Abundance, Distribution, and Growth of Flounders in the South-Eastern Chukchi Sea

By

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Introduction

During August 1959 the US Bureau of Commercial Fisheries in conjunction with the University of Washington and US Atomic Energy Commission conducted an investigation of the types, distribution, and abundance of marine fauna inhabiting the south-eastern Chukchi Sea (ALVERSON, WILIMOVSKY, and WILKE, 1960). The investigation was a facet of the Atomic Energy Commission's "Chariot Project" to study the feasibility of utilizing nuclear explosives for large-scale excavation projects, e.g., harbours or canals. An excavation project site has been selected at the mouth of Ogotoruk Creek between Cape Thompson and Cape Seppings on the north-west coast of Alaska. The environmental study programme was designed to determine the biological effect (or cost) of the anticipated nuclear explosion prior to any actual detonation. The US Bureau of Commercial Fisheries and the University of Washington Department of Oceanography and Laboratory of Radiation Biology participated in the marine ecological investigation of the region.

Field investigations were conducted aboard the Bureau's exploratory fishing vessel "John N. Cobb" from 5. August to 31. August. The small sizes of the pleuronectids taken and their apparent scarcity in the region created considerable interest in this group of fishes. Therefore, we examined the Chukchi Sea catches of pleuronectids to provide information on (1) species composition, (2) relative inter-species abundance, (3) geographic and bathymetric distribution, (4) size and age composition, and (5) possible commercial value of the resource.

Region of Explorations

The Chukchi Sea (Fig. 1) is bordered on the west by Siberia, on the east by Alaska, and on the north by the Arctic ice pack. It is generally considered to extend eastward along the Alaskan coast to Point Barrow.

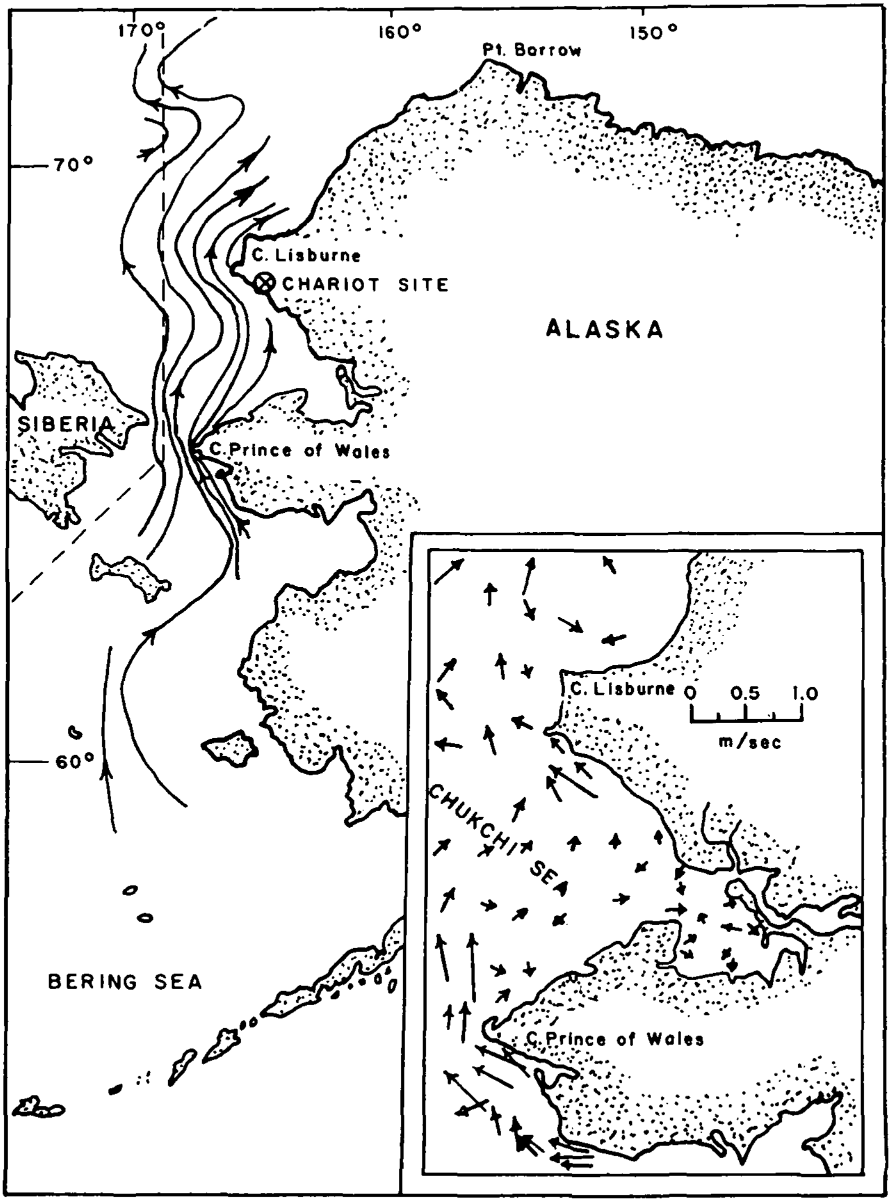

Figure 1. Summer current flow pattern in surface layer of the Bering Sea and Chukchi Sea (after LAFOND and PRITCHARD, 1952 and FLEMING and Staff, 1960).

Marine explorations were conducted from Bering Strait (65° 20′ N latitude) to north of Cape Lisburne (69° 17·2′ N latitude) and from Kotzebue Sound (163°48′W longitude) to the United States—Soviet convention line of 1867. The region within these boundaries, most of which lies north of the Arctic Circle, comprises an area of about 63,000 km^2. The sea in this region is generally shallow with a maximum depth of about 62 m (34 fms).

During the late autumn, winter, and spring the region is covered by sea ice. Ice break-up occurs during late June or July. In the latter part of August and early September the ice recedes to its northern limit and re-formation of ice generally commences during the latter part of September. Considerable fog covers the sea during August, and as there are few radio navigational aids in the region, precise positioning is difficult. The hydrography of the region is considered briefly in the Discussion.

