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# Studies on the Ecology of the Herring in the Northern Part of the Okhotsk Sea in Summer—IV

## On the Pursuit of "Ayan Group" Using Scale Pattern

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As a method of pursuit investigation of fish group chiefly composed of 4 year-old fish ("Ayan group") in 1973, scale patterns of herring taken from the different areas in the northern part of the Okhotsk Sea in 1974 and 1975 were examined. The results of analyzing the scale ratio $R_i$/fork length relationships showed that the fish with scale pattern of Ayan type had mixed with those of Tauisk type in the summers of the fifth and the sixth year of life. In addition, the fish with $r_2/r_3$ ratios larger than 0.80, which can be used as an indicator of presence of Ayan group in 1973, were included in samples at frequencies (26–40%) greater than could be expected. The mixing area of these two scale types almost coincides with the distribution area of the older fish group of the Okhotsk Population in each year. These results indicate that the majority of 4 year-old fish found in the area of Ayan in 1973 had recruited to the adult stock of the Okhotsk Population during the fifth year of life, at the latest.

The Okhotsk Population is of the greatest abundance of Pacific herring, *Clupea harengus pallasi,* nowadays. The adult fish remove from the coastal waters to offshore areas after spawning and remain scattered widely until July. In August their distribution area dwindles and large-sized concentrations are formed chiefly in the area of Tauisk in the northern part of the Okhotsk Sea.[1–3] On the other hand, during this period the fish group chiefly composed of young fish of 4 years old ("Ayan group") is usually found in the waters around the Ayan, but several problems arose along with the stock system of this fish group. Namely, remarkable differences were found in several biological characteristics, fork length, maturity index, and body weight/fork length relationship, between the 4 year-old groups in the areas of Tauisk and Ayan in 1971[4], in addition, the samples in 1972 and 1973 also showed a similar tendency to above (Unpublished data in part).[5]

In the previous paper[5], as the results of examining scale patterns and fork lengths at the annulus formation of herring in 1971 and 1973 it became evident that the 4 year-old groups in the areas of Tauisk and Ayan had lived under different circumstances since the first year of life. However, these fish groups are not always isolated from each other through the stages in development, it was also found that there is a considerably closed relationship between them.

A clue to elucidate the stock system of Ayan group can be found from the following distribution pattern of herring during this study period: The fish group chiefly composed of 4 year-old fish was found consistently around the area of Ayan in the summers of 1971–1973, while within this area the fish older than 5 years old were not so many and were predominant chiefly in the area of Tauisk. Naturally, this means that the 4 year-old fish being the main part of Ayan group in each year either recruited to the fish group composed of fish older than 4 years old, which is already known of the Okhotsk Population[6], or removed to elsewhere except in the northern part of the Okhotsk Sea by the following summer. From this reason, it is considered that the pursuit investigation of fish is a reliable method for elucidating the stock system of Ayan group.

The present paper deals with the examinations of scale patterns of herring taken from the different areas in the northern part of the Okhotsk Sea in 1974 and 1975, as a method of pursuit investigation of 4 year-old group found in the area of Ayan in 1973.

## Materials and Methods

Samples were collected from the different stations in the northern part of the Okhotsk Sea where experimental fishing for salmon was carried out

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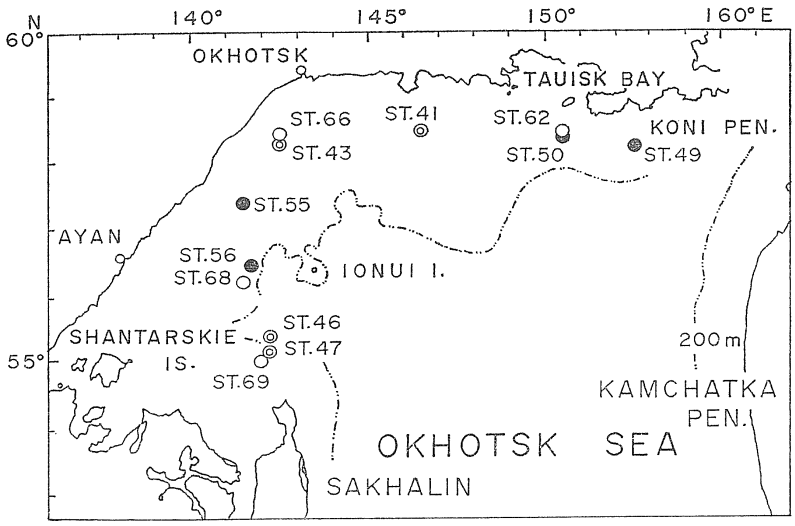


**Fig. 1.** Locations where samples were collected in the northern part of the Okhotsk Sea in August, 1974 and 1975. ●: 1974, ○: 1975. (◎: Locations of each station in Fig. 2).

by the R/V "Oyashio Maru" in August, 1974 and 1975. Only the data of eight stations were used, where a relatively large number of herring were caught: The geographical positions of each station are shown in Table 1 and Fig. 1. The gill nets used was the same as that in the previous years. Namely, it was composed of fixed series of mesh sizes, *i.e.* 30, 35, 42, 48, 55, 63, 72 mm streched length, and others: The amount of nets was also identical three tans for each mesh size. Individuals of one hundred to five hundred fish were sampled at random from the catch by the net with each mesh size. When the catch was poor, all fish caught were sampled. They were frozen immediately after capture and examined after melting in the laboratory. Fork lengths were measured to the nearest millimeter for all individuals of fish after scales were removed. Then, body weights (to the nearest 1 g) and gonad weights (to the nearest 0.1 g) were also recorded.

