Cottidae

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This section describes the abundance and distribution trends for species of the family Cottidae commonly collected in the San Francisco Estuary. In some cases, factors are identified that affect the abundance and distribution of a species. The description of how each species uses the estuary is then compared to what is known of its life history from investigations of other coastal habitats. For uncommonly collected species, brief summaries of size at capture, and dates and locations of capture are combined in a single section at the end.

The family Cottidae is composed of primarily small, bottom dwelling, nearshore, marine species. Most species have large heads, mouths, and pectoral fins, followed by a tapered body, a slim caudal peduncle and moderately-sized tail. Cryptic coloration and lack of a swim bladder make them well suited to a demersal existence. In general, cottids spawn adhesive eggs on hard substrates that hatch into planktonic or semi-planktonic larvae and develop into demersal juveniles and adults (Wang 1986).

Nine species of cottids were collected from the San Francisco Estuary between 1980 and 1995 (Table 1): Pacific staghorn sculpin, *Leptocottus armatus*; prickly sculpin, *Cottus asper*; bonehead sculpin, *Artedius notospilotus*; brown Irish lord, *Hemilepidotus spinosus*; red Irish lord, *Hemilepidotus hemilepidotus*; scalyhead sculpin, *Artedius harringtoni*; cabezon, *Scorpaenichthys marmoratus*; fluffy sculpin, *Oligocottus snyderi*; and tidepool sculpin, *Oligocottus maculosus* (Robins and others 1991). All are native to the eastern Pacific Ocean or to streams draining into it. All are marine species, except for the Pacific staghorn sculpin and the prickly sculpin, which are euhaline and freshwater species, respectively, although larvae of prickly sculpin are tolerant of salt water (Wang 1986).

Table 1 Total catch by species for cottids collected between January 1980 and December 1995. See Methods chapter, Table 1 for duration of use for each gear type.

Species	*Plankton Net Larvae*	*Plankton Net Juveniles*	*Beach Seine*	*Otter Trawl*	*Midwater Trawl*
Pacific staghorn sculpin	5,576	1	5,143	13,015	468
Prickly sculpin	9,985	21	3	66	1
Bonehead sculpin	34	0	0	79	1
Brown Irish lord	9	0	0	3	0
Red Irish lord	0	0	0	1	0
Scalyhead sculpin	0	0	0	1	0
Cabezon	131	0	2	0	0
Fluffy sculpin	0	0	1	0	0
Tidepool sculpin	4	0	0	0	0

Pacific Staghorn Sculpin

Introduction

The Pacific staghorn sculpin, *Leptocottus armatus*, ranges from San Quintin Bay, Baja California, to Chignik, Alaska (Miller and Lea 1972). It inhabits waters from the intertidal zone to a depth of 91 m (Miller and Lea 1972) and is common in brackish water and occasionally in freshwater (Jones 1962, Pearcy and Myers 1974, Moyle 1976). It is one of the most commonly caught species by pier and dock anglers, and it is likely to be the 1st fish caught by many young coastal anglers, particularly in the San Francisco region (Frey 1971, Karpov and others 1995). It has commercial value only as a baitfish.

Spawning occurs from October through April and peaks in January and February (Jones 1962, Wang 1986). The staghorn sculpin spawns both in estuaries and on the open coast (Wang 1986). Eggs are demersal, temporarily adhesive, and are deposited in clusters on a variety of substrates (Jones 1962, Wang 1986). In laboratory experiments, eggs hatched 9 to 14 days after fertilization at 15 °C. A salinity of 26‰ produced the best hatch of normal, healthy larvae (Jones 1962). At hatching, larvae measure 3.8 to 4.9 mm (Jones 1962). They are planktonic and can tolerate lower salinities better than the eggs can (Jones 1962, Wang 1986). Wang (1986) found few juveniles >10–15 mm TL in plankton samples and believed staghorn become demersal at this size. Larval and juvenile staghorn sculpins are common in bays and estuaries. They use shallow marine, brackish, and fresh water as nursery areas (Jones 1962, Eldridge and Bryan 1972, Pearcy and Myers 1974, Nybakken and others 1977, Greer and others 1980, Horn 1980, Bottom and others 1984, Bayer 1985, Wang 1986).

As the fish grow, they move to deeper water (Jones 1962). Sexual maturity is reached toward the end of or soon after their 1st year (Jones 1962, Tasto 1975). After spawning, adults leave the shallow spawning grounds for deeper, offshore areas (Tasto 1975). Adults reach a maximum size of about 305 mm TL (Miller and Lea 1972).

The staghorn sculpin is one of the most abundant demersal fish in the San Francisco Estuary as well as in other west coast estuaries (Levy and Levings 1978, Horn 1980, Bayer 1981, Bottom and others 1984), and because of its numbers and feeding behavior, it may be one of the most important predators of estuarine invertebrates (Tasto 1975, Karl 1979, Posey 1986, Armstrong and others 1995). In turn, staghorn sculpin provide food for a variety of wading and diving birds (Tasto 1975, Bayer, 1985). Thus, the staghorn sculpin is an important link in the estuarine food chain.

Methods

Staghorn sculpin were categorized as larvae, age 0, and adults for analyses. Fish collected in the plankton net were classified as larvae unless they possessed a full complement of dorsal fin rays. Fish 10 to 20 mm caught in the beach seine and otter trawl were assumed to have settled from the plankton and to be fully developed; hence, they were classified as age 0. Since staghorn sculpin mature in September at or near the end of their first year (Jones 1962, Tasto 1975), fish older than age 0 are classified as adults. An October 1 hatching date was assumed for all fish. Separation of age-0 and adult fish was accomplished by visual inspection of beach seine and otter trawl length-frequency data (mm TL). Cutoff lengths used to separate age classes for each month from October to September were as follows: 50, 60, 70, 80, 90, 100, 112, 127, 146, 166, 172, and 178 mm TL. Fish hatched in the fall were identified as part of next calendar year's year class; thus, fish hatched from October 1 to December 31, 1994 were part of the 1995 year class.

Annual abundance indices for larvae were calculated from plankton net data based upon an October to September index period. For both age–0 and adult fish, annual abundance indices were calculated from otter trawl data using February to September index periods (we did not sample from November through January in many years). Annual distribution (mean CPUE by region) analyses were based upon the same time period for each age group. Seasonal abundance indices were calculated as monthly means by age group for 1981 to 1988. Seasonal distribution was calculated as mean CPUE by age group, region, and month for 1981 to 1988. The depth distribution of each staghorn sculpin age group was the average monthly CPUE in the beach seine (intertidal areas) and in the otter trawl shoal stations (subtidal areas) and channel stations (deep areas) for 1981 to 1988. The depth cutoff between shoal and channel stations is about 6 m. Seasonal salinity and temperature distributions were calculated as the mean ±1 standard deviation of CPUE-weighted bottom salinity and bottom temperatures by month and age group for 1981 to 1988.

Results

Catch and Length Analyses

All gear types collected staghorn sculpin in substantial numbers (see Table 1). Larvae caught with the plankton net ranged from 3.0 to 14.3 mm TL but almost all were 4.0 to 10.3 mm TL. Of the 3,302 measured, only 7 larvae were <4.0 mm and only 31 were >10.3 mm. Fish collected with the beach seine ranged from 9 to 297 mm TL and those in the otter trawl from 19 to 272 mm TL (Figure 1). Age–0 fish in the 10 to 20 mm size range were first captured in November and were last caught in May. Based upon increases in modal length, age–0 fish grew at about 13.6 mm per month from February to September. The largest age–0 fish reached 180 to 190 mm by September. There was some overlap in length between age–0 fish and adults from March to September. Adult fish appeared to be primarily age 1. They grew slowly, averaging about 4.2 mm per month from October to April. Few fish >210 mm were captured.

Abundance and Distribution of Larvae, Juveniles, and Adults

Annual Abundance

Larval abundance was moderate in 1981, declined slowly to a minimum of 24,739 in 1983, increased slightly in 1984, then increased sharply to a maximum of 132,317 in 1985 (see Figure 2, Table 2). Larval abundance declined again from 1985 to 1988, then increased slightly in 1989.

Between 1980 and 1988, abundance of age–0 staghorn sculpin was higher in even than in odd years, except for 1985 (Figure 2, Table 3). From 1989 to 1995, abundance was higher in odd years. Maximum abundance was reached in 1986 and the minimum in 1981. Adult abundance was highest in 1986, lowest in 1991, and consistently low from 1988 to 1995 (see Figure 2, Table 4).

