Age and Growth of Blackfin Flounder *Glyptocephalus stelleri* in the East Sea, Korea

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Abstract

Age and growth of *Glyptocephalus stelleri* in the East Sea of Korea were determined, from monthly samples of commercial catches, caught by the eastern sea Danish seine fishery in 2007. The annuli of *G. stelleri* are formed once a year, with the boundary between opaque and translucent zones forming in September. Relationships between total length (TL) and total weight (TW) were $TW=0.002TL^{3.392}$ ($r^2=0.970$) for females and $TW=0.002TL^{3.335}$ ($r^2=0.961$) for males. TLs at annuli formation in otoliths were back-calculated from the otolith-length relationship and were adjusted to von Bertalanffy growth curves to $L_{\infty}=39.71(1 - \exp^{(-0.152(t+1.156)})$ for females and $L_{\infty}=32.16(1 - \exp^{(-0.213(t+0.879)})$ for males. From the age of 3 years, females grew faster than males ($P<0.05$).

Key words: *Glyptocephalus stelleri*, Blackfin flounder, Age, Growth

Introduction

Blackfin flounder *Glyptocephalus stelleri* is distributed in the East Sea and South Sea of Korea, Japan, Sakhalin, Tatar Strait, South Kurils Strait, and Bering Sea (Matarese et al., 1989; Choi et al., 2002). This benthic fish, mostly inhabits depths of more than 300 m moving to the coast water during its spawning season (Choi et al., 2002; Fedorov et al., 2003; National Fisheries Research and Development Institute, 2004).

G. stelleri are caught by gill nets, longlines, eastern sea Danish seines and bottom trawls in the East Sea, and the catch ratio of this fish reaches up to 54.9% of the total flounder catches in the East Sea (National Fisheries Research and Development Institute, 2010). Recent increases in the flounder

catches are related to increases in the catch of *G. stelleri*. Recently *G. stelleri* was selected as one of the species for a stock rebuilding project in the East Sea, and research on its ecology has been promoted. There have been many studies on *G. stelleri*, including studies on its age and growth (Hashimoto, 1953; Ishida and Kitakata, 1953), larvae (Okiyama, 1963), spawning ecology (Ivankova, 1974), feeding (Hayase and Hamai, 1974; Pushchina, 2000), and geographic distribution (Shvydkii and Vdovin, 2001; Tokranov, 2008). Studies of the biology and ecology of *G. stelleri* in Korean waters have included research on growth (Lee, 2008) and reproduction (Cha et al., 2008), and the species has also been reported in wider studies of fish (Park et al., 2007; Yoon et al., 2008; Lee, 2011).

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Research conducted in Korea on Pleuronectidae species includes studies of the ages and growths of *Limanda herzensteini* (Choi et al., 1986), *Verasper variegatus* (Jeon et al., 1996), *Pleuronectes yokohamae* (Park, 1997) and *Kareius bicoloratus* (Jun and Im, 2004).

The present study analyzed data on the age and growth of *G. stelleri*. These results can be used to provide a resource management plan for the continuous exploitation of *G. stelleri* resources.

Materials and Methods

Fish sampling and data collection

The *G. stelleri* samples were caught by the eastern sea Danish seine fishery in the sea adjacent to Gangwon-do, Korea, in 2007 (Fig. 1). Monthly samples were collected from landing ports at Mukho and Sokcho. The fish were sexed and total lengths (TL) and total weight (TW) were measured to the nearest 0.1 cm and 0.1 g, respectively.

Age determination

A pair of left/right otoliths was extracted and, after the removal of organic matters on the surface, they were dried and treated for easy observation by grinding close to the nucleus with sandpaper. Translucent and opaque zones appeared alternately in the otolith (Fig. 2A). Annuli were found at the boundary between opaque and translucent zones, and these were analyzed on a PC monitor (with the image analyzer package iSolution Lite, IMT i-Solutin Inc., Daejeon, Korea) connected to a dissecting microscope.

The otolith radius (R) was measured along the longest axis from the otolith center to the posterior margin, and the ring radius (r_n) was measured in μm from the otolith center to each annulus (Fig. 2B).

Fig. 1. The sampling area of the Blackfin flounder *Glyptocephalus stelleri* caught by the eastern sea Danish seine in the East Sea.