Sampling Gear and Methods of Analysis

Otter trawl

Demersal fishes were sampled with a 400-mesh eastern otter trawl (Greenwood, 1958) having 11·4 cm mesh throughout (stretched measurement, opening including one knot). To ensure retention of small fish, a 3·8 cm mesh liner 100 meshes in circumference and 200 meshes in length was inserted into the cod-end portion of the trawl. All otter trawl hauls were of one-half hour duration, counted as the time the net was on the bottom.

Station pattern

A three-phase ecological investigation was conducted to assess the abundance and distribution of the general marine fauna. Phase I entailed a survey of the demersal and benthonic forms within the region. During this phase, stations were occupied on a predetermined grid at intervals of about 36 km. Stations were occupied at distances of approximately 148 km seaward and about 148 km north and south of the Chariot site. Phase II involved detailed sampling of the area adjacent to the excavation site. Stations were interspaced between Phase I locations so that stations occupied were not more than 18 km apart. This work was carried out at distances approximately 74 km north and south of the Chariot site. Phase III provided a survey of pelagic fauna and will not be reported here. The position of each station was determined by celestial bearings when feasible and by radio or radar fixes at other times. In several instances it was necessary to fix the vessel position by dead-reckoning. After the position was established and routine meteorological and hydrographic data were recorded, the trawl net was set and towed for thirty minutes.

Field collection and age determination procedures

Field identification of specimens was made following each fishing effort and the number and sizes of fishes caught were recorded. Fish specimens were preserved in a neutral 4% solution of formaldehyde or by freezing.

Ages of specimens of *Hippoglossoides robustus* and *Limanda aspera*, the two most numerous pleuronectids taken in the Chukchi Sea, were determined by

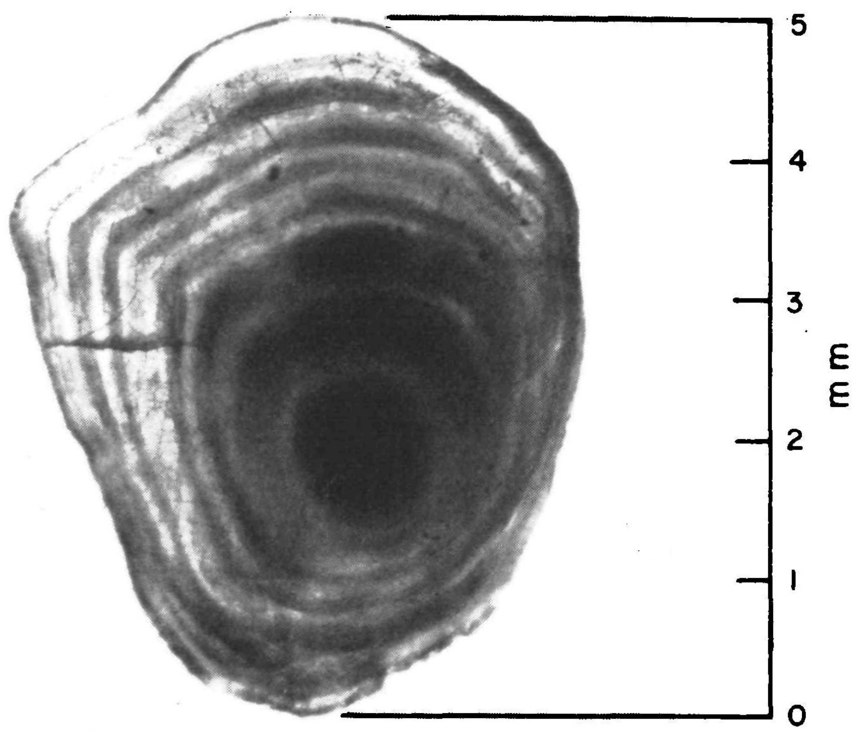

Figure 2. Photograph of an otolith with eight annuli from a female *Hippoglossoides robustus* 177 mm in total length.

counting the "annular rings" on their otoliths. The use of otoliths and scales for determining the age of Arctic flounders is well documented (MOISEEV, 1953; MUSIENKO, 1957).

Otoliths were removed from fish that had been preserved by freezing and from fish stored in formalin. A number of methods were tried to find the one bringing out most clearly the annular marks in the otoliths. Conventional methods, including cleaning the otoliths in ammonia and then soaking them in glycerin for about 24 hours provided only fair definition of the annuli.

As shown in Figure 2, excellent definition of the annuli resulted from soaking the otoliths in a solution of papain, a plant enzyme (Nutritional Biochemicals Corp., Cleveland, Ohio). Treatment with papain both cleans and clears the otoliths. Cleaning probably results from hydrolysis of adhering protein. The clearing action is not fully understood, but probably occurs as a result of the alteration or removal of the protein matrix of the otolith. Otoliths cleared in papain return to their original opaque condition after they are removed from solution and allowed to dry. However, they may be cleared again by immersion in water.

The papain solution is prepared by dissolving one to two grammes of papain in 100 ml of distilled water or in 100 ml of 0·1 molar phosphate buffer. After removing the undissolved material by filtration, the solution should be stored at refrigerated temperatures where it will remain stable for at least two weeks. For otoliths which have been stored in glycerin the unbuffered solution should be used to prevent precipitation of salt crystals on the surface of the otoliths.

Papain is fast acting—otoliths of *H. robustus* and *L. aspera* were cleaned and cleared within one hour after being placed in solution. We also have used papain on a few otoliths of red snappers (*Sebastodes ruberrimus*) and polar cod (*Boreogadus saida*) with excellent results, and believe papain (and possibly other enzymes) may have great potential value for cleaning and clearing otoliths and cleaning scales of other species.

The otoliths of *H. robustus* were photographed and the film positive was projected on a table-top screen (Southward, 1961). Direct age determinations were made by counting the rings on the projected images of the otoliths. Lengths of *H. robustus* at previous ages were determined by measuring the distance from the centre of the nucleus of the projected image of the otolith to the outer edge of each annulus and calculating the length of the fish at each age of life. The latter involved the assumption that the body length/otolith radius relationship is linear and that the intercept of the regression line expressing this relationship is zero.

The otoliths of *L. aspera* were read with a binocular microscope using transmitted light. No indirect age determinations were made for this species.

Two readings of each fish were made several days apart without reference to the previous reading or to the length of the fish. If the first and second readings differed, a third reading was made. All readings were made by the senior author.