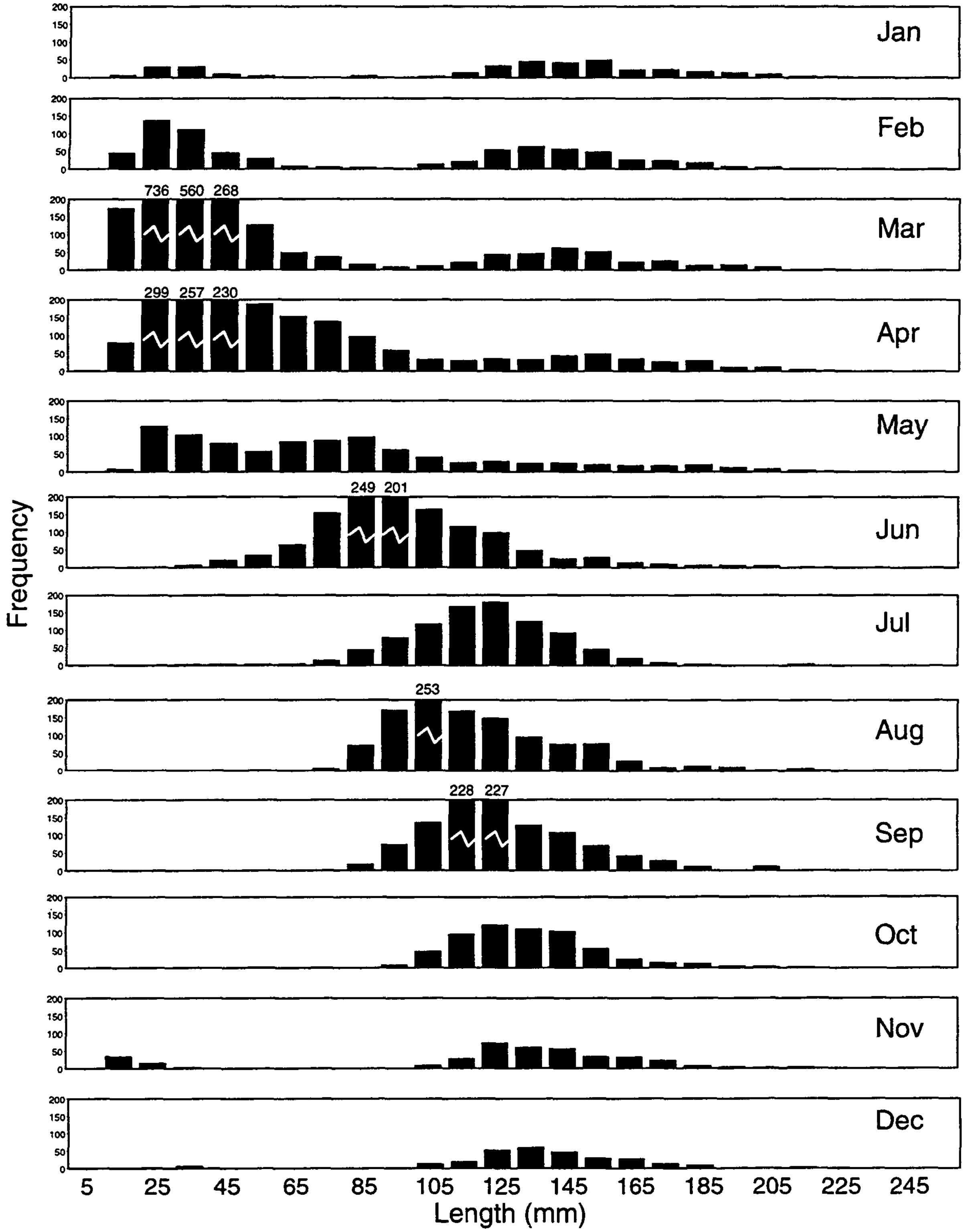

Figure 1 Length frequency (mm TL) of Pacific staghorn sculpin collected with the beach seine (1981 to 1986) and otter trawl (1981 to 1988)

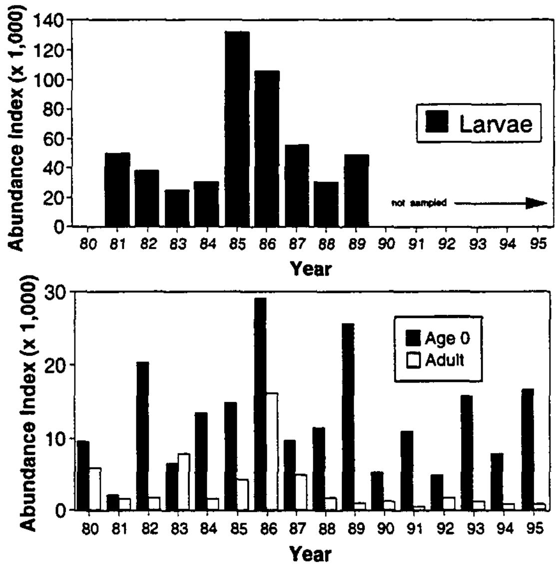

Figure 2 Annual abundance of Pacific staghorn sculpin larvae collected with the plankton net (top), and age–0 and adult fish collected with the otter trawl (bottom). In 1980, plankton sampling was insufficient to calculate an index for larvae.

Table 2 Monthly abundance of larval Pacific staghorn sculpin captured in the plankton net from 1980 to 1989. Annual abundance indices are in the far right column. Monthly abundance indices are in the bottom row (mean 1981 to 1989 monthly abundance).

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct–May*
1980					126574	43947	15000	5591	0	0	0	0	
1981	0	1910	26271	190556	99837	67245	12435	0	565	0	0	0	49782
1982	1129	2222	8055	36970	183628	56581	20805	0	0	0	0	0	38674
1983	7157	2285	25252	76938	75223	8116	1469	1469	0	0	0	0	24739
1984	0	1827	5322	48688	153813	32293	3332	0	0	0	0	0	30659
1985	0	23821	87549	346660	400070	171077	27570	1791	0	0	0	0	132317
1986	0	1074	47735	522580	159401	80842	33883	0	0	0	0	0	105689
1987	0	2865	86158	92634	193995	63425	5733	0	0	0	0	0	55601
1988	753	1433	11748	77068	103738	41816	6841	0	1074	0	0	0	30425
1989	0	1074	15828	116872	131334	123576	0	0					48586
1981–1989	1130	4680	37261	174012	171213	65174	14009	408	205	0	0	0	

Table 3 Monthly abundance of age-0 Pacific staghorn sculpin captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Monthly abundance indices are in the bottom row (mean 1981 to 1989 monthly abundance).

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Feb–Sep*
1980					668	775	2662	3242	12494	30844	16212	9458	9544
1981	189	0	111	219	0	959	4443	2417	1261	2377	2885	2852	2149
1982	0	0	0	0	0	0	2697	16421	45096	9060	45294	45091	20457
1983	0	0	0	156	0	1017	1368	1506	15397	20392	11606	1090	6547
1984	0	0	0	0	0	0	3284	2251	34811	53731	5062	8680	13477
1985	48	0	0	0	0	622	492	1702	29953	18177	36918	30756	14828
1986	134	0	0	0	281	3511	10913	11929	25333	49658	81408	50400	29179
1987	0	0	188	76	313	0	0	844	7028	20212	19433	30010	9730
1988	0	243	62	0	0	414	3507	11803	33780	30075	4276	7601	11432
1989	0	0	0	0	250	404	4899	26127	32023	25007	90903		25659
1990					0	542	1200	3955	6224	12352	14410	3912	5324
1991	0				0	2312	2741	6564	19832	28757	14504	12717	10928
1992	0				0	1733	4990	11022	11305	2769	2494	5772	5011
1993	352				0	0	5366	37625	16982	37477	23969	4470	15736
1994	0				97	657	919	1904	16148	6948	29197	7330	7900
1995	0			0	0	6293	7559	16825	29504	34730		21129	16577
1996	0	0	0										
1981–1989	41	27	40	50	94	770	3511	8333	24965	25410	33087	22060	

Table 4 Monthly abundance of adult Pacific staghorn sculpin captured in the otter trawl from 1980 to 1995. Annual abundance indices are in the far right column. Monthly abundance indices are in the bottom row (mean 1981 to 1989 monthly abundance).

