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Abstract.—Distribution, recruitment, and feeding habits of young-of-the-year (Y.O.Y., ≤80 mm SL) California halibut were investigated during the spring and early summer months of 1983–1985 in shallow water (0–6 m) near Alamitos Bay-Long Beach Harbor. Y.O.Y halibut were most abundant in fully-protected waters; semi-protected waters contained one-half to one-quarter the number of Y.O.Y halibut. No Y.O.Y halibut were collected at the exposed coast site.

Newly recruited halibut ranged from 8 to 12 mm SL and were approximately 20 to 29 days old. Gammarid amphipods, mysids, teleosts, and harpacticoid copepods were the major food items of Y.O.Y halibut. Recruitment was significantly greater in 1983 and 1984 than in 1985 (catch-per-unit-effort in 1983 > 1984 > 1985).

Introduction

The California halibut (*Paralichthys californicus*) is a major commercial and sport species in California. Commercial landings of halibut have steadily declined since recording began (Frey 1971). The commercial catch of halibut has declined since 1915, exhibiting progressively decreasing peaks in the 1930's, 1940's, 1960's, and early 1980's. Although the catch rose in 1981 (to 1.2 million pounds), it dropped off again in 1982 through 1984 (R. Collins, California Dept. of Fish and Game unpubl. data). Gill-netting pressure has increased (especially in southern California) over the last three to four years which may account, in part, for the slightly higher catches and subsequent decrease in landings. The “El Nino” event of 1982–1983 may also have had an impact on commercial catches through a northward shift in the distribution of adults. Catches from sport landings of California halibut showed a similar pattern to the commercial landings from the 1940's until about 1972 when the minimum size limit of 22 inches was put into effect. Thereafter, sport catch has remained very low. This trend may be best explained by the fact that sport boat fishing for halibut is no longer profitable and generally has been curtailed. The most probable explanations for the overall decline include over-exploitation of adult stocks by commercial fishing and destruction and alteration of nursery habitats (Plummer et al. 1983).

Although the actual status of the current halibut fishery is under debate, it seems clear that population levels are depressed relative to historical levels. Despite its

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historical importance to the commercial and sport fishery, until recently little has been known about the life history and ecology of California halibut. Frey (1971) summarized some of the information up to 1970 on the life history of California halibut. California halibut range from Long Beach, Washington to Magdalena Bay, Baja California with both the center of the commercial fishery and population center being from central California to northern Baja. Frey (1971) reported that halibut spawn in shallow water (9–20 m) from February to July. Halibut are relatively long-lived (up to 30 yr) females growing faster and attaining larger sizes than males. Males mature at about 2–3 years while females mature later at a much larger size (4–6 years). Some notable errors by Frey (1971) include the statement that halibut eggs are demersal and that settlement of juveniles occurs as early as June. Based on the information gathered since 1970, it is known that halibut eggs are planktonic like their larvae and settlement can occur as early as February. Additionally, the aforementioned depth range of spawning in California halibut may not be entirely correct and is currently being investigated using egg data (R. J. Lavenberg, LACMNH pers. comm.).

A study by Haaker (1975) presented information on younger stages of California halibut occupying the bay/estuarine environment of Anaheim Bay, California. He found that halibut in the year classes of 0 to 2+ primarily occupied the bay and presented information on growth, diet, movements, parasites, and some limited information on recruitment of YOY into the bay.

Plummer et al. (1983) presented valuable data on food habits in juvenile and adult halibut from open coast locations in the vicinity of San Onofre-Oceanside, California. These authors also summarized existing information on both the diet of halibut and on the habitats of the critical young-of-the-year (YOY) stage. They speculated that YOY halibut occur primarily in embayments along the California coast (see table 3, Plummer et al. 1983) and not in shallow coastal waters.

Reliable information on the spawning and the distribution of eggs and various larval stages of California halibut is only now becoming available. It has been known for some time that halibut spawn in nearshore, coastal waters primarily from February–July (Frey 1971; Gruber et al. 1982). However, the actual depth range of spawning is not known at this time. The planktonic eggs of halibut have recently been identified and information on their distribution within the nearshore waters should be forthcoming (R. Lavenberg pers. comm.). Halibut larvae were first described by Ahlstrom and Moser (1975) and have been recently distinguished (Ahlstrom et al. 1984) from the larvae of fantail sole (Xystreurys liolepis) within a limited size range. Planktonic larval stages (≤10 mm SL) occur throughout the water column, mainly over 12–45 m bottom depths within approximately 2–5.5 km of shore in the San Onofre-Oceanside region (Barnett et al. 1984 and unpubl. rep.). Larger larvae occur closer to shore. Halibut larvae are most abundant in the plankton in the San Onofre-Oceanside region during March–September (Barnett et al. 1984). Plummer et al. (1983) suggested that halibut larvae probably metamorphose in coastal water and migrate into embayments. The western Atlantic congener, Paralichthys dentatus, spawns offshore in coastal waters and larvae probably move into estuaries after metamorphosing nearshore (Smith and Daiber 1977). A similar species from the western Pacific, Paralichthys olivaceus, shows a similar pattern of life history in Japan (Minami 1982). Further, ichthyoplankton surveys of several bays and estuaries in southern California have shown
halibut larvae to be rare within the bays themselves (White 1977; Horn and Allen 1980; Leithiser 1981).

