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Age and growth of the red tilefish, *Branchiostegus japonicus* in the northern East China Sea

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Abstract: *Age and growth of the red tilefish, Branchiostegus japonicus in the northern East China Sea were examined from right otoliths of 591 fish. Marginal increment analysis showed that annual ring formation occurs during the early winter months, supporting the hypothesis that one growth ring is deposited each year. Growth of red tilefish was expressed by von Bertalanffy's equation as* $TL_t = 61.5 [1 - \exp\{-0.150(t - 0.312)\}]$ *for males and* $TL_t = 50.6[1 - \exp\{-0.162(t + 0.337)\}]$ *for females, where* TL_t *is the total length in cm and t is age in years. It was found that females during the first 3 years grew larger than males, but after 3 years females were smaller than males. This phenomenon may be closely related to sexual maturity of red tilefish.*

Key words: *Red tilefish, Branchiostegus japonicus, Otolith, Age and growth, East China Sea*
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Introduction

Red tilefish, *Branchiostegus japonicus* is one of the important fishery resources in the East China Sea and is mainly caught with bottom long lines and drift gill nets in Korea. However, the fishery catch of this species in Korea and Japan steadily decreased during the last decade (Fig. 1), hence it was an important task to perform stock assessment and management in order to prevent the resource depletion.

The determination of fish age and growth is fundamental information in fish stock assessment (Sparre and Venema, 1998), while in the East China Sea there have been very few studies on age and growth of red tilefish except for the Hayashi (1976a,b) study. The previous study Hayashi (1976a,b) was conducted in the central and southern East China Sea using a method of otolith-reading.

On the other hand, long-term fluctuations in water temperature, a major environmental factor affecting growth of fish (Brown *et al*., 1989; Methot and Kramer, 1979; Wootton, 1990; Dua and Kumar, 2006), in the coastal waters of Korea have been described (Kang, 2000; Jeong *et al*., 2003; Min and Kim, 2006), while the recent information on age and growth dynamics of the red tilefish in the northern East China Sea is very poor.

Successful fisheries management requires precise and accurate age and growth information because inaccurate information can lead to serious errors in stock assessments and possibly overexploitation (Campana, 2001). The aim of this study is to obtain recent information on age and growth of the red tilefish, *Branchiostegus japonicus*, in the northern East China Sea to provide accurate information on stock structure.

Materials and Methods

The fishery catch of red tilefish in Korea and Japan were obtained from monthly reports of the Ministry of Maritime Affairs and Fisheries of Korea and reports of the Ministry of Agriculture, Forestry and Fisheries of Japan, respectively. The fishery catch in Japan shown in Fig. 1 was summed in Yamaguchi, Fukuoka, Saga, Nagasaki and Kumamoto located along the southern coast of Japan (Fig. 2).

Samples used in this study were monthly collected from the fish landed by bottom long lines in the northern East China Sea from December 2005 to December 2006. A major fishing ground of the coastal long line fishery is shown in Fig. 2. The red tilefish collected were stored with ice and were immediately measured after we returned to the laboratory.

In addition, the smaller specimens in the northern East China Sea were obtained from bottom trawl hauls conducted by the National Fisheries Research and Development Institute during October 26 to November 8, 2006 (Fig. 2). The net had a net height with 10-15 m and a cod end with a 10 mm mesh aperture, and was towed for 1 hr at 2.0-3.8 knots.

On the other hand, the total length and body length of all specimens were measured to the nearest 0.1 cm, and body weight was measured to the nearest 0.1 g recording the sex. The paired otoliths were then removed and kept in glass vials. The right otoliths were observed with transmitted and/or reflected light and the opaque zones were counted. The distance from the focus (F) to the outer margin of the opaque band of ring mark (ring radius, r_1-r_n) and the otolith radius (R) were measured on a transverse plane along a straight line through the focus (Fig. 3).

