Summary

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The San Francisco Bay Study collected over 128 species of fishes, caridean shrimp, and *Cancer* crabs from 1980 to 1995, representing a large proportion of the estuary's macrofauna. Species not well sampled include those associated with rocky substrates, eel grass beds, and some shallow water habitats, such as tidal marshes, and also larger species that avoided our nets. Generally, the midwater trawl and beach seine were most effective in collecting age–0 fish; in addition to age–0 fish, the otter trawl was also effective in collecting shrimp and age–0 crabs. In the preceding chapters, we described estuarine use, including distributional patterns, abundance trends, and occurrence by salinity and temperature for the most commonly collected species. In this chapter, we provide an overview of the physical environment, occurrence by salinity and temperature, life history strategies or categories, timing and location of reproduction and rearing, and abundance trends.

Physical Environment

The environmental setting for the study period was far from "average." Alternating "wet" and "dry" or "critical" years bracketed a 6–year drought, one of the most severe of the century. The "wet" years included several years with very high outflow and the highest outflow year of the century (1983). In addition, sea surface temperatures were above average for much of the study period, with several sequential El Niño events. The largest El Niño event occurred in 1982–1983.

Physical factors that influence the estuary's biota can be broadly categorized as riverine, oceanic, or estuarine. Riverine factors are generally related to the magnitude and duration of freshwater outflow and include currents, sediment and nutrient inputs, temperature, and the amount and quality of upstream spawning and rearing habitat. The most important oceanic factors are nearshore surface currents, upwelling, and water temperature. Estuarine factors, including salinity, temperature, gravitational circulation, and tidal currents, are the result of the interaction of oceanic and riverine factors with estuarine bathymetry and geography. The gradations of shallow to deep water, open to structured habitats, and salt to fresh water combine to create a myriad of habitats. The estuarine habitat for each species expands and contracts as the physical environment changes on tidal, seasonal, annual, and even decadal scales.

Occurrence by Salinity and Temperature

The salinity and temperature gradations in the estuary, in conjunction with a species' salinity and temperature tolerance ranges, provide a good indication of the potential distribution of many species. In general, changes in salinity and temperature are as predictable as the seasons—increased precipitation and cool weather lead to lower salinities and temperatures in winter than summer. More specifically for the temperature gradient, the winter trend is for the lower estuary to be warmer than the upper estuary (Figures 1A and 1C), and the summer trend is for the lower estuary to be cooler than the upper estuary (Figures 1B and 1D).

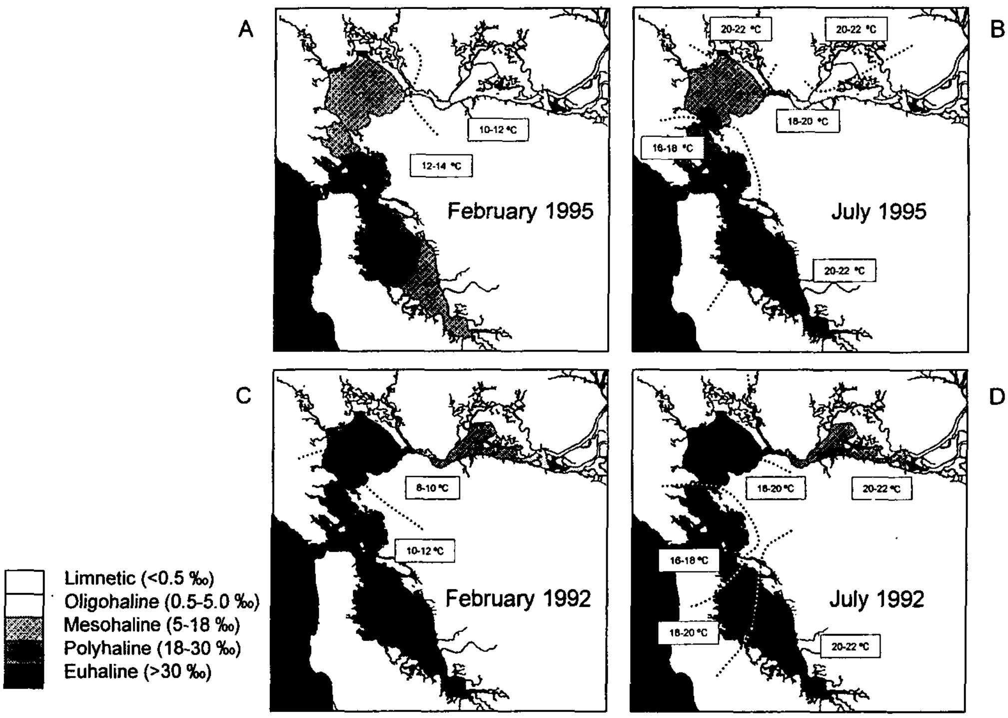

Figure 1 Isohalines and isotherms for winters and summers of "wet" (1995) and "dry" (1992) years: (A) February 1995, (B) July 1995, (C) February 1992, and (D) July 1992

The areas that fall within a species' salinity and temperature tolerances also vary from year to year, but interannual changes are not as predictable as seasonal changes. The factors affecting salinity and temperature are different; whereas salinity varies with outflow, temperature varies with outflow, weather, and ocean influences. In a high outflow year, such as 1995, the limnetic, oligohaline, and mesohaline zones increased and the euhaline zone decreased (see Figure 1A and 1B). In low outflow years, such as 1992, there was often no limnetic zone within the study area and the euhaline zone increased (see Figures 1C and 1D). Temperature was cooler in winters of high outflow years than low outflow years (see Figures 1A and 1C), but there were relatively little temperature differences in summer (see Figures 1B and 1D). Because there is no direct relationship between salinity and temperature, the boundaries of the thermal and salinity gradients do not consistently align; therefore, a species' distribution may be restricted by either or both of these variables.