Year	*Oct*	*Nov*	*Dec*	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Feb–Sep*
1980					23662	16283	1158	2614	1664	857	864	189	5911
1981	7584	14775	2112	2998	2571	1565	5241	2380	326	216	1161	162	1703
1982	3865	2440	1292	16048	1317	752	1769	7038	1729	211	1370	230	1802
1983	16761	9864	3746	14139	9571	21150	20080	5206	3385	1286	2308	55	7880
1984	5530	5054	4983	460	974	3286	3264	3042	1336	1212	0	216	1666
1985	19523	4057	5895	7427	17956	3970	6352	2819	2540	0	487	243	4296
1986	31453	23957	28926	19870	47146	37556	25237	5906	5535	1367	2662	3213	16078
1987	7193	4627	7442	8010	17279	8916	2787	2874	1952	2391	1974	1163	4917
1988	11229	4583	12444	6106	2978	2541	6255	2881	192	0	0	0	1856
1989	807	541	501	299	1287	2153	1937	597	659	0	403		1005
1990					5909	2272	612	1947	0	0	0	0	1343
1991	2574				1619	435	307	591	406	688	0	0	506
1992	6731				4419	2723	2712	4411	622	0	0	0	1861
1993	1940				2336	3292	1298	2036	1263	0	297	0	1315
1994	1959				2190	2194	568	817	730	270	297	0	883
1995	567			1541	703	2245	0	1290	1584	0		865	955
1996	1556	4841	4772										
1981–1989	11549	7766	7482	8373	11231	9099	8102	3638	1962	743	1152	660	

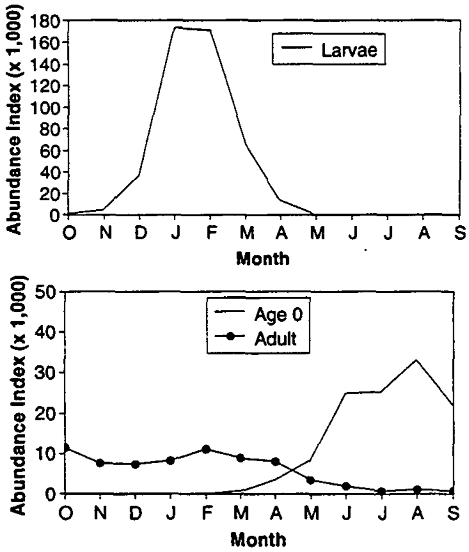

Figure 3 Seasonal abundance of Pacific staghorn sculpin larvae collected with the plankton net (top), and age–0 and adult fish collected with the otter trawl (bottom). Data are mean abundance indices by month for 1981 to 1988.

Seasonal Abundance

Larval staghorn sculpin were initially collected in October and abundance rapidly increased to a maximum in January (Figure 3, see Table 2). Abundance remained high through February, then declined sharply to very low levels in May and June. None were collected after June.

A few age–0 staghorn sculpins were collected from October through February when their abundance began a rapid increase to June (see Figure 3, see Table 3). Peak age–0 abundance occurred in August, followed in September by a sharp decline as the spawning period approached.

Throughout the November to April spawning period, adult abundance remained stable except for a slight increase in February (see Figure 3, Table 4). After February, abundance declined steadily to a minimum in July and remained low until October.

Annual Distribution

Larval staghorn sculpins were collected from South Bay to the west delta, but were rare in the west delta (Figure 4). Few larvae were collected in Suisun Bay, and none were collected there during the high outflow years 1982 and 1983. In most years with low outflow during the spawning period (1981, 1987 to 1989), larval CPUE was highest in San Pablo Bay. In the low outflow year 1985, larval CPUE was highest in South Bay, a distribution pattern found in most high outflow years (for example, 1982, 1983, 1986). Thus, larval CPUE tended to be higher in San Pablo Bay during dry years and in South Bay during wet years.

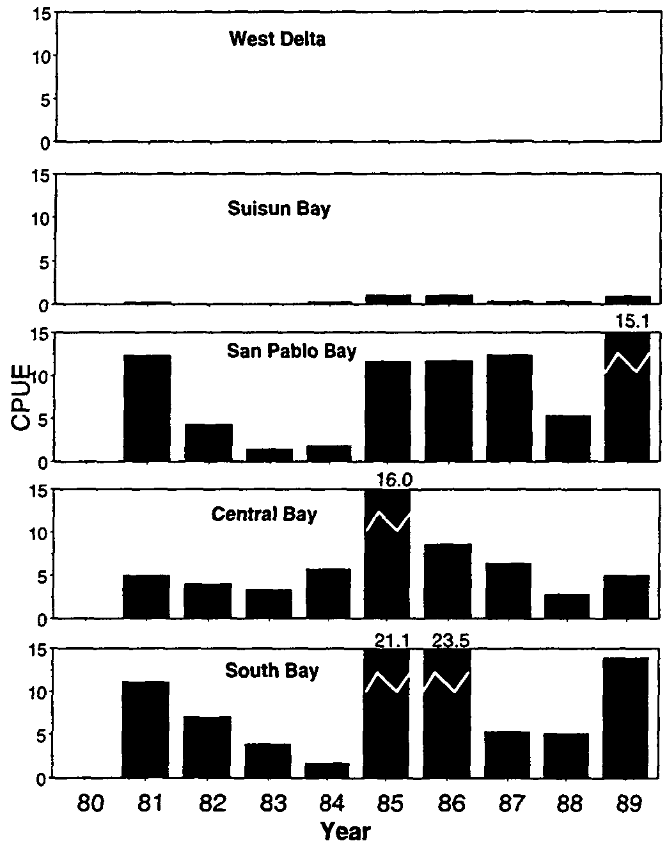

Figure 4 Annual distribution of Pacific staghorn sculpin larvae collected with the plankton net. Data are mean CPUE by region for October to September.

By the time age–0 staghorn sculpins were captured by the otter trawl, they had moved upstream relative to larvae. Age–0 staghorn were collected from South Bay to the west delta in all years except 1982 and 1983, when none were captured in the west delta (Figure 5). From 1980 through 1988, age–0 CPUE was highest in San Pablo Bay in every year except 1985 and 1987, when it was highest in Central Bay. After 1988, maximum CPUE shifted between Central Bay, San Pablo Bay and Suisun Bay (see Figure 5). Other indications for the upstream movement of age–0 fish relative to larvae were the higher CPUE in Suisun Bay compared to South Bay, and the substantial use of the west delta during most low outflow years (for example, 1981, 1985, 1988, and 1990 to 1992).

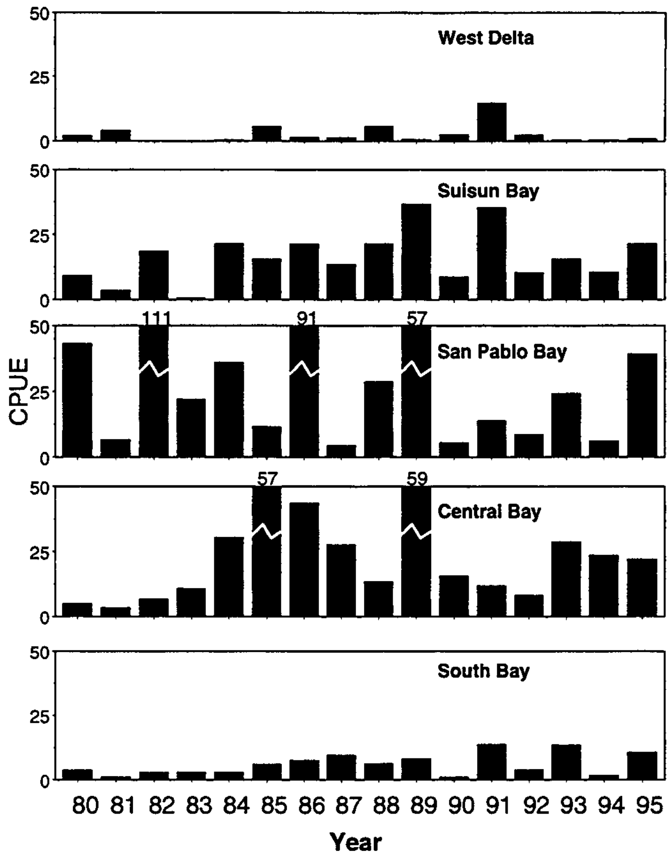

Figure 5 Annual distribution of age–0 Pacific staghorn sculpin collected with the otter trawl. Data are mean CPUE by region for February to September.

