Age and Growth of Barbel Steed *Hemibarbus labeo* in Goe-san Lake in Korea

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Abstract

Age and growth of *Hemibarbus labeo* caught from Goe-san Lake in South Korea from March to November, 2011, were studied. A total of 201 specimens was collected, ranging from 110 to 580 mm in total length (TL). Males and females made up 47.9% and 52.1% of the sample, respectively. Marginal increment analyses showed that vertebral increments, each composed of one opaque and one hyaline zone, were deposited annually. Opaque edges were prevalent from June to July. The relationship between TL and vertebral radius was linear, with equations of $R = 0.0087 TL - 0.208$ (male) and $R = 0.0097 TL - 0.272$ (female). Regression equations between TL and total weight (TW) were $TW = 9 \times 10^{-6} TL^{2.987}$ (male), $TW = 8 \times 10^{-6} TL^{3.014}$ (female), and $TW = 9 \times 10^{-6} TL^{2.988}$ (combined sexes), according to the von Bertalanffy growth equation. Back-calculated TL was expressed using the von Bertalanffy equation as follows: $L_t = 438.25(1 - e^{-0.176(t+0.164)})$ for males, $L_t = 483.36(1 - e^{-0.147(t+0.115)})$ for females, and $L_t = 464.86(1 - e^{-0.162(t+0.176)})$ for the sexes combined. The growth performances were 4.526, 4.536, and 4.544, respectively.

Key words: Age, Growth, Barbel steed, *Hemibarbus labeo*, Goe-san Lake

Introduction

The barbel steed (*Hemibarbus labeo* Pallas, 1776) is a primary freshwater fish that prefers deep pools with running water in lower and middle river reaches, and forms schools. The species is carnivorous, feeding on shrimps and aquatic insects (Lin et al., 2010). It is well-defined and can be distinguished from congeners based on the broad and thick lateral lobes of the lower lop with folds (Yue, 1998). It is widely distributed in eastern Asia, from Vietnam to Russia. The limited ability of the species to migrate makes this family of obvious biogeographical interest, because their distribution closely reflects the geographical evolution of the landscape (Durand et al., 2002). This species is popular with anglers, and is a palatable, economical fish that is rich in nutrients (Novomodny et al., 2004).

Studies of *H. labeo* have been mainly conducted in Asia, almost all in China. Some researchers have used molecular methods to identify *Hemibarbus* species. Lv (2008) showed that the genetic diversity of *H. labeo* was high. They also inferred that *H. labeo* from Korea and Japan should be treated as synonym of *H. labeo* from China. Artificial reproduction of the species has also been studied recently. Xu et al. (2009) studied the reproduction of reared *H. labeo* in the Wusuli River. Luo et al. (2011) spent much time studying techniques for the artificial propagation of *H. labeo*. However, studies on growth are limited. The embryonic development of *H. labeo* was observed in the lower reaches of Fujiang River by He
et al. (1999). Xu et al. (2007) studied the effects of food and temperature on the growth of *H. labeo*. Lv (2008) compared the morphological characters and their correlations in *H. labeo* that were 1-2 years old. Scale and growth characteristics were studied in *H. labeo* by Lv et al. (2008). In Korea, no study of the age and growth of this species has been previously conducted, although several studies have examined infection status (Kim et al., 2008) and cytogenetic characters for the species identification of *Hemibarbus* (Bang et al., 2008).

In this study, vertebrae were used to determine the age of *H. labeo*. The aim was to determine the age composition and pattern of the *H. labeo* population, and to estimate the growth based on age. Such measurements can provide essential data for the assessment of fish stocks (Hilborn and Walters, 1992), and would provide useful information and reference data for fish management and exploitation in Goe-san Lake. Such information will also be helpful for guiding the future culture of this species in Korea.

