

SETTLEMENT OF JUVENILE CALIFORNIA HALIBUT, *PARALICHTHYS CALIFORNICUS*, ALONG THE COASTS OF LOS ANGELES, ORANGE, AND SAN DIEGO COUNTIES IN 1989

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ABSTRACT

Juvenile California halibut (*Paralichthys californicus*) typically occur in bay nursery grounds along the coast of California and the west coast of Baja California. Recent surveys using small-meshed beam trawls indicate that some settlement to the bottom also occurs in shallow coastal areas of southern California. This survey of halibut settlement in bay and coastal areas was designed to determine (1) the relative settlement rates of juvenile halibut in bay and coastal environments and (2) the survival of small juveniles in the shallow coastal zone. Areas off Los Angeles, Orange, and San Diego counties were surveyed from April to September 1989. Three stations were sampled at each of four coastal sites (Hermosa Beach, Long Beach, San Onofre, and Carlsbad) and two bay sites (Anaheim Bay and Agua Hedionda Lagoon). A 1.0-m beam trawl was used in bays and a 1.6-m beam trawl along the coast. A total of 288 samples was collected at depths of 0–3 m in bays and 6–13 m along the coast. These samples indicated that juvenile California halibut did settle into shallow coastal waters of the areas surveyed during 1989. Settlement was greatest at Anaheim Bay, Hermosa Beach, and Long Beach. The settling halibut remained in bays throughout the study period. Although transforming fish were also found at coastal sites throughout the study period, successful settlement occurred only from July to September and then only in the semiprotected sites (Hermosa Beach and Long Beach).

RESUMEN

Los juveniles del lenguado de California (*Paralichthys californicus*) se encuentran en general en las bahías criaderas a lo largo de la costa de California y de la costa occidental de la península de Baja California. Estudios recientes con red de arrastre de bao de malla fina indican que el establecimiento en el fondo se da en ciertas áreas costeras de poca profundidad del sur de California. Este estudio del establecimiento del lenguado en bahías y áreas costeras fue

diseñado con el propósito de: (1) determinar el reclutamiento relativo de los juveniles, y (2) determinar la supervivencia de los juveniles pequeños en las zonas poco profundas. Se estudiaron algunas áreas costeras de los condados de Los Angeles, Orange y San Diego, de abril a septiembre de 1989. Se tomaron muestras en cuatro localidades costeras (Hermosa Beach, Long Beach, San Onofre y Carlsbad) y en dos lagunas costeras (Anaheim Bay y Agua Hedionda Lagoon). Se muestrearon tres estaciones en cada localidad utilizando una red de arrastre de bao de 1.0 m en las lagunas y una red de 1.6 m en las áreas costeras. Se colectaron 288 muestras en total, a profundidades de 0–3 m en las lagunas y de 6–13 m a lo largo de la costa. El estudio de estas muestras indicó que en 1989 los juveniles del lenguado de California se reclutaron en las aguas costeras poco profundas de los condados investigados. El mayor reclutamiento se presentó en Anaheim Bay, Hermosa Beach y Long Beach. Los juveniles permanecieron en las bahías costeras durante el período de estudio. Si bien también se encontraron algunos individuos en otros sitios costeros durante el estudio, el reclutamiento exitoso ocurrió solamente de julio a septiembre y únicamente en los sitios semiprotectidos (Hermosa Beach y Long Beach).

INTRODUCTION

California halibut (*Paralichthys californicus*) is an important species to the ecology and fisheries of coastal southern California. As a juvenile it is a characteristic component of the bay (i.e., coastal lagoon) fish community. As an adult it is an important ambushing predator of nearshore fishes (M.J. Allen 1982) and an important species in the marine sport and commercial fisheries of California (NMFS 1985; CDFG 1989).

Crucial portions of habitat are being threatened by human encroachment. California halibut are generally thought to require bays for nursery grounds, and thus these areas may be crucial to their survival (Haaker 1975; Kramer and Hunter 1987; L.G. Allen 1988a; Kramer, in press). Most small juveniles are found in bays; it is only at a larger size

that halibut move to coastal waters, where they recruit to the fisheries (Haaker 1975).

Until recently, little was known about the settlement of California halibut from the plankton to the bottom. The abundance of juveniles in bays has been known for some time (Haaker 1975), as has the paucity of small juveniles (<150 mm) in open coastal areas (M.J. Allen 1982; Plummer et al. 1983). However, the distribution and biology of newly settled juveniles has only recently been studied (Kramer and Hunter 1987; L.G. Allen 1988a, b; Kramer and Hunter 1988; L.G. Allen et al., in press; Kramer, in press).

Surveys in the vicinity of Alamitos Bay in 1983–85 indicated that recently settled California halibut were most abundant in the protected habitat of Alamitos Bay, less abundant in the semiprotected habitat of Long Beach Harbor, and least abundant on the open coast at Sunset Beach (L.G. Allen 1988a). Recent surveys in bays and open coast areas of San Diego County revealed little coastal settlement in 1987, but substantial coastal settlement in 1988 (Kramer and Hunter 1987, 1988; Kramer, in press). Another survey in 1988 along the open, near-shore coast of southern California from Point Conception, Santa Barbara County, to San Mateo Point, Orange County, found that the greatest numbers of settling individuals occurred in southern Santa Monica Bay and in Long Beach Harbor (L.G. Allen et al., in press).

Thus, although settlement of California halibut to the open coast of southern California has been described, little is known of halibut's interannual settlement success there. Because of the importance of California halibut to the fisheries, and the continuing encroachment of human activity in the bay nursery grounds, it is important to continue studies of settlement patterns.

The objective of this study was to determine the relative settlement and survival of juvenile California halibut in selected bay and coastal environments of Los Angeles, Orange, and San Diego counties during the spring and summer of 1989.

METHODS

Study Area

The study area extended from Hermosa Beach to Carlsbad, California. Within this area six sites were surveyed: Hermosa Beach, Long Beach, Anaheim Bay, San Onofre, Carlsbad, and Agua Hedionda Lagoon (figures 1 and 2). These included two bay sites

(Anaheim Bay and Agua Hedionda Lagoon), two semiprotected coastal sites (Hermosa Beach and Long Beach), and two exposed coastal sites (San Onofre and Carlsbad). The Agua Hedionda Lagoon, Carlsbad, and San Onofre sites are located in San Diego County and have been sampled in previous surveys (Kramer and Hunter 1987, 1988). Anaheim Bay is in Orange County; Long Beach and Hermosa Beach are in Los Angeles County.

The bay sites are fully protected from offshore swells; the semiprotected coastal areas are partially protected; and the exposed coastal sites are more fully exposed to offshore swells. Depending on wind and swell direction, the Hermosa Beach site may be variably exposed or protected during the year. It is protected from swells from the south or southwest during the summer by the Palos Verdes Peninsula and offshore islands but is exposed to western swells, which occur primarily during the winter (Maloney and Chan 1974). The Long Beach site is protected from swells from the northwest, west, and southwest by the Palos Verdes Peninsula, breakwaters, and offshore islands. The San Onofre site is fully exposed to swells from the south and the southwest, and the Carlsbad site to swells from the west and south.