Results

From 6. August to 30. August 1959 a total of 74 stations was occupied in the south-eastern Chukchi Sea and Kotzebue Sound area. The otter trawl was used to sample demersal fish populations at 59 of the 74 stations (Fig. 3), the hauls being made in waters ranging from 13–62 m (7–34 fms).

Species of flounders

A total of 289 pleuronectids composed of six species was taken with the otter trawl. The number of individuals captured is shown by species in Table 1.

Of the six species of pleuronectids collected in the Chukchi Sea by the "John N. Cobb" two (*Pleuronectes quadrituberculatus* and *Atheresthes stomias*) apparently have not been previously taken north of the Bering Strait. *Atheresthes stomias* was known previously from the eastern Bering Sea south to California and *Pleuronectes quadrituberculatus* from the Bering Sea and Gulf of Alaska.

Hippoglossoides robustus occurs in waters adjacent to eastern Kamchatka, in the Okhotsk Sea, and in the Bering Sea, and was noted in the Chukchi Sea

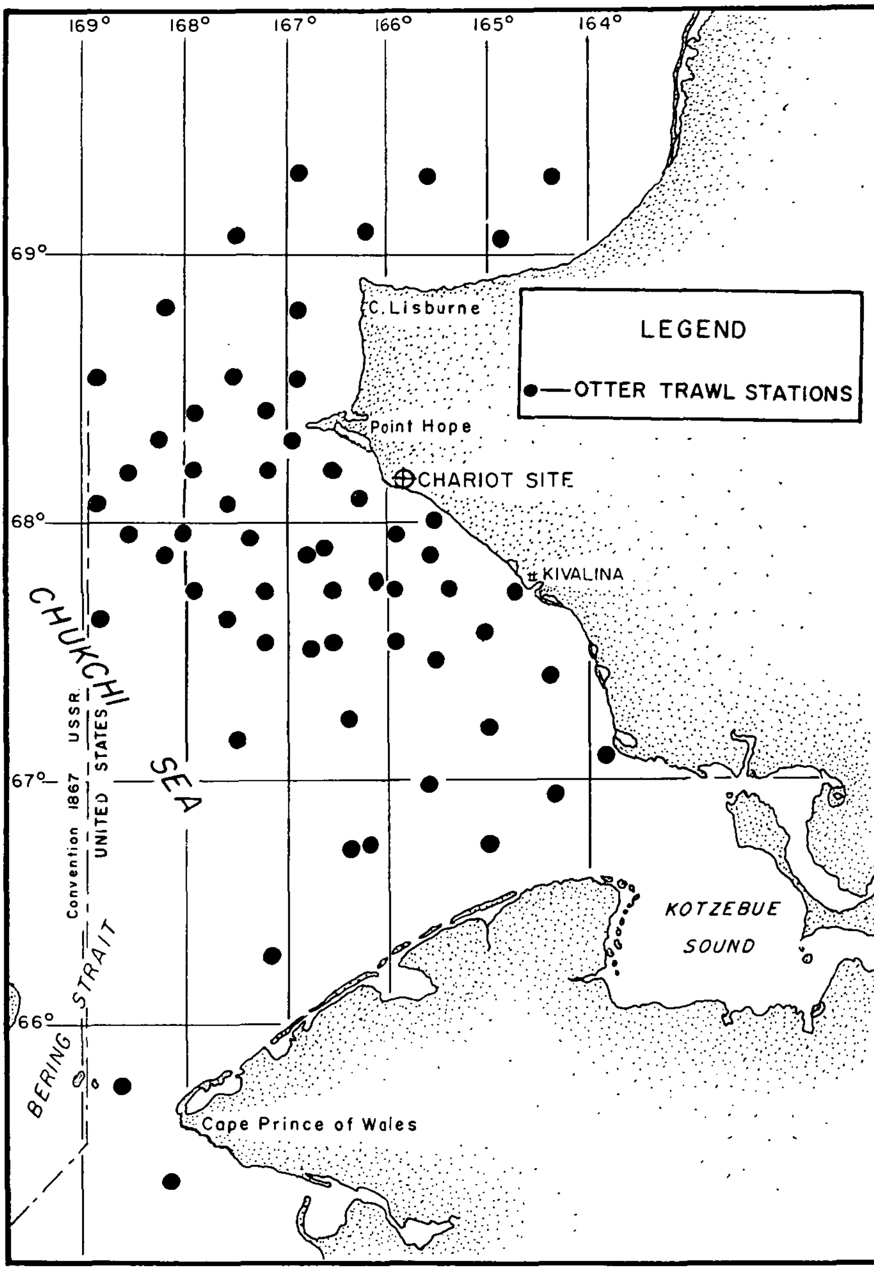

Figure 3. Location of otter trawl stations in the south-eastern Chukchi Sea.

Table 1

Number of pleuronectids taken in the south-eastern Chukchi Sea, August 1959

Species	Number captured
Hippoglossoides robustus (Gill and Townsend)	252
Limanda aspera (Pallas)	31
Pleuronectes quadrituberculatus (Pallas)	3
Liopsetta glacialis (Pallas)	1
Atheresthes stomias (Jordan and Gilbert)	1
Platichthys stellatus (Pallas)	1
	289

Table 2

Distribution of *Hippoglossoides robustus* by depth of capture in the south-eastern Chukchi Sea

(Original records in fms)

Depth range fathoms	Depth range metres	Number of ½-hour hauls	Number of fish caught
<10	<18	2	0
10–14	18–26	13	3
15–19	27–35	3	0
20–24	36–45	16	58
25–29	46–54	16	120
30–34	55–63	9	71
	Total	59	252

Table 3

Distribution of *Limanda aspera* by depth of capture in the south-eastern Chukchi Sea

(Original records in fms)

Depth range fathoms	Depth range metres	Number of ½-hour hauls	Number of fish taken
<10	<18	2	1
10–14	18–26	13	26
15–19	27–35	3	3
20–34	36–63	41	1
	Total	59	31

Table 4

Distribution of *Hippoglossoides robustus* and *Limanda aspera* according to bottom water temperature

(Original records in °F)