Although adult staghorn sculpins were collected from all regions during the study period, they were uncommon in Suisun Bay and were only collected in the west delta in 1986 (Figure 6). South Bay CPUE increased substantially during the high outflow years 1983 and 1986, but not in other high outflow years. Maximum adult CPUE was found in Central Bay except for the low outflow years 1981 and 1988 to 1991, when it was in San Pablo Bay. Adult staghorn were most broadly distributed during 1986, their year of maximum abundance (see Figure 2).

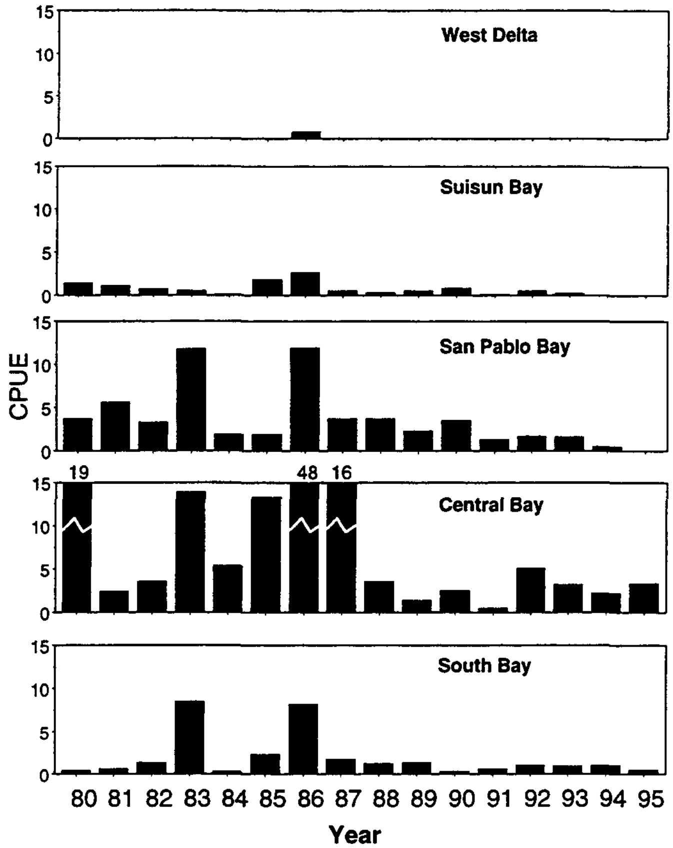

Figure 6 Annual distribution of adult Pacific staghorn sculpin collected with the otter trawl. Data are mean CPUE by region for February to September.

Seasonal Distribution

In October, staghorn sculpin larvae were evenly distributed from South Bay to San Pablo Bay (Figure 7). In December, as larval densities increased, the first collections of larvae occurred in Suisun Bay. Larval density reached a maximum in South and San Pablo bays in January and in Central and Suisun bays in February. February was the only month when staghorn larvae were collected in the west delta. In March, CPUE declined in all regions except Suisun Bay. Between March and June, CPUE declined to zero from the west delta downstream to San Pablo Bay in successive months. In June, the last few larvae were collected in South and Central bays.

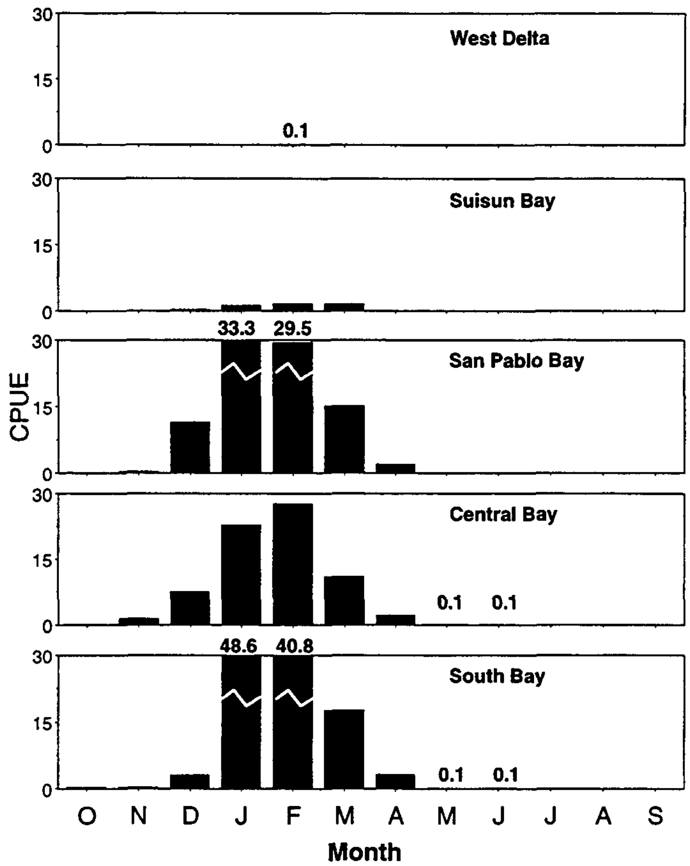

Figure 7 Seasonal distribution of Pacific staghorn sculpin larvae collected with the plankton net. Data are mean CPUE by region for 1981 to 1988.

Age–0 staghorn sculpins recruited to the otter trawl sporadically from October to February (Figure 8). Beginning in March or April, recruitment increased in all regions. Age–0 fish used Suisun Bay and the west delta more often than larvae (see Figures 7 and 8). After June, numbers of age–0 fish declined in South Bay and remained at much lower levels through September. However, in Central Bay, CPUE remained high through September after peaking in July. Age–0 fish density peaked in San Pablo Bay in June at a level higher than any other region and remained high through September. In Suisun Bay, CPUE increased through September. After June, CPUE in the west delta declined to low levels in July and August, but increased sharply to its highest level in September.

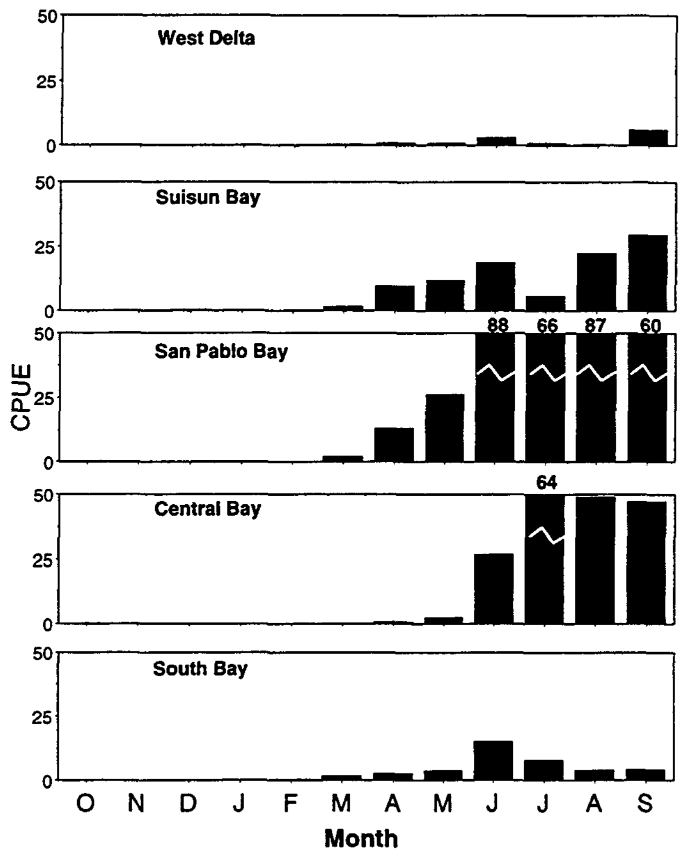

Figure 8 Seasonal distribution of age–0 Pacific staghorn sculpin collected with the otter trawl. Data are mean CPUE by region for 1981 to 1988.

From October to December, adult staghorn sculpins were found in all regions (Figure 9). Their numbers decreased in all regions in November and continued to decline in the west delta and Suisun Bay through March and April. From November to February, CPUE in San Pablo Bay remained stable, whereas it increased in Central and South bays. Beginning in March and continuing through the summer, CPUE declined in South, Central, and San Pablo bays.

Age–0 staghorn sculpins were taken almost exclusively in the intertidal zone from October to February (Figure 10). Density in the intertidal zone increased exponentially from December to March, yet very few were caught on shoals or in channels during this period. From March to July, many age–0 fish moved to deeper water, first to shoals, then to channels. By September, density in channels was higher than in shoals for the first time, and few fish remained in intertidal areas.

