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Morphological changes and allometric growth in hatchery-reared Chinese loach *Paramisgurnus dabryanus* (Dabry de Thiersant, 1872)*

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Abstract The length-weight relationship and allometric growth patterns of hatchery-reared Chinese loach, *Paramisgurnus dabryanus* (Dabry de Thiersant, 1872), were determined from hatching to 60 days after hatching. A best power model was estimated for the length-weight relationship during the early life stages. Positive allometric growth for the head segment, trunk length, tail length and eye diameter was also found in the early life stages, while body depth, tail depth, tail fin length, pectoral fin length and barbel length displayed a negative coefficient. During the subsequent early developmental stage, the growth coefficients showed a clear and common tendency towards isometry for all measured body ratios. The allometric growth changes in Chinese loach during the early stage are possibly the result of selective organogenesis directed towards survival priorities.

Keyword: *Paramisgurnus dabryanus*; early life stages; length-weight relationship; allometric growth

1 INTRODUCTION

Length-weight relationship (LWR) has many applications in stock assessment, monitoring fish stocks, ecological studies and species conservation programs (Froese, 2006; Vicentin et al., 2012). LWR may also be used in estimating several components in models of fish population dynamics (Guibiani and da S Horlando, 2014). The various ontogenic life stages of fish, especially the early life stages, have different LWR patterns; however, no LWR information is available on Chinese loach (Froese and Pauly, 2014).

During the early life stages of fish species, a change in body shape, which results from the growth of its components at different relative rates (allometric growth), reflects the close relationship between the ontogeny of morphology and function (Çoban et al., 2009). Allometric growth can be used in fisheries, biological studies, and aquaculture to evaluate the developmental plasticity of a species (Gisbert and Doroshov, 2006). During early developmental stages, fish undergo a change in shape, which increases their ability to perform vital biological functions (e.g. respiration, sensory functions and feeding) for survival (Russo et al., 2007; Peña and Dumas, 2009; Khemis et al., 2013). Consequently, the body structure and specific organs/systems of fish species develop according to their importance for primary functions. As previously mentioned, knowledge of allometric growth patterns is crucial from an aquacultural point of view.

Chinese loach, *Paramisgurnus dabryanus* (Dabry de Thiersant, 1872), an omnivorous freshwater fish, is one of the most commercially important cultured species in East Asia, especially in China and Korea (Zhang et al., 2015). In recent years, the culture of Chinese loach has become more widespread with increasing market demand in China. However, the

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Table 1 Abbreviations and descriptions of morphometric characteristics measured during early development of Chinese loach

Characteristics	Abbreviations	Description on fish
Total length	TL	From tip of snout to tip of the caudal fin
Standard length	SL	From tip of snout to base of caudal fin rays
Head length	HL	From tip of snout to the margin of gill cover
Trunk length	TRL	From the margin of gill cover to anus
Tail length	TAL	From anus to tip of the caudal fin
Eye diameter	ED	Parallel to the longitudinal axis of the body
Head depth	HD	Vertical distance from gill cover to abdomen
Body depth	BD	Vertical distance from base of dorsal fin to abdomen
Tail depth	TD	Minimum depth of the caudal peduncle
Pectoral fin length	PFL	From tip to the base of the pectoral fin
Tail fin length	TFL	From tip to the base of the tail fin
Barbel length	BL	From tip to the base of the third pair of barbel

majority of Chinese loach larvae are obtained from the wild because of high rates of mortality during hatchery production of larvae. It is well known that wild larvae are reluctant to accept an artificial compound diet and, thus, survival is of wild-caught larva is inconsistent. This is one of the main constraints in the cultivation of Chinese loach. In addition, limited information is available on the Chinese loach's early life history, which is also a limiting factor for the aquaculture development of this species. Therefore, the aim of this study was to determine the allometric growth patterns during the early life stages of the Chinese loach from hatching to 60 days after hatching (DAH) and, thereby, improve our knowledge of its early life stages.

