



Growth Patterns of Endemic Fish Species from the Lancang River, Southwest China

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ABSTRACT

This study provided estimates of length-weight relationships (LWRs) and length-length relationships (LLRs) of seven endemic fish species collected from the Lancang River, Southwest China and its tributaries. Totally, 435 specimens belonging to 3 families and 5 genera were collected from 2018 to 2022, using various types of fishing techniques. Total length (TL), standard length (SL) and body weight (BW) of each specimen were measured to the nearest 0.1 cm and 0.1 g, respectively. This study presents the first public records of LWRs parameters of *Garra mirofrontis*, *Sikukia longibarbata*, *Sikukia flavicaudata*, *Schistura kengtungensis*, *Glyptothorax macromaculatus* and *Glyptothorax zanaensis*, except for *Onychostoma gerlachi*. The allometric coefficient b values for all LWRs ranged from 2.7540 to 3.1038, and the r^2 values for all LWRs estimates ranged from 0.9705 to 0.9858. Comparison of b value with the expected value 3 showed that growth pattern of *S. longibarbata* and *G. zanaensis* were negative allometric, while others performed isometric growth pattern. The mean condition factor (K) of these seven species ranged from 1.31 to 2.77. The mean relative weight ranged between 100.43 to 101.94. This study updated information for FishBase and provided new record of maximum standard length for three species, namely, *G. mirofrontis* (16.50 cm), *S. longibarbata* (20.00 cm), and *S. flavicaudata* (26.50 cm). The findings of this study are essential for the management and conservation of locally indigenous fish and fisheries.

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Authors' Contribution

All authors contributed to the study conception and design. Material preparation, data collection and analysis were performed by HPD, TZ, ZMZ and YY. The first draft of the manuscript was written by HPD and all authors commented on previous versions of the manuscript. All authors read and approved the final version of the manuscript.

Key words

Length-weight relationship, Length-length relationship, Condition factor, Relative weight, Lancang River

INTRODUCTION

The Lancang-Mekong River is an important international river, located in Southeast Asia. As a typical longitudinal river, the river watershed covers various landscape types and has a fish fauna of exceptional diversity surpassed only by the Amazon watershed (Rainboth *et al.*, 2012). Nearly 200 fish species have been recorded in the river of China section, most of which are endemic species (Hong *et al.*, 2021). However, with the rapid population growth and economic development of countries in the river basin, especially the cascade development in the upper and middle reaches, fish diversity and fishery resources of the Lancang River are experiencing serious threats, which manifested as fish diversity and

fish resource decline, homogenization of fish assemblages, miniaturization of fish individual (Li *et al.*, 2013; Ngor *et al.*, 2018; Zhang *et al.*, 2018). Even so, basic biological information on most endemic fish species in the Lancang River is still limited (Li *et al.*, 2019).

Length-weight relationships (LWRs) are basic fish biological data, integrating important information of fish life history including lipid storage, body morphology, and growth rate (Zhang *et al.*, 2017). They are important in fish biology, ecology, fishery management, and conservation (Froese, 2006). According to LWRs, researchers can easily determinate fish weight from length or vice versa, evaluate fishery production, compute condition factor and relative weight (Patrick *et al.*, 2021). Besides, LWRs facilitate biometric and morphological comparisons between fish species in the same taxonomic group or between fish populations from different regions or periods (Froese, 2006; Çiçek *et al.*, 2022). The “ b ” value calculated from length-weight relationship is usually used to describe the growth patterns of fish according to the comparison the “ b ” value and the ideal value “3” (Pauly, 1984).

Condition factor and relative weight are other indices calculated from length and weight measurements. Condition factor is used to assess the fullness, nutrition, and the effect of environmental variability on fish (Le Cren,

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1951; Lizama *et al.*, 2002; Stevenson and Woods, 2006). Relative weight (W_r) integrates important physiological components of fish life history and offers a strong, accessible metric for managers to assess the overall health and fitness of fish populations, as well as population-level responses to ecosystem disturbances (Rypel *et al.*, 2006; Rypel and Layman, 2008).

