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Distribution and Abundance of Juvenile Halibut in the Southeastern Bering Sea

by

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ABSTRACT

The southeastern Bering Sea is a vast nursery area for halibut. The International Pacific Halibut Commission (IPHC) has studied the juveniles inhabiting this area since 1963. These fish move to the shallow flats during the summer and return to deeper water during the winter. This seasonal movement has become less extensive with a measurable cooling trend observed in recent years. Relative abundance, size composition, growth, and mortality changed during the period of study. The abundance of juveniles varied inversely with the estimates of incidental catch of halibut by the trawl fishery. The abundance index declined from 31.0 in 1966 to 3.1 in 1972 but has increased consistently in recent years to 18.9 in 1977. Differing environmental conditions and changes in the abundance of the spawning stock also may have affected the strength of year classes. The interchange of halibut between the Bering Sea and Gulf of Alaska is discussed.

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INTRODUCTION

The Bering Sea is one of the world's most productive areas for demersal fishes. The vast continental shelf of the southeastern Bering Sea is especially important to young fish. It is a major nursery area for Pacific halibut *(Hippoglossus stenolepis)* that are harvested as adults by the North American setline fishermen. Species such as walleye pollock *(Theragra chalcogramma)* and yellowfin sole *(Limanda aspera)* are exploited extensively by Japanese, Soviet, and South Korean trawl fisheries. Young halibut are particularly vulnerable to capture in the foreign trawl fisheries and usually die even when discarded. Research by the International Pacific Halibut Commission (IPHC) has shown that this incidental catch has seriously affected recruitment to the setline fishery and is one of the causes for the decline in stock abundance. The setline catch of halibut from the eastern Bering Sea was over 11 million pounds (4,990 m.t.) in 1963 but decreased to only 286,000 pounds (130 m.t.) in 1973. The decrease in catch has been accompanied by a decline in catch per unit of effort (CPUE).

Beginning in 1963 and annually since 1965, IPHC has monitored the distribution and abundance of juvenile halibut in the southeastern Bering Sea and the results are described in this paper. Changes in growth and mortality are examined in relation to the environment and the incidental catch of halibut by the trawl fishery. Evidence that a substantial proportion of the juveniles in the eastern Bering Sea originate from spawning in the Gulf of Alaska is also presented. The reciprocal movement of adults from the Bering Sea to the Gulf is also discussed.

SAMPLING METHODS

A sampling pattern consisting of lines of stations approximately perpendicular to the shore of the Alaska Peninsula was established. Stations on each line were separated by 15 minutes of latitude and longitude, e.g., station 5C is located at 57° 00′ N, 160° 00′ W and station 5D is at 57° 15′ N, 160° 15′ W (Figure 1). Based on the occurrence of halibut during exploratory surveys in 1963 and 1965, a group of stations was selected to be fished annually to measure the relative abundance of halibut. These "index stations" have been sampled during June since 1966. Halibut spend their first two summers in shallow inshore areas, consequently five stations at depths of 15 to 25 meters were added between lines 9 and 12 and have been sampled with small mesh nets since 1968. These added stations were designated as "inshore stations".

Since 1966, six commercial trawlers were utilized for the surveys. The *M/V Tordenskjold* has been used for the last 5 years, 1973-1977. The size of the vessels has ranged from 60 to 198 gross tons and engine power varied from 200 to 500 horsepower. The speed of trawling was regulated to approximately 3 nautical miles per hour. The so-called 400-mesh eastern otter trawl with a 71-foot (21.6 m) headrope and a 94-foot (28.7 m) groundrope was the principal sampling tool. Body and wings of the trawl were 4.5-inch (115 mm) netting fitted with a 3.5-inch (90 mm) codend. The small mesh trawl net used to collect smaller halibut from the inshore stations was constructed of 2.5-inch (64 mm) netting in the wings and body with a 1.25-inch (32 mm) codend. The headrope was 47 feet (14.3 m) and the groundrope 57 feet (17.4 m). More detailed specifications of both nets have been described by Myhre (1969). A standard haul was 60 minutes for the large mesh net and 15 minutes for the small net. Water temperature was recorded by mechanical bathythermograph casts.

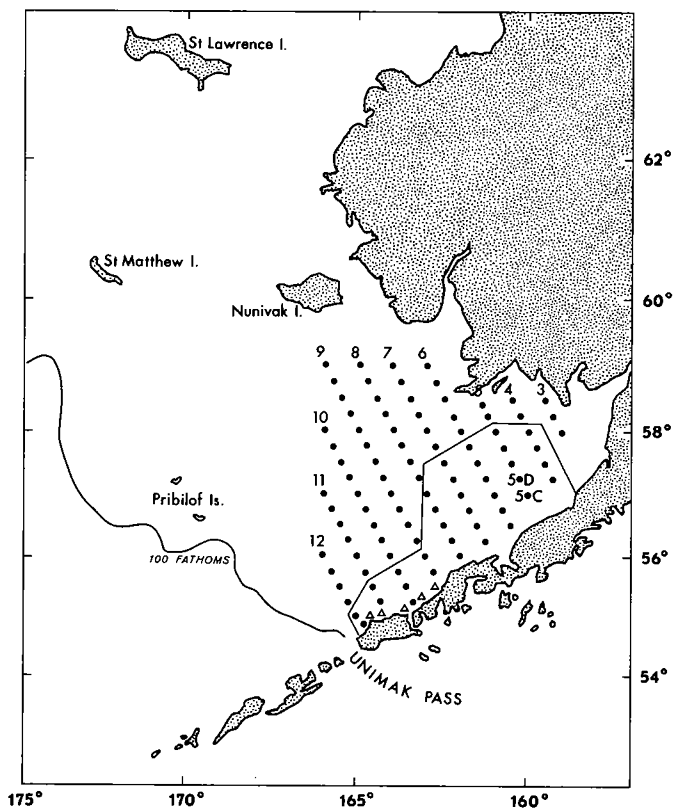

Figure 1. Sampling stations in the Bering Sea. Index stations are enclosed by the solid line and inshore stations are designated by the open triangles.