To determine the general pattern of species occurrence by salinity and temperature, the mean salinity and temperature (±1 standard deviation) were plotted for the 54 most commonly collected species (Figures 2 and 3). The salinity plots form a sigmoid-shaped curve with inflection points between the limnetic and oligohaline salinities and the mesohaline and polyhaline salinities (see Figure 2). Most species were collected from polyhaline and euhaline salinities and only a few were limited to the limnetic or oligohaline regions. The low number of limnetic and oligohaline species is partially due to the concentration of stations downstream of the delta. Generally, the species found at the extreme ends of the salinity gradient (euhaline and limnetic) were collected from relatively narrow salinity ranges (small standard deviations), whereas those from primarily mesohaline salinities had wider salinity ranges (larger standard deviations). Many species with a wide salinity range are either anadromous or partially anadromous (for example, longfin smelt, chinook salmon, and American shad). Most of the others are catadromous, with some migrating long distances from their marine spawning areas to their low salinity nursery areas (for example, starry flounder and *Crangon franciscorum*).

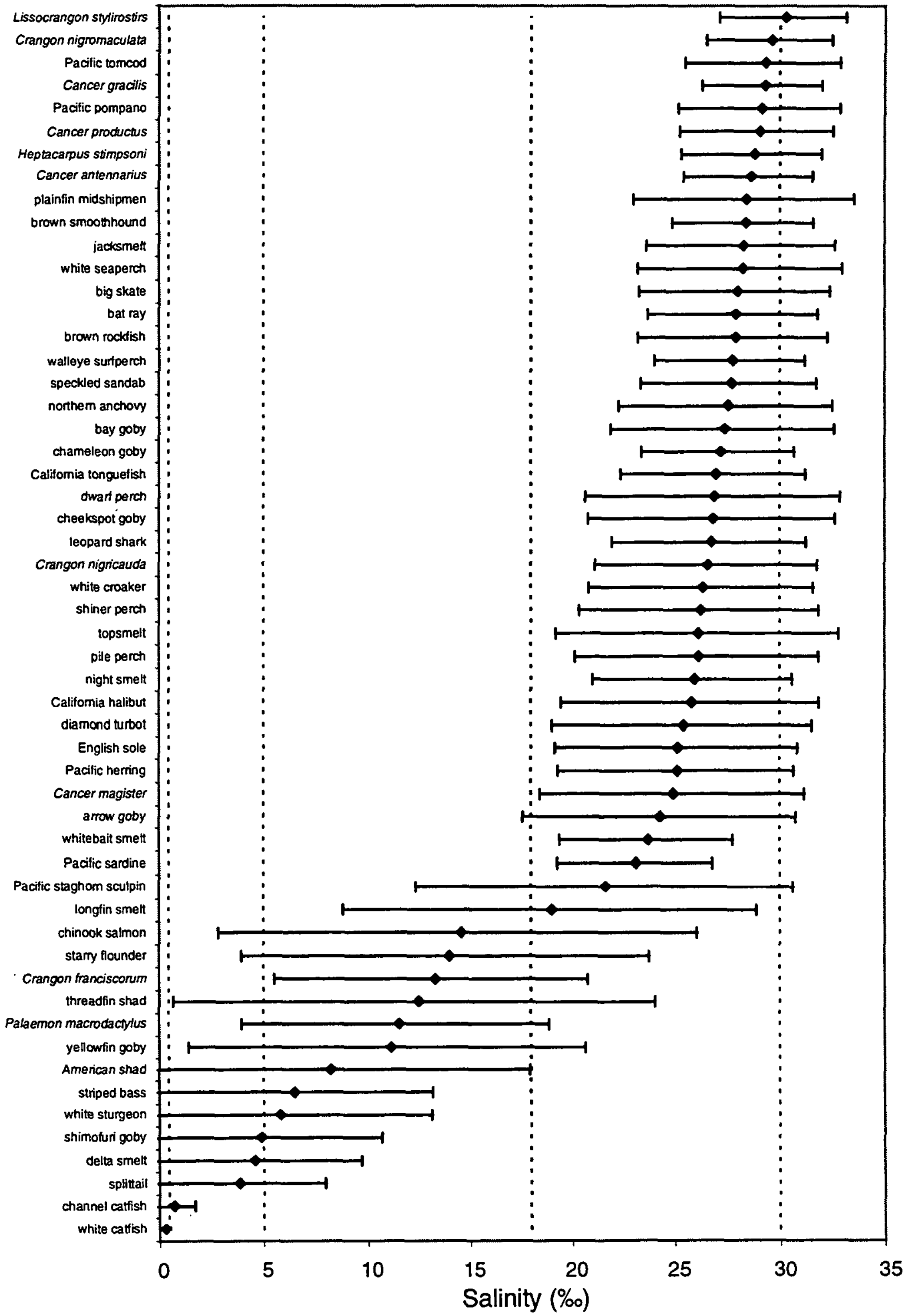

Figure 2 Mean salinity (‰) ±1 standard deviation for the 54 most commonly collected species of fishes, shrimps, and crabs. Data from beach seine for topsmelt, arrow goby, and dwarf perch, otter trawl for shrimps, crabs, and demersal fishes, and midwater trawl for pelagic fishes. CPUE weighted by surface salinity for beach seine, bottom salinity for otter trawl, and water column average salinity for midwater trawl. The vertical lines are the boundaries for *the Venice system of salinity classification.*

