catch per hour and total catch did not (Figure 29b). These

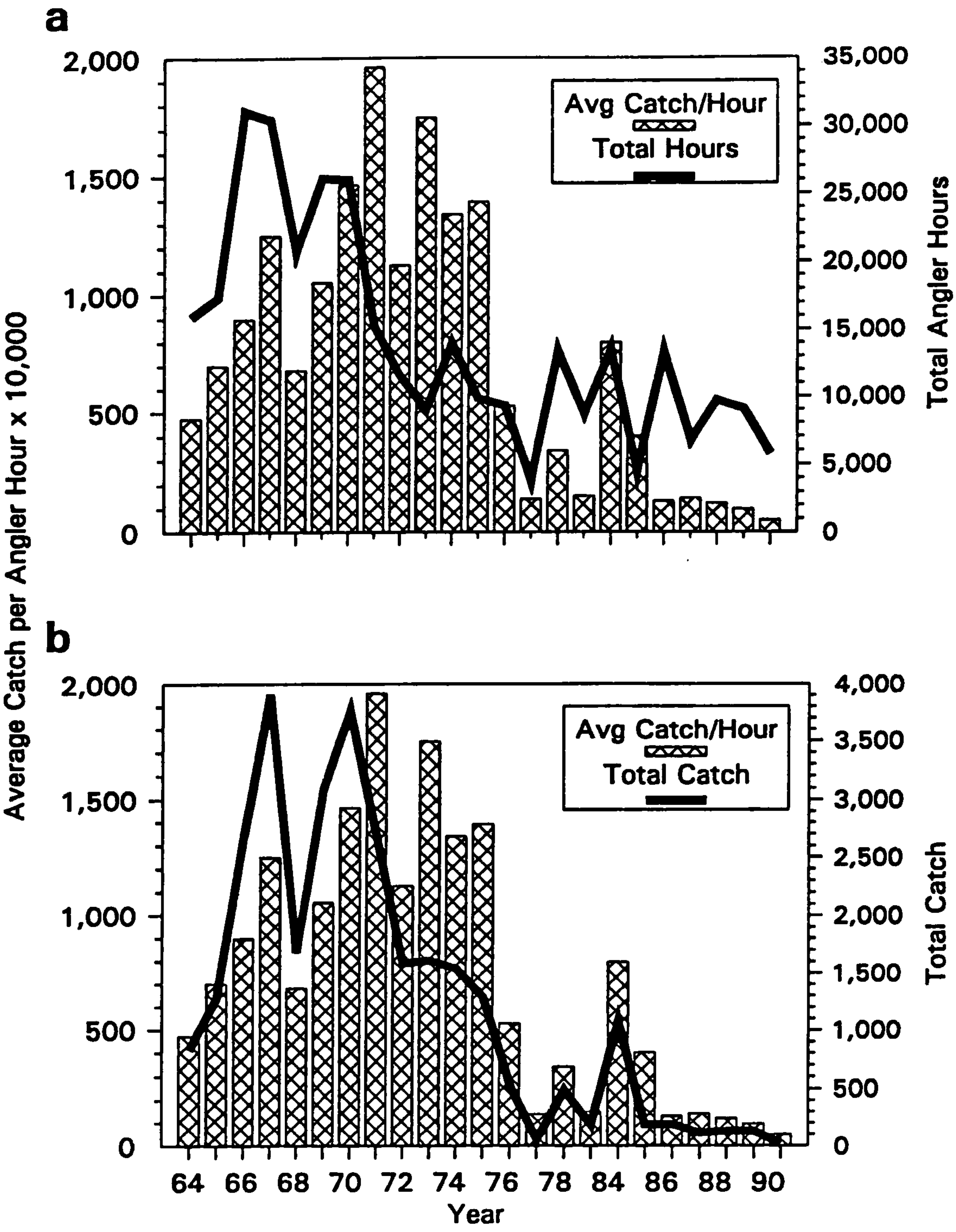


Figure 29. Starry flounder catch and fishing effort in San Pablo Bay based on Commercial Passenger Fishing Vessel log data from 1964-1990. A January through May period was use to calculate annual data. Data for the years 1979, and 1981-1983 were not available during analyses, nor were they plotted.

data suggest that numbers of starry flounder vulnerable to this fishery have declined in the Bay since the early to mid-1970s. This may have resulted from an over harvest in the Bay, an unfavorable change in in-bay conditions (i.e. reduced freshwater outflow, lower food base, increased pollution etc.) causing emigration, a reduction in recruitment to the Bay or some combination of these factors.

Commercial starry flounder landings for the San Francisco Bay Area (Figure 30, Appendix 3) showed an increase between 1975 and 1977; at the same time average catch per hour of starry flounder from San Pablo Bay CPFV logs dropped off sharply. Most starry flounder in the CPFV catch were probably two years old or older (> 200 mm FL). If these fish moved offshore most would have been recruited into the commercial fishery within their first or second year in the ocean (see Orcutt 1950). The patterns of catch for CPFV in San Pablo Bay and the commercial catch landed in the San Francisco Bay Area suggest that older starry flounder left the Bay in the mid-1970s for some reason and became vulnerable to commercial fishing gear. This appears to indicate a real decline in abundance of older starry flounder within the Bay since the mid-1970s.

CDFG Bay Study starry flounder abundance indices showed a downward trend starting about 1983 (Figure 31). Although abundance has fluctuated upward somewhat in 1990 and 1991, overall abundance for both young-of-the-year (YOY) and one-year-old (ONEPLUS) starry flounder has been consistently low since 1986. Such continued low indices indicate that recruitment to and/or survival of starry flounder in the Bay has been very poor for the past five years.

Starry Flounder Model and Biological Support

In previous analyses using CDFG Bay Study 1980-1985 data (CDFG 1987) the relationship between young-of-the-year (YOY) starry flounder abundance and outflow was not