Only the scales taken from the same part as that described in the previous paper[5], *i.e.* scales from the center of fish body—left side as a rule—were examined. The surface features of scale were magnified fifty times using a Universal Projector UP–360, and $R$ (scale radius to anterior margin) and $r_i$ (scale radius to annulus $i$) were measured on recording card along the longest axis from the nucleus of scale to anterior margin. Measurements of scale were made on the samples of 5 years old in 1974 and 6 years old in 1975 (1970 year-class): The number of individuals observed mas 147 fish and 519 fish, respectively (Table 1). The individuals with abnormal or regenerated scales were omitted to measure, in addition to the fish having no scales in the parts designated.

**Table 1.** Dates and locations where samples were collected, and number of individuals observed and the catches of herring in the northern part of the Okhotsk Sea, 1974 and 1975

| Sea area | No. of fishing station | Date | Location | | No. of observed fish | | No. of catch (fishes) | |
|---|---|---|---|---|---|---|---|---|
| | | | Latitude | Longitude | n | n′*1 | c | c′*2 |
| Tauisk | 49 | 1974 Aug. 17 | 58°–18′N | 152°–34′E | 177 | 42 | 198 | 132 |
| | 50 | 18 | 58°–28′ | 150°–30′ | 120 | — | 139 | 105 |
| Okhotsk | 55 | 25 | 57°–27′ | 141°–27′ | 202 | — | 493 | 237 |
| Ayan | 56 | 26 | 56°–30′ | 141°–40′ | 314 | 105 | 330 | 214 |
| Tauisk | 62 | 1975 Aug. 21 | 58°–30′ | 150°–30′ | 164 | — | 166 | 52 |
| Okhotsk | 66 | 28 | 58°–30′ | 142°–30′ | 225 | — | 227 | 59 |
| Ayan | 68 | 30 | 56°–15′ | 141°–30′ | 674 | 352 | 1962 | 1521 |
| | 69 | 31 | 55°–00′ | 142°–00′ | 906 | 167 | 947 | 235 |

*1 Number of scale examined. *2 1970 year-class.

**Table 2.** Mean ($\overline{R_i}$) and standard deviation ($\delta$) of scale ratio $R_i$ ($i$=1–5), and difference between $\overline{R_3}$ and $\overline{R_2}$ for the herring of 1970 year-class collected from the different stations, 1974 and 1975

| Station | Mesh size (mm) | n | $\overline{R_1}\pm\delta$ | $\overline{R_2}\pm\delta$ | $\overline{R_3}\pm\delta$ | $\overline{R_4}\pm\delta$ | $\overline{R_5}\pm\delta$ | $\overline{R_3}-\overline{R_2}$ |
|---|---|---|---|---|---|---|---|---|
| St. 49 | 48 | 42 | 32.45±4.4 | 57.94±3.7 | 79.40±3.2 | 93.49±1.5 | — | 21.43 |
| St. 56 | 55 | 106 | 33.86±6.6 | 61.37±9.2 | 81.43±6.2 | 93.06±2.5 | — | 20.06 |
| St. 68 | 48 | 155 | 33.82±4.8 | 60.07±7.0 | 78.52±5.2 | 87.53±3.0 | 95.66±1.4 | 18.45 |
| | 55 | 91 | 34.27±6.1 | 60.53±7.4 | 78.65±5.2 | 88.64±2.5 | 95.96±1.4 | 18.12 |
| | 63 | 106 | 34.54±5.7 | 60.31±7.6 | 77.59±5.5 | 87.76±2.8 | 95.40±1.4 | 17.28 |
| St. 69 | 48 | 56 | 35.33±4.4 | 61.41±6.3 | 79.63±4.4 | 88.83±2.8 | 96.01±1.8 | 18.22 |
| | 55 | 63 | 35.49±4.7 | 61.60±7.9 | 79.25±5.4 | 88.85±2.8 | 95.60±1.6 | 17.65 |
| | 63 | 48 | 36.24±4.6 | 62.71±7.2 | 79.94±4.4 | 88.83±2.1 | 95.55±1.3 | 17.23 |

## Results

*The $R_i$/Fork Length Relationship*

Means of scale ratio $R_i/(r_i\times10^2/R)$ for the 5 and 6 year-old fish taken by each mesh at the four stations in the summers of 1974 and 1975 are given in Table 2. To investigate the presence of Ayan group, the $R_i$/fork length relationships for each sample were first analyzed. As described in the previous paper[5], the scale patterns of 4 year-old fish collected in this study area were divided roughly into the two types of Tauisk and Ayan, though the differences among year-classes are also seen. For the 1970 year-class the former is one represented with the sample of St. 41 shown in Fig. 2 and the difference between the distance from the 1st to the 2nd annulus and that from the 2nd to the 3rd annulus is not so large. On the other hand, the latter is predominant at St. 46 and St. 47 and is characterized by the small scale growth between the 2nd and the 3rd annulus: Such a distinctive feature, however, is not so obvious in smaller fish, and for this reason the position of the 2nd annulus ($R_2$) for the Ayan sample shows wide variation.