At all sites, stations were located randomly within blocks stratified by depth. The water depth of the blocks ranged from 0.0 to 0.8 m, 1.0 to 1.5 m, and 3.0 to 3.5 m in bays, and from 6 to 8 m, 8 to 11 m, and 11 to 15 m along the coast. For analyses, these blocks are represented as stations with depths of 0.5, 1.0, and 3.0 m in the bays and 6.0, 10.0, and 13.0 m

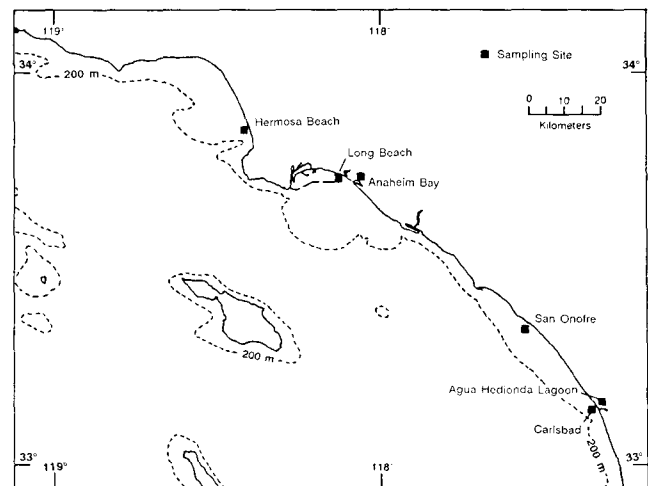


Figure 1. Locations of beam trawl surveys for juvenile California halibut (*Paralichthys californicus*), April–September 1989.

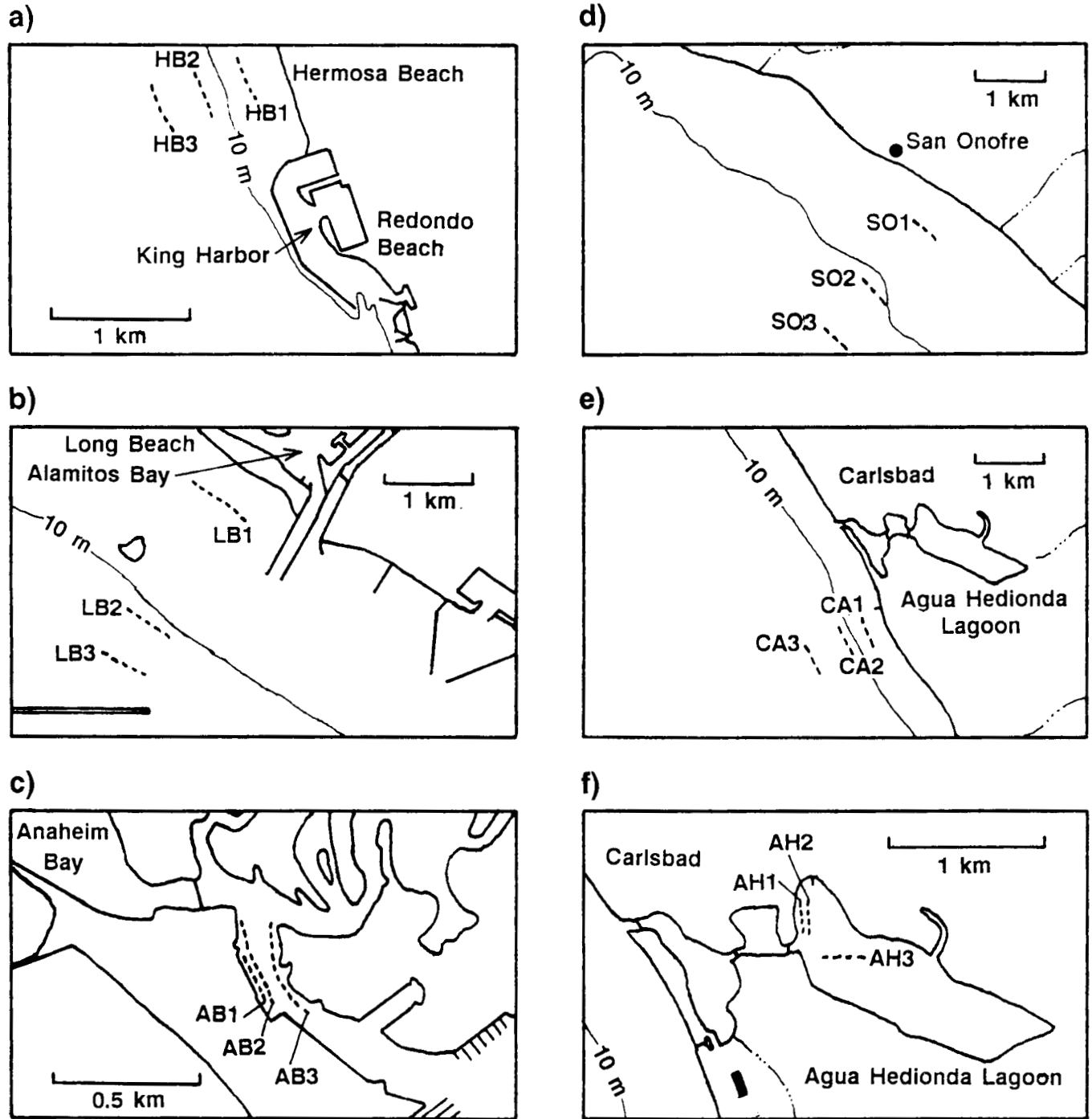


Figure 2. Stations sampled by beam trawl along the southern California coast, April–September 1989: a, Hermosa Beach; b, Long Beach; c, Anaheim Bay; d, San Onofre; e, Carlsbad; and f, Agua Hedionda Lagoon.

along the coast, approximately the same depths as sampled by Kramer and Hunter (1987, 1988). Station coordinates are given in MBC 1990.

Sampling Methods

Fish were collected with the same nets used by Kramer and Hunter (1987, 1988). Coastal samples

were collected with a 1.6-m beam trawl and bay samples with a 1.0-m beam trawl. All nets had 2.5-mm stretch-mesh netting. The beam trawls were equipped with a wheel and revolution counter (meter wheel) which recorded the distance that the trawl traveled on the bottom, although the meter wheel occasionally clogged with plant debris. At coastal

stations loran C coordinates (longitude and latitude) were recorded at the beginning and end of each haul. In the bays, 200-m trawl paths were measured and marked with buoys to provide a separate indication of towing distance, in case the meter wheel fouled. Depth was measured with sonar at coastal sites and with a sounding line at bay sites.