All halibut were measured (total length) and the otolith from the blind side was removed from three fish in each centimeter size group through 64 cm for age determination and the sex of these fish was determined by examining the gonads. An age-length relation was determined annually to estimate the age of halibut not included in the otolith sample. Basic data on the length and age frequencies of halibut and the catch of halibut and other species have been reported previously (Best 1969a, 1969b, 1970, and 1974).

The surveys were extended north and west in 1966, 1967, and 1968 to determine the timing and extent of the juvenile migrations. During and after

1969, the summer surveys were limited to the southeastern Bering Sea. A special survey was conducted on the continental slope west of Unimak Pass to depths of 400 meters during February and March 1970 to obtain information on winter distribution of juveniles. Additional information on the distribution of halibut was obtained from king crab surveys conducted by the National Marine Fisheries Service (NMFS).

DISTRIBUTION OF JUVENILE HALIBUT

Optimum Temperature

According to Natarov and Novikov (1970), the water temperature of the southeastern Bering Sea changes with the inflow of Alaskan Stream Water, an important water mass in the Gulf of Alaska[1]. Kihara and Uda (1969) used T-S diagrams to identify three water masses in the southeastern Bering Sea: Alaskan Stream Extension Water, Alaskan Coastal Water, and Boreal Cold Water. They discussed the distribution of these water masses and certain demersal fishes but did not mention halibut. Data from the 1963 and 1965 IPHC surveys showed that halibut were present in all the described water masses but were scarce in the Boreal Cold Water. This water mass is the coldest and apparently temperature, or limiting factors related to temperature, deter the migration of halibut.

Water temperature near the bottom, recorded during the surveys, ranged from a low of –1.7° C at a station near mid-shelf in 1975 to a high of 10.5° C at a shallow station in Bristol Bay in 1965. During the IPHC surveys of the late 1960's, few halibut were caught at stations with temperatures of 2° C or less and catches were largest when the temperature was 4° or 5° C. Soviet research trawlers in the southeastern Bering Sea reported the highest catch per hour at water temperatures of 3.5° to 5.5° C (Novikov 1964). The Fisheries Agency of Japan (FAJ) (1972) reported increased catches of juvenile halibut taken when bottom temperatures were above 5° C. Commercial halibut fishing usually is conducted in water of 3° to 8° C (Thompson and Van Cleve 1936).

A marked cooling of the waters of the southeastern Bering Sea has occurred since 1967 (McLain and Favorite 1976). Fujii et al. (1974) reported the cooling trend in the southeastern Bering Sea and a southerly shift in the distribution of chum salmon *(Oncorhynchus keta)*. Some of the IPHC stations, at which halibut had been taken in previous years, could not be sampled during 1972 and 1975 because of drifting pack ice. No halibut were taken at several ice-free stations in the eastern part of the sampling grid where temperatures were 0° C or lower. In recent years, the 2° C isotherm has been much closer to Unimak Pass during June and juvenile halibut were concentrated in that area (Figures 2A and 2B). The limiting effect of the 2° C isotherm on halibut has not been as distinct under this lower temperature regime. Halibut were taken at temperatures below 0° C; however, the largest catches continued to be taken at temperatures near 4° C.

Warmer water temperatures were encountered again in 1977 and halibut were caught at 32 of the 34 index stations. The distribution of juveniles throughout the survey area was similar to that of 1967 (Figure 2A).

[1] After this report was in preparation, Favorite et al. (1976) published a comprehensive report on the oceanography of the Subarctic Pacific Region which contains useful information on the Bering Sea.