**Materials and Methods**

**Sampling and data collection**

*H. labeo* were sampled from Goe-san Lake divided into upstream, midstream, and downstream areas (Fig. 1). Monthly samples from the lake were collected from March 2011 to February 2012, because the water in the lake was mostly frozen during January and February. In December and March, it was difficult to fish for barbel steel due to the low fish activities at lower temperatures. Fish were sampled by hook and line fishing, as well as from gill nets (length, 20 m; width, 1 m; mesh size, 5.0 cm and 7.5 cm) in Goe-san Lake. In the field, the samples were kept in insulated cans with ice bags for transportation to the laboratory. In the laboratory, the specimens were measured (total length [TL]) and weighed (total weight [TW]). We macroscopically examined the gonads of both sexes of *H. labeo* from Goe-san Lake, based on color and size.

The relationship between TL and TW was determined by fitting the data to a potential relationship for males and females using the equation:

\[ TW = a \cdot TL^b, \]

where TW is in grams, TL is in centimeters, and \(a\) and \(b\) are the parameters to be estimated.

**Vertebrae selection and preservation**

The first to third vertebrae were removed and immersed in 8-10% potassium hydroxide for 24 h to remove the muscle and connective tissue. Then they were washed with running water, the remaining tissue was brushed out, and the vertebrae were fixed by immersion in 70% alcohol until further observation (Joung et al., 2005).

**Determination of age and aging precision**

Ages were determined by counting the opaque zones in the vertebrae with an image processing system consisting of a computer, a video camera microscope (Zeiss DV8; Carl Zeiss, Jena, Germany) and the Optical Pattern Recognition System software package of Image-Pro Plus version 4.1 (Fig. 2).

Vertebrae were read twice at an interval of 20 days. They were read randomly to avoid bias in assigning ages. The average percentage error (APE) and coefficient of variation (CV) were used to compare age readings (Beamish and Fournier, 1981):
Age and Growth of *Hemibarbus labeo*

The growth performance ($\varphi'$) of a species can be captured by the growth index (Munro and Pauly, 1983). This value was used to compare the growth parameters obtained in the present work to those reported by others,

$$\varphi' = \lg K + 2 \lg L_\infty,$$

where $R$ is the number of times each fish was aged, $X_i$ is the $i$th age determination of the $j$th fish, and $X_j$ is the mean age calculated for the $j$th fish.

To validate the rings as indicators of fish age, rings were counted and radii were measured. The number of rings must show a directly proportional relation to vertebra size and fish length to be considered a growth indicator. This relationship was assessed by linear regression using the Fraser-Lee equation (Francis, 1990):

$$TL = a + bR,$$

where $R$ is the scale radius, and $a$ and $b$ are the parameters to be estimated.

Marginal increment (MI) analysis was used to validate the periodicity of growth (Lai et al., 1996):

$$MI = \frac{R - r_i}{r_i - r_{i-1}},$$

where $R$ represents the scale radius, and $r_i$ and $r_{i-1}$ are the annular radii of the last and penultimate annuli, respectively. The period of annulus formation was considered that for which MI displayed its smallest value.

**Estimation of growth**

Measurements were used for back-calculating size from growth rings. Length at previous age was estimated based on the linear regression between TL and vertebral radius using the Fraser-Lee method (Natanson et al., 1995),

$$[TL]_n = \left(\frac{R}{V_R}\right)[TL] - a + a,$$

where $[TL]_n$ is the back-calculated length at growth ring $n$, $R_n$ is the vertebra radius at the time $n$, $V_R$ is the vertebra radius at capture, $TL$ is that at capture, and $a$ is the intercept on the length axis of the linear relationship between $TL$ and vertebra radius.

The growth curve was modeled using the von Bertalanffy growth equation:

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

where $L_t$ is the TL at age $t$, $L_\infty$ is asymptotic length, $K$ is the coefficient of growth, and $t_0$ is the theoretical age when the predicted mean length is zero. The regression of fecundity on TL was analyzed. The ages at maturation by sex were calculated from this equation when the length at maturation was determined.