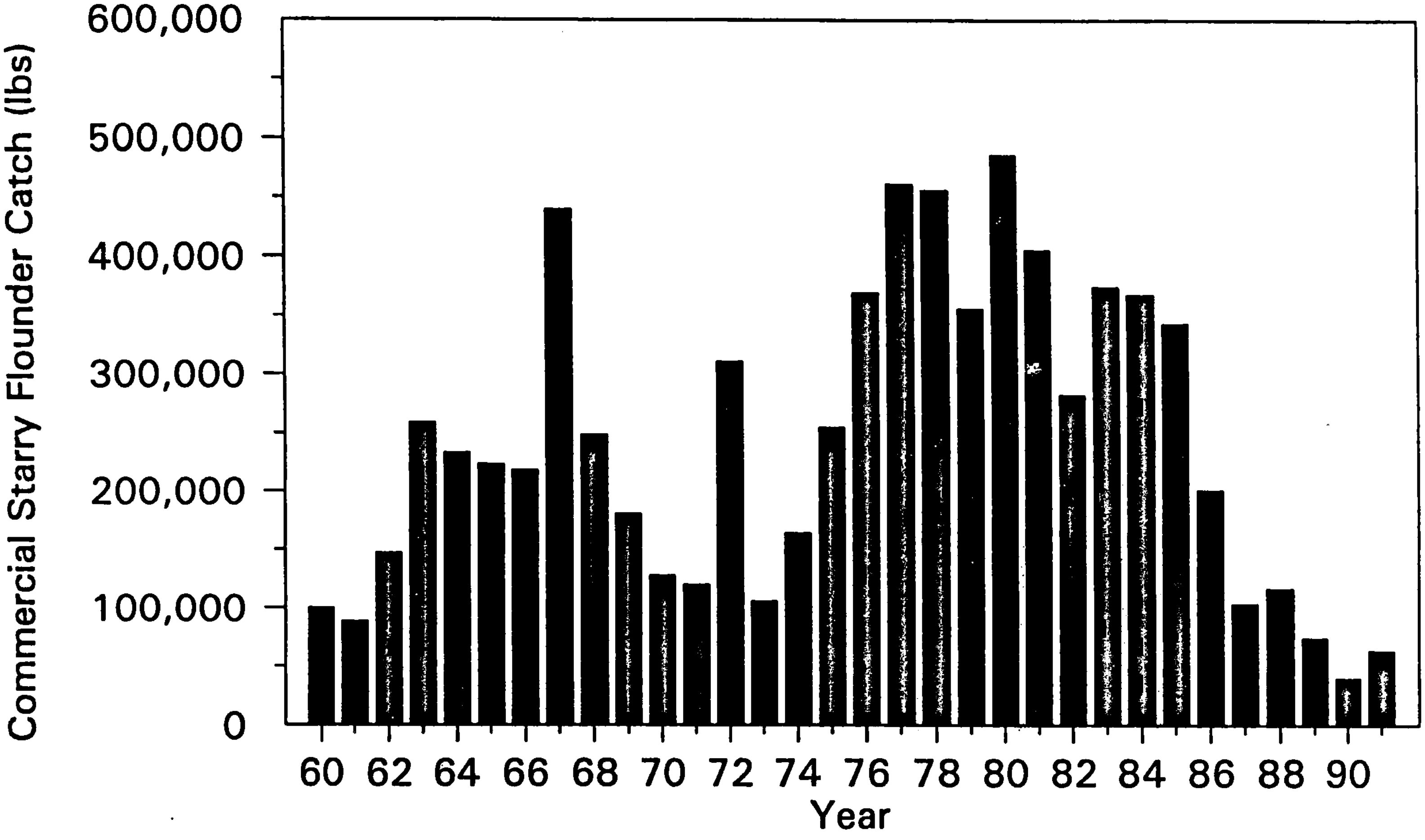


Figure 30. Annual total commercial landings of starry flounder in the San Francisco Bay Area (Pillar Point to Bodega Bay including ports within San Francisco Bay) in pounds from 1960 through 1991.

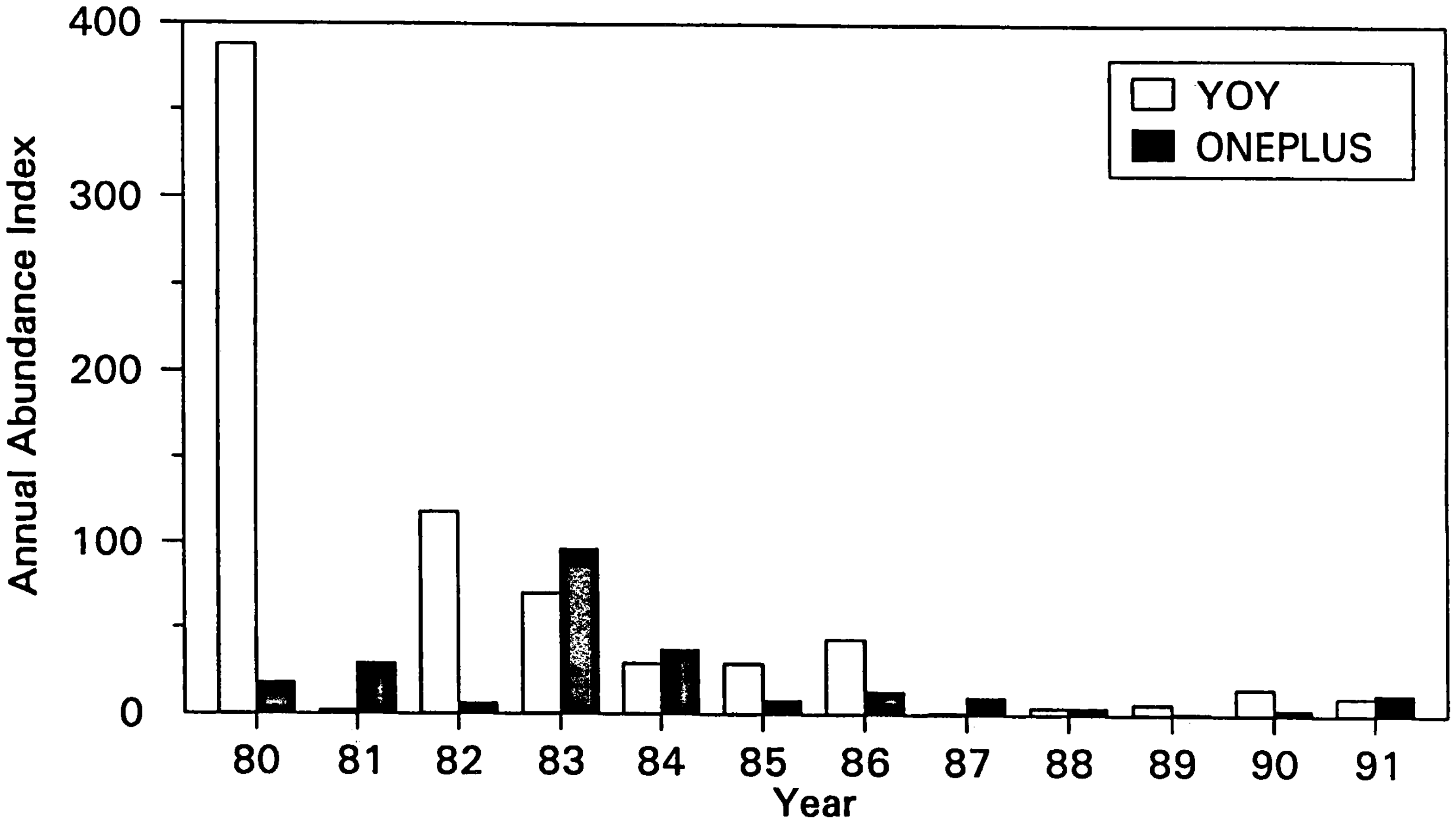


Figure 31. CDFG Bay Study starry flounder young of the year (YOY) and one year old (ONEPLUS) annual indices based upon otter trawl sampling from May through October and February through October for YOY and ONEPLUS fish, respectively. Data for 1989 represent sampling through August only for each age group. Data for 1991 are preliminary.

apparent with only six data points available. YOY starry flounder were frequently distributed upstream of the CDFG Bay Study sampling area (Radtke 1966, CDFG unpublished data), suggesting a potential bias in YOY abundance indices. Since YOY starry flounder select fresh and brackish water for nursery habitat, a greater proportion of this habitat will be upstream of the Bay Study sampling area in low outflow years than in high outflow years, which could result in a spurious correlation. The distribution of one-year-old (ONEPLUS) starry flounder appeared to be mostly within the Bay Study sampling area (IESP 1991). For this reason the February through May abundance index of ONEPLUS starry flounder was used as a less biased surrogate for the YOY index in more recent analyses. These ONEPLUS starry flounder indices were compared to outflow in the previous year to determine the relationship between outflow and abundance. Specifically, the abundance of ONEPLUS flounder in the Bay was hypothesized to be directly related their immigration success and early in-bay survival as transforming larvae and small juveniles during the spring of the previous year.