Fig. 3 shows the plots of $R_i$ on fork length for 5 year-old fish taken by the 48 mm mesh at St. 49 in the area of Tauisk in 1974. Within this sample there is no indication of presence of Ayan group; namely, the difference between the distance from the 1st to the 2nd annulus and that from the 2nd to the 3rd annulus is not so large as a rule, in addition, the variations of $R_1$ to $R_3$ are also considerably small as is evident from Table 2. However, in the case of 5 year-old fish taken at St. 56 in the area of Ayan in the same year 1974, it was seen that there are remarkable variations of

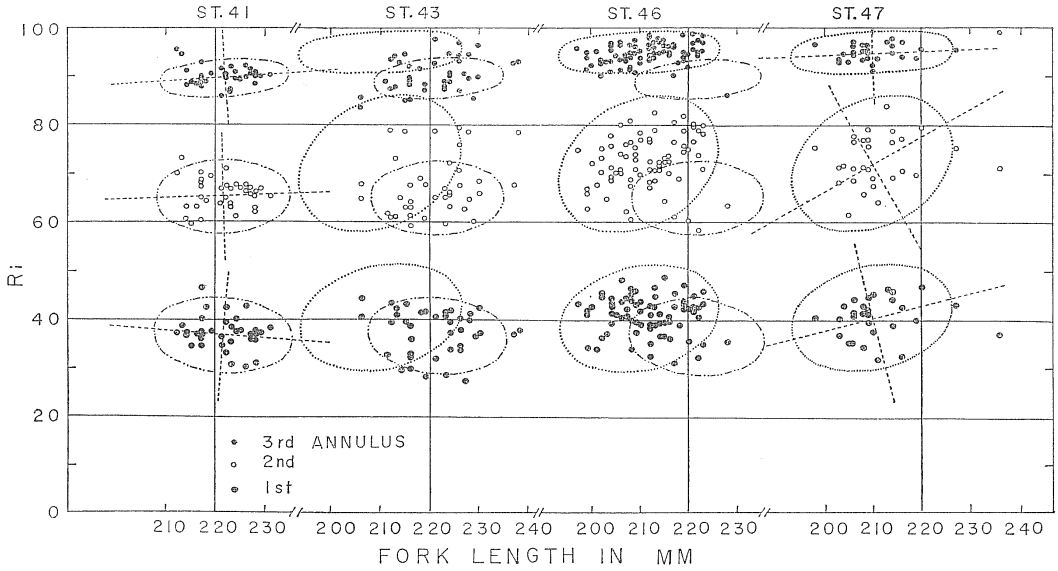


**Fig. 2.** Relationship between fork length and scale ratio $R_i$ ($r_i\times10^2/R$), where $r_i$ ($i$=1–3) is scale radius to each annulus and $R$ is scale radius to anterior margin, for the 4 year-old herring taken by the net of 48 mm mesh, 1973. For comparison rejection ellipses of 5% level of significance for the samples of St. 41 and St. 47 are superimposed on the points plotted for St. 43 and St. 46 respectively. (TAKAHASHI, 1978).

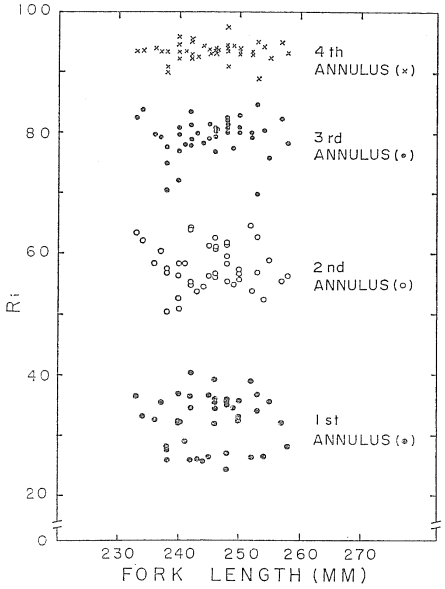


Fig. 3. Relationship between fork length and scale ratio $R_i(r_i \times 10^2/R)$, where $r_i(i=1\text{–}4)$ is scale radius to each annulus and $R$ is scale radius to anterior margin, for the 5 year-old herring taken by the net of 48 mm mesh at St. 49, 1974.

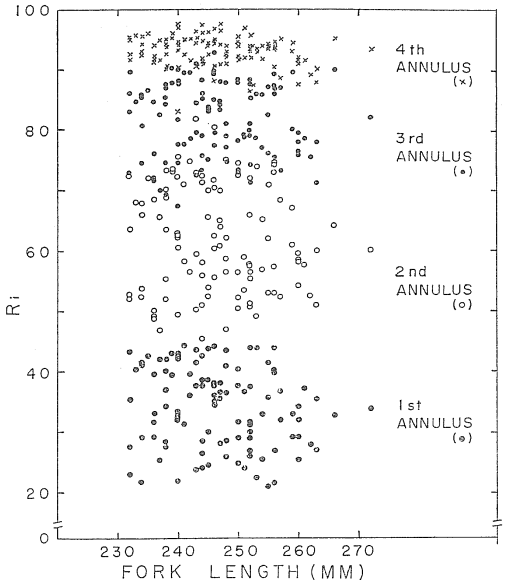


Fig. 4. Relationship between fork length and scale ratio $R_i(r_i \times 10^2/R)$, where $r_i(i=1\text{–}4)$ is scale radius to each annulus and $R$ is scale radius to anterior margin, for the 5 year-old herring taken by the net of 55 mm mesh at St. 56, 1974.

$R_1$ to $R_3$, especially of $R_2$ (Fig. 4). This shows that the fish with remarkably different scale patterns, possibly of Tauisk and Ayan types, are mixed in the sample. Such a tendency is also seen in the samples of 6 year-old fish taken at St. 68 in the area of Ayan in 1975, and a particular attention was given to the sample from the 55 mm mesh because of few overlap in the distributions of $R_2$ on fork length.

