

Comparative Analysis of the Morphometric Changes in Ussurian bullhead, *Leiocassis ussuriensis*, and Korean bullhead, *Pseudobagrus fulvidraco*, in the Early Period of Growth

Sang Gu Lim¹, Hyoung Kyun Han¹, Jung Ha Kang², Hye Jung Park³, Ji Su Oh³, Ji Su Lim³,
In Bon Goo³ and †In-Seok Park³

¹Inland Aquaculture Research Center, National Fisheries Research & Development Institute,
Jinhae 645-758, Republic of Korea

²Biotechnology Research Division, National Fisheries Research & Development Institute,
Busan 619-705, Republic of Korea

³Division of Marine Environment and Bioscience, Korea Maritime and Ocean University,
Busan 606-791, Republic of Korea

ABSTRACT : Morphometric changes in the Ussurian bullhead, *Leiocassis ussuriensis*, and the Korean bullhead, *Pseudobagrus fulvidraco*, were observed during the early period of growth. Yolk length, yolk height, and yolk volume in the two species decreased within 9 days post-hatching (DPH) ($p < 0.05$). The body lengths and body heights of both species increased gradually to 150 and 130 DPH, respectively ($p < 0.05$). The horizontal distance between the anteriormost extension of the head and the anterior insertion of the pectoral fin, the anteriormost extension of the head \times the verticality position of the anterior insertion of the primary dorsal fin rays, and the anterior insertion of the primary dorsal fin \times the anterior insertion of the pectoral fin were greater in the Korean bullhead than in the Ussurian bullhead ($p < 0.05$). However, the relative sizes of the head region, pectoral fin, ventral fin, and anal fin were greater in the Ussurian bullhead than in the Korean bullhead ($p < 0.05$), and relative body depth and the size of the outer-mandible barbel were greater in the Korean bullhead than in the Ussurian bullhead ($p < 0.05$). The growth curves of the morphometric characteristics of both species were divided into three types.

Key words : Korean bullhead, *Pseudobagrus fulvidraco*, Morphometric characteristic, Ussurian bullhead, *Leiocassis ussuriensis*

INTRODUCTION

The use of morphometric analyses to discriminate between genetically discrete groups within a fish species is limited by the difficulty of identifying environmentally induced variations in body shape (Ihssen et al., 1981; Currens et al., 1989; Park et al., 2001). Both the truss and classical

dimensions are used to describe the fish body shape (Hubbs & Lagler, 1947; Sträuss & Bookstein, 1982). The truss dimensions consist of a systematically arranged set of distances that are measured between a set of preselected anatomical landmarks (Sträuss & Bond, 1990). These landmarks are identified based on local morphological features and are chosen to divide the body into functional units

Manuscript received 29 August 2013, Received in revised form 3 September 2013, Accepted 11 September 2013

† Corresponding Author : In-Seok Park, Division of Marine Environment Bioscience, College of Ocean Science and Technology, Korea Maritime and Ocean University, Busan 606-791, Republic of Korea. Tel : +82-51-410-4321, Fax : +82-51-405-4322, E-mail : ispark@kmou.ac.kr

This is an Open Access article distributed under the terms of the Creative Commons Attribution Non-Commercial License (<http://creativecommons.org/licenses/by-nc/3.0>) which permits unrestricted non-commercial use, distribution, and reproduction in any medium, provided the original work is properly cited.

(Sträuss & Bond, 1990). The truss dimensions, which include the components of body depth and length along the longitudinal axis, have theoretical advantages over the classical morphometric characteristics in the discrimination of groups (Park et al., 2007).

The Ussurian bullhead, *Leiocassis ussuriensis*, belongs to the family Bagridae and is found in several Korean rivers (the Daedong River, Amnok River, Imjin River, Han River, and Geum River, and recently in the Nakdong River) (Kim et al., 1997). It is a nocturnal fish, living in slow-moving rivers with bottoms of mud or sand. Its chewy flesh has an excellent taste of umami, and together with the Korean bullhead, *Pseudobagrus fulvidraco*, it is an essential ingredient of the spicy freshwater fish stew of Korea (Lim et al., 2012).

The Korean bullhead belongs to the Siluriformes, in the family Bagridae (Park & Lee, 1996). It occurs throughout Asia, and is commonly found in the West Sea and South Sea, as well as the midstream and downstream reaches of rivers in Korea (Park & Lee, 1996; Kim & Park, 2002). The Korean bullhead body lacks scales and the head is flat. It is a predominantly carnivorous fish that feeds preferentially at night (Lee, 1993). In common with Ussurian bullhead, it is highly valued for its taste and together with the catfish or carp, is the main component of a spicy freshwater fish stew. Consequently, the demand for the Korean bullhead is increasing (Lee, 1993).

Yolk absorption and early growth have been investigated extensively in the rainbow trout, *Oncorhynchus mykiss*, and the chum salmon, *O. keta*, and eye development has been studied in the dark-banded rockfish, *Sebastes inermis*, and the dotted gizzard shad, *Konosirus punctatus* (Zhang et al., 1995; Park et al., 1996; Park et al., 2006; Park et al., 2012). However, there have been few similar studies of the Ussurian bullhead or Korean bullhead, two species with similar spawning seasons and habitats.

In this study, we investigated and compared the process of yolk absorption in these two species and examined the changes in their morphometric characteristics during their early development. Our results should provide important

data for basic research into yolk absorption and the external and internal changes that occur in larval fish.

MATERIALS AND METHODS

1. Experimental fish

We examined juvenile specimens of the Ussurian bullhead, *L. ussuriensis* ($n = 30$), and the Korean bullhead, *P. fulvidraco* ($n = 30$). On June 28, 2012, we obtained fertilized eggs of both species from the Southern Island Fishery Research Institute of the National Fisheries Research and Development Institute of Korea. The larvae were reared and bred at the Fisheries Genetics and Breeding Sciences Laboratory, Korea Maritime University, Busan, Korea, in 10 tanks (100 ℓ) that included a circulation pump, an aeration system, and a temperature control system. Dissolved oxygen levels were maintained with an air pump, and the water temperature was maintained at $26 \pm 0.5^\circ\text{C}$.

2. Morphometric characteristics

Using digital Vernier calipers (CD-20CP, Mitutoyo, Japan) and an electric balance (JW-1, Korea); the morphometric dimensions and body weights were measured in units of 0.1 mm and 0.01 g, respectively. To measure the eye diameter (ED), yolk length (YL), yolk height (YH), and yolk volume (YV), we fixed 50 larvae each of the Ussurian bullhead and the Korean bullhead in 10% neutral formalin every day from one day post-hatching (1 DPH) to 9 DPH. We also measured the larvae of both species in the yolk stage using the same method. We measured standard length (L_s), YL, YH, and ED according to DPH. Volume = $\pi/6 \times a \times b^2$, where a is yolk length and b is yolk height (Park et al., 1996).

Ussurian bullhead ($n = 50$) and Korean bullhead larvae ($n = 50$) were randomly selected every 10 DPH from 10 DPH to 150 DPH and 130 DPH, respectively, and fixed in 10% neutral formalin. Body outline measurements were made for 25 distances between landmarks for both truss and classical dimensions (Table 1, Fig. 1). We measured the Ussurian bullhead and Korean bullhead to the nearest

Table 1. Morphometric dimensions of the Ussurian bullhead, *Leiocassis ussuriensis*, and the Korean bullhead, *Pseudobagrus fulvidraco*, examined in this study*

Morphometric dimensions	
- Horizontal distance -	
Standard length	<i>L_s</i>
Horizontal distance between the most anterior extension of the head and the anterior insertion of the ventral fin	HHAV
Horizontal distance between the most anterior extension of the head and the anterior insertion of the pectoral fin	HHAP
Horizontal distance between the most anterior extension of the anal fin and the anterior insertion of the caudal fin	HDAC
Length of the fin rays of the primary dorsal fin	LPDF
Length of the fin rays of the pectoral fin	LPF
Length of the fin rays of the ventral fin	LVF
Length of the fin rays of the anal fin	LAF
Upper maxilla barbel length	UMaxBL1
Lower maxilla barbel length	LMaxBL1
Outer mandible barbel length	OManBL
Inner mandible barbel length	IManBL
Eye diameter	ED
- Direct distance -	
Truss dimension	
Most anterior extension of the head × longest point of gill cover from maxilla	1 × 9
Anterior insertion of primary dorsal fin × anterior insertion of the pectoral fin	2 × 8
Anterior insertion of primary dorsal fin × verticality position of the primary dorsal fin ray's anterior insertion	2 × 7
Anterior insertion of primary dorsal fin × anterior insertion of the ventral fin	2 × 6
Anterior insertion of primary dorsal fin × posterior insertion of the anal fin	2 × 5
Anterior insertion of secondary dorsal fin × anterior insertion of the pectoral fin	3 × 8
Anterior insertion of secondary dorsal fin × verticality position of the primary dorsal fin ray's anterior insertion	3 × 7
Anterior insertion of secondary dorsal fin × anterior insertion of the ventral fin	3 × 6
Anterior insertion of secondary dorsal fin × posterior insertion of the anal fin	3 × 5
Classical dimension	
Most anterior extension of the head × anterior insertion of the primary dorsal fin	1 × 2
Most anterior extension of the head × verticality position of the primary dorsal fin ray's anterior insertion	1 × 7
Anterior insertion of primary dorsal fin × anterior insertion of the caudal fin	2 × 4

* Each dimension is shown in Fig. 1.