Analyses developed during 1991 compared ONEPLUS starry flounder abundance to outflow between December and May of the previous year, and resulted in a significant positive relationship ($r^2 = 0.537$, $p < 0.005$, Table 10). We hypothesized that freshwater outflow assisted spawners in locating the Bay, assisted larvae and juveniles in locating and immigrating into the Bay, and reduced salinities over shallow water areas to create nursery habitat.

Although earlier outflow periods showed stronger relationships with starry flounder abundance in the Bay (Table 10), Bay Study data indicated that the March through June outflow period was most critical. During this period most of the larval and juvenile immigration occurred

(Ganssle 1966, CDFG 1987). Also, we hypothesized that the size and location of shallow, brackish water, nursery habitat was most important for recently settled and small juveniles during this same period. Comparing the log of average March-June outflow at Chipps Island and the log of the average February-May ONEPLUS starry flounder abundance index for the next year resulted in a significant positive relationship ($r^2 = 0.467$, $p<0.05$, Figure 32).

Table 10. Coefficient of determination values for the relationships between Log_{10} Bay Study YOY starry flounder abundance indices and Log_{10} average monthly outflow during selected periods, and between Log_{10} Bay Study ONEPLUS starry flounder abundance indices and the same outflow parameters during the previous year (i.e. year of recruitment to the Bay).

Outflow Period	Coefficient of Determination (r^2) for YOY Abundance	Coefficient of Determination (r^2) for ONEPLUS Abundance
December-June	0.542	0.546
December-May	0.532	0.537
January-June	0.528	0.524
January-May	0.519	0.513
February-June	0.475	0.505
February-May	0.466	0.494
March-June	0.445	0.467
March-May	0.422	0.448

Larvae and transforming starry flounder (< 10 mm TL) have been collected by the Bay Study in San Francisco Bay from March-June in the plankton net. Other researchers have

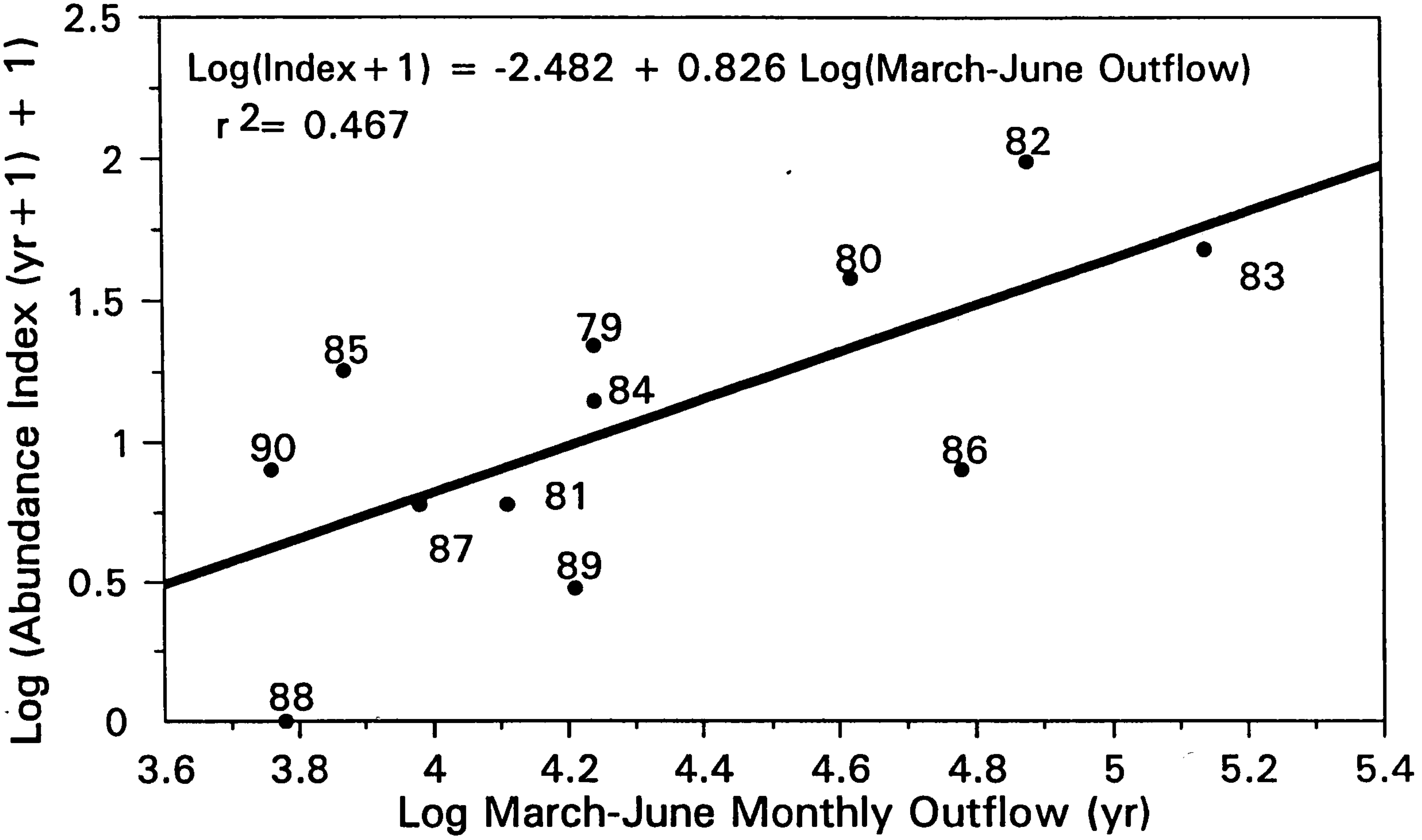


Figure 32. Relationship between $\log_{10}$ average March through June monthly outflow at Chipps Island in year=0 (i.e. when they recruited to the estuary) and $\log_{10}$ average February through May abundance of one-year-old starry flounder collected in year+1.

noted a similar period of immigration (Radtke 1966, Ganssle 1966, Wang 1986). This period overlaps the average annual peak unimpaired outflow period (i.e. December-May, see Figure 23). Starry flounder larvae migrating from coastal marine water may be able to use salinity gradients to locate the Bay as has been suggested for invertebrates (Hughes 1969); tidal and gravitational currents during this period also are probably important in assisting immigration (Weinstein et al. 1980, Boehlert and Mundy 1987). The low number of transforming larvae collected (89 between 1980 and 1988) and the fact that starry flounder become bottom dwelling at a small size (<10 mm TL), suggest that recently transformed starry flounder move rapidly through the Bay to very shallow, fresh or slightly brackish water.

Small starry flounder juveniles (<50 mm TL) were collected by the otter trawl starting in May and June, primarily from shallow water (<7 m) with bottom salinities of less than 22 ppt (Figure 33a and 33b). Data used to determine depth and salinity distributions are biased high because of depth limitations using a deep draft boat for trawling and because the Bay Study does not sample extensively in the Delta or other adjacent freshwater areas where juvenile starry flounder are known to occur (Radtke 1966).

Freshwater outflow affects the distribution of YOY starry flounder in the Bay. YOY starry flounder were distributed from the West Delta downstream to at least western San Pablo Bay during high outflow years (1980, 1982, 1983, 1984, 1986; Figure 34a). During the remaining low outflow years, with the exception of 1985, few were collected downstream of Suisun Bay (Figure 34a). These distribution patterns indicate that during high outflow years the extensive shallow mud flats of San Pablo Bay were used as nursery habitat, but in low outflow years they were not.