Although information on various aspects of the life history and ecology of California halibut is rapidly becoming available, little was known about the critical young-of-the-year stage prior to this study. This gap in information and the hypotheses about the distribution of early life history stages presented by previous authors (primarily Plummer et al. 1983) served as the impetus for the current study. The purpose of this paper is to present information on the young-of-the-year stage (≤80 mm SL) of the California halibut based on a three-year study (1983–1985) primarily in the area of Alamitos Bay-Long Beach Harbor, California. Specifically, this paper presents information on: 1) length frequencies and recruitment (i.e., settlement from the plankton) during 1983–1985; 2) estimated growth rates; 3) age-length relationships; 4) food habits; 5) patterns of distribution; and 6) recruitment success during the three years of the study.

Methods and Materials

Study Sites

Sampling was carried out primarily in the vicinity of Alamitos Bay-Long Beach Harbor in 1983–1985 (Fig. 1). Supplemental sampling was carried out in 1984 in the vicinity of San Onofre-Oceanside which served as a comparison site (Aqua Hedionda, near Carlsbad, California, Oceanside Harbor, and five open coast sites
10 km apart). At each location specific areas were ranked according to overall exposure to marine weather/swell influence. Embayment stations (Alamitos Bay and Aqua Hedionda) were designated as fully protected habitats. Long Beach and Oceanside harbors were designated as semi-protected habitats. Open coast sites were considered to be exposed habitats (Sunset Beach and five other sites from San Clemente to Oceanside).

**Sampling Procedure**

Sampling gear and effort varied over the three years of the study in an attempt to increase sampling efficiency and to satisfy the requirements of various funding agencies. In all three years, small seines were utilized to sample shore stations within Alamitos Bay. The seine used measured 4.9 m x 1 m and consisted of 2 mm knotless, nylon mesh. In 1984, non-shore sampling was carried out using a 2 m beam trawl consisting of 2 mm knotless, nylon mesh. This method was found to have limited use in soft-substrate areas. Subsequently, in 1985, the non-shore stations were sampled with a 2 m otter trawl consisting of 4 mm mesh in the wings and 2 mm mesh in the bag. The otter trawl sampled effectively over all substrates encountered.

Seine samples from each of the three years of the study consisted of at least three replicates on each sampling date. The seine was hauled parallel to shore for 10 m and then pivoted straight onto the shoreline. This method of sampling covered approximately 65 m² per haul. A total of 78 seine hauls were made in the three years.

Otter trawl and beam trawl samples were deployed and retrieved in an identical manner. Five replicate, three minute tows were made randomly at each station with both the beam trawl (1984; N = 45) and the otter trawl (1985; N = 105) towed behind a 5 m Boston Whaler. The stations, as previously mentioned, corresponded to fully-protected, semi-protected, and exposed habitats at depths of 3–6 m. Beam trawl stations in the San Onofre-Oceanside area were sampled using an 8 m vessel (Raden).

Sampling in the Alamitos Bay region was carried out at approximately two-week intervals from 4 May to 27 July in 1983 (5 dates), 12 April to 20 June in 1984 (4 dates) and 13 March to 24 July in 1985 (8 dates). Supplemental sampling in the area of San Onofre-Oceanside was carried out on 13–15 June and 25 June 1984.

Surface temperature and salinity were recorded at each station using a Hydrolab sensing device, a bucket thermometer and an AO refractometer. Bottom temperature and salinity were recorded using the Hydrolab unit. All halibut caught in the seines or trawls were counted and measured alive on shore or on board the boat. In 1985, subsamples of at least ten individuals per date were either placed on ice for preliminary age determination or preserved in 10% formalin for later gut content analysis. Abundance of other fish and invertebrate species in the hauls was also noted.

In the laboratory, otoliths were dissected out and read using a light microscope. Growth rings were read in the sagitta of 10 individuals between 14 and 45 mm SL. We assumed that all rings represented daily growth checks.