To determine the period of annulus formation, the monthly variation in the marginal index (MI) was calculated by the following equation:

$$MI = \frac{R - r_n}{r_n - r_{n-1}}$$

R is otolith radius and r_n is the ring radius to the n -th annulus.

Relationships between TW-TL and TL-R

Relationship between TW and TL was estimated by $TW = aTL^b$, where a and b are parameters. Relationship between TL and otolith radius (R) was estimated by linear regression analysis.

Fig. 2. Otolith of the Blackfin flounder *Glyptocephalus stelleri* by cutting dimension. (A) Otolith microphotographs of *Glyptocephalus stelleri* in September (50 $\times$, transmitted light; O, opaque zone; T, translucent zone). (B) Count of annual mark (reflected light; F, focus; R, radius).

Growth function

Growth in length of *G. stelleri* was obtained from the growth function of Von Bertalanffy (1938). The parameters obtained by the Walford method (Walford, 1946) were used as the initial values of the growth formula, which was presumed by nonlinear regression (Microsoft Excel solver routine):

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

L_t is the TL at age t , L_{∞} is the theoretical maximum length, K is the growth coefficient, and t_0 is the theoretical age at length zero.

Statistical analysis

An analysis of covariance (ANCOVA) was used to compare weight-length relationships between sexes, and growth difference between males and females for each age was examined by t -tests in the SPSS version 12.0 (SPSS INC., Chicago, IL, USA).

Results

Size composition

The total number of *G. stelleri* collected in the survey was 6,843, of which 3,064 were females and 3,779 males. TL was 9.5 - 38.1 cm for females and 8.6 - 29.5 cm for males, showing

that females are longer than males (Fig. 3).

Age determination

Monthly variation in MI was highest in July, low in August and September, showing an increasing trend from October (Fig. 4). The annuli of *G. stelleri* were formed from around September at the boundary between opaque and translucent zones in the otolith.

The average ring radius from the otolith center to each annulus is shown in Table 1. It ranged from $r_1 = 1.152 \pm 0.110$ mm to $r_9 = 3.782 \pm 0.340$ mm in females and from $r_1 = 1.160 \pm 0.106$ mm to $r_7 = 3.180 \pm 0.098$ mm in males. The average ring radius female was apparently longer than for males, for each age group.

Length-radius and weight-length relationship

Relationship between R and TL is shown in Fig. 5. There were significant differences in this relationship between males and females (ANCOVA, $F = 5.670$, $P < 0.05$), with $TL = 7.901R + 1.619$ ($r^2 = 0.737$) for females and $TL = 7.892R + 1.297$ ($r^2 = 0.685$) for males.

Relationship between TW and TL is shown in Fig. 6. It was $TW = 0.002TL^{3.392}$ ($r^2 = 0.970$) for females and $TW = 0.002TL^{3.335}$ ($r^2 = 0.961$) for males.

The average TL s for each annulus were back-calculated from the for going relationship between R and TL based on the average ring radii to the annuli (Table 2). The estimated TL s of

Table 1. Mean ring radius on the otolith of the Blackfin flounder *Glyptocephalus stelleri* in the East Sea

Sex	Estimated age	Number of samples	Mean otolith ring radius(mm)								
			r_1	r_2	r_3	r_4	r_5	r_6	r_7	r_8	r_9
Female	1	4	1.062								
	2	12	1.136	1.689							
	3	76	1.171	1.765	2.176						
	4	179	1.168	1.778	2.218	2.556					
	5	110	1.153	1.736	2.176	2.538	2.820				
	6	39	1.077	1.673	2.133	2.503	2.816	3.060			
	7	17	1.114	1.682	2.126	2.515	2.831	3.095	3.307		
	8	4	1.152	1.681	2.111	2.490	2.829	3.141	3.409	3.576	
	9	3	1.090	1.621	2.068	2.454	2.779	3.080	3.346	3.579	3.782
Weighted mean			1.152	1.748	2.186	2.541	2.819	3.076	3.329	3.577	3.782
S.D.			0.110	0.151	0.173	0.189	0.205	0.221	0.261	0.320	0.340
Male	1	5	1.137								
	2	14	1.143	1.746							
	3	98	1.177	1.770	2.172						
	4	130	1.153	1.730	2.147	2.470					
	5	66	1.155	1.704	2.104	2.437	2.713				
	6	7	1.134	1.707	2.106	2.436	2.728	2.941			
	7	2	1.209	1.768	2.227	2.523	2.789	3.004	3.180		
Weighted mean			1.160	1.737	2.146	2.459	2.717	2.955	3.180		
S.D.			0.106	0.141	0.157	0.173	0.188	0.148	0.098

Fig. 3. Length frequency distribution of the Blackfin flounder *Glyptocephalus stelleri* in the East Sea from January to December 2007.