1 mm using a Vernier calipers (CD-20CP; Japan). Their weights were measured with an electronic scale according to DPH.

The following horizontal distances were measured: *L_s*, the horizontal distance between the anteriormost head and the anterior insertion of the ventral fin (HHAV), the horizontal distance between the anteriormost extension of the head and the anterior insertion of the pectoral fin (HHAP), the horizontal distance between the anteriormost extension

of the anal fin and the anterior insertion of the caudal fin (HDAC), the length of the fin rays of the primary dorsal fin (LPDF), the length of the fin rays of the pectoral fin (LPF), the length of the fin rays of the ventral fin (LVF), the length of the fin rays of the anal fin (LAF), the upper maxilla barbel length (UMaxBL), the lower maxilla barbel length (LMaxBL), the outer mandible barbel length (OManBL), the inner mandible barbel length (IManBL), and ED. Other

distances (truss morphometric dimensions and classical morphometric dimensions) were direct distance measurements.

The external truss morphometric dimensions measured were as follows: 1 × 9, the anteriormost extension of the head × the longest point of the gill cover from the maxilla; 2 × 8, the anterior insertion of the primary dorsal fin × the anterior insertion of the pectoral fin; 2 × 7, the anterior insertion of the primary dorsal fin × the vertical position of the anterior insertion of the primary dorsal fin ray; 2 × 6, the anterior insertion of the primary dorsal fin × the anterior insertion of the ventral fin; 2 × 5, the anterior insertion of the primary dorsal fin × the posterior insertion of the anal fin; 3 × 8, the anterior insertion of the secondary dorsal fin × the anterior insertion of the pectoral fin; 3 × 7, the anterior insertion of the secondary dorsal fin × the vertical position of the anterior insertion of the primary dorsal fin ray; 3 × 6, the anterior insertion of the secondary dorsal fin × the anterior insertion of the ventral fin; and 3 × 5, the anterior insertion of the secondary dorsal fin × the posterior insertion of the anal fin (Fig. 1B). Each

external morphometric dimension was analyzed relative to *Ls*.

The external classical morphometric dimensions measured were as follows: 1 × 2, the anteriormost extension of the head × the anterior insertion of the primary dorsal fin; 1 × 7, the anteriormost extension of the head × the vertical position of the anterior insertion of the primary dorsal fin ray; and 2 × 4, the anterior insertion of the primary dorsal fin × the anterior insertion of the caudal fin (Fig. 1B). Each external morphometric dimensions was analyzed relative to *Ls*.

We sampled the larvae every five days from 1 DPH to 10 DPH, and thereafter at 10 day intervals. *Ls* and the body weight of each larva were measured, and their relationship analyzed. The values given are morphometric dimensions/*Ls*.

3. Statistical analysis

The study was performed in triplicate and the results are reported as means ± SD (*n* = 30), unless otherwise stated. The data were analyzed with one-way analysis of variance (ANOVA) using the SPSS statistical package (SPSS 9.0, SPSS Inc., Chicago, IL, USA). The means were compared with Duncan's multiple range test and were considered significantly different at *p* < 0.05.

RESULTS

Table 2 lists four morphometric dimensions/*Ls* for the Ussurian bullhead, *L. ussuriensis*, and the Korean bullhead, *P. fulvidraco*, from 1 DPH to 9 DPH. In the Ussurian bullhead, ED was 19.4 at 1 DPH. Thereafter, the eye/*Ls* ratio decreased to 6.6 at 9 DPH (*p* < 0.05). YL also decreased from 31 to 6.4 by 9 DPH and this rate of decrease was greater than for any other dimension (*p* < 0.05). YH decreased gradually from 4.7 to 2.1 by 9 DPH (*p* < 0.05). From 1 DPH to 9 DPH, YL was always greater than YH (*p* < 0.05). In the Korean bullhead up to 9 DPH, the values for ED, YL, and YH decreased from 18.4 to 6.8, from 30.4 to 6.5, and from 4.5 to 2.3, respectively (*p* < 0.05).

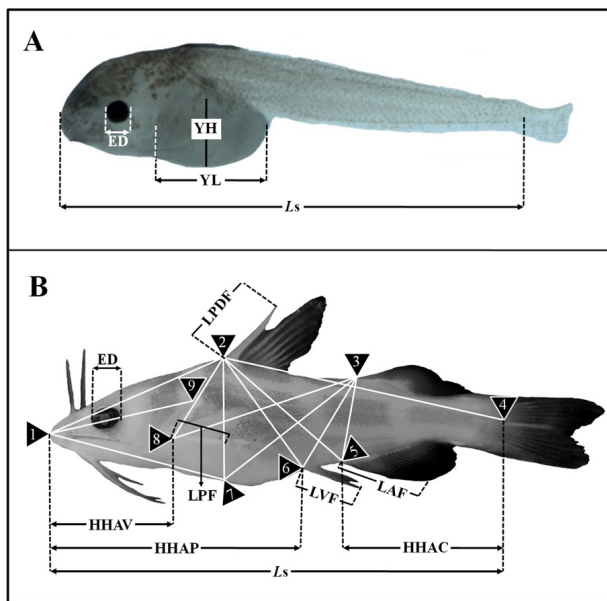


Fig. 1. Morphometric measurements between each landmark for the Ussurian bullhead, *Leiocassis ussuriensis*, and the Korean bullhead, *Pseudobagrus fulvidraco*, examined in this study. Larva in the yolk stage (A) and juvenile (B) of the Korean bullhead. For abbreviations, see Table 1. YL: yolk length; YH: yolk height.

Table 2. Results of Duncan's multiple range test for differences in four characteristics of the Ussurian bullhead, *Leiocassis ussuriensis*, and the Korean bullhead, *Pseudobagrus fulvidraco*, from 1 DPH to 9 DPH*

Day post hatched	Morphometric dimension/Ls (%)			
	ED	Yolk		
		Length	Height	Volume
Ussurian bullhead				
1	19.4 ± 2.34 ^A	31.4 ± 3.12 ^A	4.7 ± 0.66 ^A	1,633.5 ± 2.59 ^A
2	15.6 ± 2.26 ^B	28.7 ± 6.50 ^B	4.3 ± 0.11 ^B	1,249.7 ± 3.16 ^B
3	12.5 ± 1.64 ^C	22.9 ± 2.92 ^C	4.4 ± 0.25 ^C	1,044.0 ± 4.15 ^C
4	10.7 ± 1.29 ^D	23.1 ± 1.10 ^D	4.5 ± 0.24 ^D	1,101.6 ± 5.20 ^D
5	7.4 ± 1.70 ^E	20.7 ± 8.64 ^E	4.6 ± 0.34 ^E	1,031.5 ± 1.62 ^E
6	9.6 ± 1.14 ^F	22.8 ± 4.17 ^F	4.6 ± 0.20 ^F	1,136.1 ± 2.21 ^F
7	8.0 ± 3.00 ^G	22.5 ± 3.66 ^G	4.6 ± 0.32 ^G	1,121.2 ± 1.53 ^G
8	7.4 ± 1.35 ^H	17.7 ± 2.25 ^H	4.5 ± 0.47 ^H	760.9 ± 5.23 ^H
9	6.6 ± 3.16 ^I	6.4 ± 3.73 ^I	2.1 ± 0.91 ^I	66.4 ± 1.04 ^I
Korean bullhead				
1	18.4 ± 3.14 ^A	30.4 ± 1.14 ^A	4.5 ± 1.72 ^A	1,449.7 ± 3.02 ^A
2	14.7 ± 2.46 ^B	28.5 ± 4.12 ^B	4.5 ± 0.66 ^B	1,359.1 ± 1.36 ^B
3	11.5 ± 1.53 ^C	22.5 ± 1.98 ^C	4.1 ± 0.21 ^C	981.0 ± 2.36 ^C
4	10.7 ± 1.29 ^D	22.1 ± 1.13 ^D	4.4 ± 0.28 ^D	1,028.6 ± 1.62 ^D
5	9.5 ± 1.58 ^E	23.1 ± 6.44 ^E	4.3 ± 0.44 ^E	1,051.1 ± 1.08 ^E
6	8.4 ± 1.28 ^F	21.3 ± 3.71 ^F	4.1 ± 0.28 ^F	929.6 ± 1.21 ^F
7	8.0 ± 2.08 ^G	21.1 ± 3.53 ^G	4.1 ± 0.33 ^G	921.2 ± 5.26 ^G
8	7.2 ± 1.94 ^H	17.6 ± 2.87 ^H	4.0 ± 0.38 ^H	660.9 ± 1.25 ^H
9	6.8 ± 2.96 ^I	6.5 ± 2.81 ^I	2.3 ± 0.48 ^I	79.4 ± 2.01 ^I

* Data were analyzed using one- and two-way ANOVA after transformation to the arcsine of the square root. Different capital letters on the values indicate a statistically significant difference among days after hatching ($p < 0.05$). Each dimension is shown in Fig. 1. ED: eye diameter. Volume = $\pi/6 \times a \times b^2$ (a is yolk length; b is yolk height; after Park et al., 1996).

Of these measures, YL showed the greatest rate of decrease and YH the lowest rate ($p < 0.05$). YL was always greater than YH ($p < 0.05$). Both species showed similar trends in their early morphometric dimensions.