Gut contents were examined for 67 individuals from the field subsamples which ranged in size from 7 to 77 mm SL. Digestive tracts were removed under a stereo-
Fig. 2. Length frequency histograms for four comparable sampling dates in each year of the study, 1983–1985. Size classes are depicted in 5 mm intervals.

dissecting microscope, opened up, and the contents emptied into a petri dish. Items were identified to the lowest possible taxon and counted. The sorted items were then placed in aluminum pans, dried to a constant weight in a 50°C oven, and then weighed on an analytical Mettler balance to the nearest 0.001 g.

Statistical Procedures

Relative growth rates were determined for all three years by comparing the mean lengths of halibut for each sampling period. Age-length relationships were determined by least-squares linear regression. Gut content data were summarized as percent frequency of occurrence (F), percent number (N), percent dry-weight (W), and by calculation of the Index of Relative Importance. IRI (Pinkas et al. 1972) was calculated as follows:

\[ \text{IRI} = (N + W)F. \]

Food habit data were compiled separately for all individuals (N = 67), and for individuals ≤20 mm SL (N = 29), and for individuals 20–77 mm SL (N = 38), since the most noticeable shift in diet occurred at approximately 20 mm SL.

Differences in the distribution of YOY halibut among the three types of habitats (locations) in the Alamitos Bay area were analyzed using Friedman’s non-parametric method for randomized blocks (Sokal and Rohlff 1969). Data from 1984 beam trawls and from 1985 otter trawls were analyzed separately.

A comparison of recruitment success between the three years of the study was based on replicate small seine hauls collected from the shore within Alamitos Bay. Catch-per-unit-effort (CPUE) for each sampling date within each year was
Table 1. YOY halibut mean length and growth rates for four comparable dates in 1983, 1984, and 1985 in Alamitos Bay.

<table>
<thead>
<tr>
<th>Year</th>
<th>Date</th>
<th>( x ) length (mm)</th>
<th>( x ) growth rate (mm/month)</th>
<th>N YOY halibut</th>
<th>( x ) growth (mm/month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>4 May</td>
<td>21.30</td>
<td>6.82</td>
<td>31</td>
<td>31</td>
</tr>
<tr>
<td></td>
<td>17 May</td>
<td>19.67</td>
<td>3.47</td>
<td>36</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>1 June</td>
<td>21.26</td>
<td>1.64</td>
<td>53</td>
<td>3.18</td>
</tr>
<tr>
<td></td>
<td>14 June</td>
<td>29.17</td>
<td>3.63</td>
<td>47</td>
<td>18.25</td>
</tr>
<tr>
<td>1984</td>
<td>12 April</td>
<td>21.48</td>
<td>3.05</td>
<td>23</td>
<td>30.71</td>
</tr>
<tr>
<td></td>
<td>15 May</td>
<td>30.32</td>
<td>7.45</td>
<td>17</td>
<td>8.04</td>
</tr>
<tr>
<td></td>
<td>6 June</td>
<td>44.86</td>
<td>8.97</td>
<td>14</td>
<td>18.97</td>
</tr>
<tr>
<td></td>
<td>20 June</td>
<td>62.33</td>
<td>5.93</td>
<td>2</td>
<td>37.44</td>
</tr>
<tr>
<td>1985</td>
<td>10 April</td>
<td>19.75</td>
<td>6.31</td>
<td>18</td>
<td>21.48</td>
</tr>
<tr>
<td></td>
<td>15 May</td>
<td>19.20</td>
<td>11.37</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td></td>
<td>29 May</td>
<td>26.50</td>
<td>11.58</td>
<td>16</td>
<td>15.64</td>
</tr>
<tr>
<td></td>
<td>12 June</td>
<td>47.00</td>
<td>17.01</td>
<td>3</td>
<td>43.93</td>
</tr>
</tbody>
</table>

![Paralichthys californicus](Harpacticoid Copepods)

Fig. 3. Major food items occurring in the guts of YOY halibut from 7 mm to 77 mm in length. The area of each rectangle is proportional to the overall importance of a food item in the diet (IRI).
compared using the non-parametric Kruskal-Wallis test for differences of location in ranked data (Sokal and Rohlf 1969).

Parametric analyses were not carried out since the data were not normally distributed. Catch data in all cases were heavily skewed to the right due to zero catches. In addition, variances among the factor levels were consistently heteroscedastic. Neither various transformations nor combinations of replicates could overcome these problems.