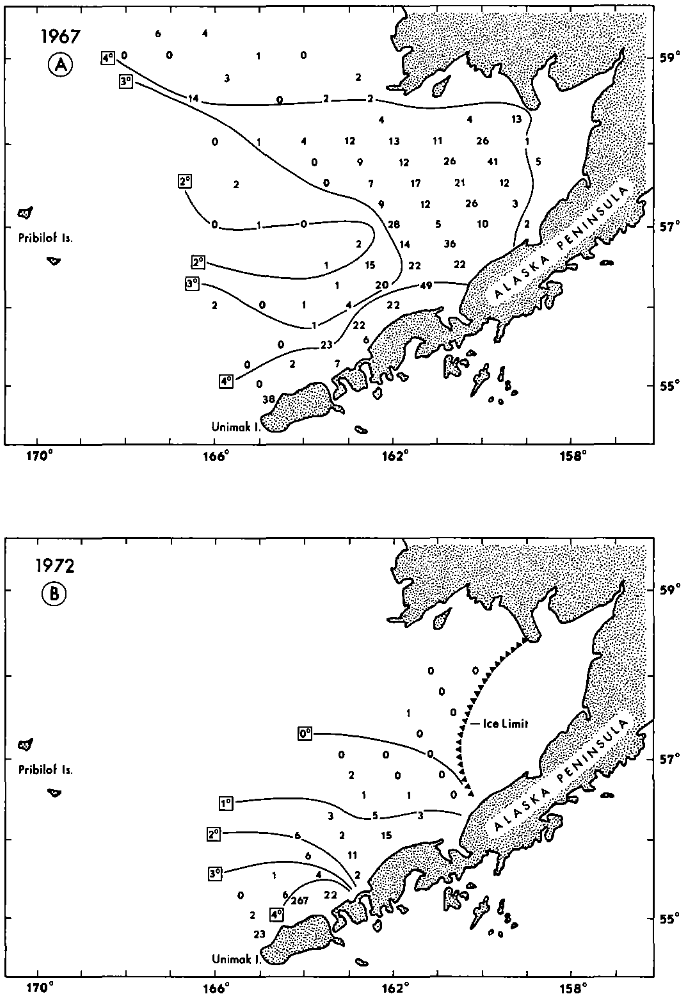

Figure 2. Distribution of halibut, in number per 60-minute haul, and approximate location of bottom isotherms (°C) in June 1967(A) and June 1972(B).

Seasonal Movements

Data from surveys by IPHC, FAJ, the U.S.S.R. research agency (TINRO), and NMFS show a distinct seasonal pattern of movement for halibut in the Bering Sea. During winter, the flats are covered with ice and bottom temperatures drop to 0° C or lower (Dodimead et al. 1963) and halibut are concentrated in warmer water along the outer edge of the continental shelf from Unimak Island to the Pribilof Islands. These winter concentrations of halibut were found to be vulnerable to trawl fishing (Hoag and French 1976). As water temperatures rise, halibut and other demersal fishes move to shallow areas of the continental shelf to feed (Fadeev 1963, 1970; Novikov 1964; Koto and Maeda 1965; Maeda et al. 1967). During the summer months, halibut are dispersed over most of the Bering Sea flats wherever suitable temperatures occur.

Juvenile halibut were abundant at depths of 330 to 370 meters between Unimak Pass and the Pribilof Islands in March 1970 (IPHC 1971) and few halibut were taken at shallower depths. Novikov (1964) reported concentrations of halibut in the same area in March from 1957 to 1961 when abundance of halibut was greater than at present. In April 1970, J. F. Karinen (personal communication) reported an abundance of halibut near the northern entrance of Unimak Pass (ca. 54° 40′ N, 165° 09′ W). Hauls were made at depths of 80 and 104 meters and bottom temperatures were 3.1° and 3.8° C. On the same cruise, temperatures in Bristol Bay, east of 164° W longitude, were –1.0° to 1.4° C, and no halibut were taken. Data on the distribution of halibut during May 1965 were reported by FAJ (1967a).

> "The trawl operations in the Bering Sea were conducted mostly during May. Out of 97 hauls, 41 were made on the Bering Sea Flats in water shallower than 200 m and 56 sets along the edge of the shelf in the depth of 200-450 m. A total of 163 halibut were incidentally caught by 10 hauls out of the 41 on the Flats, while 1,010 halibut were caught by 42 hauls out of 56 on the edge."

As warming progresses, young halibut move eastward along the north side of the Alaska Peninsula and usually are found throughout Bristol Bay in June. By late June, they move northward toward Nunivak Island. An IPHC survey in the vicinity of St. Matthew Island (60° 30′ N) during the latter part of June 1968 found bottom temperatures to be 0° C or less and only 10 halibut were caught in 14 hauls. Temperatures of 4° C or greater were encountered south of 59° 30′ N latitude and catches increased to 86 fish in 5 hauls. NMFS conducted an extensive trawl survey of the eastern Bering Sea between August and October 1975 and found that halibut were generally restricted to Bristol Bay. The largest catches were made close to the Alaska Peninsula, and only a few were taken north of 59° N latitude (IPHC 1976). When summer temperatures are relatively low, the migration of halibut is inhibited because less of the usual feeding grounds reach the preferred temperature and do not maintain this level as long.

The farthest north that halibut have been taken during IPHC surveys was 62° 30′ N latitude. Two juveniles were caught in three hauls at this latitude during July 1967 (Best 1969a), a year of relatively high water temperatures (Maeda et al. 1968). In an earlier survey, Ellson et al. (1949) reported capturing a "small" halibut at 64° 15′ N latitude in September. R. S. Wolotira (personal communication) reported the capture of an adult halibut at 66° 02′ N, 168° 02′ W during a NMFS trawl survey of the area north of St. Lawrence Island in September 1976.

Juvenile Tagging Experiments

During IPHC summer surveys from 1963 through 1970, all viable halibut over 25 cm were tagged. Out of 5,495 tags released, only 8 were recovered; of these, 2 were recovered near the release site, 5 were returned from deeper water during the winter (Figure 3), and 1 was returned from the Gulf of Alaska. In other tagging experiments conducted in the spring, juvenile halibut were released in deeper water of the continental shelf. Although only 8 were recovered on the flats in the summer (Dunlop et al. 1964), these recoveries confirm the theory that there is a seasonal interchange of halibut between shallow and deep areas of the southeastern Bering Sea.