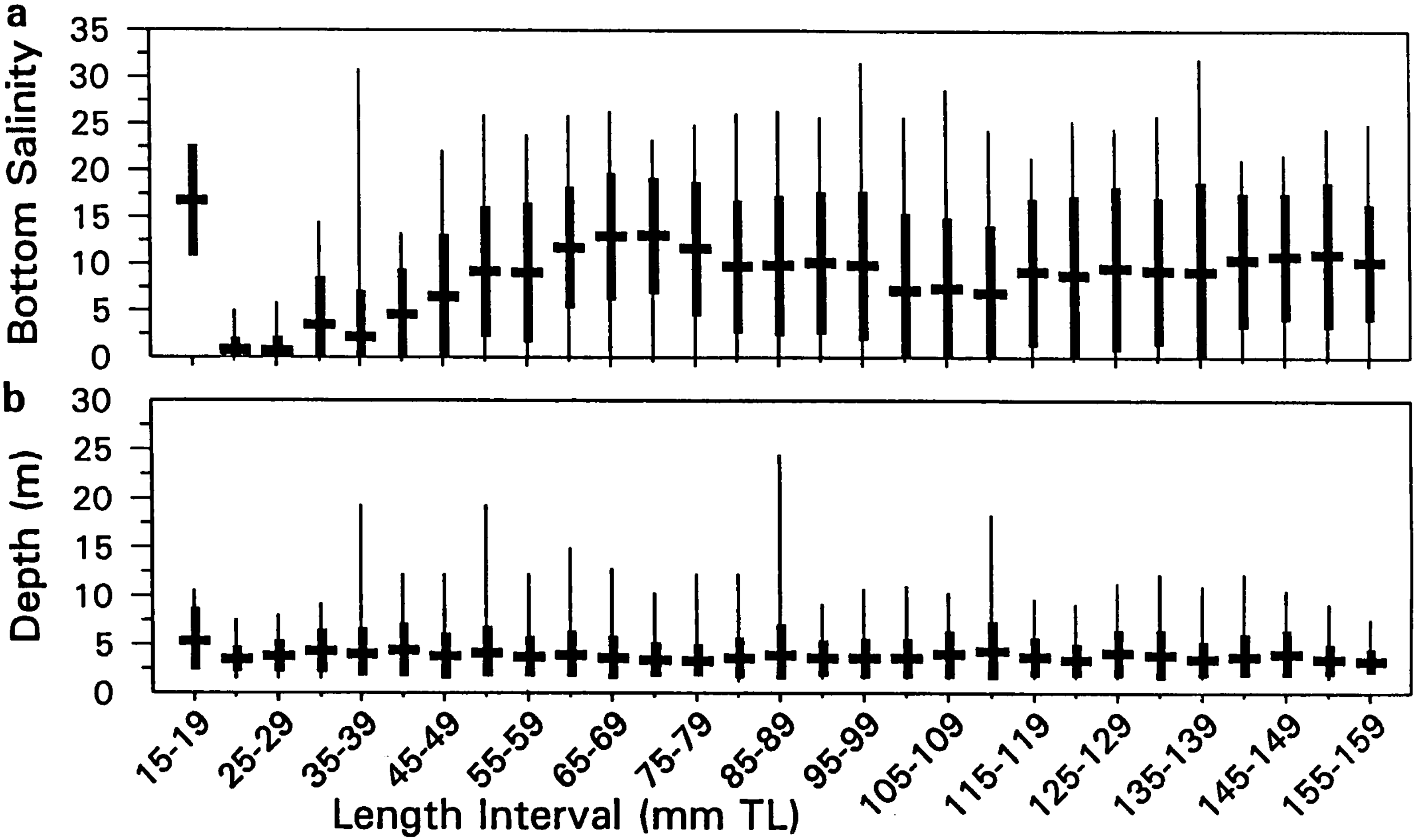


Figure 33. a. Average (horizontal bar), standard deviation (vertical bar) and range (vertical line) of bottom salinities (ppt) at the point of capture of starry flounder separated into 5 mm length intervals. Based upon starry flounder collected in the otter trawl between 1981 and 1990. b. same as above for depth (m).

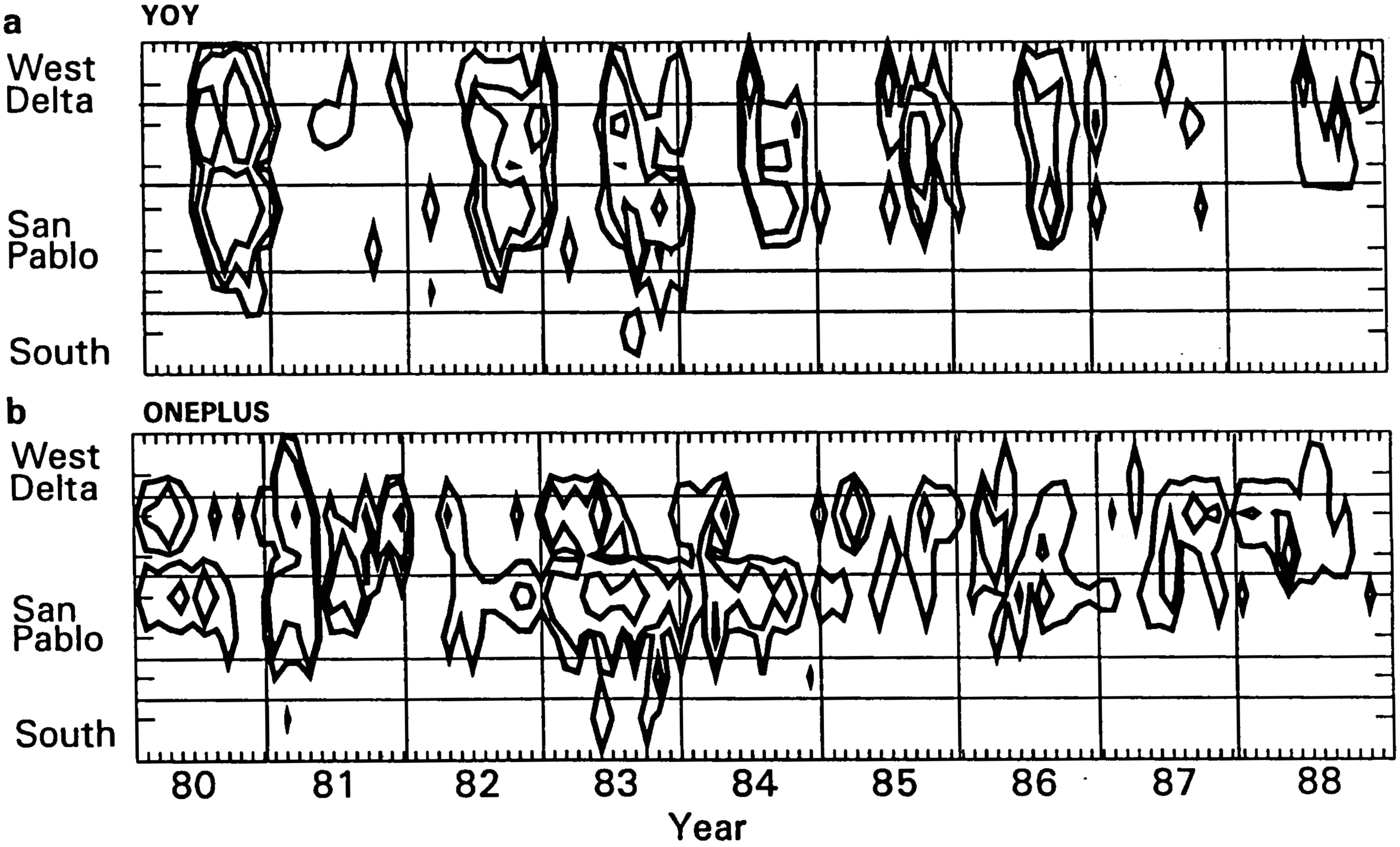


Figure 34. a. Topographic representation of the geographical (vertical axis) and temporal (horizontal axis) distribution of YOY starry flounder collected by the otter trawl in San Francisco Bay from 1980 through 1988. Based upon the average catch per 10,000 m^2 by area and month. Contours are at 1, 5, and 25 fish per 10,000 m^2. b. Topographic and temporal representation of ONEPLUS starry flounder distribution. Contours the same as for YOY.