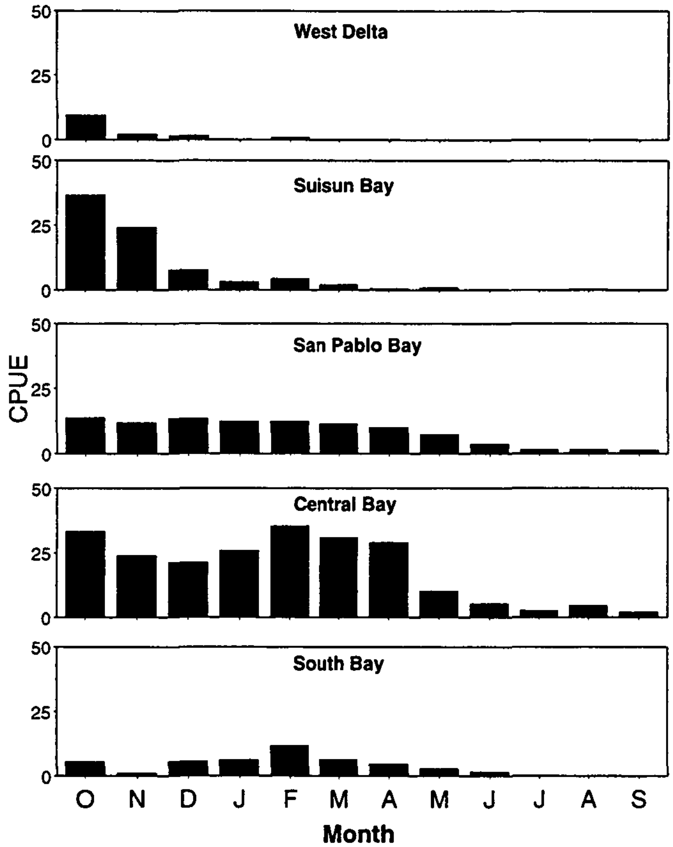

Figure 9 Seasonal distribution of adult Pacific staghorn sculpin collected with the otter trawl. Data are mean CPUE by region for 1981 to 1988.

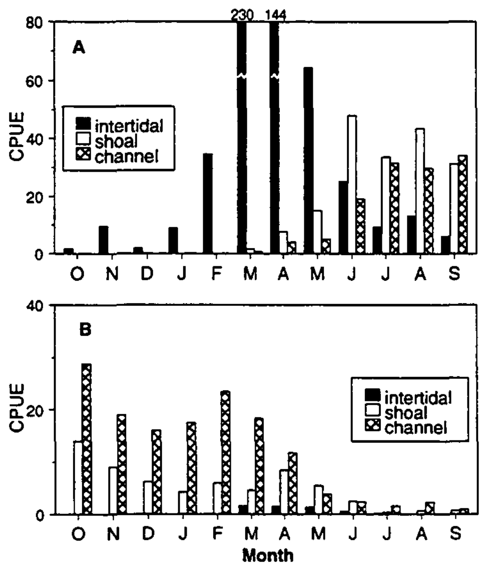

Figure 10 Depth distribution by month of (A) age–0 and (B) adult Pacific staghorn sculpin collected with the beach seine (intertidal) and the otter trawl (shoal and channel). Data are mean CPUE by month and age group for 1981 to 1986 for the beach seine and for 1981 to 1988 for the otter trawl.

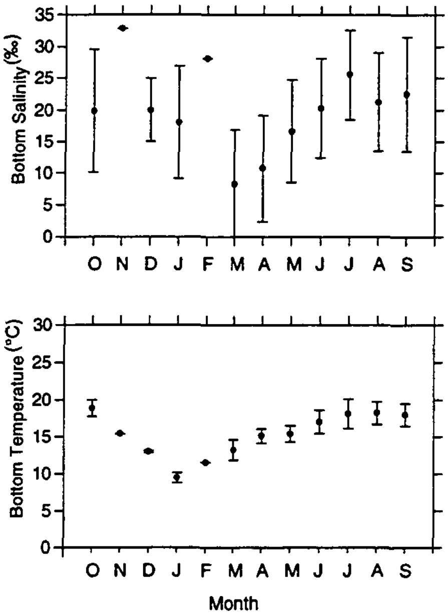

Figure 11 Salinity and temperature distributions of age–0 Pacific staghorn sculpin collected with the otter trawl. Data are mean ±1 standard deviation CPUE-weighted bottom salinity and bottom temperature by month for 1981 to 1988.

The trend toward increased use of channels rather than shoal and intertidal areas seen for age–0 staghorn sculpin in September continued for adult fish in October and reached a peak in February (see Figure 10). Adult fish were collected in intertidal areas from March to July only. During these months, shoal use increased in April, then CPUE declined in both channels and shoals. In May and June, shoal CPUE was equal to or higher than that of channels, but the reverse was true for all other months (see Figure 10).

Salinity and Temperature

Age–0 staghorn sculpins were captured throughout the salinity range found in the estuary, <0.1‰ to >34‰. The few fish collected by the otter trawl from October to February came from water with a mean salinity of about 19‰ to 20‰ or higher (Figure 11). From March through July, as numbers increased in the otter trawl and as estuarine salinities increased, age–0 fish were found in steadily increasing salinities. Starting at a mean of 8.3‰ in March, the salinity increased to of 25.6‰ in July, before declining to 21‰ and 22.5‰ in August and September.

Age–0 staghorn sculpins were in water with a mean temperature of 9.5 °C in January (see Figure 11). Temperatures at which they were found rose steadily to about 18 °C in July, stabilized until September, and reached a high point of about 19 °C in October.

The movement of adult fish out of the west delta and Suisun Bay from October to December was reflected in the increased mean salinity in December to 26.5‰ (Figure 12). After the December peak, declining estuarine salinities caused by high outflow were responsible for most of the downward shift in salinity to a minimum of 15.2‰ in March. Otherwise, the continued emigration from the less saline west delta and Suisun Bay during this period should have increased their salinity range. After March, adult fish were collected from increasingly saline waters through summer (see Figure 12). This increase was due partly to increasing estuarine salinities and partly to a continued downstream movement (see Figure 9). Even when their salinity range reached a maximum in July, adult fish were still collected at salinities as low as 9.5‰.

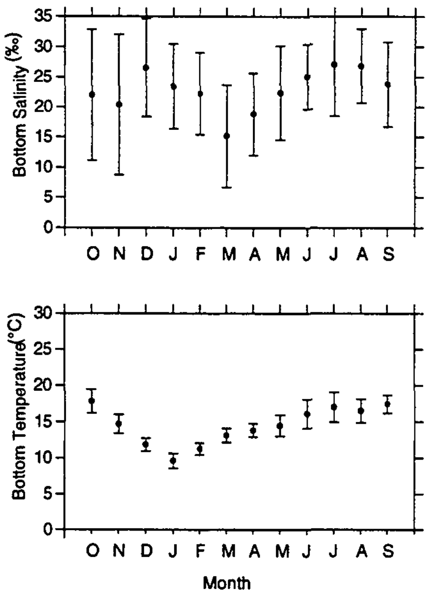

Figure 12 Salinity and temperature distributions of adult Pacific staghorn sculpin from the otter trawl. Data are mean ±1 standard deviation CPUE-weighted bottom salinity and bottom temperature by month for 1981 to 1988.

Adult staghorn sculpins were found at temperatures ranging from 6.6 °C in January to 22.1 °C in September. Monthly mean temperatures ranged from 9.6 °C in January to 17.8 °C in October (see Figure 12). Their temperature distribution was fairly stable during summer at means of 16.1 to 17.8 °C from June to October, then decreased rapidly in winter. Although the salinity and temperature distributions of age–0 and adult fish overlapped, age–0 fish were usually found in fresher, warmer water than adults.