**Results**

**Sample composition**

The caught *H. labeo* ranged in size from 125.0 mm to 421.0 mm in TL and from 11.65 g to 599.26 g in TW. Of the 201 specimens collected, 97 (48.26%) were identified as males, ranging from 125.0 to 387.3 mm and 14.65 g to 550.98 g, while the other 104 (51.74%) individuals were females from 150.0 mm to 421.0 mm and 28.72 g to 599.26 g (Table 1). TLs ($\pm$ SD) of males and females were 250.7 ($\pm$ 51.66) mm and 301.5 ($\pm$ 46.92) mm, respectively. Females were larger than males. The length-frequency distribution is shown in Fig. 3. There was a significant difference in length-frequency dis-
of the TW-TL regressions did not differ significantly between sexes (ANCOVA test for equal slopes: $F_{\text{male}} = 0.991$, $P > 0.05$; ANCOVA test for intercepts: $F_{\text{female}} = 15.68$, $P > 0.05$). The regression equations were developed as $TW = 9 \times 10^{-6} TL^{2.987}$ (male) and $TW = 8 \times 10^{-6} TL^{3.014}$ (female) (Fig. 4). The equation for the combined sexes was $TW = 9 \times 10^{-6} TL^{2.988}$. The obtained values (b) were not significantly different from 3 ($t$-test, male: $t = 1.35$, $P > 0.05$; female: $t = 2.01$, $P > 0.05$), so the hypothesis of isometric growth was accepted for this species (Pauly, 1984).

**Period of ring formation**

MI analysis (Fig. 5) showed a trend of increasing MI width from spring to autumn. Significant differences among months were found (one-way ANOVA for males: $F = 14.44$, $P < 0.05$; $F = 21.78$, $P < 0.05$). As shown in Fig. 4, the minimum increments in both sexes occurred in June, increased gradually from June to October, and attained the maximum value in October. Except for the MI value in winter, the rings formed annually, and the same results have been found in some other freshwater fish including *Ictalurus punctatus* (Appelget and Smith, 1951), *Glyptosternon maculatum* (Ding et al., 2011), *Silurus glanis* (Alp et al., 2011), and *Schizothorax o’connori* (Ma et al., 2011). Therefore, annual ring formation appears to be completed during June to July in Goe-san Lake.

**Ageing structure and ageing precision**

Age estimates ranged from 2 to 10 years for females and from 1 to 8 years for males, based on the examination of 201 vertebral centers. Each vertebra was read twice (Fig. 6). The APE estimated from the two readings ranged from 0.02 to 0.39 (mean, 0.18), and the CV ranged from 0.04 to 0.78 (mean, 0.23). The paired $t$-test applied to compare the age assigned by the two readings revealed significant differences ($P < 0.05$) (Fig. 6). The older the fish, the greater the bias.

**Relationship between TL and vertebral radius**

The relationship between the TL and vertebral radius was

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**Table 1.** Composition of total length (mm) and total weight (g) of *Hemibarbus labeo* from April to November

<table>
<thead>
<tr>
<th>Month</th>
<th>Sex</th>
<th>Total length (mm)</th>
<th>Total weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Male</td>
<td>Female</td>
<td></td>
</tr>
<tr>
<td>April</td>
<td>4</td>
<td>11</td>
<td>210.1-370.1</td>
</tr>
<tr>
<td>May</td>
<td>10</td>
<td>20</td>
<td>170.0-387.3</td>
</tr>
<tr>
<td>July</td>
<td>26</td>
<td>22</td>
<td>168.8-380.4</td>
</tr>
<tr>
<td>August</td>
<td>18</td>
<td>10</td>
<td>148.0-397.2</td>
</tr>
<tr>
<td>September</td>
<td>31</td>
<td>5</td>
<td>148.0-421.0</td>
</tr>
<tr>
<td>October</td>
<td>10</td>
<td>18</td>
<td>125.0-383.0</td>
</tr>
<tr>
<td>November</td>
<td>10</td>
<td>6</td>
<td>168.0-362.0</td>
</tr>
<tr>
<td>Total</td>
<td>109</td>
<td>92</td>
<td>125.0-421.0</td>
</tr>
</tbody>
</table>

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**Fig. 4.** Relationship of total length and total weight in the samples of *Hemibarbus labeo*.

**Fig. 5.** Monthly change of marginal growth index (MI) for male and female of *Hemibarbus labeo*. 

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tributions between the two populations from upstream-midstream and downstream ($d_{\text{max}} = 0.2035$, $P < 0.05$).
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Back-calculated length at the time of annulus formation

Back-calculated TLs were obtained from the corrected ring radius using the Fraser-Lee method, which gives the TL at the time of ring formation for males, females, and combined sexes. There was no indication of Rose Lee’s phenomenon, in which computed sizes at a given age tend to be smaller when derived from measurements of older fish (Francis, 1990).