2 MATERIAL AND METHOD

2.1 Larval rearing

P. dabryanus larvae were obtained from Hubei Wuyuan Agricultural Developmental Co. Ltd. (Jingzhou, China). Spawners were obtained from a nearby market and the fertilized eggs were obtained from a mix of females. Larvae were reared in three tanks (9 m×2 m×1 m) with a water depth of 0.5 m and a rearing density of 1 000 larvae/m^2. Water temperature, dissolved oxygen, and pH were monitored daily. Water temperature was raised to 24–25°C and kept constant using a steam-heated iron pipeline installed on the bottom of the tanks. During the experiment, oxygen and pH ranged from 6.5–7.5 mg/L and 8.0–8.5, respectively.

From initial feeding at 4 DAH until 10 DAH, larvae were fed a rotifer diet composed of *Brachiouns* spp., *Asplanchnidae* spp. and *Filinia* spp. at a density of 10 individuals/mL. From 10 to 35 DAH, the diet was composed of cladocera dominated by *Diaphanosoma* spp. and *Moina* spp. at a density of 5 individuals/mL. From 30 DAH until the end of the experiment, larvae were fed a commercial compound diet (crude protein 35%, crude lipid 7%) at a feeding rate of 5% per day.

2.2 Sample collection

To monitor growth, 30 individuals were collected before food distribution each morning from hatching to 60 DAH. Total length (TL, mm) was measured individually with a digital vernier calipers to the nearest 0.01 mm. Body mass (BM, mg) was also determined to the nearest 0.1 mg after drying with filter paper. Thereafter, the following morphometric characteristics were measured (to the nearest 0.1 mm) for each sampled individual (n=10–20) under a stereomicroscope (Nikon SMZ1500, Nikon Corporation, Japan) with a micrometric ocular (Pro-Microscan DP300) and a digital vernier calipers: total length (TL), standard length (SL), head length (HL), trunk length (TRL), tail length (TAL), eye diameter (ED), head depth (HD), body depth (BD), tail depth (TD), pectoral fin length (PFL), tail fin length (TFL), and the third pair of barbel length (BL) (Table 1).

2.3 Statistical analysis

Curve estimates (created with SPSS 18.0, SPSS Inc., Chicago, IL, USA) were used to assess the best regression model of the LWR. Allometric growth was analyzed using simple linear regression with the log-transformed data according to the equation $\log Y = \log a + b\log SL$, where Y is the morphometric characteristic, a is the intercept, and b is the growth coefficient. Growth was considered isometric when

b=1; allometrically positive when b>1, and allometrically negative when b<1. Regression analysis via SPSS 18.0 was used to develop the allometric regression equations.

The inflection point of the growth curve was determined according to van Snik et al. (1997) and Gisbert (1999). First, the SL–Y data set was sorted according to increasing SL. Then, two regressions lines were calculated: one for SL_{min} to $SL_{intermediate}$ and another for $SL_{intermediate}$ to SL_{max}, where $SL_{intermediate}$ varied iteratively from SL_{min+2} to SL_{max-2}. A t-test was used to determine if b for SL_{min}–$SL_{intermediate}$ and $SL_{intermediate}$–SL_{max} differed significantly at the 0.05 level of significance. The $SL_{intermediate}$ value was utilized that resulted in the largest significant t as the inflection point.

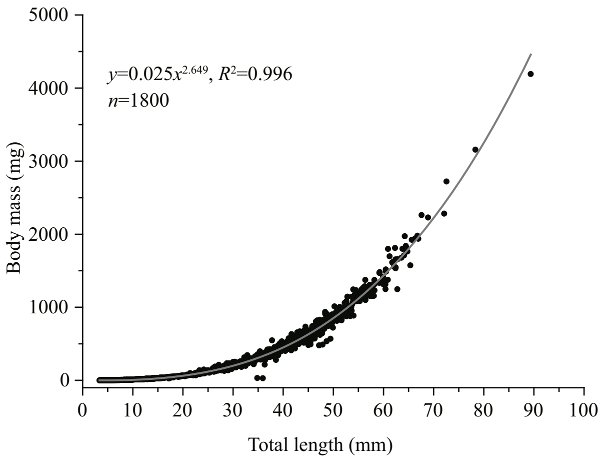


Fig.1 Length-weight relationship of Chinese loach during the larval and juvenile stages

3 RESULT

3.1 Length-weight relationship

In the present study, 1800 hatchery-reared Chinese loach individuals were examined. The best power model for LWR from curve estimates was a regression equation of $BM=0.025\times TL^{2.649}$ (Fig.1).