Coastal trawling was conducted from the R/V *Westwind*, a 14.6-m research vessel. Bay trawling at 1.0-m and 3.0-m stations was conducted from a 5.2-m Boston whaler. At the 0.5-m stations the beam trawl was pulled by two field workers on foot.

Three 10-min (coast) or 200-m (bay) trawls were attempted during daylight hours at each site's three stations, for a total of nine replicates per site. This should have resulted in 54 samples per survey, but lost or broken nets and heavy loads of algae often reduced the available sampling time. Thus fewer replicates were completed at some stations. Physical characteristics of each tow are given in MBC 1990.

Each of the six sites was sampled in April, May, June, July, August, and September of 1989. These were the months of major settlement of California halibut into the coastal environment off San Diego County during 1988 (Kramer and Hunter 1988), although settlement into bays can begin as early as November.

Although this study emphasized California halibut, all fish captured were retained for identification and measurement. Most were returned to the laboratory for processing; however, large specimens were identified to species, measured, weighed, and released in the field. Because transforming halibut and other juvenile fishes are small, most debris (and invertebrates) was returned to the lab for closer examination; only large debris was discarded in the field. Specimens and debris were fixed in buffered 10% Formalin-seawater.

In the laboratory the samples were rinsed of Formalin after about a week and transferred to 70% isopropyl alcohol. Samples were then sorted to separate fish from invertebrates and debris. Fish were identified to species, measured, and weighed. The standard length (SL) of each bony fish or total length of each cartilaginous fish was measured to the nearest millimeter. For abundant species, subsamples of up to 200 individuals were measured separately. The total weight of each species in a sample was weighed on a Mettler balance to the nearest 0.01 g.

Near-bottom water samples were collected at each station with Van Dorn bottles, generally after the last haul at the station. Temperature and pH of these samples were measured in the field with a Hor-

iba analyzer. Station values of these oceanographic parameters are given in MBC 1990.

Data Analysis

The bottom area actually sampled in each tow was calculated using meter-wheel readings or distances measured in the field. When fouling had occurred or the meter-wheel reading was obviously too low, the distance traveled was estimated. This estimate was 200 m in bays and 315 m along the coast. The coastal estimate was based on the average distance attained by all "good" tows. The area sampled was computed as the product of the distance towed and the width of the trawl—1.0 m for bays and 1.6 m for the coast. Estimated areas for replicates with extremely low readings were 200 m² for bays and 504 m² for the coast.

Length-frequency histograms of California halibut were generated for each survey and were plotted by area and month. Densities of halibut size groups at various sites were also determined. The relationship between settlement and temperature was determined by linear regression analysis.

RESULTS

Sampling Effort

From April to September, 288 trawl samples were collected, 36 to 52 each month. All stations were sampled, but fewer than three replicates were obtained at some stations because of fouling by algae or sand. Totals of 190 samples were collected along the coast and 98 in the bays; of the coastal samples, 95 were collected at semiprotected and 95 at exposed stations. From 47 to 50 samples were collected at each site, 29 to 35 at each depth in the bays, and 60 to 64 at each depth along the coast.

The total area sampled was 11.5 ha, 1.6–2.1 ha per month. A total of 9.7 ha was sampled along the coast and 1.8 ha in bays; along the coast 4.8 ha were sampled in the semiprotected habitat and 4.9 in the exposed habitat. At each coastal site, 2.4–2.5 ha were sampled; at each bay site 0.9 ha were sampled. At each depth zone within the bays, 0.6–0.7 ha were sampled; at each depth zone along the coast, 3.1–3.5 ha were sampled.

Physical Oceanography

Monthly near-bottom water temperatures at stations in this study ranged from 13.8° to 24.7°C (table 1). Monthly temperatures at stations along the coast ranged from 13.8° to 22.0°C and in bays from 18.3°

TABLE 1
 Water Temperature and pH in Coastal and Bay Habitats, 1989

| Month | Coastal | | | | Bay | | | |
|-------------------------|---------|------|------|-----|------|------|------|-----|
| | Min. | Max. | Mean | SD | Min. | Max. | Mean | SD |
| Temperature (°C) | | | | | | | | |
| April | 15.0 | 18.2 | 16.4 | 0.9 | 18.3 | 21.7 | 19.7 | 1.1 |
| May | 13.9 | 18.3 | 16.6 | 1.5 | 18.3 | 18.9 | 18.6 | 0.3 |
| June | 14.4 | 18.1 | 16.2 | 1.3 | 18.9 | 22.8 | 20.9 | 1.3 |
| July | 17.3 | 22.0 | 20.1 | 1.2 | 21.3 | 24.7 | 23.1 | 1.1 |
| August | 13.8 | 21.1 | 17.9 | 2.7 | 21.0 | 23.0 | 22.2 | 0.9 |
| September | 16.1 | 20.4 | 18.0 | 1.2 | 20.3 | 22.8 | 21.2 | 0.8 |
| pH | | | | | | | | |
| April | 7.2 | 7.7 | 7.5 | 0.1 | 7.3 | 7.9 | 7.7 | 0.2 |
| May | 7.4 | 7.8 | 7.7 | 0.1 | 7.7 | 8.2 | 8.0 | 0.2 |
| June | 6.6 | 7.6 | 7.3 | 0.3 | 6.6 | 6.9 | 6.8 | 0.1 |
| July | 7.3 | 7.9 | 7.7 | 0.1 | 7.9 | 8.0 | 8.0 | 0.1 |
| August | 7.4 | 10.2 | 8.1 | 0.1 | 7.9 | 8.2 | 8.1 | 0.1 |
| September | 7.9 | 8.3 | 8.1 | 0.1 | 7.8 | 8.1 | 7.9 | 0.1 |

to 24.7°C. Means ranged from 18.6° to 23.1°C in the bays and from 16.2° to 20.1°C along the coast. Monthly mean temperatures at sampling sites were greater in the bays than along the coast (table 1; figure 3). In the bays the highest mean temperature occurred in July and the lowest in May. Along the coast the highest mean temperature also occurred in July, but the lowest occurred in June. The highest temperatures in both bay and coastal areas were during the last three months of the survey period.

Hydrogen ion concentration (pH) in this study ranged from 6.6 to 10.2 (table 1). pH values had a greater range along the coast than in the bays; however, monthly means had a greater range in the bays than along the coast. The monthly mean pH values at bay sites were generally equal to or higher than those found at coastal sites, except in June and September, when values were higher along the coast. Along the coast the lowest mean pH occurred in June and the highest in August and September. In the bays the lowest pH also occurred in June and the highest in August.