Growth equation and growth performance

Von Bertalanffy growth equations were determined from the back-calculated TLs of males, females, and combined sexes. The equations were $L_t = 438.25(1 - e^{-0.175(t+0.164)})$, for males, $L_t = 483.36(1 - e^{-0.147(t+0.115)})$ for females, and $L_t = 464.86(1 - e^{-0.162(t+0.176)})$ for the sexes combined (Fig. 8). The growth performances were 4.526, 4.536, and 4.544, respectively. There was no significant difference in the von Bertalanffy growth curves ($F$-test, $P > 0.05$) between sexes.

Discussion

This study reports on the age and growth of $H. \text{labeo}$ in Goe-san Lake, using vertebrae as an age determinant marker. Katsanevakis and Maravelias (2008) stated that the choice of the best growth model is subjective and should be in some cases based on the decision of the researcher, founded on experience with the species and previous studies to interpret the viability of estimated parameters and goodness-of-fit. Caillet and Goldman (2004) mentioned that there has been an increase in the use of both verification and validation methodologies in fish growth. Using a combination of verification and validation approaches is most likely to produce convincing results. In this study, scales and vertebrae could have been used to determine fish age by comparison with other calcified structures in the authors experience, but Lv et al. (2008) studied the growth of $H. \text{labeo}$ from scales. Therefore, we chose to use vertebrae as a comparison.

Vertebral rings occur systematically as length increases. Their formation is probably more directly related to factors other than size (Pratt and Casey, 1983). All of the factors influencing the formation of the opaque zone are not clear, but several hypotheses explaining its deposition have been reported. Food shortages and food deprivation caused by migration and spawning (Yosef and Casselman, 1995) may affect zone formation. In this study, the water flow rate of a dam directly affected an increase in food availability in March and April,
corresponding to the time of opaque band formation, suggesting that the fast growth of *H. labeo* might be correlated to its feeding behavior. However, the underlying mechanisms governing band deposition still need to be determined.

In this study, *H. labeo* grew relatively fast during the first 3 years of life, and attained about 40% of maximum length during the third year. The highest growth rate occurred in the first year (Fig. 8). After the second year, the annual growth rate dropped rapidly. This is consistent with the results of Lv et al. (2008), and may be related to physiological changes caused by factors such as food availability, temperature, and sexual maturity.

The growth performance of fish reflects prevailing abiotic conditions such as temperature regime, as well as the ability of a species to meet its nutritional requirements (Beamesderfer and North, 1995). This value was also used to compare the growth parameters obtained in the present work to those reported by others. A comparison of the parameters of von Bertalanffy growth equations from the literature (Table 2) showed that male *H. labeo* have higher growth potential than females in Goe-san Lake, and that the growth potential of *H. labeo* collected from the Wusulijiang River in China us lower than that of *H. labeo* collected from Goe-san Lake. This may be related to the good conditions in this lake, which is not overexploited.

### Acknowledgments

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### References


<table>
<thead>
<tr>
<th>Study Location</th>
<th>Group</th>
<th>Length</th>
<th>Size range (mm)</th>
<th>n</th>
<th>$L_\infty$ (mm)</th>
<th>K (/y)</th>
<th>$t_0$ (y)</th>
<th>$\beta$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Korea</td>
<td>Male</td>
<td>TL</td>
<td>125-387</td>
<td>97</td>
<td>438.25</td>
<td>0.175</td>
<td>-0.164</td>
<td>4.344</td>
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<tr>
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<td>Female</td>
<td>TL</td>
<td>150-421</td>
<td>104</td>
<td>483.36</td>
<td>0.147</td>
<td>-0.115</td>
<td>3.466</td>
</tr>
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<td>201</td>
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<td>0.162</td>
<td>-0.176</td>
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<td>415.7</td>
<td>0.233</td>
<td>-0.232</td>
<td>3.972</td>
</tr>
</tbody>
</table>

TL, total length; BL, body length.
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