Cancer Crabs

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Introduction

Cancer crabs were the most common genus of brachyuran crabs collected by the San Francisco Bay Study's monitoring program from 1980 to 1996. Six species were collected in the otter trawl, 4 in the beach seine, and 5 in the ringnets (Table 1). Four of these species are the focus of this chapter: *Cancer magister*, the Dungeness crab; *C. productus*, the red rock crab; *C. antennarius*, the brown rock crab; and *C. gracilis*, the slender crab. The 2 other species, *C. anthonyi*, the yellow crab, and *C. jordani*, the hairy rock crab, are briefly reviewed.

Table 1 *Cancer* spp. catch by species and gear type at all stations and surveys from 1980 to 1996

Species	*Otter trawl*	*Beach seine*	*Ringnet*	*Total*
Cancer magister	4962	357	4580	9899
Cancer gracilis	3390	1	403	3794
Cancer productus	640	2	2704	3346
Cancer antennarius	1498	3	576	2077
Cancer anthonyi	42	0	4	46
Cancer jordani	2	0	0	2

Cancer magister supports a substantial commercial fishery and a smaller sport fishery in central California coastal waters. This is a male-only fishery, with a minimum size of 153 mm (6 inches) carapace width (CW) for the commercial fishery and 147 mm (5.75 inches) CW for the sport fishery. It is currently illegal to keep *C. magister* of any size caught in the San Francisco Estuary. The central California commercial fishery is discussed in more detail in the *C. magister* section.

Cancer productus and *C. antennarius*, along with *C.anthonyi* in southern California, collectively constitute the commercial rock crab fishery in California. Usually, only the claws are taken, although a limited market for live crabs has developed in recent years. There is a small sport fishery for rock crabs in San Francisco Bay. They are commonly caught using baited nets and traps from piers and jetties in Central Bay, northern South Bay, and lower San Pablo Bay. The minimum commercial size for rock crabs is 108 mm (4.25 inches) CW and the recreational minimum size is 102 mm (4 inches) CW, with a bag limit of 35 crabs per day.

Pacific coast *Cancer* species share many life history traits. Mating, which is between a soft shell female and hard shell male, occurs from spring to fall, depending on the species. Peak larval hatching is in winter or spring; all species have 6 planktonic larval stages (5 zoeal and 1 megalopal). Most juveniles settle in spring or summer and pass through 10 to 12 instars before maturity. Males grow faster than females, mature at a larger size, and reach a larger maximum size. The maximum number of instars is 12 or 13, but maximum age and size varies by species and location. Although *Cancer* crabs are demersal, substrate preference varies by species, ranging from sand to complex rocky reefs. All *Cancer* crabs are omnivores, but

the ability to eat hard-shelled organisms, such as mussels and barnacles, varies with claw morphology, which differs by species.

Methods

Methods common to all species are presented here and species-specific methods are presented in the individual species' sections that follow. Larval data were used only for seasonal abundance and a general description of distribution; zoeal data were available from 1980 to 1985 and megalopal data from 1980 to 1988. Only data from 1982 to 1993 for the original 9 stations were used for the ringnet abundance indices; although this survey changed substantially in 1994, the 1994 data were used in the size frequency and salinity-temperature analyses. Age–0 crabs were separated from age–1+ crabs by visual inspection of the monthly size frequency data and for some species, size-at-age information from the literature. Both the otter trawl and ringnet data were used for the sex ratio by size class, annual and seasonal abundance, and salinity and temperature analyses. Generally the otter trawl data were used for the annual and seasonal distributional analyses and the ringnet data were used for very general descriptions of distribution. All sizes are carapace width.

Cancer magister

Cancer magister, the Dungeness crab, ranges from Point Conception to the Aleutian Islands (Schmitt 1921, MacKay 1942, Dahlstrom and Wild 1983). It prefers sandy bottoms and has been collected from the intertidal to 230 m, but it is not abundant in waters >90 m. Male *C. magister* mature at about 116 mm and reach a reported maximum size of 210 mm and females mature at about 100 mm and reach a reported maximum size of 182 mm (Cleaver 1949, Butler 1960, Orensanz and Gallucci 1988). Both sexes probably live no more than 8 years (Butler 1961). Estuaries are important nursery areas for *C. magister* throughout much of its range (Tasto 1983, Emmett and Durkin 1985, Gunderson and others 1990).

Cancer magister supports a large commercial fishery from northern California to British Columbia. The San Francisco area fishery, which occurs exclusively along the coast outside of the San Francisco Estuary, historically made a major contribution to California landings. Landings from the San Francisco area reached a peak of almost 9 million pounds during the 1956–1957 season but declined to under 2 million pounds each season since 1961–1962 except for 1987–1988 and 1994–1995, when landings were 3.1 and 2.9 million pounds, respectively (Figure 1).

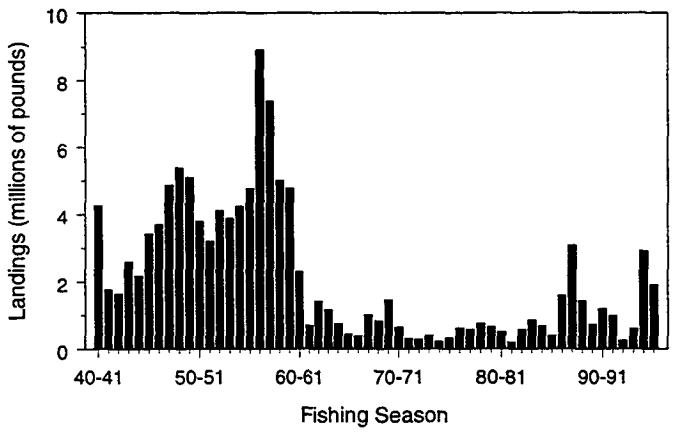

Figure 1 Commercial landings (millions of pounds) of *C. magister* from the San Francisco area (Princeton to Bodega Bay) by fishing season from 1940 to 1996

Mating occurs from March through May in the ocean and peak hatching occurs from late December to mid-January in the Gulf of the Farallones. *Cancer magister* larvae pass through the 6 planktonic stages over 105 to 125 days and are often carried far from the coast by currents after several larval stages. Possibly aided by currents, megalopae (the last larval stage) return to the nearshore coastal area and newly settled crabs immigrate to central San Francisco Bay from March to June (Reilly 1983a). Early instar crabs are most common in the channels north of the Golden Gate the first 2 to 3 months after immigration. By September, age–0 crabs are widely distributed in San Pablo and lower Suisun bays (Tasto 1983). In April and May age–1 crabs begin to consolidate near or in the channels and emigrate to the ocean, and by September most have emigrated.

A tagging study demonstrated that *C. magister* rearing in the San Francisco Estuary grew at about twice the rate of ocean-reared crabs and had an average size of approximately 100 mm 1 year after hatching (Collier 1983). Increased food availability, particularly crustaceans, and warmer estuarine temperatures may be responsible for this rapid growth (Tasto 1983). Estuary-reared crabs are probably recruited to the fishery 3 years after hatching, whereas ocean-reared crabs enter the fishery 4 to 5 years after hatching. Estimates of the number of juvenile crabs in the estuary, as a percentage of the total number of juveniles in the estuary and Gulf, ranged from 38% to 82% from 1975 to 1978 (Tasto 1983).

Cancer magister is both an important predator and prey in nearshore coastal and estuarine habitats (Pauley and others 1989). It is an omnivore and diet varies with size. In Grays Harbor, Washington, smaller crabs (<60 mm commonly preyed on small bivalves, medium sized crabs (60 to 100 mm) consumed more crustaceans (primarily *Crangon*) and small fish, and larger crabs consumed more small fish than bivalves and crustaceans (Stevens and others 1982). A variety of fish, including brown smoothhound, big skate, white sturgeon, green sturgeon, pile perch, Pacific staghorn sculpin, white croaker, and starry flounder, prey on *C. magister* in the estuary (McKechnie and Fenner 1971, Reilly 1983b). Pacific staghorn sculpin are the major predator of age–0 *C. magister* in Grays Harbor (Fernandez and others 1993).

Methods

Age–0 *C. magister* were separated from age–1+ crabs based on sizes from the literature (Collier 1983) and visual inspection of the monthly size frequency data (Table 2, Figures 2 and 3). Although age–0 *C. magister* did not enter the estuary until April or May, they were assigned January as a birth month because this is when peak hatching occurs in the Gulf of the Farallones. All sizes reported are carapace width (CW).

Table 2 Sizes used to separate age–0 from age–1+ C. magister

Month	*Size (mm)*
April	20
May	35
June	55
July	70
August	80
September	90
October	105
November	115
December	125

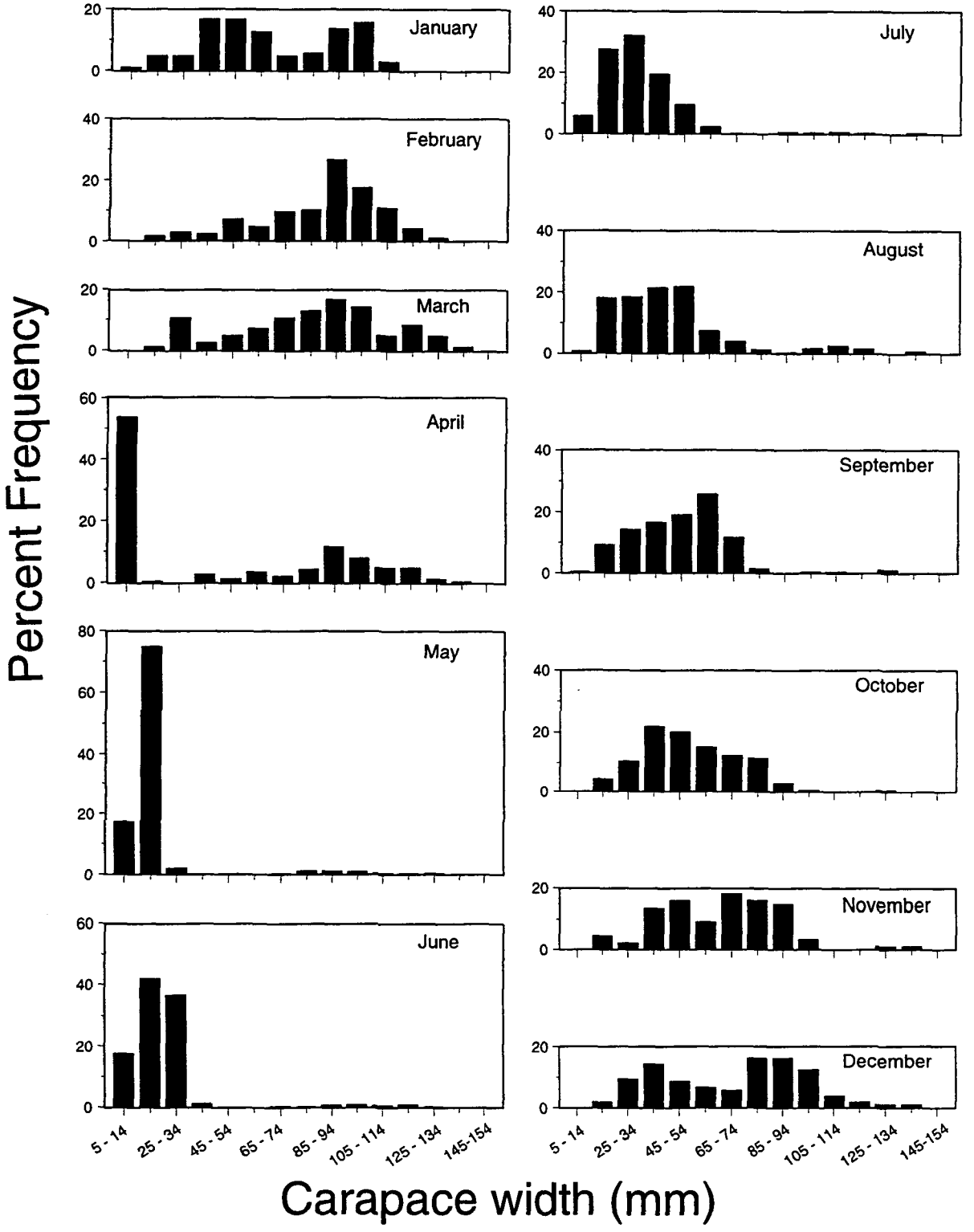

Figure 2 Size frequency of *C. magister* by month collected with the otter trawl. Size classes are every 10 mm, from 5 to 155 mm.

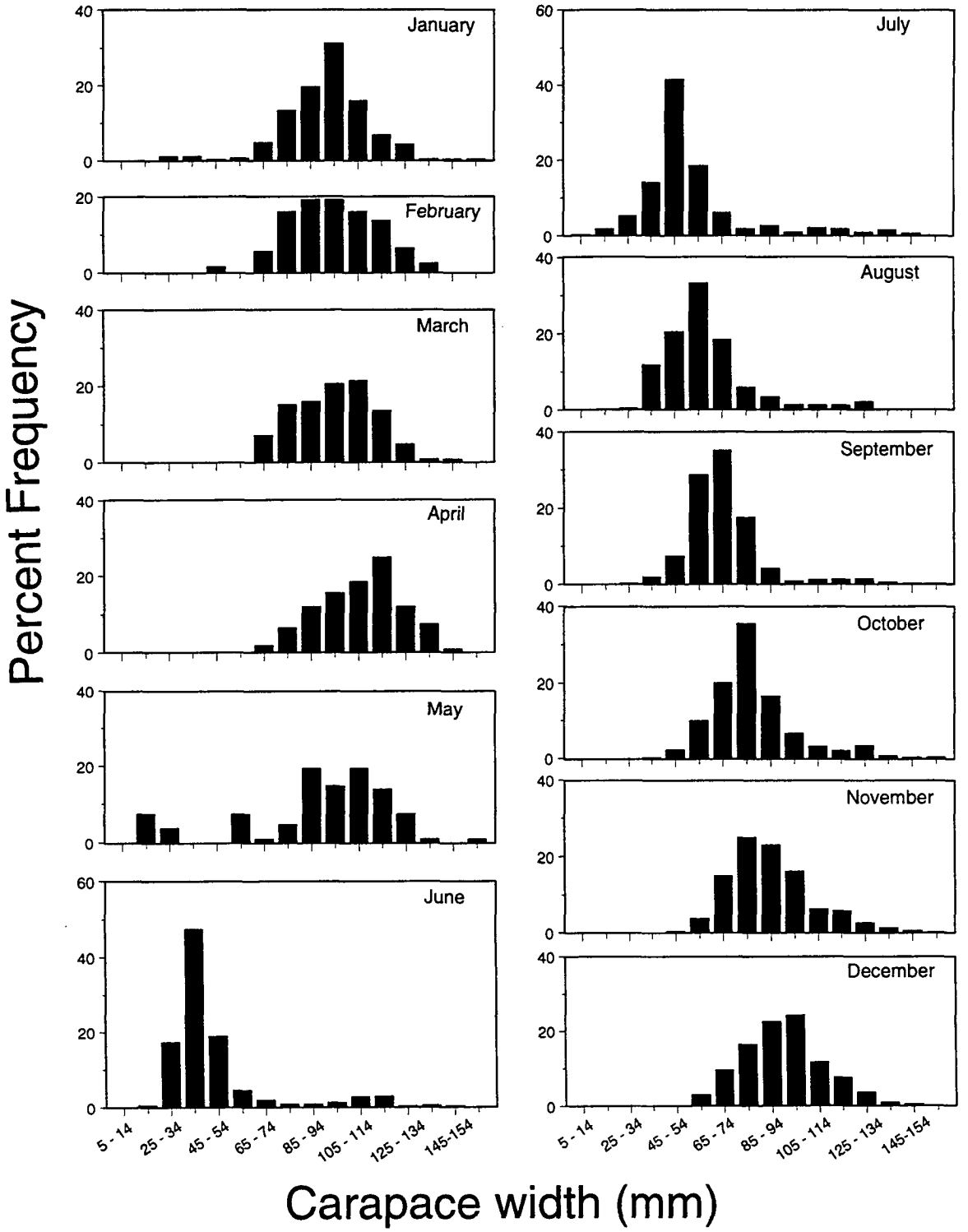

Figure 3 Size frequency of *C. magister* by month collected with the ringnets. Size classes are every 10 mm, from 10 to 165 mm.

The annual index periods selected were as follows: May through July for age–0 *C. magister* from the otter trawl, July through December for age–0 crabs from the ringnets, February through August for age–1+ crabs from the otter trawl, and January through August for age–1+ crabs from the ringnets. Note that the age–1+ indices from the ringnets were calculated only for 1983 through 1989, years in which we sampled all 12 months. For the seasonal distribution analyses, 1985 was selected as a representative year for age–0 crabs and 1985 and 1986 as representative "dry" and "wet" years for age–1+ crabs.

Results

Size Frequency

The largest female *C. magister* we collected was 136 mm and the largest male 200 mm. Twelve males were >150 mm and were probably age–2 crabs. No ovigerous females were collected. Most of the smallest *C. magister* (5 to 14 mm) entered the estuary from April through June (see Figure 2). Growth was rapid, and by December the median size was approximately 75 to 94 mm in the otter trawl (see Figure 2) and 85 to 104 mm in the ringnets (see Figure 3). A few smaller crabs (<35 mm) were collected in all months, which is evidence of either continual larval hatching and recruitment to the estuary or more likely, sporadic immigration of ocean-reared crabs.

For all sizes and both gear types, male *C. magister* outnumbered females 1.4:1, but this was primarily due to the large number of larger (>90 mm) males collected by the ringnets. The male to female ratio was 1.1:1 for the 30 to 59 mm size class, approximately equal for the 60 to 89 mm size class, and 3:1 for crabs >90 mm.

Abundance

Although *C. magister* was overall the most commonly collected species in the otter trawl and ringnets (see Table 1), there were large interannual variations in its abundance in both gear types. For example, in the otter trawl, age–0 indices ranged from 0 in 1983 and 1992 to over 11,000 in 1988 (Figure 4A, Table 3). The next highest indices (approximately 3,000) occurred in 1984 and 1985, whereas the indices from all other years were substantially lower. The high 1988 index was primarily due to very high May abundance (see Table 3). After May, abundance declined rapidly and the July 1988 index was less than either the July 1984 or July 1985 indices. The age–0 ringnet indices generally corresponded to the otter trawl indices; the major difference was that the highest ringnet index occurred in 1985, followed by 1984 and 1988 (Figure 4B, Table 4). The age–1+ *C. magister* annual indices tended to follow the age–0 indices with a 1 year lag (Figure 5, Tables 5 and 6). The highest age–1+ indices occurred in 1985, 1986, and 1989 and the lowest indices occurred in 1984, 1993, and 1994.

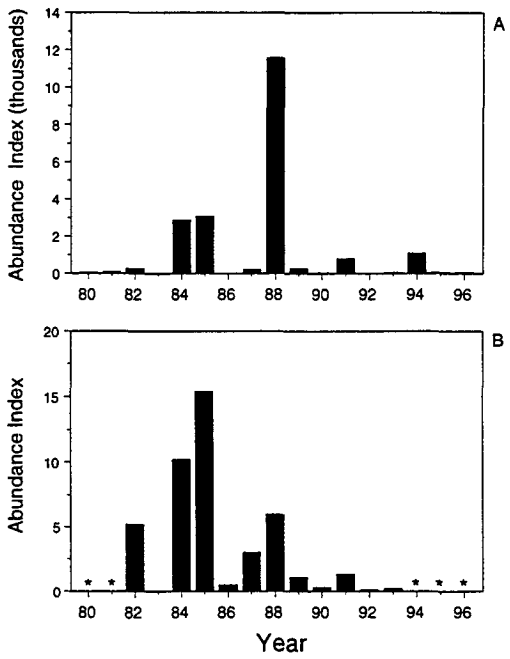

Figure 4 Annual abundance indices of age–0 *C. magister*: (A) otter trawl (1980 to 1996), the index period is May to July; (B) ringnets (1982 to 1993), the index period is July to December. Asterisk (*) indicates no survey.

