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The age and growth of the yellowfin sole (*Limanda aspera*) in Hecate Strait, British Columbia

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I. INTRODUCTION

The yellowfin sole (Limanda aspera) is a common inhabitant of the colder regions of the North Pacific Ocean. Its centre of abundance appears to be in the eastern Bering Sea. There it has been heavily exploited by Japanese trawlers since 1954, and more recently by Soviet vessels. In 1961, the Bering Sea catch of yellowfin sole accounted for more than 55% of the world catch of flounders. Smaller populations also inhabit various other waters of the northeastern Pacific. One of these, and one which appears to be completely isolated from all others, is in Skidegate Inlet, Queen Charlotte Islands, B.C. (an inlet adjacent to Hecate Strait). This population is small and consists of such small fish that they appear only rarely and incidentally in catches of Canadian trawlers.

The geographical isolation of the Skidegate Inlet population has prompted a study of the age and growth of this species and a comparison has been made with results of studies conducted on other populations in colder, more northerly regions of the North Pacific. Because the species has been of little or no economic value to the Canadian fishery, efforts to collect data on the population have been sporadic and incidental to studies on a more important species which occurs in Skidegate Inlet. Accordingly, it is not to be expected that this report will provide a complete and conclusive analysis of age and growth. However, the results are sufficiently clear for general appraisal, and at the same time expose inadequacies in existing knowledge, which will require in future more thorough investigation.

II. GENERAL BIOLOGY OF THE SPECIES

According to Norman (1934), four species of the genus Limanda are found in the North Pacific Ocean.[1] All four of the species have been identified around Japan. In addition, two species possibly synonymous with Pseudopleuronectes herzensteini and P. yokohamae have also been recorded as Limanda near Japan (Abe, 1963). Only one species, L. aspera (Pallas), has been recorded from the North American side of the North Pacific Ocean.

In Asian waters, the southern limit of the yellowfin is the northeastern coast of Korea and the Hokkaido coast. Its range extends northward through the Sea of Japan to the Sea of Okhotsk and to the Bering Sea, with the northernmost record being from the adjoining Chukchi Sea. On the North

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[1] Pertseva-Ostroumova (1961) departs from tradition by considering L. sakhalinensis synonymous with L. aspera, and L. proboscidea as a northern subspecies of L. punctatissima.

American side, as has been mentioned already, the yellowfin sole is abundant in the southeastern Bering Sea. From Unimak Pass eastward along the southern shores of the western Alaska Peninsula the yellowfin sole is a common inhabitant of the shallower waters. In the Gulf of Alaska itself, however, the species occurs only sporadically and according to the results of surveys conducted by the International Pacific Halibut Commission (Anon, 1964), the most easterly occurrence of this species was encountered at about longitude 146°W (the survey covered the Gulf of Alaska from 135°W to Unimak Pass, 166°W long.). Alverson et al. (1964) reported no yellowfin sole present in the southeastern Alaska region. However, since their survey covered depths of only 50 fathoms (91 m) or deeper, the opportunities for capture of yellowfin were considerably reduced. It is presumed that occasional specimens are to be found in the shallower regions to the south of Southeastern Alaska but, aside from these scattered occurrences, the population occurring in Skidegate Inlet may well be the only self-supporting one eastwards of the Alaska Peninsula. The southernmost record of occurrence of this species along the North American coast is reported as Barkley Sound, British Columbia (Clemens and Wilby, 1962).

In contrast to the wide geographical distribution, the bathymetric distribution of the yellowfin sole is quite restricted. According to Fadeev (1963), yellowfin on the Bering Sea flats are abundant on the edge of the continental shelves between 150 and 250 m depth in winter, and in shallow water of 10 to 60 m in summer. In the Gulf of Alaska, they live in the shallower waters, at depths of 0 to 100 m (Alverson et al., 1964). In the Japan and Okhotsk seas, they are also reported by Japanese fishermen to be abundant in shallow waters.

Bering Sea yellowfin sole generally spawn in the summer months (Pertseva-Ostroumova, 1961). Almost all spawnings reported occurred between June and August, and showed a tendency to be earlier in the south and later in the north. The spawning season of the Hecate Strait population is unknown. It might be supposed, however, to occur in the spring because investigation notes on February 21 and 22, 1951, show that "all female yellowfin sole ranging from 24 to 35 cm in length are sexually mature with definite eggs". Further evidence to suggest a spring spawning will be presented later. Moiseev (1953), Fadeev (1963) and Pertseva-Ostroumova (1961) reported that the spawning groups concentrated in rather warm shallow zones.

Moiseev (1953) reported female yellowfin sole from Peter the Great Bay matured in their third or fourth year at lengths of about 20 to 23 cm. Fadeev (1963) reported on the age and length at maturity of yellowfin from the Bering Sea flats. Males were mature at ages from four to seven years (14 to 28 cm), and females from five to ten years (19 to 36 cm).

The growth curve of the yellowfin sole in Peter the Great Bay (Moiseev, 1953) is shown in Fig. 1. From the figure it is recognized that the female grows more rapidly than does the male, and that both sexes continue to grow at a fairly constant rate after reaching the age of maturity.

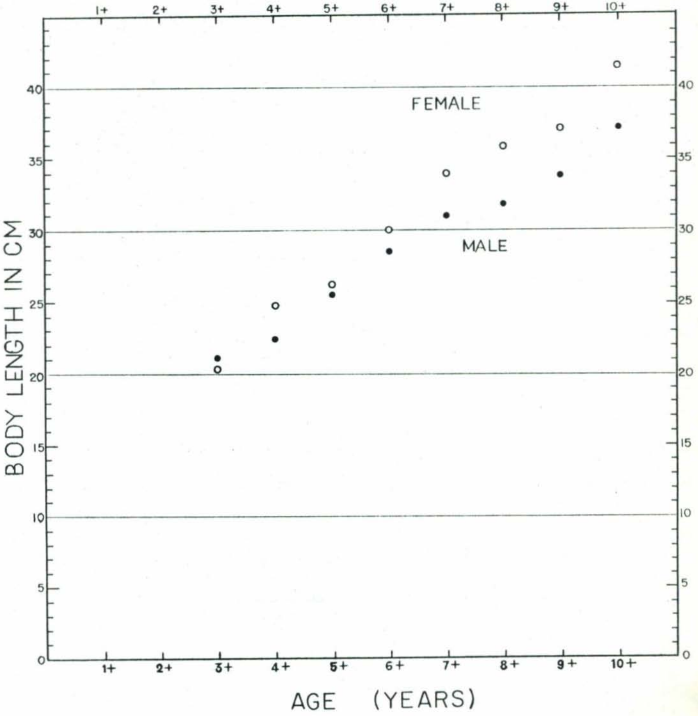

Fig. 1. Average length of yellowfin sole by age in Peter the Great Bay (Moiseev, 1953).

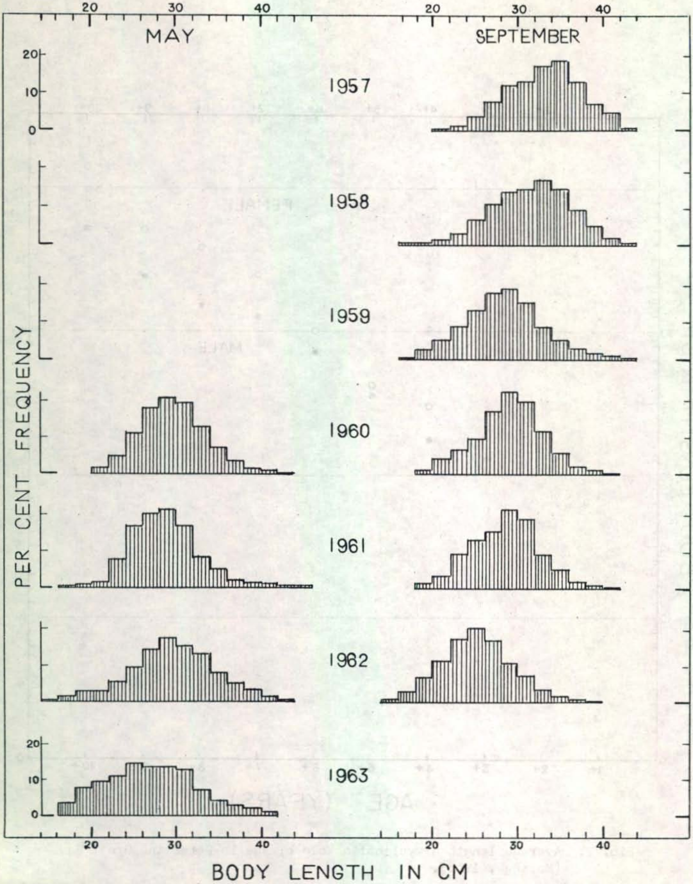

Fig. 2. Length-frequency distribution of yellowfin sole caught by the Japanese fishery on the Bering Sea Flats in May and September of successive years.