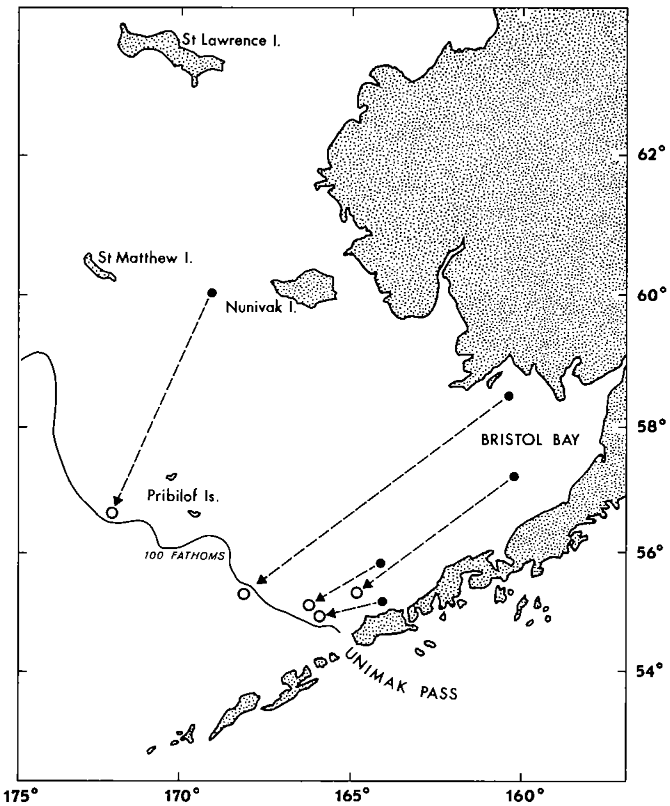

Figure 3. Winter-spring recovery locations (○) of five tags released (•) during IPHC summer trawl surveys.

Size and Age

Length data from IPHC surveys suggest that juvenile halibut school by size. No young-of-the-year halibut have been caught to date; either they are too small to be retained by the sampling gear or are not present at the time of the surveys. One-year-old halibut are caught with the small-mesh trawl at depths less than 25 meters along the shore of the Alaska Peninsula and the Aleutian Islands, but have not been taken at offshore stations. The largest catches of 1-year-olds have been near Unimak Pass during late June and early July. Two-year-olds are taken regularly at inshore stations and are present at many of the shallower grid stations. Age 3 fish dominate catches in Bristol Bay and 4- and 5-year-olds are dominant near Nunivak Island (Figure 4). Larger juveniles move greater distances and utilize a larger proportion of the flats for summer feeding. Takahashi (1969) reported a similar distribution of ages.

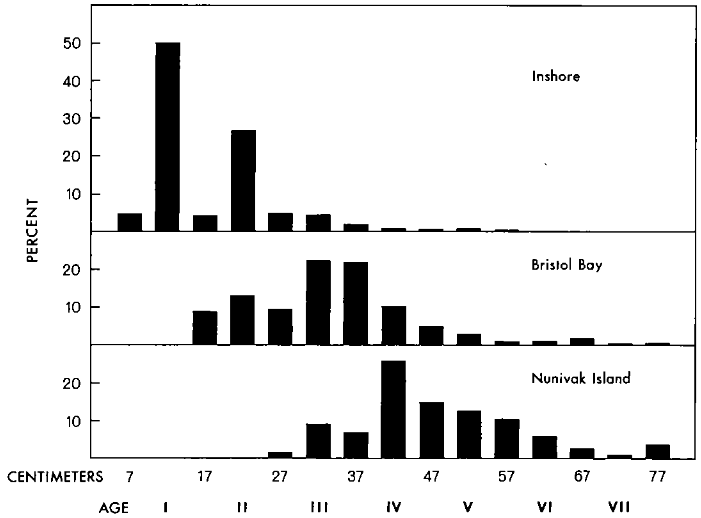

Figure 4. Length and age frequencies of halibut from inshore stations (July 1968), Bristol Bay (June 1967), and Nunivak Island (July 1967). Lengths are the mid-points of 5 cm size groups.

ABUNDANCE

The index stations (Figure 1) have been sampled during June since 1966 to provide estimates of relative abundance. The mean number of halibut caught per hour trawled from these stations was used as the annual index of abundance. The abundance index decreased from 31.0 fish per hour in 1966 to 3.1 fish per hour in 1972 and then increased to 18.9 in 1977 (Table 1). Abundance indices of 45.9 and 26.3 were obtained from the surveys of 1963 and 1965 respectively, but these surveys were not comparable to those of later years. Not all of the stations were sampled and sampling began in May and continued into August.

Table 1. Relative abundance of juvenile halibut by age groups from the Bering Sea index stations, 1966-1977.

Year	Age 2	3	4	5	6	7	Index of Abundance
	Number per hour trawled						
1966	0.2	17.2	4.9	7.6	0.9	0.2	31.0
1967	0.6	4.3	4.6	6.0	0.5	0.6	16.6
1968	0.3	6.4	1.8	3.1	0.5	0.4	12.5
1969	2.7	4.1	4.7	0.4	0.7	0.2	12.8
1970	0.4	8.8	2.0	0.7	0.2	—	12.1
1971	3.7	2.6	7.6	0.3	—	—	14.2
1972	0.1	2.0	0.5	0.4	0.1	—	3.1
1973	0.1	3.7	1.9	0.7	0.2	—	6.6
1974	0.1	1.2	3.7	0.8	0.3	—	6.1
1975	0.5	3.2	5.3	2.0	0.7	0.1	11.8
1976	0.3	6.5	4.5	1.2	0.3	0.1	12.9
1977	0.4	5.4	9.5	2.1	1.4	0.1	18.9

Although sampling gear, area, and time have been standardized at the index stations, oceanographic conditions have varied. The cooling trend observed since 1967 apparently delayed the movement to summer feeding grounds and affected the distribution of halibut during the surveys. Major changes in the annual distribution will affect catches at individual stations, but if the fish remain in the index area, the average catch per hour for all stations should still provide an estimate of relative abundance. For example, in 1972, the incidence at stations in the eastern part of the survey area was low, whereas the incidence at western stations near Unimak Pass was above average (Figure 2B). Evidence that halibut were distributed outside the index area was noted in 1972 and 1973, when water temperatures were lower than usual. In 1972, for example, 267 juveniles were caught at a shallow station (Figure 2B); more than twice the total (106) from the index area. This station is not sampled every year and, therefore, is not included in the abundance index. Three-year-old halibut were about four times their average abundance at inshore stations in 1972 and 1973, an indication that fewer had moved into the index area and suggesting that the abundance was underestimated.