3.2 Allometric growth

Allometric growth equations between the 10 measured morphometric characteristics and standard length during the larval development stage (1–60 DAH) are presented in Fig.2. Growth of head length was allometically positive (b=2.60) until the inflection point at 5.04 mm standard length. Thereafter, the growth rate increased to being allometrically negative (b=0.69). Head depth showed positive allometric growth (b=2.44) until the inflection point at 4.20 mm standard length. Thereafter, the growth rate increased to being allometrically negative (b=0.82).

Trunk length showed positive allometric growth (b=1.51) until inflection point at 6.02 mm standard length, and decreased thereafter to being nearly isometric (b=1.05). Growth of tail length was allometrically positive (b=1.43) until the inflection point at 6.23 mm standard length. Although the growth coefficient decreased after the inflection point, tail length growth remained allometically positive (b=1.14). Pectoral fin length and barbel length showed negative allometric growth (b=0.84 and 0.81, respectively) until the end of the experiment.

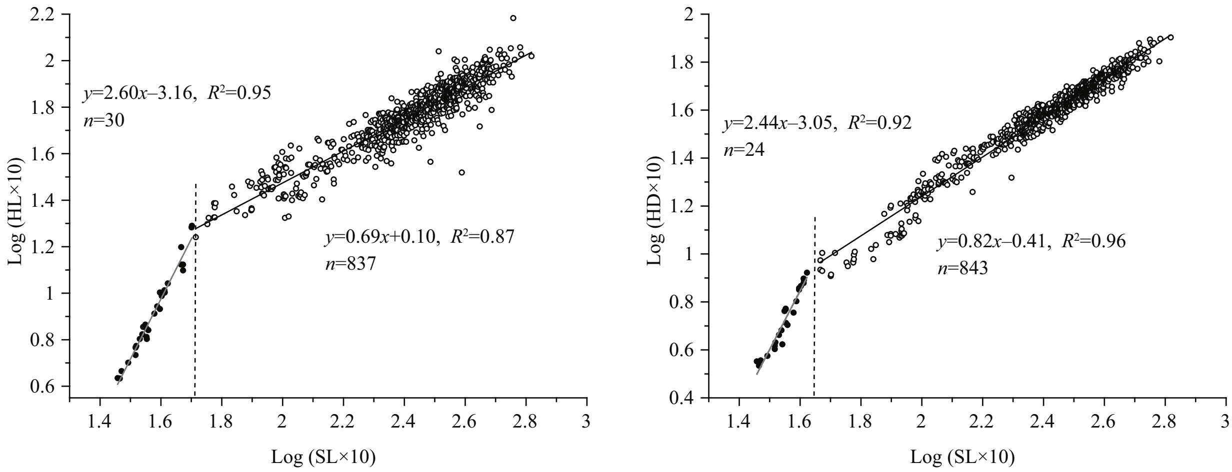
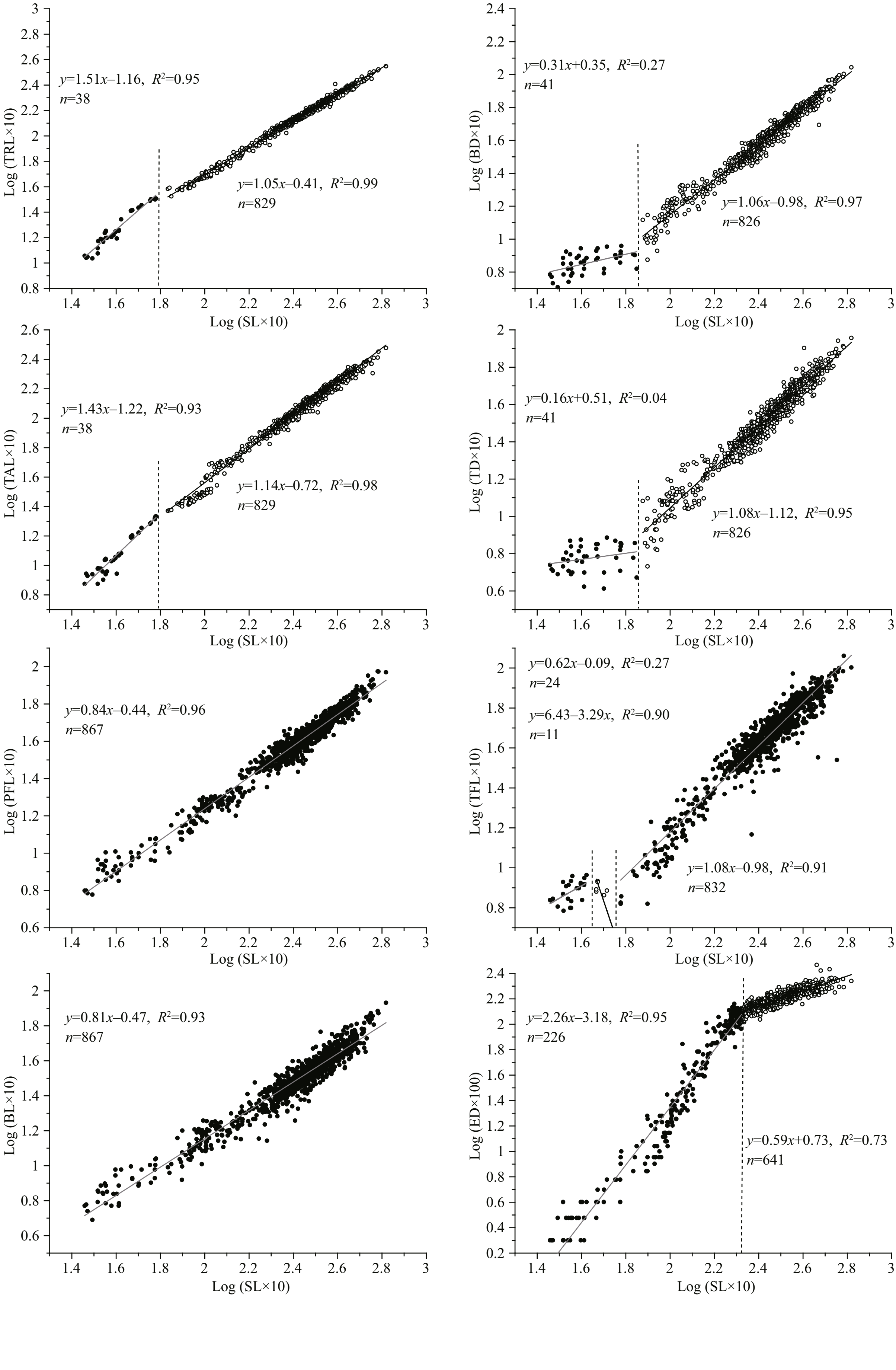


Fig.2 Allometric growth equations between 10 measured morphometric characteristics and standard length during Chinese loach development

SL: standard length; HL: head length; TRL: trunk length; TAL: tail length; TFL: tail fin length; PFL: pectoral fin length; BL: barbel length; ED: eye diameter; HD: head depth; BD: body depth; TD: tail depth.

To be continued

Fig.2 Continued



A similar growth pattern was found with body depth and tail depth: allometrically negative growth (*b*=0.31 and 0.16, respectively) was observed until the inflection point at 7.07 mm standard length, and increased thereafter to being nearly isometric (*b*=1.06 and 1.08, respectively).