Discussion

The Pacific staghorn sculpin completes its entire life cycle within the estuary, but length frequency data suggest adult fish emigrate or die before their 2nd spawning cycle: there were few fish ≥180 mm present between November and April (see Figure 1). Adults (primarily age 1) appeared to migrate to the open coast after their 1st spawning (City of San Francisco, Bureau of Water Pollution Control, unpublished data). Adult distribution shifted toward Central Bay from February to July as their abundance declined after spawning, suggesting emigration to the coast. In June 1983, when abundance of age–1 fish was low in the estuary, otter trawl sampling in the Gulf of the Farallones collected 201 age–1 fish (1982 year class) and 6 age–2 fish (1981 year class based upon length frequency) in 7 tows (City of San Francisco, Bureau of Water Pollution Control, unpublished data). Similarly, in June 1984, another smaller group of age–1 fish was caught in the Gulf of the Farallones. Very few age–0 fish were collected in the Gulf of the Farallones (<10 in 35 trawls from October 1982 to June 1984), indicating that most reared in the estuary; therefore, age–1 fish must have migrated to the coast after spawning and remained there through their next spawning cycle. In Anaheim Bay, a similar spring-summer decline in abundance of age–1 fish was also observed and was attributed to mortality and emigration to the open coast of surviving post-spawning fish, although no coastal sampling was conducted to confirm the emigration (Tasto 1975). In other trawl studies, staghorn sculpin age classes were combined, so no shifts in geographical distribution could be detected (Haertel and Osterberg 1967, Fierstine and others 1973, Bottom and others 1984). By contrast, Jones (1962) used otoliths to age 146 adult staghorn from the shrimp fishery in San Francisco Bay and found substantial numbers of age–2 and age–3 fish present. Moreover, the size range (125 to 189 mm TL) of age–2 fish completely overlaps that of fish identified as age 1 by this study during November to April (see Figure 1). This suggests little or no growth in length from age 1 to age 2, as length frequency data clearly indicates that fish can grow to 125 to 189 mm by December to February, only a couple months past their 1st birthday. The length range of age–3 fish (165 to 239 mm) also conflicted with the no-growth hypothesis, as these fish were distinctly larger than the age–2 fish, indicating strong growth between these age groups. Regardless of the accuracy of aging, the shrimp trawl data indicate that older age groups were present in the estuary (Jones 1962).

Based on the collection of larvae, staghorn sculpin spawned throughout the estuary, but spawning in Suisun Bay and the west delta occurred only in low outflow years. In October and November, adult fish moved out of Suisun Bay and the west delta, possibly to spawn. This occurred before or coincident with salinity reductions in these regions. In the laboratory, eggs successfully hatched in salinities from 10.2‰ to 34.3‰, but hatching success was best at intermediate salinities of 17.6‰ and 26.4‰ (Jones 1962). Salinities >10.0‰ did not occur in Suisun Bay and the west delta during winter except in low outflow years. Thus, spawning would usually have to take place downstream from Suisun Bay to be successful.

Age–0 fish moved inshore and toward freshwater soon after settlement, dispersing to all regions of the estuary. This movement occurred from February to May when salinities were at or near annual lows. Similar movements of juveniles into brackish water were observed in Walker Creek, a tributary to Tomales Bay, California, (Jones 1962), and in the Squamish River Estuary, British Columbia (Levy and Levings 1978). Even in the absence of reduced salinities an inshore movement of juveniles occurs in central and southern California bays (Karl 1979, Horn 1980, Yoklavich and others 1991); this movement is apparently enhanced by a slight reduction in salinity (Fierstine and others 1973). In conjunction with the downstream shift of maturing and mature fish, this represents an ontogenic shift in salinity distribution.

Prickly Sculpin

Introduction

The prickly sculpin, *Cottus asper*, is common in coastal streams from the Kenai Peninsula, Alaska to the Ventura River, southern California, and is widespread in the low elevation streams of California's Central Valley (Moyle 1976). Its larvae and juveniles are tolerant of a wide range of water conditions and are commonly found in brackish water (Pearcy and Myers 1974, Moyle 1976, Bottom and others 1984, Jones and Bottom 1984, Wang 1986). It is characterized over most of its range by visible prickles over most of its body; however, in California's Central Valley the smooth-skinned form is typical (Moyle 1976).

Spawning occurs from late February through June, but primarily in March and April in California (Krejsa 1965). Males move to fresh or brackish water spawning areas and prepare nests by digging small hollows under rocks or other solid objects; females follow when ripe (Krejsa 1965, 1967). Eggs are laid in clusters on the ceiling of the nest and are guarded by the male (Krejsa 1967, Moyle 1976). Males may spawn with more than 1 female. At 10 to 12 °C in the laboratory, eggs hatch 19 to 20 days after fertilization (Mason and Machidori 1976). Larvae begin swimming soon after hatching and are swept downstream to slower water where they remain planktonic for 3 to 5 weeks (Krejsa 1967, Mason and Machidori 1976, Moyle 1976). They metamorphose and settle to the bottom at about 12 mm TL (Krejsa 1967, Mason and Machidori 1976). Juveniles hatched from eggs spawned in or near an estuary eventually migrate upstream into tributaries (McLarney 1968). They may begin migrating soon after settling (Moyle 1976) or may remain in the estuarine zone until the summer of the following year before migrating (Mason and Machidori 1976).

As prickly sculpin grow they select pool habitats with progressively deeper and slower water, and better cover (Mason and Machidori 1976). Fish mature during their 2nd, 3rd or 4th year of life depending upon their stock (Patten 1971) at 40 to 70 mm SL (Moyle 1976). They reach a maximum length of about 300 mm TL, but are usually <130 mm (Eschmeyer and others 1983).

Methods

In the plankton net, fish <11 mm were classified as larvae and were measured to the nearest mm TL. Due to the low number of juvenile and adult fish caught, no separation of age groups was made for abundance and distribution analyses. Abundance and distribution analyses for larvae were based upon the plankton net catch and for juveniles and adults combined, the otter trawl catch was used for analysis.

Results

Catch and Length Analyses

Prickly sculpin collected with the plankton net ranged from 4.5 to 50 mm TL, but most were between 5.0 and 7.4 mm TL (Table 5). Prickly sculpin caught with the otter trawl, the beach seine, and midwater trawl ranged from 27 to 137 mm, collectively (Table 6). Since prickly sculpin mature at lengths of 40 to 70 mm SL (Moyle 1976), both juvenile and adult fish were caught (see Table 6). Length modes at 30 to 39, 70 to 79 and 110 to 119 mm, suggest at least 3 age groups were caught.

Abundance and Distribution of Larvae, Juveniles, and Adults

Annual Abundance

Annual, larval prickly sculpin abundance was highest from 1982 to 1984 and next highest in 1986 (Table 7). Abundance was lowest from 1988 to 1989. Larval catch was higher in high outflow years than in low outflow years.

Juvenile and adult prickly sculpin were collected in only half the years sampled, and except for 2 fish collected in 1992, all were collected during high outflow years (Table 8). The peak catch of 23 occurred in 1983.

Seasonal Abundance

Larvae were collected from January to May in all years, and to September in 1983 (see Table 7). Larval abundance usually peaked in March, but peaked in May in 1982. Few larvae were collected after May.

Although juvenile and adult fish were collected in almost every month of the year, most were collected from May to July (see Table 8). A few fish were collected during the high outflows in the falls of 1982 and 1983, and in the winters of 1984 and 1986.

Annual Distribution

Larvae were collected in all regions but catch was highest in Suisun Bay and lowest in South Bay (Table 9). In the low outflow years, 1985 and 1988, larval catch was highest in the west delta. Larvae were present in South Bay only in the high outflow years, 1980, 1982, 1983, and 1986.

Juveniles and adults were only collected in Suisun Bay and the west delta: 56 in Suisun Bay and 10 in the west delta. Fish were collected in Suisun Bay during all high outflow years. One or 2 fish were collected in the west delta in all high outflow years, except 1980 when none were caught.

Table 5 Length frequency of prickly sculpin collected with the plankton net from 1980 to 1988. Eighteen fish ranging from 14.3 to 50 mm were not included.

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
4.5–4.9			4	5	2				1				12
5.0–5.4	4	21	83	161	127	4	5	1					406
5.5–5.9	22	126	345	599	330	8							1430
6.0–6.4	60	384	919	581	258	5	3						2210
6.5–6.9	17	107	243	72	33								472
7.0–7.4	8	81	101	30	15								235
7.5–7.9	1	8	22	7	11								49
8.0–8.4		8	15	7	11								41
8.5–8.9	1	2	4	6	9								22
9.0–9.4			13	5	10								28
9.5–9.9			7	2	7								16
10.0–10.4			5	5	2								12
10.5–10.9			6	3	3								12
11.0–11.4	1												1
11.5–11.9													0
12.0–12.4					1								1
12.5–12.9				1									1
Total	115	737	1767	1501	820	17	8	1	1	0	0	0	4967

Table 6 Length frequency of prickly sculpin collected with the otter trawl from 1980 to 1995

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
20–29					2	1	2						5
30–39					6	5	3						14
40–49				1	1	2	1						5
50–59					1	7	1						9
60–69	1					1	3				1		6
70–79				2	1	3	2		1			1	10
80–89				1							1		2
90–99					1	1	1				1		4
100–109		1			1	1	1						4
110–119						2	2			1			5
120–129													
130–139										1	1		2
Total	1	1	0	4	13	23	16	0	1	2	4	1	66

Table 7 Annual and seasonal abundance (total catch) of prickly sculpin larvae collected with the plankton net. No plankton sampling occurred in January 1980 or after May 1989.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Abundance*
1980		148	370	146	70								735
1981	88	130	192	120	15								545
1982	18	184	596	481	702	32							2013
1983	3	101	1158	718	1135	10	8	1	1				3134
1984	5	180	456	412	85								1138
1985	1	34	194	184	14	1							428
1986	7	112	372	422	130	4							1047
1987	21	55	229	202	7	1							515
1988	4	35	85	21	9								154
1989	2	32	28	205	9								276
Total	149	1011	3680	2911	2176	48	8	1	1	0	0	0	9985

Table 8 Annual and seasonal abundance (catch) of prickly sculpin from the otter trawl. See the Methods chapter, Table 1 for the months of sampling missed with this gear.