As stated earlier, 1-year-olds are not available at the offshore stations. Age 2 halibut usually are too small to be completely retained by the 3.5-inch mesh codend. The 3- and 4-year-olds provide the best estimate of year class strength. When the numbers of 3- and 4-year-old fish (Table 1) of each year class were combined, the apparent strength was greater for year classes in odd years than in even years. This cycle of year class strength also was noted in data from the 1963 and 1965 surveys. The CPUE of the Bering Sea setline fishery also shows the pattern of increased relative abundance for fish spawned in odd-numbered years since the 1961 year class. The alternating cycle of year class strength was not evident during the recent period of cooler water.

Year Class	1963	1964	1965	1966	1967	1968	1969	1970	1971	1972	1973
Abundance	21.8	6.1	11.1	6.1	16.4	3.1	3.9	7.4	6.5	7.7	16.0

The cyclic change coincided with a 2-year cycle of weather conditions in the eastern Bering Sea between 1960 and 1970. Konishi and Saito (1974) reported warmer air temperatures and prevailing winds from the south during the spring of odd-numbered years, with the exception of 1965, and colder temperatures and northerly winds in even-numbered years. The weather cycle changed in 1971 and temperatures remained relatively cool until 1977. However, the average bottom temperature in 1973 was warmer than 1972 or 1974 (IPHC 1976) and the 1973 year class has shown an increase in relative abundance. Thus, the prevailing wind pattern may influence the strength of the Alaska Stream inflow and the relative number of halibut larvae that enter the southeastern Bering Sea.

Factors other than the environment also have affected the abundance of juvenile halibut. Incidental catches by trawls increased the mortality of juveniles during the 1960's, and this is discussed in a later section of the report. As indicated by the CPUE in the North American setline fishery, the abundance of mature halibut also declined during the 1960's and may have affected year class strength.

Not only has the abundance of halibut decreased during the surveys, the age composition also has changed. No 7-year-old halibut were caught from 1970 through 1974 and the proportion of 5- and 6-year-olds has decreased (Table 1).

The long-term decrease of older juveniles also was evident in a comparison of length frequencies of trawl-caught halibut from earlier surveys. For several years prior to the IPHC surveys, the U.S. Fish and Wildlife Service (now NMFS) conducted surveys for king crab in the same general area now sampled by IPHC and provided information on the halibut in the catches (King 1949). The length frequencies of halibut caught on several surveys are compared in Figure 5: in 1947, prior to the development of foreign trawling; in 1959, during the period of yellowfin sole exploitation; in 1963, after the peak of yellowfin sole fishing; and in 1972, after the development of the pollock fishery. The codend mesh size was not standard in these years. For instance, a 5-inch (127 mm) mesh was used in 1947, a 3.5-inch (90 mm) mesh with a 1.5-inch (38 mm) liner was used in 1959, and a 3.5-inch mesh without liner was used in 1963 and 1972. Larger mesh allows the smaller fish to escape and shifts the length frequency towards larger sizes. Myhre (1969) calculated that the 50% selection size for halibut was about 26 and 40 cm for the 3.5- and 5-inch codends respectively. Even if the majority of halibut less than 40 cm escaped the nets used in 1947, the trends indicate that the proportion of large juveniles has declined substantially during this 25-year period.

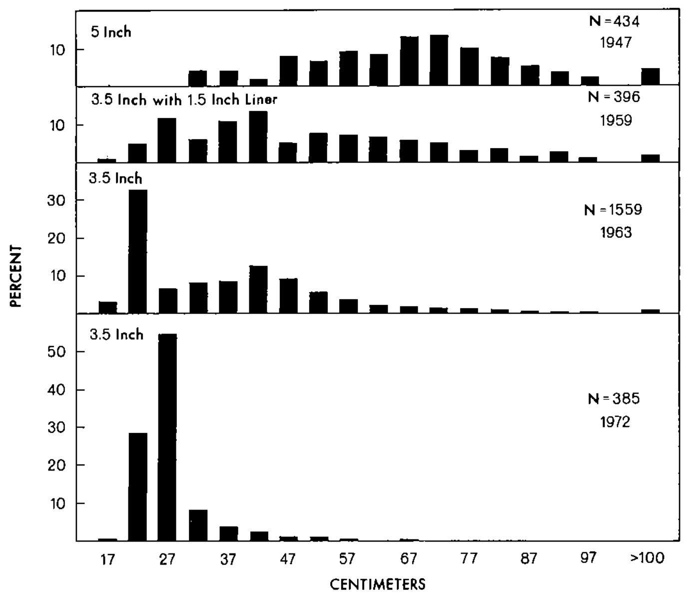

Figure 5. Length frequency of halibut from trawl catches in the southeastern Bering Sea in 1947, 1959, 1963, and 1972. Lengths are the mid-points of 5 cm size groups.