The length compositions of the yellowfin sole caught by the Japanese fleets on the Bering Sea flats during the years 1957-63 are given in Fig. 2. With reference to the September length composition, it should be noted that the modal size has decreased year by year. We might compare these length frequencies with the growth curve of Fig. 1. In the 1957 sampling, the mode consists of fish of about ten years of age (34-36 cm in length). In 1962, the mode consisted of five-year-olds (24-26 cm). In 1962, the oldest fish in the catch were about ten years of age.

III. MATERIALS AND METHODS

The date, location and size of samples used in this study are shown in Table I. Body length and sex were recorded for all individuals, and in one sample the state of maturity was noted. The body length, from the tip of the snout to the end of the caudal fin, is expressed in centimetres. Most otoliths (2745 in all) were taken from the blind side of the head, and were preserved and stored in 50% aqueous glycerin with the addition of thymol as an anti-fermentation agent. This method appears superior to that used in Japan, where otoliths are kept in dry condition for short periods of storing and in olive oil for longer periods. Otoliths were illuminated on a black background and read with the aid of a binocular microscope. The number of transparent zones was counted and the otolith radius along the longest axis was measured. In some samples, the radius of each annulus was measured from the focus to the outer margin of each transparent zone along the longest axis. To indicate the certainty of ring enumeration, the following arbitrary categories were introduced: 0, unreadable; 1, readable, but not certain; 2, certain. Data from these categories were selectively used in analyzing the results.

IV. RESULTS OF EXAMINATION OF OTOLITHS FROM SKIDEGATE INLET YELLOWFIN SOLE

(a) Relationship between otolith radius and body length.

A linear regression of otolith radius on body length for each sample shows a high correlation that varies little with month or year of sampling (Fig. 3, Table II). No transformation of measurements was considered necessary because the range of measurements was small and the original measurements of body length were approximate (to the nearest cm).

Otoliths of the eyed side are more elongate and thus have longer radii than otoliths from the blind side. Even among otoliths from the blind side, shape differences cause individual radii to vary to an appreciable degree. To reduce the effect of these variations when comparing otolith measurements, standardized otolith radii were calculated from the body length of that fish, using the following otolith radius-body length equations:

Table I. Materials used for age determination

Sample number	Year	Month	Date	Location	Sample size	Number of otoliths read
1	1945	March	1	Skidegate	111	108
2	1946	January	11-15	"	90	90
3	1946	January	18-26	"	286	249
4	1947	February	13	"	205	201
5	1947	February	19	"	64	64
6	1947	February	20	"	266	233
7	1947	February	22	"	508	460
8*	1951	February	21-22	"	227	197
9*	1958	August	18	"	250	223
10**	1961	February	13	Kitkatla	47	14
11	1963	August	9	Skidegate	129	129
12**	1964	August	24	Unimak	203	191
13	1966	February	28	Skidegate	359	347
Total					2745	2506

* Omitted from the study because of biased relationship between otolith radius and body length.

** Used as a comparison.

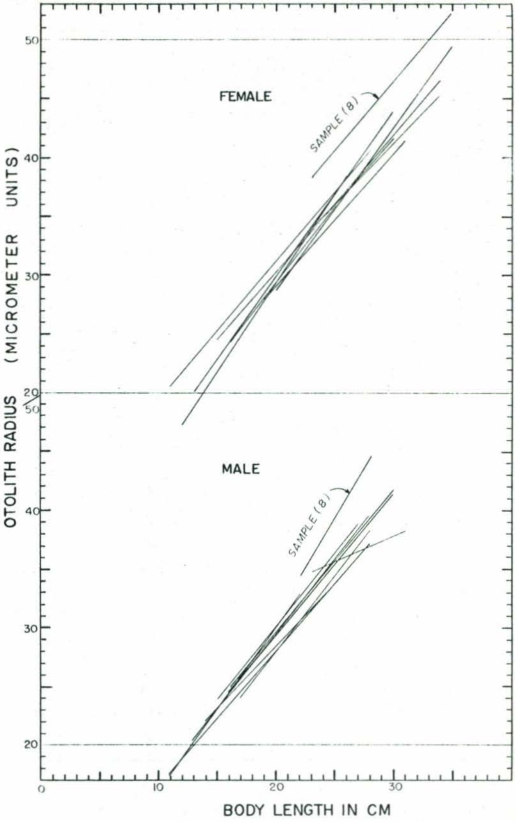

Fig. 3. Linear relations between otolith radius and body length by sample. Lengths of regression lines correspond to the sample ranges.

Table II. Coefficients of the relationships between otolith radius and body length

Sample number	Sex	Sample size	Mean body length	Mean otolith radius	Regression coefficient	Intercept	Correlation coefficient
1	Male	52	20.15	30.27	1.250	5.10	0.859
1	Female	59	22.37	33.27	1.405	1.84	0.888
2	Male	8	26.00	36.75	1.610	-5.00	0.972
2	Female	81	28.91	40.75	1.120	8.40	0.603
3	Male	42	26.67	36.36	0.453	24.28	0.236
3	Female	243	27.69	39.23	1.160	7.11	0.665
4	Male	8	28.63	38.13	1.800	-13.40	0.636
4	Female	198	29.37	40.60	0.979	11.85	0.470
5	Male	40	21.95	30.48	1.300	1.94	0.971
5	Female	24	24.00	33.54	1.115	6.78	0.911
6	Male	124	24.13	34.28	1.210	5.08	0.683
6	Female	139	26.33	37.61	1.372	1.49	0.881
7	Male	250	23.16	33.43	1.209	5.41	0.743
7	Female	255	24.85	35.78	1.307	3.30	0.867
8*	Male	7	23.86	37.57	1.705	-3.17	0.843
8*	Female	215	29.27	45.43	1.155	11.62	0.538
9*	Male	127	16.14	28.78	1.408	1.92	0.862
9*	Female	123	17.26	30.29	1.506	-0.76	0.914
10**	Male	33	29.67	39.03	0.594	21.50	0.509
10**	Female	14	32.21	43.43	1.377	-0.92	0.953
11	Male	59	17.42	25.59	1.078	6.81	0.884
11	Female	67	19.39	28.73	1.269	4.12	0.850
12**	Male	106	18.17	25.79	1.157	4.77	0.919
12**	Female	80	20.48	31.66	1.181	7.47	0.878
13	Male	181	20.51	29.78	1.275	3.63	0.829
13	Female	177	23.23	33.92	1.134	7.57	0.798

* Showing biased relationship.

** Sampled in locations other than Skidegate Inlet.

$$\text{Males} \quad - \quad y = 4.5 + 1.2x$$

$$\text{Females} \quad - \quad y = 6.5 + 1.2x$$

where y is otolith radius in micrometer units and x is body length in cm. These equations were derived from the total array of otolith radius-body length measurements. Each measurement of an otolith is standardized by application of the following coefficient:

$$\frac{\text{Standardized otolith radius}}{\text{Observed otolith radius}}$$

This coefficient is appropriate for that particular fish; therefore, if an otolith has grown in linear relationship with body length, the standardized annulus radius should be proportional to body length at time of annulus formation.

Samples 8 and 9 (see Table I) were omitted from the study because of a biased total otolith radius-body length relationship. No reason for the bias is known.

(b) Description of the annuli

1. Centre annulus

The region inside the first distinct annulus has an intermediate appearance between transparent and opaque; it is considered to be an opaque zone, but the opacity is not high. Hence, if any transparent zone occurs within the region it is difficult to discern. In some otoliths, however, a narrow transparent zone was actually observed in the inner region. These were recorded as a centre ring, the radius of which was measured in every case. The occurrence of various sizes of the centre ring are shown in Table III. Of all otoliths examined, 46% displayed the centre annulus. The radius of this annulus showed a rather clear unimodal distribution. Some centre annuli were quite narrow and obscure, and enumeration was thus quite subjective, unlike that for the subsequent annuli.