Fig. 2 shows the growth curves for the Ussurian bullhead. The increase in Ls was $y = 5.0x - 3.56$, $R^2 = 0.9675$ (y is standard length in mm, x is DPH), and the increase in bodyweight was $y = 60.5x - 65.44$, $R^2 = 0.9939$ (y is bodyweight in mg, x is DPH). The increases in Ls and bodyweight showed a positive relationship. Ls increased by 33.6 mm from 10 DPH to 40 DPH. Thereafter, the Ussurian bullhead ultimately grew to 81.9 mm (Fig. 2). The bodyweight of the Ussurian bullhead had increased to 1,014.2

mg at a steady rate by 150 DPH (Fig. 2). The rate of increase in bodyweight was more regular than the increase in Ls (Fig. 2). Bodyweight/ Ls was $y = 11.6x - 7.17$, $R^2 = 0.965$ (y is bodyweight in mg, x is Ls in mm) (Fig. 3A). Bodyweight and Ls increased proportionally (Fig. 3A). Although the average bodyweight/ Ls was 11, when Ls was 20–37 mm, bodyweight/ Ls was 5.6, which indicates a slower increase in bodyweight than in Ls (Fig. 3A).

Fig. 4 shows the growth curves for the Korean bullhead. The increase in Ls was $y = 5.0x - 3.84$, $R^2 = 0.9545$ (y is Ls in mm, x is DPH), and the increase in bodyweight was $y = 56.678x - 56.152$, $R^2 = 0.988$ (y is bodyweight in mg, x is DPH). The increases in Ls and bodyweight showed

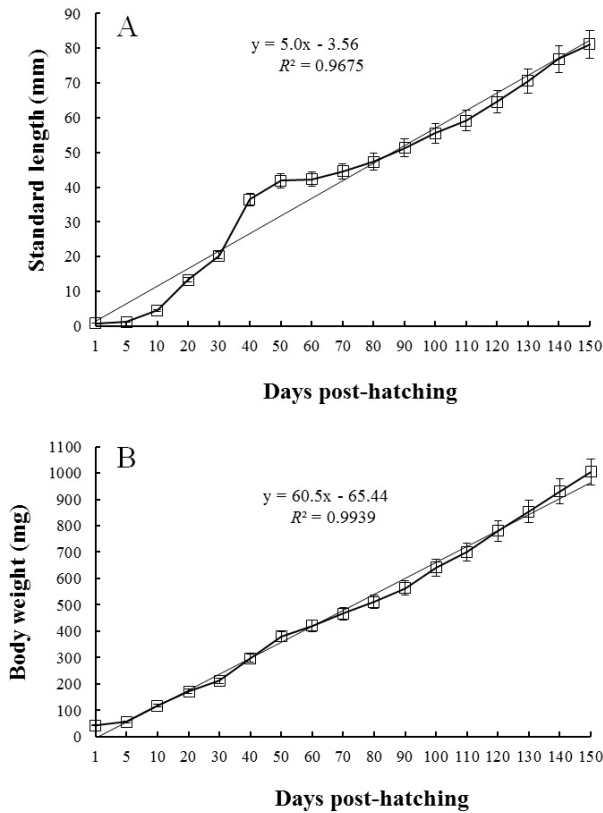


Fig. 2. Curves for growth (A) and changes in bodyweight (B) of the Ussurian bullhead, *Leiocassis ussuriensis*, in the early period of growth.

a positive relationship. *Ls* increased to 36.7 mm from 30 DPH to 40 DPH. Thereafter, the Korean bullhead ultimately grew to 71.5 mm (Fig. 4). The bodyweight of the Korean bullhead increased rapidly to 161.3 mg from 5 DPH to 10 DPH, and to 463.1 mg from 60 DPH to 70 DPH (Fig. 4). By 130 DPH, the bodyweight of the Korean bullhead had increased at a steady rate to 835.4 mg (Fig. 4). Body weight/*Ls* was $y = 10.4x + 12.69$, $R^2 = 0.908$ (y is bodyweight in mg, x is *Ls* in mm) (Fig. 3B). Bodyweight and *Ls* increased proportionally (Fig. 3B). Although the average bodyweight/*Ls* was 10, when *Ls* was 1–5 mm, bodyweight/*Ls* was 25, and when *Ls* was 43–45 mm, bodyweight/*Ls* was 50, which shows a faster increase in bodyweight than in *Ls* (Fig. 3B). However, when *Ls* was 4.7–37 mm, bodyweight/*Ls* was 2.5, which shows a slower increase of bodyweight than in *Ls* (Fig. 3B). Both species

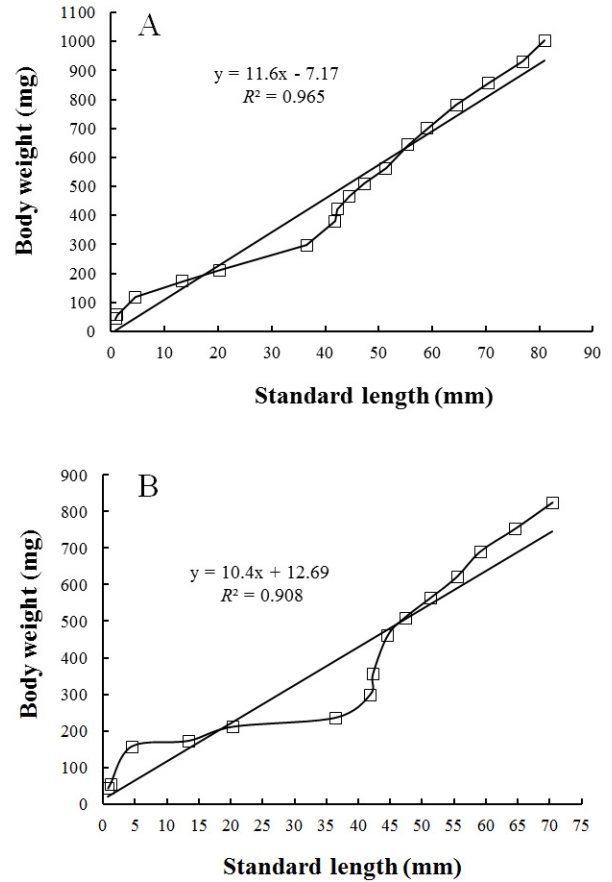


Fig. 3. Relationship between standard length and bodyweight in the Ussurian bullhead, *Leiocassis ussuriensis* (A), and the Korean bullhead, *Pseudobagrus fulvidraco* (B), from hatching to 130 days post-hatching.

showed similar trends in their early growth.

Table 3 lists 24 morphometric dimensions/*Ls* for the Ussurian bullhead, measured every 10 days from 10 DPH to 150 DPH. HHAP, HHAV, HDAC, 1×2 , 1×9 , 1×7 , 2×8 , 2×6 , 3×8 , LAF, and IManBL did not differ significantly at 20 DPH, and 2×5 did not differ significantly from 30 DPH to 150 DPH ($p > 0.05$). Furthermore, 2×7 and 3×7 did not differ significantly by 150 DPH ($p > 0.05$). During 150 DPH, 3×6 and LPF decreased gradually, whereas 3×5 , 2×4 , LPDF, LVF, UMaxBL, LMaxBL, OManBL, and ED gradually increased ($p < 0.05$). The dimension 2×4 increased to 106.6%, LVF increased to 158.2%, and LMaxBL increased to 553.3%, and these dimensions showed the greatest growth rates in the external

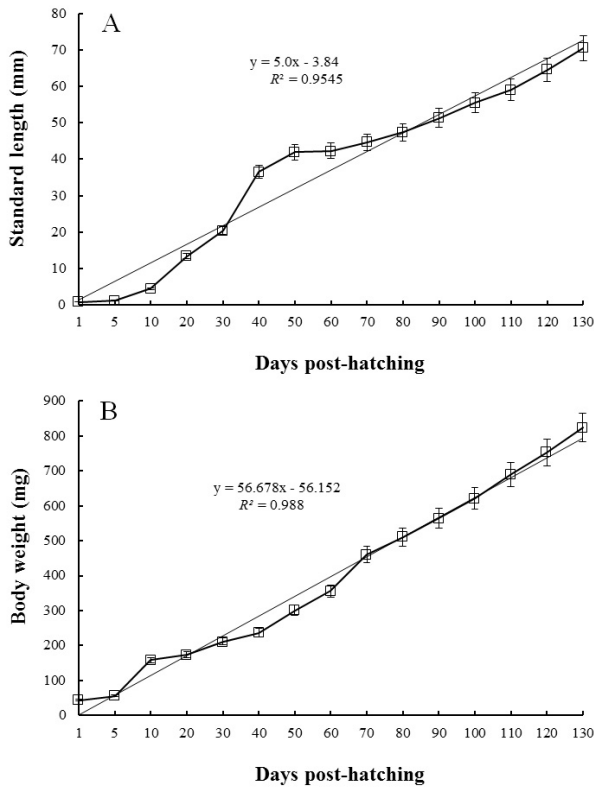


Fig. 4. Curves for growth (A) and changes in bodyweight (B) of the Korean bullhead, *Pseudobagrus fulvidraco*, in the early period of growth.

characteristics of the fish, in section of fin and in section of barbell, respectively ($p < 0.05$).