GROWTH

Rogers (1973) reported that sea surface temperature in the vicinity of Adak Island in 1972 was below average and the mean length of age .1 (fish that have spent one winter in the ocean) sockeye salmon *(Oncorhynchus nerka)* was the smallest observed in 17 years. The size of age .1 sockeye salmon at Adak Island was positively correlated with fresh water temperature the previous spring at the time of seaward migration. Apparently, the lower temperature of recent years also reduced the growth of young halibut.

Growth of the 1962, 1968, and 1971 year classes was selected to show the apparent effects of the changed environment (Figure 6). The 1962 year class is the earliest class with estimates of average sizes at ages 1 through 6, which were obtained during the warm period (1963-1968). Growth of the 1968 year class slowed noticeably during the extremely cold year of 1971. The 1971 year class, and all subsequent year classes which were spawned during the cooler period, have been 10% to 20% smaller at each age than the 1962 year class. This suggests that it will take about 1 year longer for Bering Sea halibut to grow through the juvenile stage (64 cm). Consequently, entry into the fishable stock also will be delayed. The "t" test for unequal samples (Snedecor 1950) was used to compare the mean length at ages 1, 3, 4, 5, and 6 of the 1962 and 1971 year classes. There was no survey in 1964; consequently, no measurements of 2-year-olds of the 1962 year class were available. The mean length of the 1971 year class was found to be significantly smaller ($p \leq 0.01$) than the 1962 year class at ages 1 through 6. In general, halibut of the 1971 year class were significantly smaller ($p = 0.02$) in size than those of the 1962 year class using the multiple independent pairwise comparison procedure of Miller (1966).

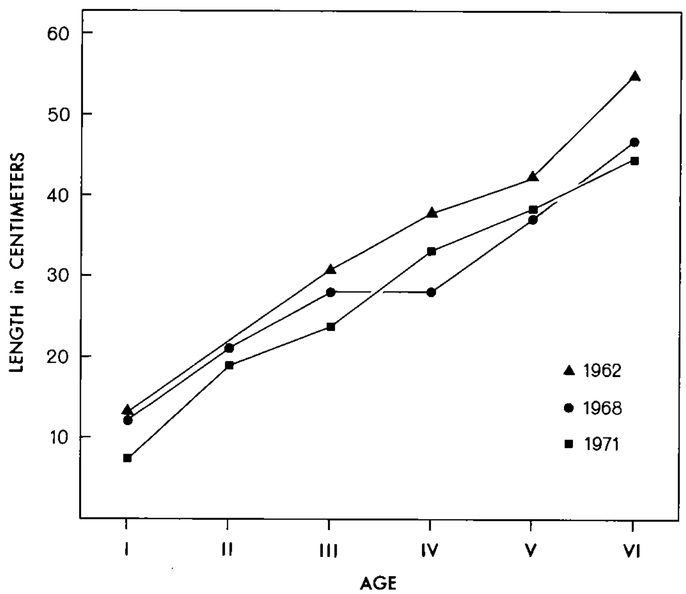

Figure 6. Average length of the 1962, 1968, and 1971 year classes through age 6.

MORTALITY

Annual mortality, or disappearance, rates were calculated from the catch of each year class in successive years (Table 1). The calculated rates include the effect of natural and fishing deaths, recruitment, emigration, and immigration. The estimates obtained by this method fluctuated widely from year to year. Changes in the availability of juveniles within the index area undoubtedly contributed to the variability. To reduce the variability of the estimates, an average annual mortality rate ($\bar{A}$) was calculated by comparing the number of 4-, 5-, and 6-year-olds of one year with the number of 5-, 6-, and 7-year-olds the following year:

$$\bar{A} = 1 - \frac{N_5 + N_6 + N_7}{N_4 + N_5 + N_6}.$$

Although 3-year-olds are an important factor in the abundance of juveniles, they were excluded from the estimate of mortality because they have not been fully recruited in the catches since 1971 (Table 1). The age of recruitment into the index area apparently has increased from age 3 to age 4. One possible reason is the reduced growth rate. The estimates of $\bar{A}$ for the period of 1966 through 1976 were:

	1966	1967	1968	1969	1970	1971	1972	1973	1974	1975	1976
$\bar{A}$	.47	.64	.76	.84	.90	.94	.10	.61	.42	.80	.40

The large change in apparent mortality between 1971 and 1972 probably was the result of abnormally low catches in 1972 (see page 12). The estimate for 1971, therefore, probably was high and that for 1972 probably was low.

A large scale trawl fishery, which catches small halibut incidentally, has been operating in the southeastern Bering Sea throughout the period of our surveys. Japanese fishermen began trawling for yellowfin sole during the summer months in the eastern Bering Sea in 1954. By 1958, the U.S.S.R. had developed a trawl fishery for yellowfin sole during the winter and spring months. The two fleets removed over 1.3 billion pounds (610,000 m.t.) of yellowfin sole in 1961, and catches declined thereafter (Bakkala et al. 1976). The trawl fishery now has shifted to a year-round fishery for pollock; however, the flounder fishery continues to operate at a low level of harvest. The catch of pollock was over 4.4 billion pounds (1,800,000 m.t.) in 1972, three times the largest annual catch of the earlier yellowfin sole fishery. IPHC expressed concern about the effect of this trawl fishery on juvenile halibut as early as 1961 (IPHC 1962).