Table 3 Monthly and annual abundance indices of age–0 *C. magister* collected with the otter trawl from 1980 to 1996. The index period is May to July.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Jul*
1980		0	0	0	0	117	19	19	173	142	58	31	45
1981	0	0	0	0	58	108	116	88	58	174	27	134	94
1982	0	0	0	115	556	189	58	0	0	162	0	19	268
1983	0	0	0	0	0	0	0	19	0	0	0	19	0
1984	0	0	0	388	2481	3673	2497	1489	1104	1643	92	193	2884
1985	0	0	0	31	640	6750	1825	668	1179	775	708	348	3072
1986	0	0	0	0	0	0	14	19	0	14	34	14	5
1987	0	0	0	0	85	377	121	162	21	41	138	168	194
1988	0	0	0	1601	26652	6698	1384	340	347	90	81	95	11578
1989	0	0	0	0	273	365	152	113					263
1990		0	0	0	0	65	27	0	14	14			31
1991		0	0	0	192	1511	685	141	236	305			796
1992		0	0	0	0	0	0	0	0	0			0
1993		0	0	0	0	108	54	0	7	0			54
1994		0	0	0	180	1957	1153	574	285	128			1097
1995	0	0	0	0	54	31	89		379	324	216	676	58
1996	0	0	0	0	54	0	144	26	48	68	0	61	66
1981–1988, 1996	0	0	0	237	3392	1977	684	312	306	330	120	117	

Table 4 Monthly and annual abundance indices of age–0 *C. magister* collected with the ringnets from 1982 to 1993. The index period is July to December. CPUE x 10.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jul–Dec*
1982					0	1	9	80	123	31	60	20	52
1983	0	0	0	0	0	0	0	0	0	1	0	0	0
1984	0	0	0	0	11	168	88	141	174	76	61	72	102
1985	0	0	0	0	0	8	3	56	283	201	191	188	154
1986	0	0	0	0	0	0	0	1	2	2	9	16	5
1987	0	0	0	0	0	0	21	18	40	63	18	19	30
1988	0	0	0	0	2	176	64	97	56	19	79	43	60
1989	0	0	0	0	0	1	2	3	5	28	18	19	11
1990							1	0	0	2	10	8	3
1991							7	9	10	21	19	13	13
1992							0	0	0	1	2	1	1
1993							2	3	1	0	4	3	2
1983–1989	0	0	0	0	2	50	26	46	81	58	54	51	

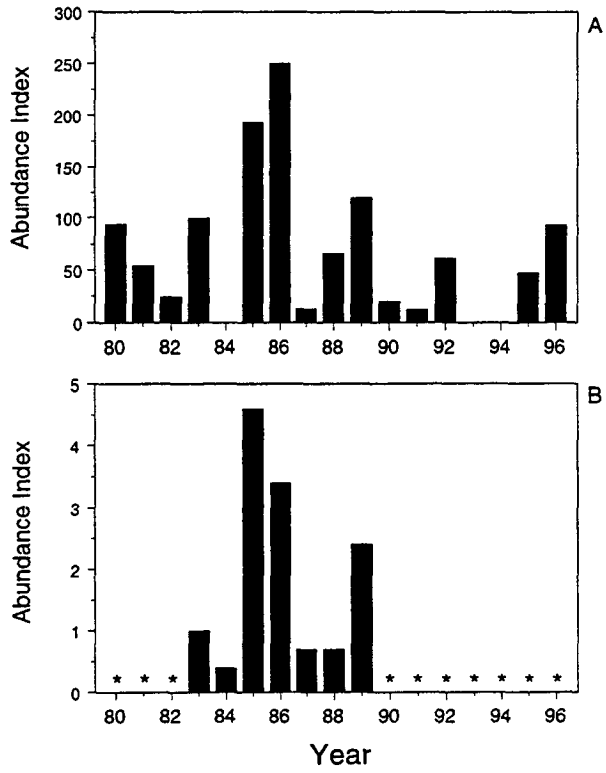

Figure 5 Annual abundance indices of age–1+ *C. magister*: (A) otter trawl (1980 to 1996), the index period is February to August; (B) ringnets (1983 to 1989), the index period is January to August. Asterisk (*) indicates no survey or no data.

Table 5 Monthly and annual abundance indices of age–1+ *C. magister* collected with the otter trawl from 1980 to 1996. The index period is February to August.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Aug*
1980		414	44	77	77	19	27	0	0	0	0	0	94
1981	0	134	38	77	19	19	93	0	0	0	0	19	54
1982	22	19	0	0	93	0	0	54	0	0	0	19	24
1983	19	93	0	514	27	31	0	27	0	0	0	0	99
1984	0	0	0	0	0	0	0	0	0	0	0	0	0
1985	223	454	126	227	330	153	34	27	19	0	0	27	193
1986	566	683	220	154	366	208	27	92	0	7	0	0	250
1987	7	40	0	19	26	0	7	0	0	0	27	0	13
1988	74	111	48	183	7	91	0	19	0	0	0	0	66
1989	177	74	211	190	47	127	154	38					120
1990		28	21	59	19	14	0	0	0	0			20
1991		21	14	7	14	27	0	0	7	0			12
1992		198	26	125	68	7	0	0	0	0			61
1993		0	0	0	0	0	0	0	0	0			0
1994		0	0	0	0	0	0	0	0	0			0
1995	47	146	81	27	27	0	0		0	0	27	0	47
1996	541	227	153	0	216	0	0	54	54	0	0	0	93
1981–1988, 1996	161	196	65	130	120	56	18	30	8	1	3	7	

Table 6 Monthly and annual abundance indices of age–1+ *C. magister* collected with the ringnets from 1983 to 1989. The index period is January to August. CPUE × 10.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jan–Aug*
1982					19	6	1	8	14	8	10	4	
1983	24	28	1	19	0	1	2	1	0	1	3	0	10
1984	1	1	0	0	0	19	3	6	2	1	1	0	4
1985	133	62	76	40	40	7	3	3	13	16	13	7	46
1986	148	1	31	22	38	8	0	21	8	11	13	8	34
1987	21	13	4	10	1	2	4	1	4	6	8	6	7
1988	8	9	16	0	4	8	4	4	3	2	4	2	7
1989	56	24	12	33	10	17	23	19	10	18	10	0	24
1990							2	1	1	2	7	3	
1991							2	0	1	0	1	0	
1992							1	0	1	0	1	0	
1993							2	0	0	0	0	1	
1983–1989	57	20	20	17	13	9	6	8	6	7	8	3	

Table 7 Monthly catch of *C. magister* zoeae (1980 to 1985) and megalopae (1980 to 1988)

Month	*Zoeae*	*Megalopae*
January	142	0
February	10	0
March	0	1
April	0	24
May	0	11
June	0	2
July	0	0
August	0	0
September	0	0
October	0	0
November	0	0
December	0	0

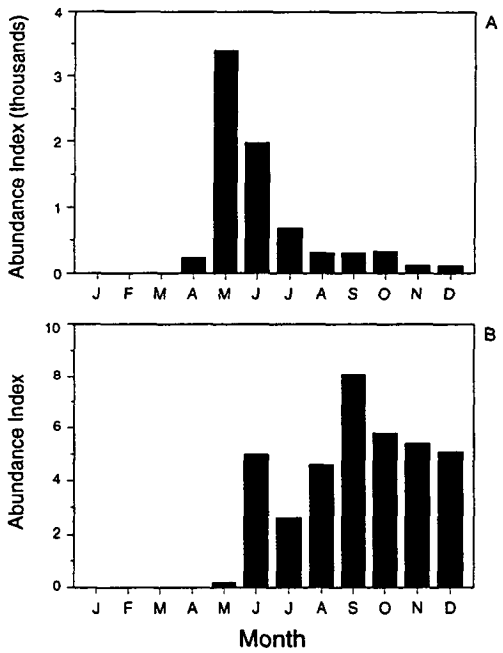

Figure 6 Monthly abundance indices of age–0 *C. magister*: (A) otter trawl (1981 to 1988 and 1996) and (B) ringnets (1983 to 1989)

Cancer magister zoeae were collected only in January and February but megalopae were collected from March through June (Table 7). The first age–0 crabs were usually collected with the otter trawl in April or May (see Table 3), although in years with low abundance the first collections were as late as August (for example, 1983). Age–0 *C. magister* were typically most abundant from May through July in the otter trawl (Figure 6A). The most notable exception was in 1995, when abundance peaked in December (see Table 3). This peak was comprised of crabs 25 to 60 mm that had recently immigrated to the estuary from the ocean rather than recently settled crabs. Age–0 catches in the ringnets increased over the summer and usually peaked in September or October (Figure 6B), except in 1988 when ringnet abundance peaked in June (see Table 4).

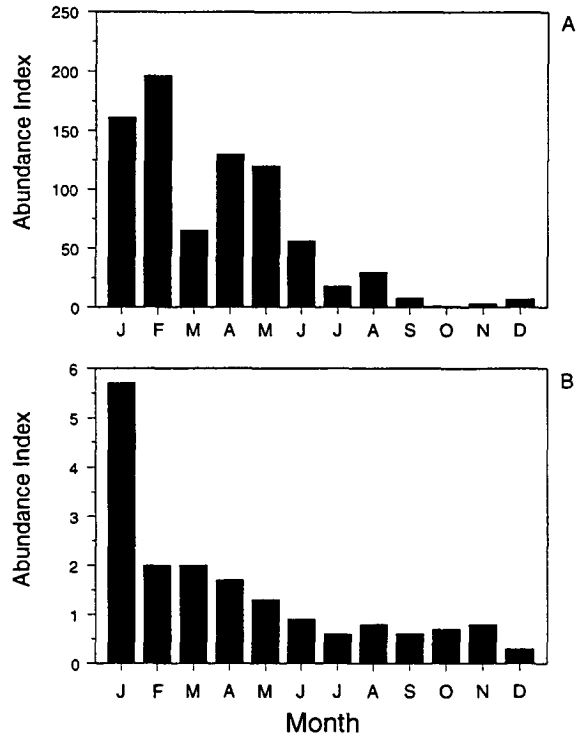

Figure 7 Monthly abundance indices of age–1+ *C. magister*: (A) otter trawl (1981 to 1988 and 1996) and (B) ringnets (1983 to 1989)

Abundance of age–1+ *C. magister* in the otter trawl was relatively high until May and few crabs were collected after August (Figure 7A, see Table 5). In the ringnets, abundance appeared to decrease dramatically from January to February and then slowly through July (Figure 7B, see Table 6). It remained at low but stable levels through December. The monthly indices did not decrease steadily every year; some of the extreme fluctuations in catch may have been because crabs moved from the sampling area or were less vulnerable to the sampling gear during high outflow events. For example, the ringnet CPUE decreased precipitously from 148 to 1 from January to February 1986 (see Table 6) during an extremely high outflow event (see Introduction chapter, Figure 2). Although CPUE increased in March, it never recovered to the pre-outflow event level. Examination of the size frequency data also indicated that a small number of ocean-reared age–1+ crabs immigrated to the estuary in some years.

Distribution

Cancer magister zoeae were restricted to Central Bay, but megalopae were collected from South Bay near Oakland to upper San Pablo Bay (stations #104 and #320, see Methods chapter, Figure 1). Age–0 *C. magister* were most commonly collected in Central, San Pablo, and Suisun bays during the index period of May through July (Figure 8). Because of the months and gear type, these data most accurately represent the distribution of early instar crabs within the estuary. There was little interannual difference in distribution during these months—crabs were concentrated in Central Bay in all years except 1981, 1984, and 1994, when CPUE was highest in San Pablo Bay. Crabs used Suisun Bay primarily in years with low freshwater outflow (for example, 1988 and 1994) and were collected in the west delta only in 1988.

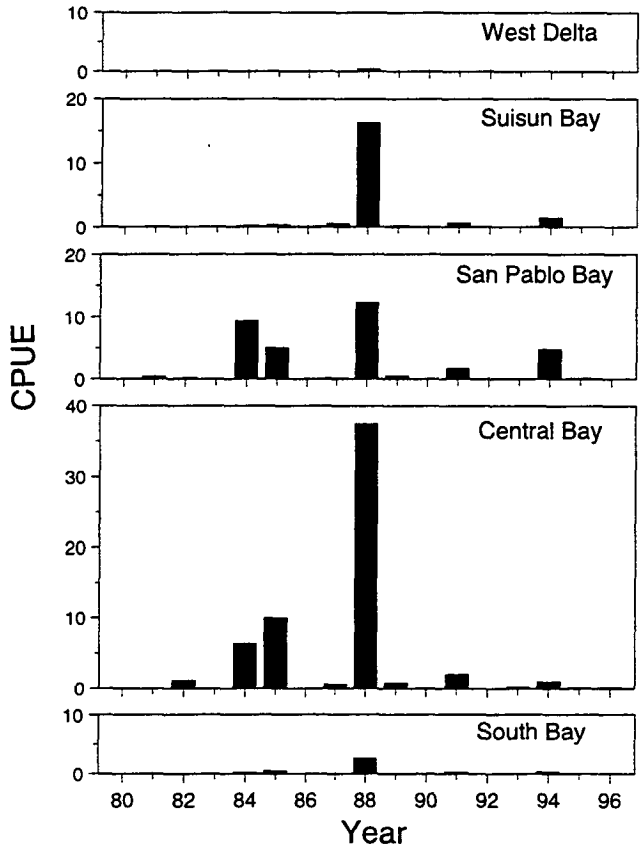

Figure 8 Annual distribution (CPUE) of age–0 *C. magister* collected with the otter trawl for May to July from 1980 to 1996

The annual distribution of age–1+ *C. magister* varied more with outflow than the distribution of age–0 *C. magister*, probably because winter and spring months were used to calculate the average CPUE. Age–1+ crabs were concentrated in Central Bay during the high outflow years 1982, 1983, 1986, 1995, and 1996, in San Pablo Bay in 1980, 1981, and 1985, and in Suisun Bay during the 1987 to 1992 drought (Figure 9).

The first age–0 *C. magister* were usually collected by the otter trawl in Central Bay and lower San Pablo Bay in April or May (Figure 10). Over a period of 1 to 2 months they moved upstream, and their distribution was centered in San Pablo or Suisun bays through December. Although not shown in Figure 10, age–0 crabs were first collected in the channels and moved to the shoals through summer. In years with high outflow, age–1+ *C. magister* moved to San Pablo and Central bays in winter before emigrating to the ocean (Figure 11). In years with low outflow, age–1+ crabs remained in San Pablo and Suisun bays (primarily Carquinez Strait) through winter and emigrated in late spring and summer (Figure 12). Examination of the sex and size frequency data revealed that female *C. magister* emigrated when they reached maturity, but males stayed in the estuary for at least 1 molt past maturity. Consequently, most of the age–1+ *C. magister* collected in the estuary were males and a few males remained in the estuary at least 2 years.

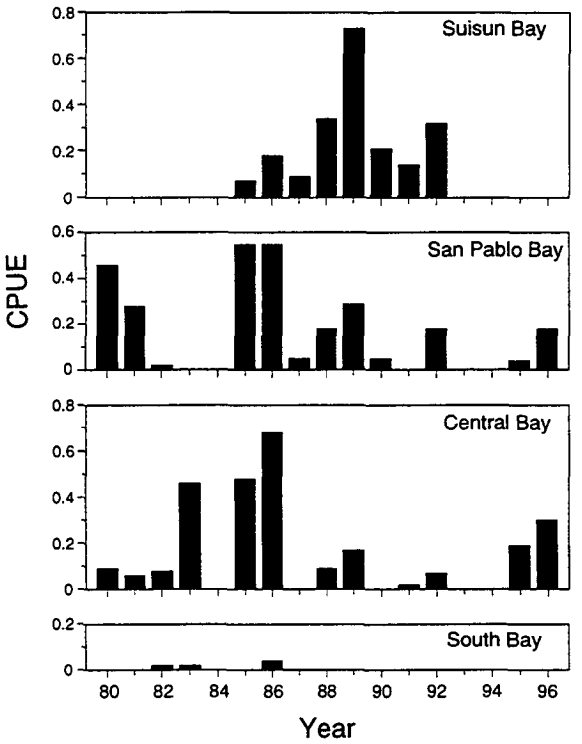

Figure 9 Annual distribution (CPUE) of age–1+ *C. magister* collected with the otter trawl for February to August from 1980 to 1996

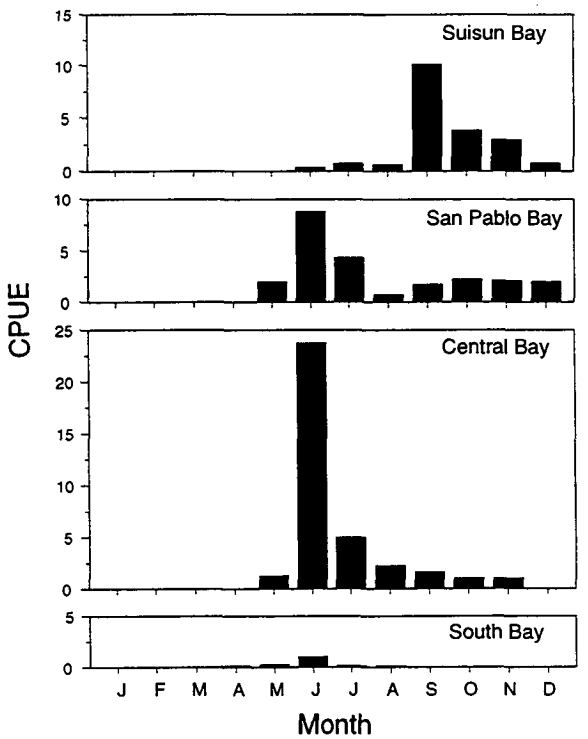

Figure 10 Monthly distribution (CPUE) of age–0 *C. magister* collected with the otter trawl in 1985

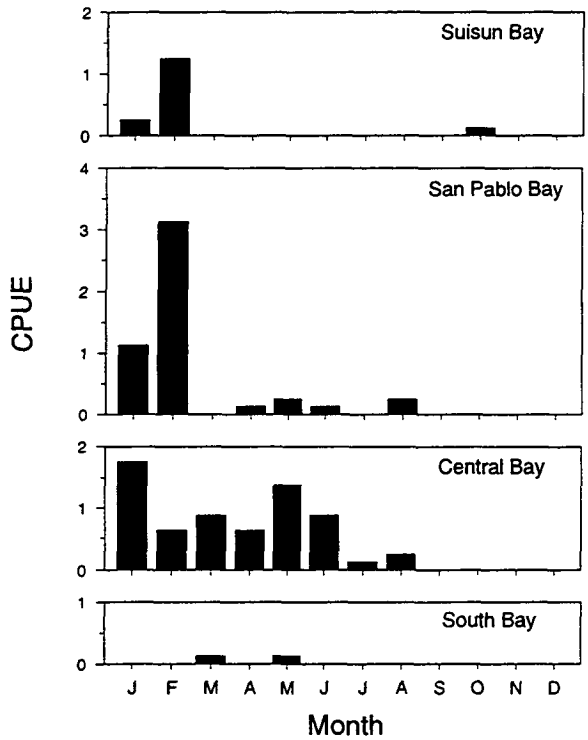

Figure 11 Monthly distribution (CPUE) of age–1+ *C. magister* collected with the otter trawl in 1986

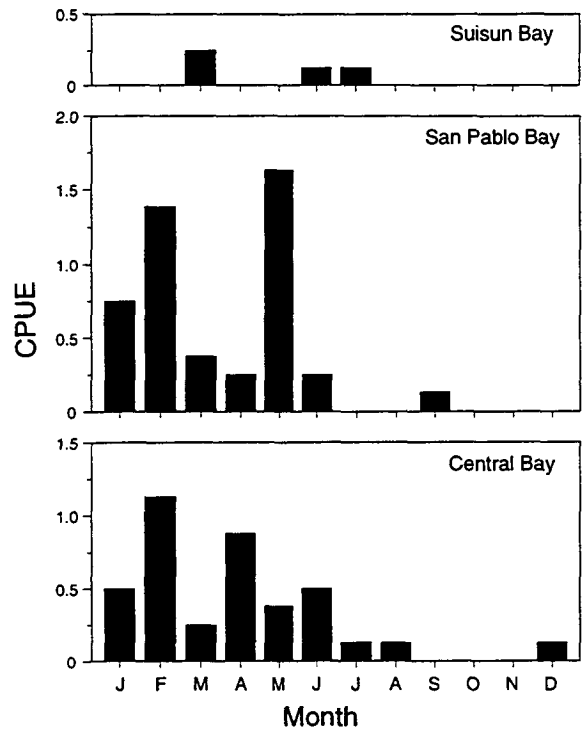

Figure 12 Monthly distribution (CPUE) of age–1+ *C. magister* collected with the otter trawl in 1985

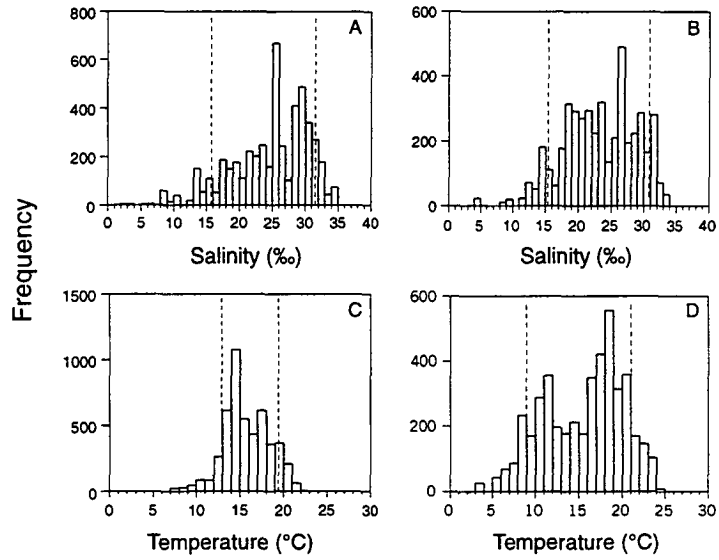

Figure 13 Salinity (‰) and temperature (°C) distributions of all sizes of *C. magister* collected with the otter trawl (1980 to 1996) and ringnets (1982 to 1994): (A) salinity, otter trawl; (B) salinity, ringnets; (C) temperature, otter trawl; (D) temperature, ringnets. Dashed vertical lines are the 10th and 90th percentiles.

