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<tr>
<th>Title</th>
<th>Studies on Sharks―XVI Age and Growth of Eiraku Shark Galeorhinus japonicus (MÜLLER et HENLE)</th>
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<td>Author(s)</td>
<td>Tanaka, Sho; Chen, Che-Tsung; Mizue, Kazuhiro</td>
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Studies on Sharks-XVI

Age and Growth of Eiraku Shark *Galeorhinus japonicus*

(MÜLLER et HENLE)

Sho TANAKA*, Che-Tsung CHEN**, and Kazuhiro MIZUE*

Age and growth of Eiraku shark *Galeorhinus japonicus* which was collected from September 1972 to October 1976 at the western waters of Kyushu were studied by means of reading the rings of the vertebral centrum. The transparent zone is formed between autumn and early spring while the opaque zone between spring and summer. The maximum number of ring was 10 in male and 14 in female. The relationship between centrum radius R (mm) and total length L (mm) is indicated by the following equations:

- **Male**: \( \log R = 1.0366 \log L + 0.2736 \)
- **Female**: \( \log R = 1.3467 \log L - 0.6335 \).

The von Bertalanffy growth equations in both sexes are:

- **Male**: \( L_t = 1111 \{1 - \exp\left(-0.2435(t+0.9995)\right)\} \)
- **Female**: \( L_t = 1321 \{1 - \exp\left(-0.2005(t+1.0000)\right)\} \),

where \( L_t \) = total length in mm at age \( t \)

\( t \) = time in years.

Accordingly, the growth rate of female of this species is faster than male, and the total length of male at 10 years old attains 1035 mm and female 1175 mm. The sexual maturity of this species is about 5 years old in both sexes.

Age in teleost fishes has been generally determined by rings represented in otoliths and scales, but in elasmobranch they can not be used. Therefore, size-frequency distribution (Olsen, 1954; Aasen, 1963), tagging experiments (Holden, 1972), dorsal spine of *Squalus acanthis* (Holden and Meadows, 1962; Ketchen, 1975), toothreplacement rate (Moss, 1972), and vertebral rings (Ishiyama, 1951a, 1951b; Stevens, 1975) have been used in the age-determination of elasmobrach.

Nevertheless, there are few studies on the age-determination used the vertebral rings, especially none in small sharks such as Eiraku shark. This shark is a popular species in Nagasaki which has been used as the materials of fishpaste. The morphology of female reproductive systems of Eiraku shark *Galeorhinus japonicus* belongs to the viviparous non-placental type, and 8 to 22 embryos measuring about 210 to 250 mm in total length are born during April and June after about 10 months of the gestation period as reported by Chen and Mizue (1973). However, the age and growth of this shark have been not studied.

Since the vertebral centrum of Eiraku shark is calcified progressively and has concentric rings in both faces, thus the age and growth of this species also can be

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investigated based on centrum rings.

In elasmobranch to clarify the rings of vertebral centrum various techiques have been used. For example, Stevens (1975) used a silver nitrate technique; on the other hand Aasen (1963) clarified the rings by means of X-ray photograph. In this paper, a study on the age and growth of Eiraku shark *Galeorhinus japonicus* by reading the rings of vertebral centrum without clarifying the vertebral rings is reported.

**Materials and Methods**

41 males and 125 females of Eiraku shark *Galeorhinus japonicus* were used in this study. They were captured in the western waters of Kyushu by bottom long line and collected at the Nagasaki fish market from September 1972 to October 1976. The specimens were measured and dissected in the laboratory, and their reproductive organs were examined for sexual maturity determination. The number 6, 7, and 8 of vertebral centrums counted from cranium were collected for age-determination. The centrums were grinded along the central longitudinal axis about 0.2 mm thick with a revolving whetstone, and stuck with binding agent on the transparent plastic plates. Since by this method the rings of vertebral centrum are quite clear (Fig. 1), decalcification and staining were not performed. The sections of centrums were observed with a profile projector (×20) by reflected light. And then by slide caliper the centrum radius and ring radius were measured from the center of notochord to the edge of centrum and to the outer margin of transparent zone respectively (Fig. 1). The average value of reading on four marginal edges was taken as centrum radius and ring radius.