During the 1970 and 1971 surveys, 4,524 juvenile halibut were tagged and released in a small area just north of Unimak Pass (ca. 54° 45′ N, 164° 45′ W). IPHC research vessels recaptured 24 tags in the release area during the 1970 and 1971 tagging operations plus 2 during the 1972 survey. The Bering Sea trawl fisheries have returned 68 tags. Fifty-eight of these were recovered by the Japanese trawl fishery between December 26, 1971 and April 14, 1972, approximately 25 miles southwest of the release area in water 180 to 270 meters deep. The dates and locations of these 58 returns suggest that only one of the several motherships and independent trawlers known to have fished the area reported the recaptures. The fish were all smaller than 64 cm when recaptured.

Halibut ages 1 and 2 live in the shallow coastal areas and are largely protected from the trawl fishery. Fish of ages 3 and 4 are distributed throughout the flats during the summer and fall and are vulnerable to the trawl fishery for yellowfin sole. The mortality of 3- and 4-year-olds probably was greater in the early 1960's than at the present time. Because the current pollock fishery is conducted in deeper water, the incidental catch is concentrated on 4- to 7-year-old halibut (Hoag and French 1976).

Hoag and French (1976) estimated that the incidental catch of halibut in the entire Bering Sea was nearly 25.4 million pounds (11,519 m.t.) or nearly

7 million fish in 1971. This incidental catch by trawling reduced recruitment to the setline fishery and the potential yield loss was substantial (Hoag and Skud 1975). Except in 1972, the trends in mortality of juvenile halibut generally coincide with the magnitude of the incidental catch of halibut by foreign trawlers through 1974 (Hoag and French 1976). Based on the observed incidence of halibut in trawl catches, IPHC proposed a time-area closure for the eastern Bering Sea to reduce the incidental catch when halibut are most densely concentrated. Negotiations between the governments of Canada, Japan, U.S.S.R., and the United States developed regulations which restricted the time and area of the trawl fishery in the Bering Sea. The time-area closures for the Japanese fleet were initiated on January 1, 1974 as domestic measures and were extended in time and area in 1975 (IPHC 1976). Hoag (1976) estimated that the incidental catch of young halibut by Japanese trawlers declined about 1.5 million pounds (700 m.t.) during 1974. Data are not available to estimate the savings that resulted from the expanded closure in 1975, but projections based on the past distribution of fishing effort indicate that the incidental catch should decline an additional 900,000 pounds (400 m.t.) in 1975. The U.S.S.R. began observing the closures in 1976, and additional savings are anticipated as a result.

A measure of the benefit from the trawl closure can be seen in Table 1. The index of abundance has increased steadily since closures were initiated in 1974. The age composition of the halibut catches in the survey area also has improved. By 1977, the catch rates of most ages had approached or exceeded those of the 1960's.

ORIGIN OF THE BERING SEA HALIBUT

Definitive information on the origin and drift of halibut eggs and larvae is lacking for the Bering Sea. Spawning has been reported between December and February along the edge of the continental shelf in the western and eastern Bering Sea (Musienko 1963; IPHC 1965). The circulation patterns indicate that the eggs and larvae spawned in the eastern Bering Sea should remain within the confines of the Bering Sea, an opinion originally expressed by Thompson and Van Cleve (1936). The cyclonic circulation in the area will transport the pelagic eggs and larvae in a northwesterly direction; although an eddy may exist, the dominant flow is to the northwest. This current is of sufficient strength to transport halibut larvae to the Asian Coast during their pelagic existence (Favorite 1975).

Halibut larvae have been collected west of the Pribilof Islands during March (Musienko 1963) and from the Bering Sea side of Unimak Pass during May (Vernidub 1936; Dunlop et al. 1964). Musienko (1957) reported taking young halibut from depths of 7 to 43 m off the eastern shore of the Kamchatka Peninsula and Cape Navarin, U.S.S.R. Fish-of-the-year from 34 to 42 mm long were collected during September and October and a 1-year-old 56 mm long was collected in May. Wakabayashi[2] reported taking small halibut during a trawl survey between Unimak Pass and Cape Navarin in June 1973. Except for one haul of 54 halibut, the catches were 10 halibut or less per 30-minute haul. He reported

[2] Wakabayashi, K. (in press) Report on the biological research of groundfish in the Bering Sea and northeastern Pacific by *Wakatori Maru No. 2* in 1973. Far Seas Fisheries Research Laboratory.

taking a single fish which was 10.8 cm long off Cape Navarin. This is similar in size to 1-year-olds from the southeastern Bering Sea. Smallest juveniles were closest to shore with older, larger fish offshore. The distribution of sizes of halibut suggests that there are two groups of halibut: one in the eastern, and the other in the western Bering Sea, possibly intermingling in the central area.

Thompson and Van Cleve (1936) and Vernidub (1936) suggested that larvae originating in the Gulf of Alaska could be transported into the Bering Sea by the prevailing currents. These conclusions are supported by recent studies. Uda (1963) reported a northward movement of the surface layers into the Bering Sea through passes that are nearest to the Alaska mainland. Drift bottles released in the Gulf of Alaska and recovered in the Bering Sea also indicate a similar flow of surface currents (Thompson and Van Cleve 1936; Dodimead et al. 1963; Favorite and Fisk 1971).

Although evidence of larval transport from the Gulf of Alaska to the Bering Sea is circumstantial, there is evidence that juveniles move into the Bering Sea. Two juvenile halibut were tagged in the Pacific Ocean off Unimak Island on July 7 and August 9, 1971 and were recovered in the Bering Sea in January and April 1972. The size of those fish indicated that they were 3 or 4 years old when released.