To examine the annual periodicity of the ring formation, verification was attempted using the relative marginal increment analysis following the equation (Licandeo *et al.*, 2006):

$$MI = (R - r_n) / (r_n - r_{n-1})$$

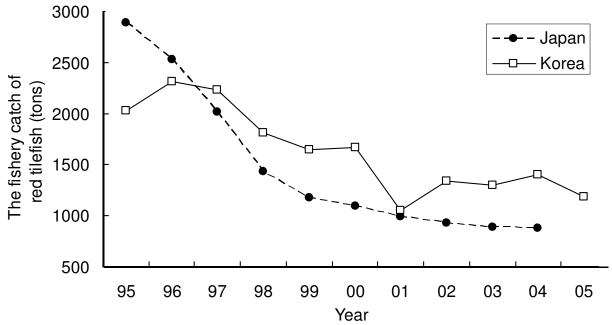

Fig. 1: Time series of the fishery catch of red tilefish in Korea and Japan, 1995-2005

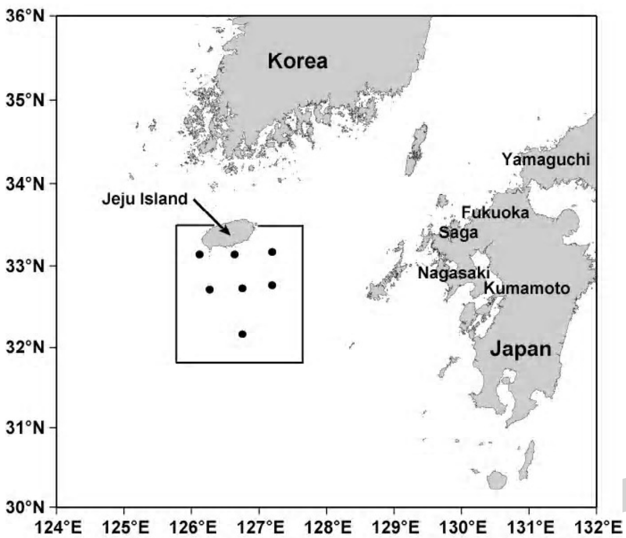

Fig. 2: The area denoted with a rectangle indicates a major fishing ground for coastal long line fishery. Black circles are sample stations of the trawl survey conducted by the National Fisheries Research and Development Institute, Korea

where MI is the marginal increment ratio, R is the otolith radius, r_n is the radius to the last complete ring and r_{n-1} is the radius to the previously completed ring. Average MI with SD was then plotted against month.

The estimate of the growth parameters were based on the von Bertalanffy growth formula (VBGF) (Sparre and Venema, 1998) expressed by the form:

$$L_t = L_\infty [1 - \exp\{-K(t - t_0)\}]$$

where, L_t is the predicted lenght at age t, L_∞ is the theoretical asymptotic length, K is the growth coefficient and t_0 is the theoretical age at zero length.

Results and Discussion

Comparison of size composition between sexes: As shown in Table 1, males and females ranged from 20.8 to 49.3 cm TL and from 19.5 to 37.7 cm TL, respectively. Female was generally smaller than male. Significant difference in total length (TL) between sexes was also found from a result of single factor ANOVA ($F_{1,589}$ = 207.10, $p < 0.001$).