Endemic fishes in the Lancang River are important components of the local biodiversity and aquatic food webs. Some endemic fish are important component of local fishery, such as *Garra mirofrontis*, *Sikukia longibarbata*, *Sikukia flavicaudata*, *Schistura kengtungensis* (Chu and Chen, 1989, 1990). However, there are few data about their biological traits, little information is available on their length and weight, especially LWRs, condition factor and relative weight. To expand the biological knowledge of these fish species and provide basic data for further research, this study provides LWRs, LLRs, condition factors, and relative weights of seven endemic fish species belonging to three families from the Lancang River, for which there is no information regarding the LWRs, even in FishBase (Froese and Pauly, 2023).

MATERIALS AND METHODS

Study area and sample collection

Samples were collected from the Lancang River and its tributaries, namely, Jidu River, Hei River, Weiyuan River, Buyuan River and Nanla River in southwest China from November 2018, June 2020, April to May and August to September 2022 (Table I, Fig. 1). Gillnets (20–40 m long, 1–3 m high, and mesh size, 1–5 cm), trap nets (20 m × 50 cm × 50 cm, mesh size 1 cm), and electrofishing (20 A, 1 V, 3000 W) were used to collect fish samples. After caught,

the specimens were identified to the species level according to the Fishes of Yunnan, China (Chu and Chen, 1989, 1990), and checklist of fishes of Yunnan (Chen, 2013). All scientific names were checked against FishBase (Froese and Pauly, 2023). For each individual, total length (TL), standard length (SL) and total weight (BW) was measured to the nearest 0.1 cm and 0.1 g, respectively. All handling procedures were performed according to the Administration Regulations of Laboratory Animals of China.

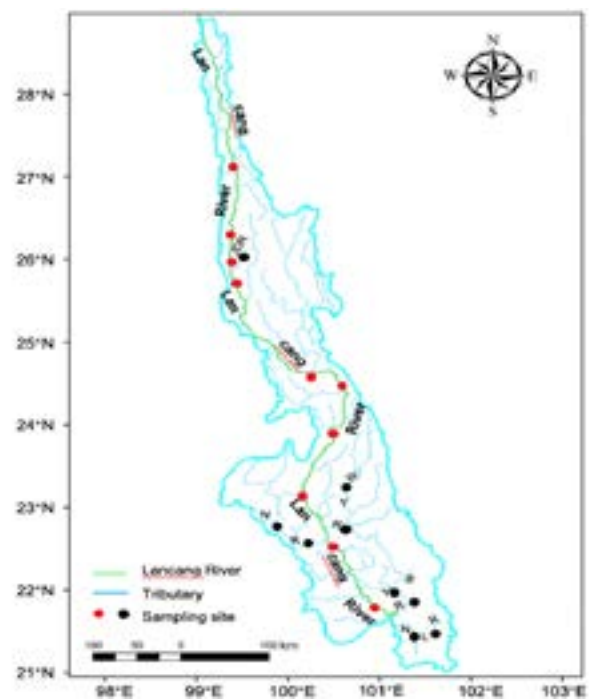


Fig. 1. Sampling sites.

Table I. Sampling sites and dates of the seven fish species from the Lancang River, China.

Family/ Species	n	Sampling river			Sampling time
		U	M	D	
Family: Cyprinidae					
<i>Garra mirofrontis</i>	87	○	○		Aug.-Sep. 2022
<i>Sikukia longibarbata</i>	63			○	Aug. 2022
<i>Sikukia flavicaudata</i>	48		○	○	Aug.-Sep. 2022
<i>Onychostoma gerlachi</i>	62		○	○	Nov. 2018; Apr.-May, Aug. 2022
Family: Nemacheilidae					
<i>Schistura kengtungensis</i>	55		○	○	Sep. 2022
Family: Sisoridae					
<i>Glyptothorax macromaculatus</i>	55		○	○	Apr.-May, Sep. 2022
<i>Glyptothorax zanaensis</i>	65	○	○		Jun. 2020; May, Sep. 2022

Specimens were collected from the mainstream and tributaries of the Lancang River. *n*, number of specimens; U, including upper stream of the Lancang River, Jidu River (JDR); M, including middle stream of the Lancang River; WYR, Weiyuan River; HR, Hei River; Down, including downstream of the Lancang River; BYR, Buyuan River, NLR, Nanla River; ○, fishes were collected.