Temp. range °F	Temp. range °C	Number of hauls	Number of *H. robustus*	Number of *L. aspera*
35–36	1·4–2·5	2	12	0
37–38	2·6–3·6	12	106	1
39–40	3·7–4·7	12	54	0
41–42	4·8–5·8	17	71	3
43–44	5·9–6·9	6	0	2
45–46	7·0–8·1	6	5	24
47–48	8·2–9·2	4	4	1
	Total	59	252	31

during the expedition of the Soviet trawler "Krasnoarmeietz" in 1933 (ANDRIIASHEV, 1937). *Limanda aspera* is widespread in the North Pacific Ocean along Asia from the Chukchi Sea to south-eastern Korea and along the west coast of North America to Vancouver Island. *Platichthys stellatus* is reported from the Bering Sea south along the Asiatic coast to Tokyo Bay, and along the coast of North America to southern California. ANDRIIASHEV (1937) reports that *P. stellatus* is common in Kotzebue Sound. *Liopsetta glacialis* has a circumpolar distribution and occurs in the Bering Sea, throughout Arctic Alaskan waters, and off northern Europe.

Distribution of catches by depth

H. robustus was most frequently taken in waters over 44 m (24 fms) in depth between Kivalina and Cape Lisburne. A tabulation of catches of *H. robustus* according to sampling intensity by 5 fms (approximately 9 m) depth intervals is shown in Table 2. A test of the hypothesis that captures of specimens were directly proportional to fishing intensity regardless of depth yielded a chi-square value of 138·0 (5 d. f.) which, at the 1% level, is significantly different from the expected value. Although considerable variation occurred in numbers of *H. robustus* taken in each drag in deeper water over 44 m (24 fms), almost all such drags contained some fish. Thus, it appears that the noted greater abundance of *H. robustus* in deeper water is a characteristic feature of the distribution of this species and is not due to chance or division of sampling effort.

In contrast to the relatively deep distribution of *H. robustus*, *L. aspera* were predominantly found in shallow waters from 18·3 to 25·6 m (10–14 fms) contiguous to the Alaska coast (Table 3). A test of the hypothesis that captures of *L. aspera* were related to effort regardless of depth gave a chi-square value of 74·9 with 3 degrees of freedom. This value is significantly different from that expected at the 1% level. A majority of the drags made in depths of 25·6 m (14 fms) or less contained one or more *L. aspera*.

L. aspera and *H. robustus* were taken together at only one station and each appeared to occupy a different part of the available bathymetric range, *H. robustus* being confined to deeper waters whereas *L. aspera* were found in the shallower waters.

Distribution of catches by temperature

Observed bottom water temperatures ranged between 2·2°C and 8·9°C (36°–48°F). The numbers of *H. robustus* and *L. aspera* captured and the number of hauls made according to temperature intervals are shown in Table 4.

Most *H. robustus* were caught at the lower temperatures. This does not appear to be an artifact of greater sampling effort in waters of low temperature. A test of the hypothesis that captures of *H. robustus* and *L. aspera* were directly related to sampling intensity gave chi-square values of 112·1 and 89·4, respectively, with 6 degrees of freedom for *H. robustus* and 4 degrees of freedom for *L. aspera*. Both these values are significantly different at the 1% level from those expected. The preference of *H. robustus* for cold water is in accord with observations of MOISEEV (1953), who stated that the species density in far eastern waters is greater at subzero centigrade temperatures than at those above

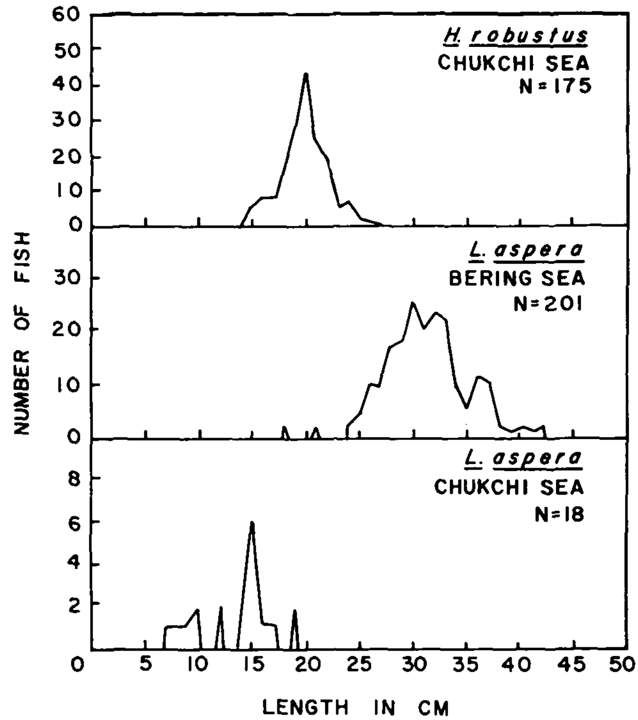

Figure 4. Length distributions of *Hippoglossoides robustus* and *Limanda aspera* (males and females combined) caught by M/V "John N. Cobb" in the south-eastern Chukchi Sea and the Bering Sea, August 1959.

zero. This would account for the greater abundance of *H. robustus* in the deeper (colder) waters of the Chukchi Sea. By contrast, *L. aspera* were generally taken in the warmer waters contiguous to the coastal areas.

Population densities and commercial potential

All of the flounders taken in the Chukchi Sea, with the exception of *Liopsetta glacialis*, are exploited commercially by trawlers in the Bering Sea. *L. aspera* occurs in large concentrations in the eastern Bering Sea south of Nunivak Island and is the major species taken in both the Japanese and Soviet trawl fisheries operating in this area. Moiseev (1953) states that *L. aspera* is the most common flounder of the far eastern waters and "in several regions large and dense concentrations exceed all other known accumulations of flounders in the oceans of the world".