Table 8 Salinity (‰) and temperature (°C) statistics for all sizes of *C. magister* from the otter trawl (1980 to 1996) and ringnets (1982 to 1994)

	Mean (Standard Deviation)	*Minimum*	*Maximum*	*10th Percentile*	*90th Percentile*
Salinity					
Otter trawl	24.7 (6.0)	1.2	34.3	15.7	31.5
Ringnets	23.3 (5.6)	1.9	33.4	15.4	30.8
Temperature					
Otter trawl	15.8 (2.6)	7.3	22.7	12.9	19.4
Ringnets	15.8 (4.6)	6.0	24.5	9.0	21.0

Salinity and Temperature

Cancer magister was common over a relatively wide range of salinities and temperatures; most individuals were collected from 15‰ to 32‰ and 9 to 20 °C (Figure 13). The mean salinities were very similar for the otter trawl and ringnets (mean = 24.7‰ and 23.3‰, respectively), as were the ranges and the 10th and 90th percentiles (Table 8). Although the mean temperatures were identical for both gear types (mean = 15.8 °C, see Table 8), *C. magister* was collected over a somewhat wider range of temperatures in the ringnets than in the otter trawl. In the ringnets, 80% of the individuals were collected from 9.0 to 21.0 °C, whereas in the otter trawl, 80% were collected from 12.9 to 19.4 °C (10th and 90th percentiles respectively).

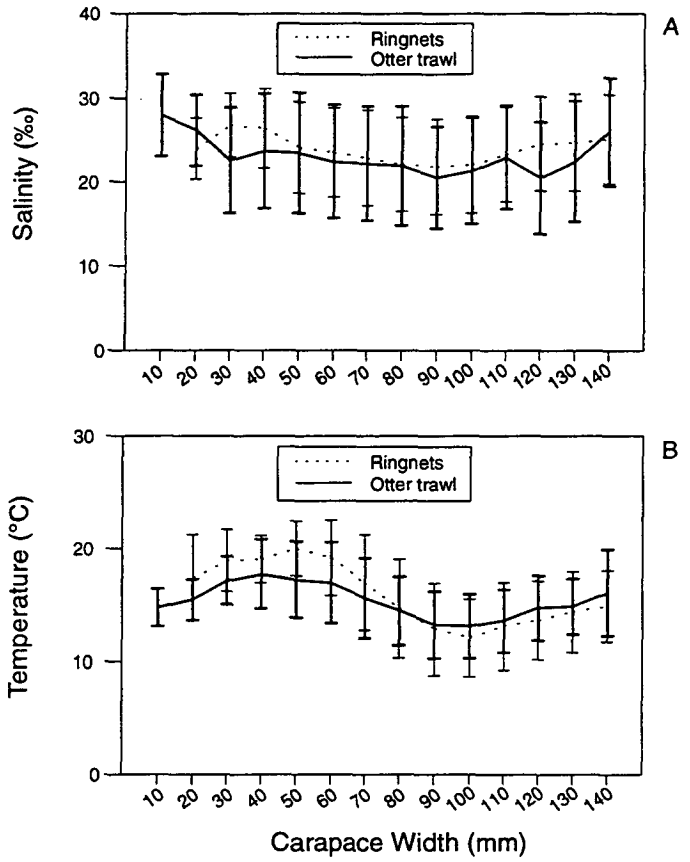

Figure 14 Mean salinity and temperature (±1 standard deviation) of *C. magister* by size class collected with the otter trawl and the ringnets: (A) salinity (‰), (B) temperature (°C). Size classes are every 10 mm, from 5 to 145 mm.

Male *C. magister* were collected at slightly higher mean salinities than females by both gear types (males at 22.7‰, females at 22.4‰ in the otter trawl, males at 23.4‰, females at 22.9‰ in the ringnets). The mean temperature at point of capture was slightly higher for males than for females in the otter trawl (males at 16.2 °C, females at 16.0 °C), but lower in the ringnets (males at 15.5 °C, females at 16.2 °C).

The mean salinity and temperature at point of capture varied by size class and to some extent, gear type. In general, the mean salinity gradually decreased with size until the crabs reached 85 to 114 mm and then increased with size (Figure 14A). In the otter trawl, the smallest size class (5 to 14 mm) was collected at a mean salinity of 28.0‰, the 85 to 94 mm size class at 20.5‰, and the 135 to 144 mm size class at 26.0‰.

Temperature at point of capture increased as size increased to 35 to 44 mm, then decreased for crabs 85 to 114 mm, and again increased as crabs grew to 135 to 144 mm (Figure 14B). In the otter trawl, the smallest crabs (5 to 14 mm) were collected at a mean temperature of 14.7 °C; the mean temperature increased to 17.7 °C for crabs 35 to 44 mm and gradually decreased for each size group to a low of 13.1 °C for crabs 95 to 104 mm before increasing again to 19.3 °C for the 135 to 144 mm size class. *Cancer magister* collected with the ringnets were consistently captured at higher temperatures than those collected with the otter trawl until they were 75 to 84 mm; above this size, they were captured at lower temperatures.

Discussion

The general distribution patterns of *C. magister* in the San Francisco Estuary by season, salinity, and temperature agree with literature results (Collier 1983, Tasto 1983). First and second instar crabs were first collected in April or May from Central Bay and the San Pablo Bay channel. Over several months, age–0 crabs moved upstream and to shoals and intertidal areas. These crabs were collected at some of the highest temperatures and the lowest salinities of all *C. magister* collected. Most females emigrated from the estuary when they matured in late fall or winter. Males generally remained in the estuary longer than females and some males remained through their second summer and fall. This differential emigration by sex agrees with the findings of Orensanz and Gallucci (1988) in Garrison Bay, Puget Sound, except that crabs in the San Francisco Estuary grew at a much faster rate than in Garrison Bay and the timing of emigration differed.

Cancer magister distribution was affected by the magnitude of freshwater outflow and to some extent, year class strength. Age–0 crabs were distributed farther upstream in low outflow years than in high outflow years, although all years with high outflow had low abundance. Freshwater outflow also affected the timing of immigration and emigration, as immigration to the estuary was apparently delayed in some high outflow years, and crabs emigrated from the estuary before they were mature if winter outflow was relatively high.

The large interannual variation in abundance of *C. magister*, from 0 in some years to very high abundance in others is notable. Tasto (1983) concluded that the year class strength of *C. magister* in the estuary was directly related to the year class strength of megalopae in the Gulf of the Farallones during spring. The effects of ocean temperature and currents on the hatching success, survival, and distribution of *C. magister* larvae are well documented—years with warm ocean temperatures or frequent winter storms resulted in poor recruitment of *C. magister* to the estuary (Lough 1976, Reilly 1983a, Wild 1983, Johnson and others 1986). During this study, there were several warm water periods (see Salinity and Temperature chapter, Figure 11), years with frequent winter storms, and years with very warm ocean temperatures combined with frequent winter storms (for example, 1982, 1983, and 1993). Abundance of age–0 *C. magister* in the estuary was never high in any of these years. But not every year with relatively cool ocean temperatures and few winter storms resulted in a strong year class (for example, 1991).

There is also evidence of interannual differences in survival of age–0 *C. magister*. Abundance of early instar crabs in the otter trawl was highest in 1988, but the 1988 ringnet index was lower than the 1984 and 1985 indices. As the ringnet index represents older crabs, this difference in relative abundance was probably due to a lower survival rate of early instar crabs in 1988. The contribution of each year class to the fishery is additional evidence that the 1988 year class was ultimately smaller than either the 1984 or 1985 year classes. The large 1984 and 1985 year classes undoubtedly contributed to the increased commercial landings in 1987 to 1988 (see Figure 1), but neither the 1990–1991 nor 1991–1992 landings increased, indicating the 1988 year class did not make a significant contribution.

Cancer magister uses the San Francisco Estuary almost strictly as a nursery area, which is unique among the *Cancer* crabs discussed in this chapter. Age–0 crabs apparently osmoregulate readily in brackish water, which is reflected by the relatively wide range of salinities *C. magister* occupied compared to *C. antennarius*, *C. gracilis*, and *C. productus*. Although *C. magister* uses San Pablo and Suisun bays to a greater extent than either *C. antennarius*, *C. gracilis*, or *C. productus*, it was not collected at substantially warmer temperatures than these 3 species.

Cancer gracilis

Cancer gracilis, the slender crab, ranges from Alaska to Baja California (Schmitt 1921). It is sometimes found intertidally on mudflats, but is more common subtidally on sandy or muddy bottoms and in eelgrass beds (Knudsen 1964, Orensanz and Gallucci 1988). *Cancer gracilis* is considered to be a stenohaline species, as it is intolerant of low salinities (Gross 1957). It is the smallest of the *Cancer* species included in this report; males have been reported to reach a maximum size of 115 mm, females 106 mm (Orensanz and Gallucci 1988).

Ovigerous *C. gracilis* are most common from December through April in Puget Sound, although many females produce more than 1 brood per year (Knudsen 1964). The reproductive season is apparently protracted: in Puget Sound, ovigerous females are present from February through August, larval hatching occurs from March through September, and juvenile settlement occurs in late summer (Orensanz and Gallucci 1988). There is limited information about the *C. gracilis* reproductive cycle in California. In Monterey Bay, peak larval abundance is from January through March (Hsueh 1991).

Reproductive aggregates, dominated by females and with a maximum aggregate density of 50 crabs/m^2, occur in summer in Puget Sound (Orensanz and others 1995). Peak mating activity occurs in August, towards the end of the larval hatching season. The minimum ovigerous size in Puget Sound is 48 mm; 50% of the females are mated at 54 mm, and the smallest mated male was 77 mm (Orensanz and others 1995). Both sexes mature at instar 10 or 11, which is within 1 year after settlement in Puget Sound. Both sexes remain in the same area all year and neither mature crabs nor ovigerous females migrate to nearshore waters (Orensanz and Gallucci 1988).

Bivalves, polychaetes, and barnacles are the primary prey items of *C. gracilis*; it is occasionally a pest in oyster beds (Knudsen 1964, Orensanz and Gallucci 1988, Jensen 1995). A variety of fishes prey on *C. gracilis* in the San Francisco Estuary. Major predators include brown smoothhound, big skate, green sturgeon, rubberlip seaperch, pile perch, and starry flounder. Minor predators include spiny dogfish, Pacific tomcod, white sturgeon, striped bass, redtail surfperch, white seaperch, staghorn sculpin, bonehead sculpin, and white croaker (CDFG, unpublished data). Boothe (1967) also reported that staghorn sculpin and starry flounder prey upon *C. gracilis*.

Methods

Male and female *C. gracilis* <35 mm were classified as age 0 and all larger crabs as age 1+. The annual index periods selected were as follows: May through October for age–0 *C. gracilis* from the otter trawl, February through October for age–1+ crabs from the otter trawl, and July through December for crabs (all age classes) from the ringnets. Age–1+ crabs from the otter trawl were used for analysis of seasonal sex ratio trends. For analysis of channel-shoal distribution, stations #215 (channel) and #243 (shoal) were selected based on the relatively high otter trawl catches of *C. gracilis*.

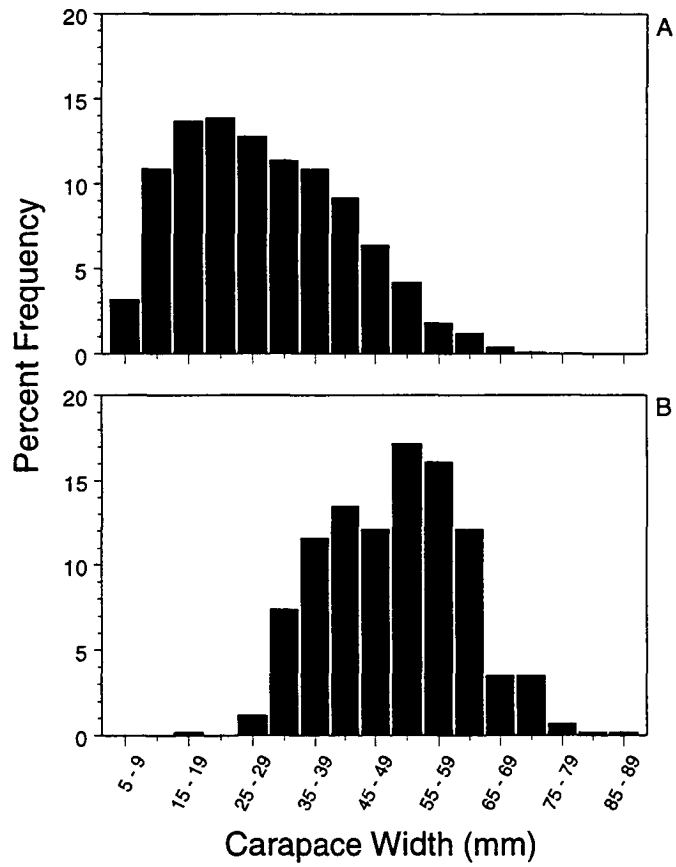

Figure 15 Size frequency of *C. gracilis*: (A) otter trawl, 1980 to 1996; (B) ringnets, 1982 to 1994. Size classes are every 5 mm, from 5 to 90 mm.

Results

Size and Size Frequency

The largest male *C. gracilis* collected by this study was 85 mm, the largest female 70 mm. A total of 57 ovigerous females was collected, ranging from 25 to 54 mm; 10 were from 25 to 34 mm and the remainder were larger. Based on the minimum ovigerous size, age–1+ *C. gracilis* from the San Francisco Estuary were mature. The otter trawl collected age–0 and age–1+ crabs (Figure 15A), whereas the ringnets collected primarily age–1+ crabs (Figure 15B). Two size groups were distinguishable in the March, April, and December otter trawl data (Figure 16). Small crabs (<15 mm) were collected every month and the mode of age–0 crabs could be readily followed from March through December.

The ratio of male to female *C. gracilis* collected by the otter trawl changed with size. For crabs 20 to 24 mm, females slightly outnumbered males; the ratio was 0.8:1. As the crabs approached maturity, even more females were collected than males and the ratio changed to 0.5:1 for crabs 30 to 34 mm. The number of males increased in the larger size classes—the sex ratio was approximately equal for *C. gracilis* 45 to 49 mm and males outnumbered females by 5:1 for crabs >50 mm. In contrast to the otter trawl, the ringnet catch was dominated by male *C. gracilis* for all size classes >30 mm. The male to female ratio was 1.5:1 for the 30 to 34 mm size class, 2.7:1 for the 45 to 49 mm size class, and 9:1 for crabs >50 mm.

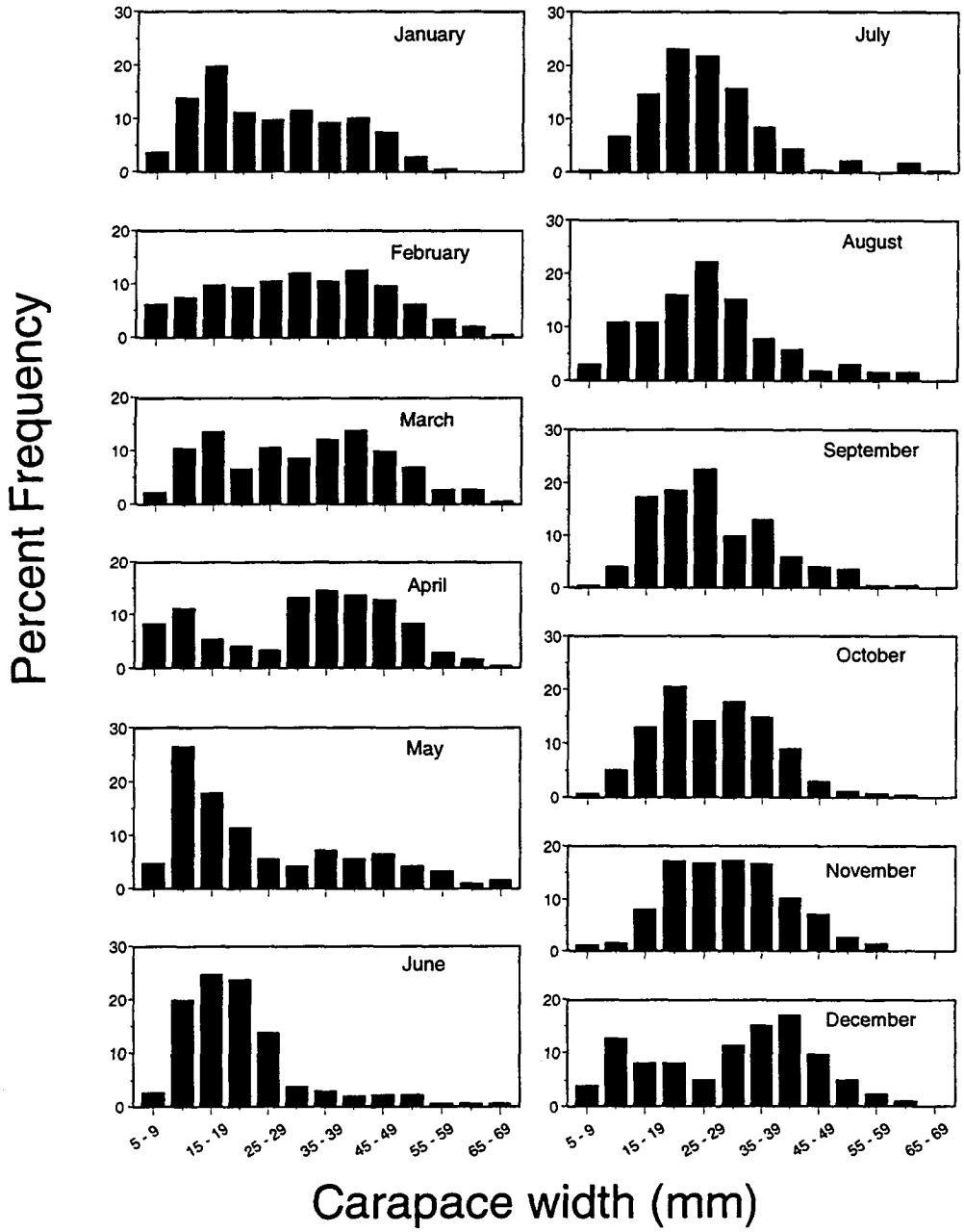

Figure 16 Size frequency of *C. gracilis* by month collected with the otter trawl. Size classes are every 5 mm, from 5 to 70 mm.