Fig. 5 shows a result examined a normality in the frequency distribution (by 0.02 intervals in terms of a unit of $R_i$) of points in the direction of $\eta_2$-axis, which is the longer axis of rejection ellipse[7] for the plots of $R_2$ on fork length, for the sample from the 55 mm mesh at St. 68 using a normal probability paper method. Thus, the cumulative percentages for points in the direction of $\eta_2$-axis lie not on one straight line but on two straight lines. This indicates that the sample of St. 68 is composed of two components with normal distribution. Although the seven individuals of fish were included in the discontinuous part of the plots of cumulative percentages, they were classified in each of the two components according to the position in the direction of $\eta_1$-axis. The plots of $R_i$ on fork length for 6 year-old fish taken by the 55 mm mesh at St. 68 are shown in Fig. 6, where rejection ellipses (at P=0.05) for each component divided by the above manner are superimposed on them. The parameters for each ellipse are given in Table 3.

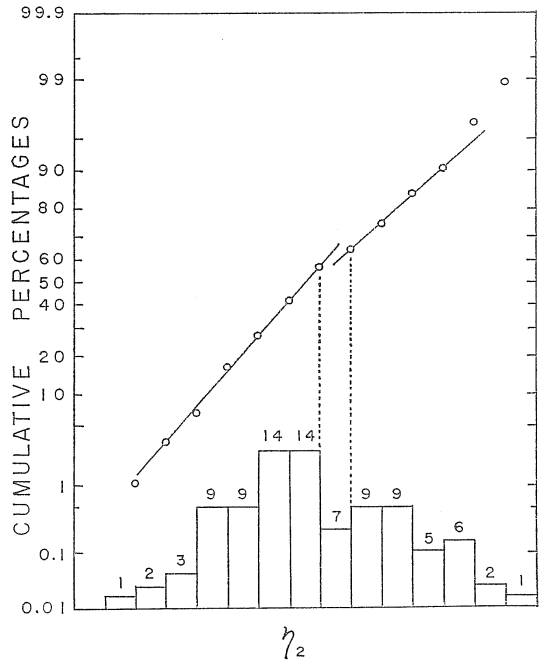


Fig. 5. Cumulative percentages and frequency distribution (number of individuals) of points in the direction of $\eta_2$-axis, which is the longer axis of rejection ellipse for regression of scale ratio $R_2$ on fork length, for the 6 year-old herring taken by the net of 55 mm mesh at St. 68, 1975.

When comparing these rejection ellipses with those for the samples of 4 years old shown in Fig. 2, it is obvious at a glance that the two components of St. 68 sample represent quite well the characteristics of scale patterns of Tauisk and Ayan types

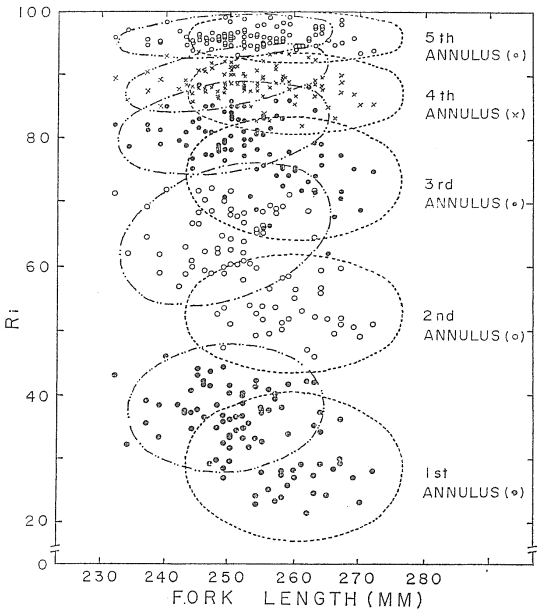


Fig. 6. Relationship between fork length and scale ratio $R_i(r_i \times 10^2/R)$, where $r_i(i=1\text{–}5)$ is scale radius to each annulus and $R$ is scale radius to anterior margin, for the 6 year-old herring taken by the net of 55 mm mesh at St. 68, 1975. The rejection ellipses of 5% level of significance for Component A and B are superimposed respectively.

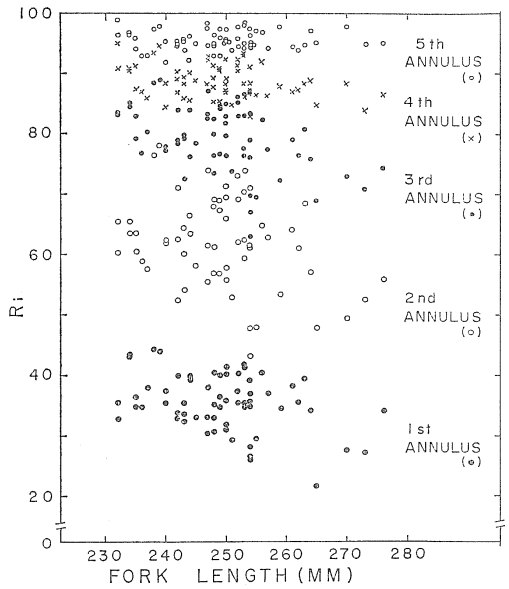


Fig. 7. Relationship between fork length and scale ratio $R_i(r_i \times 10^2/R)$, where $r_i(i=1\text{–}5)$ is scale radius to each annulus and $R$ is scale radius to anterior margin, for the 6 year-old herring taken by the net of 55 mm mesh at St. 69, 1975.