By the end of their first year of life (average 110 mm TL) most starry flounder had moved out of freshwater in the West Delta and more completely into the shallow brackish water of Suisun and San Pablo Bays (Figures 33a, 33b, 34b). By the end of their second year of life and beyond, starry flounder expanded their distribution to include the entire Bay; however, they were extremely rare in low salinity areas and some may have migrated to the open coast.

These data indicate starry flounder used the Bay for at least the first two years of their life, and that freshwater outflow had a strong influence on the distribution of YOY starry flounder. Commercial Passenger Fishing Vessel data and observations by other biologists strongly suggest that the Bay was at one time a very important habitat for older starry flounder, but now relatively few remain.

We propose that successful recruitment of YOY starry flounder to the Bay may result in part from an increasing area of brackish water nursery habitat related to increasing freshwater outflow. Starry flounder are recruited to the YOY population (i.e. most of the mortality had already occurred) by the time they reach 70 mm TL. Therefore, habitat selected by flounder < 70 mm is considered important to their survival. Over 90 percent of the starry flounder <70 mm TL were collected from water with bottom salinities less than 22 ppt (Figure 33a). Most were collected from depths less than 7 m (Figure 33b). Therefore, area of shallow water (< 7 m) with bottom salinities less than 22 ppt are considered to be critical habitat.

The areas represented by Bay Study sampling stations where measured depth and bottom salinity were within the given ranges during the April through July period (i.e. resulted from March-June outflow) were summed for each year. These habitat areas were then log transformed and compared to log transformed February-May ONEPLUS starry flounder abundance indices from the subsequent year; a positive and significant relationship resulted ($r^2 = 0.646$, $p<0.01$, Figure 35a). Habitat area for YOY flounder was significantly related to freshwater outflow ($r^2 = 0.917$, $p < 0.001$, Figure 35b).

Starry flounder abundance in the Bay probably depends upon ocean conditions as well as in-bay conditions. Favorable currents are needed to transport and maintain surface oriented pelagic eggs and larvae toward shore and close to the Bay. Onshore surface currents are primarily associated with storm systems and south winds, but larger scale ocean conditions also have an influence (Reid and Schwartzlose 1962, Bakun 1973). Storm systems and a strong, consistent, south-wind are in turn positively associated with rainfall, and rainfall with outflow.

However, the lack of an offshore current may be sufficient for nearshore spawned starry flounder larvae to remain near the Bay. Such a condition can and does result with the cessation of north winds in the fall, winter and spring (Reid and Schwartzlose 1962, Wyatt et al. 1972, Bakun 1973). Thus, it is possible for good recruitment of larvae to nearshore areas to result from conditions that may result in both high and low outflow years.

The abundance of starry flounder in the Bay appears dependent upon outflow also. Outflow and habitat relationships with abundance strongly suggest that both strong and weaker year classes can result in years with high outflow/increased habitat area (eg. 80,82,83 strong year classes, 86 weaker year class, Figures 32, 35), possibly depending upon ocean conditions; however, only weaker year classes result in years with low outflow or limited habitat conditions (Figures 32, 35).

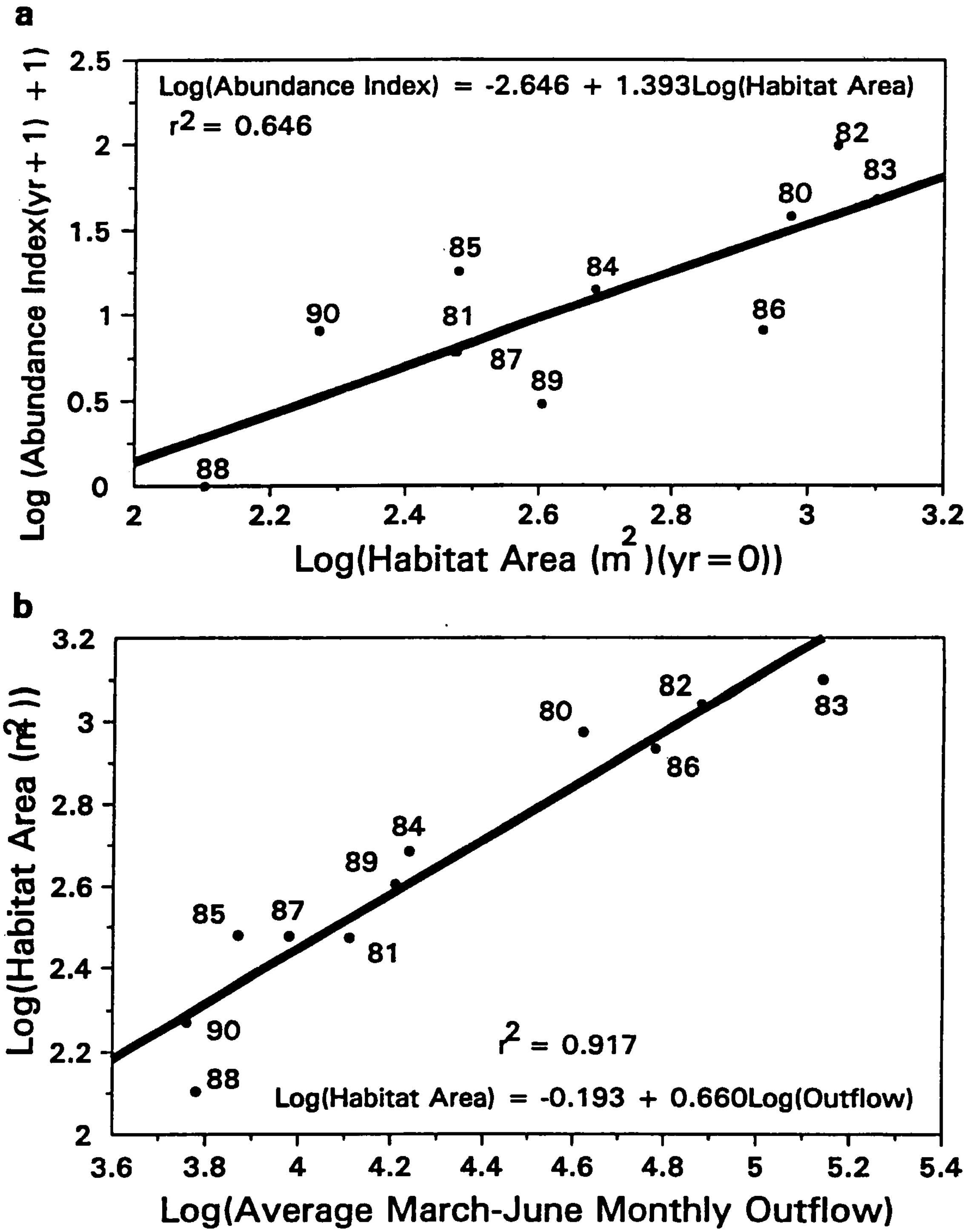


Figure 35. a. Relationship between habitat area (m^2, depth < 7 m, bottom salinities < 22 ppt between April and July) for YOY starry flounder, and the February through May abundance of ONEPLUS starry flounder the next year. b. Relationship between average March through June monthly outflow at Chipps Island, and habitat area for YOY starry flounder.