Table 4 lists 24 morphometric dimensions/*Ls* for the Korean bullhead measured every 10 days from 10 DPH to 130 DPH. HHAP, HHAV, HDAC, 1×2 , 1×9 , 1×7 , 2×8 , 2×6 , 3×8 , LPDF, and LAF did not differ significantly from 20 DPH to 130 DPH, and 2×5 did not differ significantly from 30 DPH to 130 DPH ($p > 0.05$). During 130 DPH, 3×6 and LPF decreased gradually, whereas 3×5 , 2×4 , LVF, UMaxBL, LMaxBL, OManBL, IManBL, and ED gradually increased ($p < 0.05$). The dimension 2×4 increased to 105.4%, LVF increased to 138.4%, and LMaxBL increased to 564.5%, and these showed the greatest growth rates in the external characteristics of the fish, in section of fin and in section of barbell respectively ($p < 0.05$). Among these increases, the growth rate of the barbel section was greatest ($p < 0.05$). Both species in section of fin and in section of barbell generally had the largest value and of the morphometric dimensions 3×5 and 2×4 showed increasing trends.

When we compared the morphometric dimensions/*Ls*, we found that HHAP, 1×7 , 2×8 , 2×7 , 2×6 , 2×5 ,

Table 3. Results of Duncan’s multiple range test for differences in 24 characteristics of the Ussurian bullhead, *Leiocassis ussuriensis*, by DPH*

Days post hatched	Morphometric dimension/ <i>Ls</i> (%)							
	HHAP	HHAV	HDAC	1×2	1×9	1×7	2×8	2×7
10	44.9 ± 4.06 ^{Aa}	23.0 ± 2.26 ^{Ab}	43.9 ± 3.04 ^{Ac}	32.9 ± 1.28 ^{Ad}	23.9 ± 4.36 ^{Ae}	30.8 ± 3.16 ^{Af}	19.9 ± 4.06 ^{Ag}	18.5 ± 2.85 ^{Ah}
20	48.0 ± 4.32 ^{Ba}	24.9 ± 3.82 ^{Bb}	40.0 ± 3.78 ^{Bc}	33.0 ± 5.68 ^{Bd}	27.0 ± 4.72 ^{Be}	29.0 ± 7.76 ^{Bf}	21.0 ± 4.32 ^{Bg}	18.1 ± 5.57 ^{Ah}
30	48.1 ± 2.35 ^{Ba}	24.7 ± 3.17 ^{Bb}	40.3 ± 7.45 ^{Bc}	33.8 ± 4.45 ^{Bd}	27.1 ± 1.23 ^{Be}	29.1 ± 1.45 ^{Bf}	21.1 ± 2.35 ^{Bg}	18.6 ± 2.35 ^{Ah}
40	48.3 ± 4.90 ^{Ba}	24.7 ± 2.56 ^{Bb}	40.5 ± 2.10 ^{Bc}	33.5 ± 4.77 ^{Bd}	27.3 ± 3.51 ^{Be}	29.4 ± 2.66 ^{Bf}	21.3 ± 4.90 ^{Bg}	18.8 ± 4.54 ^{Ah}
50	48.9 ± 4.06 ^{Ba}	24.3 ± 2.01 ^{Bb}	40.7 ± 4.43 ^{Bc}	33.4 ± 4.12 ^{Bd}	27.9 ± 2.66 ^{Be}	29.5 ± 1.06 ^{Bf}	21.9 ± 4.06 ^{Bg}	18.5 ± 3.43 ^{Ah}
60	48.3 ± 3.43 ^{Ba}	24.7 ± 3.18 ^{Bb}	40.1 ± 1.59 ^{Bc}	33.5 ± 5.84 ^{Bd}	27.3 ± 2.44 ^{Be}	29.1 ± 1.42 ^{Bf}	21.3 ± 4.43 ^{Bg}	18.5 ± 4.12 ^{Ah}
70	48.5 ± 3.11 ^{Ba}	24.7 ± 2.44 ^{Bb}	40.6 ± 5.47 ^{Bc}	33.9 ± 6.22 ^{Bd}	27.5 ± 5.21 ^{Be}	29.8 ± 4.91 ^{Bf}	21.5 ± 3.11 ^{Bg}	18.7 ± 3.12 ^{Ah}
80	48.8 ± 1.52 ^{Ba}	24.1 ± 2.69 ^{Bb}	40.9 ± 1.86 ^{Bc}	33.4 ± 3.23 ^{Bd}	27.8 ± 5.52 ^{Be}	29.4 ± 3.02 ^{Bf}	21.8 ± 1.52 ^{Bg}	18.4 ± 3.86 ^{Ah}
90	48.4 ± 3.16 ^{Ba}	24.2 ± 4.11 ^{Bb}	40.3 ± 3.61 ^{Bc}	33.7 ± 4.36 ^{Bd}	27.4 ± 4.16 ^{Be}	29.6 ± 6.67 ^{Bf}	21.4 ± 5.16 ^{Bg}	18.3 ± 3.44 ^{Ah}
100	47.6 ± 1.67 ^{Ba}	24.5 ± 4.38 ^{Bb}	40.2 ± 4.76 ^{Bc}	33.3 ± 2.89 ^{Bd}	27.6 ± 4.67 ^{Be}	29.7 ± 7.87 ^{Bf}	21.6 ± 1.67 ^{Bg}	18.7 ± 4.48 ^{Ah}
110	47.7 ± 2.61 ^{Ba}	24.1 ± 1.83 ^{Bb}	40.5 ± 5.47 ^{Bc}	33.1 ± 4.62 ^{Bd}	27.7 ± 3.61 ^{Be}	29.6 ± 4.17 ^{Bf}	21.7 ± 2.61 ^{Bg}	18.9 ± 1.95 ^{Ah}
120	47.3 ± 4.43 ^{Ba}	24.8 ± 3.12 ^{Bb}	40.1 ± 5.44 ^{Bc}	33.0 ± 4.78 ^{Bd}	27.3 ± 5.43 ^{Be}	29.5 ± 4.82 ^{Bf}	21.3 ± 4.43 ^{Bg}	18.2 ± 4.68 ^{Ah}
130	48.0 ± 1.88 ^{Ba}	24.5 ± 3.18 ^{Bb}	40.5 ± 3.84 ^{Bc}	33.7 ± 3.99 ^{Bd}	27.0 ± 1.88 ^{Be}	29.7 ± 6.91 ^{Bf}	21.0 ± 1.88 ^{Bg}	18.6 ± 5.79 ^{Ah}
140	47.9 ± 3.72 ^{Ba}	24.7 ± 4.22 ^{Bb}	40.3 ± 3.31 ^{Bc}	33.4 ± 2.87 ^{Bd}	27.9 ± 3.72 ^{Be}	29.7 ± 4.84 ^{Bf}	21.9 ± 3.72 ^{Bg}	18.5 ± 6.55 ^{Ah}
150	47.5 ± 4.03 ^{Ba}	24.6 ± 3.14 ^{Bb}	40.2 ± 3.34 ^{Bc}	33.9 ± 3.01 ^{Bd}	27.5 ± 3.13 ^{Be}	29.6 ± 4.69 ^{Bf}	21.5 ± 4.03 ^{Bg}	18.6 ± 4.92 ^{Ah}