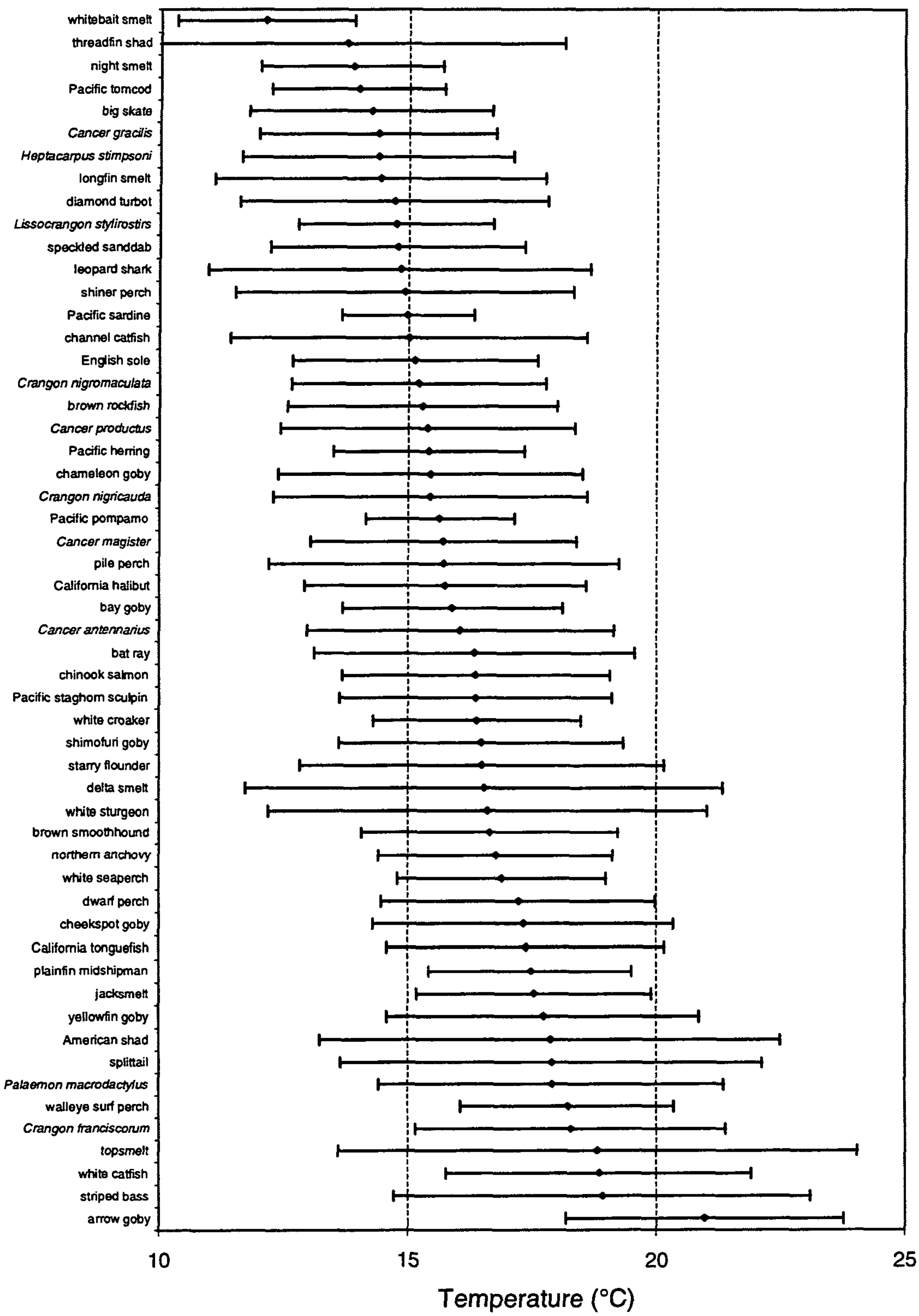

Figure 3 Mean temperature (°C) ±1 standard deviation for the 54 most commonly collected species of fishes, shrimps, and crabs. Data from beach seine for topsmelt, arrow goby, and dwarf perch, otter trawl for shrimps, crabs, and demersal fishes, and midwater trawl for pelagic fishes. CPUE weighted by surface temperature for beach seine, bottom temperature for otter trawl, and water column average temperature for midwater trawl.