respectively, except that the 6 year-old fish of Tauisk type had larger variations of $R_i$'s. Namely, the individuals in the ellipse enclosed with the dotted line (Component A) are evidently fish of Tauisk type in judging from the small difference between the distance from the 1st to the 2nd annulus and that from the 2nd to the 3rd annulus. On the other hand, for the individuals in the ellipse with the dot-dash-line (Component B) the distance between the 2nd and the 3rd annulus is considerably small as a rule and this tendency is remarkable in larger fish. This shows that the Component B is the same one as 4 year-old fish which found in the area of Ayan in August, 1973. Although the difference in positions of each annulus between these two components is large as compared with that of 4 years old shown in Fig. 2 on the whole, the main reason is that scale growth during the fourth year of life was remarkably small in fish of Ayan type. On the other hand, as to the 6 year-old fish taken at St. 69 in the area of Ayan in the same year 1975, it was difficult to separate the sample into the two components—fish of Tauisk and

Table 3. Parameters of rejection ellipse equations ($\eta_1^2/a^2+\eta_2^2/b^2=1$, where $\eta_1$ and $\eta_2$ mean the co-ordinates generated by revolving angle $\theta$, and $a$, $b$ the constant) for the regression of scale ratio $R_i$ on fork length $L$

| Component | No. of annulus ($i$) | n | $L$ (mm) | $R_i$ | $a$ | $b$ | $\theta$ |
|---|---|---|---|---|---|---|---|
| A | 1 | 35 | 259.86 | 28.68 | 11.45 | 16.50 | 86°46′ |
| | 2 | 34 | 259.76 | 52.65 | 16.70 | 9.42 | 0°31′ |
| | 3 | 34 | 259.71 | 74.02 | 9.55 | 16.62 | 87°46′ |
| | 4 | 35 | 259.86 | 87.16 | 16.48 | 6.28 | 0°03′ |
| | 5 | 35 | 259.86 | 95.92 | 16.48 | 3.94 | 0°04′ |
| B | 1 | 54 | 249.33 | 37.76 | 15.15 | 10.10 | 3°30′ |
| | 2 | 55 | 249.05 | 65.14 | 16.95 | 10.16 | 20°32′ |
| | 3 | 54 | 249.09 | 81.70 | 16.41 | 6.81 | 9°13′ |
| | 4 | 54 | 249.22 | 89.50 | 15.97 | 4.58 | 10°15′ |
| | 5 | 55 | 249.05 | 95.98 | 16.50 | 3.28 | 3°14′ |

Ellipses were calculated from the data except the points which were rejected at the 5% level of significance.

Ayan types-because of considerable overlap in the distributions as well as most sample, however, the data shows approximately a similar tendency to that from St. 68 (Fig. 7). The representative scales of Tauisk and Ayan types are shown by age-groups in Plate 1.

*Scale Ratio $r_2/r_3$*

In order to confirm the above results, the ratios of distance to the 2nd annulus to that to the 3rd annulus ($r_2/r_3$) for each sample were calculated. As described in the previous paper[5], a large difference in scale ratio $r_2/r_3$ was found between the samples of Tauisk and Ayan. Namely, for the 1970 year-class the 4 year-old fish with $r_2/r_3$ ratios larger than 0.80 was hardly included in the Tauisk samples, though 25% of Ayan sample were fish with these values. For this reason, as far as this year-class it is already known that the fish with $r_2/r_3$ ratios larger than 0.80 can be used as an indicator of presence of Ayan group.

Fig. 8 shows the frequency distributions of scale ratio $r_2/r_3$ for each sample in 1974 and 1975. No significant difference (at P=0.05) was found in the mean scale ratio $r_2/r_3$ between meshes, therefore, samples from the nets of each mesh were combined. As seen in Fig. 8, at St. 49 the fish with $r_2/r_3$ ratios larger than 0.80 is hardly included in sample, but at the other three stations, St. 56, 68, and St. 69 the fish with these values were included in samples at frequencies (26–40%) greater than could be expected. Therefore, it can be considered that the majority of 4 year-old fish in the area of Ayan in 1973 were distributed in the northern part of the Okhotsk Sea in the summers of the fifth and the sixth year of their life. These results agree well with those of $R_i$/fork length relationships as before.

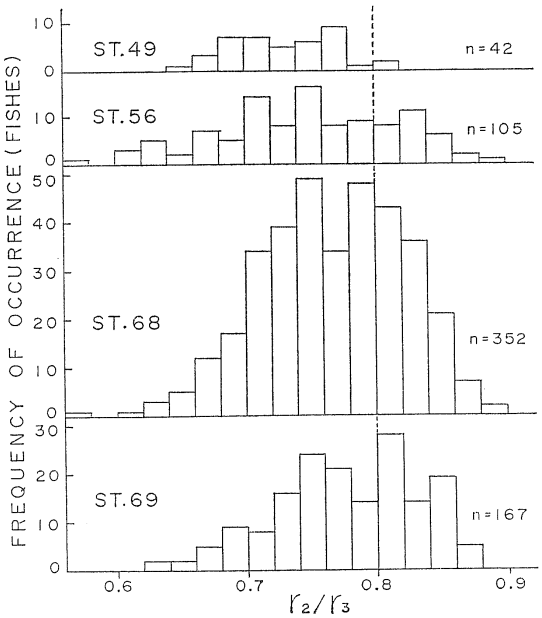


**Fig. 8.** Frequency distributions of $r_2/r_3$, where $r_2$ is scale radius to the 2nd annulus and $r_3$ is scale radius to the 3rd annulus, for the 5 year-old herring at St. 49 and St. 55 in 1974 and for the 6 year-old herring at St. 68 and St. 69, 1975.