Distribution and Settlement

Catch parameters. California halibut occurred in 55% of the samples collected. The fish were almost equally common along the coast and in the bays, being found in 56% of the coastal samples and 53% of the bay samples. We collected 762 halibut in the survey, about 2% of all the fish captured (48,994). More halibut were taken along the coast (457) than in the bays (305). Along the coast, more were taken in the semiprotected habitat (348) than in the exposed habitat (109). However, these absolute num-

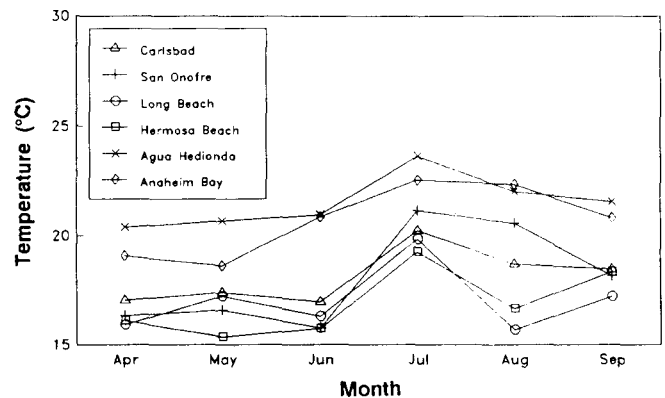


Figure 3. Mean monthly temperatures at sites surveyed for juvenile California halibut (*Paralichthys californicus*), 1989.

bers are a result of variation in sampling effort due to differences in net sizes used, tow lengths, and number of hauls. Standardization of the catch by area trawled indicated that the mean halibut density was highest (158 fish/ha; SD = 275) in the bays, intermediate (94 fish/ha; SD = 184) at semiprotected coastal sites, and lowest (25 fish/ha; SD = 44) at exposed coastal sites.

The total weight of California halibut taken in the survey was 37.7 kg, about 15% of the total fish biomass collected (243.3 kg). Total halibut biomass was much greater (36.7 kg) at coastal sites than in bays (0.9 kg). Along the coast the biomass was greater (20.8 kg) in the semiprotected habitat than in the exposed habitat (15.9 kg). Again, these absolute values result from differences in sampling effort at bay and coastal sites. Standardization by area indicated that the mean biomass density was highest (4.8 kg/

ha; SD = 9.0) in the semiprotected coastal habitat, intermediate (3.3 kg/ha; SD = 6.1) in the exposed coastal habitat, and lowest (0.5 kg/ha; SD = 1.3) in bays.

Size and population structure. California halibut ranged in size from 6 to 503 mm SL, with a mean length of 74 mm (SD = 88 mm). The population sampled by the survey was strongly skewed to the right, with a modal size of 10 mm (figure 4). Few fish were collected in the 100 to 140-mm size classes or in size classes above 350 mm.

The population structure in the bays was similar to that along the coast, being dominated by fish less than 100 mm SL (figure 5). However, the modal size was 10 mm along the coast and 20 mm in the bays. In addition, fish greater than 140 mm constituted only a small portion of the population in the bays, and no individuals of 240 mm or longer were taken. However, fish longer than 140 mm formed a significant portion of the coastal population, which included many individuals longer than 240 mm. There were few fish between 100 and 140 mm SL in the coastal population.

Distinct differences in the size-frequency distribution of California halibut were apparent when coastal sites were subdivided into semiprotected and exposed habitats (figure 6). In the exposed coastal habitat a strong mode was apparent at 10 mm; only three individuals were taken in the range of 20 to 140 mm SL. In contrast, the size-frequency distribution in the semiprotected areas was similar to that for both coastal habitats combined, with many individuals between 20 and 140 mm SL; thus 10-mm and 150- to 300-mm fish constituted a smaller percentage of the population.

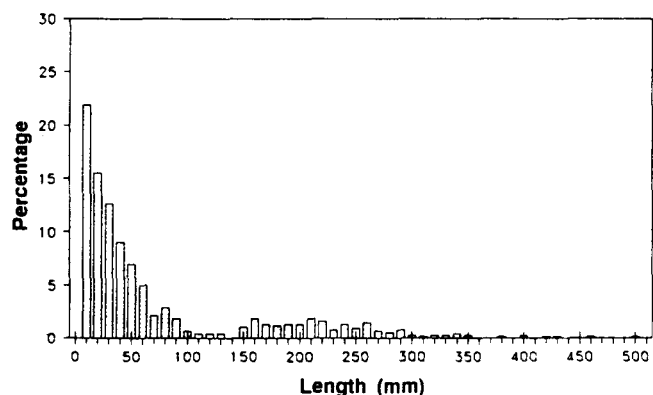


Figure 4. Overall size distribution of California halibut (*Paralichthys californicus*) in beam trawl surveys along the southern California coast, April-September 1989.

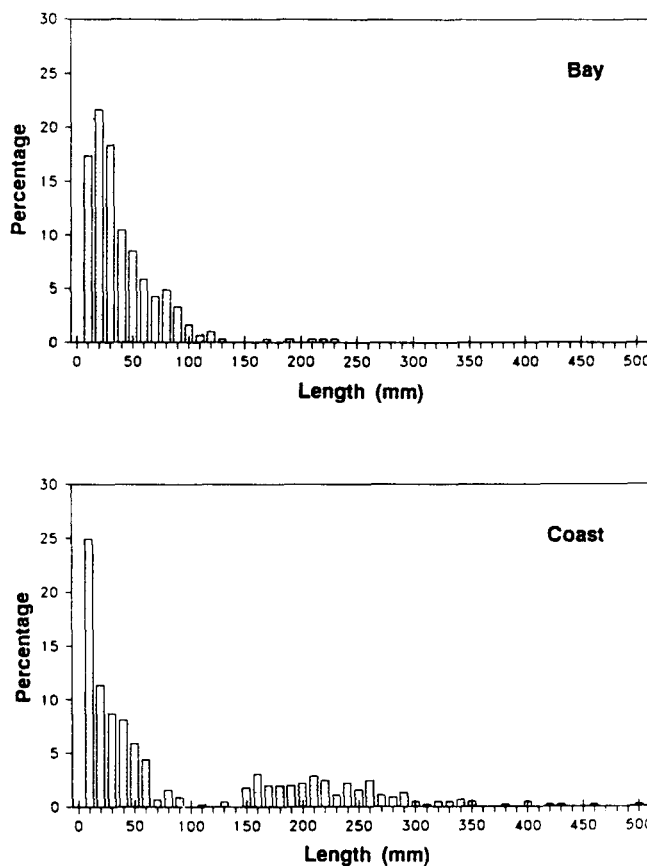


Figure 5. Size distribution of California halibut (*Paralichthys californicus*) in bay and coastal habitats along the southern California coast, April-September 1989.

