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

Jae Hyeong Yang¹, Sang Chul Yoon²*, Sung Il Lee³, Hyung Kee Cha³, Jong Bin Kim¹, Young Min Choi¹ and Jeong Ho Park¹

¹Fisheries Resources and Environment Division, East Sea Fisheries Research Institute, National Fisheries Research and Development Institute, Gangneung, Korea
²Fisheries Resources Management Division, National Fisheries Research and Development Institute, Busan, Korea
³Subtropical Fisheries Research Center, National Fisheries Research and Development Institute, Jeju, Korea
⁴Fisheries Resources and Environment Division, Southwest Sea Fisheries Research Institute, National Fisheries Research and Development Institute, Yeosu, Korea

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 $L_t=39.71\left(1 – \exp\left(-0.152(t+1.156)\right)\right)$ for females and $L_t=32.16\left(1 – \exp\left(-0.213(t+0.879)\right)\right)$ 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).
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.

### 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 \( \mu \)m from the otolith center to each annulus (Fig. 2B).

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.
Yang et al. (2012)  Age and Growth of Blackfin Flounder, Glyptocephalus stelleri

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 \( t \), \( L_{\infty} \) 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 \( r_1 = 1.152 \pm 0.110 \text{ mm} \) to \( r_9 = 3.782 \pm 0.340 \text{ mm} \) in females and from \( r_1 = 1.160 \pm 0.106 \text{ mm} \) to \( r_7 = 3.180 \pm 0.098 \text{ mm} \) 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 TLs 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 TLs of

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

<table>
<thead>
<tr>
<th>Sex</th>
<th>Estimated age</th>
<th>Number of samples</th>
<th>Mean otolith ring radius(mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>r1</td>
</tr>
<tr>
<td>Female</td>
<td>1</td>
<td>4</td>
<td>1.062</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>12</td>
<td>1.136</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>76</td>
<td>1.171</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>179</td>
<td>1.168</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>110</td>
<td>1.153</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>39</td>
<td>1.077</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>17</td>
<td>1.114</td>
</tr>
<tr>
<td></td>
<td>8</td>
<td>4</td>
<td>1.152</td>
</tr>
<tr>
<td></td>
<td>9</td>
<td>3</td>
<td>1.090</td>
</tr>
<tr>
<td></td>
<td>Weighted mean</td>
<td></td>
<td>1.152</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td></td>
<td>0.110</td>
</tr>
<tr>
<td>Male</td>
<td>1</td>
<td>5</td>
<td>1.137</td>
</tr>
<tr>
<td></td>
<td>2</td>
<td>14</td>
<td>1.143</td>
</tr>
<tr>
<td></td>
<td>3</td>
<td>98</td>
<td>1.177</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>130</td>
<td>1.153</td>
</tr>
<tr>
<td></td>
<td>5</td>
<td>66</td>
<td>1.155</td>
</tr>
<tr>
<td></td>
<td>6</td>
<td>7</td>
<td>1.134</td>
</tr>
<tr>
<td></td>
<td>7</td>
<td>2</td>
<td>1.209</td>
</tr>
<tr>
<td></td>
<td>Weighted mean</td>
<td></td>
<td>1.160</td>
</tr>
<tr>
<td></td>
<td>S.D.</td>
<td></td>
<td>0.106</td>
</tr>
</tbody>
</table>

http://e-fas.org
Fig. 3. Length frequency distribution of the 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 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, analysis are:

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

<table>
<thead>
<tr>
<th>Sex</th>
<th>Estimated age</th>
<th>Number of samples</th>
<th>Mean total length (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td>$r_1$</td>
</tr>
<tr>
<td>Female</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td></td>
<td>10.01</td>
</tr>
<tr>
<td>2</td>
<td>12</td>
<td></td>
<td>10.59</td>
</tr>
<tr>
<td>3</td>
<td>76</td>
<td></td>
<td>10.87</td>
</tr>
<tr>
<td>4</td>
<td>179</td>
<td></td>
<td>10.85</td>
</tr>
<tr>
<td>5</td>
<td>110</td>
<td></td>
<td>10.73</td>
</tr>
<tr>
<td>6</td>
<td>39</td>
<td></td>
<td>10.13</td>
</tr>
<tr>
<td>7</td>
<td>17</td>
<td></td>
<td>10.42</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td></td>
<td>10.72</td>
</tr>
<tr>
<td>9</td>
<td>3</td>
<td></td>
<td>10.23</td>
</tr>
<tr>
<td>Weighted mean</td>
<td></td>
<td></td>
<td>10.72</td>
</tr>
<tr>
<td>S.D.</td>
<td></td>
<td></td>
<td>0.87</td>
</tr>
<tr>
<td>Male</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td></td>
<td>10.27</td>
</tr>
<tr>
<td>2</td>
<td>14</td>
<td></td>
<td>10.32</td>
</tr>
<tr>
<td>3</td>
<td>98</td>
<td></td>
<td>10.59</td>
</tr>
<tr>
<td>4</td>
<td>130</td>
<td></td>
<td>10.40</td>
</tr>
<tr>
<td>5</td>
<td>66</td>
<td></td>
<td>10.41</td>
</tr>
<tr>
<td>6</td>
<td>7</td>
<td></td>
<td>10.25</td>
</tr>
<tr>
<td>7</td>
<td>2</td>
<td></td>
<td>10.84</td>
</tr>
<tr>
<td>Weighted mean</td>
<td></td>
<td></td>
<td>10.45</td>
</tr>
<tr>
<td>S.D.</td>
<td></td>
<td></td>
<td>0.84</td>
</tr>
</tbody>
</table>
otoliths in various species such as determined through observation of the sagittal sections oflucent zones clearly alternate. The ages of flounders have beenby observation of the sagittal plane, where opaque and trans-
that vertebral annuli form translucent zones (annual mark)formed opaque zones from April. Hashimoto (1953) reportedopaque and translucent zones. Lee (2008) reported otoliths
a year in September, delineated by the boundary between
(Choi et al., 1986), eye-side otoliths were used in this study.
are formed uniformly in the eye-side otoliths. Therefore, the
(Choi et al., 1986), but the annuli in the otoliths of flounders
al., 1999), Cynoglossus abbreviatus
Verasper variegatus
Cynoglossus joyneri
(Baeck and Huh, 2004a), and
Cynoglossus abbreviatus (Baek and Huh, 2004b).
The growth structures of the left/right otoliths and the an-
nulus mark formation position are different in some flounders
such as V. 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 age of G. stelleri can be determined from the otoliths
by observation of the sagittal plane, where opaque and trans-
lucent 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 of G. stelleri in Japanese and Russian sea is fast-
er 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

during winter to spring. Ishida and Kitakata (1953) reported
that otolith annuli form translucent zones from June to Sep-
tember, and that opaque zones are formed from March to May.
Thus, the results of this study show differences in the forma-
tion 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 Sep-
tember, 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. schlelegelii 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), show-
ing 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 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

\[
L_a = 39.71(1 - e^{-0.152(t+1.156)}) \quad \text{for females;} \quad L_a = 32.16(1 - e^{-0.213(t+0.879)}) \quad \text{for males (Fig. 7).}
\]

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

<table>
<thead>
<tr>
<th>Authors</th>
<th>Range of age and total length(cm)</th>
<th>Location</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Female</td>
<td>Male</td>
</tr>
<tr>
<td>This study</td>
<td>1 (10.72)-9 (31.50)</td>
<td>1 (10.45)-7 (26.39)</td>
</tr>
<tr>
<td>Hashimoto (1953)</td>
<td>1 (11.23)-5 (32.19)</td>
<td>1 (11.39)-3 (22.16)</td>
</tr>
<tr>
<td>Ishida and Kitakata (1953)</td>
<td>2 (13.13)-8 (34.23)</td>
<td>2 (13.25)-6 (26.08)</td>
</tr>
<tr>
<td>Tokranov (2008)</td>
<td>6 (24.80)-20 (50.00)</td>
<td>5 (22.30)-15 (44.50)</td>
</tr>
<tr>
<td>Lee (2008)</td>
<td>1 (12.32)-7 (27.78)</td>
<td>1 (10.63)-6 (21.55)</td>
</tr>
</tbody>
</table>
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 longevities 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.

**Acknowledgments**

We are grateful to three anonymous reviewers. This study was funded by a grant from the National Fisheries Research and Development Institute, Korea (RP-2011-FR-020).

**References**