Response to Successive Years of Low Outflow Conditions

Due to increasing consumption and export, the proportion of the freshwater supply that flows to the Bay has been decreasing. Should this trend continue, the estuary can be expected to endure a higher frequency of low outflow conditions especially during the late winter and spring months. If this is to be the case, then one question that will need to be addressed is "How will the increased salinities that will result from these low outflow conditions affect the abundance and distribution of fish and invertebrates in the estuary?". One assumption would be that under successive low outflow years, salinities in the estuary would increase and conditions would become more like a sheltered marine lagoon. Marine species would be expected to colonize further upstream and increase in abundance and at the same time estuarine species would become less abundant. To explore this hypothesis annual fish and shrimp abundance indices were calculated by embayment. The fish were divided into pelagic (those caught in the midwater trawl) and demersal (those caught in the otter trawl). Annual abundance indices were calculated for those species that comprised the majority of the catch between 1980 and 1990. The anadromous species striped bass, chinook salmon, American shad and sturgeon were not included since information on them is included in other exhibits. The specific question as to the effects of prolonged periods of low outflow conditions can be examined by comparing the abundances before and during the drought. It should be noted that this data can be used to make inter-annual comparisons on an embayment basis, but it is not suitable for making comparisons between embayments.

One major result of the drought was an overall trend of increased and sustained salinities in all embayments during the 1987 through 1991 drought period (Figures 10 and 11). Between 1980 and 1986 the salinities in South Bay were generally above 20 ppt except during high outflow periods. During the drought they remained above 25 ppt and fluctuated around 30 ppt. In Central Bay salinities fluctuated between 20 and 30 ppt, while during the drought they stayed around that of seawater. Salinities in San Pablo Bay normally fluctuated between 0 and 28 ppt, but during the 1987-1990 period they remained above 20 ppt except for brief periods in 1989 and 1991. In Suisun Bay salinities fluctuated between 0 and 15 ppt and during the drought they generally remained above 10 ppt expect for brief periods in early 1987, 1989 and 1991. Salinities in the West Delta normally are between 0 and 5 ppt, except during the drought when they seldom dropped to 0. Temperatures remained remarkably constant between years with small changes of 1 to 2 °C. noticeable in some years. Temperatures varied less seasonally in Central Bay due to ocean influences than in the upper portions of the estuary. Unlike salinity there was no consistent increase in temperature during the 1987-1991 period.

Within the demersal group in South Bay, fish species composition varied both before and during the drought. The overall abundance in South Bay during the drought years was greater than during the high flow and non drought low outflow (Table 11). These changes in the demersal fish community were expected as marine species including bay goby, brown smoothhound, California tonguefish, plainfin midshipman, English sole and white croaker increased their distribution and abundance during a time when salinities were high and relatively stable (Table 13). Only yellowfin goby, an estuarine species, decreased in abundance during the 1987-1990 period in South Bay. The pelagic fish community had a fairly stable composition with the exception of topsmelt which become rare in 1989 and 1990 compared to the previous four years (Table 14). The decrease in topsmelt abundance is puzzling since it is a species that is

Table 11. Comparison of Average Abundance Indices for Demersal Species

Embayment	High Flow Years (80,82,83,84,86)	Low Flow Years (81,85,87)	Drought Years (88,89,90)
South Bay	6156	2816	8989
Central Bay	14221	10148	10735
San Pablo Bay	5445	2903	3889
Suisun Bay	443	259	292
West Delta	277	71	85

Table 12. Comparison of Average Abundance Indices for Pelagic Species

Embayment	High Flow Years (80,82,83,84,86)	Low Flow Years (81,85,87)	Drought Years (88,89,90)
South Bay	63078	132613	83641
Central Bay	509786	446467	342548
San Pablo Bay	96901	66109	28801
Suisun Bay	25116	12850	1357
West Delta	1073	1240	474

Table 13. **Annual Abundance Indices of Demersal Species in South San Francisco Bay.**

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated.

Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
bay goby	1079	297	732	1778	209	43	475	486	3720	2146	3290
brown rockfish	39	159	14	80	67	3	15	4	15	7	0
brown smoothhound	37	79	45	5	7	28	83	32	203	166	225
California tonguefish	52	0	69	554	49	4	8	4	477	224	22
English sole	538	535	936	682	458	58	769	103	699	1031	363
plainfin midshipman	29	187	96	235	32	75	163	93	742	484	1158
shiner perch	920	2842	3080	2459	538	742	811	1112	1335	716	1154
speckled sanddab	299	31	173	879	42	13	615	353	2148	964	370
starry flounder	13	19	12	94	29	12	12	11	0	2	11
staghorn sculpin	95	38	89	334	82	152	334	169	170	225	35
white croaker	2148	246	70	624	67	65	1314	393	1975	1977	863
yellowfin goby	6	6	6	9	30	0	106	53	9	14	26

Table 14. **Annual Abundance Indices of Pelagic Species in South San Francisco Bay.**

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated.

Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
delta smelt	0	0	0	0	0	0	0	0	0	0	0
jacksmelt	157	746	768	123	1203	2199	837	895	609	897	520
longfin smelt	24	0	5	973	89	561	1	37	204	103	71
northern anchovy	9858	64681	67145	30696	103506	145718	77766	156157	78858	99644	60075
Pacific herring	3596	704	8058	1101	4804	2038	4151	17297	6758	2710	158
Pacific pompano	0	0	52	32	0	0	8	0	9	28	79
topsmelt	74	30	33	15	32	1799	283	4977	137	17	33
whitebait smelt	0	0	0	0	0	0	1	0	0	0	14

normally found in the higher salinity areas of the Bay including the hyper-saline salt ponds in South Bay. Though northern anchovy and Pacific herring abundances decreased in South Bay during the drought, the overall abundance of pelagic species in South Bay was higher in the drought years than high outflow years, and was lower than other dry years (Table 12). While South Bay became a more favorable environment for demersal species during the drought, it was utilized to a lesser extent by the major marine pelagic species by 1990.

Both pelagic and demersal species were less abundant in Central Bay during low flow years and the drought than during high flow years, (Table 11 and 12). Of the demersal species, California tonguefish, starry flounder, shiner perch and yellowfin goby decreased during the 1988-1990 period while no species showed a steady increase (Table 15). As in South Bay, the species composition of the pelagic fish community was relatively stable with the abundance of northern anchovies decreasing by half between 1987 and 1990 (Table 16). Pacific pompano abundance increased substantially during the drought compared to the 1980-1986 period. It is surprising that the abundance of both demersal and pelagic species didn't increase in Central Bay during the drought and in fact the major component of the pelagic species community decreased substantially.