![Fig. 1. Rings on vertebral centrum of *Galeorhinus japonicus* (8 rings). R is centrum radius, and *r*<sub>n</sub> ring radius.](image)

**Results and Discussion**

1. Ring

Rings as shown in Fig. 1 were observed in narrow V-shaped portion of the marginal edge of vertebral centrum and can be distinguished between transparent and opaque zone. The transparent zone is narrower and more calcified than the opaque zone.

To examine the period of ring formation, the state of centrum edge was divided into four grades and monthly occurrence of each grade was investigated. As shown in Fig. 2, the grades are:

![Fig. 2. Grades of centrum edge.](image)

I: the transparent zone forming narrowly in centrum edge
II: the transparent zone forming completely in centrum edge
III: the opaque zone forming narrowly in centrum edge
IV: the opaque zone forming widely in centrum edge.

Table 1. Monthly occurrence for the four grades of centrum edge by male (left) and female (right).

<table>
<thead>
<tr>
<th>Month</th>
<th>Grade</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>I</td>
<td>II</td>
</tr>
<tr>
<td>Jan.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Feb.</td>
<td>1 1</td>
<td></td>
</tr>
<tr>
<td>Mar.</td>
<td>1 1 1</td>
<td></td>
</tr>
<tr>
<td>Apr.</td>
<td>1</td>
<td></td>
</tr>
<tr>
<td>May</td>
<td>1 1</td>
<td></td>
</tr>
<tr>
<td>Jun.</td>
<td>3 6 2 4</td>
<td></td>
</tr>
<tr>
<td>Jul.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Aug.</td>
<td>1 1 1</td>
<td></td>
</tr>
<tr>
<td>Sep.</td>
<td>1 2</td>
<td></td>
</tr>
<tr>
<td>Oct.</td>
<td>2 2 3 3</td>
<td></td>
</tr>
<tr>
<td>Nov.</td>
<td>0</td>
<td></td>
</tr>
<tr>
<td>Dec.</td>
<td>1 1</td>
<td></td>
</tr>
</tbody>
</table>

However, it is still difficult to decide the grade of centrum edge according to the increase of the ring.

Table 1 shows monthly occurrence of the four grades by sex. It is inferred that the transparent and opaque zone are formed once a year in male and female. Especially in winter, due to lack of specimens, the ring formation in male is doubtful. But the transparent zone seemingly formed during 8 months between autumn and spring, while the opaque zone formed between late spring and summer. Meanwhile, the formation of transparent zone in female occurred during 6 months between autumn and early spring, and the opaque zone formed between spring and summer. Accordingly, although the formation period of each zone is slightly difference in both sexes, it seems that the formation of transparent zone as well as opaque zone is in a cycle of one half a year. In this paper, the former was treated as the ring, which is considered as annual ring.

Ishiyama (1951a, 1951b) has supposed that the calcified rings in Japanese Black-skate *Raja fusca* and *Raja hollandi* are formed in the winter season. In Blue shark *Prionace glauca* (Stevens, 1975) and Porbeagle *Lamna nasus* (Aasen, 1963), by means of their size frequencies it was proved that the rings in vertebral centrum are appeared annually. But Parker and Stott (1965) described that in Basking shark *Cetorhinus maximus* the centrum ring is formed twice a year. Thus the period of ring formation in vertebral centrum of elasmobranch is still unclear. In Eiraku shark *Galeorhinus japonicus* it needs to collect more specimens in order to make a general conclusion.