Results of the survey by "John N. Cobb" indicate that the population density of flatfishes in the south-eastern Chukchi Sea during August 1960 was extremely low compared with regions where flounders are commercially exploited. The entire catch of 289 flounders taken during 59 hauls of 30-minute duration with a standard commercial trawl is estimated to have weighed less than 23 kg. *H. robustus*, the dominant flatfish taken, occurred at 36 stations, with a maximum catch of 30 individuals off Point Hope. *L. aspera*, the second most

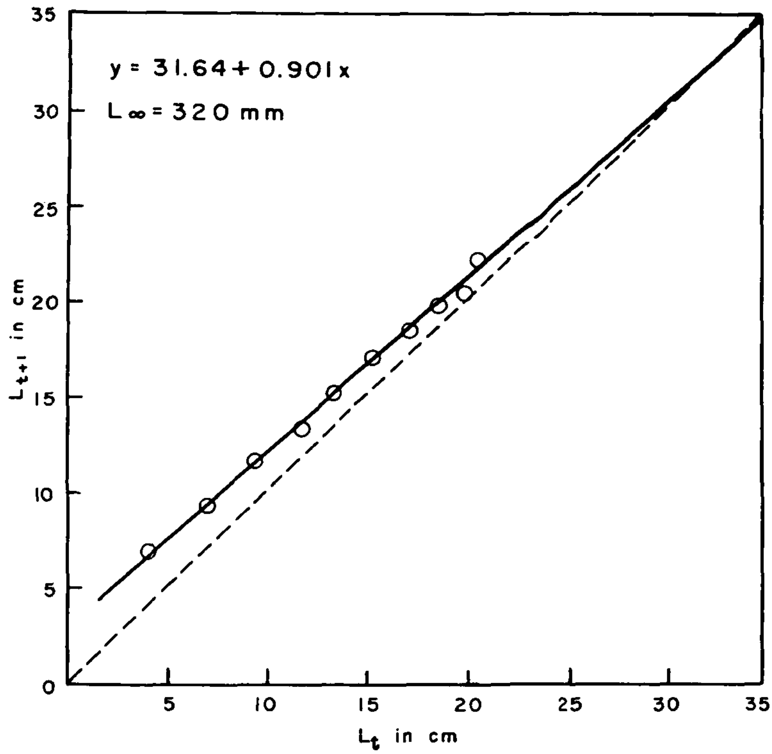

Figure 5. Relationship between L_t and L_{t+1} for female *Hippoglossoides robustus* from the south-eastern Chukchi Sea, where L_t is body length at age t, and L_{t+1} is body length at age $t + 1$. Regression line fitted to observed values shown as circles.

abundant flounder, was taken at 8 stations with a maximum catch of 18 also being taken in the general area off Point Hope.

The aggregate catch of all species of demersal fishes taken in the Chukchi Sea survey was estimated at less than 180 kg; the level of productivity for groundfishes, as compared with areas in which commercial trawl fisheries operate, was extremely low. If the sampling was representative, there is no likelihood that trawling could be profitably pursued in these far northern waters. There is, of course, the possibility that large numbers of groundfishes might migrate into the area from the Bering Sea during other seasons of the year; however, heavy ice that prevails during much of the year would preclude fishing operations during the autumn, winter, and spring.

Sizes of flounders

All of the flounders taken in the Chukchi Sea were smaller than accepted by markets in the States of Washington and Oregon (US). *H. robustus* ranged from 14 to 26 cm and averaged 19·9 cm in total length (Fig. 4). The next most abundant flounder, *L. aspera*, ranged from 7 to 19 cm and averaged 13·5 cm in length.

Both of the above species commonly attain much larger sizes in the Bering Sea. Ellson, Powell, and Hildebrand (1950) reported catching commercial-sized flathead sole (a mixture of *H. robustus* and the closely related species *H. elassodon*) of an average length exceeding 40 cm in several areas within the eastern Bering Sea. Much larger *L. aspera* than were caught in the Chukchi Sea were taken by "John N. Cobb" in the Bering Sea (Fig. 5). Over 76% of some 1,300 *L. aspera* measured from catches of "Oshoro Maru" in the Bering Sea in 1956 (Faculty of Fisheries, Hokkaido University, 1957) exceeded the length of the largest individual of this species taken by "John N. Cobb" in the Chukchi Sea.

Sex ratio

A striking characteristic of the *H. robustus* population sampled in the Chukchi Sea was the dominance of females. Out of a sample of 98 fish for which the sex was determined, 90 were females. The preponderance of female *H. robustus* cannot be explained by failure of the gear to adequately sample the smaller males; *L. aspera* of a smaller size than the smallest *H. robustus* were taken by the same gear. The prevalence of female *H. robustus* may reflect an ability of the female to better survive rigorous winter conditions in the Chukchi Sea than the males.

Most of the female *H. robustus* and *L. aspera* were mature. Examination of females showed the ova were well developed but discharge of ova was not possible by moderate external pressure. Most males contained milt which could be extruded by application of slight external pressure.

Age and growth

It cannot be determined from the limited samples whether or not the growth rings counted in the otoliths are formed annually. However, a measure of the clarity or readability of the otoliths is provided by the percentage agreement of the first and second readings.

The ages of 89 *H. robustus* examined from the Chukchi Sea ranged from 6 to 13 years. Ninety per cent of the *H. robustus* in the samples were 7, 8, and 9 year-olds. Eight year-olds were the dominant age-group, comprising 58% of the total. Identical ages were obtained for the first and second readings in 71% of the cases. Only 2% of the second readings differed by more than one year from the first readings, and none differed by more than three years.

For *L. aspera* the first and second readings were the same in 70% of the cases. The remaining 30% of the readings differed by one year.

The age-length relationship of *H. robustus* was investigated by three methods. The first method involved determining the mean length of each age-group in the samples.

The second method used the following formula to calculate the size of each fish at each year of its life.

$$\text{Length of fish at end of year X} = \frac{\begin{pmatrix}\text{Length of fish}\\ \text{at capture}\end{pmatrix}\begin{pmatrix}\text{Radius of otolith included}\\ \text{in annulus of year X}\end{pmatrix}}{\text{Total radius of otolith}}$$

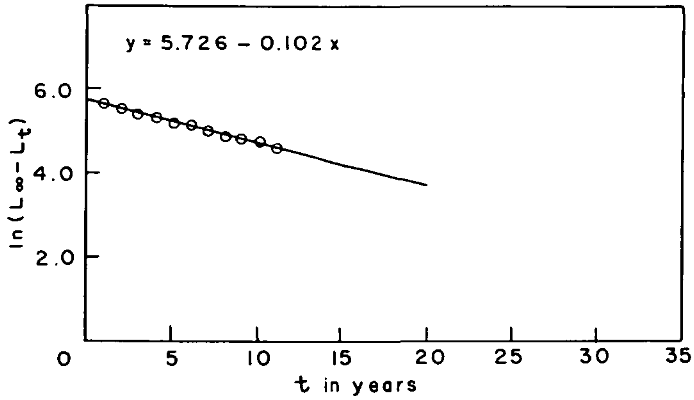

Figure 6. Relationship between t and ln (L_∞ − L_t) for female *Hippoglossoides robustus*, where t = age in years and ln (L_∞ − L_t) = the natural logarithm of the difference between the asymptotic age, L_∞, and the body length, L_t, at age t. Circles are observed values for ages (t) 1 through 11 years from which the regression line was calculated.