The temperature plots form a continuous progression without sharp changes or break points (see Figure 3). Those species with the narrowest ranges (smallest standard deviations) are marine species that use the lower estuary opportunistically, including night smelt, Pacific tomcod, Pacific sardine, and Pacific pompano. Species with the widest temperature ranges (largest standard deviations) include anadromous species that rear in the estuary (for example, delta smelt, white sturgeon, splittail, striped bass, and American shad) and starry flounder, which migrate from the ocean to rear in the upper estuary. The exceptionally wide range for threadfin shad, a freshwater species, is probably an artifact of fish transported downstream of the delta by high outflow events some years.

Life History Strategies

Although the estuary's fishes, shrimps, and crabs have various life history strategies, they can be broadly categorized as either resident, seasonal, or anadromous (Table 1). Resident species generally spend their entire lives in the estuary and use several strategies to retain larvae in the estuary, including reproduction during low outflow periods, adhesive eggs, vertical migration of larvae, and partial anadromy. Many of the common residents inhabit shallow water and do not migrate extensively within the estuary (topsmelt, arrow goby, and dwarf perch), whereas others are partially anadromous (delta smelt) or partially catadromous (yellowfin goby and *Palaemon macrodactylus*).

Table 1 Categories of estuarine use for the most commonly collected species of fishes, shrimps, and crabs[a]

	Seasonal Inhabitants[b]			
Resident[c]	*Obligate Nursery*[d]	*Non-obligate Nursery*[e]	*Opportunist*[f]	*Anadromous*
Palaemon macrodactylus[g]	*Crangon franciscorum*	*Crangon nigromaculata*	*Lissocrangon stylirostris*	white sturgeon
Cancer gracilis	Pacific herring	*Crangon nigricauda*	big skate	American shad
delta smelt	jacksmelt	*Heptacarpus stimpsonii*	northern anchovy	chinook salmon
splittail	plainfin midshipman	*Cancer antennarius*	Pacific sardine	longfin smelt
topsmelt	pile perch	*Cancer magister*	threadfin shad[g]	striped bass[g]
dwarf perch	shiner perch	*Cancer antennarius*	night smelt	
Pacific staghorn sculpin	white seaperch	*Cancer productus*	whitebait smelt	
arrow goby	brown rockfish	brown smoothhound	white catfish[g]	
bay goby	starry flounder	leopard shark	channel catfish[g]	
chameleon goby[g]		bat ray	prickly sculpin	
cheekspot goby		white croaker	Pacific pompamo	
shimofuri goby[g]		walleye surfperch	Pacific tomcod	
yellowfin goby[g]		California halibut		
diamond turbot		California tonguefish		
		English sole		
		speckled sanddab		

[a] None of these categories are exclusive, but are meant to provide a basis for comparing general estuary use patterns.
[b] Seasonal = some life-stage found in the estuary or species found both in estuary and nearshore.
[c] Resident = most individuals usually complete their entire life cycle in the estuary.
[d] Obligate nursery = species that require the estuary as a nursery.
[e] Non-obligate nursery = species that use the estuary as an extension of nearshore coastal nursery.
[f] Opportunist = species that use the estuary as an extension of their nearshore distribution.
[g] Introduced species.

Seasonal species may spend an essential part of their life cycle in the estuary or opportunistically use the estuary. The most common life cycle use of the estuary is as a nursery area, either obligatory or non-obligatory. For obligate species, reproduction or rearing occurs almost exclusively within estuaries and year class success is largely dependent on estuarine conditions. Pacific herring, jacksmelt, and many surfperches are obligate species that immigrate to the estuary to reproduce. Note that all of these species have adhesive eggs or bear live young, characteristics that reduce loss of eggs and young from the estuary. Other estuarine obligates, such as the shrimp *Crangon franciscorum* and starry flounder, reproduce in the ocean and small juveniles or post-larvae immigrate to the estuary to rear. For the non-obligate nursery species, the portion of the year class that rears in the estuary may vary widely by year, and year class success is usually independent of estuarine conditions. Non-obligates species include those that reproduce in the ocean and enter the estuary as small juveniles, such as *Cancer magister*, brown rockfish, and English sole.

Opportunists use the estuary as an extension of their usual habitat; for these species, use of the estuary is not critical for their survival. Many coastal species are opportunists and under favorable conditions some, such as the northern anchovy, reproduce, rear, and forage in the estuary, whereas others (big skate and Pacific pompano) use the estuary primarily for foraging. Several freshwater species, such as white catfish and threadfin shad, are also opportunists; their abundance in the estuary is a function of salinity and increases in high outflow years.

Anadromous species reproduce in freshwater and rear in higher salinities, including the ocean. Some, such as longfin smelt and striped bass, rear in the mesohaline and polyhaline areas of the estuary and include individuals that may never enter the ocean. Others, such as chinook salmon and American shad, use the estuary primarily as a migration corridor.

Reproduction and Rearing

Estuaries are well known as important nurseries for fishes and invertebrates throughout the world. Although larvae and juveniles of many species were collected all year in the San Francisco Estuary, all species had a peak reproduction period (Table 2).

Most of the species that reproduce in the ocean do so in winter and early spring, before the onset of upwelling. This strategy results in retention of larvae near the coast, and most importantly, near the mouths of estuaries. Included in this group are starry flounder, English sole, brown rockfish, the *Cancer* crabs, and *Crangon* shrimp. Notable exceptions include speckled sanddab, which spawn during upwelling, and California halibut, which, in the northern portion of their range, apparently spawn in fall, when ocean temperatures reach their seasonal maxima.