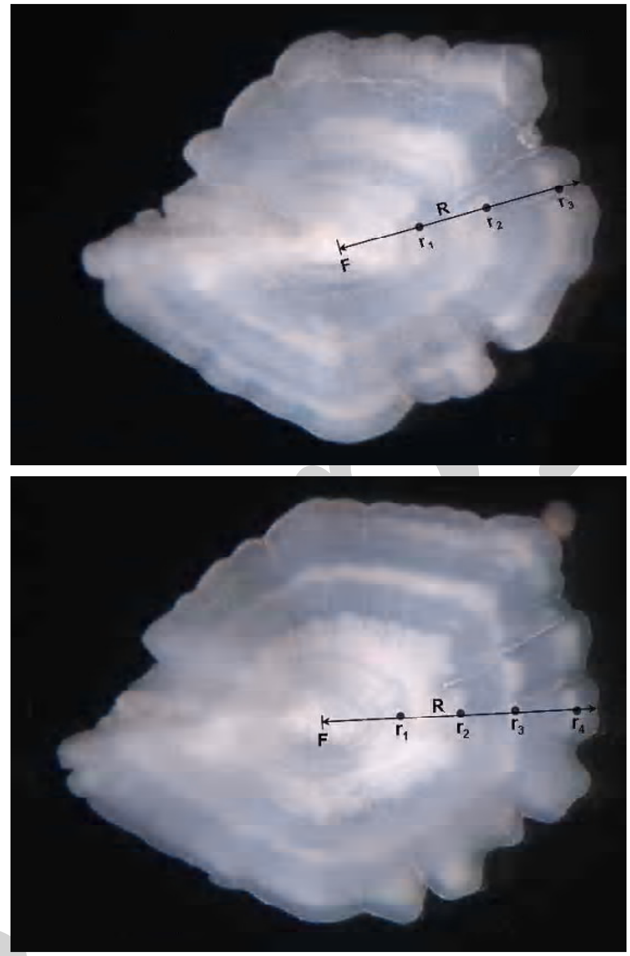

Fig. 3: Otolith of the red tilefish, *Branchiostegus japonicus*, female, 20.2 cm TL (top) and 26.5 cm TL (bottom), collected in December 2006. F, r_1-r_4 and R are focus, annual ring radii and otolith radius, respectively

Table - 1: Size distribution of the red tilefish sampled for age determination in the northern East China Sea from December 2005 to December 2006

Total length (cm)	Number of specimens		
	Male	Female	Total
19.1-22.0	5	16	21
22.1-25.0	30	104	134
25.1-28.0	25	135	160
28.1-31.0	65	69	134
31.1-34.0	63	14	77
34.1-37.0	43	2	45
37.1-40.0	11	4	15
40.1-43.0	2	0	2
43.1-46.0	2	0	2
46.1-49.0	0	0	0
49.1-52.0	1	0	1
Total	**247**	**344**	**591**

Aging and validation: Significant differences among months were found in the marginal increment analysis (single factor ANOVA for male: $F_{11,221}$ = 7.57, $p < 0.001$; for female: $F_{11,303}$ = 9.69, $p < 0.001$; Fig. 4). As shown in Fig. 4, since the minimum increments in both

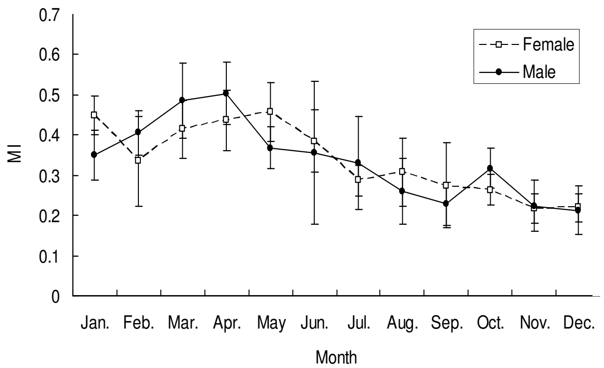

Fig. 4: Monthly changes in the marginal increment ratio (MI) for red tilefish. Vertical bars are mean ± SD

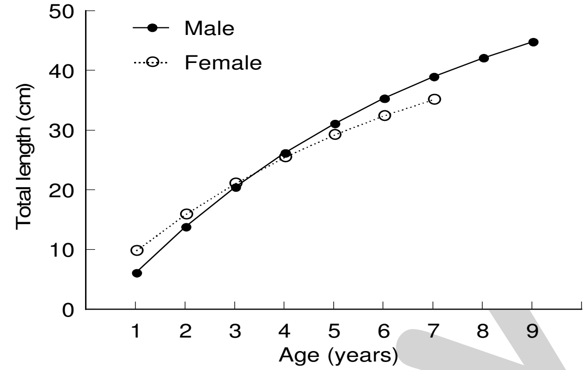

Fig. 6: Von Bertalanffy growth curves in male and female red tilefish. Circles are the back-calculated total length at age in years