2. First annulus

The first annulus is the clearest annulus of an otolith. The main reason is that the opacity of the opaque zone outside the first annulus is usually very high. Frequency distributions of the standardized radii of the first annuli are shown in Fig. 4 by sample and number of annulus group. From this figure it is apparent that there is a trend to decreasing length of radii for the first annulus, with an increase in the number of annuli on the otolith, i.e., with age of fish. Some variation of the position of the modes within an age group is also evident. However, as will be seen later, the position of the first ring, while variable, does not overlap with that of any other ring.

Table III. Number of otoliths with centre ring and centre ring radius frequency.

Sample Number	Year	Month	Date	Number of otoliths read	Otoliths having centre ring		Centre ring radius (frequency)						
					Number	Percentage	2	3	4	5	6	7	8
1	1945	March	1	108	28	25.9	4	6	8	6	3	1	
2	1946	January	11-15	90	52	57.8	1	5	17	20	6	2	1
3	1946	January	18-26	249	126	50.6		3	28	52	29	14	
4	1947	February	13	201	120	59.7	2	4	23	43	32	13	3
5	1947	February	19	64	21	32.8			1	9	5	6	
6	1947	February	20	233	105	45.1		1	20	40	31	12	1
7	1947	February	22	460	216	47.0		4	23	73	72	39	5
11	1963	August	9	129	56	43.4	5	5	6	14	17	4	5
13	1966	February	28	347	133	38.3	10	26	44	40	11	2	
Total				1881	857	45.6							

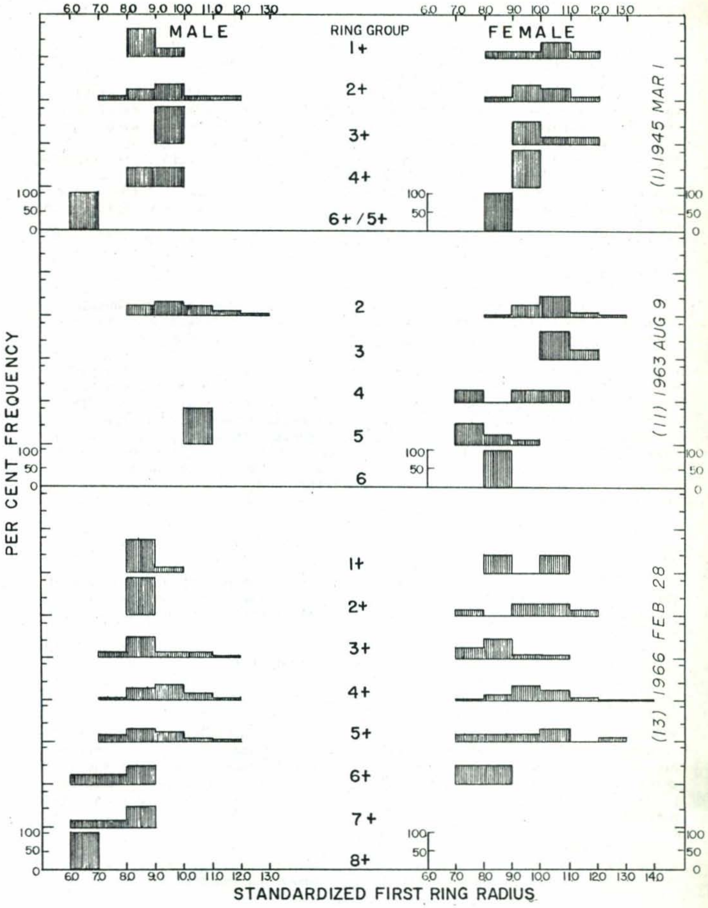

Fig. 4. Size and frequencies of first ring radius for various ages of yellowfin sole in samples (1), (11) and (13) (certainty 2 fish only).

3. Second annulus

Ths second annulus is not clear in its appearance and is less stable in its position than the first annulus. The second annulus may be overlooked when its transparency is low, and it is narrow in width. There is also a possibility in reading a false ring if the opaque zone outside the annulus is too weak. Actually, accessory rings occur often in this position. For example, certain fish sampled in summer (August 18, 1958 and August 9, 1963) after formation of the second annulus, displayed transparent margins. Although not demonstrated, many uncertain readings exist because of the difficulty in defining the second ring.

4. Subsequent annuli

There is no common characteristic attributable to subsequent annuli although on most otoliths clear annuli are observable. The width of the transparent zone compared to the opaque zone varies between individuals.

The frequency distributions of the radii of all annuli of category 2 otoliths for the same samples as in Fig. 4 are shown in Fig. 5 (the histograms for the first annuli are identical to the total frequencies in Fig. 4). The radii of the last annulus from all category 2 otoliths are shown in the frequency histograms of Fig. 6. The annulus radii, although they cover wide ranges, display mostly unimodal distribution, and the intervals between the modes decrease as the number of annuli increases. Samples for the later period (Nos. 11 and 13, taken in 1963 and 1966) show smaller radii for every annulus than those of the earlier period.

(c) Condition of the margin of the otolith

Observations on the seasonal changes in the character of the margin of the otolith are important to an estimation of the time of annulus formation. The problem has been investigated, utilizing the monthly samples. Two points were considered:

1. The ratio of individuals having transparent margins in a total sample, and
2. Amount of growth outside the last ring.

In the first instance, the counts and ratios of individuals having transparent margins are shown by sample in Table IV and Fig. 7. All otoliths of categories 1 and 2 are considered. Although the yearly changes cannot be determined because of the limitations of the samplings, it is likely that the proportion of transparent margins decreases from a maximum in January through March to a minimum in August.

In the second instance, the distance from the outer edge of the last transparent zone to the margin of the otolith along the longest axis - designated as marginal growth - has been measured and examined.

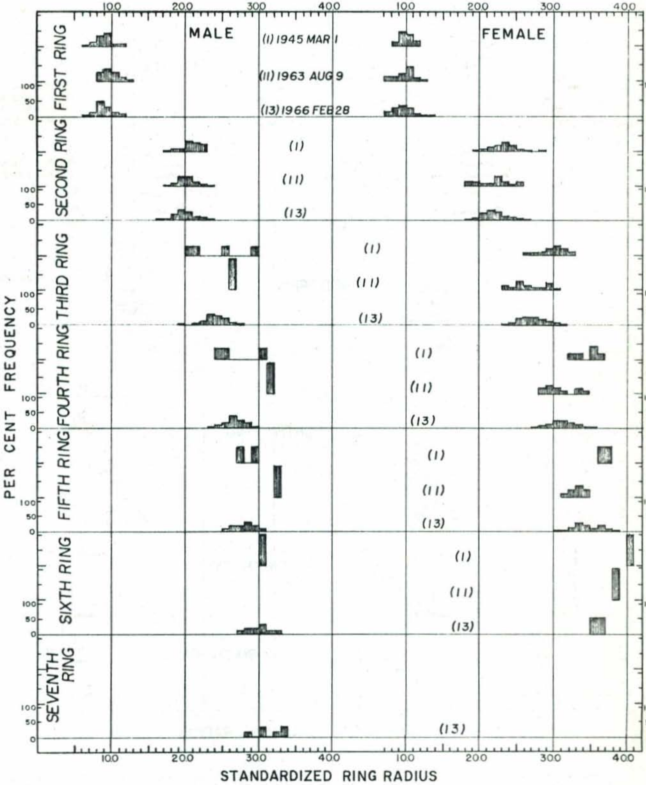

Fig. 5. Size and frequencies of ring radius at each ring by sex in samples (1), (11) and (13) (certainty 2 fish only).