The majority of the anadromous species also reproduce in late winter and spring, when water temperatures are increasing, freshwater flows transport eggs and larvae to downstream nursery areas, and phytoplankton and zooplankton blooms usually occur. Included in this group are longfin smelt and American shad.

For coastal species that enter the estuary to spawn or pup, the reproductive period ranges from winter through summer. As mentioned above, all of these species have a mechanism for retention of their eggs or young in the estuary. Pacific herring and jacksmelt, which have pelagic larvae, spawn in winter or late spring. The live-bearing surfperches and elasmobranchs give birth in late spring and summer, whereas plainfin midshipman, which are nest builders, reproduce in summer.

Table 2 Salinity, location, and timing of peak larval hatching or pupping for the most commonly collected species of fishes, shrimps, and crabs. ♦ indicates peak, + *indicates lesser amount of hatching or pupping.*

	Salinity					Location							Peak hatching or pupping											
Species	Limnetic (0-0.5 ‰)	Oligohaline (0.5 - 5 ‰)	Mesohaline (5 - 18 ‰)	Polyhaline (18 -30 ‰)	Euhaline (>30 ‰)	Rivers and Streams	Delta	Suisun Bay	San Pablo Bay	Central Bay	South Bay	Ocean	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
white croaker				♦	♦				+	♦	+	♦	♦	♦	♦	♦	+				+	+	+	♦
starry flounder					♦					+		♦	♦	♦	♦	+				+	+	+	+	♦
English sole					♦							♦	♦	♦	♦	+	+						+	♦
Pacific staghorn sculpin			♦	♦					♦	♦	♦	+	♦	♦	♦	+							+	+
Pacific herring				♦	+				+	♦	♦	+	♦	♦	♦	+								+
longfin smelt	♦	+				♦	♦	+					♦	♦	♦	♦	+							+
brown rockfish					♦							♦	♦	♦	♦	+								
Pacific tomcod					♦							♦	♦	♦	♦	♦	+	+						
yellowfin goby			+	♦				+	♦	+	♦		+	♦	♦	♦	+	+	+					
Pacific sardine					♦							♦	♦	♦	♦	♦	♦	♦	♦	♦	♦			
prickly sculpin	♦	+				♦	♦	+						♦	♦	♦	♦							
white sturgeon	♦					♦								+	♦	♦	♦							
jacksmelt				♦	♦				♦	♦	♦			+	♦	♦	♦	♦	♦	+				
Pacific pompano					♦							♦			♦	♦	♦	♦						
splittail	♦	+				♦	♦	+							+	♦	♦	+						
arrow goby				+	♦				+	♦	♦					♦	♦	♦	♦	+				
delta smelt	♦	♦				♦	♦	+								♦	♦	♦	+					
striped bass	♦					♦	♦									+	♦	♦	+					
plainfin midshipman				♦	♦				♦	♦	♦					+	♦	♦	♦	♦	♦	+		
threadfin shad	♦					♦											♦	♦	♦	+				
inland silverside	♦	♦				♦	♦	♦	+								♦	♦	♦	♦				
chameleon goby				♦	♦					+	♦						♦	♦	♦	♦	♦			
California tonguefish					♦							♦					♦	♦	♦	♦	♦	♦		
speckled sanddab					♦							♦				+	+	♦	♦	♦	♦	+		
topsmelt				♦	♦				+	+	♦						+	♦	♦	♦	+			
American shad	♦					♦											+	♦	♦	♦	+			
cheekspot goby				♦	♦				♦	♦	♦							♦	♦	♦	♦	♦		
northern anchovy			+	♦	♦				♦	♦	♦	♦				+	+	+	♦	♦	♦	+		
bay goby				♦	♦				♦	♦	♦							+	♦	♦	♦	♦	♦	+
California halibut					♦					♦		♦	+	+	+				+		♦	♦	♦	+
diamond turbot				♦	♦				♦	♦	♦	+				+	+	+	+	+	♦	♦	♦	+
chinook salmon (fall run)	♦					♦																♦	♦	♦

Table 2 (Continued) Salinity, location, and timing of peak larval hatching or pupping for the most commonly collected species of fishes, shrimps, and crabs. ♦ indicates peak, + *indicates lesser amount of hatching or pupping.*