As a result of centrum observation of centrum observation of the embryos which are probably born immediately, the ring could not be recognized. Hence it is suppo-
sed that the first ring was not formed in the uterus. However, the average centrum radius of full-term embryos was 1.11 mm and the first ring radius of postnatal vertebral centrum was 1.33 mm in male and 1.37 mm in female. The second ring radius in male and female was 3.18 mm and 3.13 mm respectively. These facts indicate that the first ring in vertebral centrum for this species is formed shortly after parturition.

Stevens (1975) described that the first ring in vertebral centrum of Blue shark Prionace glauca represents a birthmark and succeeding rings are formed at yearly interval. Although the time of the first ring formation greatly influence the early growth of shark, in this study the first ring considered as a birthmark and the succeeding rings are treated as annual rings.

The primary factor of annual ring formation in the vertebral centrum of elasmobranch as well as in the case of teleost fishes, is still unclear. It has been suggested that it may be due to the seasonal change of temperature, the increase and decrease of food quantity or the physiological demands for a strengthening of the vertebral cartilage (Stevens, 1975). At present the factor is still unknown, but it may be related to seasonal change of temperature according to the period of ring formation.

2. Growth

The results of total length measurement of the specimens were 602 mm to 1056 mm for male and 527 mm to 1155 mm for female. The relationship between the number of centrum rings and the total length is shown in Fig. 3 and Fig. 4 for male and female respectively. The maturity of female was determined by the condition of ovary and uterus (Fig. 4). The annual ring of male could be observed until tenth while in female until fourteenth. Each ring group of both sexes was not collected in the same period and also there is a variation in individual growth, so that the variation of total length is found even in the same ring group. The data show that the female grow faster than the male. Consequently we treated male and female differently.

Fig. 5 and Fig. 6 show the relationship between centrum radius R (mm) and total length L (mm) for male and female respectively. The relationship was determined by linear regression of log R against log L. By the least square method the regression equation and its coefficient of correlation "r" are obtained as following:

Male : log R=1.0366 log L+0.2736
\(r=0.9145\) \(\ldots(1)\)

Female : log R=1.3467 log L−0.6335
\(r=0.9031\) \(\ldots(2)\).

The coefficients of correlation in both male and female indicate statistically a high level of significance (F−test at \(\alpha=0.01\)).

From the average ring radius which was obtained by the measurement of each ring radius which was obtained by the measurement of each ring group, it was found neither Lee's phenomenon nor anti-Lee's phenomenon. Table 2 gives the number of
Fig. 4. Relationship between the number of centrum rings and the total length of female *Galeorhinus japonicus*. Open circle, closed circle, and cross mark indicate immature, mature, and pregnant respectively.

Fig. 5. Relationship between the centrum radius and the total length of male *Galeorhinus japonicus*.

samples, the average value of ring radius \( r_n \) and the standard deviation. The average value of ring radius in male was calculated without including the data of tenth ring, because as shown in Fig. 3 there are none of eighth and ninth rings data and only one of tenth ring. The Walford graph of average ring radius \( r_n \) in male and female is shown Fig. 7, where each point nearly fits its regression line. Thus it suggests that the rings are formed periodically. The regression equation of Walford line and its coefficient of correlation "r" are:

\[
\begin{align*}
\text{Male} & : r_{n+1} = 0.7885 \ r_n + 1.59 \\
& \quad (r = 0.9964) \quad \ldots \ldots (3) \\
\text{Female} & : r_{n+1} = 0.8438 \ r_n + 1.38 \\
& \quad (r = 0.9964) \quad \ldots \ldots (4).
\end{align*}
\]

However, since it was mentioned that the first ring represents a birthmark and the succeeding rings are annual, in the above equations the first point which represents second ring plotted against first ring was excluded.

Furthermore, the total length \( l_n \) at the time of ring formation can be calculated by using the equation (1) and (2) and the average value of ring radius \( r_n \). The result
Table 2. Number of samples, mean value and standard deviation of ring radius (mm), and calculated total length (mm) at the time of ring formation.