Results

**Length Frequencies**

Young-of-the-year halibut ranged from 7–77 mm SL (the age-class cut-off). The vast majority of new recruits ranged between 8 and 12 mm SL. These individuals were generally clear with some visible melanophores indicating that they had only recently metamorphosed from the plankton. The smallest specimen collected (7 mm SL) had its upper eye partially migrated to the eyed-side. Eye migration was completed in all other new recruits.

Length frequency data from four comparable dates in each of the three years (Fig. 2) indicate that recruitment was strong and relatively continuous in 1983 with evidence of a persistent year class. In 1984, the recruitment was more sporadic
with relatively high CPUE at times. An identifiable, persistent year class was not apparent in 1984. The recruitment and occurrence of YOY halibut in the nearshore areas was very light and sporadic throughout the 1985 sampling period. In each of the three years, there is some indication of multiple modes in length frequency. This is particularly evident in 1984 and 1985.

*Estimated Growth Rates*

Grand mean growth rates (mm/month) for each year ranged from 10.71 (1983) to 29.78 (1985) (Table 1) based on mean lengths of YOY halibut per sampling date. The values for 1983 are the most reliable since the size class was strongest and most persistent during that year. The sporadic nature of recruitment in 1984 and 1985 makes growth estimates misleading and highly variable.

*Preliminary Age Determination*

Due to difficulty in reading the sagittae, age analysis was limited to 10 individuals between 14 and 45 mm SL. The otoliths of specimens greater than 50 mm SL were too thick to be read accurately by transmitted light. The age-length relationship from these 10 individuals can be described by the linear equation \( Y = 0.45x - 2.7 \) \((r = 0.947; P < 0.01)\) where \( Y \) is the standard length (mm SL).
and \( x \) is the number of growth rings. Based on this preliminary analysis, the smallest individual examined (14 mm SL) was approximately 42 days old. The largest (45 mm SL) was about 100 days old. Assuming linearity, we predict that new recruits at 8–12 mm SL are between 20 and 29 days old.

**Stomach Content Analysis**

The diet of all YOY halibut (7 mm–77 mm SL) was dominated by gammarid amphipods (IRI = 2027), mysids (1436), teleost fishes (901), and harpacticoid copepods (801) (Fig. 3). The diet of individuals 20 mm SL or less (Fig. 4) was dominated by harpacticoids (IRI = 4724), small gammarid amphipods (3300), and polychaetes (369). The dominant items in halibut between 20 mm and 80 mm SL (Fig. 5) were mysids (IRI = 3387), larger gammarid amphipods (2448), and teleosts (1703). Teleosts dominated the diet by weight (61.8% dry weight) and were found primarily in the stomachs of larger (>50 mm SL) YOY halibut.

**Distribution Among Locations**

The general patterns of distribution for 1984 and 1985 were virtually identical in the Alamitos Bay area, although the location difference in 1984 was not statistically significant \( \chi^2[2] = 3.17; P \sim 0.22 \) due to low sample size, but was significant in 1985 \( \chi^2[2] = 8.36; P < 0.05 \). Comparison sampling in 1984 near San Onofre-Oceanside yielded a nearly identical pattern of distribution between the three locations (protected, Aqua Hedionda, CPUE = 2.3; semi-protected, Oceanside Harbor, CPUE = 0.4, and exposed, five open coast stations, CPUE =
The greatest concentration of YOY halibut in the Alamitos area occurred in fully protected waters (CPUE of 2.1 in 1984 and 1.2 in 1985) (Fig. 6). The semi-protected habitat contained between one-half and one-quarter the concentration of YOY halibut. Recruitment of halibut was not observed in the exposed, open coast habitat off Sunset Beach. In 75 trawls taken in the exposed, open coast stations in both the Alamitos and San Onofre-Oceanside areas, only one YOY halibut (35 mm SL) has been captured in the 3 to 6 m depth range. No new recruits were ever collected in these exposed areas.

Recruitment Success

As indicated by the length frequency plots (Fig. 2), recruitment success varied greatly in the three years of the study based on small seine data from Alamitos Bay. Seine CPUE (±2 S.E.) was highest in 1983 (4.6 ± 1.6) followed by 1984 (3.1 ± 3.4) and 1985 (0.1 ± 0.1). A comparison among the three years showed these differences in CPUE to be highly significant $\chi^2[2] = 11.83; P < 0.005$.

Discussion

Feeding Habits

Young-of-the-year halibut exhibited a marked ontogenetic shift in diet. Recently recruited (<20 mm SL) halibut fed mainly on small, substrate-oriented prey such as harpacticoid copepods and small gammarid amphipods. YOY halibut larger than about 20 mm SL appeared to shift to larger prey items which are probably less substrate oriented, including mysids, teleosts (principally gobies), and larger gammarid amphipods. As YOY halibut within Alamitos Bay get larger, teleost fishes become more and more important to their diet.