Year	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
1980				1	1								2
1981													0
1982						4	2				1	1	8
1983					1	8	10		1	1	2		23
1984	1			3	1	2				1			8
1985													0
1986		1			4	3							8
1987													0
1988													0
1989													0
1990													0
1991													0
1992					2								2
1993					3	2	2						7
1994													0
1995					1	4	2				1		8
Total	1	1	0	4	13	23	16	0	1	2	4	1	66

Table 9 Annual distribution of larval prickly sculpin collected with the plankton net. Data are total annual catch by region.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*West Delta*
1980	3	9	190	437	96
1981		3	10	308	224
1982	1	39	297	1327	349
1983	14	139	764	1992	225
1984		4	92	681	361
1985			6	173	249
1986	8	44	343	454	198
1987			6	305	204
1988				74	80
1989			6	169	101
Total	26	238	1714	5920	2087

Discussion

The prickly sculpin was primarily collected seasonally in the study area, returning to freshwater soon after larval settlement or when salinities increased during summer. This was similar to migration patterns observed elsewhere, in which settled juveniles left brackish water and migrated into freshwater during summer (Shapavolv and Taft 1954, Krejsa 1965, 1967).

The catch of all age groups of prickly sculpin in the study area increased during periods of high freshwater outflow. Meng and Moyle (1994) also found this to be true in Suisun Marsh. As a winter-spring spawner with planktonic larvae, the prickly sculpin uses river outflow to disperse its larvae, the higher the outflow the broader the dispersal downstream. In addition, higher outflows create more freshwater habitat and may have led to better recruitment, as was the case for longfin smelt, another winter-spawning species with planktonic larvae (CDFG 1992). This larval dispersal and juvenile tolerance of brackish water enables prickly sculpin in coastal drainages to periodically exchange genetic material through the exchange of individuals. Prickly sculpin are found in tributaries in every region of the estuary (Leidy 1984).

We could not determine whether adults made a downstream migration in preparation for spawning as was observed elsewhere (Shapavolv and Taft 1954, Krejsa 1967, Mason and Machidori 1976). The few adult-sized fish were caught primarily in the late spring and early summer, after the spawning period. These fish may represent weakened post-spawning individuals washed into the study area.

Bonehead Sculpin

Introduction

The bonehead sculpin, *Artedius notospilotus*, is an uncommon cottid ranging from Point San Telmo, Baja California, to Puget Sound, Washington (Miller and Lea 1972). It inhabits intertidal areas to waters roughly 46 m deep (Miller and Lea 1972). It is taken incidentally in both sport and commercial fisheries, but is not used.

Little is known of bonehead sculpin ecology; it has a sparse distribution and few taxonomic characters to identify larvae of this genus. It grows to a maximum size of about 250 mm TL (Miller and Lea 1972).

Methods

Due to low numbers of larvae and older individuals, our analyses was limited to length frequency (mm TL), and abundance and distribution based upon total catch. All data were used with no corrections made for months not sampled.

Results

Catch and Length Analyses

Larvae of the genus *Artedius* could not be keyed to species, but the numeric dominance of juvenile and adult bonehead sculpin relative to other *Artedius* species in the estuary (that is, scalyhead sculpin, *A. harringtoni*; padded sculpin, *A. fenestralis*; and smoothhead sculpin, *A. lateralis*), led to the classification of *Artedius* larvae as bonehead (Aplin 1967, Wang 1986, Pearson 1989, this study). Thirty-four putative bonehead sculpin larvae were collected and 25 were measured (Tables 1 and 10). These larvae ranged from 2.6 to 7.4 mm TL and about half were 3.0 to 4.5 mm TL (see Table 10). Only 1 unmeasured bonehead sculpin was captured in the midwater trawl. In the otter trawl, 79 fish ranging from 49 to 157 mm TL were caught, but only 1 fish was larger than 129 mm (Table 11). Length data were not sufficient to separate age groups.

Table 10 Length frequency (mm TL) of bonehead sculpin larvae collected with the plankton net from 1980 to 1988

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
2.5 - 2.9				1	1								2
3.0 - 3.4			4	1									5
3.5 - 3.9			5										5
4.0 - 4.4		1	1		2								4
4.5 - 4.9		2			1								3
5.0 - 5.4				1									1
5.5 - 5.9		2				1			1				4
6.0 - 6.4													
6.5 - 6.9													
7.0 - 7.4			1										1
Total	0	5	11	3	4	1	0	0	1	0	0	0	25

Table 11 Length frequency (mm TL) of bonehead sculpin collected with the otter trawl from 1980 to 1995

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
45 - 49										1			1
50 - 54			1										1
55 - 59			1						1		1		3
60 - 64		1	1						2				4
65 - 69		2						1	1				4
70 - 74		2	1									2	5
75 - 79									1				1
80 - 84	1	2	2			1				1	2		9
85 - 89			3			1						1	5
90 - 94	1	1		1					1			1	5
95 - 99		4	2	1		1							8
100 - 104	2	2	1		4	2							11
105 - 109			3			1	1						5
110 - 114		1		1	1		1	1					5
115 - 119					1	3							4
120 - 124			1		1								2
125 - 129		1	2				1	1					5
130 - 134													
135 - 139													
140 - 144													
145 - 149													
150 - 154													
155 - 159				1									1
Total	4	16	18	4	7	9	3	3	6	2	3	4	79

Abundance and Distribution

Bonehead sculpin larvae were collected during only 6 of the 10 years sampled: 1980, 1981, 1982, 1984, 1985 and 1989. Twenty-seven of the 34 larvae were caught in 1980 and 1981 (15 and 12 larvae respectively), 4 were caught in 1982 and 1 each in the remaining years. Most were collected from February to June (see Table 10). Two larvae were not measured in March and 8 were not measured in May. Eighty-five percent of the total catch (n = 34) came from South Bay, 12% from Central Bay, and 3% from San Pablo Bay.

Juvenile and adult bonehead sculpin were caught in every year except 1980, 1988 and 1989 (Table 12). The peak catch was 15 in 1993. They were most abundant in Central Bay, followed by South Bay, and were only rarely caught in San Pablo Bay or upstream; none were collected in the west delta (see Table 12). Bonehead sculpin were collected throughout the year, but catches were highest in February and March (see Table 11) when larval numbers were also highest (see Table 10).

Table 12 Annual abundance and distribution (catch) of bonehead sculpin by region collected with the otter trawl

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Suisun Bay*	*Total*
1980					0
1981	2	1	3		6
1982	1				1
1983	2	2			4
1984		8			8
1985		1			1
1986	2	1			3
1987	1		1		2
1988					0
1989					0
1990	2	6			8
1991		9			9
1992	1	6		1	8
1993	3	12			15
1994	2	5			7
1995		7			7
Total	16	58	4	1	79

Discussion

The bonehead sculpin appears to be an uncommonly collected resident species, confined primarily to the polyhaline and euhaline regions of the estuary. This species may inhabit rocky substrates as other cottids do, and other sampling data suggests it may be nocturnal. Thus, it may be more abundant in the estuary than the catches indicate due to limited sampling of rocky substrates and after dark. In March 1990, 32 one-meter beam trawl samples were taken in San Pablo Bay over 2 complete tidal cycles, 16 during the day and 16 at night (CDFG, unpublished data). Eight bonehead sculpin (68 to 110 mm TL) were collected, all at night. Although darkness may have reduced net avoidance, Secchi disc depths of ≤45 cm suggest visibility was poor throughout sampling and probably not an important factor.