Calculation from the above formula of mean lengths at various ages was accomplished by determining a separate value for each fish, based upon the body length and otolith radius of that fish. A scatter diagram of body length versus otolith radius for female *H. robustus* indicated a general linear relationship between the two variables, although the intercept of the fitted regression line suggests that the otoliths are not formed until females reach a length of about 85 mm. A relatively wide scatter of the data and the unreasonable intercept value made it undesirable to use a single regression equation for all fish.

The third method utilized the Bertalanffy growth equation as outlined by BEVERTON (1954). This equation was applied to mean lengths of female *H. robustus* calculated from the body length/otolith radius relationship. Males were excluded due to their scarcity in the samples. The equation for the fitted Bertalanffy growth curve of length at age is

$$L_t = L_\infty [1 - e^{-k(t-t_0)}]$$

where L_t = length at age t
L_∞ = average asymptotic (maximum) length of fish
k = a constant
and t_0 = the hypothetical age at which the fish would have been zero length if it had always grown according to the Bertalanffy relationship.

Regression lines ($y = a + bx$) fitted to values of L_t and L_{t+1} and to values of t and ln ($L_\infty - L_t$), shown in Figures 5 and 6 respectively, yielded the following estimated Bertalanffy parameters for female *H. robustus*.

L_∞ = 320 millimetres
k = 0·10
t_0 = — 0·41 years

Table 5

Age and length relationship for female and male *Hippoglossoides robustus* from the south-eastern Chukchi Sea as determined from observed mean lengths of age-groups in samples, from mean lengths calculated by body length/otolith radius relationship, and from lengths determined by Bertalanffy growth equation

Body length in millimetres

Age	Females			Males	
	Observed	Body length/otolith radius relationship	Bertalanffy method	Observed	Body length/otolith radius relationship
1	–	40	44	–	40
2	–	69	71	–	65
3	–	94	96	–	86
4	–	116	118	–	107
5	–	135	138	–	120
6	179	152	156	148	136
7	187	170	172	155	149
8	194	185	187	169	164
9	211	198	200	–	173
10	206	205	212	–	180
11	226	222	222	–	185
12	–	–	232	–	191
13	–	–	241	205	200
14	–	–	249	–	–
15	–	–	256	–	–
16	–	–	262	–	–
17	–	–	268	–	–
18	–	–	273	–	–
19	–	–	277	–	–
20	–	–	282	–	–

Length at different ages as determined by the three methods of analysis are shown for *H. robustus* in Table 5. Observed lengths of the various age-groups sampled and lengths calculated for each age-group from the body length/otolith radius relationship are shown in Figure 7. The relatively large discrepancies between observed and calculated mean lengths for the younger age-groups probably are the result of the trawl net retaining the larger members of those age-groups. The smaller discrepancies between observed and calculated mean lengths of the older age-groups, which probably are less affected by net selectivity, can be attributed to the fact that the calculated lengths are those attained before the start of the growing season, whereas the observed lengths are those attained during the growing season.

As shown in Table 5, lengths at different ages calculated from the Bertalanffy growth equation correspond well with those determined from the body length/otolith radius relationship. The Bertalanffy growth analysis was used to provide estimates of lengths of *H. robustus* at ages 1 to 20 years.

All three methods indicate a slow rate of growth for female *H. robustus* and an even slower rate of growth for males. Whether or not *H. robustus* in the Bering Sea and other regions south of the Chukchi Sea have a similar slow rate of growth cannot be determined because of the lack of published data. According to MUSIENKO (1957) the young of *Hippoglossoides elassodon*, a species closely related to *H. robustus*, apparently grow more slowly in the northern part of the Okhotsk Sea and in the Bering Sea (Anadyr and Olyutorskii Gulfs) than off south Sakhalin and Kamchatka.

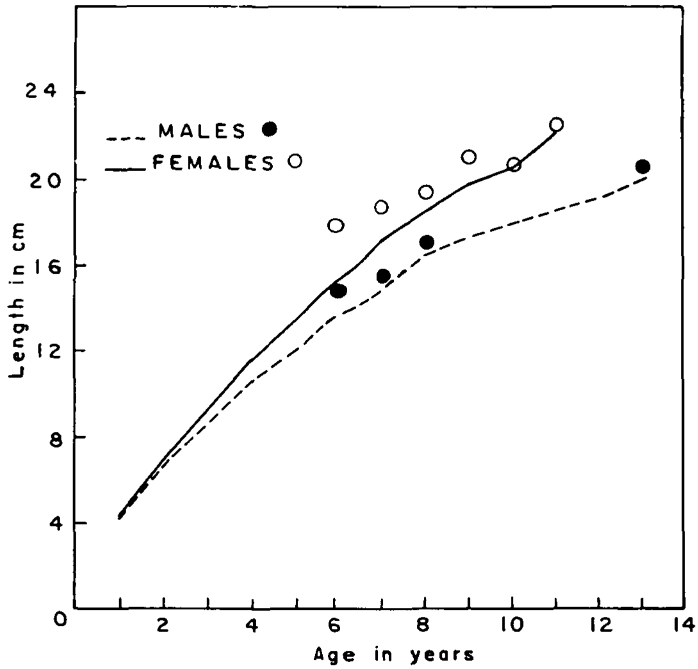

Figure 7. Age-length relationship of male and female *Hippoglossoides robustus* from the south-eastern Chukchi Sea determined from body length/otolith radius relationship (lines) and from observed values (circles).