Length and weight analyses

Length-weight relationship (LWRs) was calculated using the power function: $BW = aSL^b$

Condition factor was estimated as $K = 100 BW / SL^3$

Relative weight was estimated as $W_r = 100 BW / (a SL^b)$ where BW is the total weight (g), SL is the standard length (cm), a is the intercept of the regression, b is the allometric coefficient and K is the condition factor. Logarithmic transformation was performed and log-log plots of length and weight were used to eliminate outliers prior to the regression analysis of BW on SL as suggested by Froese (2006). Since no outliers were observed in this study, the log-log plots were not provided. Parameters a and b were estimated using linear regression analysis based on 10 logarithms: $\log BW = \log a + b \log SL$. The 95% confidence limits (CIs) of parameters a and b were estimated. Determination coefficient (r^2) calculated from the regression analysis was used to evaluate the fit of LWRs estimate. Besides, the relationship between TL and SL was analysed by linear regression for the $TL = p + qSL$, where TL is the total length (cm) and p and q is the regression coefficient (Zhang *et al.*, 2017).

Statistical analysis

T-test suggested by Pauly was performed to estimate the variation of allometric coefficient b with the expected value 3. When the b value does not differ significantly

from 3 ($p > 0.05$), weight growth is considered isometric, indicating that a fish proceeds in the “same” dimension as the cube of length. Otherwise, weight gain is allometric, including positive ($b > 3$) and negative ($b < 3$) (Pauly, 1984). All analyses were performed using IBM SPSS Statistics software (version 25.0; SPSS Inc. Ltd.) and Excel (Microsoft Office, 2021) at a significance level of 0.05.

RESULTS

Length and weight analyses

In the present study, 435 specimens belonging to three families, five genera, and seven species were collected. Descriptive statistics and estimated LWRs and LLRs parameters of the seven fish species are listed in Tables II and III. The LWRs for all fish species studied in this study were extremely significant ($p < 0.001$), with all r^2 values over 0.95, indicating that the LWR estimates for all species fit well and highly reliable. The intercept value a ranged between 0.0122 for *G. macromaculatus* and 0.0335 for *S. longibarbata*, and the b value ranged from 2.7540 (*S. longibarbata*) to 3.1038 (*G. macromaculatus*). All b values remained within the expected range of 2.5 – 3.5 (Forese, 2006). The LWRs for six species were reported for the first time to FishBase, except for *O. gerlachi*.

Table II. Descriptive statistics (Mean±SD, ranges in brackets) and estimated parameters of LWR ($BW = a SL^b$) for seven endemic fish species the Lancang River, Southwest China, from 2018 to 2022.

Species	n	SL (cm)	BW (g)	a	95% CI of a	b	95% CI of b	r^2	Growth pattern
<i>Garra mirofrontis</i> *	87	9.82 ± 2.74 (5.40-16.50)	25.81 ± 10.64 (3.50-97.70)	0.0244	0.0199-0.0289	2.9576	2.8756-3.0395	0.9845	I
<i>Sikukia longibarbata</i> *	63	11.17 ± 3.87 (5.10-20.00)	33.87 ± 11.89 (4.00-135.40)	0.0335	0.0267-0.0402	2.7540	2.6695-2.8385	0.9858	N
<i>Sikukia flavicaudata</i> *	48	16.68 ± 5.82 (7.40-26.50)	177.35 ± 61.97 (15.00-556.70)	0.0255	0.0152-0.0358	3.0248	2.8795-3.1701	0.9744	I
<i>Onychostoma gerlachi</i>	62	12.24 ± 3.73 (6.60-22.00)	37.28 ± 13.11 (4.10-160.10)	0.0157	0.0120-0.0194	2.9999	2.9044-3.0954	0.9844	I
<i>Schistura kengtungensis</i> *	55	5.31 ± 1.23 (3.50-8.40)	2.71 ± 1.90 (0.80-8.90)	0.0192	0.0156-0.0228	2.8779	2.7642-2.9917	0.9819	I
<i>Glyptothorax macromaculatus</i> *	55	6.69 ± 1.57 (4.00-11.00)	5.30 ± 1.90 (1.00-22.50)	0.0122	0.0088-0.0155	3.1038	2.9590-3.2486	0.9705	I
<i>Glyptothorax zanaensis</i> *	65	6.02 ± 1.21 (4.50-9.70)	3.16 ± 1.23 (1.40-12.50)	0.0196	0.0158-0.0235	2.7699	2.6600-2.8799	0.9771	N

n, number of specimens; *, newly recorded LWR to FishBase; bold, new maximum record of standard length to FishBase; n, sample size; S.D., standard deviation; a and b, regression parameters; CI, confidence limits; r^2 , coefficient of determination; I, isometric growth; N, negative allometric growth.