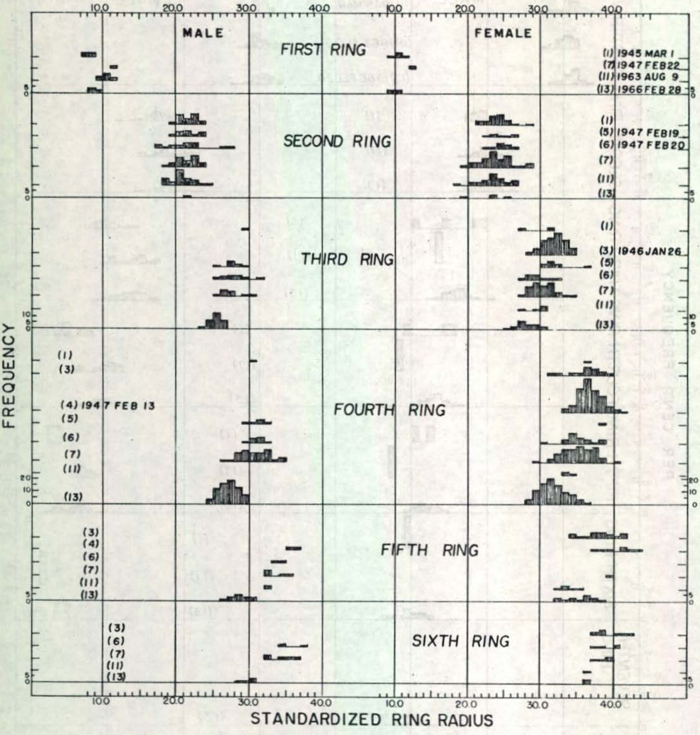

Fig. 6. Size and frequencies of last ring radius by sample, sex and ring group (certainty 2 fish only).

Table IV. Number and percentage of otoliths with transparent edge. (Fish of certainties 1 and 2).

Sample number	Year	Month	Date	Number of otoliths read	Otoliths with transparent edges	
					Number	Percentage
1	1945	March	1	108	97	89.8
2	1946	January	11-15	90	89	98.8
3	1946	January	18-26	249	244	98.0
4	1947	February	13	201	180	89.6
5	1947	February	19	64	55	85.8
6	1947	February	20	233	180	77.3
7	1947	February	22	460	399	86.7
11	1963	August	9	129	13*	10.1
13	1966	February	28	347	329	94.8

* Those which are considered to be "false transparent" are omitted.

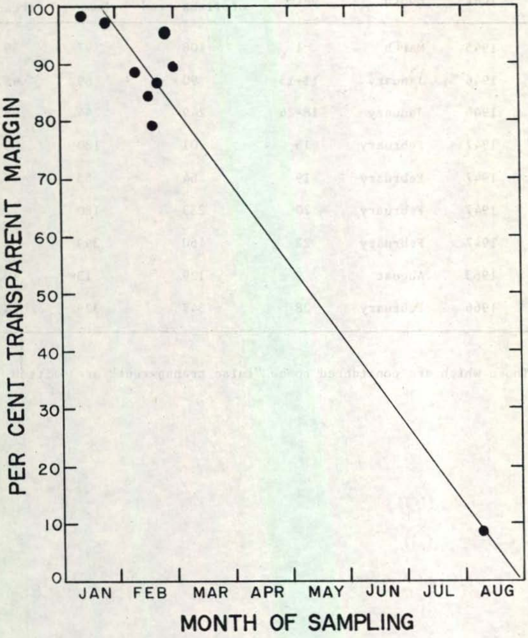

Fig. 7. Seasonal change in percentage transparent margin in otolith samples.

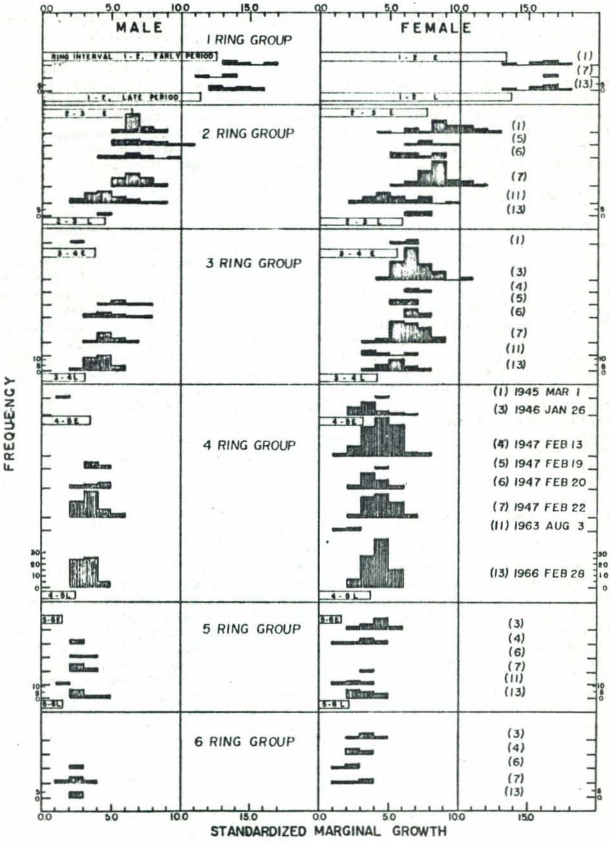

Fig. 8. Frequency distributions of marginal growth of the otoliths by sample, sex and ring group, compared with corresponding ring intervals. -- Early period: 1945-1947 (sample 1-7). Late period: 1963-1966 (11-13).

Figure 8 shows the frequency distribution of the standardized marginal growth of otoliths which belong to category 2; these samples are limited to those having transparent margins in winter samples and opaque margins in summer samples. In Fig. 8 the marginal growth is compared with the annulus interval, calculated from average annulus radii in Fig. 6. The marginal growth in summer samples is about one half the annulus interval; in the winter samples the marginal growth is about the same size or greater than the interval. During the period January through March, an increase in marginal growth was not evident, probably because the samplings extended over several years and because growth is reduced during these months. Here again, the marginal growth in the later period samples (numbers 11 and 13) is less than that recorded for the early period samples.

As noted above, otoliths having opaque margins in winter samples and those having transparent margins in summer samples are omitted from Fig. 8. The frequency distribution of the extent of marginal growth of these anomalous individuals belonging to categories 1 and 2 are shown in Fig. 9. All anomalous individuals in the winter samples in Fig. 9 show much less marginal growth than those in Fig. 8. This fact means that these individuals deposited the transparent zones later than did the normal individuals. An investigator noted on February 28, 1945 (records at Biological Station, Nanaimo, B.C.) "Good examples of second year just completed and white checks are beginning to show in the winter growth already." On the other hand, the anomalous individuals in the summer samples (#11) showed much greater growth prior to the clear margin than do the normal individuals in Fig. 9. From this fact, we can speculate that these anomalous individuals were late in deposition of the transparent zones. Further, these individuals which were classified as age 1+ had the same body-length and total otolith radii as individuals with two annuli.

(d) Size composition by number of annuli

Figure 10 shows the size composition of Hecate Strait yellowfin sole by sample. There is a marked variation among samples which might result from changes in fishing time and area, mesh size, or the condition of sampling. While the actual reason is unknown, the mesh size is presumably most responsible. Comparing the size composition of the fish in Fig. 10 with that shown for Bering Sea fish in Fig. 2, fish from Skidegate Inlet have a similar size composition to that of yellowfin sole from the Bering Sea flats after some years of exploitation. Size composition by sampling year, sex, number of annuli and by "certainty category" is presented in Figure 11. The anomalous individuals were assigned to appropriate age groups and are included in the figure. The distributions are mainly unimodal and few differences in mode between category 1 and category 2 otoliths are evident.

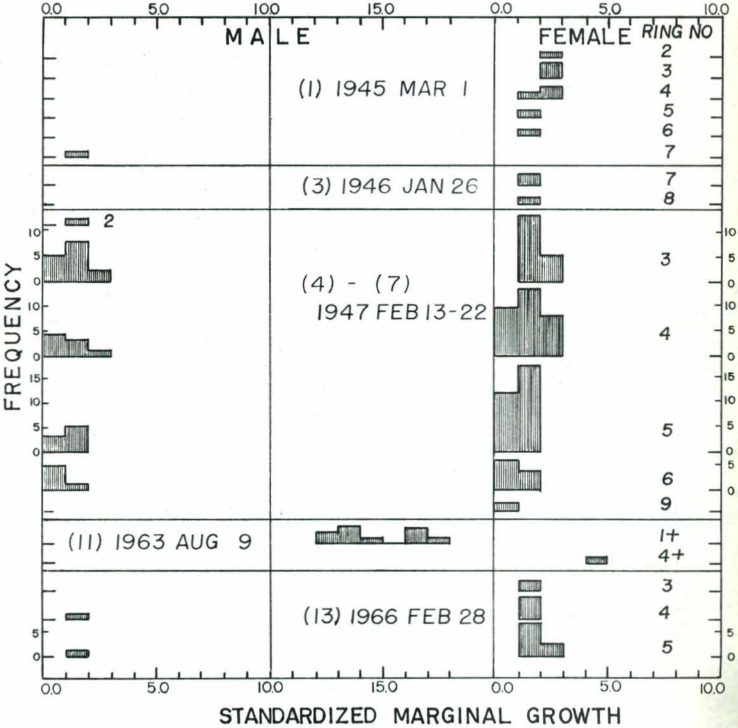

Fig. 9. Frequency distributions of marginal growth of otoliths of anomalous individuals by year, sex and ring group.