Fig. 4. Monthly changes in marginal index of the Blackfin flounder *Glyptocephalus stelleri* in the East Sea from January to December 2007.

Fig. 5. Relationship between otolith radius and total length of Blackfin flounder *Glyptocephalus stelleri* in the East Sea from January to December 2007.

females were longer than those of males for all ages. The result of *t*-test used to examine the growth difference for each age between males and females showed no significant difference from age 1 to 2 ($P > 0.05$), but a significant difference from age 3 ($P < 0.05$). It is assumed that the growth differential between male and female *G. stelleri* appears from the age of 3.

Growth function

The Von Bertalanffy growth functions of male and female *G. stelleri* derived from nonlinear regression analysis are:

Fig. 6. Relationship between otolith radius and total length of Blackfin flounder *Glyptocephalus stelleri* in the East Sea from January to December 2007.

Table 2. Back-calculated total length at the formation of annuli in otolith of the Blackfin flounder *Glyptocephalus stelleri* in the East Sea

Sex	Estimated age	Number of samples	Mean total length(mm)								
			r ₁	r ₂	r ₃	r ₄	r ₅	r ₆	r ₇	r ₈	r ₉
Female	1	4	10.01								
	2	12	10.59	14.97							
	3	76	10.87	15.56	18.81						
	4	179	10.85	15.66	19.14	21.81					
	5	110	10.73	15.33	18.81	21.67	23.90				
	6	39	10.13	14.84	18.47	21.39	23.87	25.80			
	7	17	10.42	14.91	18.42	21.49	23.99	26.07	27.75		
	8	4	10.72	14.90	18.30	21.29	23.97	26.43	28.55	29.87	
	9	3	10.23	14.43	17.95	21.01	23.57	25.95	28.06	29.90	31.50
Weighted mean			10.72	15.43	18.89	21.69	23.89	25.92	27.92	29.88	31.50
S.D.			0.87	1.19	1.37	1.49	1.62	1.75	2.06	2.53	2.69
Male	1	5	10.27								
	2	14	10.32	15.07							
	3	98	10.59	15.26	18.44						
	4	130	10.40	14.95	18.24	20.79					
	5	66	10.41	14.74	17.91	20.53	22.71				
	6	7	10.25	14.77	17.92	20.52	22.82	24.51			
	7	2	10.84	15.25	18.87	21.21	23.30	25.01	26.39		
Weighted mean			10.45	15.01	18.23	20.70	22.74	24.62	26.39		
S.D.			0.84	1.11	1.24	1.36	1.49	1.17	0.78

Fig. 7. The von Bertalanffy growth curves in total length estimated by a non-linear regression method of Blackfin flounder *Glyptocephalus stelleri* in the East Sea from January to December 2007.

$L_t = 39.71(1 - \exp^{-0.152(t+1.156)})$ for females; $L_t = 32.16(1 - \exp^{-0.213(t+0.879)})$ for males (Fig. 7).

DISCUSSION

The age of *G. stelleri* can be determined from the otoliths by observation of the sagittal plane, where opaque and translucent zones clearly alternate. The ages of flounders have been determined through observation of the sagittal sections of otoliths in various species such as *Pleuronectes herzensteini* (Choi et al., 1986), *Verasper variegatus* (Jeon et al., 1996), *P. yokohamae* (Park, 1997), *C. pinetorum herzensteini* (Choe et al., 1999), *Cynoglossus joyneri* (Baek and Huh, 2004a), and *Cynoglossus abbreviatus* (Baek and Huh, 2004b).

The growth structures of the left/right otoliths and the annulus mark formation position are different in some flounders such as *V. variegatus* (Jeon et al., 1996) and *P. herzensteini* (Choi et al., 1986), but the annuli in the otoliths of flounders are formed uniformly in the eye-side otoliths. Therefore, the eye-side otoliths were used in this study.