The densities of size groups varied from site to site (figure 7). Settling and recently settled individuals (<21 mm) were most dense in Anaheim Bay, followed by Hermosa Beach and Carlsbad. The densities of this size group were low at Long Beach and San Onofre, and the group was absent at Agua Hedionda Lagoon. Larger age 0 fish (21-100 mm) were more than twice as dense in Anaheim Bay as at Hermosa Beach, the area with the next greatest density. Densities of this size group were low at Long Beach and Agua Hedionda Lagoon, and the group was virtually absent at Carlsbad and San Onofre. Older fish (>100 mm) were most dense at Hermosa Beach, followed by Carlsbad and Long Beach. The density of this size group was low in Agua Hedionda Lagoon and Anaheim Bay, and at San Onofre. In areas where it was present, the 21 to 100-mm group dominated.

Changes in the population structure of California halibut with time differed between bay and coastal

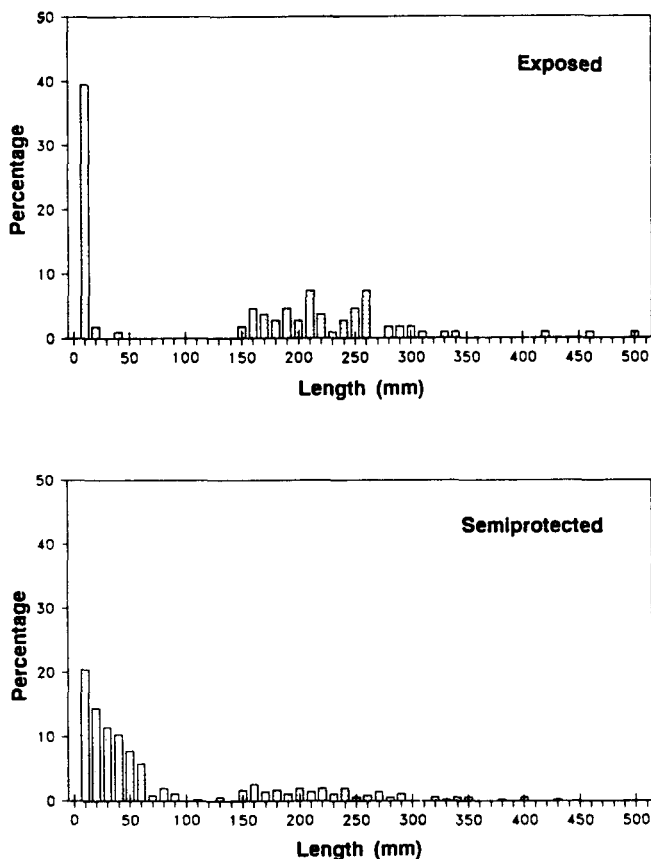


Figure 6. Size distribution of California halibut (*Paralichthys californicus*) in exposed and semiprotected coastal habitats along the southern California coast, April–September 1989.

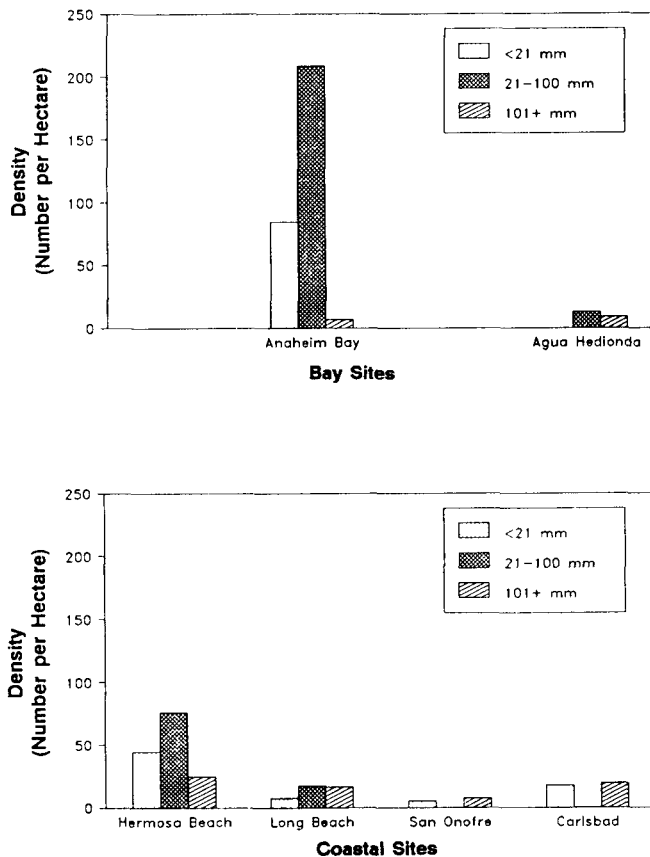


Figure 7. Mean density (number of fish/ha) of juvenile California halibut (*Paralichthys californicus*) at sampling sites off southern California, April–September 1989.

habitats (figures 8 and 9). In bays the primary mode consisted of 10-mm fish from April to June, and 20- to 40-mm fish from July to September (figure 8). Fish of 50 mm SL or less were relatively abundant in all months, and some larger fish were occasionally captured. In August and September the percentage of 50- to 100-mm fish increased.

In the coastal habitat, the 10-mm size class predominated from April to July, the 20-mm class in August, and the 50-mm class in September (figure 9). Although fish greater than 150 mm were present in all months, individuals of 20 to 100 mm SL were rare until August and September, when they became abundant. However, this size group was found only at semiprotected coastal sites (Hermosa Beach and Long Beach).

The settlement of California halibut, as indicated by the monthly density of fish <21 mm, varied by site and time (figure 10). From April to June and in

September, settlement was highest at Anaheim Bay; from July to August it was highest at Hermosa Beach. In Anaheim Bay settlement was already high in April and increased greatly from May to June. Settlement dropped dramatically in July, then returned to relatively high levels again in August and September. At Hermosa Beach settlement showed a gradual increase from April to August and fell to very low levels in September. Settlement was greatest in May at Long Beach, and in July at Carlsbad and San Onofre.

California halibut settled into different locations at different temperatures (figure 11). In Anaheim Bay, settlement was high from 18.5° to 22.3°C, with a peak at 21°C. Settlement dropped dramatically at 22.5°C (in July). However, at Hermosa Beach, settlement occurred between 15.5° and 19.5°C, with a peak at 16.8°C. At Carlsbad settling halibut were found from 17° to 20.5°C, at Long Beach primarily