In the present study, the scale ratio $r_2/r_3$ of the same fish was treated under assumption as the value is constant regardless of age. In order to verify this assumption, the relationship between $r_2/r_3$ and fork length for data combined the fish of different ages was examined. For the present purpose, however, the mixed sample of Tauisk and Ayan types is not available because of large difference in scale pattern between them as described earlier, so the data of St. 38, 41 (in 1973), St. 49, and the Component A of St. 68 were used.

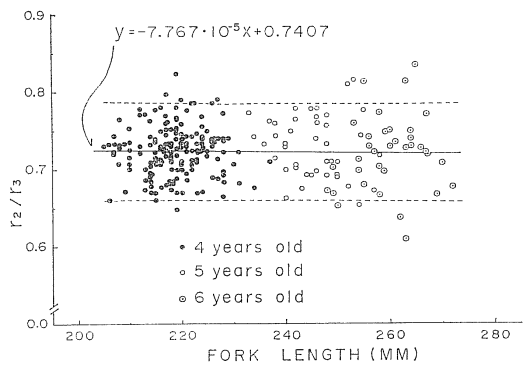


**Fig. 9.** Regression line and 95% confidence limits of $r_2/r_3$ on fork length for the herring of 1970 year-class with the scale pattern of Tauisk type. These lines were obtained from the data except the points which were rejected at the 5% level of significance.

As is evident in Fig. 9, the regression of $r_2/r_3$ to fork length is a straight line with a remarkably small slope (regression coeficient $b=-7.767\times 10^{-5}$). Therefore, it can be considered that the value of scale ratio $r_2/r_3$ of the same fish is approximately constant at least as far as the three age-groups treated in this study.

*Change in Distribution of Older Fish Group*

In the northern part of the Okhotsk Sea the fish older than 5 years old were concentrated consistently in the area of Tauisk in the summers of 1971–1973 and it was confirmed that they are of the Okhotsk Population. For this reason, if the 4 year-old group around the area of Ayan are distributed in this study area-probably in Tauisk-in the following summer, it may be concluded that

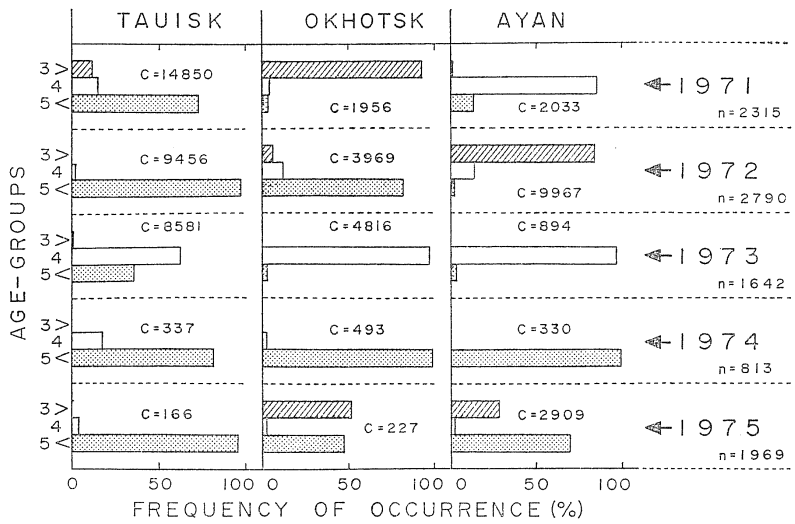


**Fig. 10.** Age frequency distributions, by year and area, of herring taken in the northern part of the Okhotsk Sea in the summers of 1971–1975. c: Number of catch

they must be recruit to the older fish group of the Okhotsk Population.

The 5 and 6 year-old fish with the scale pattern of Ayan type, however, were included at high percentages in the samples of the area of Ayan, while at St. 49 in the area of Tauisk the fish of Ayan type were hardly included in the sample as described before. Namely, it seems likely that the 4 year-old group of Ayan type in 1973 had distributed chiefly in the area of Ayan in the summers of the fifth and the sixth year of life as well.

As shown in Fig. 10, in the summers of 1971–1973 the fish older than 5 years old were catched in great numbers in the area of Tauisk, and in only small numbers in the area of Ayan. But, in 1974 the fish older than 5 years old consisted of the main part of catches from the area of Tauisk to Ayan, in addition, in 1975 they seem to be concentrated in the area of Ayan. Such a tendency also appeared on the data of commercial catch. Namely, according to the statistical data of Hokkaido Regional Fisheries Research Laboratory[8–10], although in 1971–1973 catch per unit of effort (ton/1000 tans) of fish older than 5 years old during August and September was the most highest in the area of Tauisk, in 1974[11] was rather high in the area of Okhotsk. Therefore, it is assumed that in 1974 and 1975 the main distribution area of older fish group of the Okhotsk Population in summer was altered from the usual area of Tauisk to Okhotsk-Ayan.

From the above, it can be considered that the older fish group of Ayan type had not separated from that of the Okhotsk Population geographically but had recruited to it. This is also evident from the fact of mixing of fish older than 5 years olds with the scale patterns of Tauisk and Ayan types as before.