Abundance

Cancer gracilis was the 2nd most common species of *Cancer* crab collected by the otter trawl, but ranked 4th in the ringnets (see Table 1). The annual abundance of age–0 crabs was relatively low through the 1980s and increased in the early 1990s; the highest index was in 1994, followed by 1991 and 1993 (Figure 17A, Table 9). The abundance trend of age–1+ *C. gracilis* was similar to the trend for age–0 crabs, with the highest indices during the 1990s (Figure 17B, Table 10). This trend was not shared by the ringnet data, where the annual highest indices were in 1987, 1988, and 1992 (Figure 18, Table 11). Note the ringnet sampling stopped in 1993, so the otter trawl and ringnet indices are not entirely comparable.

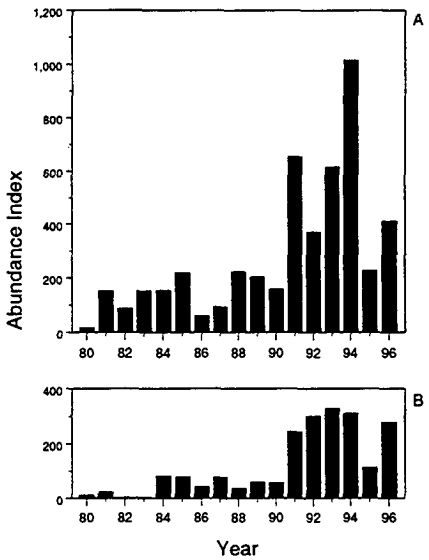

Figure 17 Annual abundance indices of *C. gracilis* collected with the otter trawl from 1980 to 1996: (A) age 0, the index period is May to October; (B) age 1+, the index period is February to October

Table 9 Monthly and annual abundance indices of age–0 *C. gracilis* collected with the otter trawl from 1980 to 1996. The index period is May to October.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Oct*
1980		36	0	0	0	27	0	27	0	46	0	0	17
1981	0	0	0	0	0	50	181	494	27	162	27	0	152
1982	0	0	0	0	309	0	31	27	0	155	0	0	87
1983	185	0	216	0	0	31	54	216	54	552	568	108	151
1984	514	784	243	243	243	328	189	27	135	0	73	58	154
1985	0	27	54	27	212	471	173	108	85	270	27	27	220
1986	127	842	0	0	0	166	27	81	0	81	27	54	59
1987	212	127	189	27	54	0	0	54	81	366	730	595	93
1988	568	108	162	189	529	437	235	135	0	0	54	216	223
1989	54	27	135	135	90	414	166	144					204
1990		982	1383	139	77	143	117	220	324	73			159
1991		1023	1866	634	771	1402	561	577	418	208			656
1992		227	139	166	298	229	687	54	543	413			371
1993		379	545	379	541	252	942	541	491	930			616
1994		297	135	204	846	2192	417	1248	1067	328			1016
1995	539	572	301	27	54	0	27		838	216	2947	622	227
1996	1776	144	27	135	410	406	139	588	216	707	85	807	411
1981–1988, 1996	376	226	99	69	195	210	114	192	66	255	177	207	

Table 10 Monthly and annual abundance indices of age–1+ *C. gracilis* collected with the otter trawl from 1980 to 1996. The index period is February to October.

	Jan	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		108	0	0	0	0	0	0	0	0	91	0	12
1981	0	0	54	0	0	0	88	0	0	62	0	85	23
1982	0	31	0	0	0	0	0	0	0	0	0	0	3
1983	0	0	36	0	0	0	0	0	0	0	27	54	4
1984	0	54	27	27	27	27	243	0	162	162	27	162	81
1985	27	0	54	0	0	81	65	189	54	247	81	92	77
1986	19	379	0	0	0	0	0	0	0	0	81	38	42
1987	135	216	100	54	154	0	27	81	54	0	127	127	76
1988	108	54	135	0	27	54	0	54	0	0	0	27	36
1989	27	27	270	54	31	27	0	0					58
1990		81	270	100	27	0	27	0	0	0			56
1991		649	626	433	100	127	81	81	81	38			246
1992		541	1554	324	216	27	27	0	19	0			301
1993		496	433	1085	464	144	54	108	100	81			329
1994		356	502	166	533	54	193	297	460	235			311
1995	225	491	216	85	0	0	0		81	27	2055	1676	113
1996	901	595	351	220	54	135	27	162	189	784	146	185	280
1981–1988, 1996	132	148	84	33	29	33	50	54	51	139	54	86	

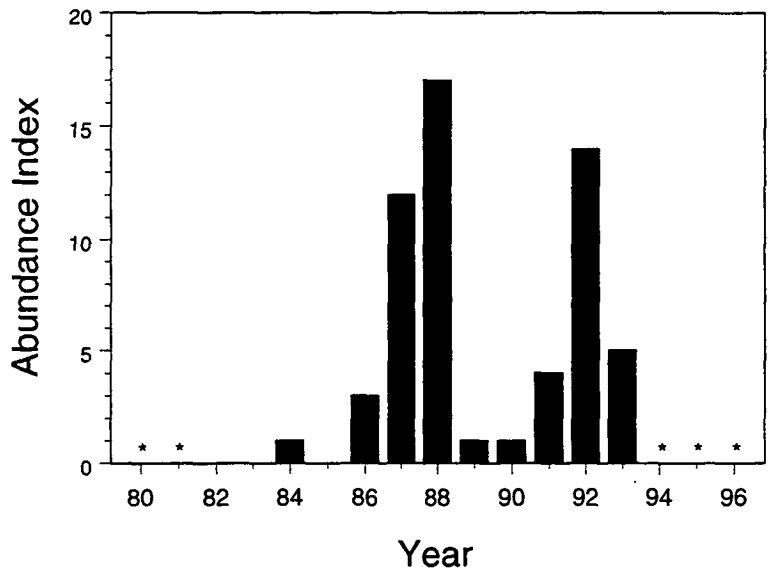

Figure 18 Annual abundance indices (CPUE x 10) of all sizes of *C. gracilis* collected with the ringnets from 1982 to 1993. The index period is July to December. Asterisk (*) indicates no survey.

Table 11 Monthly and annual abundance indices of age–1+ *C. gracilis* collected with the ringnets from 1982 to 1993. The index period is July to December. CPUE × 10.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jul–Dec*
1982					0	0	0	0	0	0	1	0	0
1983	0	0	0	0	0	0	0	0	0	0	2	0	0
1984	0	0	0	0	0	0	4	0	0	0	0	0	1
1985	0	0	0	0	0	0	0	0	0	1	0	0	0
1986	0	0	0	0	0	0	2	9	2	3	0	0	3
1987	1	0	0	6	26	21	47	8	10	2	0	4	12
1988	0	1	0	0	0	3	90	12	1	0	1	0	17
1989	0	0	0	0	0	1	1	0	1	0	1	0	1
1990							4	0	0	0	0	0	1
1991							12	0	1	1	7	0	4
1992							1	42	22	11	6	2	14
1993							12	8	11	0	0	0	5
1983–1989	0	0	0	1	4	4	21	4	2	1	1	1	

Table 12 Monthly catch of *C. gracilis* stage 2 to 5 zoeae (1980 to 1985) and megalopae (1980 to 1988)

Month	*Zoeae*	*Megalopae*
January	84	28
February	382	3
March	1076	52
April	1556	59
May	111	5
June	73	34
July	80	121
August	100	24
September	61	13
October	100	0
November	352	2
December	331	4

Ovigerous females were collected in all months except August and November and were most common from January through May. Zoeae were collected all year but abundance appeared to be bimodal; the highest catches were from February through April and in November and December (Table 12). Megalopae were collected in all months except for October, with the highest catches in March, April, and July (see Table 12). Although age–0 *C. gracilis* were relatively abundant in most months (Figure 19), in many years there were 1 or 2 distinct abundance peaks, usually from late spring to summer or from fall to winter. For example, in 1987 and 1988, age–0 crabs were most abundant from October 1987 through January 1988 and in May and June 1988 (see Table 9).

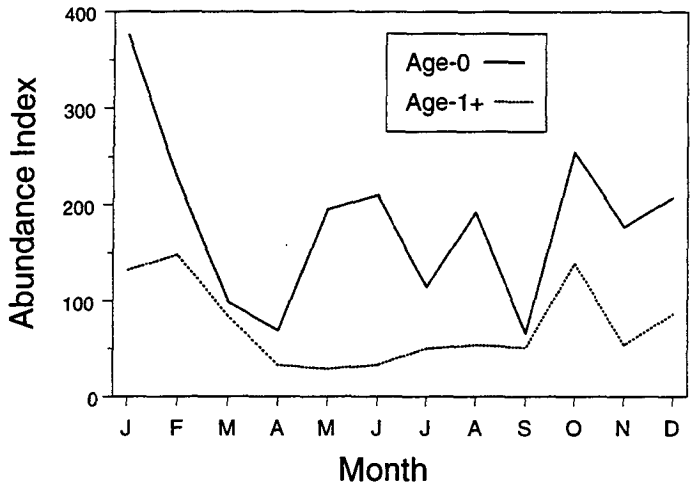

Figure 19 Monthly abundance of age–0 and age–1+ *C. gracilis* collected with the otter trawl from 1981 to 1988 and 1996

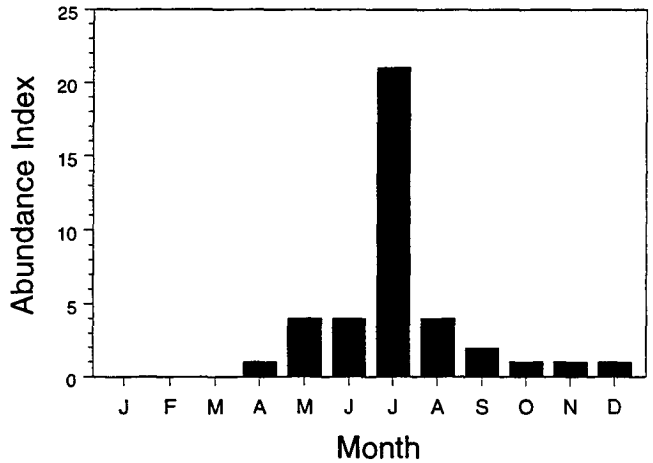

Figure 20 Monthly abundance (CPUE x 10) of all sizes of *C. gracilis* collected with the ringnets from 1983 to 1989

Age–1+ *C. gracilis* were generally most abundant from October through March in the otter trawl (see Figure 19), but in several years abundance was high through May (for example, 1993 and 1994) and increased as early as August or September (see Table 10). In contrast to the otter trawl, abundance was highest in the ringnets from May through September (Figure 20). There is no evidence of a winter abundance peak in any year (see Table 11), although year-round sampling was limited to 1983 through 1989 with this gear.

Age–1+ males outnumbered females from February through September in the otter trawl (Figure 21), but females comprised at least 60% of the age–1+ catch from November through January. In the ringnets, males outnumbered females in all months, although total catch was very low in winter.

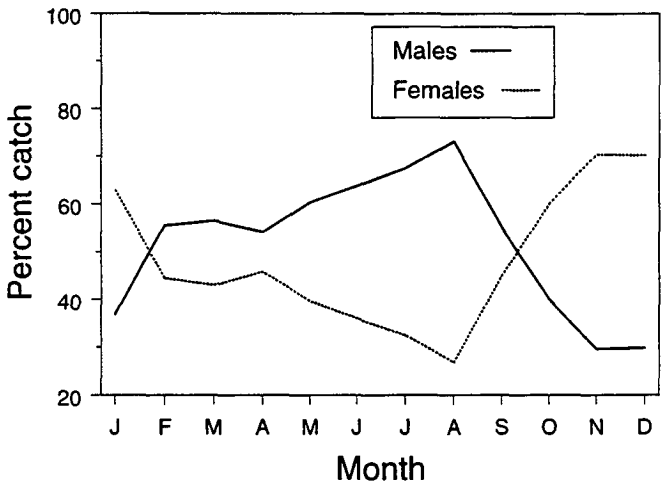

Figure 21 Monthly percent catch of male and female age–1+ *C. gracilis* collected with the otter trawl

Distribution

Cancer gracilis was common from northern South Bay to lower San Pablo Bay. None were collected upstream of San Pablo Bay. Smaller crabs (<40 mm) were more widely distributed than larger crabs. Over all the months and years, the otter trawl collected more *C. gracilis* at channel stations than at shoal stations. Catches were highest at the channel stations south of Treasure Island and east of Tiburon (stations #110 and #215, see Methods chapter, Figure 1). In the ringnets, most *C. gracilis* were collected at the Paradise station #294 (see Methods chapter, Figure 3).

Cancer gracilis zoeae were concentrated in Central Bay, but there were relatively high catches of early stage zoeae in the southernmost part of South Bay. A few early stage zoeae were collected in San Pablo Bay and as far upstream as Carquinez Strait. Late stage zoeae and megalopae were most commonly collected in Central Bay.

Age–0 *C. gracilis* were concentrated in Central Bay in all years (Figure 22). This age class used San Pablo Bay to a greater extent in low outflow years than in high outflow years (for example, 1994 and 1995). There was also a general trend of expanding distribution with increasing abundance. The center of distribution of age–1+ *C. gracilis* was also in Central Bay in all years (Figure 23). As for age–0 crabs, the use of San Pablo Bay was greater in low outflow years.

Neither age–0 nor age–1+ *C. gracilis* showed strong evidence of seasonal movements between regions of the estuary (Figures 24 and 25). Age–0 crabs probably used San Pablo Bay seasonally, as CPUE was highest there in summer and fall.

Although *C. gracilis* used channels more than shoals, crabs moved seasonally between these habitats. For the selected channel-shoal pair of stations, catches of age–1+ *C. gracilis* were higher at the channel station (#215) from November through April and at the shoal station (#243) from May through October (Figure 26). The shoal catch in summer and fall was primarily composed of male *C. gracilis*. Females were common in the channel in winter, but total catch of females at both the channel and shoal stations decreased in summer.

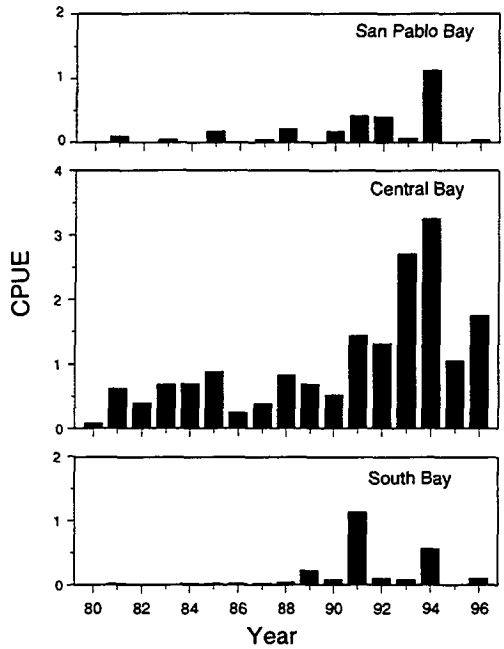

Figure 22 Annual distribution (CPUE) of age–0 *C. gracilis* collected with the otter trawl for May to October from 1980 to 1996

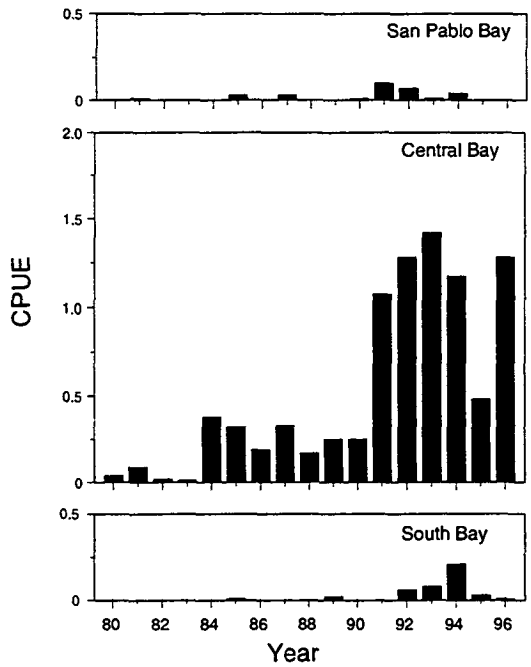

Figure 23 Annual distribution (CPUE) of age–1+ *C. gracilis* collected with the otter trawl for February to October from 1980 to 1996

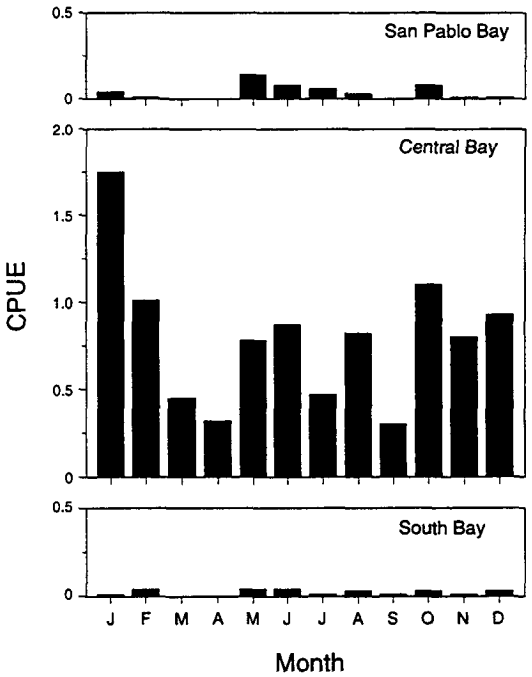

Figure 24 Monthly distribution (CPUE) of age–0 *C. gracilis* collected with the otter trawl from 1981 to 1988 and in 1996

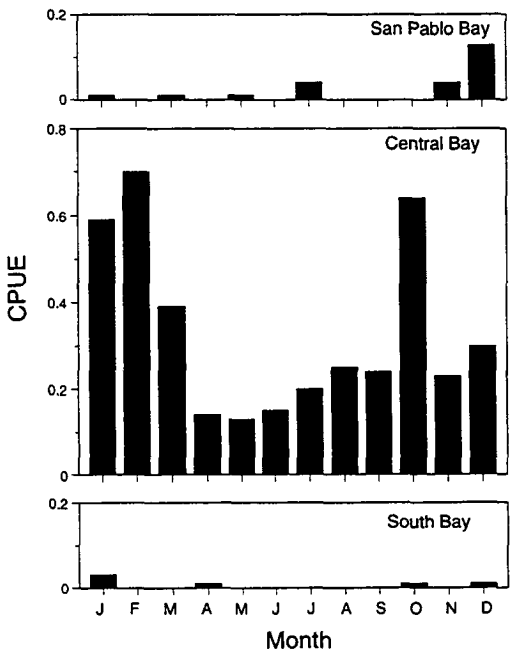

Figure 25 Monthly distribution (CPUE) of age–1+ *C. gracilis* collected with the otter trawl from 1981 to 1988 and in 1996

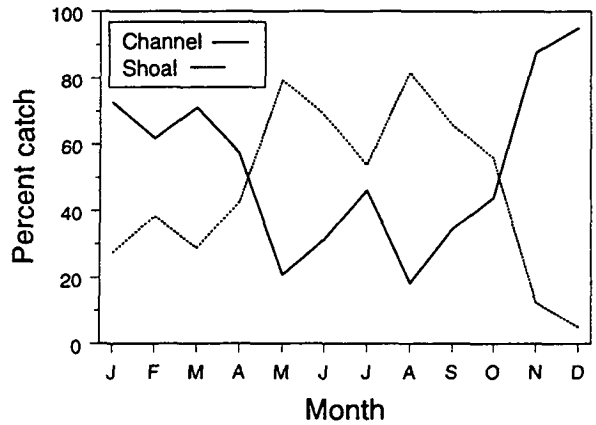

Figure 26 Channel-shoal percent catch of *C. gracilis* by month from 1988 to 1996 at station #215 (channel) and station #243 (shoal)

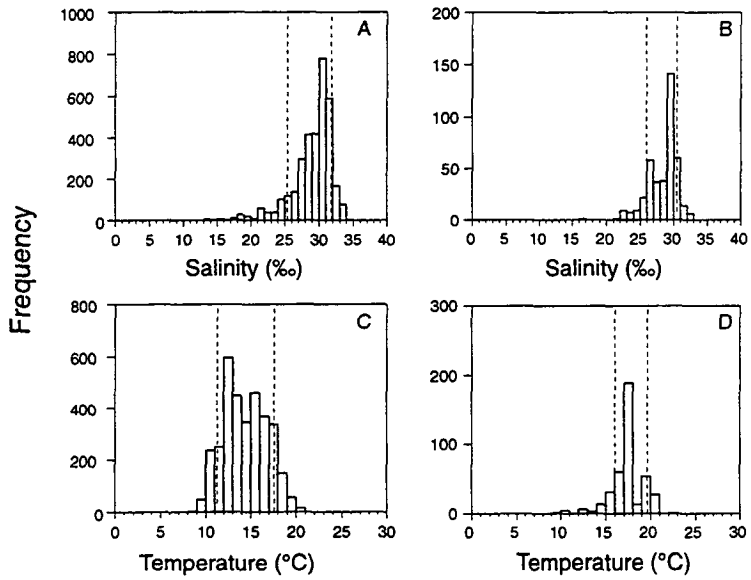

Figure 27 Salinity (‰) and temperature (°C) distributions of all sizes of *C. gracilis* collected with the otter trawl (1980 to 1996) and ringnets (1982 to 1994): (A) salinity, otter trawl; (B) salinity, ringnets; (C) temperature, otter trawl; (D) temperature, ringnets. Dashed vertical lines are the 10th and 90th percentiles.