Table III. Descriptive statistics (Mean±SD, ranges in brackets) and estimated parameters of LLR ($TL = p + q SL$) for seven endemic fish species sampled in the Lancang River, Southwest China, from 2018 to 2022.

Species	n	TL (cm)	SL (cm)	p	95% CI of p	q	95% CI of q	r ²
<i>Garra mirofrontis</i>	87	12.60 ± 3.25 (7.00-20.50)	9.82 ± 2.74 (5.40-16.50)	1.0616	0.7451- 1.3781	1.1776	1.1466- 1.2087	0.9853
<i>Sikukia longibarbata</i>	63	14.20 ± 4.55 (6.50-24.70)	11.17 ± 3.87 (5.10-20.00)	1.1383	0.7587- 1.5179	1.1710	1.1388- 1.2031	0.9886
<i>Sikukia flavicaudata</i>	48	20.80 ± 7.34 (8.90-33.50)	16.68 ± 5.82 (7.40-26.50)	-0.1231	-0.7715- 0.5254	1.2537	1.2170- 1.2905	0.9903
<i>Onychostoma gerlachi</i>	62	15.30 ± 4.55 (8.20-27.30)	12.24 ± 3.73 (6.60-22.00)	0.4265	0.1434- 0.7096	1.2159	1.1938- 1.2381	0.9952
<i>Schistura kengtungensis</i>	55	6.40 ± 1.37 (4.30-9.80)	5.31 ± 1.23 (3.50-8.40)	0.5163	0.3434- 0.6892	1.1133	1.0815- 1.1450	0.9894
<i>Glyptothorax macromaculatus</i>	55	8.10 ± 1.71 (5.10-13.10)	6.69 ± 1.57 (4.00-11.00)	0.9137	0.6935- 1.1339	1.0795	1.0475- 1.1116	0.9886
<i>Glyptothorax zanaensis</i>	65	7.23 ± 1.21 (5.50-10.80)	6.02 ± 1.21 (4.50-9.70)	1.3136	1.0237- 1.6034	0.9828	0.9355- 1.0300	0.9661

n, sample size; S.D., standard deviation; p and q, regression parameters; CI, confidence limits; r², coefficient of determination.

The t-test showed that the b values of *S. longibarbata* ($t = 5.8130$, $p < 0.05$) and *G. zanaensis* ($t = 3.9092$, $p < 0.05$) were significantly less than 3 indicating that these two fish may manifest negative allometric growth pattern. The b values of the other five fish species, namely, *G. mirofrontis* ($t = 1.1999$), *S. flavicaudata* ($t = 0.3431$), *O. gerlachi* ($t = 0.0411$), *S. kengtungensis* ($t = 1.7392$), *G. macromaculatus* ($t = 1.5713$), were not significantly different from 3 (all $p > 0.05$). Growth pattern of these five fish could be isometric.

Besides, all LLRs were extremely remarkable ($p < 0.001$) with all determination coefficient (r^2) were > 0.96 . This study reported new maximum standard length for three fish species, namely, *G. mirofrontis* (16.5 cm), *S. longibarbata* (20.0 cm), and *S. flavicaudata* (26.5 cm), for the first time to FishBase (Froese and Pauly, 2023).

Condition factor and relative weight

Condition factors of the seven fish species studied in this study ranged from 1.09 to 3.86 (Table IV). The lowest mean condition factor was observed in *G. zanaensis*, with a mean value of 1.31 ± 0.11 , while the highest mean condition factor was observed in *S. flavicaudata*, the mean value was 2.77 ± 0.11 . The mean relative weight range of the seven fish species was 100.43-101.94 (Table IV), all around 100, indicating a balance between prey availability and predator density of these fish populations in their habitat.

Table IV. Condition factors (K) and relative weight (W_r) for seven fish species sampled in the Lancang River, Southwest China, from 2018 to 2022. The values are Mean±SD with ranges in brackets.