A reverse movement also has been documented; three juveniles tagged in the eastern Bering Sea have been recovered from the Gulf of Alaska. One fish tagged north of Unimak Island in 1961 was recovered in Shelikof Straits near Kodiak Island in 1969. A second fish released during the 1966 IPHC survey near Nunivak Island was recovered 6 years later near Cape St. Elias in the central Gulf of Alaska. The third juvenile released west of the Pribilof Islands in 1967 was recovered in 1972 from inside waters of southeastern Alaska. Recoveries of adult halibut released in the eastern Bering Sea have been reported from the Gulf of Alaska and as far south as Cape Mendocino, California (IPHC 1962, 1972). The Fisheries Agency of Japan (1967b) reported that " . . . most of the halibut tagged east of the Pribilof Islands move significantly eastward . . . as was observed in the past. Those released west of 175° W did not show significant eastward movement but most of them moved toward the Asian Continent." Dunlop et al. (1964) calculated a 24% emigration of tagged halibut over 80 cm long from the Bering Sea. They implied the existence of two groups of halibut in the eastern Bering Sea, one migratory and the other nonmigratory. The emigrants were younger (less than age 12) and faster growing than halibut recovered in the Bering Sea. This eastward movement of halibut to the Gulf of Alaska may counterbalance the westward drift of eggs and larvae in the Alaska Stream. Significantly, no adult halibut tagged in the Gulf of Alaska have ever been recovered in the Bering Sea.

The westward transport of halibut eggs and larvae by the Alaskan Stream, movement of juveniles through the Aleutian passes into the Bering Sea, and the persistent eastward movement of tagged halibut indicates that some of the young halibut in the southeastern Bering Sea were spawned in the Gulf of Alaska. The northwesterly transport along the continental slope of halibut eggs and larvae spawned in the Bering Sea to nursery areas on the east coast of Kamchatka Peninsula of eastern U.S.S.R. also is suggested, although definitive information on origin and movements of halibut in the western Bering Sea is lacking. Carefully planned experiments are needed to determine the relationship of the stocks of halibut in the western and eastern Bering Sea and in the Gulf of Alaska. Canada and the U.S. agreed to conduct a joint tagging study with the U.S.S.R. in the Bering Sea. IPHC participated on behalf of the North American governments and halibut were tagged during the summers of 1975 and 1976 (IPHC 1976), but returns from these taggings cannot be expected in significant numbers for several years.[3]

[3] One halibut tagged on July 5, 1975 at 61° 18′ N, 175° 12′ E at Kamchatka was recovered by an American fisherman on May 19, 1977 off the Shumagin Islands in the Gulf of Alaska.

SUMMARY

Since 1963, IPHC has studied the distribution and abundance of juvenile halibut in the nursery area of the southeastern Bering Sea. The principal sampling gear was a 400-mesh eastern otter trawl with a 3.5-inch (90 mm) mesh codend. A trawl with smaller mesh was used to collect the youngest halibut at shallow inshore stations.

In winter, halibut concentrate at the edge of the continental shelf. With spring warming, they move onto the shallow flats and disperse. Maximum northward distribution occurs in August or early September. The largest juveniles made the longest migrations. The northern limit of juvenile halibut was 62° 30′ N latitude in 1967, but the extent of this movement varies with environmental conditions. Ocean temperatures between 1970 and 1976 were lower than during the period 1966 to 1969, and the northward movement of juvenile halibut has been noticeably reduced. Young halibut tend to school by size. The smallest are caught in shallow water, whereas larger juveniles dominate the catch in deeper water.

Mean size at each age has decreased. An annual index of abundance calculated from 34 index stations has declined from 31.0 fish per hour in 1966 to 3.1 in 1972 and subsequently increased to 18.9 in 1977. A large-scale trawl fishery for demersal species has operated in the Bering Sea since 1958. A preliminary estimate indicated the incidental catch of halibut by trawling was nearly 25.4 million pounds (11,519 m.t.) or about 7 million fish in 1971. Time-area restrictions on the trawl fishery suggested by IPHC were adopted to provide some degree of protection for the Bering Sea halibut from the extensive trawl fishery. An estimated 1.5 million pounds (700 m.t.) of young halibut were saved from incidental capture by trawlers in 1974 as a result of the time-area closures. Extension of the time-area closures is expected to provide additional protection to the juvenile halibut. Improvement in the abundance of juvenile halibut has been observed coincident with a reduction of the incidental catch by trawling. Although the incidental catch by the trawl fishery is substantial, it is only one of several factors that may affect the abundance of juvenile halibut. Differing environmental conditions and changes in the abundance of the spawning stock also may influence the relative strength of year classes in the Bering Sea.

Oceanographic circulation of the Bering Sea indicates that eggs and larvae spawned in the area will remain there. The existence of separate stocks of halibut in the eastern and western Bering Sea is hypothesized on the basis of size distribution and ocean currents.

Oceanographic and drift bottle studies suggest that juvenile halibut in the southeastern Bering Sea may be transported from the Gulf of Alaska during their pelagic larval life. A few juveniles tagged in the western Gulf of Alaska were recovered in the Bering Sea, and a substantial number of adult halibut tagged in the eastern Bering Sea have been recovered in the Gulf of Alaska, indicating that the halibut of the eastern Bering Sea and the Gulf of Alaska are interrelated.

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