Table 3. Continued

Days post hatched	Morphometric dimension/Ls (%)							
	2 × 6	2 × 5	3 × 8	3 × 7	3 × 6	3 × 5	2 × 4	LPDF
10	23.1 ± 3.61 ^{Ab}	27.9 ± 1.26 ^{Ai}	33.0 ± 2.16 ^{Aj}	32.7 ± 4.56 ^{Ad}	19.2 ± 3.88 ^{Ag}	14.8 ± 2.89 ^{Ak}	68.1 ± 2.28 ^{Al}	12.9 ± 4.06 ^{Am}
20	25.4 ± 4.96 ^{Bb}	28.0 ± 4.06 ^{Ai}	36.9 ± 3.82 ^{Bj}	33.4 ± 3.78 ^{Ad}	18.0 ± 3.12 ^{Bh}	15.0 ± 3.14 ^{Bk}	68.0 ± 7.76 ^{Al}	14.0 ± 4.32 ^{Bm}
30	25.6 ± 1.89 ^{Bb}	30.1 ± 0.98 ^{Bi}	36.7 ± 3.17 ^{Bj}	33.7 ± 4.45 ^{Ad}	18.8 ± 4.59 ^{Bh}	15.1 ± 3.76 ^{Bk}	70.1 ± 1.45 ^{Bl}	14.1 ± 2.35 ^{Bm}
40	25.5 ± 4.87 ^{Bb}	30.3 ± 1.03 ^{Bi}	36.7 ± 2.56 ^{Bj}	33.6 ± 2.11 ^{Ad}	18.5 ± 2.44 ^{Bh}	15.3 ± 2.51 ^{Bk}	70.6 ± 2.66 ^{Bl}	14.3 ± 4.90 ^{Bm}
50	25.6 ± 5.01 ^{Bb}	30.9 ± 4.47 ^{Bi}	36.3 ± 2.01 ^{Bj}	33.8 ± 4.43 ^{Ad}	18.4 ± 3.16 ^{Bh}	15.9 ± 3.16 ^{Bk}	70.5 ± 1.06 ^{Bl}	14.9 ± 4.06 ^{Bm}
60	25.4 ± 3.94 ^{Bb}	30.3 ± 1.51 ^{Bi}	36.7 ± 3.18 ^{Bj}	33.5 ± 3.65 ^{Ad}	18.5 ± 5.84 ^{Bh}	17.3 ± 3.57 ^{Ch}	72.1 ± 1.42 ^{Cl}	14.3 ± 4.43 ^{Bm}
70	25.7 ± 2.61 ^{Bb}	30.5 ± 1.45 ^{Bi}	36.7 ± 2.44 ^{Bj}	33.3 ± 5.47 ^{Ad}	18.9 ± 6.22 ^{Bh}	17.5 ± 3.19 ^{Ch}	72.8 ± 4.91 ^{Cl}	14.5 ± 3.11 ^{Bm}
80	25.1 ± 4.12 ^{Bb}	30.8 ± 1.85 ^{Bi}	36.1 ± 2.69 ^{Bj}	33.6 ± 4.67 ^{Ad}	17.4 ± 4.33 ^{Ch}	17.8 ± 3.52 ^{Ch}	72.4 ± 3.02 ^{Cl}	14.8 ± 1.52 ^{Bm}
90	25.3 ± 4.51 ^{Bb}	30.4 ± 1.52 ^{Bi}	36.2 ± 4.11 ^{Bj}	33.7 ± 3.61 ^{Ad}	17.7 ± 3.61 ^{Ch}	17.4 ± 4.16 ^{Ch}	72.6 ± 6.67 ^{Cl}	14.4 ± 5.16 ^{Bm}
100	25.5 ± 4.12 ^{Bb}	30.6 ± 1.71 ^{Bi}	36.5 ± 4.38 ^{Bj}	33.4 ± 4.76 ^{Ad}	17.3 ± 2.89 ^{Ch}	17.6 ± 4.67 ^{Ch}	72.7 ± 7.87 ^{Cl}	14.6 ± 1.67 ^{Bm}
110	24.9 ± 3.56 ^{Bb}	30.7 ± 2.77 ^{Bi}	36.1 ± 1.83 ^{Bj}	33.3 ± 5.47 ^{Ad}	17.1 ± 3.88 ^{Ch}	17.7 ± 3.61 ^{Ch}	72.6 ± 4.17 ^{Cl}	14.7 ± 2.61 ^{Bm}
120	25.1 ± 3.22 ^{Bb}	30.3 ± 3.19 ^{Bi}	36.8 ± 3.12 ^{Bj}	33.2 ± 5.44 ^{Ad}	17.0 ± 4.78 ^{Ch}	17.3 ± 5.43 ^{Ch}	72.5 ± 4.82 ^{Cl}	14.3 ± 4.43 ^{Bm}
130	24.9 ± 2.26 ^{Bb}	30.0 ± 3.29 ^{Bi}	36.5 ± 2.84 ^{Bj}	33.1 ± 3.84 ^{Ad}	17.7 ± 3.24 ^{Ch}	17.0 ± 1.88 ^{Ch}	72.7 ± 6.91 ^{Cl}	14.0 ± 1.88 ^{Bm}
140	25.2 ± 3.39 ^{Bb}	30.9 ± 3.63 ^{Bi}	36.7 ± 4.22 ^{Bj}	33.6 ± 3.31 ^{Ad}	17.4 ± 3.11 ^{Ch}	17.9 ± 3.72 ^{Ch}	72.7 ± 4.84 ^{Cl}	14.9 ± 3.72 ^{Bm}
150	25.4 ± 4.81 ^{Bb}	30.5 ± 4.14 ^{Bi}	36.6 ± 3.14 ^{Bj}	33.7 ± 3.34 ^{Ad}	17.9 ± 3.01 ^{Ch}	17.5 ± 3.13 ^{Ch}	72.6 ± 4.69 ^{Cl}	14.5 ± 4.03 ^{Bm}
	LPF	LVF	LAF	UMaxBL	LMaxBL	OManBL	IManBL	ED
10	17.5 ± 2.85 ^{Ah}	9.1 ± 3.61 ^{An}	16.9 ± 4.06 ^{Ah}	2.8 ± 2.89 ^{Ao}	3.0 ± 2.16 ^{Ao}	2.5 ± 2.85 ^{Ah}	2.9 ± 4.36 ^{Ae}	5.1 ± 3.61 ^{An}
20	16.1 ± 5.57 ^{Bk}	10.4 ± 4.96 ^{Bn}	18.0 ± 4.32 ^{Bh}	3.0 ± 3.14 ^{Bo}	4.9 ± 3.82 ^{Bo}	3.1 ± 5.57 ^{Bk}	3.0 ± 4.72 ^{Be}	5.4 ± 4.96 ^{Bn}
30	16.6 ± 2.35 ^{Bk}	12.6 ± 1.89 ^{Cn}	18.1 ± 2.35 ^{Bh}	6.1 ± 3.76 ^{Bo}	7.7 ± 3.17 ^{Co}	6.6 ± 2.35 ^{Bk}	6.1 ± 1.23 ^{Be}	5.6 ± 1.89 ^{Cn}
40	16.8 ± 4.54 ^{Bk}	12.5 ± 4.87 ^{Cn}	18.3 ± 4.90 ^{Bh}	6.3 ± 2.51 ^{Bo}	9.7 ± 2.56 ^{Dp}	6.8 ± 4.54 ^{Bk}	6.3 ± 3.51 ^{Be}	5.5 ± 4.87 ^{Cn}
50	16.5 ± 3.43 ^{Bk}	12.6 ± 5.01 ^{Cn}	18.9 ± 4.06 ^{Bh}	7.9 ± 3.16 ^{Bo}	11.3 ± 2.01 ^{Ep}	7.5 ± 3.43 ^{Bk}	6.9 ± 2.66 ^{Be}	5.6 ± 5.01 ^{Cn}
60	16.5 ± 4.12 ^{Ck}	14.4 ± 3.94 ^{Dm}	18.3 ± 7.43 ^{Bh}	7.3 ± 3.57 ^{Cn}	12.7 ± 3.18 ^{Fo}	7.5 ± 4.12 ^{Ck}	7.3 ± 2.44 ^{Be}	5.4 ± 3.94 ^{Dm}
70	16.7 ± 3.12 ^{Ck}	14.7 ± 2.61 ^{Dm}	18.5 ± 3.11 ^{Bh}	8.5 ± 3.19 ^{Cn}	12.7 ± 2.44 ^{Fo}	8.7 ± 3.12 ^{Ck}	8.5 ± 5.21 ^{Be}	5.7 ± 2.61 ^{Dm}
80	16.4 ± 3.86 ^{Ck}	14.1 ± 4.12 ^{Dm}	18.8 ± 1.52 ^{Bh}	8.8 ± 3.52 ^{Cn}	12.1 ± 2.69 ^{Fo}	8.4 ± 3.86 ^{Ck}	8.8 ± 5.52 ^{Be}	5.1 ± 4.12 ^{Dm}
90	16.3 ± 3.44 ^{Ck}	14.3 ± 4.51 ^{Dm}	18.4 ± 5.16 ^{Bh}	9.4 ± 4.16 ^{Cn}	12.2 ± 4.11 ^{Fo}	8.3 ± 3.44 ^{Ck}	8.4 ± 4.16 ^{Be}	5.3 ± 4.51 ^{Dm}
100	16.7 ± 4.48 ^{Dk}	14.5 ± 4.12 ^{Dm}	18.6 ± 1.67 ^{Bh}	9.6 ± 4.67 ^{Cn}	12.5 ± 4.38 ^{Fo}	8.7 ± 4.48 ^{Dk}	8.6 ± 4.67 ^{Be}	5.5 ± 4.12 ^{Dm}
110	16.9 ± 1.95 ^{Dk}	14.9 ± 3.56 ^{Dm}	18.7 ± 2.61 ^{Bh}	9.7 ± 3.61 ^{Cn}	12.1 ± 1.83 ^{Fo}	8.9 ± 1.95 ^{Dk}	8.7 ± 3.61 ^{Be}	5.9 ± 3.56 ^{Dm}
120	16.2 ± 4.68 ^{Dk}	14.1 ± 3.22 ^{Dm}	18.3 ± 4.43 ^{Bh}	10.3 ± 5.43 ^{Cn}	12.8 ± 3.12 ^{Fo}	8.2 ± 4.68 ^{Dk}	8.3 ± 5.43 ^{Be}	5.1 ± 3.22 ^{Dm}
130	16.6 ± 5.79 ^{Dk}	14.9 ± 2.26 ^{Dm}	18.0 ± 1.88 ^{Bh}	10.0 ± 1.88 ^{Cn}	16.5 ± 3.18 ^{Fk}	8.6 ± 5.79 ^{Dk}	8.0 ± 6.88 ^{Be}	5.9 ± 2.26 ^{Dm}
140	16.5 ± 6.55 ^{Dk}	14.2 ± 3.39 ^{Dm}	18.9 ± 3.72 ^{Bh}	10.9 ± 3.72 ^{Cn}	16.7 ± 4.22 ^{Fk}	8.5 ± 6.55 ^{Dk}	8.9 ± 3.72 ^{Be}	5.2 ± 3.39 ^{Dm}
150	16.6 ± 4.92 ^{Dk}	14.4 ± 4.81 ^{Dm}	18.5 ± 4.03 ^{Bh}	10.5 ± 3.13 ^{Ch}	16.6 ± 3.14 ^{Fk}	8.6 ± 4.92 ^{Dk}	8.5 ± 3.13 ^{Be}	5.4 ± 4.81 ^{Dm}

* For abbreviations and each dimension, see Table 1 and Fig. 1. Data were analyzed using one- and two-way ANOVA after transformation to the arcsine of the square root. Different capital letters on the values indicate statistically significant differences among days after hatching ($p < 0.05$). Different small letters on the values indicate statistically significant difference among morphometric dimension/Ls ratios ($p < 0.05$).