Haaker (1975) found a similar pattern of dietary shift in young halibut from Anaheim Bay although the smallest halibut he examined were in the 40–50 mm SL range. Young halibut in Anaheim Bay shifted ontogenetically from small crustaceans and gobies initially to an almost exclusively piscivorous diet in older specimens. Plummer et al. (1983) examined the stomach contents of 336 California halibut (109 to 689 mm SL) trawled from 6 to 30 m depths off San Onofre and near Oceanside. The gut contents were dominated by northern anchovies (*Engraulis mordax*) and large mysids (notably *Neomysis kadiakensis*). Smaller halibut (<250 mm SL) mainly contained mysids. Larger individuals (>300 mm SL) mainly contained northern anchovy and other juvenile and adult fishes. It seems clear that halibut from most habitats exhibit a shift in diet according to size. They feed first (<100 mm SL) on small benthic crustaceans, and as they increase in size, larger prey are incorporated into their diet. Large mysids and small fishes become increasingly important in the diet of medium (100–300 mm SL) size fish. Finally, larger fishes are the almost exclusive prey of larger halibut (>300 mm SL).

Halibut occurring in bays probably encounter a different range of prey items in different abundances than those in nearshore areas. Haaker (1975) found gobies to be important food items from YOY halibut in Anaheim Bay. However, Plummer et al. (1983) determined that mysids were important in the diet of juvenile halibut from coastal waters. From the present study, it was evident that YOY halibut of equivalent size were feeding on different prey items in Alamitos Bay.
as compared to YOY in Long Beach Harbor. YOY halibut within Alamitos Bay contained mainly harpacticoids, gammarids, and gobies, while those of comparable size in Long Beach Harbor contained mostly mysids which were abundant in the area.

Recruitment and Distribution

Halibut were recruited at sizes ranging from 8 to 12 mm SL in the Alamitos Bay area. This corresponds to an age of between 20 and 29 days based on the preliminary age-length relationship determined by examination of otoliths. If this aging is accurate, the planktonic larval period of halibut is, therefore, somewhere in the realm of 20 to 29 days after hatching.

No significant correlation between water temperature and the appearance of new recruits was evident in any of the three years of the study. In 1985, new recruits were sampled at temperatures ranging from 16.4°C to 22.9°C. Recruitment was sporadic and appeared to be independent of temperature in the nursery areas, at least in 1985. Water temperatures during the sampling times varied little in both 1983 (18.3–19.5°C) and 1984 (19.2–21.9°C).

This study has provided the first direct evidence in support of the view set forth by Plummer et al. (1983), that young-of-the-year California halibut occupy “embayments” almost exclusively. The results of the present study clearly show that in the area of Alamitos Bay YOY halibut recruit successfully to and are found only in protected or semi-protected waters. Concentrations of YOY halibut are greatest in the protected water within Alamitos Bay. This pattern may be consistent for the entire Southern California Bight since an almost identical pattern of distribution for YOY halibut was found independently in the San Onofre-Oceanside area further south in southern California.

A model of YOY halibut distribution based on these findings states that “recruitment of halibut will occur anywhere that there are relatively calm waters (protected or semi-protected) and these areas will be nursery areas for the young-of-the-year halibut.” Calm waters might include not only bays/estuaries and harbors, but also the leeward sides of points and islands. This general, verbal model allows predictions to be made of where YOY halibut should recruit and occur. These predictions can be tested by sampling for YOY halibut with appropriate gear in areas in question at the correct time of year.

The variable recruitment success of YOY halibut among the three years in the study area is intriguing but, as yet, cannot be explained. The most successful recruitment of the three years based on CPUE was 1983, followed by 1984 with a sporadic, “medium” recruitment, and by 1985 with a sporadic, light recruitment. A few of the many possible explanations include: 1) general oceanographic conditions off the Alamitos Bay area were very different in the three years, 2) productivity within this nearshore area possibly varied, 3) the El Niño event of 1982–1983 had some effect on halibut populations, 4) stronger net transport upcoast in 1983 may have brought more potential recruits into the area from southern waters, and 5) fishing pressure on spawning adults offshore of general Alamitos Bay area in the form of gill-netting may have had an effect over the last three years. Whatever the reason, it is clear that some event or events strongly influenced the recruitment success and/or the larval survivorship in the Alamitos Bay-Long Beach Harbor area for the three years, 1983–1985.
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California Dept. of Fish and Game, unpubl. data.


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