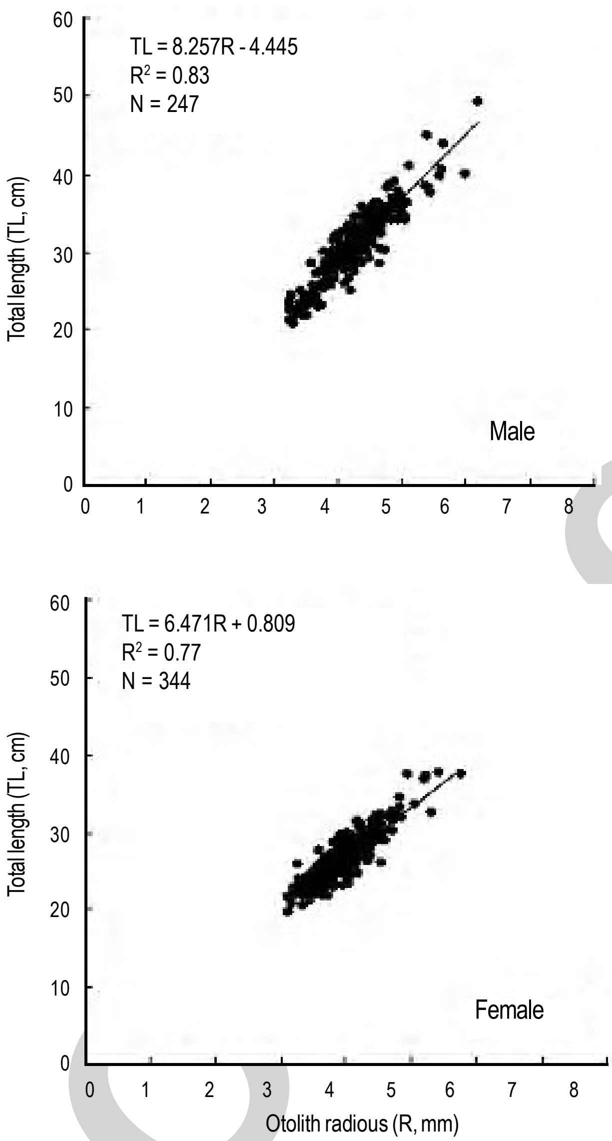

Fig. 5: Relationships between otolith radius and total length for male and female red tilefish

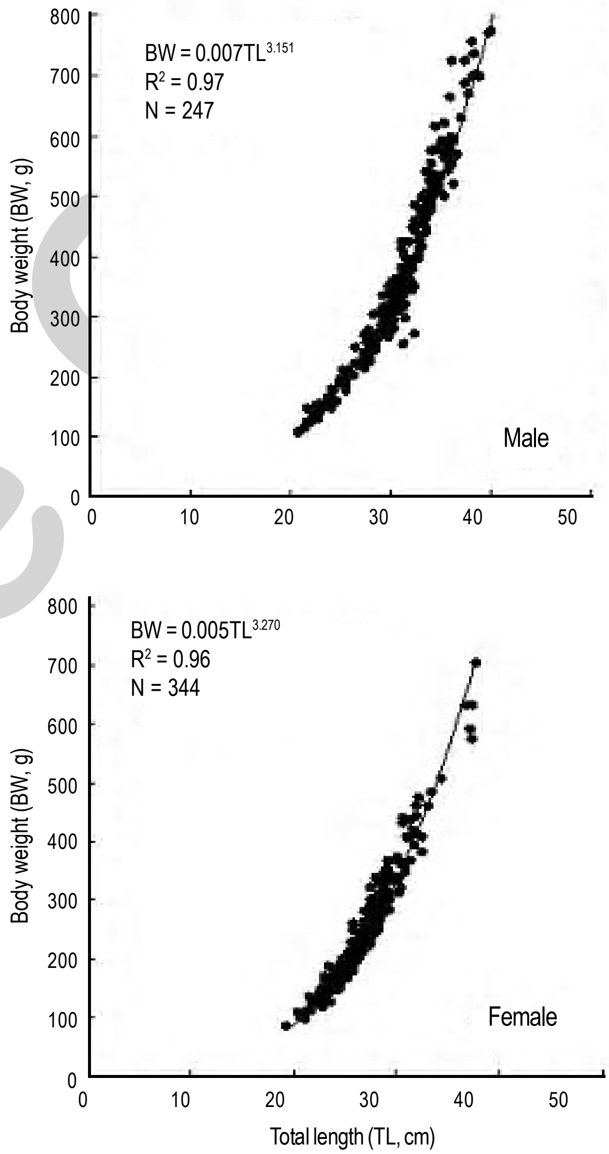

Fig. 7: Relationships between total length and body weight for male and female red tilefish