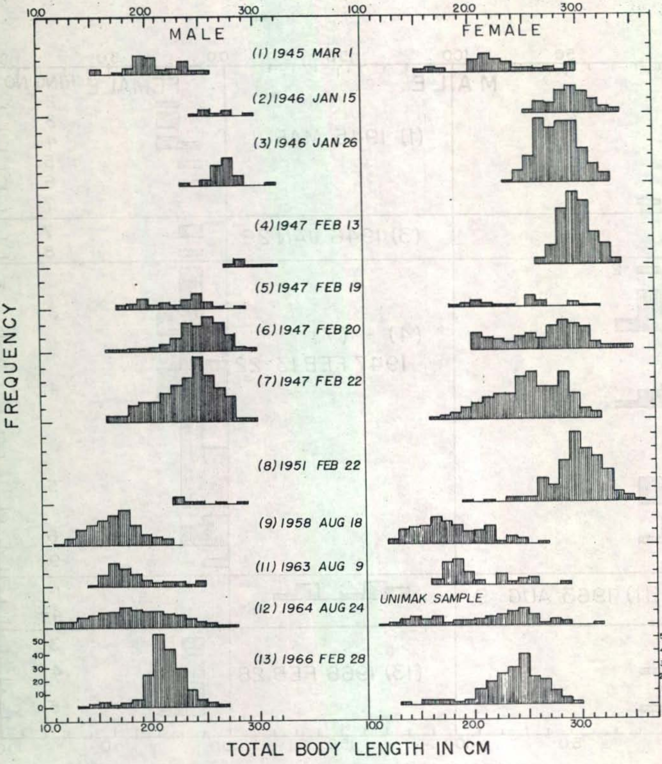

Fig. 10. Sample size compositions by sex. See Table I for detail.

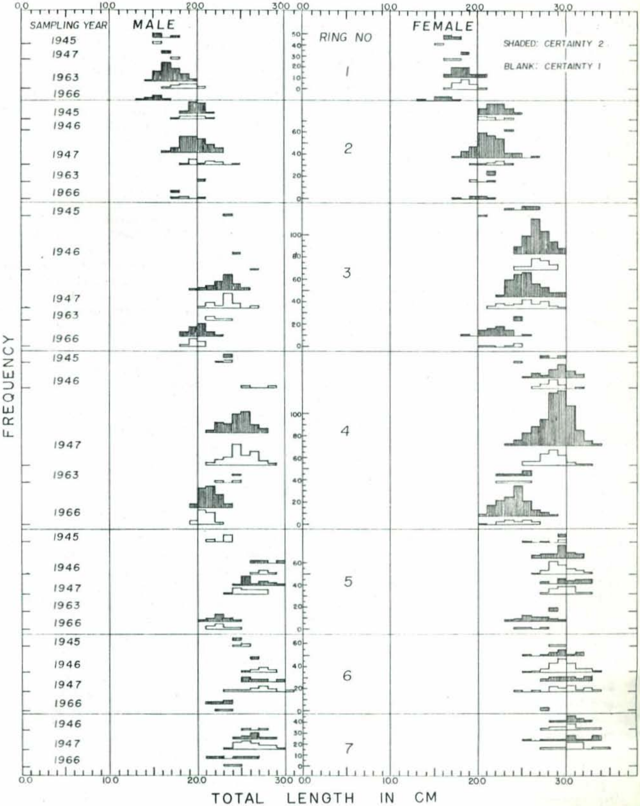

Fig. 11. Size compositions by year, sex, number of ring and certainty category of reading.

V. DISCUSSION

A. Age determination

The position of annuli (except the centre annuli) in the otoliths of category 2 appear relatively stable (Fig. 5 and 6). As seen in Fig. 6, the frequency distribution of standardized annulus radius by annulus group in the samples are generally unimodal, but the stability of the distributions becomes less as the ring number increases. Between early and late samples, significant difference in radii appears for all annuli; this is discussed below.

As shown in Fig. 7, more than 90% of the otolith margins are transparent in winter and opaque in summer. Such otoliths are considered normal. This suggests that the transparent zone is formed in winter and that the marginal growth takes place after that time and up to the next winter when another transparent zone is formed. Marginal growth of some anomalous individuals in the samples examined was much less in winter samples and much greater in summer samples than those of normal individuals (compare Fig. 8 and 9). It is considered that deposition of the transparent zones in the anomalous individuals took place early in the winter samples and late in the summer samples.

False transparent margins occurring in August samples (#9 and 11) are limited to the second annulus group; they are distinguishable from a true annulus because of their variable condition and because the ring is narrow.

From the above facts, the writer considers annuli are deposited annually in Skidegate Inlet yellowfin sole. A number of studies on the age determination of fish using their otoliths have reported that the transparent zone in otoliths was formed once a year in wintertime; rough scaled sole (Ishida et al., 1952), Pacific sardine (Sato and Kaga, 1952), Pacific pollock (Ishida, 1954) and Kurogashira flounder (Morita and Ohara, 1965).

The annulus intervals plotted in Fig. 8 (calculated from the averages of the annulus radii in Fig. 6) are greater than the distances from the centre of the otolith (focus) to the first ring as shown in Fig. 4. Such large intervals are considered to be too great for the first year growth of the yellowfin sole which are believed to be hatched in spring (Section II) and therefore might be expected to show little growth in the first year of life. It is probable, therefore, that the centre annulus described in Section IV (b.1) corresponds to the first annulus (observed in 46% of the otoliths) and it has been formed when the otoliths are at an early stage of development. This hypothesis is supported by a comparison of centre annulus radii between Skidegate Inlet yellowfin sole and specimens from the Unimak region in the western Gulf of Alaska. Unimak sole have smaller radii, spawn in the summer, and have a shorter "first year" life (Section V.b below). We might assume, then, the first and subsequent annuli of the Skidegate Inlet yellowfin actually represent the second and subsequent annuli in the life of the fish.

Regarding the "certainty category", the differentiation is somewhat subjective, and varies according to the conditions in which the otoliths are preserved. However, Fig. 11 does not suggest any appreciable difference in size composition by age between "certainty categories". The readings of category 1 otoliths (readable but uncertain) are considered to be useful for some purposes. Category 1 otoliths appear more frequently as older fish are encountered in the samples. Similarly, the proportion of "category 0" otoliths (unreadable) increases as the size of fish increases. Figure 12 shows the proportion of "category 0" otoliths in each size class compared to the total length frequency distribution. In analysis of age composition, this trend should be carefully considered. The proportion of "category 0" readings is higher for males than for females.

B. Growth

The growth curves of Skidegate Inlet yellowfin sole, based on average body length and utilizing category 2 readings, are shown in Fig. 13. Average lengths were calculated for age groups in which five or more fish were available. Two time-periods were considered -- 1945-47 and 1963-66. The lengths are plotted at mid-year intervals for the samples taken in winter because of the belief that hatching occurs in late spring or early summer. The average length at each age is indicated by the point in the figure.

From the growth curve of the Skidegate Inlet yellowfin sole during the early summer (1945-47 in Fig. 13) it is evident that there is a difference in growth between sexes which begins to be evident at 2.5 years of age and increases with age. In the early sampling period, fish of both sexes show retardation of growth at about 6.5 years of age (length 30 cm for females and 26 cm for males). The growth curve for the late sampling period (1963-66 in Fig. 13) indicates a slower growth rate than indicated in the early samples -- about 1 cm less at 2.5 years and about 4 cm less at 6.5 years for both sexes.