Salinity and Temperature

Most *C. gracilis* were collected at salinities ranging from 25‰ to 32‰ and temperatures from 11 to 18 °C (Figure 27). *Cancer gracilis* was collected at very similar mean salinities in the otter trawl and ringnets (mean = 29.1‰ and 28.4‰, respectively) (Table 13), but was collected at a substantially lower mean temperature in the otter trawl than in the ringnets (mean = 14.3 °C and 17.3 °C, respectively) (see Table 13). Males and females were collected at almost identical mean salinities and temperatures in the otter trawl, but females were collected at a slightly lower mean salinity and temperature and than males in the ringnets. There were no salinity or temperature trends with size (Figure 28).

Table 13 Salinity (‰) and temperature (°C) statistics for all sizes of *C. gracilis* collected with the otter trawl (1980 to 1996) and ringnets (1982 to 1994)

	Mean (Standard Deviation)	*Minimum*	*Maximum*	*10th Percentile*	*90th Percentile*
Salinity					
Otter trawl	29.1 (3.0)	13.7	34.3	25.4	31.8
Ringnets	28.4 (2.2)	16.0	33.0	25.9	30.5
Temperature					
Otter trawl	14.3 (2.4)	8.7	20.8	11.3	17.6
Ringnets	17.3 (1.7)	9.8	22.5	16.0	19.6

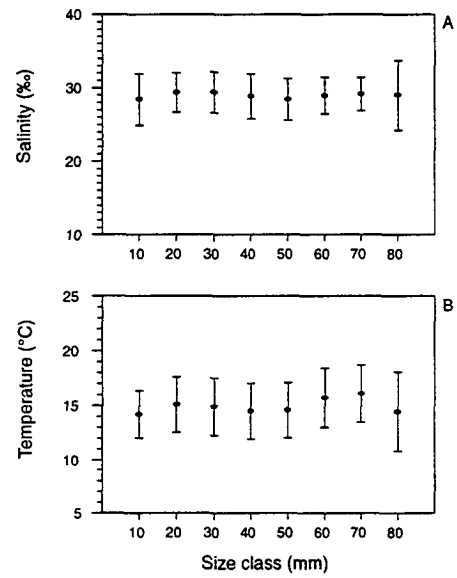

Figure 28 Mean salinity and temperature (±1 standard deviation) for *C. gracilis* by size class collected with the otter trawl and ringnets: (A) salinity (‰) and (B) temperature (°C). Size classes are every 10 mm, from 5 to 85 mm.

Discussion

Cancer gracilis was most common in the relatively cool, euhaline waters of Central Bay, as is typical of a "marine" species. Of the 4 species of *Cancer* crabs included in this report, *C. gracilis* was collected at the highest mean salinity and the lowest mean temperature in the otter trawl, although the mean salinity was only <1‰ higher than the mean salinity for *C. antennarius* and *C. productus*. The San Francisco Estuary probably functions more as an extension of the preferred nearshore coastal habitat of *C. gracilis* than as a nursery. This is similar to how *C. antennarius* and *C. productus* are proposed to use the estuary in this report. The relatively high number of ovigerous females collected combined with limited evidence of a seasonal emigration indicates that at least some *C. gracilis* are resident in the estuary. This observation is also supported by the conclusion that mature *C. gracilis* did not emigrate to the ocean from Garrison Bay, Washington (Orensanz and Gallucci 1988).

Although mature *C. gracilis* do not move extensively in the San Francisco Estuary, age–0 crabs are more widely distributed than age–1+ crabs. Age–1+ crabs also move seasonally between the channels and

shoals, with catches higher on shoals in summer and in channels in winter. The peak ringnet abundance in summer corresponds with this movement from channels to shoals.

The relatively high catches of *C. gracilis* in the otter trawl relative to the ringnets probably reflects a preference for open sandy and muddy substrates rather than pilings and other protected areas. Also, it may be displaced from rocky or protected areas by the larger species of *Cancer* crabs common to the estuary (R. Tasto, personal communication, see "Notes").

Although *C. gracilis* abundance decreased in high outflow years, this trend is somewhat masked by increasing abundance through the 1990s. The high salinities present all year in Central Bay during the 1987–1992 drought (see Introduction chapter, Figure 2) created a stable environment which may have resulted in the initial increase of *C. gracilis* abundance in 1991. Other factors, yet unknown, may have contributed to the continued high abundance after the drought ended. Interestingly, abundance of *C. antennarius* and *C. productus* also increased over the study period, although not all peak abundance years were common for all 3 species.

There were multiple cohorts of *C. gracilis* in most years and evidence of a protracted breeding season, which agrees with the literature. Age–1+ males were more common in summer, especially over the shoals, and females were more common in winter. The ringnet catch was also dominated by age–1+ males in summer. This distributional pattern indicates a spatial segregation of the sexes, especially in summer. Breeding aggregates of females, as found in Puget Sound during the summer (Orensanz and others 1995), could result in this pattern of sex segregation if the female-dominated aggregates were infrequently sampled.

Cancer productus

Cancer productus, the red rock crab, ranges from Alaska to San Diego, California. It is primarily found in bays and protected coastal waters, associated with rocky areas, gravel, and coarse sand (Schmitt 1921, Garth and Abbott 1980). Juveniles settle on spatially complex substrates, but move to more open areas as they grow (Orensanz and Gallucci 1988). Although *C. productus* is most common in intertidal and shallow subtidal areas, it has been collected to at least 91 m. The largest reported male was 190 mm and the largest female 168 mm (CDFG unpublished data, as cited in Carroll and Winn 1989).

In Puget Sound, *C. productus* mates from June to August, ovigerous females are most abundant from December to March, and peak larval hatching is in March and April (Knudsen 1964). Female *C. productus* migrate to deeper water in winter for larval hatching and return to shallow water, including estuaries, in May and June to join the males (Orensanz and Gallucci 1988). In the intertidal zone of Puget Sound, males dominated the catch from January to May, but females were more common than males from July to October (Knudsen 1964). The larval period is relatively long—97 days at 11 °C (Trask 1970). Peak juvenile settlement occurs in April and May in Coos Bay, Oregon, (Selby 1980) and in July and August in Friday Harbor, Washington (Orensanz and Gallucci 1988). Most *C. productus* mature within 1 year after settlement in Puget Sound (about 60 mm, instar 10) and pass though a maximum of 13 instars (Orensanz and Gallucci 1988).

In southern California coastal waters the highest catches of *C. productus* were in fall and the lowest in summer (Winn 1985). In Coos Bay the highest catches were also in the fall, but the lowest catches were from November to January (Selby 1980). The low winter catches in Oregon were hypothesized to be a result of a downstream migration in response to decreasing salinities.

The large chelae of *C. productus* make it adept at preying upon hard-shelled organisms such as snails, clams, mussels, and barnacles (Carroll and Winn 1989, Robles and others 1989). In the San Francisco Estuary, *C. productus* is a major prey item of brown smoothhound, big skate, green sturgeon, and rubberlip seaperch, and a minor prey item of leopard shark, bat ray, staghorn sculpin, cabezon, white croaker, and starry flounder (CDFG, unpublished data).

Methods

Male and female *C. productus* <50 mm were classified as age 0 and all larger crabs as age 1+. The annual index periods selected were as follows: April through October for age–0 *C. productus* from the otter trawl, February through October for age–1+ crabs from the otter trawl, and July through December for crabs (all age classes) from the ringnets. Age–1+ crabs from the otter trawl and ringnets were used for analysis of seasonal sex ratio trends. *Cancer productus* catches were not sufficient at any of the otter trawl stations for a channel-shoal analysis.

Results

Size and Size Frequency

The largest male collected by this study was 160 mm and the largest female 137 mm. Only 3 ovigerous females, ranging from 88 to 92 mm, were collected. The otter trawl collected mostly age–0 crabs <45 mm (Figure 29A), whereas the ringnet catch was dominated by crabs >40 mm (Figure 29B). Small (5 to 19 mm) *C. productus* were most numerous from May through August in the otter trawl.

Cancer productus catches were strongly biased toward males from 20 to 49 mm, with a male to female ratio of 2.3:1 for this size class. Females slightly outnumbered males from 55 to 79 mm (ratio 0.9:1), whereas males dominated all size classes >80 mm (ratio 2:1).

Abundance

Cancer productus was the 4th most commonly collected species of *Cancer* crab in the otter trawl but ranked 2nd in the ringnet survey (see Table 1). Age–0 abundance was low during the early 1980s, increased in 1986, and fluctuated through the mid-1990s (Figure 30A, Table 14). The highest annual index was in 1996, followed closely by 1994, 1990, 1988, and 1991. All of these years, except for 1996, had relatively low freshwater outflow (see Introduction chapter, Figure 2). Age–1+ indices were relatively low through 1988 and the highest indices were in 1991, 1992, and 1994 (Figure 30B, Table 15). Usually the years with the highest outflow had the lowest age–1+indices (for example, 1980, 1982, 1983, 1986, and 1995). The ringnet indices, which were dominated by age–1+ crabs, were also usually lower in years with high outflow (1982, 1983, 1986) than in years with low outflow (Figure 31, Table 16). The exception was 1992, which had a low abundance index but also low outflow.

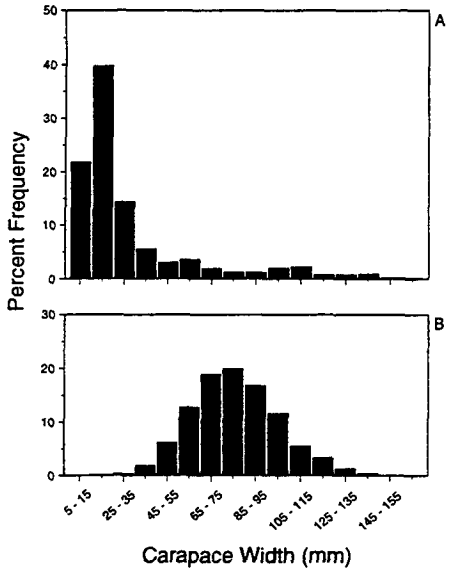

Figure 29 Size frequency of *C. productus*: (A) otter trawl, 1980 to 1996; (B) ringnets, 1982 to 1994. Size classes are every 10 mm, from 5 to 165 mm.

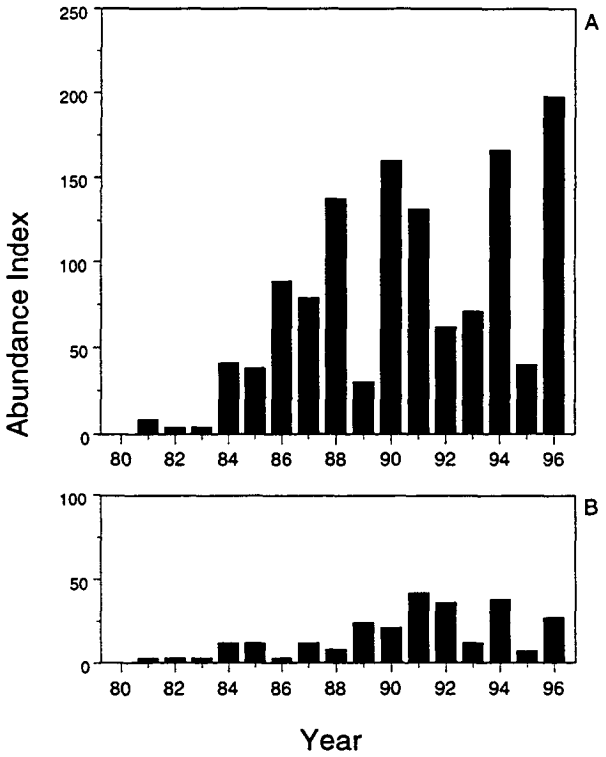

Figure 30 Annual abundance indices of *C. productus* collected with the otter trawl from 1980 to 1996: (A) age 0, the index period is April to October; (B) age 1+, the index period is February to October

Table 14 Monthly and annual abundance indices of age–0 *C. productus* collected with the otter trawl from 1980 to 1996. The index period is April to October.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Apr–Oct*
1980		85	0	0	0	0	0	0	0	0	0	0	0
1981	19	0	0	0	0	0	0	66	0	0	0	31	9
1982	0	0	0	0	0	27	0	0	0	0	0	0	4
1983	31	0	0	0	0	31	0	0	0	0	0	0	4
1984	0	0	54	0	0	117	0	50	0	121	63	82	41
1985	125	0	63	27	0	46	148	19	27	0	19	94	38
1986	31	156	0	0	0	19	69	380	94	58	0	0	89
1987	0	0	94	27	19	154	81	54	81	135	212	31	79
1988	0	90	54	81	193	116	100	363	58	54	46	108	138
1989	0	58	81	27	19	19	0	85					30
1990		108	27	0	136	414	128	239	54	146			160
1991		104	58	0	63	266	190	139	139	127			132
1992		54	162	155	108	54	27	0	65	27			62
1993		54	54	27	27	85	31	100	112	112			71
1994		268	27	81	224	247	177	69	220	144			166
1995	92	54	81	0	0	0	0		58	179	117	310	40
1996	463	31	0	297	283	58	279	144	200	127	273	220	198
1981–1988, 1996	74	31	29	48	55	63	75	120	51	55	68	63	

Table 15 Monthly and annual abundance indices of age–1+ *C. productus* collected with the otter trawl from 1980 to 1996. The index period is February to October.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		0	0	0	0	0	0	0	0	0	0	0	0
1981	0	0	0	0	0	31	0	0	0	0	0	0	3
1982	0	0	0	0	31	0	0	0	0	0	0	0	3
1983	0	0	0	0	0	0	27	0	0	0	0	54	3
1984	0	0	0	0	0	0	0	27	0	81	0	54	12
1985	27	0	0	0	0	54	27	0	27	0	100	0	12
1986	54	31	0	0	0	0	0	0	0	0	0	0	3
1987	0	0	0	27	0	0	0	0	27	54	0	27	12
1988	0	0	0	27	0	46	0	0	0	0	0	0	8
1989	0	0	0	35	0	0	81	54					24
1990		27	81	27	27	27	0	0	0	0			21
1991		27	0	0	81	162	0	0	81	27			42
1992		0	54	54	0	108	81	0	0	27			36
1993		0	0	58	27	0	0	0	0	27			12
1994		58	121	27	81	0	0	0	27	27			38
1995	85	0	27	0	0	27	0		0	0	0	81	7
1996	19	0	31	27	0	54	27	27	27	54	0	0	27
1981–1988, 1996	11	3	3	9	3	21	9	6	9	21	11	15	

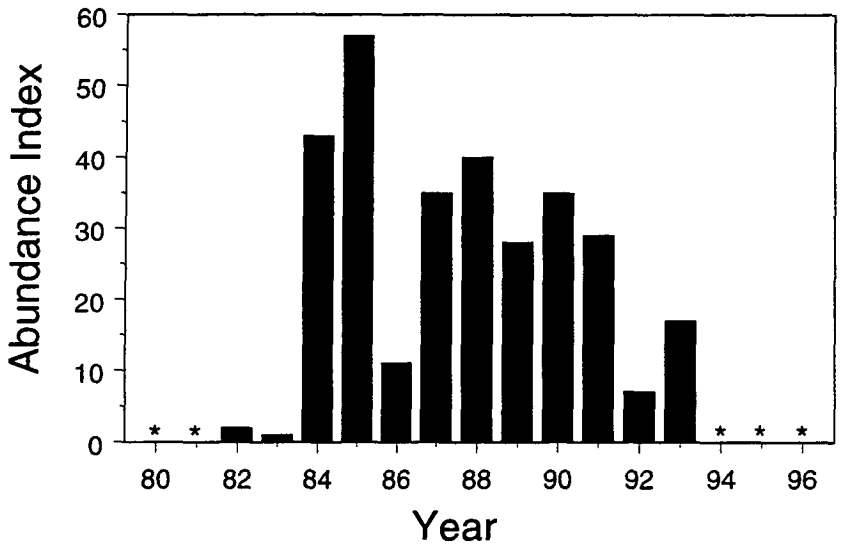

Figure 31 Annual abundance indices (CPUE × 10) of all sizes of *C. productus* collected with the ringnets from 1982 to 1993. The index period is July to December. Asterisk (*) indicates no survey.