<table>
<thead>
<tr>
<th>Sex</th>
<th>Number of ring</th>
<th>Number of samples</th>
<th>Ring radius and standard deviation</th>
<th>Calculated length</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1  2  3  4  5  6  7  8  9  10  11  12  13  14</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>M</td>
<td>40  40  35  26  17  6  3</td>
<td>M</td>
<td>1.33 3.18 4.16 4.82 5.35 5.76 6.23</td>
<td>233 538 697 805 889 955 1030</td>
</tr>
<tr>
<td>F</td>
<td>125 124 120 116 100 77 51 37 28 17 12 6 6 2</td>
<td>F</td>
<td>0.11 0.26 0.20 0.24 0.19 0.23 0.30</td>
<td>318 592 736 828 893 944 983 1020 1055 1088 1125 1172 1195 1205</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>0.14 0.30 0.29 0.32 0.33 0.37 0.35 0.36 0.37 0.34 0.35 0.24 0.26 0.00</td>
<td></td>
</tr>
</tbody>
</table>

is shown in Table 2. Fig. 8 shows the Walford graph represented by the calculated total length \( l_n \). And it shows that the data fit the following equations:

Male: \( l_{n+1} = 0.7839 \ l_n + 266 \)  \( (r=0.9962) \) \ldots \ldots (5) 

Female: \( l_{n+1} = 0.8183 \ l_n + 227 \)  \( (r=0.9957) \) \ldots \ldots (6).
To obtain the equation (5) and (6) the first point for male and female is also omitted as in the case of equation (3) and (4).

From the equation (5) and (6) the von Bertalanffy growth equations of both male and female at the ring formation are obtained, but at the age (from birth in years) are not. In order to obtain the growth equation at the age, the following calculation should be performed.

Since the total length at birth which was calculated from Walford graph by the Y-axis intercept is not the real one, therefore it can be found from the embryos which were collected from 19 females during the parturition period of April to June. Then the average total length and its standard deviation are:

- Male: 225±16.7 mm (112 embryos)
- Female: 224±16.1 mm (115 embryos)

Hence no statistical difference is recognized in the total length of male and female. Thus the length at birth in both sexes are about 240 mm.

The growth coefficients given by the equation (5) and (6) are constant at the
ring formation as well as at the age. Therefore, Walford line for length at the age can be expressed by the following equations:

\[
\text{Male} \quad l_{n+1} = 0.7839 \, l_n + 240 \quad \ldots \ldots (7)
\]

\[
\text{Female} \quad l_{n+1} = 0.8183 \, l_n + 240 \quad \ldots \ldots (8).
\]

The commonly used form of von Bertalanffy growth equation is:

\[
L_t = L_\infty \left(1 - \exp \left(-K(t-t_0)\right)\right) \quad \ldots \ldots (9),
\]

where \(L_t\) = length at age \(t\), \(t_0\) = age,
\(L_\infty\) = asymptotic length, \(K\) = growth coefficient, and \(t_0\) = hypothetical age.

Then using the equation (7) and (8), the asymptotic length \(L_\infty\) and the growth coefficient \(K\) of the growth equation could be found:

\[
\text{Male} \quad L_\infty = 1111 \text{ mm, } K = 0.2435
\]

\[
\text{Female} \quad L_\infty = 1321 \text{ mm, } K = 0.2005.
\]

To obtain the hypothetical age \(t_0\) at which the shark would have been zero length, the equation (9) is rearranged into the following form:

\[
t_0 = t + \frac{1}{K} \log_e \frac{L_\infty - L_t}{L_\infty} \quad \ldots \ldots (10).
\]

Using \(t=0\), \(L_t = 240\), and the above-mentioned value of \(L_\infty\) and \(K\) in both sexes; and then from the equation (10), \(t_0\) is obtained \(-0.9995\) for male and \(-1.0000\) for female. Thus the Bertalanffy equation at the age is:

\[
\text{Male} \quad L_t = 1111 \left(1 - \exp \left[-0.2435(t+0.9995)\right]\right) \quad (11)
\]

\[
\text{Female} \quad L_t = 1321 \left(1 - \exp \left[-0.2005(t+1.0000)\right]\right) \quad (12)
\]

where \(L_t\) = total length in mm at age \(t\)

\(t\) = age in years.