Let us compare our results with the growth curve of the Peter the Great yellowfin sole as estimated by Moisseev (1953) as shown in Fig. 1. The average lengths at 2.5 years of age are 16 cm for the females and 15 cm for males, an intermediate size between the early and the late sampling period for Hecate Strait. The values at 6.5 years of age are close to those in the early sampling period (Fig. 13). Moiseev's growth curves show the steady increase at about 2.5 cm per year at ages greater than 6.5 years, which differs greatly from the Hecate Strait or Skidegate Inlet growth curves. However, yellowfin sole in Peter the Great Bay have the fastest growth rate of all populations examined in far eastern waters, according to Moiseev (1953) and Fadeev (1965). Fadeev (1965) reported the difference of 6.2 cm in body length at 6.5 years of age (and more at older ages) between samples from Peter the Great Bay and the Unimak region of the Gulf of Alaska (sexes mixed; data not usable for determining growth rates of the two sexes). Further, a Walford plot applied to Moiseev's data shows a straight line of slope 1.0 for both sexes and this suggests too rapid growth at higher ages.

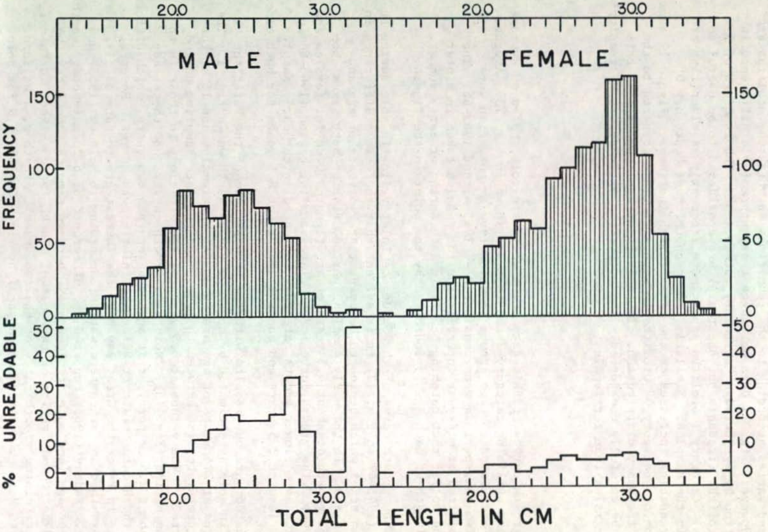

Fig. 12. Total sample size composition and percentage of unreadable otoliths by size class.

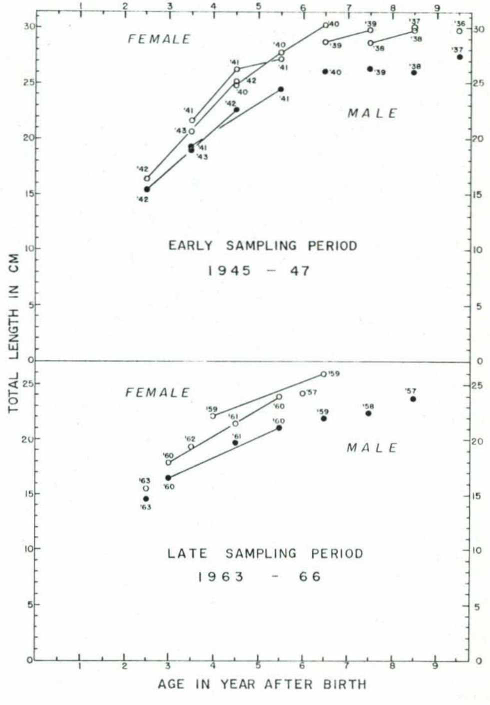

Fig. 13. Average body length at each age by sampling period, sex and brood year class. Females shown by open circles, males by solid circles.

Can we conclude that the growth rate decreases from the early period to the late period? As noted above, the samples in the late period (#11 and 13) have shorter annulus radii, are smaller at any given age, and show less marginal growth on the otolith than do those in the early period. This information supports the conclusion of a decrease in growth to some degree. However, the otoliths sampled in the early period (almost 20 years ago) may have become unreadable (annuli indistinguishable). These errors would lead to the erroneous discovery of a greater growth rate. The writer, after noting the large difference in growth rate between the two periods, carefully read all otoliths again but could not find any noticeable checks which would constitute a 'loss' of annulus. Of course, the sampling variation shown in the length distributions of Fig. 10 is also of importance to the conclusions. The later samples were obtained by small-mesh shrimp trawls and the smaller fish were selected. The differences in growth between year classes of one or two centimetres observed in Fig. 13 are considered to be normal fluctuations. Figure 13 shows rather smooth growth curves approaching an asymptote. An identical phenomenon is created by the uniformly decreasing annulus radii intervals shown in Fig. 5 and 6. All these data, however, are treated in the aggregate (not individually) and may not necessarily reflect individual growth patterns. In the process of otolith reading, sudden decreases in the intervals between certain annuli were observed in a number of individuals. These phenomena might be related to the physiological changes in the fish at maturity. However, lack of information on specific fish does not allow further analysis. In addition, the relatively few observations for older fish prevents a critical examination of possible inflections in the growth curve.

From the early sampling data for each sex, a Walford line was constructed, with L_{x+1} plotted against L_x, where L_x is the length at age x and L_{x+1} is the length at age x+1 (Fig. 14). Regression equations obtained by least squares estimation are as follows:

$$\text{Males:} \quad L_{x+1} = 8.59+0.697L_x$$

$$\text{Females:} \quad L_{x+1} = 11.14+0.642L_x$$

Therefore, in terms of von Bertalanffy's expression: $L_x = L_\infty(1-e^{-K(x-x_0)})$, it is found that K, the growth coefficient, is 0.360 for males and 0.443 for females. The calculated asymptotic length (L_∞) is 28.4 cm for the males and 31.1 cm for the females.

Let us now consider the variation of the first annulus radius. The standardized annulus radii may be considered to be proportional to body length at 2.5 years of age. As seen in Fig. 4, the 4+ age group (5.5 years after birth) of both sexes have the largest first annulus radii in the age group of sample #13. This suggests that there are yearly fluctuations in the deposition of the first-year annulus, i.e., variations in annual growth. Figure 4 shows that with the exception of the 4+ group, the older fish show smaller first annulus radius. It does not seem likely that the first-year annulus radius decreases as the otolith grows. Two other explanations follow:

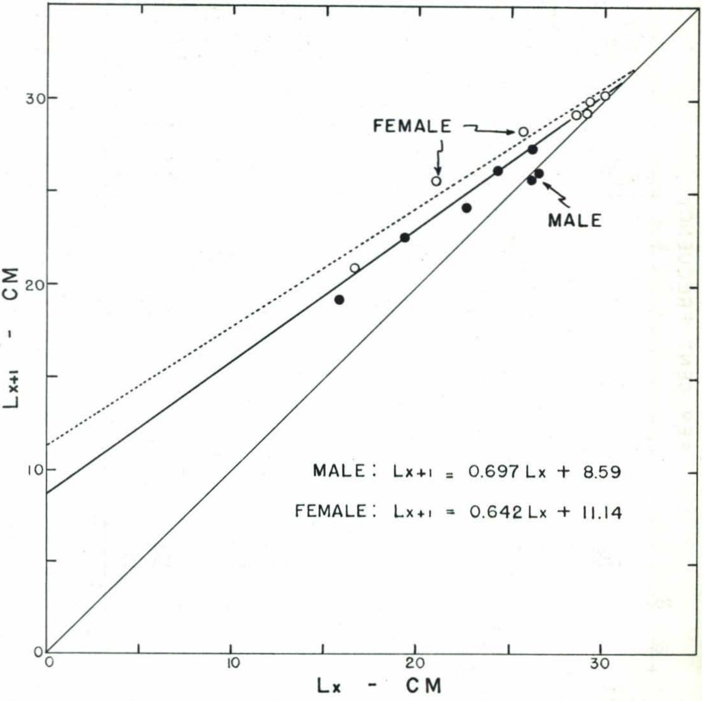

Fig. 14. Walford's finite differences diagram for body length of the Hecate Strait yellowfin sole during 1945 and 1947 sampling years.