Table 16 Monthly and annual abundance indices of all sizes of *C. productus* collected with the ringnets from 1982 to 1993. The index period is July to December. CPUE × 10.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jul–Dec*
1982					0	0	0	0	10	1	0	2	2
1983	0	0	0	0	1	0	0	0	0	1	6	0	1
1984	33	6	7	2	0	2	33	21	24	103	17	57	43
1985	43	17	24	20	40	40	29	43	104	67	51	46	57
1986	27	0	0	0	1	0	1	16	13	16	6	18	11
1987	10	10	34	17	47	30	40	40	37	37	21	35	35
1988	21	11	10	13	21	31	83	40	23	49	24	20	40
1989	26	1	1	7	8	14	30	28	38	42	19	18	28
1990							40	29	24	50	43	20	35
1991							63	20	39	22	20	11	29
1992							14	9	4	7	3	8	7
1993							2	20	12	24	29	16	17
1983–1989	23	6	11	8	16	17	31	27	34	45	20	28	

Table 17 Monthly catch of *C. productus* zoeae (1980 to 1985) and megalopae (1980 to 1988)

Month	*Zoeae*	*Megalopae*
January	5288	0
February	3969	1
March	3621	2
April	8130	19
May	9975	1
June	3355	10
July	1377	1
August	1247	1
September	1433	0
October	1526	0
November	6883	21
December	7290	0

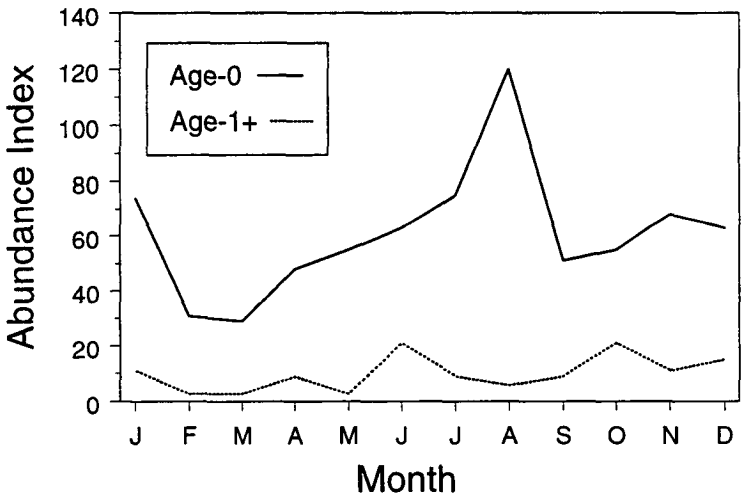

Figure 32 Monthly abundance of age–0 and age–1+ *C. productus* collected with the otter trawl from 1981 to 1988 and in 1996

Cancer productus zoeae were most abundant from November through January and in April and May, and megalopae were most abundant from March through June (Table 17). Age–0 *C. productus* were least abundant in February and March; the indices increased steadily from April though August (Figure 32, see Table 14). Abundance may be bimodal, as the index increased again from November to January. Age–1+ *C. productus* from the otter trawl were generally least abundant from February through May and most abundant from July through October (see Figure 32, see Table 15). The lowest ringnet indices were from February through April; the indices then increased slowly to a peak in October (Figure 33, see Table 16).

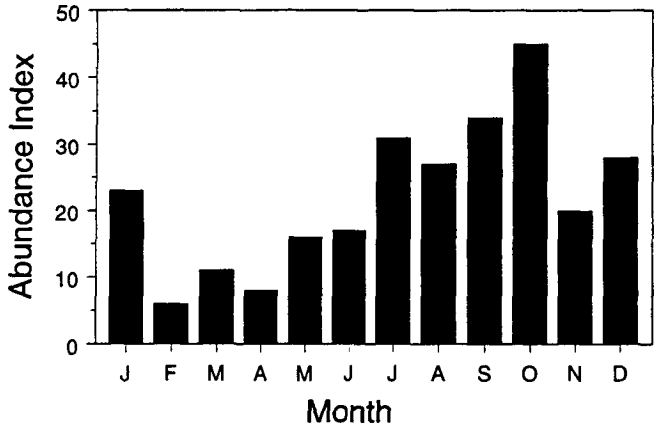

Figure 33 Monthly abundance (CPUE × 10) of all sizes of *C. productus* collected with the ringnets from 1983 to 1989

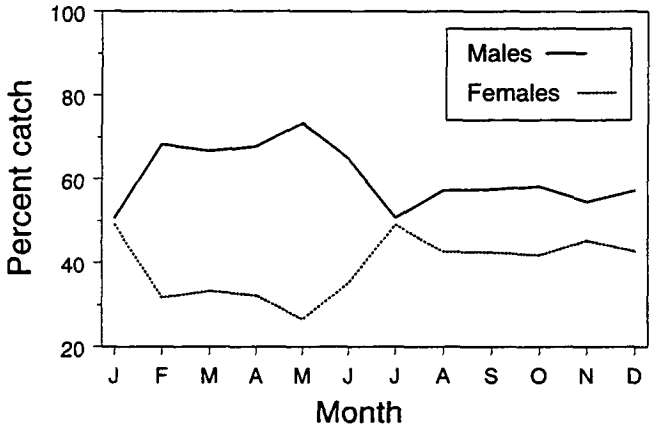

Figure 34 Monthly percent catch of male and female age–1+ *C. productus* collected with the otter trawl and ringnets

Overall, male *C. productus* outnumbered females approximately 3:2, but the magnitude of this dominance changed with time. Males accounted for at least 65% of the age–1+ catch from February through June but only 50% to 60% of the catch all other months (Figure 34).

Distribution

Cancer productus zoeae were concentrated in Central Bay, but were occasionally collected as far upstream as Carquinez Strait. Most megalopae were collected in Central Bay. Although age–0 and age–1+ crabs were collected with the otter trawl from South Bay, near the Dumbarton Bridge to Carquinez Strait, they were most common in the northern portion of South Bay (stations #108 and #109), Central Bay (especially station #213), and lower San Pablo Bay (station #323) (see Methods chapter, Figure 1). Smaller crabs (<35 mm) were more widely distributed than larger crabs and crabs >75 mm were generally restricted to Central Bay. The highest ringnet catches were at the Point Pinole (#396), Paradise (#294), and Muni Pier (#293) stations (ordered by catch).

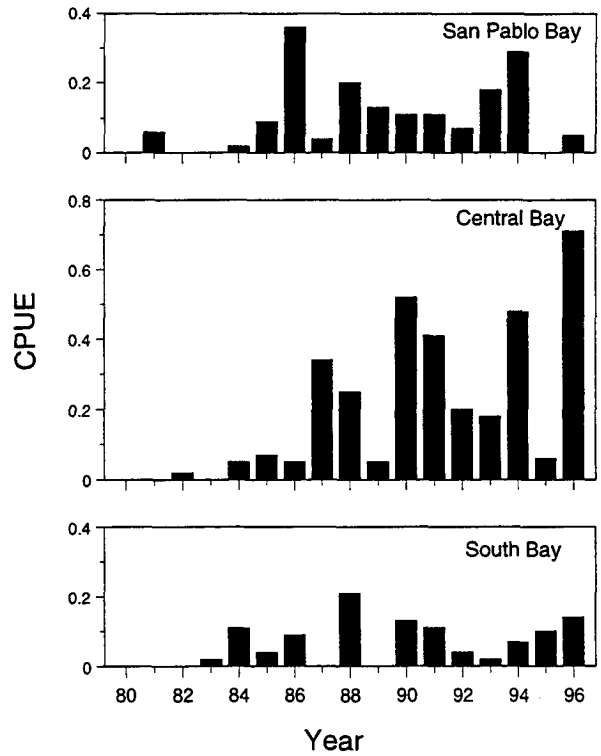

Figure 35 Annual distribution (CPUE) of age–0 *C. productus* collected with the otter trawl for April to October from 1980 to 1996

Distribution of age–0 *C. productus* was centered in Central Bay most years (Figure 35). In years with relatively low abundance, CPUE was often highest in South Bay (1983, 1984, 1995) or San Pablo Bay (1981, 1985, 1985, and 1989), which may reflect low, sporadic catches. Age–1+ crabs were concentrated in Central Bay in all years except for 1981, when CPUE was highest in South Bay (Figure 36).

There was some seasonal movement of age–0 *C. productus*, as CPUE was highest in South Bay in winter and Central Bay in spring and summer (Figure 37). Distribution expanded to San Pablo Bay in summer and to South Bay in fall. There is little evidence of seasonal movements of age–1+ *C. productus*; some crabs may move from Central Bay to South Bay in winter (Figure 38).

Salinity and Temperature

Most *C. productus* were collected at salinities ranging from 23‰ to 32‰ and temperatures from 10 to 20 °C (Figure 39). The otter trawl mean salinity (28.4‰) was slightly higher than the ringnet mean salinity (27.5‰), while the otter trawl mean temperature (15.4 °C) was slightly lower than the ringnet mean temperature (15.7 °C) (Table 18). Male and female *C. productus* were collected at nearly identical salinities and temperatures by both gear types. The major difference was in the otter trawl, where females were collected at a somewhat lower mean salinity than males (14.6‰ compared to 15.2‰).

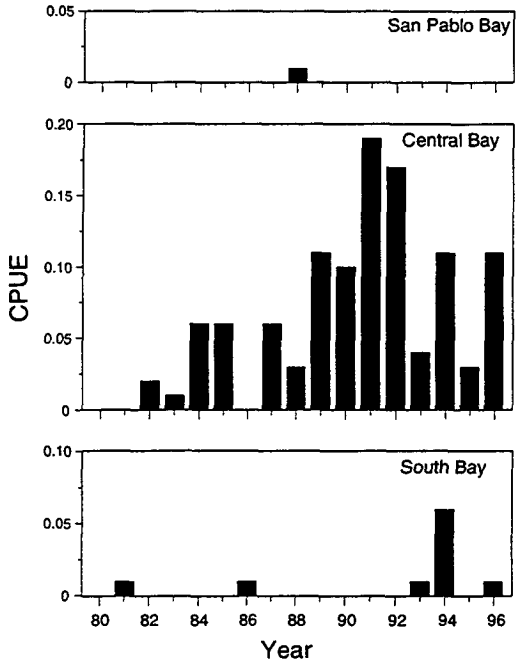

Figure 36 Annual distribution (CPUE) of age–1+ *C. productus* collected with the otter trawl for February to October from 1980 to 1996

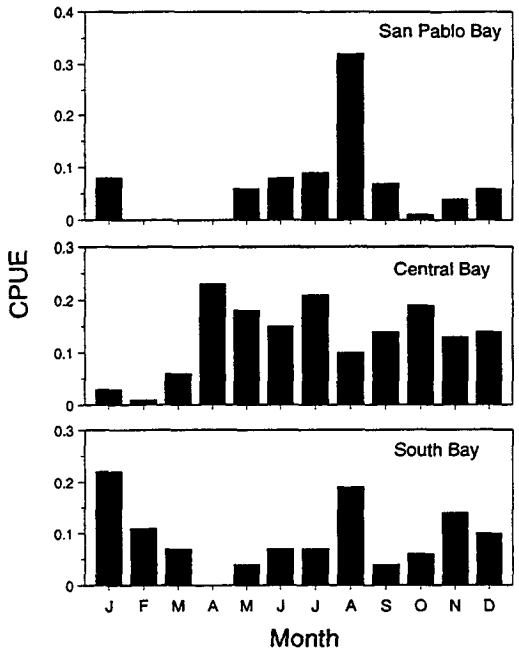

Figure 37 Monthly distribution (CPUE) of age–0 *C. productus* collected with the otter trawl from 1981 to 1988 and in 1996

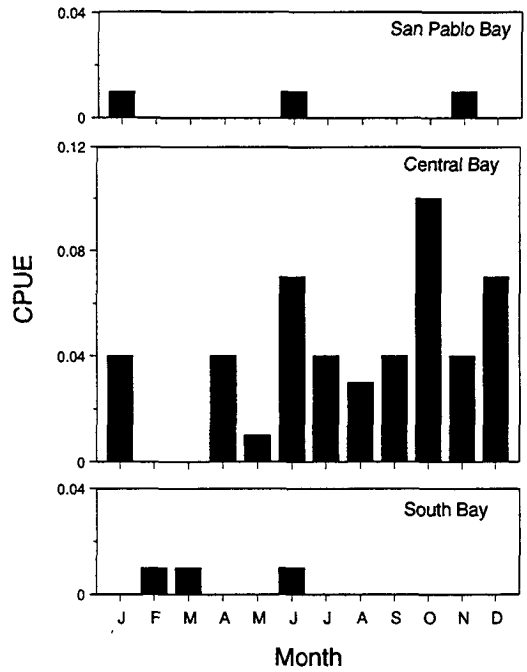

Figure 38 Monthly distribution (CPUE) of age–1+ *C. productus* collected with the otter trawl from 1981 to 1988 and in 1996

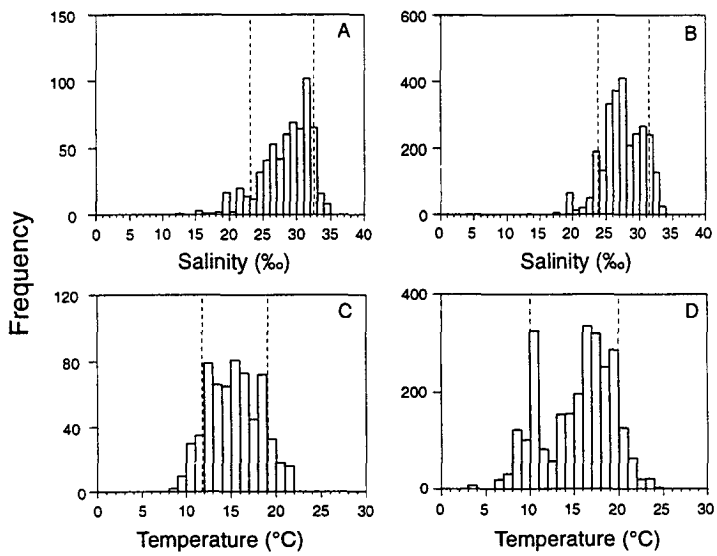

Figure 39 Salinity (‰) and temperature (°C) distributions of all sizes of *C. productus* collected with the otter trawl (1980 to 1996) and ringnets (1982 to 1994): (A) salinity, otter trawl; (B) salinity, ringnets; (C) temperature, otter trawl; (D) temperature, ringnets. Dashed vertical lines are the 10th and 90th percentiles.

Table 18 Salinity (‰) and temperature (°C) statistics for all sizes of *C. productus* from the otter trawl (1980 to 1996) and ringnets (1982 to 1994)

	Mean (Standard Deviation)	*Minimum*	*Maximum*	*10th Percentile*	*90th Percentile*
Salinity					
Otter trawl	28.4 (3.7)	12.5	34.4	23.1	32.5
Ringnets	27.5 (3.1)	14.0	34.0	23.8	31.4
Temperature					
Otter trawl	15.4 (2.9)	8.3	22.0	11.8	19.1
Ringnets	15.7 (3.9)	6.0	24.5	10.0	20.0

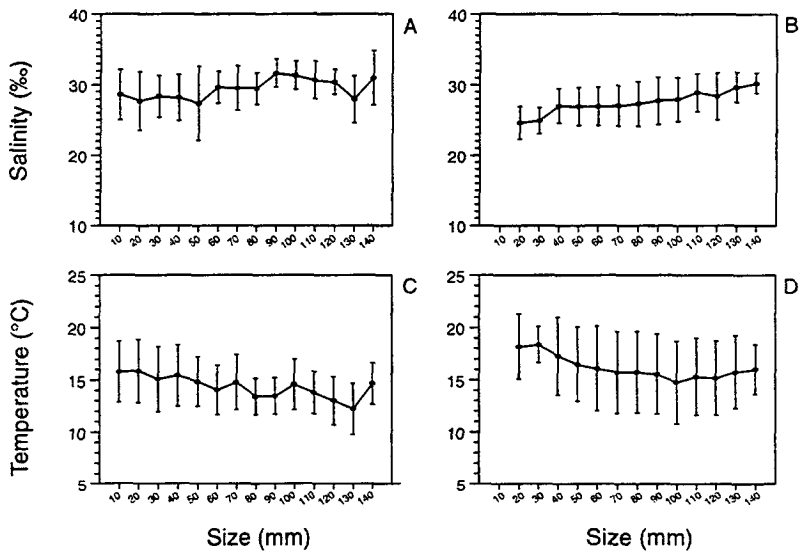

Figure 40 Mean salinity (‰) and temperature (°C) (±1 standard deviation) for *C. productus* by size class collected with the otter trawl and ringnets: (A) salinity, otter trawl; (B) salinity, ringnets; (C) temperature, otter trawl; (D) temperature, ringnets. Size classes are every 10 mm, from 5 to 145 mm for the otter trawl, and 15 to 145 mm for the ringnets.

The mean salinity at point of capture increased slightly with size, especially in the ringnets (Figures 40A and 40B). In contrast, the mean temperature at point of capture decreased with size (Figures 40C and 40D). This trend was also stronger for the ringnet collected crabs.

Discussion

Most *C. productus* use the San Francisco Estuary opportunistically, as an extension of the preferred nearshore coastal habitat. Although some *C. productus* probably rear in the estuary, it is not an important nursery area. *Cancer productus* is widely distributed in the estuary, but it is most common in Central and lower San Pablo bays. This distributional pattern combined with the relatively high salinities at which *C. productus* was collected is consistent with *Cancer* species which do not readily osmoregulate in brackish water (for example, *C. antennarius* and *C. gracilis*). Note that based on the 10th and 90th percentiles, *C. produc-*

tus was collected over a slightly wider salinity range in the otter trawl and ringnets than either *C. antennarius* or *C. gracilis*.

Annual abundance indices were low in the early 1980s and increased through the mid-1990s, a trend which is shared with *C. antennarius* and *C. gracilis*. However, the year in which abundance first increased and was highest differed by species. All 3 species had several years of high abundance (for example, 1994 and 1996) and low or decreased abundance (for example, 1982, 1983, and 1995) in common. Freshwater outflow apparently affects *C. productus* abundance to some extent, as indices were generally lower in high outflow years than in low outflow years. This is probably due to decreased salinities in the estuary, but may also be related to unfavorable ocean currents associated with frequent winter storms.

The relatively high abundance of *C. productus* in the ringnets compared to the otter trawl is probably because crabs of all sizes prefer areas with structure rather than open channels or shoals. Although *C. productus* was not common enough in the otter trawl to analyze seasonal movement from channel to shoals, the increased abundance in the ringnets in summer may reflect a movement from deeper water. Alternatively, this abundance increase may be due to immigration to the estuary from the ocean. Some *C. productus* undoubtedly emigrate from the estuary in response to decreased salinities in winter and immigrate to the estuary as salinities increase in summer. A similar migration pattern has been reported in Coos Bay, Oregon (Selby 1980).

Seasonal abundance trends of zoeae, megalopae, and small juveniles correspond with the findings of other researchers. The dominance of males from February to May is similar to the Puget Sound results, where males outnumbered females from January to May (Knudsen 1964). The most likely scenario is that females emigrate from the estuary for larval hatching in the winter and immigrate back to the estuary starting in June. This female migration has been hypothesized to facilitate estuarine use by *C. productus* (Orensanz and Gallucci 1988) and is probably initiated by decreasing salinities. The dominance of males in the smaller, pre-puberty size classes (<50 mm), and females in the size classes associated with puberty (55 to 79 mm) has not been reported in the literature, but is reported for *C. antennarius* in this chapter.

Cancer antennarius

Cancer antennarius, the brown rock crab, ranges from Oregon to Baja California and is most common from Point Conception to San Francisco (Carroll and Winn 1989). It mainly inhabits rocky intertidal and subtidal areas along the outer coast (Garth and Abbott 1980) and has been collected to 79 m (Jensen 1995). In southern California coastal waters *C. antennarius* is most abundant at rock-sand interfaces and extensive rocky reefs (Winn 1985). It is reported to be a strictly marine species which does not readily osmoregulate in brackish water (Jones 1941, Gross 1957). *Cancer antennarius* lives to 7 years and males reach a maximum size of 160 mm and females about 150 mm (Carroll 1982).

In central California, ovigerous *C. antennarius* are present in all months, but are most common in winter (Carroll 1982). Females produce at least 2 broods per instar and 1 brood per season (Shields 1984). Larvae are most abundant in spring and early summer and 1st instar crabs are most common in late spring and summer (Carroll 1982, Winn 1985). Both sexes mature at 60 to 80 mm (the 10th to 12th instars), which is 2 years after settlement in central California (Carroll 1982).

The highest catches of *C. antennarius* in southern California occurred in October and November and the lowest catches from June to August (Winn 1985). Similar seasonal trends were reported from central California, where the fall abundance peak was attributed to an increase in females (Carroll 1982). Male abundance remained relatively stable throughout the year and, overall, males outnumbered females 1.4:1.

Carroll hypothesized that females migrated inshore in fall in response to warmer water temperatures, but a concurrent tagging study showed no seasonal trends in crab movement. From a literature review, Orensanz and Gallucci (1988) concluded that both male and female *C. antennarius* remain in the same area all year.