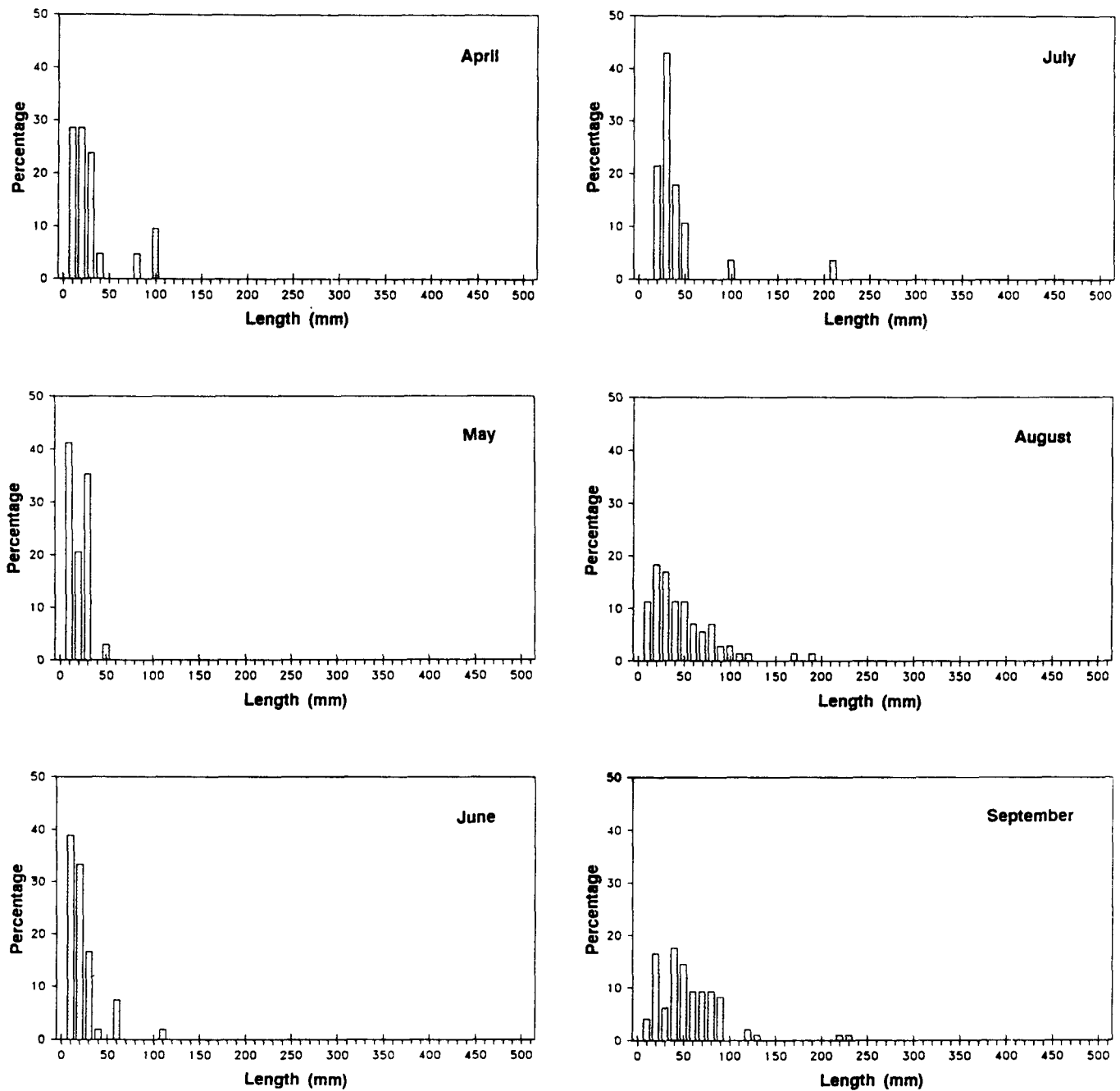


Figure 8. Monthly size distribution of California halibut (*Paralichthys californicus*) in bay habitats of southern California, 1989.

at 17°C, and at San Onofre at 21.2°C. The regression of density of settling individuals versus temperature ($y = 1.680x - 5.3$; $r = 0.0096$; $r^2 = 0.009$; d.f. = 34; figure 12) was not significant at $p = 0.05$. The regression of the log ($x + 1$) density versus temperature ($y = -0.02x + 1.436$; $r = 0.088$; $r^2 = 0.007$; d.f. = 34) was also not significant.

DISCUSSION

Juvenile California halibut have been known for some time to occur in bays of southern California. Haaker (1975) found large numbers of juveniles in Anaheim Bay and suggested that they remain there until they reach about 200 mm, at which time they emigrate to the coast. Nets used in Haaker's study