and 3 × 5 of the Korean bullhead were higher than those of the Ussurian bullhead ($p < 0.05$), and HHAV, HDAC, 1 × 2, 1 × 9, 3 × 7, 2 × 4, and LPF were lower in the Korean bullhead than in the Ussurian bullhead ($p < 0.05$), whereas 3 × 8, LPDF, UMaxBL, LMaxBL, IManBL, and ED did not differ significantly between the two species

($p > 0.05$). At 10 DPH, the increase in 3 × 8 was greater in the Korean bullhead (34.0 ± 2.16%) than in the Ussurian bullhead (33.0 ± 2.16%, $p < 0.05$), but at 130 DPH, the increase in 3 × 8 was similar in the Korean bullhead (36.5 ± 3.18%) and the Ussurian bullhead (36.5 ± 2.84%, $p > 0.05$). During the experimental period, 3 × 6 of the

Table 4. Results of Duncan's multiple range test for differences in 24 characteristics of the Korean bullhead, *Pseudobagrus fulvidraco*, by DPH*

Days post hatched	Morphometric dimension/Ls (%)							
	HHAP	HHAV	HDAC	1 × 2	1 × 9	1 × 7	2 × 8	2 × 7
10	50.8 ± 3.95 ^{Aa}	21.0 ± 2.26 ^{Ab}	35.7 ± 2.94 ^{Ac}	36.9 ± 1.28 ^{Ad}	22.9 ± 4.36 ^{Ae}	35.8 ± 3.16 ^{Af}	20.9 ± 4.06 ^{Ag}	20.5 ± 2.85 ^{Ah}
20	50.2 ± 3.38 ^{Ba}	21.9 ± 3.82 ^{Bb}	36.1 ± 3.16 ^{Bc}	37.0 ± 5.68 ^{Bd}	23.0 ± 4.72 ^{Bc}	37.0 ± 7.76 ^{Bf}	22.0 ± 4.32 ^{Bg}	21.1 ± 5.57 ^{Ah}
30	50.9 ± 2.85 ^{Ba}	21.7 ± 3.17 ^{Bb}	36.5 ± 2.45 ^{Bc}	37.8 ± 4.45 ^{Bd}	23.1 ± 1.23 ^{Bc}	37.1 ± 1.45 ^{Bf}	22.1 ± 2.35 ^{Bg}	22.6 ± 2.35 ^{Ah}
40	50.1 ± 3.39 ^{Ba}	21.7 ± 2.56 ^{Bb}	36.6 ± 3.19 ^{Bc}	37.5 ± 4.77 ^{Bd}	23.3 ± 3.51 ^{Bc}	37.4 ± 2.66 ^{Bf}	22.3 ± 4.90 ^{Bg}	22.8 ± 4.54 ^{Ah}
50	50.6 ± 3.21 ^{Ba}	21.3 ± 2.01 ^{Bb}	36.5 ± 3.24 ^{Bc}	37.4 ± 4.12 ^{Bd}	23.9 ± 2.66 ^{Bc}	37.5 ± 1.06 ^{Bf}	22.9 ± 4.06 ^{Bg}	22.5 ± 3.43 ^{Ah}
60	51.3 ± 2.91 ^{Ba}	21.7 ± 3.18 ^{Bb}	36.6 ± 2.98 ^{Bc}	37.5 ± 5.84 ^{Bd}	23.3 ± 2.44 ^{Bc}	37.1 ± 1.42 ^{Bf}	22.3 ± 4.43 ^{Bg}	22.5 ± 4.12 ^{Ah}
70	50.9 ± 3.58 ^{Ba}	21.7 ± 2.44 ^{Bb}	36.8 ± 3.91 ^{Bc}	37.9 ± 6.22 ^{Bd}	23.5 ± 5.21 ^{Bc}	37.8 ± 4.91 ^{Bf}	22.5 ± 3.11 ^{Bg}	22.7 ± 3.12 ^{Ah}
80	51.3 ± 2.82 ^{Ba}	21.1 ± 2.69 ^{Bb}	36.7 ± 2.79 ^{Bc}	37.4 ± 3.23 ^{Bd}	23.8 ± 5.52 ^{Bc}	37.4 ± 3.02 ^{Bf}	22.8 ± 1.52 ^{Bg}	22.4 ± 3.86 ^{Ah}
90	51.4 ± 3.29 ^{Ba}	21.2 ± 4.11 ^{Bb}	36.8 ± 3.87 ^{Bc}	37.7 ± 4.36 ^{Bd}	23.4 ± 4.16 ^{Bc}	37.6 ± 6.67 ^{Bf}	22.4 ± 5.16 ^{Bg}	22.3 ± 3.44 ^{Ah}
100	51.5 ± 2.32 ^{Ba}	21.5 ± 4.38 ^{Bb}	36.6 ± 4.16 ^{Bc}	37.3 ± 2.89 ^{Bd}	23.6 ± 4.67 ^{Bc}	37.7 ± 7.87 ^{Bf}	22.6 ± 1.67 ^{Bg}	22.7 ± 4.48 ^{Ah}
110	51.1 ± 3.98 ^{Ba}	21.1 ± 1.83 ^{Bb}	36.5 ± 5.32 ^{Bc}	37.1 ± 4.62 ^{Bd}	23.7 ± 3.61 ^{Bc}	37.6 ± 4.17 ^{Bf}	22.7 ± 2.61 ^{Bg}	22.9 ± 1.95 ^{Ah}
120	51.8 ± 4.43 ^{Ba}	21.8 ± 3.12 ^{Bb}	36.4 ± 5.18 ^{Bc}	37.0 ± 4.78 ^{Bd}	23.3 ± 5.43 ^{Bc}	37.5 ± 4.82 ^{Bf}	22.3 ± 4.43 ^{Bg}	22.2 ± 4.68 ^{Ah}
130	51.9 ± 1.91 ^{Ba}	21.5 ± 3.18 ^{Bb}	36.3 ± 4.98 ^{Bc}	37.0 ± 3.99 ^{Bd}	23.7 ± 1.88 ^{Bc}	37.8 ± 6.91 ^{Bf}	22.2 ± 1.88 ^{Bg}	22.2 ± 5.79 ^{Ah}
	2 × 6	2 × 5	3 × 8	3 × 7	3 × 6	3 × 5	2 × 4	LPDF
10	27.1 ± 3.61 ^{Ab}	33.9 ± 1.26 ^{Ai}	34.0 ± 2.16 ^{Aj}	30.7 ± 4.56 ^{Ad}	19.2 ± 4.15 ^{Ag}	17.8 ± 2.89 ^{Ak}	61.1 ± 2.28 ^{Al}	13.9 ± 4.06 ^{Am}
20	28.4 ± 4.96 ^{Bb}	33.0 ± 4.06 ^{Ai}	36.9 ± 3.82 ^{Bj}	30.4 ± 3.78 ^{Ad}	20.0 ± 3.12 ^{Bh}	18.0 ± 3.14 ^{Bk}	62.0 ± 7.76 ^{Al}	14.0 ± 4.32 ^{Bm}
30	28.6 ± 1.89 ^{Bb}	35.1 ± 0.98 ^{Bi}	36.7 ± 3.17 ^{Bj}	30.7 ± 4.45 ^{Ad}	20.8 ± 4.59 ^{Bh}	18.1 ± 3.76 ^{Bk}	64.1 ± 1.45 ^{Bl}	14.1 ± 2.35 ^{Bm}
40	28.5 ± 4.87 ^{Bb}	35.3 ± 1.03 ^{Bi}	36.7 ± 2.56 ^{Bj}	30.6 ± 2.11 ^{Ad}	20.5 ± 2.44 ^{Bh}	18.3 ± 2.51 ^{Bk}	64.6 ± 2.66 ^{Bl}	14.3 ± 4.90 ^{Bm}
50	28.6 ± 5.01 ^{Bb}	35.9 ± 4.47 ^{Bi}	36.3 ± 2.01 ^{Bj}	30.8 ± 4.43 ^{Ad}	20.4 ± 3.16 ^{Bh}	18.9 ± 3.16 ^{Bk}	64.5 ± 1.06 ^{Bl}	14.9 ± 4.06 ^{Bm}
60	28.4 ± 3.94 ^{Bb}	35.3 ± 1.51 ^{Bi}	36.7 ± 3.18 ^{Bj}	30.5 ± 3.65 ^{Ad}	20.5 ± 5.84 ^{Bh}	18.3 ± 3.57 ^{Ch}	64.1 ± 1.42 ^{Cl}	14.3 ± 4.43 ^{Bm}
70	28.7 ± 2.61 ^{Bb}	35.5 ± 1.45 ^{Bi}	36.7 ± 2.44 ^{Bj}	30.3 ± 5.47 ^{Ad}	20.9 ± 6.22 ^{Bh}	18.5 ± 3.19 ^{Ch}	64.8 ± 4.91 ^{Cl}	14.5 ± 3.11 ^{Bm}
80	28.1 ± 4.12 ^{Bb}	35.8 ± 1.85 ^{Bi}	36.1 ± 2.69 ^{Bj}	30.6 ± 4.67 ^{Ad}	20.4 ± 4.33 ^{Ch}	18.8 ± 3.52 ^{Ch}	64.4 ± 3.02 ^{Cl}	14.8 ± 1.52 ^{Bm}
90	28.3 ± 4.51 ^{Bb}	35.4 ± 1.52 ^{Bi}	36.2 ± 4.11 ^{Bj}	30.7 ± 3.61 ^{Ad}	20.7 ± 3.61 ^{Ch}	18.4 ± 4.16 ^{Ch}	64.6 ± 6.67 ^{Cl}	14.4 ± 5.16 ^{Bm}
100	28.5 ± 4.12 ^{Bb}	35.6 ± 1.71 ^{Bi}	36.5 ± 4.38 ^{Bj}	30.4 ± 4.76 ^{Ad}	20.3 ± 2.89 ^{Ch}	18.6 ± 4.67 ^{Ch}	64.7 ± 7.87 ^{Cl}	14.6 ± 1.67 ^{Bm}
110	28.9 ± 3.56 ^{Bb}	35.7 ± 2.77 ^{Bi}	36.1 ± 1.83 ^{Bj}	30.3 ± 5.47 ^{Ad}	20.1 ± 3.88 ^{Ch}	18.7 ± 3.61 ^{Ch}	64.6 ± 4.17 ^{Cl}	14.7 ± 2.61 ^{Bm}
120	28.1 ± 3.22 ^{Bb}	35.3 ± 3.19 ^{Bi}	36.8 ± 3.12 ^{Bj}	30.2 ± 5.44 ^{Ad}	20.0 ± 4.78 ^{Ch}	18.3 ± 5.43 ^{Ch}	64.5 ± 4.82 ^{Cl}	14.3 ± 4.43 ^{Bm}
130	28.1 ± 2.26 ^{Bb}	35.6 ± 3.29 ^{Bi}	36.5 ± 3.18 ^{Bj}	30.4 ± 3.84 ^{Ad}	20.0 ± 3.99 ^{Ch}	18.5 ± 1.88 ^{Ch}	64.4 ± 6.91 ^{Cl}	14.1 ± 1.88 ^{Bm}
	LPF	LVF	LAF	UMaxBL	LMaxBL	OManBL	IManBL	ED
10	12.5 ± 2.85 ^{Ah}	9.1 ± 3.61 ^{An}	6.9 ± 4.06 ^{Ah}	2.9 ± 2.59 ^{Ao}	3.1 ± 2.29 ^{Ao}	2.9 ± 3.51 ^{Ah}	2.5 ± 3.66 ^{Ae}	4.2 ± 4.21 ^{An}
20	11.1 ± 5.57 ^{Bk}	10.4 ± 4.96 ^{Bn}	8.0 ± 4.32 ^{Bh}	3.1 ± 3.14 ^{Bo}	4.8 ± 3.61 ^{Bo}	3.2 ± 5.63 ^{Bk}	3.1 ± 4.32 ^{Be}	4.5 ± 4.02 ^{Bn}
30	11.6 ± 2.35 ^{Bk}	11.6 ± 1.89 ^{Cn}	8.1 ± 2.35 ^{Bh}	5.1 ± 3.76 ^{Bo}	7.3 ± 3.27 ^{Co}	6.5 ± 2.92 ^{Bk}	6.0 ± 2.93 ^{Be}	5.1 ± 3.87 ^{Cn}
40	11.8 ± 4.54 ^{Bk}	11.5 ± 4.87 ^{Cn}	8.3 ± 4.90 ^{Bh}	6.5 ± 2.51 ^{Bo}	9.6 ± 2.65 ^{Dp}	7.2 ± 4.41 ^{Bk}	6.1 ± 3.21 ^{Be}	5.4 ± 4.13 ^{Cn}
50	11.5 ± 3.43 ^{Bk}	12.6 ± 5.01 ^{Cn}	8.9 ± 4.06 ^{Bh}	7.3 ± 3.16 ^{Bo}	11.5 ± 2.11 ^{Ep}	7.5 ± 3.63 ^{Bk}	6.5 ± 2.36 ^{Be}	5.4 ± 4.89 ^{Cn}
60	11.5 ± 4.12 ^{Ck}	12.4 ± 3.94 ^{Dm}	8.3 ± 7.43 ^{Bh}	7.9 ± 3.57 ^{Cn}	12.9 ± 3.59 ^{Fo}	8.1 ± 4.05 ^{Ck}	7.2 ± 2.95 ^{Be}	5.4 ± 3.62 ^{Dm}
70	11.7 ± 3.12 ^{Ck}	12.7 ± 2.61 ^{Dm}	8.5 ± 3.11 ^{Bh}	8.4 ± 3.19 ^{Cn}	13.7 ± 2.65 ^{Fo}	8.3 ± 3.98 ^{Ck}	8.0 ± 5.12 ^{Be}	5.5 ± 2.57 ^{Dm}
80	11.4 ± 3.86 ^{Ck}	12.1 ± 4.12 ^{Dm}	8.8 ± 1.52 ^{Bh}	8.7 ± 3.52 ^{Cn}	13.8 ± 2.57 ^{Fo}	8.5 ± 3.61 ^{Ck}	8.1 ± 5.02 ^{Be}	5.6 ± 4.31 ^{Dm}
90	11.3 ± 3.44 ^{Ck}	12.3 ± 4.51 ^{Dm}	8.4 ± 5.16 ^{Bh}	9.1 ± 4.16 ^{Cn}	13.9 ± 4.02 ^{Fo}	9.2 ± 3.47 ^{Ck}	8.4 ± 4.31 ^{Be}	5.7 ± 4.26 ^{Dm}
100	11.7 ± 4.48 ^{Dk}	12.5 ± 4.12 ^{Dm}	8.6 ± 1.67 ^{Bh}	9.5 ± 4.67 ^{Cn}	14.6 ± 4.32 ^{Fo}	9.7 ± 4.63 ^{Dk}	8.5 ± 4.27 ^{Be}	5.8 ± 4.06 ^{Dm}
110	11.9 ± 1.95 ^{Dk}	12.9 ± 3.56 ^{Dm}	8.7 ± 2.61 ^{Bh}	9.7 ± 3.61 ^{Cn}	15.8 ± 1.56 ^{Fo}	9.8 ± 3.65 ^{Dk}	8.7 ± 3.39 ^{Be}	5.9 ± 3.67 ^{Dm}
120	11.2 ± 4.68 ^{Dk}	12.1 ± 3.22 ^{Dm}	8.3 ± 4.43 ^{Bh}	10.1 ± 5.43 ^{Cn}	16.5 ± 3.94 ^{Fo}	10.2 ± 4.69 ^{Dk}	8.8 ± 5.62 ^{Be}	5.9 ± 3.39 ^{Dm}
130	11.1 ± 5.79 ^{Dk}	12.6 ± 2.26 ^{Dm}	8.1 ± 1.88 ^{Bh}	10.5 ± 1.88 ^{Cn}	17.5 ± 3.36 ^{Fk}	10.7 ± 5.45 ^{Dk}	8.8 ± 6.19 ^{Be}	5.9 ± 2.61 ^{Dm}