The large chelae of *C. antennarius* are efficient in crushing mollusk shells. Gastropods (for example, *Tegula*), cockles, barnacles, hermit crabs, and abalone are common prey items along the open coast (Carroll and Winn 1989). In the San Francisco Estuary, *C. antennarius* was frequently consumed by brown smoothhound and rubberlip seaperch, and occasionally consumed by big skate, pile perch, staghorn sculpin, and starry founder (CDFG, unpublished data). Staghorn sculpin and starry flounder were also reported to prey upon *C. antennarius* by Boothe (1967).

Methods

Male and female *C. antennarius* <50 mm were classified as age 0 and all larger crabs as age 1+. The annual index periods selected were as follows: May through October for age–0 *C. antennarius* from the otter trawl, February through October for age–1+ crabs from the otter trawl, and July through December for crabs (all age classes) from the ringnets. Age–1+ crabs from the otter trawl and ringnets were used for analysis of seasonal sex ratio trends. For analysis of channel-shoal distribution, stations #109 (channel) and #142 (shoal) were selected based on the relatively high catches of *C. antennarius*.

Results

Size and Size Frequency

The largest male *C. antennarius* collected by this study was 134 mm, the largest female was 129 mm. Only 12 ovigerous females were collected, ranging from 44 to 117 mm. Three were from 44 to 52 mm and the remainder >64 mm. The otter trawl primarily collected age–0 crabs <35 mm (Figure 41A), while the ringnets primarily collected age–1+ crabs (Figure 41B). From June through December, a mode of smaller crabs was readily distinguishable in the otter trawl (Figure 42). Larger crabs were collected by the otter trawl in most months, but were most common from January through June.

Overall, male *C. antennarius* were more common than females, but this dominance changed with size. The male to female ratio was 2:1 for crabs 20 to 49 mm, 1.4:1 for crabs 50 to 74 mm, 0.6:1 for crabs 75 to 109 mm, and 1.5:1 for crabs >110 mm. The ratio of males to females was 1:1 in the ringnets, which collected more large crabs, and 1.7:1 in the otter trawl, which collected more small crabs.

Abundance

Cancer antennarius was the 3rd most commonly collected species in the otter trawl and the ringnets but was rarely collected in the beach seine (see Table 1). Overall, it was the least common of the 4 *Cancer* crabs included in this report. The annual abundance indices of age–0 crabs in the otter trawl were relatively low from 1980 to 1992, but increased significantly in 1993 (Figure 43A, Table 19). Because the otter trawl catch of age–1+ crabs was relatively low in all years (total annual catch ranged from 0 to 24), the abundance and distributional trends should be interpreted cautiously. The abundance indices of age–1+ crabs from the otter trawl increased later in the study period, with the highest indices in 1991, 1993, 1994, and 1996 (Figure 43B, Table 20). In contrast, the annual abundance trend from the ringnets (dominated by age–1+ crabs) was bimodal, with the highest indices from 1985 to 1988 and in 1992 (Figure 44, Table 21).

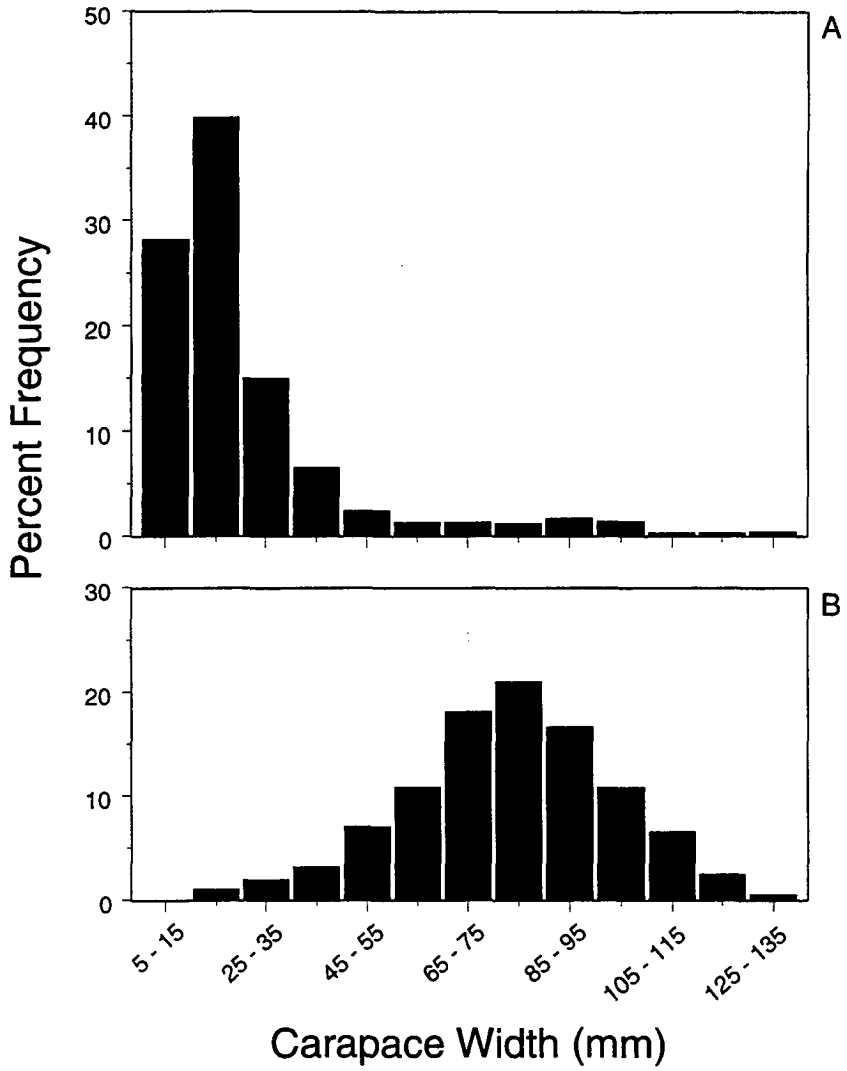

Figure 41 Size frequency of *C. antennarius*: (A) otter trawl, 1980 to 1996; (B) ringnets, 1982 to 1994. Size classes are every 10 mm, from 15 to 135 mm.

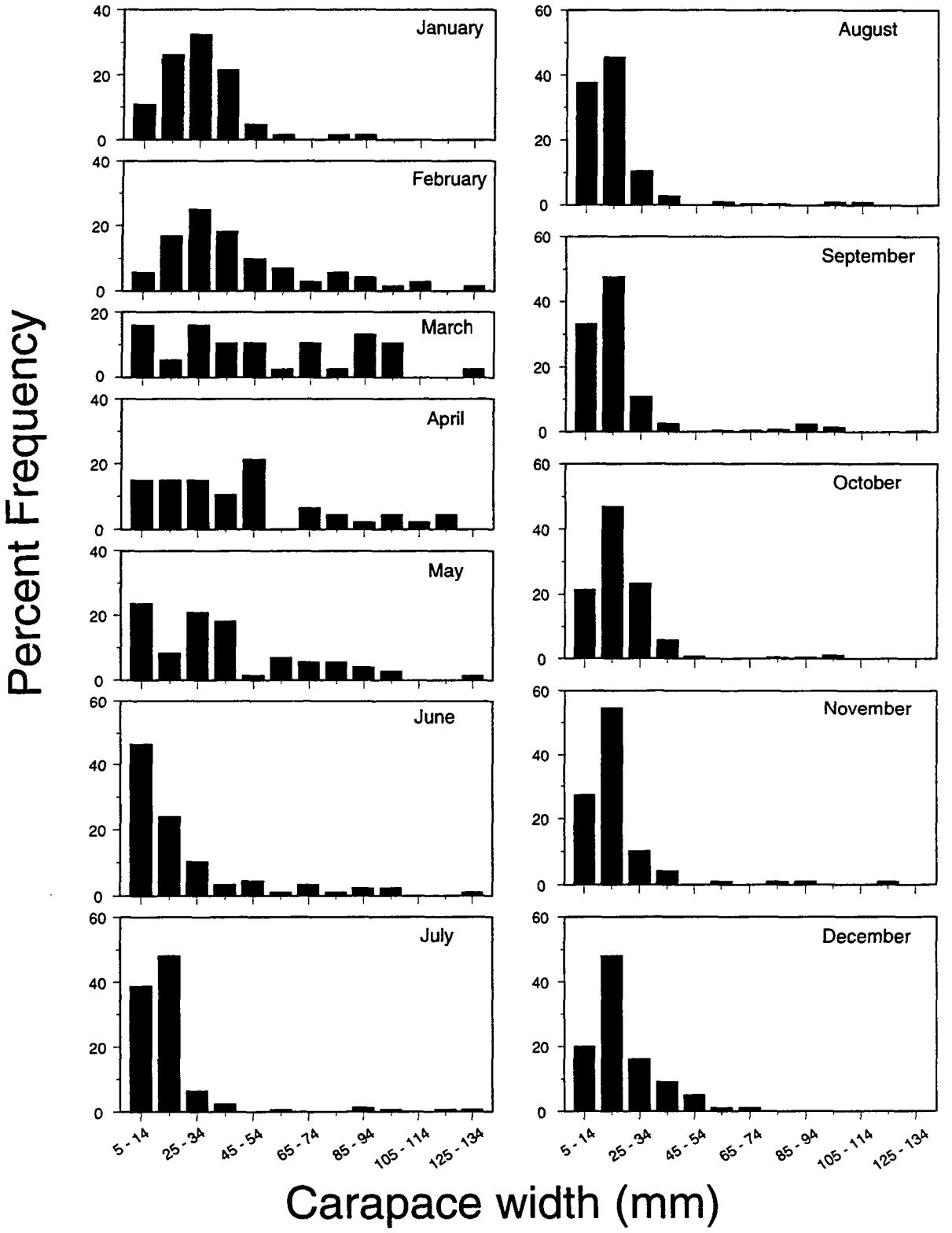

Figure 42 Size frequency of *C. antennarius* by month collected with the otter trawl. Size classes are every 10 mm, from 5 to 135 mm.

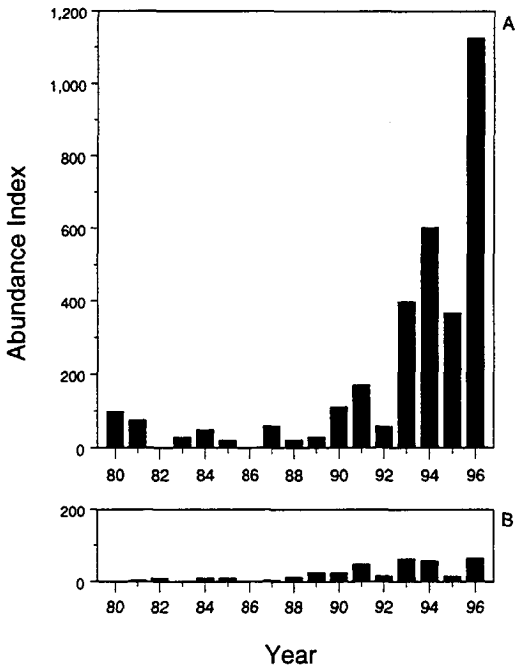

Figure 43 Annual abundance indices of *C. antennarius* collected with the otter trawl from 1980 to 1996: (A) age 0, the index period is May to October; (B) age 1+, the index period is February to October

Table 19 Monthly and annual abundance indices of age–0 *C. atennarius* from the otter trawl from 1980 to 1996. The index period is May to October.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*May–Oct*
1980		31	0	27	0	0	0	0	0	594	19	31	99
1981	27	0	0	0	43	31	0	313	31	36	0	0	76
1982	36	0	0	0	0	0	0	0	0	0	0	31	0
1983	0	0	0	0	54	0	27	0	85	0	0	0	28
1984	54	54	31	27	0	27	58	85	132	0	242	85	50
1985	117	0	58	0	0	89	0	0	31	0	0	0	20
1986	0	0	0	0	0	0	0	0	0	0	63	31	0
1987	109	177	31	0	0	58	150	27	0	132	246	58	61
1988	54	54	0	0	50	0	27	0	19	31	0	0	21
1989	0	27	0	0	85	0	0	31					29
1990		0	0	27	27	0	135	146	216	150			112
1991		144	46	54	216	19	219	119	296	158			171
1992		96	104	81	131	46	19	0	58	104			60
1993		171	54	243	0	81	660	601	576	467			398
1994		192	117	109	31	731	332	659	1174	688			603
1995	651	58	27	54	27	0	58		735	1015	210	491	367
1996	310	108	0	108	189	58	1097	1957	1754	1699	1332	1184	1126
1981–1988, 1996	79	44	13	15	37	29	151	265	228	211	209	154	

Table 20 Monthly and annual abundance indices of age–1+ *C. atennarius* from the otter trawl from 1980 to 1996. The index period is February to October.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Feb–Oct*
1980		0	0	0	0	0	0	0	0	0	36	0	0
1981	0	0	0	0	0	0	0	0	31	0	0	0	3
1982	0	0	0	0	0	0	0	27	0	53	0	0	9
1983	0	0	0	0	0	0	0	0	0	0	0	0	0
1984	0	0	0	0	0	0	27	54	0	0	0	27	9
1985	0	27	0	27	27	0	0	0	0	0	0	0	9
1986	0	0	0	0	0	0	0	0	0	0	0	0	0
1987	0	27	0	0	0	0	0	0	0	0	81	0	3
1988	0	31	0	0	27	27	0	0	0	27	0	0	12
1989	0	27	0	122	0	0	27	0					25
1990		0	81	0	27	27	0	0	27	54			24
1991		27	54	0	0	0	27	54	270	0			48
1992		27	0	0	0	81	0	27	0	0			15
1993		135	270	27	27	27	0	27	54	0			63
1994		135	27	81	162	81	0	0	27	0			57
1995	81	27	54	0	27	0	0		0	0	0	27	14
1996	27	85	0	81	225	81	27	0	27	54	0	27	64
1981–1988, 1996	3	19	0	12	31	12	6	9	6	15	9	6	

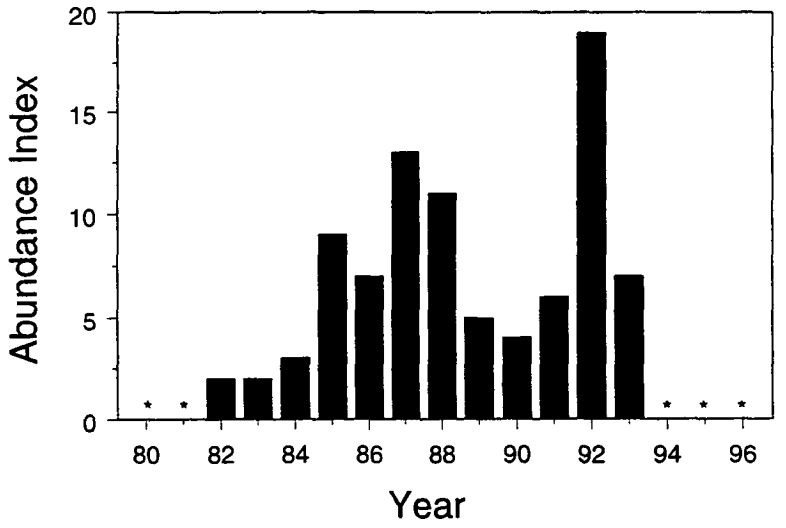

Figure 44 Annual abundance indices (CPUE × 10) of all sizes of *C. antennarius* collected with the ringnets from 1982 to 1993. The index period is July to December. Asterisk (*) indicates no survey.

Table 21 Monthly and annual abundance indices of *C. antennarius* collected with the ringnets from 1982 to 1993. The index period is July to December. CPUE × 10.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Jul–Oct*
1982					0	0	1	4	0	1	0	2	2
1983	0	0	0	0	0	0	0	0	0	1	9	1	2
1984	5	2	1	0	3	4	1	2	3	8	1	4	3
1985	4	1	0	0	3	0	0	2	9	3	29	8	9
1986	3	0	0	0	0	8	0	9	12	3	7	9	7
1987	2	1	9	10	17	4	11	9	21	18	11	6	13
1988	0	7	9	4	4	9	8	12	7	10	18	9	11
1989	6	1	2	1	3	12	10	3	11	0	1	3	5
1990							12	4	4	1	1	2	4
1991							20	3	2	1	6	2	6
1992							15	3	10	16	27	41	19
1993							0	9	14	7	4	7	7
1983–1989	3	2	3	2	4	5	4	5	9	7	11	6	

Table 22 Monthly catch of *C. antennarius* stage 2 to 5 zoeae (1980 to 1985) and megalopae (1980 to 1988)

Month	*Zoeae*	*Megalopae*
January	277	18
February	1609	17
March	748	62
April	36905	88
May	387	98
June	160	169
July	174	427
August	30	19
September	155	6
October	360	4
November	454	1
December	320	67

Cancer antennarius zoeae and megalopae were collected all year, but zoeae were most common from February through April and megalopae were most common from March through July (Table 22). Eight of the 12 ovigerous females were collected from December through April and the remainder from June through August. Age–0 crabs were most abundant from July through December in the otter trawl (Figure 45, see Table 19). Seasonal abundance of age–1+ crabs from the otter trawl was possibly bimodal, with peaks in fall and spring (see Figure 45, see Table 20). But in the ringnets, *C. antennarius* was most abundant in fall (Figure 46, see Table 21). Age–1+ male *C. antennarius* outnumbered females from February through May, while females generally outnumbered males from July though January (Figure 47).