Table - 2: Mean ring radii (± S.D.) for each age group of red tilefish

Age	N*[1]	Ring radii (mm)								
		r1	r2	r3	r4	r5	r6	r7	r8	r9
Male										
2	6	1.97±0.13	3.20±0.13							
3	40	1.55±0.07	2.70±0.07	3.45±0.07						
4	69	1.48±0.03	2.57±0.04	3.35±0.05	3.88±0.05					
5	77	1.40±0.03	2.41±0.04	3.20±0.04	3.80±0.05	4.24±0.05				
6	41	1.34±0.04	2.36±0.05	3.13±0.06	3.78±0.07	4.27±0.08	4.62±0.08			
7	11	1.27±0.06	2.29±0.08	3.08±0.07	3.76±0.07	4.35±0.09	4.80±0.14	5.15±0.20		
8	2	1.18±0.22	2.02±0.48	2.83±0.54	3.48±0.63	4.11±0.62	4.56±0.58	4.96±0.51	5.30±0.54	
9	1	1.26	2.19	3.03	3.79	4.36	5.38	5.38	5.80	6.08
W.M.*[2]	247	1.44±0.17	2.50±0.25	3.26±0.15	3.82±0.11	4.26±0.09	4.66±0.15	5.14±0.24	5.47±0.49	6.08
BCL*[3]		7.57	16.22	22.49	27.08	30.71	34.03	38.01	40.69	45.73
Female										
2	12	2.10±0.14	3.21±0.17							
3	139	1.62±0.02	2.75±0.04	3.49±0.04						
4	120	1.51±0.03	2.56±0.03	3.33±0.04	3.85±0.04					
5	56	1.31±0.04	2.32±0.05	3.11±0.06	3.70±0.06	4.13±0.06				
6	15	1.41±0.10	2.40±0.11	3.20±0.13	3.84±0.14	4.33±0.16	4.68±0.17			
7	2	1.38±0.06	2.43±0.11	3.29±0.06	4.08±0.05	4.65±0.12	5.07±0.22	5.42±0.43		
W.M.*[2]	344	1.54±0.23	2.61±0.26	3.35±0.13	3.81±0.15	4.19±0.30	4.72±0.39	5.42±0.43		
BCL*[3]		10.77	17.69	22.50	25.46	27.91	31.37	35.86		

*[1] = number of otoliths used, *[2] = weighted mean, *[3] = back-calculated length (cm)

Table - 3: Comparison of the VBGF parameters for red tilefish. Parameters are given in body length (cm)

Author	Hayashi (1976)		Yoo (The author)	
Sex	Male	Female	Male	Female
L (cm)	34.9	31.1	52.5	43.0
K (year^{-1})	0.304	0.297	0.150	0.162
t_0 (year)	-0.377	-0.533	0.413	-0.218
N	819	744	247	344

sexes occurred during November to December, an annual ring formation appears to be completed during November to December in the northernEast ChinaSea.

Growth curves: Age estimates in this study were determined for 591 specimens. The study examined relationship between otolith radius (R) and total length (TL) because of legal necessity of minimal prohibition size for catch (Fig. 5), but the previous study (Hayashi, 1976b) examined relationship between otolith radius and body length (BL). In this study, growth curves was also made using the data of body length to compare to the values of the VBGF parameters found by the previous study (Table 3), while the calculation procedure not shown here. As shown in Fig. 3, these were approximately linear and the least-squares equations were as follows:

Male: $TL = 8.257R - 4.445$, $R^2 = 0.83$, $p < 0.001$
Female: $TL = 6.471R - 0.809$, $R^2 = 0.77$, $p < 0.001$

where TL is total length in cm and R is otolith radius in mm.

The mean radii of each successive otolith ring at each estimated age for males and females are shown in Table 2. Lee's phenomenon was found for the mean ring radii and the weighted mean radii of each ring were used to estimate the back-calculated length at age as shown in Table 2 (Yamaguchi *et al*., 1996).