In San Pablo Bay the overall abundance of demersal species was less in the drought and low outflow years than in the high outflow years and the abundance of pelagic species was as much as four times less during the 1988-1990 drought period as in the high flow years (Tables 11 and 12). Bay goby, brown smoothhound, and speckled sanddab all increased during the drought compared to earlier years, but the increase was not constant (Table 17). This increase in marine demersal species was expected; however, it was interesting that more marine species did not respond in a

Table 15. **Annual Abundance Indices of Demersal Species in Central San Francisco Bay.**

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated. Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
bay goby	317	656	1564	4956	1586	640	3082	2954	900	3803	3648
brown rockfish	153	98	49	215	363	99	108	146	223	19	126
brown smoothhound	58	40	144	263	68	50	144	146	258	242	166
California tonguefish	124	25	179	776	429	115	22	73	63	14	9
English sole	3111	1037	1180	1826	3722	3236	1603	577	809	946	476
plainfin midshipman	148	643	355	641	649	500	976	4063	1175	867	1023
shiner perch	1549	1643	3054	1546	1044	1275	2830	1480	1361	292	550
speckled sanddab	3055	283	1701	1307	560	826	1315	1242	1191	1764	816
starry flounder	107	87	148	233	153	69	71	105	55	44	12
staghorn sculpin	458	137	259	566	865	1595	2024	990	386	1241	421
white croaker	442	340	342	791	1130	2410	2047	2699	2784	2554	3929
yellowfin goby	18	32	13	117	70	29	257	104	18	17	3

Table 16. **Annual Abundance Indices of Pelagic Species in Central San Francisco Bay.**

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated. Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
delta smelt	0	0	0	0	0	0	0	0	0	0	0
jacksmelt	486	3637	854	1632	2917	6071	2248	1594	1255	1851	1174
longfin smelt	6581	218	837	18188	3022	1508	1765	340	1106	380	140
northern anchovy	156773	296317	293218	229982	1108512	315128	484085	640106	382903	275171	320903
Pacific herring	51583	7057	120403	4456	14151	44421	46313	20574	11597	26658	2448
Pacific pompano	77	811	334	228	32	0	16	785	424	405	1096
topsmelt	0	142	90	0	2	357	60	71	49	7	24
whitebait smelt	0	0	0	3	82	265	0	0	38	5	11

Table 17. Annual Abundance Indices of Demersal Species in San Pablo Bay.

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated. Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
bay goby	273	381	1037	241	918	49	569	693	533	1857	1149
brown rockfish	18	7	8	0	12	4	7	0	7	0	1
brown smoothhound	23	0	27	9	13	17	43	35	64	47	69
California tonguefish	1	3	0	4	2	14	0	9	47	11	0
English sole	445	1374	397	22	1051	1295	126	378	1552	799	393
plainfin midshipman	192	103	356	159	57	56	1123	275	437	379	255
shiner perch	504	718	465	77	105	152	546	117	468	112	131
speckled sanddab	202	38	19	5	28	7	295	132	423	297	41
starry flounder	945	100	289	522	459	94	176	49	17	9	19
staghorn sculpin	878	215	1766	599	805	245	1402	193	487	712	132
white croaker	3954	178	169	136	1594	10	1817	1474	453	134	225
yellowfin goby	384	99	144	215	168	25	1426	170	151	210	31

Table 18. Annual Abundance Indices of Pelagic Species in San Pablo Bay.

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated. Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
delta smelt	0	0	6	76	15	0	2	0	0	0	0
jacksmelt	134	376	187	88	163	1004	79	254	126	107	125
longfin smelt	4208	556	34373	7860	979	2267	764	254	279	186	185
northern anchovy	50394	20844	169382	81342	57205	67102	56484	99535	36137	31571	12957
Pacific herring	4608	502	3976	171	5635	4703	6348	831	4275	290	161
Pacific pompano	0	0	0	0	0	0	0	0	0	0	1
topsmelt	11	1	3	4	5	25	5	20	3	0	0
whitebait smelt	0	0	0	0	0	53	0	0	0	2	0

similar manner. Northern anchovy was the only pelagic species whose abundance decreased at a steady rate during the 1988-1990 period (Table 18). It is understandable why longfin smelt didn't do well during the drought period in San Pablo Bay. The failure of the more marine species including northern anchovy, Pacific herring, jacksmelt, and topsmelt, to exploit the increased high salinity habitat suggests that other factors may have been limiting.

The most dramatic change in abundance occurred in Suisun Bay during the drought period of 1988-1990. The demersal species abundance decreased by almost half compared to either the drought and other low outflow years with the dry years being the lowest (Table 11). The pelagic species decreased by a factor of two in low flow years compared to high flow years and by a factor of over ten in the drought years in relation to the low flow years (Table 12). Pelagic species abundance during the drought averaged only 5% of the abundance in the high flow years. Demersal marine species moved into Suisun Bay during the drought as in the case of brown smoothhound sharks or increased their abundance as in the case of bay goby, English sole, plainfin midshipman, speckled sanddab and white croaker (Table 19). However, in terms of overall abundance, this increase didn't make up for the lowered starry flounder and yellowfin goby abundance. During the drought period both the marine pelagic species northern anchovy and Pacific herring and the estuarine pelagic species longfin smelt all decreased in abundance in Suisun Bay (Table 20). The appearance of Pacific pompano in Suisun Bay in 1990 represents an upstream extension of this species distribution.

In the West Delta area the abundance of demersal species was slightly higher in the drought years than in the low outflow years; however, it was greater in the high outflow years by a factor of 3 (Table 11 and 21). This is due in part to the increased salinities that occurred during

Table 19. Annual Abundance Indices of Demersal Species in Suisun Bay.

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated.

Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
bay goby	0	2	2	0	1	0	3	6	3	36	18
brown rockfish	0	0	0	0	0	0	0	0	0	0	0
brown smoothhound	0	0	0	0	0	0	0	1	3	0	0
California tonguefish	1	0	0	0	0	0	0	0	0	0	0
English sole	1	2	0	0	0	0	0	1	8	20	4
plainfin midshipman	6	53	1	13	11	2	5	35	33	6	52
shiner perch	0	1	0	0	0	0	0	0	0	0	0
speckled sanddab	0	0	1	1	0	0	1	11	22	3	1
starry flounder	260	68	144	72	29	96	46	24	21	17	19
staghorn sculpin	85	30	106	8	97	122	131	87	134	210	57
white croaker	16	1	0	1	1	1	0	4	1	22	3
yellowfin goby	385	65	96	31	307	20	352	145	22	121	39

Table 20. Annual Abundance Indices of Pelagic Species in Suisun Bay.

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated.

Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
delta smelt	126	107	71	72	48	1	26	2	0	9	8
jacksmelt	0	4	1	0	4	2	0	4	1	3	0
longfin smelt	4490	2404	8506	1197	2084	1771	887	3595	622	173	81
northern anchovy	6652	25744	1279	169	93653	8156	5835	3147	1378	878	825
Pacific herring	52	19	381	0	34	341	16	62	50	28	9
Pacific pompano	0	0	0	0	0	0	0	0	0	0	7
topsmelt	0	0	0	0	0	0	0	0	0	0	0
whitebait smelt	0	0	0	0	0	0	0	0	0	0	0

Table 21. Annual Abundance Indices of Demersal Species in the West Delta.

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated.

Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
bay goby	0	0	0	0	0	0	0	0	0	0	0
brown rockfish	0	0	0	0	0	0	0	0	0	0	0
brown smoothhound	0	0	0	0	0	0	0	0	0	0	0
California tonguefish	0	0	0	0	0	0	0	0	0	0	0
English sole	0	0	0	0	0	0	0	0	0	4	0
plainfin midshipman	2	0	0	0	0	0	0	0	0	0	0
shiner perch	0	0	0	0	0	0	0	0	0	0	0
speckled sanddab	0	0	0	0	0	0	0	0	0	0	0
starry flounder	125	42	18	21	65	21	29	6	17	4	38
staghorn sculpin	18	34	0	0	4	49	21	13	53	6	24
white croaker	0	0	0	0	0	0	0	0	0	0	0
yellowfin goby	117	30	69	0	623	5	274	12	6	93	10

Table 22. Annual Abundance Indices of Pelagic Species in the West Delta.

Abundance indices were based on February through October catches. Values for September and October 1989 were estimated.

Shaded area represents the current drought.

Species	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990
delta smelt	109	417	39	15	48	36	225	52	76	100	56
jacksmelt	0	0	0	0	0	0	0	0	0	0	0
longfin smelt	4049	787	170	0	171	178	503	467	536	54	50
northern anchovy	0	472	0	0	0	259	0	852	329	0	46
Pacific herring	0	0	0	0	34	193	0	6	176	0	0
Pacific pompano	0	0	0	0	0	0	0	0	0	0	0
topsmelt	0	0	0	0	0	0	0	0	0	0	0
whitebait smelt	0	0	0	0	0	0	0	0	0	0	0

the 1988-1990 period. The situation was different for the pelagic species where the low outflow years abundance was greater than either the high outflow or drought years and the drought years was lower than the high flow years by a factor of over 2 (Table 12). The pelagic species are directly affected by high outflows in the West Delta. In 1982 and especially 1983 the high outflows moved most of the pelagic species downstream (Table 22). This resulted in the abundances in high outflow years being lower than those in the low outflow years. There were no pelagic or demersal species that had a consistent decrease or increase during the drought in the West Delta area. Only one marine demersal species, English sole, appeared in the lower rivers area in 1989 and this represents an upstream range extension for this species.

With the exception of South Bay and to a lesser extent San Pablo Bay, the average abundance of demersal fish species was only slightly greater in the drought years than in the low outflow years and with the exception of South Bay, the demersal species were always more abundant in the high outflow years than in either the low flow or drought years. This suggests that successive low outflow years, as during the drought, did not result in increased abundances of marine or estuarine demersal fish species while high outflow years did. The pelagic species were less abundant during the drought years than in the low outflow years and in the case of San Pablo Bay, Suisun Bay, and the West Delta, the decrease was substantial. The exception of South Bay suggests that singular low outflow years were better than high outflow years for pelagic species there.

Overall the estuary responded in a negative manner during the drought years. Species composition shifted in some cases favoring more marine species as with the caridean shrimp, and for many species distributions expanded. In the upstream sections of the estuary (San Pablo Bay, Suisun Bay and West Delta) successive low flow years resulted in a decreased abundance of the estuary dependent species and a decrease in abundance of the major fish and shrimp prey species, Crangon franciscorum, northern anchovy, Pacific herring and longfin smelt.

The original hypothesis stated that as the estuary became more saline due to decreased freshwater outflow, the abundance and distribution of marine species would increase and estuarine species would decrease. Estuarine species responded to the extended period of low outflow years as expected; however, only a few of the marine species increased and a large number of the most abundant and important prey species found in the estuary decreased. In short, the estuary did not fare well during the 1988 through 1990 period.

The mechanisms behind the observed decreases in abundances in Central, San Pablo, and Suisun bays during the successive low outflow years are most likely a combination of direct and indirect outflow influences on abundance and distribution as discussed earlier in the this report, ocean conditions, and decreased productivity. The role of ocean conditions and productivity are difficult to assess with the available data. These clearly are areas where additional research is needed.

If the estuary is to endure an increased frequency of low outflow years, especially successive low outflow years, the expected result will be a decreased abundance of many marine and most estuarine fish and shrimp. Since many of these affected species comprise the major prey species for many of the important sport and commercial species as well as many marine birds and mammals, these populations will also be impacted.

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Appendix 1. Shrimp annual abundance indices, 1980-91. By species and total.

Year	*C. franciscorum*	*C. nigricauda*	*C. nigromaculata*	*Palaemon*	*Heptacarpus*	*Lissocrangon*	Total
1980	5343	1255	49	121	94	0	6862
1981	2587	651	15	127	36	0	3415
1982	8498	495	31	83	75	0	9182
1983	9304	1152	363	33	80	0	10932
1984	6820	355	152	171	67	80	7645
1985	1329	505	68	91	92	22	2108
1986	6061	1344	188	106	92	140	7930
1987	3345	2716	300	58	328	56	6804
1988	2300	2856	288	39	299	7	5789
1989*	2859	3350	347	137	671	3	7367
1990**	1820	5118	908	103	561	19	8602
1991**	1294	5349	1332	150	1448	8	9580
All	4438	1937	311	99	283	30	7099

* January through August
** February through October

Appendix 2. Longfin Smelt Abundance Indices. Striped Bass Fall Midwater Trawl sampling began in 1967 and was conducted annually, except for 1974 and 1979. Bay Study sampling began in 1980. Indices for 1991 have not been calculated.

YR	Striped Bass Fall MWT	Bay Study MWT YOY	Bay Study MWT ONEPLUS	Bay Study OT YOY	Bay Study OT ONEPLUS
67	81737				
68	3318				
69	59497				
70	6535				
71	15988				
72	760				
73	5897				
74	ND				
75	2809				
76	654				
77	204				
78	6676				
79	ND				
80	31155	5472	25	3942	4
81	2202	51	736	102	355
82	62929	11697	177	8938	62
83	11876	1304	5491	823	2112
84	7459	947	635	1250	425
85	992	165	1233	303	172
86	6160	749	298	285	76
87	1508	86	887	53	124
88	743	53	392	23	60
89	456	34	199	21	47
90	239	23	66	13	7
91	134				

Appendix 3. Starry flounder abundance indices and catch data. Commercial Passenger Fishing Vessel (CPFV) data from CDFG unpub. data. The Bay Study Feb-May ONEPLUS index was incremented by one to allow log transformation in analyses. This index is used as a surrogate for YOY abundance. ND=no data.

YR	CPFV Catch per Hr.	CPFV Total Annual Catch	Commercial Landings in S.F. Bay Area	Bay Study OT YOY Annual Abundance	Bay Study OT ONEPLUS Feb-May index+1	Bay Study OT Annual Abundance ONEPLUS Feb-Oct
60			100,190			
61			88,538			
62			147,652			
63			259,178			
64	472	823	233,776			
65	700	1276	223,533			
66	898	2687	218,828			
67	1249	3904	440,328			
68	682	1681	248,693			
69	1055	3094	181,276			
70	1465	3754	128,048			
71	1959	2679	120,308			
72	1127	1582	311,238			
73	1746	1608	105,972			
74	1341	1539	164,362			
75	1393	1292	254,657			
76	528	534	369,680			
77	139	53	461,288			
78	340	488	455,917			
79	ND	ND	355,623			
80	151	183	486,048	388	22	18
81	ND	ND	405,494	2	38	29
82	ND	ND	282,529	118	6	6
83	ND	ND	374,128	70	98	96
84	799	1076	368,223	29	48	37
85	401	183	342,992	29	14	8
86	131	187	201,509	43	18	13
87	142	110	103,522	1	8	10
88	122	129	116,678	4	6	4
89	97	127	74,367	6	1	1
90	50	17	40,336	15	3	3
91	ND	ND	63,453	10	8	12