	Salinity					Location							Period hatching or pupping											
	Limnetic (0-0.5 ‰)	Oligohaline (0.5 - 5 ‰)	Mesohaline (5 - 18 ‰)	Polyhaline (18 -30 ‰)	Euhaline (>30 ‰)	Rivers and Streams	Delta	Suisun Bay	San Pablo Bay	Central Bay	South Bay	Ocean	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Live bearers																								
dwarf perch				♦	♦				♦	♦	♦	♦				♦	♦	♦	♦	♦				
walleye surfperch				♦	♦					♦	♦	♦					♦	♦						
shiner perch				♦	♦				♦	♦	♦	♦					♦	♦	♦					
pile perch				♦	♦				+	♦	♦	♦					♦	♦	♦					
white seaperch				♦	♦					♦	♦	♦					♦	♦	♦	♦				
leopard shark				♦	♦				+	♦	♦	♦			+	♦	♦	+						
brown smoothhound				♦	♦				+	♦	♦	♦				♦	♦	♦	+	+				
big skate				♦	♦				+	♦	+	♦		+	+	+	+	♦	♦					
bat ray				♦	♦				+	♦	♦	♦				+	+	♦	♦	♦	+			
Invertebrates																								
Heptacarpus stimpsonii					♦					♦	♦	+	♦	♦	+			+	+	+			+	♦
Crangon franciscorum				♦	♦				+	♦	♦	♦	♦	♦	♦	♦	+	♦	♦	+				
Crangon nigricauda				+	♦				+	♦	♦	♦	♦	♦	♦	♦	+	+	♦	♦	♦	+		
Lissocrangon stylirostris					♦							♦	+	♦	♦	♦	♦	+						
Crangon nigromaculata					♦					♦		♦	+	♦	♦	♦	♦	♦	+	+	+			
Palaemon macrodactylus		♦	♦					♦	♦								+	♦	♦	♦	+			
Cancer magister					♦							♦	♦	♦	♦	♦	+							+
Cancer productus					♦					♦		♦	+	♦	♦	♦	♦	♦	+				+	+
Cancer gracilus				♦	♦					♦		♦	+	♦	♦	♦	♦	♦	+					
Cancer antennarius					♦					♦		♦	+	♦	♦	♦	♦	♦	♦	+				+

Resident species also reproduce over a relatively long period, although most of their larvae hatch in late spring and summer. Included in this group are delta smelt, arrow goby, topsmelt, and cheekspot goby. Winter spawning residents include staghorn sculpin and yellowfin goby, whereas bay goby and diamond turbot are residents that primarily reproduce in late summer and fall.

The duration of estuarine rearing varies widely—species may rear in the estuary for only a few months (for example, walleye surfperch) to several years (for example, starry flounder and brown rockfish). Most rearing is from late spring through early fall (Table 3); the late fall and winter spawners rear earlier than the spring and summer spawners. For some ocean species, there is a long interval between larval hatching and estuarine use. For example, California tonguefish and speckled sanddab have long pelagic phases and months pass between larval hatching and settlement or immigration of juveniles. Some species emigrate from the estuary well before maturity (for example, English sole), whereas others emigrate at or after maturity (for example, *Cancer magister* and brown rockfish).

The nursery area is often not the same as the spawning or pupping location for many of the species that immigrate to the estuary to reproduce and some of the residents (see Table 3). For example, Pacific herring spawn in polyhaline and euhaline salinities (see Table 2) but rear in mesohaline and polyhaline areas (see Table 3). Yellowfin goby, which are partially catadromous, spawn in mesohaline and polyhaline salinities (see Table 2) but rear in oligohaline and mesohaline areas (see Table 3).

Concurrent with the migration to lower salinities to rear, juveniles of most species move to warmer, shallow water. As they mature, larger juveniles migrate to deeper, cooler, more saline water. Many species begin emigrating from their upstream rearing areas or from the estuary in late summer or early fall, when water temperatures reach their seasonal maxima. Thus, there is a common temperature pattern associated with growth. For most species, temperature initially increases and then decreases with size. This pattern is due to ontogentic changes in temperature tolerances coupled with the seasonal temperature cycle.

Abundance Trends

Many estuarine species had similar abundance trends (Table 4) and these trends were often related to physical factors. Although species can be grouped by abundance trends, these groups may oversimplify our conception of the mechanisms controlling abundance. For example, the species whose abundance increased with outflow (see Table 4) generally benefited from the increased area or volume of oligohaline and mesohaline nursery habitat in high outflow years (CDFG 1992). But for some species, such as longfin smelt, this positive response to outflow may be partially due to increased transport of larvae from upstream spawning areas to nursery areas. For species that reproduce in the ocean, such as starry flounder and *Crangon franciscorum*, increased abundance may be also a result of increased transport of larger larvae and juveniles into the estuary by gravitational currents or increased immigration of juveniles in response to some cue present in "estuarine" waters.

Table 3 Salinity, location, and timing of juvenile rearing (age-0) for the most commonly collected species of fishes, shrimps, and crabs. ♦ indicates peak, + indicates lesser amount of rearing.