## Discussion

In the present study, we tried the pursuit investigation of Ayan group using the scale pattern, as the results, it was confirmed that the 4 year-old group being the main part of Ayan group in 1973 had recruited to the older fish group of the Okhotsk Population. Moreover, if we consider this result in relation to the fact that the fish older than 5 years old are concentrated consistently in the area of Tauisk for the past many years, a serious fact such as the 4 year-old group in the area of Ayan also consistently recruits to the adult stock of the Okhotsk Population during the fifth year of life at the latest can be drawn. From these reasons, there seems no doubt that the Ayan group is of the Okhotsk Population. Therefore, it can be considered that almost all the herring found in this study area belong to the Okhotsk Population which spawn in the coastal waters from the Tauisk Bay to the waters around the Shantarskie Islands.

Otherwise, in 1974 and 1975 Ayan group was not found anywhere in the northern part of the Okhotsk Sea. This reason can be found from Fig. 11, showing the age frequency distributions of herring taken in this study area in 1971–1975, by year. The occurrence of fish groups composed of a few age-groups must be restricted severely by the abundance of year-classes[6]. Namely, the absence of Ayan group in 1974 and 1975 is due to

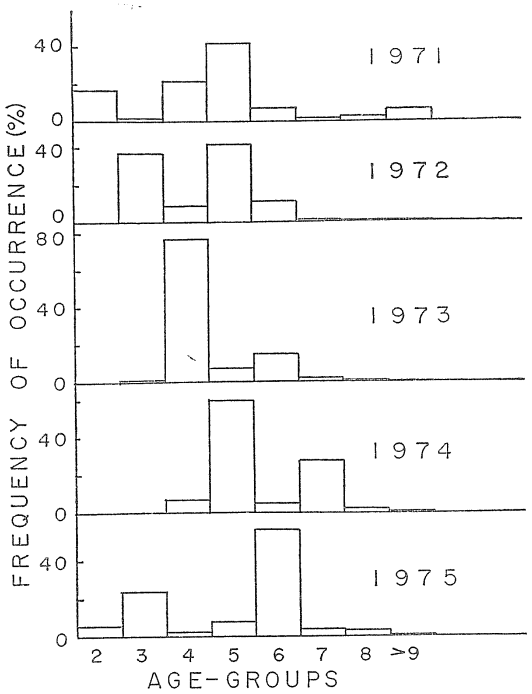


Fig. 11. Age frequency distributions of herring (areas combined) taken in the northern part of the Okhotsk Sea in the summers of 1971–1975.

the low abundance of the 1971 and 1972 year-classes, respectively.

We could not clarify fully the mechanism of occurrence and disappearance of Ayan group. Development of gonad, however, seems to be a factor which cannot be overlooked. Fig. 12 shows the frequency distributions of maturity index (gonad weight $\times 10^2$/body weight$-$gonad weight) of 4 year-old fish taken in both the areas of Tauisk and Ayan, 1971 and 1973. Although there is a remarkably difference in maturity index between these two areas, for female fish it is seen that there are roughly two distribution modes on both sides of maturity index value 1.0: one lies in the Tauisk sample, and the other in the Ayan sample.

The results of histological examination of ovaries, which are ones fixed with Bouin's solution after melting, indicated that the oocytes of fish with maturity index values less than 1.0 were below 0.20 mm in diameter and were of the peri-nucleolus stage. On the other hand, those of fish with maturity index values more than 1.0 are comparatively large (0.20–0.28 mm) and were regarded as ones which the vitellogensis have already begun in judging from the exsistance of oocyte membrance. For this reason, it can be considered that the majority of 4 year-old fish in the area of Ayan will spawn in the following spring.

According to AYUSHIN[2], the Okhotsk Population usually spawn in the spring of the fifth year of life, and a similar fact is reported by TYURNIN[12]. Accordingly, the 4 year-old group in the area of Ayan seems not to be the previous spawning run but the next year's spawning run. From the above, it seems likely that the disappearance of Ayan group in each year is due to recruitment to the adult stock with sexual maturity. Otherwise, whether the 4 year-old group in the area of Tauisk will spawn in the following spring as the same as that in the area of Ayan or not was not confirmed, because they were in the earlier stage of sexual maturity. Although this 4 year-old group usually mixed with the fish group older 5 year-old, considering the fact that the progress of their sexual maturity is delayed rather than that in the area of Ayan,

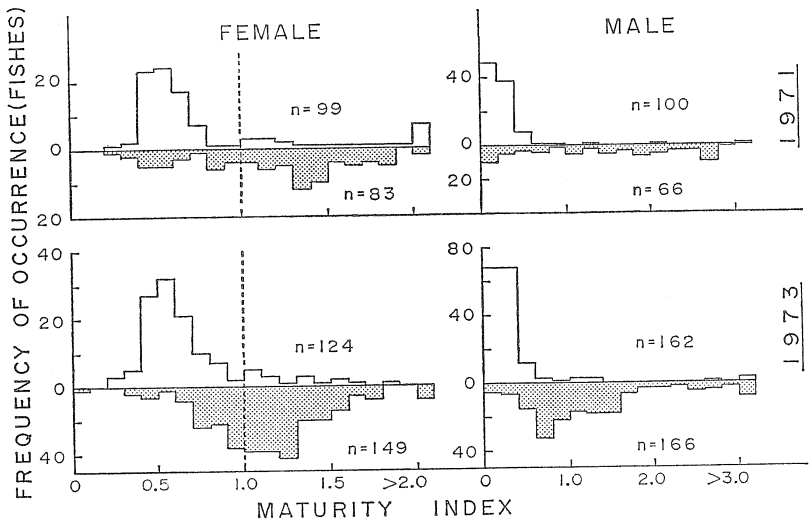


Fig. 12. Maturity index distributions of 4 year-old herring in the northern part of the Okhotsk Sea in August, 1971 and 1973. □: Tauisk area, ▦: Ayan area.

it can not be considered that they have already recruited to the adult stock as the spawning run. Therefore, it seems likely that there is no special reason for the cause of occurrence of these two 4 year-old group except the geographical difference of spawning areas within the northern part of the Okhotsk Sea.