ANDRIIASHEV (1937) reported that specimens of *H. robustus* ranging in length from 64 to 164 mm in the Soviet collection from the Chukchi Sea were all juveniles. Our samples of *H. robustus* from the Chukchi Sea were characterized by an absence of juveniles; most of the specimens examined were mature. They ranged from 144 to 255 mm in length and from 6 to 13 years in age.

Age-length distributions for *L. aspera* taken in the Bering Sea are shown in Table 6 and for the Chukchi Sea in Table 7. The lengths shown are means observed for each age-group in the samples. Because of the small number of specimens of *L. aspera* available, lengths were not calculated for this species from the body length/otolith radius relationship or from the Bertalanffy growth equation.

The fish from the Chukchi Sea were young, ranging in age from 1 to 6 years, compared with those from the Bering Sea which were from 7 to 13 years old. Based on the small samples, the age-length relationship does not appear dissimilar for the two areas (Fig. 8).

At first glance, the similar age-length relationship indicated for *L. aspera* taken in the Bering Sea and in the Chukchi Sea is difficult to reconcile with MOISEEV's (1946) observation that the growth-rate of this species is reduced in northern regions of rigorous hydrographical regimes. However, MOISEEV's samples were from Asian and Siberian waters where colder temperatures prevail. Also, it is possible that the *L. aspera* taken by "John N. Cobb" in the Chukchi Sea may have recently arrived there from regions to the south.

Table 6

Observed age and length distribution of female and male *Limanda aspera* from the Bering Sea

Body length in cm	Females 7	8	9	10	11	12	13	Total	Males 7	8	9	10	Total
	Indicated age in years												
15·1–16·0	1	–	–	–	–	–	–	1	–	–	–	–	–
16·1–17·0	–	–	–	–	–	–	–	–	–	–	–	–	–
17·1–18·0	–	–	–	–	–	–	–	–	–	–	–	–	–
18·1–19·0	–	–	–	–	–	–	–	–	–	–	–	–	–
19·1–20·0	–	–	–	–	–	–	–	–	1	–	–	–	1
20·1–21·0	1	–	–	–	–	–	–	1	–	–	–	–	–
21·1–22·0	–	–	–	–	–	–	–	–	–	–	–	–	–
22·1–23·0	–	–	–	–	–	–	–	–	–	–	–	–	–
23·1–24·0	1	–	–	–	–	–	–	1	–	–	–	–	–
24·1–25·0	–	–	–	–	–	–	–	–	–	–	–	–	–
25·1–26·0	–	–	–	–	–	–	–	–	–	–	–	1	1
26·1–27·0	–	–	–	–	–	–	–	–	–	–	–	–	–
27·1–28·0	–	–	1	–	–	–	–	1	–	–	–	–	–
28·1–29·0	–	–	–	1	–	–	–	1	–	–	–	–	–
29.1–30.0	–	–	–	1	1	1	–	3	–	–	–	–	–
30·1–31·0	–	–	–	–	–	–	–	–	–	–	–	–	–
31·1–32·0	–	–	–	–	–	–	–	–	–	–	–	–	–
32·1–33·0	–	–	–	–	–	–	–	–	–	–	–	–	–
33·1–34·0	–	–	–	–	–	–	–	–	–	–	–	–	–
34·1–35·0	–	–	–	–	–	–	–	–	–	–	–	–	–
35·1–36·0	–	–	–	–	–	1	–	1	–	–	–	–	–
36·1–37·0	–	–	–	–	–	–	–	–	–	–	–	–	–
37·1–38·0	–	–	–	–	–	–	1	1	–	–	–	–	–
Total	3	–	1	2	1	2	1	10	1	–	–	1	2

Table 7

Observed age and length distribution of female and male *Limanda aspera* from the south-eastern Chukchi Sea

Body length in cm	Females 1	2	3	4	5	6	Total	Males 1	2	3	4	5	6	Total
	Indicated age in years													
8·1– 9·0	1	–	–	–	–	–	1	–	–	–	–	–	–	–
9·1–10·0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
10·1–11·0	–	1	–	–	–	–	1	–	–	–	–	–	–	–
11·1–12·0	–	–	–	–	–	–	–	–	–	1	–	–	–	1
12·1–13·0	–	1	1	–	–	–	2	–	–	–	–	–	–	–
13·1–14·0	–	–	–	1	–	–	1	–	–	1	–	–	–	1
14·1–15·0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
15·1–16·0	–	–	–	1	–	–	1	–	–	–	–	–	–	–
16·1–17·0	–	–	–	–	–	1	1	–	–	–	1	–	–	1
17·1–18·0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
18·1–19·0	–	–	–	–	–	–	–	–	–	–	–	–	–	–
19·1–20·0	–	–	–	–	1	–	1	–	–	–	–	–	–	–
Total	1	2	1	2	1	1	8	–	–	2	1	–	–	3

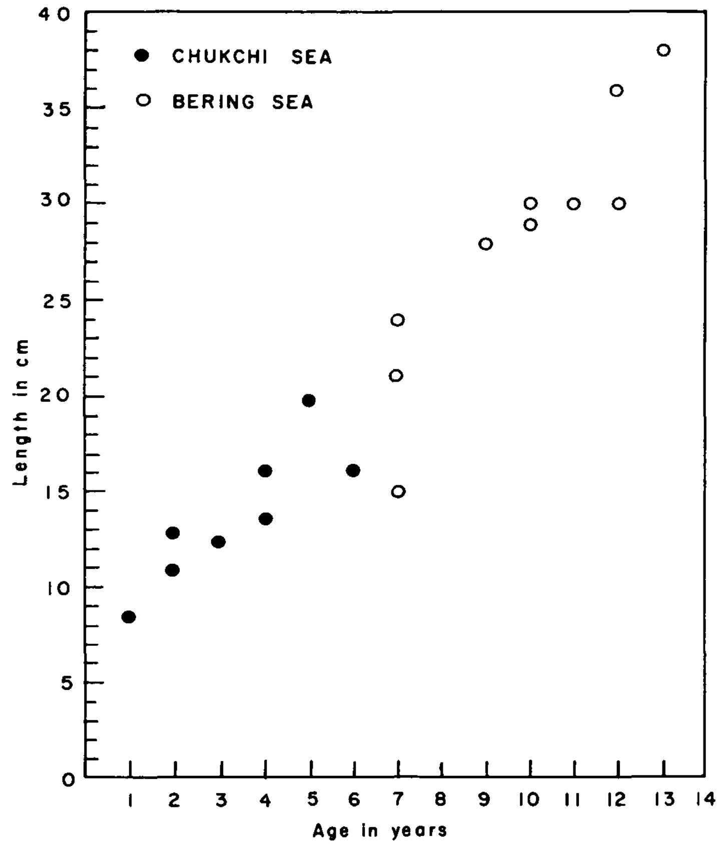

Figure 8. Age-length relationship for female *Limanda aspera* from the south-eastern Chukchi Sea and from the Bering Sea.