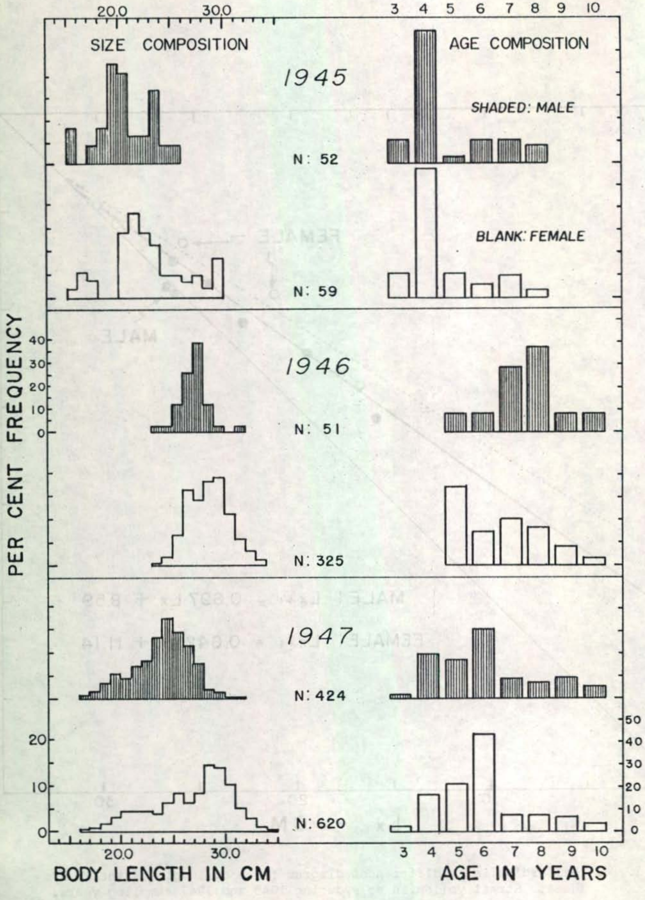

Fig. 15. Size and age compositions by year and sex in the early Hecate Strait yellowfin sole samples.

1. It may be assumed that for 1+ fish (2.5 years old) and for 2+ fish to a somewhat less extent, that the larger fish are more frequently taken in the sampling processes than the smaller ones. This may explain the larger first year annulus for the younger fish.

2. The fact that the older fish in samples show small first annulus radii suggests that the small fish mature later and survive longer. In populations which are lightly exploited, such as Skidegate Inlet yellowfin sole, the slower growing individuals of the stock may have a lower natural mortality rate.

These two assumptions are quite arbitrary and there is no documented support. They suggest some problems for future exploration and point out problems of representative sampling.

C. Age composition

It is now possible to estimate the age composition of the samples. However, the age composition may not be representative when we consider the sampling variation as indicated by the length frequency distribution in Fig. 10. Interesting information on fluctuations in abundance of each brood year may be obtained from the early samples (1945-47).

The 1945-47 size and age compositions by sex are shown in Fig. 15. The size composition material includes all individuals, but the age composition data use only category 1 and category 2 individuals. The 1941 year class is dominant, except for males in 1946. Males sampled in 1946 were unusually large fish, and may not have constituted a representative sample from the population. The 1940 year class appears less abundant than its predecessor through the three sampling years. While sampling variation makes it impossible to evaluate the absolute magnitude of the year classes, there do appear to be significant fluctuations in brood years. The presence of a dominant year class through three consecutive sampling years gives some support to the reliability of the otolith readings.

D. Comparison with the Unimak sample

Yellowfin sole captured near Unimak Island, Alaska, were sampled on board the research vessel G.B. Reed during the summer of 1964. Length, sex, maturity and age determination material have been preserved at the Nanaimo Station. The writer has attempted to compare the characters and measurements of the otoliths of yellowfin sole from Skidegate Inlet with those from the Unimak area in order to support some of the assumptions involved in otolith reading. The methods employed in an examination of Skidegate Inlet samples were applied to the Unimak area samples. The Unimak samples consisted of 138 fish caught around Unga and Shumigan Islands on August 9, 1964, and of 67 fish captured near Unimak Island on August 16, 1964. While the relationship between these two groups is not known, the writer combined them for the purpose of comparison with the Skidegate samples.

In the waters around these islands, the yellowfin sole are presumed to be part of the southern distribution of the main population of the southeastern Bering Sea, but no accurate information exists to support this hypothesis.

Length frequency distribution of the sample is shown in Fig. 10. It does not differ markedly from the late period samples from Skidegate Inlet. Compared with the length distribution of Japanese catches in the Bering Sea flats (Fig. 2), however, it is clear that the sample consists of quite small fish. Two factors may account for this:

1. Mesh selection, and

2. Migration of large mature fish to other regions for spawning.

As seen in Table II, the Unimak samples do not differ in otolith radius and body length relationship from those of Skidegate Inlet samples, therefore the same equation is used to standardize otolith measurements for the Unimak sample.

With the exception of the centre annulus, the shape of the otolith and the appearance of the annuli under the microscope are not different from those from Skidegate Inlet. The centre annulus is wider and clearer than in the Skidegate Inlet sample; but there is little difference in the first and subsequent annuli. Only three of 192 otoliths in categories 1 and 2 from the Unimak sample lacked the centre annulus. In categories 1 and 2 Skidegate Inlet otoliths, 1024 of the 1881 otoliths lacked the centre annulus.

Frequency distributions of the centre annulus radius of otoliths from the Unimak area and Skidegate Inlet are compared in Fig. 16. Both sexes are combined as there is apparently no difference by sex with respect to annulus radii. Skidegate Inlet samples are separated by time to check temporal variations. For the early Skidegate Inlet samples, the average centre annulus radius was 5.3 units; for late samples, 4.5 units; and for the Unimak samples, 3.0 units. The radius of the centre annulus may be considered to reflect the length of time from hatching to first winter, and thus the difference in radii corresponds to the difference in spawning time between the two areas (on the assumption that growth in each area is the same). Yellowfin sole in the southeastern Bering Sea spawn during June through August (Fadeev, 1965), therefore Skidegate Inlet yellowfin sole probably spawn some time earlier than do Bering Sea sole. The observations above support the conclusion that the centre ring corresponds to the first annulus in the Skidegate Inlet population (as mentioned in Section V(a)). There is considerable difference in the average centre annulus radius between the early and late Skidegate Inlet samples; the radius is shorter in the late samples, as is the case with subsequent annuli. However, no further consideration about the difference is possible.

The frequency distribution of the standardized annulus radius for each annulus of category 2 otoliths from the Unimak sample is shown in Fig. 17 (same method of presentation as in Fig. 5). The frequency distribution of the

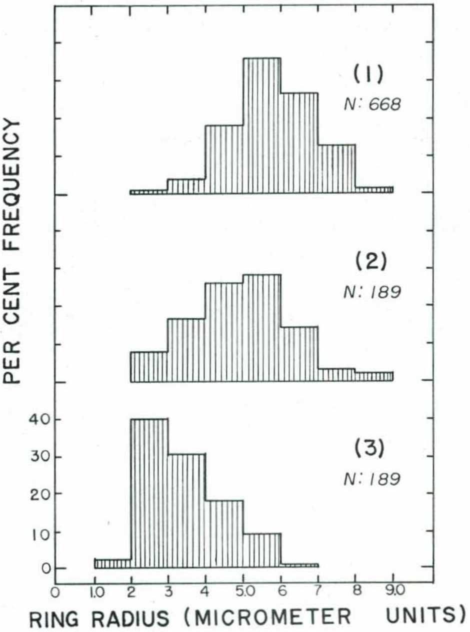

Fig. 16. Frequency distributions of center ring radius in three sample groups, both sexes and both certainty categories 1 and 2 included: (1) early Hecate Strait samples; (2) late Hecate Strait samples; and (3) Unimak samples.

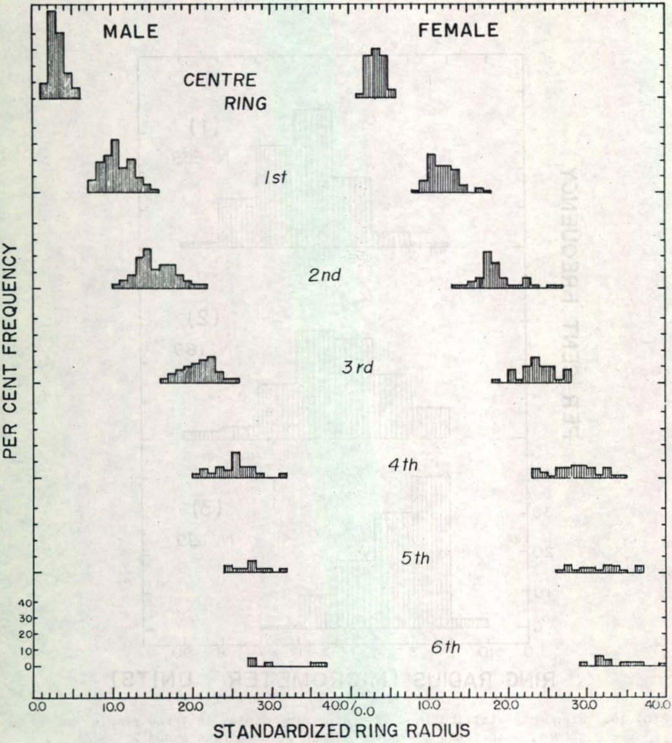

Fig. 17. Standardized ring radius frequency distributions by sex and ring group in the Unimak sample (certainty 2 fish only).