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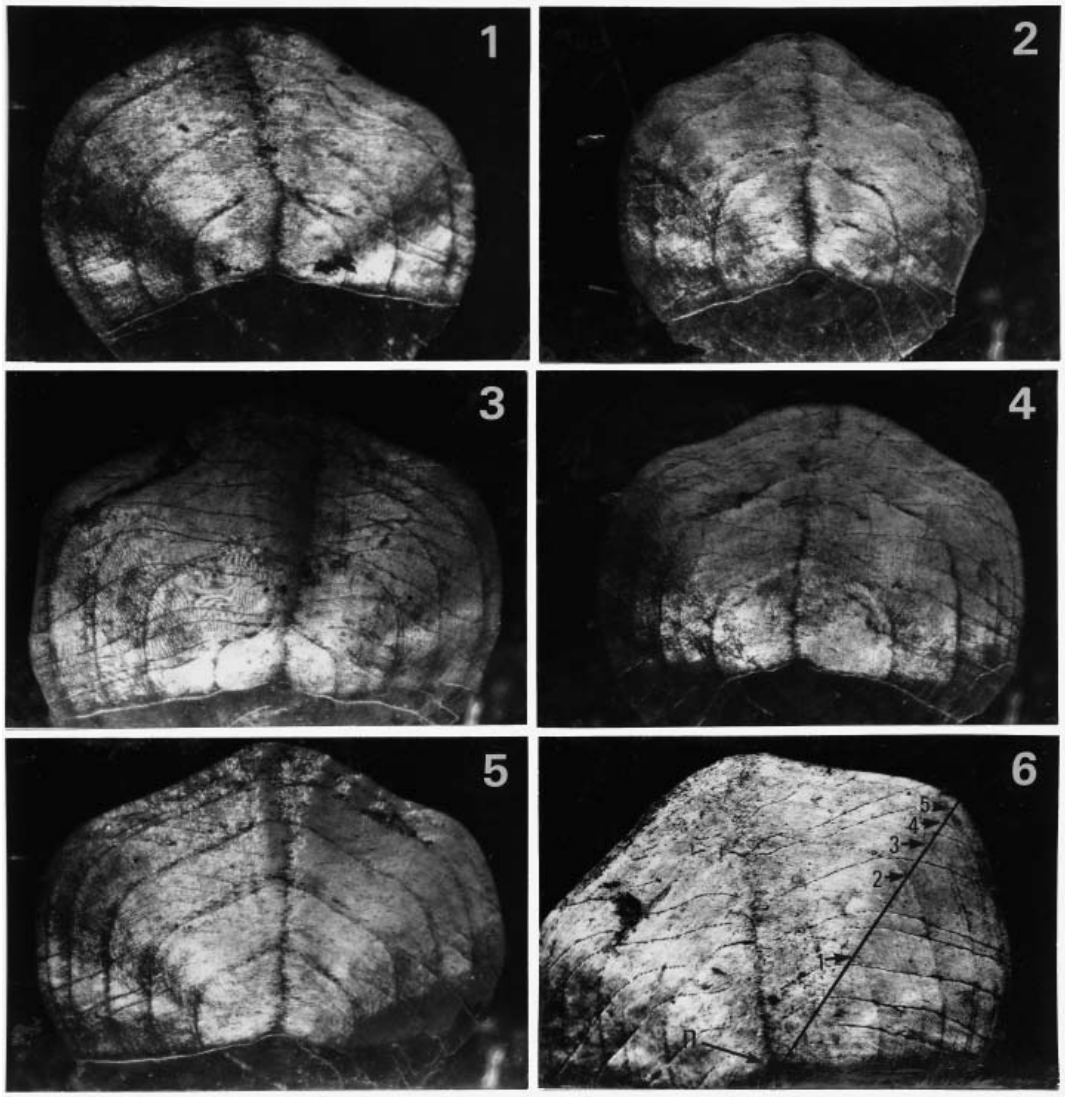
**Plate 1.**




Scale of *Clupea harengus pallasi*

1. Tauisk type (*R*: 4.04 mm, 4 years old of 219 mm in fork length collected on Aug. 18, 1973).
2. Ayan type (*R*: 4.06 mm, 4 years old, 216 mm *FL*, Aug. 23, 1973).
3. Tauisk type (*R*: 4.90 mm, 5 years old, 256 mm *FL*, Aug. 27, 1974).
4. Ayan type (*R*: 4.42 mm, 5 years old, 250 mm *FL*, Aug. 27, 1974).
5. Tauisk type (*R*: 4.90 mm, 6 years old, 267 mm *FL*, Aug. 30, 1975).
6. Ayan type (*R*: 5.10 mm, 6 years old 247 mm *FL*, Aug. 30, 1975).

*R*: scale radius to anterior margin.