The von Bertalanffy growth equations derived from the back-calculated lengths were as follows:

Male: $TL_t = 61.5[1 - \exp\{-0.150(t - 0.312)\}]$
Female: $TL_t = 50.6[1 - \exp\{-0.162(t + 0.337)\}]$

where t is age in years and TL_t is total length in cm at age t. The growth of females during the first 3 years was higher than that of males, but after 3 years males tended to grow larger than females (Fig 6).

The relationship between total length (TL, cm) and body weight (BW, g) is shown in Fig. 7. The equations were as follows:

Male: $BW = 0.007TL^{3.151}$, $R^2 = 0.97$, $p < 0.001$
Female: $BW = 0.005TL^{3.279}$, $R^2 = 0.96$, $p < 0.001$

The von Bertalanffy growth equations for body weight were as follows:

Male: $BW_t = 3032.8[1 - \exp\{-0.150(t - 0.312)\}]^{3.151}$
Female: $BW_t = 1935.9[1 - \exp\{-0.162(t + 0.377)\}]^{3.279}$

Furthermore, Table 3 shows the values of the VBGF parameters calculated using the data of body length (BL, cm) in order to compare to the values found by the previous study (Hayashi, 1976b). The values of L_∞ and K estimated in this study were larger and smaller than the values, respectively, for the Hayashi (1976b) study (Table 3).

The recent information on age structure and growth dynamics of red tilefish in the East ChinaSea is successfully provided by our aging study, and the information is greatly useful to conduct more accurate and precise stock assessment of the species. As shown in Table 3, the results of this study on the growth curve of red tilefish differed from those of the similar aging study conducted in the central and southern East China Sea (Hayashi, 1976b). The values of L_∞ estimated using the data of body length in this study were larger than the values recorded by Hayashi (1976b). This is probably due to different regions and sampling methods (Licandeo *et al*., 2006). In general, L and growth coefficient K are inversely correlated (Uehara and Shimizu, 1996) and this is goodly reflected in the results of Hayashi (1976b) and our studies (Table 3).

In addition, as a result of the marginal increment analysis in this study, marginal increments showed a minimum during November to December (Fig. 4), supporting the credible hypothesis that one growth ring is deposited each year. However, Hayashi (1976b) reported that an annual ring is formed in late winter or early spring. It has been generally known that annual ring formation occurs in response to spawning activity (Baeck and Huh, 2004; Shimose and Tachihara, 2006; Takahashi *et al*., 1995) and the low water temperature in winter (Kwok and Ni, 2000). It has been known that the spawning period of red tilefish in the waters around Jeju Island is from September through November (Choi *et al*., 2006). Further, Jeong *et al*. (2003) reported that sea surface temperature (SST) in the southern coast of Korea was 0.94$_\infty$ warmer during the past 35 years and Kang (2000) reported that SST in the coastal waters of Jeju Island during the last 30 years has an increasing tendency in winter. Thus, considering the results of the previous studies mentioned above (Hayashi, 1976b; Jeong *et al.*, 2000; Kang, 2000), the earlier annual ring formation is possibly due to the water temperature raised in and around Jeju Island, implying that the ring formation for red tilefish may be related to water temperature better than spawning activity.

On the other hand, according to Hayashi (1976b), male grew larger than female. Moreover, as a result of our study, total length of male was averagely higher than that of female (Table 1). The present study is furthermore clear the detail of increasing length differences between females and males with age. Namely, females during the first 3 years grew larger than males, but after that females were smaller than males (Fig. 6). Choi *et al*. (2004) reported that type of sex differentiation in red tilefish might be undifferentiated gonochorism and the total length observed in sexual maturity of female and male was 23.0 and 25.0 cm, respectively. As shown in Fig. 6, males after about 25 cm TL grew larger than females. Hence, until females reach sexual maturity they grow larger in order to hold the egg cases and mature ova inside the body cavity (Licandeo *et al.*, 2006) and after the sexual maturity females slowly grow due to depletion of energy for spawning. In order to confirm this, more detailed description on relationship between age and growth dynamics and reproductive biology in the red tilefish is indispensable.

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