* For abbreviations and each dimension, see Table 1 and Fig. 1. Data were analyzed using one- and two-way ANOVA after transformation to the arcsine of the square root. Different capital letters on the values indicate statistically significant differences among days after hatching ($p < 0.05$). Different small letters on the values indicate statistically significant differences among the morphometric dimension/Ls ratios ($p < 0.05$).

Korean bullhead increased from $19.2 \pm 4.15\%$ to $20.0 \pm 3.99\%$, whereas that of the Ussurian bullhead decreased from $19.2 \pm 3.88\%$ to $17.4 \pm 3.24\%$. At 10 DPH, LVF and OManBL did not differ significantly between the two species ($p > 0.05$), but LVF and OManBL were higher in the Ussurian bullhead than in the Korean bullhead at 130 DPH ($p < 0.05$). Thus, the increases in LVF and OManBL were faster in the Ussurian bullhead than in the Korean bullhead. In both species, LAF increased during the experimental period, but LAF was greater in the Ussurian bullhead than in the Korean bullhead ($p < 0.05$). The relative sizes of the head region, pectoral fin, ventral fin, and anal fin were greater in the Ussurian bullhead than in the Korean bullhead ($p < 0.05$), and the relative body depth and size of the outer mandible barbel were greater in the Korean bullhead than in the Ussurian bullhead ($p < 0.05$).

As shown in Fig. 5A, the morphometric characteristics measured in this study were classified into three different patterns of increase. The dimensions 2×5 , 3×5 , and 2×4 are the main traits of each curve (Fig. 5A). When L_s was 42 mm, only the length of each dimension of the 2×5 series increased. At the same point, the length of each dimension of the 3×5 series decreased, and each dimension of the 2×4 series increased more rapidly than L_s (Fig. 5A). As shown in Fig. 5B, the morphometric characteristics measured in this study can also be classified into three different patterns of increase. HHAV, 2×5 , and 3×5 are the main traits on each curve (Fig. 5B). When L_s was 42 mm, the three curves showed a change in trend. The length of each dimension of the HHAV series decreased and the length of each dimension of the 2×5 and 3×5 series increased more rapidly than L_s (Fig. 5B).