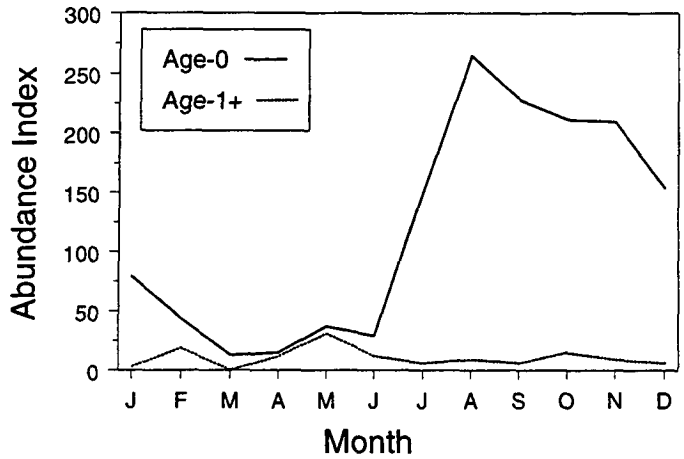

Figure 45 Monthly abundance indices of age–0 and age–1+ *C. antennarius* collected with the otter trawl from 1981 to 1988 and in 1996

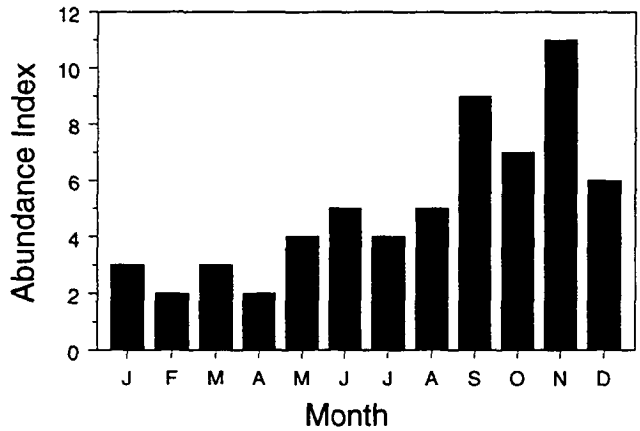

Figure 46 Monthly abundance indices (CPUE × 10) of all sizes of *C. antennarius* collected with the ringnets from 1983 to 1989

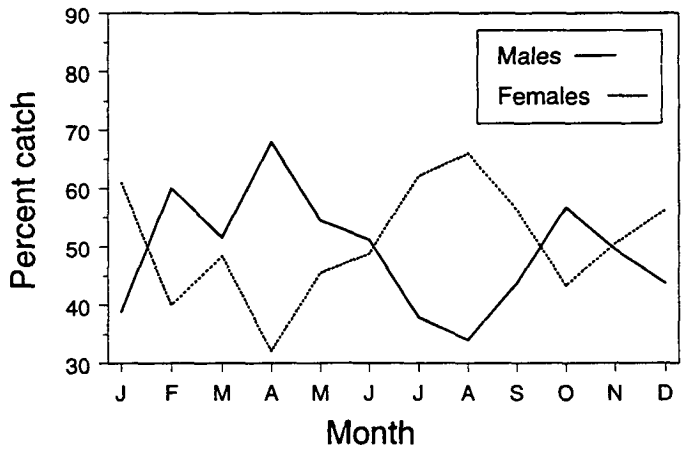

Figure 47 Monthly percent catch of male and female age–1+ *C. antennarius* collected with the otter trawl and ringnets

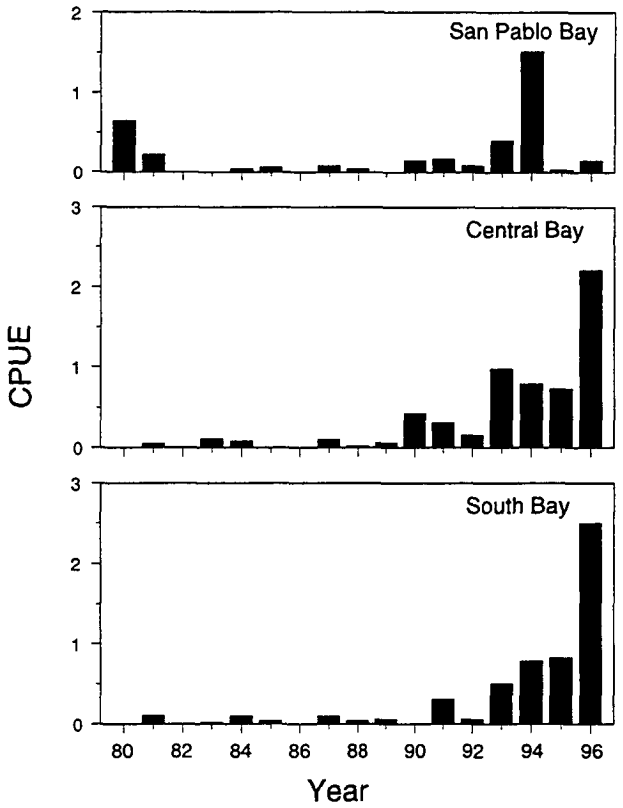

Figure 48 Annual distribution (CPUE) of age–0 *C. antennarius* collected with the otter trawl for May to October from 1980 to 1996

Distribution

Cancer antennarius zoeae were concentrated in South and Central bays; only a few zoeae were collected in San Pablo Bay and Carquinez Strait. Later stage zoeae and megalopae were most common in Central Bay. Age–0 *C. antennarius* were more widely distributed in the estuary than age–1+ crabs, as age–0 crabs were commonly collected from mid-South Bay through lower San Pablo Bay and age–1+ crabs were common only in Central Bay and lower San Pablo Bay. Age–0 crabs were most common near San Leandro and Oakland, with the highest catches at 2 shoal stations (#105 and #142) and 2 nearby channel stations (#108 and #109) (see Methods chapter, Figure 1). In the otter trawl, age–1+ crabs were most common at the Central Bay channel stations, especially station #213, and in the ringnets they were most commonly collected at the Muni Pier (#293) and Point Pinole (#396) stations.

The distribution of age–0 *C. antennarius* prior to 1993, when abundance was low, was very mixed relative to outflow (Figure 48). But from 1993 to 1996, when abundance was high, the center of distribution of age–0 crabs changed with outflow: CPUE was highest in South Bay in 1995 and 1996 (both "wet" years), in Central Bay in 1993 (an "above normal" year), and in San Pablo Bay in 1994 (a "critical" year). The distribution of age–1+ crabs from the otter trawl apparently did not shift upstream in low outflow years, as this age class was most common in Central Bay in all years except for 1981, when CPUE was highest in South Bay (Figure 49). But there was evidence of an upstream shift of larger crabs in the ringnet data, as *C. antennarius* was collected at the Point Pinole (#396) station in lower San Pablo Bay in all years except 1982 and 1983 (both "wet" years) and as far upstream as Crockett (Carquinez Strait) in several of the "dry" or "critical" years.

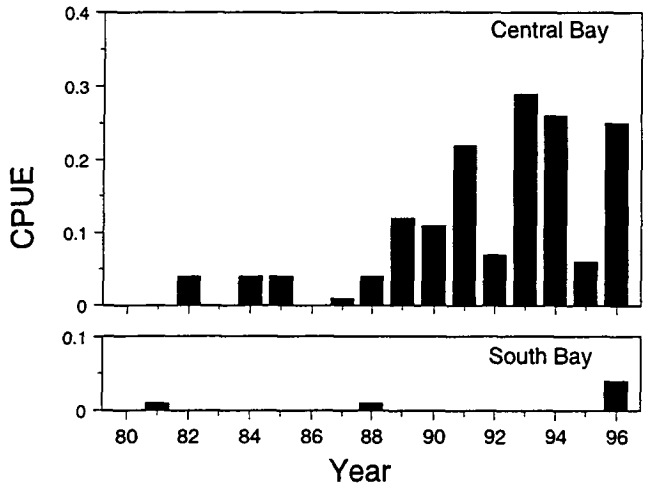

Figure 49 Annual distribution (CPUE) of age–1+ *C. antennarius* collected with the otter trawl for February to October from 1980 to 1996

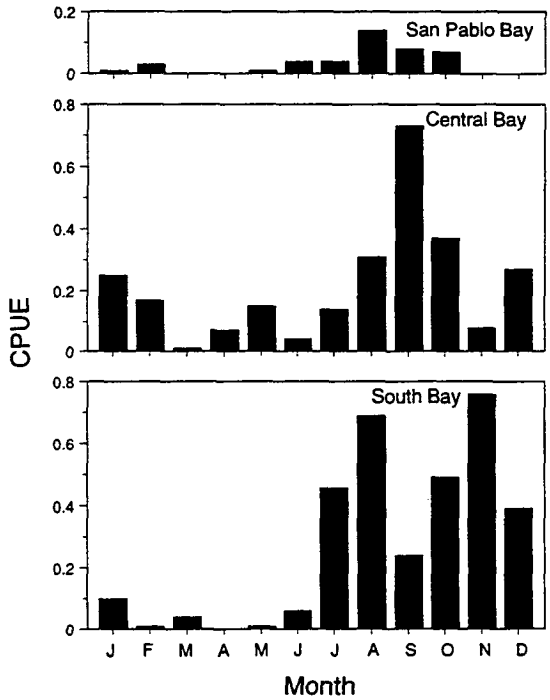

Figure 50 Monthly distribution (CPUE) of age–0 *C. antennarius* collected with the otter trawl from 1981 to 1988 and in 1996

Age–0 *C. antennarius* may move seasonally in the estuary, as they were more common in Central Bay from January through May and in South Bay from July through December (Figure 50). There is also some seasonal use of San Pablo Bay, where the highest CPUE was from June through October. But the otter trawl data show no evidence of a seasonal movement of age–1+ *C. antennarius*, as CPUE was highest in Central Bay in all months (Figure 51). However, there was a trend of increasing ringnet catches in San Pablo Bay from June through November.

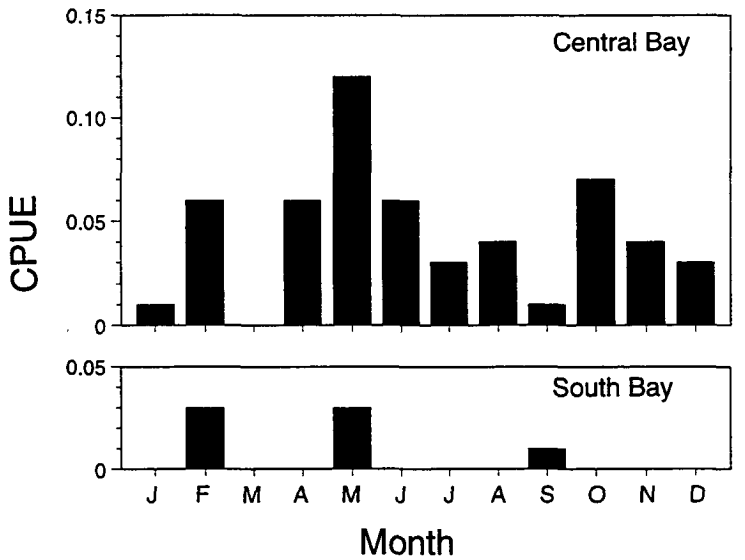

Figure 51 Monthly distribution (CPUE) of age–1+ *C. antennarius* collected with the otter trawl from 1981 to 1988 and in 1996

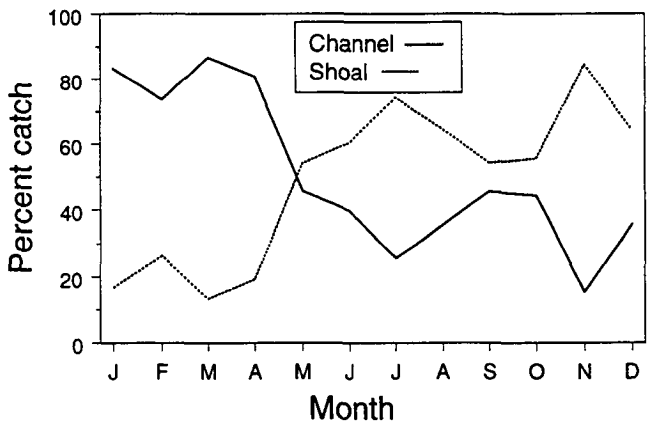

Figure 52 Channel-shoal percent catch of *C. antennarius* by month from 1988 to 1996 at station #109 (channel) and station #142 (shoal)

Cancer antennarius apparently move seasonally from channels to shoals within the estuary. For the selected channel-shoal station pair (stations #109 and #142), crabs were more common at the channel station from January through April and at the shoal station from June through December (Figure 52).

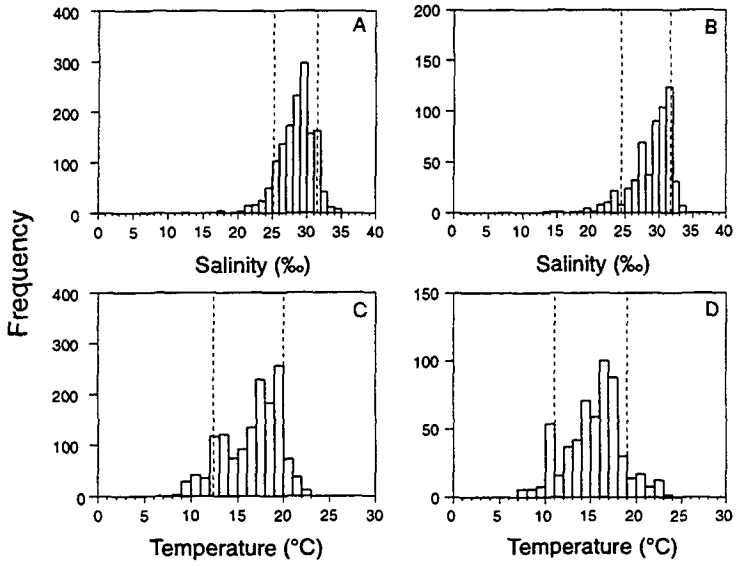

Figure 53 Salinity (‰) and temperature (°C) distributions of all sizes of *C. antennarius* collected with the otter trawl (1980 to 1996) and ringnets (1982 to 1994): (A) salinity, otter trawl; (B) salinity, ringnets; (C) temperature, otter trawl; (D) temperature, ringnets. Dashed vertical lines are the 10th and 90th percentiles.

Table 23 Salinity (‰) and temperature (°C) statistics for all sizes of *C. antennarius* from the otter trawl (1980 to 1996) and ringnets (1982 to 1994)

	Mean (Standard Deviation)	*Minimum*	*Maximum*	*10th Percentile*	*90th Percentile*
Salinity					
otter trawl	28.5 (2.5)	12.5	34.4	25.2	31.5
ringnets	29.0 (3.0)	13.6	34.0	24.5	31.7
Temperature					
otter trawl	16.7 (3.0)	8.1	22.6	12.4	20.0
ringnets	15.7 (3.1)	8.0	24.0	11.0	19.0

Salinity and Temperature

Most *C. antennarius* were collected at salinities ranging from 25‰ to 32‰ and temperatures from 11 to 20 °C (Figure 53). *Cancer antennarius* was collected at similar salinities in the otter trawl and ringnets (mean = 28.5‰ and 29.0‰, respectively), but at slightly higher temperatures in the otter trawl than the ringnets (mean = 16.7 °C and 15.7 °C, respectively) (Table 23). Female *C. antennarius* were collected at slightly higher salinities and lower temperatures than males in both gear types.

There was a slight increase in salinity with size (Figure 54A); the mean salinity was 28.5‰ for the 15 to 24 mm size group (n = 591) and 30.0‰ for the 95 to 104 mm size group (n = 81). There was also a decrease in temperature with size (Figure 54B), as the mean temperature was 17.4 °C for the 15 to 24 mm size group and 15.2 °C for the 95 to 104 mm size group.

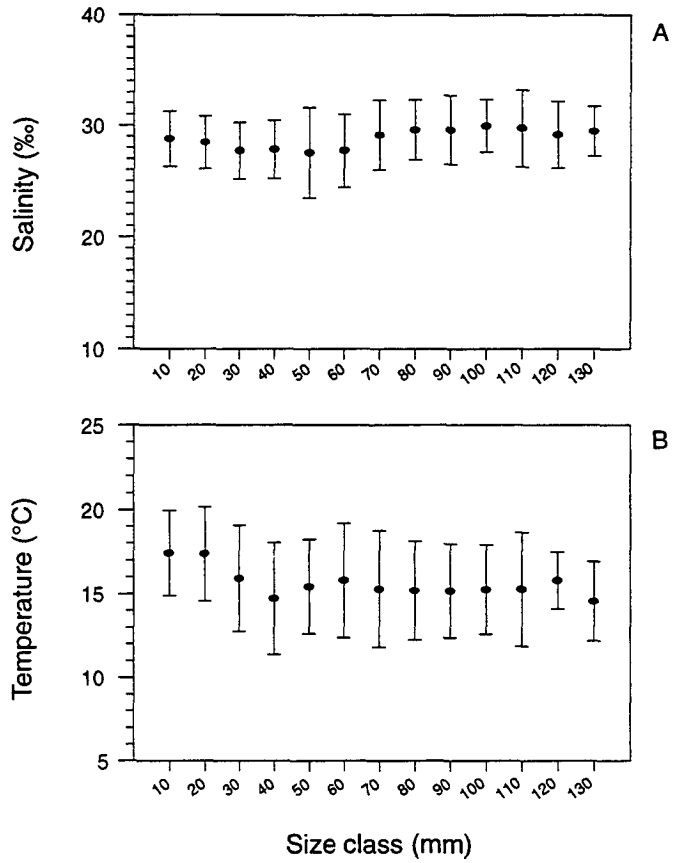

Figure 54 Mean salinity and temperature (±1 standard deviation) for *C. antennarius* by size class collected with the otter trawl and ringnets: (A) salinity (‰) and (B) temperature (°C). Size classes are every 10 mm, from 5 to 135 mm.

Discussion

It has been proposed that *C. antennarius*, which is considered to be a "marine" species, is not a successful inhabitant of estuaries (Orensanz and Gallucci 1988). Our data appear to partially support this conclusion for the San Francisco Estuary, as the abundance of *C. antennarius* was relatively low compared to *C. magister* and *C. gracilis* from the otter trawl and *C. magister* and *C. productus* from the ringnets. The low otter trawl catches are not unexpected, as *C. antennarius*, like *C. productus*, prefers rocky substrates which are not sampled effectively by this gear. The relatively low ringnet catches may be a function of limited estuarine use by *C. antennarius* due to salinity tolerance or exclusion from preferred protected habitats by the larger rock crab, *C. productus*. Although *C. antennarius* was collected at slightly higher salinities than *C. productus* in both the otter trawl and ringnets, it was collected at slightly lower salinities than *C. gracilis* in the otter trawl. For whatever reasons, *C. antennarius* apparently uses the estuary opportunistically as an extension of its nearshore coastal habitat and is usually not resident in the estuary.

Because *C. antennarius* was not as commonly collected in the otter trawl as the other species of *Cancer* crabs included in this chapter, it is difficult to interpret some of the abundance and distribution data. The trend of increasing annual abundance indices through the 1990s is similar to the abundance trends reported for *C. gracilis* and *C. productus*, with some high abundance years in common (for example, 1994 and

1996). The same factors may affect year class strength of *C. antennarius*, *C. gracilis* and *C. productus*, but not *C. magister*, in the estuary.

Based on the peak abundance of zoeae, megalopae, and small age–0 crabs, peak settlement of 1st instar *C. antennarius* is in late spring. There is a gradual movement of age–0 crabs to the shoals, especially in the northern portion of South Bay. Older crabs move back to the channels in late fall and by winter age–1+ crabs are concentrated in Central Bay, where most remain. Some age–1+ *C. antennarius*, especially females, may emigrate from the estuary in winter and early spring. This emigration is probably in response to decreasing salinities. Some age–1+crabs probably immigrate to the estuary as salinities again increase through summer and early fall.

An overall male to female ratio which favors males has been previously reported (Carroll 1982), but the dominance of males in the smaller, pre-puberty size classes (<75 mm), and females in the post-puberty size classes (80 to 110 mm) has not. We may have incorrectly identified some of the smaller females (<30 mm) as males, but this would explain only a portion of the bias towards males. The increase in the number of females in June and the relatively large number of mature females collected may be due to a migration of mature female *C. antennarius* to shallower waters, including the estuary, after egg incubation and hatching. An increase in female *C. antennarius* along the central California coast in the fall was attributed to a migration from deeper, cooler waters to warmer, shallower waters (Carroll 1982). Water temperatures in Central Bay are usually warmer than ocean temperatures from March through November (see Salinity and Temperature chapter, Figure 12), which includes most of the months in which mature female *C. antennarius* were more common than males.

Other *Cancer* Species

In addition to the 4 species discussed in this chapter, the San Francisco Bay Study monitoring program collected 46 *C. anthonyi* and 2 *C. jordani* (see Table 1). *Cancer anthonyi* ranges from Baja California to Humboldt Bay, and is most common south of Point Conception (Carroll and Winn 1989). Specimens collected by this study ranged from 7 to 122 mm, and all but 8 were <50 mm. One ovigerous female (113 mm) was collected. No *C. anthonyi* were collected or were identified prior to 1987 and the otter trawl catches were highest from 1990 to 1994 (Table 24). This trend of increasing catches in the early 1990s was also reported for *C. antennarius*, *C. gracilis*, and *C. productus* in this chapter. Although *C. anthonyi* were distributed from mid-South Bay to lower San Pablo Bay, the majority were collected in Central Bay. Salinity at point of collection ranged from 23.9‰ to 33.0‰ and temperature from 10.5 to 19.6 °C.

Cancer jordani ranges from Baja California to Neah Bay, Washington, but is not common north of Oregon (Jensen 1995). Both specimens were 14 mm and were collected from the northern portion of South Bay stations (#108 and #142). Because *C. jordani* is easily confused with *C. antennarius* in the field, it is probably more common in the San Francisco Estuary than indicated by our collections.

Table 24 Annual catch of *Cancer anthonyi* in the otter trawl and ringnets

Year	*Otter trawl*	*Ringnets*
1987	0	1
1988	3	2
1989	1	0
1990	11	1
1991	9	0
1992	5	0
1993	5	0
1994	5	
1995	1	
1996	1	

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Notes

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