The total length \(L_t\) by age which was obtained from the equation (11) and (12) is shown in Table 3, and the growth curves for male and female are given in Fig. 9.

From this figure as well as shown in Fig. 3 and Fig. 4, it is clearly that the growth of female is faster than male. Moreover, the growth rates of male and female in Fig. 9 are almost the same as those in Fig. 3 and Fig. 4 respectively. The comparison of the calculated growth rate of male in Fig. 9 and the observed one in Fig. 3 shows the coincidence of both values. But for female the comparison of both growth rates in Fig. 9 and Fig. 4 indicates bigger value of calculated growth rate than the observed one, especially in the maximum total length. The asymptotic length \(L_\infty\) is larger 55 mm in male and 176 mm in female than the observed maximum length which is 1056 mm in male and 1155 mm in female. Since these differences are small compared with total length, it may be neglected.

Chen and Mizue (1973) described that the total length at sexual maturity in this species is about 85 cm in male and 84 to 102 cm in female. Hence, it is suggested that the male reaches sexual maturity at 5 years old while the female between 4 and 6 years old. Furthermore, from the pregnancy examination in each ring group, it was
Table 3. Calculated total length ($L_t$) of *Galeorhinus japonicus* by age, using the von Bertalanffy growth equation.

<table>
<thead>
<tr>
<th>Age (years)</th>
<th>Total length (mm)</th>
<th>Age (years)</th>
<th>Total length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>0</td>
<td>240</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>428</td>
<td>436</td>
<td></td>
</tr>
<tr>
<td>2</td>
<td>576</td>
<td>597</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>691</td>
<td>729</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>782</td>
<td>836</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>853</td>
<td>924</td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>909</td>
<td>996</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>953</td>
<td>1055</td>
<td></td>
</tr>
</tbody>
</table>

Fig. 9. Growth curves of male and female *Galeorhinus japonicus*. Open circle indicates male, closed circle female. The ranges of the total length at the attainment of sexual maturity are cited from Chen and Mizue (1973).

found that the pregnancy rate in the fifth ring group (about 4.5 years old) is 30.4% and the sixth ring group (about 5.5 years old) is 69.2%. These facts lead to the conclusion that the female of Eiraku shark has been already matured at 5 years old. And since the maximum number of ring can be observed until fourteenth in female, the maximum age of the Eiraku shark can be assumed at least 15 years old.

According to Olsen (1954) the sexual maturity age of School shark *Galeorhinus australis*, the same genus with our study, is 8 years old for male and 10 years old for
female. His result seems to be unduly long compared with the above mentioned. Nevertheless it is difficult to make the comparison with another species, because even in the same species such as *Squalus acanthias* the sexual maturity age is different according to its living waters (Holden and Meadows, 1962; Ketchen, 1975). In Sandbar shark *Carcharhinus milberti* the maturity age is about 3 years old (Wass, 1973), while in male Basking shark *Cetorhinus maximus* between 6 and 8 years old (Parker and Stott, 1965). For Japanese dogfish *Mustelus manazo*, according to Tanaka and Mizue (1978), the estimated maturity is at 2 to 3 years old. And judging from Tucker and Newnham (1957) suggestion on the length of Blue shark *Prionace glauca* at sexual maturity and stevens (1975) reports on its growth curve, we can consider that the maturity of the Blue Shark is between 5 and 6 years old. Thus the age of sexual maturity is different by species.

References