Discussion

Because of the paucity of published information on the Chukchi Sea, it is desirable to review some of its salient geographical and oceanographical features. So doing might shed light on the probable origin of its flounders and their occurrence at seasons of the year other than in summer, the time the samples were taken.

In the region explored, the Chukchi Sea occupies a shallow basin, having a maximum depth of about 62 m. Most of the region lies north of the Arctic Circle and is covered by ice for more than 7 months of the year. Because of the high latitude, there is a wide range in the seasonal amount of solar radiation received.

The summer hydrographic regime of the Chukchi Sea does not appear severe enough to account for the scarcity of flounders and slow growth of *H. robustus*, the dominant flounder taken there. Summer surface and subsurface temperatures are similar to those prevailing in the Bering Sea, several hundred kilometres to the south (LAFOND and PRITCHARD, 1952). Warm water apparently occurs near the east coast of the Chukchi Sea to greater depths than it does in the Bering Strait. With a possible exception near the northern coast of Norway, nowhere else in the world are waters of such relatively high temperatures carried poleward to as high latitudes (FLEMING and Staff, 1959).

Surface isotherms and isohalines are oriented generally south to north. While relatively warm, low salinity water is found at all depths on the Alaskan side of the Chukchi Sea in the summer, the offshore trend of isotherms suggests that lower temperatures exist off the Siberian coast opposite Seward Peninsula (LAFOND and PRITCHARD, 1952). In contrast to the relatively warm summer temperatures, bottom temperatures in the south-eastern Chukchi Sea during the long winter period of ice coverage approach freezing (about −1·6°C).

As shown in Figure 1, a strong current runs northward from the Bering Sea through Bering Strait and thence through the south-eastern Chukchi Sea. Current speeds averaging between 0·25 and 0·50 m/sec. have been reported in the eastern Chukchi Sea along the Alaskan coast during summer at all depths from the surface to within a few metres of the bottom (FLEMING and Staff, 1959). Because of these strong northerly currents many planktonic organisms, including the eggs, larvae, and young of some invertebrates and fishes, found in the Chukchi Sea probably originate in the Bering Sea. This northerly movement of water between the Bering Sea and the Chukchi Sea is in contrast to a reported southerly movement along the Siberian coast.

Food does not appear to be a limiting factor to the summer occurrence of flounders in the south-eastern Chukchi Sea, as large quantities of benthic invertebrates were taken by "John N. Cobb" through much of the region. The relative availability of food items during the winter months is largely unknown.

If *H. robustus* and *L. aspera* spawn in the eastern Chukchi Sea, the relatively fast flowing currents probably carry their pelagic eggs northward away from the spawning grounds into regions where conditions are unfavourable to their further development.

Based on a synthesis of known and inferred information, the following is advanced as our most cogent interpretation of factors governing the occurrence of *H. robustus* and *L. aspera* in the Chukchi Sea.

Spawning of both species in the south-eastern Chukchi Sea probably is relatively unsuccessful due to the prolonged harsh temperature regime and because the relatively fast-flowing currents would sweep the eggs and larvae northward into regions where perhaps even more severe conditions prevail. The addition of most recruits is therefore largely dependent upon the northward transport of eggs, larvae, and young fish into the Chukchi Sea by waters passing through the Bering Strait.

Most *L. aspera* would not survive the winter in the Chukchi Sea and probably are too small to migrate to the Bering Sea, the nearest region of suitable winter habitat. Consequently, of the few *L. aspera* present in the Chukchi Sea in the summer, most would arrive the same year from the Bering Sea. This would account for their scarcity and the fact that those taken in the Chukchi Sea were relatively young fish, none in our samples exceeding 6 years of age.

Since *H. robustus* commonly occurs in waters of a temperature of 0°C or below along the shores of Asia, at least some members of this species probably survive winter in the Chukchi Sea. The presence of fish as old as 13 years in our samples suggests that *H. robustus* are resident to the Chukchi Sea, although there is evidence to suggest that this is a fairly recent development. ANDRIIASHEV

(1937) stated that prior to 1933 *H. robustus* had not been found north of Bering Strait. He suggested that an observed noticeable increase in the warm current through Bering Strait in 1933 may have carried the eggs and even the pelagic larvae northward into the Chukchi Sea and remarked that future studies would show if this species is adapted to the Chukchi Sea or whether the young would migrate back south. This study suggests that the species is now resident in the Chukchi Sea.

The low density of *H. robustus* probably results from a high natural mortality, relatively unsuccessful spawning, or few recruits being carried into the Chukchi Sea. There remains the possibility that *H. robustus* has an inherent low population density throughout all areas of its occurrence.

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Summary

Six species of pleuronectids were caught by the US Bureau of Commercial Fisheries research vessel "John N. Cobb" in the south-eastern Chukchi Sea during exploratory fishing in August 1959. Two of the species, *Pleuronectes quadrituberculatus* and *Atheresthes stomias*, had not previously been found north of the Bering Strait.

All pleuronectids were characterized by a low abundance and small size. Growth of *Hippoglossoides robustus* and *Limanda aspera*, the two most numerous pleuronectids encountered, was found to be slow, with males growing even slower than females. Ages of these flounders were determined by counting the annular rings in their otoliths. A solution of papain, a plant enzyme, was found to be superior to conventional methods for cleaning and clearing the otoliths.

From an evaluation of oceanographic features of the region it appears that the presence of *Hippoglossoides robustus* and *Limanda aspera* in the south-eastern Chukchi Sea largely depends upon transport of eggs, larvae, and young fish into the Chukchi Sea by waters originating south of the Bering Strait.

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