DISCUSSION

Although limited, research related to the early growth of the Ussurian bullhead and Korean bullhead has shown that when they hatch, both species have absorbed the whole yolk sac and begun to emerge (Dill, 1969, 1977; Brannon, 1972; Zhang et al., 1995). However, it is unclear

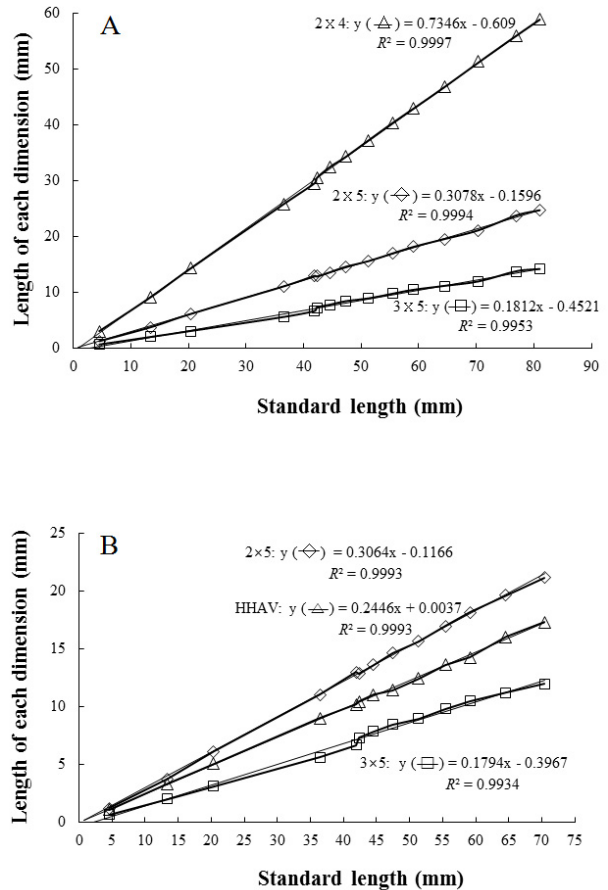


Fig. 5. A: Relationships between standard length and the direct distance between the anterior insertion of the primary dorsal fin and the posterior insertion of the anal fin (2×5), the direct distance between the anterior insertion of the secondary dorsal fin and the posterior insertion of the anal fin (3×5), and the direct distance between the anterior insertion of the primary dorsal fin and the anterior insertion of the caudal fin (2×5) in the Ussurian bullhead, *Leiocassis ussuriensis*, from hatching to 150 days post-hatching; **B:** Relationships between standard length and the horizontal distance between the anteriormost extension of the head and the anterior insertion of the ventral fin (HHAV), the direct distance between the anterior insertion of the primary dorsal fin and the posterior insertion of the anal fin (2×5), and the direct distance between the anterior insertion of the secondary dorsal fin and the posterior insertion of the anal fin (3×5) in the Korean bullhead, *Pseudobagrus fulvidraco*, from hatching to 130 days post-hatching. For abbreviations and each dimension, see Table 1 and Fig. 1.

how the yolk sac changes in shape from the start of its absorption. In this study, YL decreased with time. After

hatching, YH also decreased, but the reduction was smaller than that in YL. Consistent with the reductions in YL and YH, YV also decreased, and the reduction in YV was greatest of the three dimensions. The rates of decline in these measures were similar in the Ussurian and Korean bullheads, but the decline in YV was greater in the Korean bullhead than in the Ussurian bullhead (Table 2). This decrease in YV means that, as in alevin, the juvenile reverts from endogenous feeding to exogenous feeding after the yolk sac declines (Dill, 1969, 1977; Brannon, 1972; Zhang et al., 1995).

The body length and bodyweight of the Ussurian and Korean bullheads increased gradually (Figs 2 and 4). The rate of increase in body length was similar in both species, but their growth rates in terms of bodyweight differed, increasing more in the Ussurian bullhead. The growth rate of body length was also the same in both fish species, whereas the growth rate of bodyweight differed between the species (Figs 2 and 4). Bodyweight/*L*s increased more rapidly in the Ussurian bullhead than in the Korean bullhead (Fig. 3). This means that the rate of bodyweight increase in the Ussurian bullhead was greater than that in the Korean bullhead.

The truss dimensions are the primary units of classification and are based on the external anatomical markers normally assessed in fish (Sträuss & Bond, 1990). The truss dimensions are length measurements that refer to the ratio between the width of the fish's body and the axis of the fish's length. Theoretically, the truss dimensions are a better measure of the fish's shape than the classical dimensions (Sträuss & Bookstein, 1982; Currens et al., 1989). Most of the morphometric traits of the Ussurian bullhead and Korean bullhead tended to increase during the study period ($p < 0.05$; Tables 5 and 6). The two fish species did not differ significantly in the 2×7 and 3×7 sections of body height; nor did HHAV, HHAA, or HDMC differ in the two species during the experimental period ($p < 0.05$). After hatching, these shapes and ratios did not change significantly with time, and in the section of the barbel, the pectoral fin in both fish species decreased

together, suggesting that the pectoral fin showed little growth as bodyweight increased, whereas of all the parameters measured, the abdominal fin in both fish species increased most. As a result, in the early growth of the two fish species, the size of the abdominal fin changed significantly. The three typical for the Ussurian bullhead and Korean bullhead are shown in Figs 5 and 6, respectively.

As mentioned above, there has been insufficient research into the early growth of the Ussurian and Korean bullheads, which have similar habitats and spawning seasons. In this study, the histological changes, morphometric characteristics, and the absorption of the yolk sac were investigated from 1 DPH to 150 and 130 DPH, respectively. These results will provide useful indices for the successful rearing of the Ussurian bullhead and Korean bullhead.

ACKNOWLEDGMENTS

This research was supported by a research grant (RP-2013-AQ-143) from the National Fisheries Research and Development Institute, Korea. The comments of anonymous reviewers greatly improved the quality of the manuscript. We declare that all experiments in this study comply with the current laws of Korea (Ordinance of Agriculture, Food and Fisheries, No. 1, Regarding Experimental Animals, no. 9932) and the Korea Maritime and Ocean University Research Ethics Guidelines.

REFERENCES

- Brannon EL (1972) Mechanisms controlling migration of sockeye salmon fry. *Int Pacific Salmon Fish Comm Bull* 21:86.
- Currens KP, Sharpe CS, Hjort R, Schreek CB, Li HW (1989) Effects of different feeding regimes on the morphometrics of chinook salmon (*Oncorhynchus tshawytscha*) and rainbow trout (*O. mykiss*). *Copeia* 3:689-695.
- Dill LM (1969) The sub-gravel behaviour of Pacific salmon larvae. In: Northcote TG (ed.), *Symposium*

- on Salmon and Trout in Streams, H.R. MacMillan Lectures in Fisheries, 1968, University of British Columbia, Vancouver, pp 89-99.
- Dill PA (1977) Development of behaviour in alevins of Atlantic salmon, *Salmo salar*, and rainbow trout, *S. gairdneri*. *Anim Behav* 25:116-121.
- Hubbs CL, Lagler KF (1947) Fishes of the Great Lakes region. *Cranbrook Instit Sci* 26:186.
- Ihssen PE, Booke HE, Casselman JM, McGlade JM, Payne NR, Utter FM (1981) Stock identification: materials and methods. *Can J Fish Aquat Sci* 38:1838-1855.
- Kim BH, Kim KM, Lee YD, Song CB, Rho S (1997) Reproductive biology of the sevenband grouper, *Epinephelus septemfasciatus*; The effect of HCG on ovulation induction. *J Aquacult* 10:55-61.
- Kim IS, Park JH (2002) Freshwater Fishes of Korea. Kyo-Hak Publishing Co., Ltd, Seoul, pp.252-259.
- Lee CY (1993) About Korean endemic bagridae fishes. *Kor J Ichthyol* 5:133-134.
- Lim SG, Kim YS, Han HK, Kim KS, Kim DJ, Kang EJ, Son SG, Kim EO (2012) Induction of ovulation by hormone treatment in Ussurian bullhead, *Leiocassis ussuriensis*. *Dev Reprod* 16:271-277.
- Park I-S, Im JH, Jang CI (1996) A study on the yolk absorption and early growth in the alevin of rainbow trout, *Oncorhynchus mykiss*. *Kor J Ichthyol* 8:49-55.
- Park I-S, Im JM, Ryu DK, Nam YK, Kim DS (2001) Effect of starvation on morphometric changes in *Rhynchocypris oxycephalus* (Sauvage and Dabry). *J Appl Ichthyol* 17:277-281.
- Park I-S, Im SY, Hur JW, Jeong GS (2006) Early growth and development of eye in dotted gizzard shad, *Konosirus punctatus*. *Dev Reprod* 10:93-96.
- Park I-S, Park HJ, Gil HW, Goo IB (2012) Early growth and characteristic of histological eye development in post parturition dark banded rockfish, *Sebastes inermis*. *Dev Reprod* 16:101-106.
- Park I-S, Woo SR, Song YC, Cho SH (2007) Effects of starvation on the morphometric characteristics of olive flounder, *Paralichthys olivaceus*. *Ichthyol Res* 54:297-302.
- Park I-S, Lee CL (1996) Cytogenetic analysis of bagrid catfish, *Pseudobagrus fulvidraco* (Teleostomi: Siluriformes). *Kor J Ichthyol* 8:10-15.
- Sträuss RE, Bond CE (1990) Taxonomic methods, morphology. *Methods for Fish Biology*, Bethesda, Maryland: American Fish Society, pp 125-130.
- Sträuss RE, Bookstein FL (1982) The truss: body from reconstructions in morphometrics. *Syst Zool* 31:113-135.
- Zhang CI, Sohn MH, Seong KB, Park I-S (1995) Yolk absorption and growth of chum salmon, *Oncorhynchus keta* alevin. *Kor J Fish Aquat Sci* 28:539-548.