Tail fin length showed negative allometric growth (*b*=0.62) until the inflection point at 4.20 mm standard length, then the growth coefficient decreased to -3.29 until the inflection point at 5.99 mm standard length. Thereafter, tail fin length showed nearly isometric growth (*b*=1.08). Eye diameter showed allometrically positive growth (*b*=2.26) until the inflection point at 21.09 mm standard length, and then decreased to being allometically negative (*b*=0.59).

4 DISCUSSION

Growth in fish is increasingly being linked with changes in husbandry parameters (Katsanevakis et al., 2007). Allometric equations are the most common method used to analyze relative growth during early ontogeny in fish. In the present study, the growth coefficients determined for Chinese loach larvae and juveniles showed differential growth of body ratios during the early life stages, which supports the hypothesis that a transition in ontogenetic priorities occurs during development to enhance survival (Russo et al., 2007; Peña and Dumas 2009; Khemis et al., 2013).

Positive allometric growth of the head length and head depth in Chinese loach, from hatching to 60 DAH, is a common feature found in other fish species (Gisbert and Doroshov, 2006; Huysentruyt et al., 2009; Celik and Cirik, 2011; Çoban et al., 2012; Gao et al., 2014; Guimarães-Cruz et al., 2014; Martínez-Montaño et al., 2014; Nogueira et al., 2014). The results of the present study supports the hypothesis that the development of the encephalon and other sensory, respiratory and feeding organs is a priority during the early life stages vis-à-vis the requirement to interact with the environment (Russo et al., 2007; Peña and Dumas, 2009; Khemis et al., 2013). Once theses organs have matured, the growth rate of the head decreased with an isometric tendency, as has been reported in the other Cobitidae species, such as *Misgurnus anguillicaudatus* (Gao et al., 2014).

The positive allometric growth of trunk length exhibited in the early life stages of Chinese loach was similar to that reported in California halibut larvae (*Paralichthys californicus*) (Gisbert et al., 2002). However, a large number of studies have reported negative allometric growth of trunk length in teleosts (Gisbert, 1999; Gisbert and Doroshov, 2006; Celik and Cirik, 2011; Gisbert et al., 2014; Kupren et al., 2014a, b; Martínez-Montaño et al., 2014; Nogueira et al., 2014). This difference might contribute to the rapid development of the accessory respiratory organ (posterior intestine) in Chinese loach larvae. After the inflection points, both the trunk length and body depth displayed an isometric tendency and did not change thereafter.

Positive allometric growth of tail length has also been reported in other species (Gisbert et al., 2014; Kupren et al., 2014a; Nogueira et al., 2014), these authors suggested the results were related to the modifications in swimming performance (caudal fin) during the early life stages. However, negative allometric growth of swimming organs (caudal and pectoral fins) was observed in the present study, which may result from the demersal and adherent behavior of Chinese loach.

The visual system associated with feeding (Shand et al., 2000; Uemura et al., 2000) and avoiding predation (Kunz et al., 1983) was allometrically positive in the early life stages of Chinese loach, as reported previously for other fish species (Huysentruyt et al., 2009; Çoban et al., 2009, 2012; Lima et al., 2012; Gao et al., 2014; Gisbert et al., 2014; Kupren et al., 2014a; Martínez-Montaño et al., 2014). This is probably because this early development would enhance the probability of survival. The barbel, a sensory organ in Chinese loach, displayed allometrically negative growth in the early life stages, suggesting that, in this species, the barbel developed early and did not grow thereafter.

5 CONCLUSION

The growth coefficient results show a clear and common tendency towards isometry for all the measured body ratios during the early developmental stage of Chinese loach. Rapid head segment development associated with vital functions, such as feeding, sensing and breathing, is necessary for survival during the early life stages of Chinese loach. In addition, specific behaviors of Chinese loach is probably related to its allometric growth patterns that differed from other teleosts, such as intestinal respiration and adherent behavior. Further research is warranted to evaluate morphological abnormalities resulting from the Chinese loach's specific behavioral traits and biological performance during the larval stage. It is anticipated that this study will provide baseline information for further research.

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