Species	n	K	W_r
<i>Garra mirofrontis</i>	87	2.24 ± 0.23 (1.76-2.78)	100.43 ± 10.33 (78.62-125.65)
<i>Sikukia longibarbata</i>	63	1.90 ± 0.29 (1.43-3.02)	100.57 ± 11.69 (73.87-134.39)
<i>Sikukia flavicaudata</i>	48	2.77 ± 0.51 (1.78-3.86)	101.61 ± 18.62 (65.30-142.01)
<i>Onychostoma gerlachi</i>	62	1.58 ± 0.18 (1.24-2.13)	100.44 ± 11.40 (79.05-135.57)
<i>Schistura kengtungensis</i>	55	1.58 ± 0.15 (1.32-1.95)	100.55 ± 9.05 (82.95-124.61)
<i>Glyptothorax macromaculatus</i>	55	1.49 ± 0.20 (1.10-1.84)	100.60 ± 13.15 (74.87-123.14)
<i>Glyptothorax zanaensis</i>	65	1.31 ± 0.11 (1.09-1.54)	100.06 ± 7.85 (85.32-116.40)

n, number of specimens; S.D., standard deviation.

DISCUSSION

According to the findings of this study, all fish species analyzed showed a strong correlation between length and weight. The r^2 value ranged between 0.9705 and 0.9858, indicating that the LWR estimates for all species fit well and were highly reliable. Although the sample size of several fish specimens used in this study is small, all b values

remained within the expected range of 2.5-3.5 (Forese, 2006). According to the comparison of this b value with 3, growth pattern of fishes can be discussed. However, the parameter b is species-specific (Borah *et al.*, 2018), and some other factors would affect the b parameter, for example, sex (Compaire and Soriuer, 2020), size classes (Zambrano *et al.*, 2023), different time periods (Sun *et al.*, 2019; Douligeri *et al.*, 2023), or even different geographic populations (Singh and Serajuddin, 2017). To increase the reliability of discussing isometric versus allometric growth of the species as a whole, based on mean b , all factors affect length-weight estimates should be considered and geographic, seasonal, and inter-annual variation should be covered reasonably (Forese, 2006).

Condition factor (K), also called Fulton condition factor, is an extended index of length and weight that reflects the development and nutritional status of fish at the individual level (Dai *et al.*, 2006; Rypel and Layman, 2008). When fishes are of the same body length, the larger their body masses, the better their physiological and nutritional status, and the higher their condition factor (Jones *et al.*, 1999). The Fulton condition factor is proposed under the ideal assumption that an animal's expected body weight grows evenly with its body length. In the present study, except for *S. longibarbata* and *G. zanaensis*, the b values of the other five fish species were not significantly different from 3, conforming to the assumption. However, for most animals, including fishes, weight growth does not proceed in the "same" dimension as the cube of length (Dai *et al.*, 2006). Besides, condition factor is closely related to age, gender, environment condition, season, population density, inter-specific and intra-specific relationships (Forese, 2006; Haberle *et al.*, 2023), all aforementioned factors should be considered to evaluate the condition factor more reliable.

The mean relative weight for all fish species studied in this study all around 100, indicating a balance between prey availability and predator density of these fish populations in their habitat. According to Anderson and Neumann (1996), if relative weight (W_r) of an individual or population less than 100 may indicate problems, such as low prey availability or high predation pressure; while the relative weight (W_r) greater than 100 indicates sufficient prey or low predation pressure.

CONCLUSION

According to the information in FishBase, this paper not only reports the LWRs and LLRs for six fish species (except for *O. gerlachi*) in the Lancang River basin for the first time, but also records new maximum standard length of three species, namely, *G. mirofrontis*, *S. longibarbata*,

and *S. flavicaudata*. However, the sampling did not include sufficiently broad temporal and spatial scope making the results unrepresentative. Moreover, gender, gonad maturity, development stages, gut satiety were not considered in this study, which may also make inconclusive of LWRs, LLRs, condition factor and relative weight. Although it cannot fully represent the entire population, the preliminary estimated LWRs, LLRs, condition factor and relative weight were useful. It provided basic data of fish biology for seven endemic fish species in Lancang River, Yunnan province, China, which will be of value of reference for subsequent research and management of these species.

DECLARATIONS

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Statement of conflict of interest

The authors have declared no conflict of interest.

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