	Salinity					Location							Peak occurrence in estuary											
Species	Limnetic (0-0.5 ‰)	Oligohaline (0.5 - 5 ‰)	Mesohaline (5 - 18 ‰)	Polyhaline (18 -30 ‰)	Euhaline (>30 ‰)	Rivers and Streams	Delta	Suisun Bay	San Pablo Bay	Central Bay	South Bay	Ocean	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
bay goby				♦	♦				+	♦	♦		♦	♦	♦	♦	♦	♦	+				+	+
Pacific staghorn sculpin	+	+	♦	♦			+	+	♦	♦	+			♦	♦	♦	♦	♦	♦	♦	♦			
California halibut				♦	♦				+	♦	♦	♦	+	+	♦	♦	♦	♦					♦	♦
Pacific herring			♦	♦					♦	♦	♦				+	♦	♦	♦	♦	+	+			
jacksmelt				♦	♦				♦	♦	♦				+	♦	♦	♦	♦	♦	♦	♦	+	+
English sole			+	♦	♦				♦	♦	+	♦			+	♦	♦	♦	♦	♦	♦	♦	+	+
prickly sculpin	♦	♦	+			♦	♦	+								♦	♦	♦	+	+				
speckled sanddab				♦	♦				+	♦	♦		+			♦	♦	♦	♦	+			+	+
chinook salmon (fall run)	♦	♦	♦	♦	+	♦	♦	♦	♦	♦		♦				+	♦	♦	+					
northern anchovy			♦	♦	♦				♦	♦	♦					+	♦	♦	♦	♦	+	+		
longfin smelt		+	♦	♦	+		+	♦	♦	♦	+					+	♦	♦	♦	♦	♦	♦	+	+
splittail	♦	♦	+			♦	♦	+					+	+		+	♦	♦	♦	♦	♦	♦	+	+
white sturgeon	♦	♦	+				♦	♦	+				+	+		+	♦	♦	♦	♦	♦	♦	+	+
diamond turbot				♦	♦					♦	♦					+	♦	♦	♦	+	+			
Pacific pompano					♦					♦		♦				+	♦	♦	♦	♦	+	+		
white croaker				♦	♦				♦	♦	♦	♦					♦	♦	♦	+				
inland silverside	♦	♦	+			♦	♦	♦	+								♦	♦	♦	♦				
arrow goby				+	♦				+	♦	♦						♦	♦	♦	♦	+	+		
American shad	♦	♦	♦				♦	♦									+	♦	♦	♦	♦	+	+	
yellowfin goby	+	♦	♦				♦	♦	+		+						+	♦	♦	♦	♦	+	+	+
starry flounder	♦	♦	♦	+			♦	♦	♦	+	+	♦					+	♦	♦	♦	♦	♦	+	+
brown rockfish				+	♦				+	♦	+						+	♦	♦	♦	♦	♦	♦	♦
striped bass	♦	♦	+				♦	♦	♦		+		+	+	+		+	♦	♦	♦	♦	♦	♦	♦
California tonguefish				♦	♦				+	♦	♦							♦	♦	♦	♦	♦	+	+
threadfin shad	♦	♦	+				♦	+										♦	♦	♦	♦	♦	+	+
cheekspot goby				♦	♦				♦	♦	♦						+	+	♦	♦	♦	♦		
cheekspot goby				♦	♦				♦	♦	♦						+	+	♦	♦	♦	♦	+	+
delta smelt	♦	♦	+				♦	♦	+									+	♦	♦	♦	♦	♦	♦
topsmelt				♦	♦				+	♦	♦								♦	♦	♦	♦	+	+
plainfin midshipman				♦	♦				♦	♦	+								+	♦	♦	♦	+	
chameleon goby				♦	♦					+	♦									+	♦	♦	♦	♦
Pacific tomcod				♦	♦				+	♦										+	+	♦	♦	♦

Table 3 (Continued) Salinity, location, and timing of juvenile rearing (age-0) for the most commonly collected species of fishes, shrimps, and crabs. ♦ indicates peak, + indicates lesser amount of rearing.

	Salinity					Location							Peak occurance in estuary											
	Limnetic (0-0.5 ‰)	Oligohaline (0.5 - 5 ‰)	Mesohaline (5 - 18 ‰)	Polyhaline (18 -30 ‰)	Euhaline (>30 ‰)	Rivers and Streams	Delta	Suisun Bay	San Pablo Bay	Central Bay	South Bay	Ocean	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
Live bearers																								
white seaperch				♦	♦				+	♦	♦						+	♦	♦	♦	+	+		
walleye surfperch				♦	♦				+	♦	♦	♦					+	♦	♦	♦				
shiner perch				♦	♦			+	♦	♦	♦						♦	♦	♦	♦	♦	♦	+	+
pile perch				♦	♦				+	♦	♦	♦						+	♦	♦	+	+	+	+
dwarf perch				♦	♦				+	♦	♦	♦					♦	♦	♦	♦	+	+		
leopard shark				+	♦				+	♦	♦	♦			+	♦	♦	♦	♦	♦	♦	♦	+	+
brown smoothhound				+	♦				+	♦	♦	♦				+	♦	♦	♦	♦	+	+		
big skate				+	♦				+	♦	♦	♦		+	+	+	♦	♦	♦	♦	♦	+		
bat ray				+	♦				+	♦	♦	♦					+	+	♦	♦	♦	♦	+	+
Invertebrates																								
Crangon franciscorum		+	♦	+			+	♦	♦	+	+					+	♦	♦	♦	♦	+	+	+	
Heptacarpus stimpsoni				♦	♦				+	♦	♦	+	+				♦	♦	♦	♦				+
Crangon nigricauda			+	♦	♦			+	♦	♦	♦	+	+	+			♦	♦	♦	♦	+			+
Crangon nigromaculata				+	♦				+	♦	+	♦					♦	♦	♦	♦	♦			
Lissocrangon stylirostris					♦					♦		♦				+	+	♦	♦	♦	+	+		
Palaemon macrodactylus	+	♦	♦				♦	♦	+		+							+	♦	♦	♦	♦	+	+
Cancer gracilis				♦	♦				+	♦	+	♦	♦	♦		+	♦	♦	♦	♦		♦	♦	♦
Cancer magister			+	♦	♦			+	♦	♦	+	♦	+			+	♦	♦	♦	♦	♦	♦	♦	♦
Cancer productus				♦	♦				+	♦	+	♦	+			+	+	♦	♦	♦	+	+	+	+
Cancer antennarius				♦	♦				+	♦	♦	♦							+	♦	♦	♦	♦	+