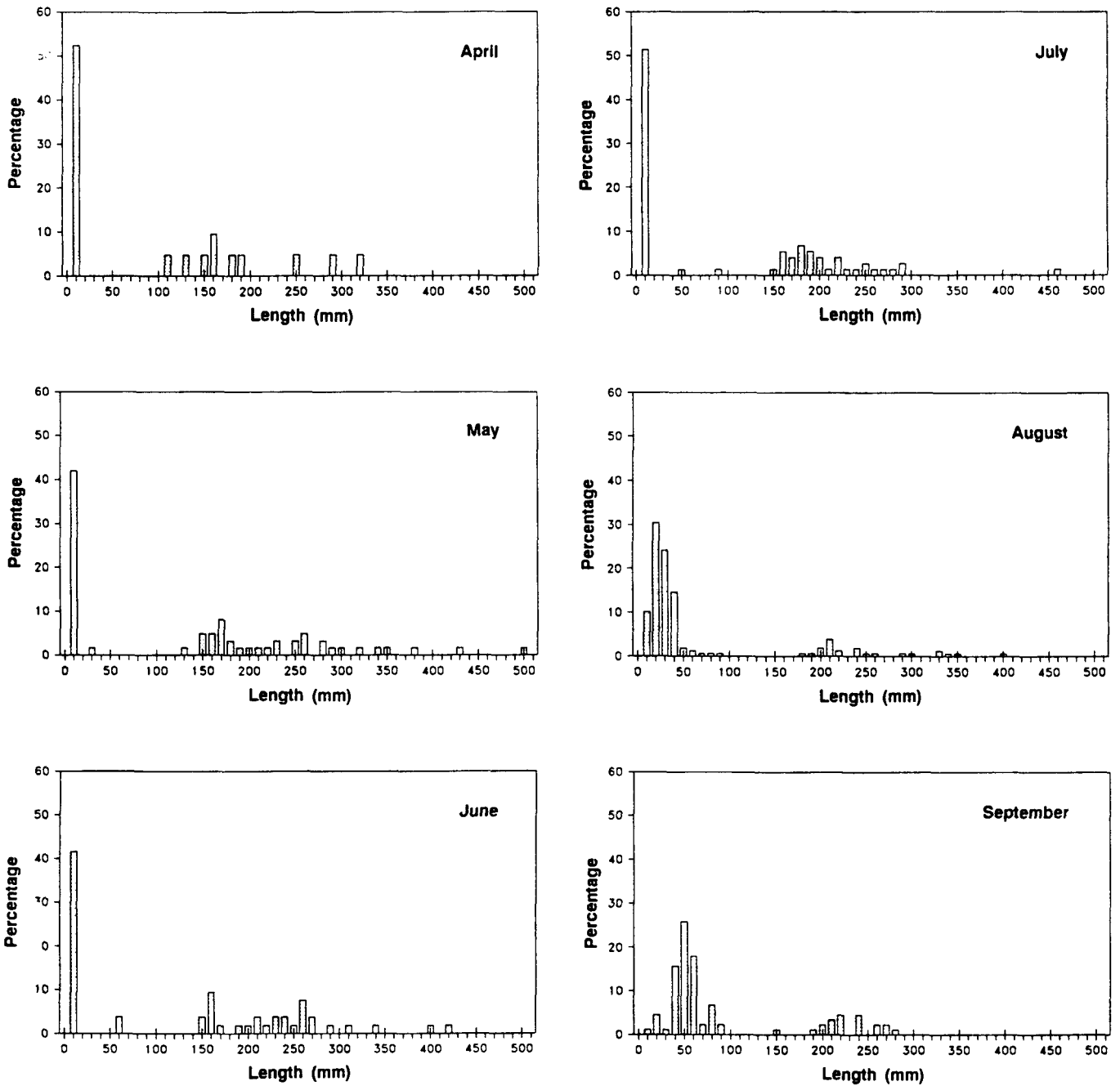


Figure 9. Monthly size distribution of California halibut (*Paralichthys californicus*) in coastal habitats off southern California, 1989.

included bag seines, commonsense seines, and small otter trawls with minimum mesh sizes of 3–6 mm (Klingbeil et al. 1975).

No California halibut smaller than 150 mm were found along the coast in 1972–73 in an extensive otter trawl survey (342 samples) (M.J. Allen 1982). However, that study sampled depths from 10 to 200 m using small otter trawls with a minimum stretch-

mesh size of 12.5 mm. Using similar gear, Plummer et al. (1983) surveyed the nearshore zone off San Onofre and Oceanside at depths of 6–30 m. They captured 1,580 California halibut, but fewer than 2% were shorter than 100 mm SL. Fish smaller than 100 mm are seasonally abundant in Elkhorn Slough, Mugu Lagoon, Alamitos Bay, Anaheim Bay, Newport Bay, Agua Hedionda Lagoon, and Mission Bay

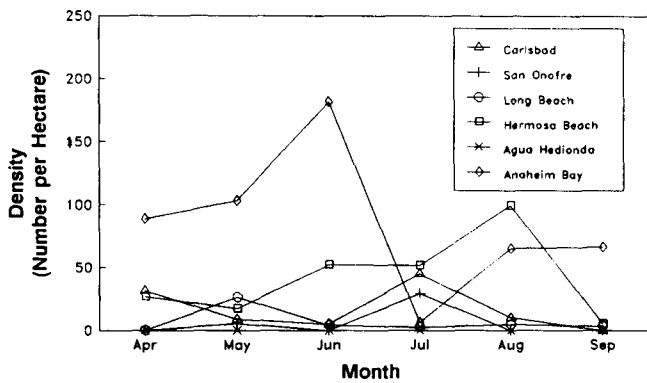


Figure 10. Monthly density (number of fish/ha) of recently settled (SL <21 mm) juvenile California halibut (*Paralichthys californicus*) at sampling sites off southern California, 1989.

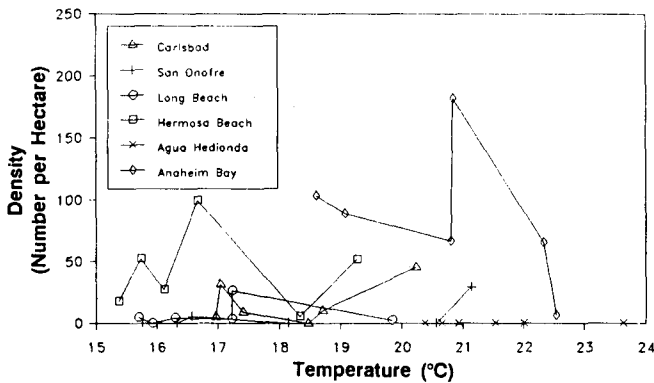


Figure 11. Relationship of density (number of fish/ha) of recently settled (SL <21 mm) juvenile California halibut (*Paralichthys californicus*) to temperature at sampling sites off southern California, April–September 1989.

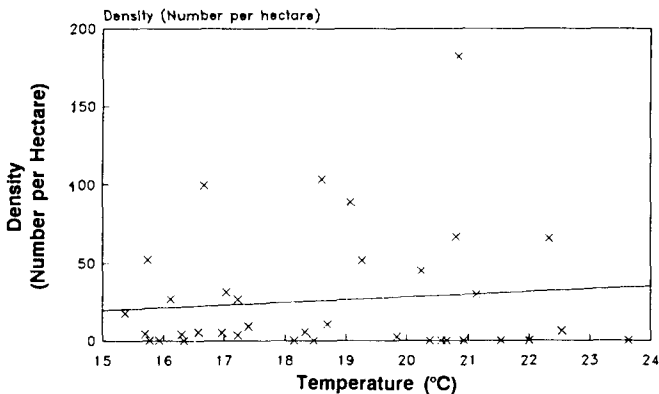


Figure 12. Relationship of density (number of fish/ha) of recently settled juvenile (SL <21 mm) California halibut (*Paralichthys californicus*) to temperature in surveys off southern California, April–September 1989.

(Haaker 1975; Plummer et al. 1983; Kramer and Hunter 1987; L.G. Allen 1988a; Kramer and Hunter 1988; Kramer, in press). Plummer et al. (1983) found no California halibut of <205 mm SL at depths less than 5 m (the surf zone) off northern San Diego

County, although individuals have occasionally been noted there. The junior author of this study has observed small California halibut near the surf zone at Torrance.

Using seines, beam trawls, and otter trawls with a minimum mesh size of 2 mm, L.G. Allen (1988a) found recently settled California halibut in protected (Alamitos Bay) and semiprotected (Long Beach Harbor) habitats. With the same gear as that used in the present study, Kramer and Hunter (1987) found that California halibut <50 mm SL were abundant in Agua Hedionda Lagoon and Mission Bay in 1987; however, individuals of this size were rare along the open coast at depths of 6–14 m. In 1988 densities were again relatively high in Agua Hedionda Lagoon and Mission Bay, and had increased in coastal areas, although they were low in San Diego Bay (Kramer and Hunter 1988). Coastal settlement was highest at La Jolla and lowest at San Onofre (Kramer, in press). L.G. Allen et al. (in press) also found coastal settlement of California halibut in 1988. Among nearshore areas at depths of 5–10 m from Point Conception to San Mateo Point, age 0 California halibut (i.e., <80 mm) were most abundant in southeastern Santa Monica Bay (El Segundo and Malaga Cove) and Long Beach Harbor (Belmont Shore); settlement was highest in July. That study used the same type of beam trawl we used along the coast for this survey, with four 5-min tows at a station.