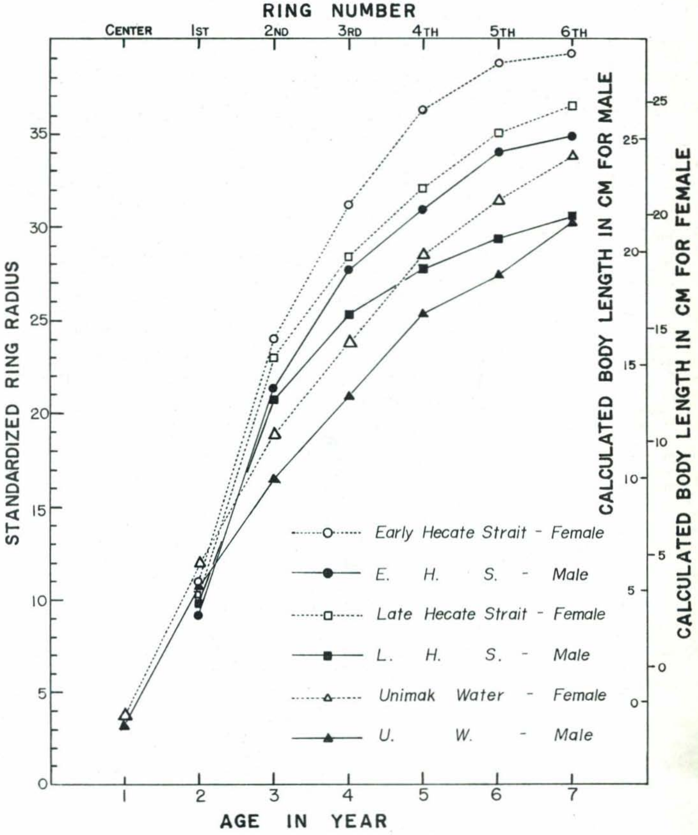

Fig. 18. Average standardized ring radii by sample group and sex, with subaxis for the corresponding body length.

centre annulus radii in Fig. 17 differs slightly from that shown in Fig. 16 because of the standardization of the measurement and the exclusion of category 1 otoliths. A comparison of Fig. 17 with Fig. 5 shows smaller radii for Unimak Island, except for the first annulus and a greater spread for the frequency distributions of the radii from the Unimak samples.

The curve depicted by average standardized annulus radius at each age for certainty-2 otoliths is shown by sex and location in Fig. 18. The Hecate Strait (Skidegate Inlet) curves were constructed from last annulus measurements only, while the Unimak curves were from every annulus measurement because of the small sample size. A comparison of the growth between the two areas is examined through annulus radii in Fig. 18. While there is some question in the inference of the growth curve from the annulus radius curve, it is examined in this manner because of the difference in sampling seasons. There is a relationship between the standardized annulus radius and body length (see Section IV(4)). Body lengths corresponding to standardized annulus radius are shown in subaxes in Fig. 18. There appears to be no difference in growth between the two areas at two years of age, but from three to seven years of age the Hecate Strait fish grow at a much faster rate. The Hecate Strait curves show more convexity than do the Unimak curves. However, this last situation may be overestimated because the annulus measurements of early rings from old fish were used in the Unimak curve but not in the Hecate Strait curve. The use of measurements of early rings from the old fish may reduce the average. The curves suggest a faster growth rate at young ages and more rapidly decreasing increments of growth for the Hecate Strait sole than for the Unimak sole. Data for growth of the yellowfin sole in the southeastern Bering Sea in 1960-61 as presented by Fadeev (1965) were not separated by sex, and there was some difference in sampling time but they do suggest a growth rate slightly greater than that for the Unimak region.

VI. SUMMARY

1. A total of 2,745 otoliths collected during the period 1945 to 1966 by Nanaimo Biological Station personnel have been used for age determination and calculations of growth of the Hecate Strait yellowfin sole.

2. In order to decrease individual variation of otolith measurements, a standardized otolith radius was calculated from the body length, based on the otolith radius-body length relationship and measurements were corrected by the coefficient:

$$\frac{\text{standardized otolith radius}}{\text{observed otolith radius}}$$

3. An annulus was designated as a transparent zone in an otolith and measurements were made to the outer edge of this zone.

4. An annulus was observed in the centre of the otolith in about 50% of the individuals and named as the centre ring in this report. It was narrow, and not clear, compared to other annuli.

5. The margin of the otolith was transparent in most cases in winter and opaque in most cases in summer.

6. There was some variation in the growth rate of the Hecate Strait yellowfin sole between the two sampling periods. Sampling suggested a higher growth rate during the sampling period 1945-47 than during a later sampling period in 1963-66. Reasons for the difference were not clear but mesh selection was believed to be chiefly responsible.

7. Growth from the early samples conformed satisfactorily with the von Bertalanffy equation, with $K = 0.360$ for males and 0.443 for females, and with corresponding asymptotic lengths L_{∞} of 28.4 and 31.1 cm.

8. Some evidence of fluctuations in year class strength was noticeable.

9. A comparison with yellowfin sole from the Unimak region of the Gulf of Alaska showed that Unimak yellowfin sole had a slower growth rate initially than Hecate Strait yellowfin sole; however, Hecate Strait yellowfin showed an earlier decrease in increments of growth than did the Unimak yellowfins.

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REFERENCES

Abe, S. 1963. Genshoku-Gyorui-Kensaku-Zukan (Colour key to fishes of Japan). Hokuryu-Kan Publishing Co., Tokyo, 358 p.

Alverson, D. L., A. T. Pruter, and L. L. Ronholt. 1964. A study of demersal fishes and fisheries of the northeastern Pacific Ocean. H. R. MacMillan lecture series. Inst. of Fisheries, Univ. of British Columbia, 190 p.

Clemens, W. A., and G. V. Wilby. 1961. Fishes of the Pacific coast of Canada. Bull. Fish. Res. Bd. Canada, No. 68, 443 p.

Fadeev, N. S. 1963. Yellowfin sole in the eastern Bering Sea. Proceedings of the VNIRO, Vol. 48, Proceedings of the TINRO, Vol. 50. Japanese translation.

1965. An outline of comparative biology of flatfishes in the southeastern Bering Sea and their stock condition. Proceedings of the VNIRO, Vol. 58, Proceedings of the TINRO, Vol. 53. Japanese translation.

Ishida, T. 1954. On the age determination and morphometrical differences of the otolith of Alaska pollock on the Hokkaido coast. Bull. Hokkaido Reg. Fish. Res. Lab., No. 11: 36-67.

Ishida, R., M. Kitakata, and T. Ishigaki. 1952. Studies on the age of flatfishes in Hokkaido. (2). Clidoderma asperrium, Teminck and Schlegel. Ibid., No. 3: 31-41.

Moiseev, P. A. 1953. Cod and flatfishes in the fareastern waters. Proceedings of the TINRO, Vol. 40. Japanese translation.

Morita, S., and M. Ohara. 1965. Ecological studies of "Kurogashira garei" (Limanda schrenki (Schmidt)) of Hokkaido. (1) On the life of spawning population. Bull. Hokkaido Reg. Fish. Res. Lab., No. 30: 45-59.

Pertseva-Ostroumova, T. A. 1961. The reproduction and development of Fareastern flounder. Publishing house of the Academy of Sciences of the USSR, Moscow. Fish. Res. Bd. Canada, Transl. Ser., No. 856, 1003 p.

Sato, S., and Y. Kaga. 1952. Studies on the age of Sardinia melanosticta. Paper 2. Bull. Hokkaido Reg. Fish. Lab., No. 3: 42-52.

Walford, L. A. 1946. A new graphic method of describing the growth of animals. Biol. Bull., 90(2): 141-147.