Table 4 General categories in abundance trends for the most commonly collected fishes, shrimps, and crabs considered in this report[a]

Increased in high outflow years	*Increased during warm water events*	*Decreased during warm water events*	*Increased in the mid-1980s*	*Increased in the 1990s*	*Decreased through the mid-1980s and 1990s*
Crangon franciscorum	*Crangon nigromaculata*	*Cancer magister*	*Crangon nigricauda*	*Crangon nigromaculata*	delta smelt
longfin smelt	Pacific sardine	Pacific herring	brown smoothhound	*Heptacarpus stimpsonii*	jacksmelt
American shad	northern anchovy	northern anchovy	leopard shark	*Cancer antennarius*	barred perch
Pacific herring[b]	white croaker	starry flounder	bat ray	*Cancer gracilis*	pile perch
yellowfin goby	California halibut		white croaker	*Cancer productus*	shiner perch
starry flounder[b]	California tonguefish		bay goby	Pacific pompano	walleye surfperch
	diamond turbot		plainfin midshipman	chameleon goby	white seaperch
			California halibut		
			diamond turbot		
			speckled sanddab		

[a] Species common only in the beach seine were excluded, as this gear was used only through January 1987.
[b] In high outflow years, indices were lower in the 1990s than in the 1980s.

Above average ocean temperatures apparently resulted in increased abundance of a group of species that includes the shrimp *Crangon nigromaculata*, Pacific sardine, white croaker, and California halibut (see Table 4). The latitudinal distribution of these species is usually centered to the south of the estuary, and increased abundance may be due to a northerly movement of juveniles and adults with warm water. Also, several of these species, including California halibut, may have more successful local reproduction during warm water periods, as higher temperatures may stimulate maturation of gonads and increase fertilization, embryonic survival, and larval survival rates. Abundance of some species may have increased after a series of warm water events. Therefore, the frequency and duration of warm water events, as well as the magnitude, may be important factors.

Abundance of *Cancer magister*, Pacific herring, northern anchovy, and starry flounder decreased with increased ocean temperatures (see Table 4). With the exception of northern anchovy, the San Francisco Estuary is near the southern limit of these species' ranges. The observed abundance decreases may be due to a northward movement of a population or subpopulation during warm water events. Warm water events may also retard maturation of gonads and decrease fertilization, embryonic survival, and larval survival rates (for example, *Cancer magister* and Pacific herring).

In the mid-1980s, abundance of a number of species increased, including the shrimp *Crangon nigricauda*, white croaker, bay goby, and speckled sanddab (see Table 4). Although several factors probably contributed to this trend, increased area with euhaline and polyhaline salinities during the 1987–1992 drought was probably most important. During the drought, several species, including bay goby and *Crangon nigricauda*, had protracted spawning and multiple cohorts. This led to the hypothesis that higher salinities present all year in the estuary enhanced nursery conditions for many species within this group. However, abundance of some species, including white croaker and California halibut, increased prior to the onset of the drought. These initial abundance increases may have been in response to the 1986–1987 El Niño; favorable estuarine conditions associated with the drought then contributed to continued high abundance.

In the 1990s, a group of species including the rock crabs (*Cancer antennarius* and *C. productus*), the shrimp *Crangon nigromaculata*, and the chameleon goby, increased in abundance (see Table 4). All of these species inhabit euhaline and polyhaline areas of the estuary. Ocean temperatures were usually above average from 1992 to 1996 (see chapter 3, Figure 11), and the abundance of several of these species increased somewhat during previous warm water events. However, freshwater outflow was relatively high in 1995 and 1996, which leads us to ask how these "marine" species may have sustained high abundance through this period. We are not certain of the mechanisms that resulted in increased abundance.

The last group of species, including the surfperches, jacksmelt, and delta smelt, is notable for decreasing abundance as of the mid-1980s (see Table 4). Although the initial year of the decline varied, none of these species recovered to previous levels in the 1990s. The decline in delta smelt abundance may be due to several factors, including entrapment zone location, reverse flows, and food abundance (Sweetnam and Stevens 1993). Likewise, the decline of the remaining species in this group has not been attributed to a single factor, although overharvest by sport anglers has been proposed for the surfperches (see chapter 13).

For many species, especially seasonal inhabitants, physical factors associated with the ocean or the rivers at least partially control abundance. Abundance of most species that rear in oligohaline salinities increased with freshwater outflow. In contrast, abundance of several species that rear in polyhaline and euhaline salinities increased in low outflow years, but most did so during the prolonged 1987–1992 drought rather than during single low outflow years. Many species responded to increased ocean temperatures. This is not surprising, as the San Francisco Estuary is situated in the transitional zone between the subtropical fauna (Point Conception south) and the cold water fauna (Cape Blanco north), and contains species from both faunas (Parrish and others 1981).

The San Francisco Bay Study has increased our understanding and appreciation of the complexity of the estuary. There are still many gaps in our knowledge, including a definition of critical life stages and the factors affecting these stages. We will continue our attempts to differentiate between causal and covarying factors. To do this, we will need to augment the study's data with other data sources when possible, and propose directions for improved monitoring and future research. The better we understand the mechanisms that regulate species' abundance, whether natural or anthropogenic, the better prepared we will be to manage the estuary's resources in future years.

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