The bonehead sculpin was not abundant in the estuary based on historic otter trawl sampling (Aplin 1967, Kinnetic Labs and Larry Walker Associates 1987, Pearson 1989). Aplin (1967) collected 20 bonehead sculpin from Central (19) and South bays (1) in 6 monthly otter trawl samples from January 1963 to December 1966. Kinnetic Labs and Larry Walker Associates (1987), trawled in the southern part of South Bay and captured 32 bonehead sculpin in monthly sampling at 5 locations between December 1981 and November 1986. Pearson (1989) collected 265 bonehead sculpin from 2,561 otter trawl samples taken in South Bay from February 1973 through June 1982. Both Aplin and Pearson obtained slightly higher catches from February through June.

If our assignment of *Artedius* larvae to *A. notospilotus* is correct, then spawning occurs from January through May. This assumes a 2 to 4 week incubation period that would shift the start of spawning back 1 month from the beginning of the larval catch (see Table 10). Movement of individuals seeking mates may have been responsible for the increased catch in the otter trawl in February and March.

Cabezon

Introduction

The cabezon, *Scorpaenichthys marmoratus*, is the largest species of the cottid family, attaining a maximum length of about 100 cm (Miller and Lea 1972). It is a common marine cottid, found from Point Abreojos, Baja California, to Sitka, Alaska, at depths from the intertidal zone to 76 m (Miller and Lea 1972). Historically, the cabezon was not targeted directly by a commercial fishery, but was taken regularly in set-line fisheries directed toward rockfish (O'Connell 1953, Frey 1971). Presently, it is an important component of the live fish catch (Bob Lea, personal communication, see "Notes").

The cabezon spawns in the subtidal and intertidal regions of the open coast between October and April from California south (O'Connell 1953, Wang 1986) and between late November and early September in Puget Sound, Washington (Lauth 1988). Eggs are demersal, temporarily adhesive and are laid on hard surfaces. Both sexes probably spawn more than once per season (O'Connell 1953, Lauth 1988). After spawning, males remain with the nest and guard it, even though the roe is poisonous (Hubbs and Wick 1951, O'Connell 1953, Wilson–Vandenberg 1992).

In 2 to 3 weeks after fertilization, eggs hatch into pelagic, surface oriented larvae that are found primarily nearshore (O'Connell 1953, Richardson and Pearcy 1977, Richardson and Washington 1980). Settlement occurs 3 to 4 months after hatching at about 38 to 40 mm TL (O'Connell 1953). Soon after settlement, juveniles move inshore to rocky, vegetated habitats, particularly tidepools (O'Connell 1953, Feder and others 1974). They move to deeper water with growth (O'Connell 1953). Male cabezon mature between ages 2 and 3, whereas, females mature between ages 3 and 5 (O'Connell 1953).

Methods

Due to low numbers of larvae and older individuals, analyses were limited to length frequency (mm TL), and abundance and distribution based upon total catch. All data were used with no corrections made for months not sampled. Annual larval catches were based on an October to September period and designated by the year beginning January 1 within the period.

Results

Between February 1980 and May 1989, 131 larval cabezon were collected, of which 108 were measured (Table 13). These larvae ranged from 4.0 to 6.7 mm TL. Larvae were collected from October through June, but most were caught from December to March. The annual larval catch ranged from 4 in 1983 and 1988 to 31 in 1985 (Table 14). There were 2 abundance modes, 1 from 1981 to 1982 and 1 from 1985 to 1986. Although larvae were collected from South Bay to San Pablo Bay, almost all were taken in Central Bay (see Table 14).

Only 2 juvenile cabezons were captured: 1 at 130 mm TL in August 1980 and 1 at 65 mm TL in May 1983. Both were caught in the beach seine at station #263 (north side of the Golden Gate) over a rock and sand substrate.

Table 13 Length frequency (mm TL) of cabezon larvae collected with the plankton net from 1980 to 1988

Length	*Jan*	*Feb*	*Mar*	*Apr*	*May*	*Jun*	*Jul*	*Aug*	*Sep*	*Oct*	*Nov*	*Dec*	*Total*
4.0 - 4.1	1												1
4.2 - 4.3													0
4.4 - 4.5		1				1							2
4.6 - 4.7		1											1
4.8 - 4.9		1	1										2
5.0 - 5.1		4	1	1	1	1					1	5	14
5.2 - 5.3		2	1	1	1						1	2	8
5.4 - 5.5	5	5	3	1							1	5	20
5.6 - 5.7	3	1									1	2	7
5.8 - 5.9	2	5	2							1	2	4	16
6.0 - 6.1	4	8	8	1								3	24
6.2 - 6.3	3	2	2	2								1	10
6.4 - 6.5	1	1											2
6.6 - 6.7		1											1
Total	19	32	18	6	2	2	0	0	0	1	6	22	108

Table 14 Annual abundance (total catch from October to September) and distribution of cabezon larvae from the plankton net. None were collected in Suisun Bay or the west delta. No correction was made for incomplete sampling in 1980 or 1989.

Year	*South Bay*	*Central Bay*	*San Pablo Bay*	*Total*
1980		4	2	6
1981		27	1	28
1982	1	19	1	21
1983		4		4
1984	1	5		6
1985	2	28	1	31
1986		11	2	13
1987		9		9
1988		4		4
1989		9		9
Total	4	120	7	131

Discussion

Based upon the few larvae collected and their distribution, it is unlikely that cabezon spawn within the estuary. The larval cabezon taken in Central Bay could easily have been spawned on the coast and transported into the estuary via tidal exchange. Older life stages are strongly associated with rocks and vegetation (O'Connell 1953, Miller and Geibel 1973), so they may be present in the estuary without being detected by our sampling. In other estuaries cabezon are present in low numbers and are associated with vegetation (Bayer 1981, Bottom and others 1984). In Elkhorn Slough, cabezon are caught on rocky bottoms and around pier pilings (Nybakken and others 1977, Yoklavich and others 1991).

Rarely Captured Species

The fluffy sculpin, *Oligocottus snyderi*, ranges from Baja California to Sitka, Alaska (Miller and Lea 1972). It is a common cottid in coastal areas attaining a maximum length of 83 mm TL and inhabiting intertidal and subtidal areas (Miller and Lea 1972). One 66 mm TL fish was collected with the beach seine at station #264 in northwestern Central Bay in October 1982.

The brown Irish lord, *Hemilepidotus spinosus*, attains a maximum length of 250 mm TL and ranges from Santa Barbara Island and Ventura, California, to Puffin Bay, Alaska (Miller and Lea 1972). It is considered uncommon and is known to inhabit depths from the intertidal zone to roughly 77 m (Miller and Lea 1972). Two larvae (expanded to 9 based upon subsampling) and 4 juveniles were collected. Both larvae were collected in February 1980 from South Bay (stations #106 and #108) and measured 6 mm TL. Three of the juveniles were captured at station #213 near Alcatraz Island: 2 in September 1985 (72 and 80 mm TL) and the 3rd in April 1989 (28 mm TL). The last (71 mm TL) was collected at station #323 in western San Pablo Bay in November 1985.

The red Irish lord, *Hemilepidotus hemilepidotus*, is a common cottid ranging from southern Monterey Bay, California, to the Sea of Okhotsk, Russia (Miller and Lea 1972). It inhabits depths from the intertidal to approximately 48 m and reaches lengths to 500 mm, but rarely grows larger than 300 mm (Miller and Lea 1972). One fish (136 mm TL) was collected at station #213, Alcatraz Island, in December 1985.

The scalyhead sculpin, *Artedius harringtoni*, is an uncommon cottid that ranges from San Miguel Island, Baja California, to Kodiak Island, Alaska (Miller and Lea 1972). It is found from the intertidal to 21 m and reaches a maximum length of 100 mm TL (Miller and Lea 1972). One scalyhead sculpin (126 mm TL) was collected at station #215 near Angel Island in June 1980.

The tidepool sculpin, *Oligocottus maculosus*, is a common cottid and ranges from White Point and Portuguese Bend, Los Angeles County, California, to the Sea of Okhotsk, USSR (Miller and Lea 1972). It is primarily found in shallow, rocky, intertidal areas where it reaches a maximum length of 89 mm TL (Miller and Lea 1972). Only 4 tidepool sculpin were collected—all larvae—from February through April. Three larvae were collected in Central Bay (2 at station #212 and 1 at #214); the 4th was collected in San Pablo Bay at station #318.

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Notes

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