Kramer (in press) compared the selectivity of various gears used in studies of small California halibut. Beach seines were found to be less effective than the 1.0-m beam trawl in capturing juvenile halibut in bays. The 1.0- and 1.6-m beam trawls were equally effective at capturing halibut <80 mm SL; however, the 1.6-m beam trawl was more effective than the 1.0-m beam trawl for collecting fish >80 mm. In the study reported here, the lack of large fish in bay catches is probably at least partly due to the decreased effectiveness of the 1.0-m trawl used in bays, compared to the 1.6-m trawl used along the coast. Kramer (in press) also found that the 1.6-m beam trawl captured a greater proportion of halibut <200 mm SL, whereas the standard 7.6-m otter trawl used in southern California coastal surveys captured more halibut >200 mm. This may partly account for the low catches of halibut of this size in otter trawl surveys (e.g., M.J. Allen 1982; Plummer et al. 1983).

The present study confirms the findings of L.G. Allen (1988a) that juvenile California halibut are more abundant in bays and semiprotected coastal locations than in exposed coastal locations. The

present study also substantiates findings of other studies (Kramer and Hunter 1987, 1988; L.G. Allen et al., in press; Kramer, in press) indicating that halibut do settle in some places along the open coast in some years. It also supports L.G. Allen et al. (in press), who found the greatest coastal settlement in southeastern Santa Monica Bay and Long Beach Harbor. It also confirms studies (Kramer and Hunter 1987; L.G. Allen 1988a; Kramer and Hunter 1988; Kramer, in press) indicating that successful settlement along the coast is low in the San Onofre-Carlsbad region.

L.G. Allen (1988a) found that the Los Angeles-Long Beach Harbor provides a nursery for California halibut. This finding is not entirely unexpected, because breakwaters protect this area from swells and large waves from the west. However, the importance of southeastern Santa Monica Bay as a nursery is less obvious. Southeastern Santa Monica Bay is an open coast that is directly exposed to western swells (Maloney and Chan 1974). However, in mid to late summer the area is protected from the predominant south and southwestern swells by the Palos Verdes Peninsula (Maloney and Chan 1974).

Juvenile California halibut have previously been observed in this area, but were not documented until recently. As noted above, small California halibut have been observed at Torrance in the past, and in some years juveniles have been found in the seawater cooling system of the Redondo Generating Station (M.D. Curtis, MBC Applied Environmental Sciences, Costa Mesa, Calif., pers. comm.). In 1988 settlement was particularly high at Malaga Cove and El Segundo (L.G. Allen et al., in press); these sites were north and south, respectively, of the Hermosa Beach site used in this study. We found settling halibut at Hermosa Beach from April to September. However, survival (or residency) of these fish only occurred there from August to September, when the Palos Verdes Peninsula provided the greatest protection from southern swells.

At least two semiprotected coastal areas of southern California — southeastern Santa Monica Bay and Los Angeles-Long Beach Harbors — seem to provide suitable nursery grounds for California halibut in some years, particularly late in the summer. The coast north of the La Jolla Peninsula may be another suitable area that is somewhat protected from swells from the south. Kramer (in press) found greater halibut settlement there (at Torrey Pines) than at San Onofre.

The site with the greatest density of recently settled California halibut in this study was Anaheim Bay. The density there in 1989 was about 25% of

that found in Alamitos Bay, which had the greatest density from 1983 to 1985 (L.G. Allen 1988a). Compared with sites sampled in 1987 (Kramer and Hunter 1987), the density of halibut at Anaheim Bay in 1989 was about 50% of that found in Agua Hedionda Lagoon (the area of greatest settlement) and was similar to that of Mission Bay (Kramer and Hunter 1987). Settlement in Mission Bay and Agua Hedionda Lagoon dropped in 1988. In 1989 no recently settled halibut were taken at Agua Hedionda Lagoon, although larger age 0 fish (21–100 mm SL) were present at low densities. Thus settlement of California halibut to bays varies interannually, and the importance of a given bay as a nursery changes from year to year.

In this study the density of recently settled California halibut along the coast at Hermosa Beach was about 50% of that found at Anaheim Bay. The density at Hermosa Beach in 1989 was about 100 times that found along the open coast off San Diego County in 1987 (Kramer and Hunter 1987) and 2–3 times greater than that found there in 1988 (Kramer and Hunter 1988). It was slightly less than that found at Malaga Cove in 1988 (L.G. Allen et al., in press).

Kramer (in press) noted that although settlement might be high along coastal San Diego County early in the year, few halibut of 40–60 mm were taken later. Possible reasons for their absence include mortality, dispersal to deep water, and dispersal to bays. Kramer surmised that dispersal to bays was most likely because (1) there is no evidence of dispersal to deep water, and (2) more fish of 21–100 mm were found in bays than fish <21 mm, indicating that settlement must be occurring elsewhere. However, we believe that mortality may be an important factor in exposed coastal areas where there are no suitable bay habitats.

The relatively high survival (or residency) of age 0 fish near Hermosa Beach in 1989 may be related to the proximity of King Harbor, which may provide needed protection, especially in times of greater exposure.

L.G. Allen (in press) found that log-transformed abundance of settling halibut along the coast was significantly and positively correlated with temperature. That study concluded that temperature has a significant influence on the settlement and subsequent distribution of age 0 halibut. But the present survey did not show any significant correlation with temperature. This lack of correlation may partly reflect the more heterogeneous study area that includes both bay and coastal sites. However, in the present study settlement was often greatest at intermediate temperatures at a given site (e.g., Anaheim Bay,

Hermosa Beach; figure 11). Other physical or biological factors are apparently more important than temperature in determining settlement at some sites.

Variations in pH are generally directly related to dissolved oxygen (DO) levels (Parsons and Takahashi 1973). When DO levels are low, pH values are generally low; when DO values are high, pH levels are high. Both DO levels and pH values are high when photosynthetic rates are high, and both are low when respiration predominates. The high pH observed along the coast in August and September and in the bays in May, July, and August may reflect high photosynthetic activities. There does not appear to be any obvious relationship of settlement to pH. Settlement was highest at Anaheim Bay during the period of lowest pH but was highest at Hermosa Beach during a period of high pH (table 1; figure 10).

CONCLUSIONS

California halibut settled from the plankton to the bottom in shallow coastal areas off southern California in 1989 in varying densities depending on habitat type.

Transforming larvae were found throughout the study area, but the abundance (survival and residency) of small juveniles was highest in the bays, intermediate in semiprotected coastal areas, and lowest in exposed coastal areas.

Benthic settlement diminished in August and September, when larger young-of-the-year became more abundant; these larger fish did not appear at exposed coastal locations.

The results of this study substantiate the results of other recent studies indicating that southeastern Santa Monica Bay and Los Angeles-Long Beach Harbors are semiprotected coastal areas that are used as nursery areas by California halibut. This study does not, however, substantiate a correlation between temperature and settlement.

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