Our results indicate that annulus of *G. stelleri* formed once a year in September, delineated by the boundary between opaque and translucent zones. Lee (2008) reported otoliths formed opaque zones from April. Hashimoto (1953) reported that vertebral annuli form translucent zones (annual mark)

during winter to spring. Ishida and Kitakata (1953) reported that otolith annuli form translucent zones from June to September, and that opaque zones are formed from March to May. Thus, the results of this study show differences in the formation of the annual mark.

The spawning period of *G. stelleri* has been reported to be April - June in the East Sea area of Korea (Cha et al., 2008), March - May in the Tottori, Japan (Tottori Prefecture Web Site, 2011), June - July in the Hokkaido, Japan (Hashimoto, 1953), April - July in Aomori, Japan (Hashimoto, 1953), May - September in Peter the Great Bay in Russia (Fadeev, 2005). Therefore, the spawning periods and formation of annual marks in *G. stelleri* show differences between sea areas.

We found that annulus formation occurred around September, with the first annulus formation at age 1.4 which is about 4 months after spawning period. Similar results have been reported for other flounders such as *Eopsetta grigorjewi* (Hwang et al., 1979), *K. bicoloratus* on the west sea coast (Jun and Im, 2004), and *S. schlegeli* inhabiting the Tongyeong marine ranch on the south coast of Korea (Park and Kang, 2007). Also, the annulus formation period of flounders in the East Sea was January - March for *P. herzensteini* (Choi et al., 1986), May for *C. pinetorum herzensteini* (Choe et al., 1999), and April - June for *L. yokohamae* (Kim et al., 1991), showing that the periods are different for each species, even when the environmental characteristics of their habitat are the same.

The growth of *G. stelleri* in Japanese and Russian sea is faster than that in the East Sea of Korea (Table 3). The maximum age of *G. stelleri* in Japanese sea is lower than that determined from the results of the present study, while the maximum age in Russian seas appears to be higher than that determined in the present study. Also, reviewing the actual size of samples, the maximum TL collected in this study was 38.1 cm, but the TL of *G. stelleri* in Russian seas was recently reported to be 62 cm by Orlov and Tokranov (2007), which is markedly longer than the fish examined in this study.

There was no significant difference between males and females in the annual growth rate of *G. stelleri* up to age 2 ($P>0.05$), but the growth rate of females was faster than that of males after age 3 ($P<0.05$). Hashimoto (1953), Ishida and Kitakata (1953), and Tokranov (2008) reported similar results, with the growth rates of females being faster than those of

Table 3. Comparison of age, total length and location of *Glyptocephalus stelleri* reported by different authors

Authors	Range of age and total length(cm)		Location
	Female	Male	
This study	1 (10.72)-9 (31.50)	1 (10.45)-7 (26.39)	East Sea, Korea
Hashimoto (1953)	1 (11.23)-5 (32.19)	1 (11.39)-3 (22.16)	Hokkaido and Hachinohe, Japan
Ishida and Kitakata (1953)	2 (13.13)-8 (34.23)	2 (13.25)-6 (26.08)	Hokkaido, Japan
Tokranov (2008)	6 (24.80)-20 (50.00)	5 (22.30)-15 (44.50)	Okhotsk, Russia
Lee (2008)	1 (12.32)-7 (27.78)	1 (10.63)-6 (21.55)	East Sea, Korea

males at an older age. The oldest specimens in this study were a 9-years-old female and a 7-years-old male. The oldest individuals in other studies have been 8 and 6 in the *G. stelleri* samples from Hokkaido Ken, Japan (Ishida and Kitakata, 1953), 5 and 3 in samples from Hokkaido Sea and Aomori Prefecture, Japan (Hashimoto, 1953), and 20 and 15 in samples from Kamchatka in the Sea of Okhotsk (Tokranov, 2008) for females and males, respectively.

Geographic differences in the growth rates and longevity of *G. stelleri* are considered to be related not only to environmental factors, but also to fishing intensity. Catches of *G. stelleri* in the East Sea have an increasing trend amounting to 54.9% of the total catches of the flounders (National Fisheries Research and Development Institute, 2010). High fishing intensity leads to the mean age of caught fish being reduced (Zhang, 1991). The low mean age of *G. stelleri* caught in the East Sea could indicate high fishing pressure. Intensive stock assessments and research on management plans are needed to rebuild the population of Korean flounders in the East Sea.

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