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Variations of Length–Weight Relationships for Six Fish Species from the Lower Yarlung Zangbo River Catchment, Tibet, China

Huiping Ding [1], Mantang Xiong [2], Yang Yang [2], Tian Zhong [1], Feng Chen [2], Yutian Gong [2], Dongya Zhang [3], Sijin Jiang [2] and Zhiming Zhang [2,*]

[1] Hubei Key Laboratory of Animal Nutrition and Feed Science, Wuhan Polytechnic University, Wuhan 430023, China; cynthiadhp@whpu.edu.cn (H.D.); zhongtsvt@whpu.edu.cn (T.Z.)
[2] Key Laboratory of Ecological Impacts of Hydraulic-Projects and Restoration of Aquatic Ecosystem of Ministry of Water Resources, Institute of Hydroecology, MWR & CAS, Wuhan 430079, China; xiongmantang@mail.ihe.ac.cn (M.X.); yangy@mail.ihe.ac.cn (Y.Y.); bengyt@hotmail.com (Y.G.)
[3] Power China Beijing Engineering Corporation Limited, Beijing 100024, China
* Correspondence: zhangzm@mail.ihe.ac.cn; Tel.: +86-027-8292-7305

Abstract: The lower reaches of the Yarlung Zangbo River are one of the most important biodiversity hotspots worldwide. With the rapid economic development in the area coupled with global climate change, the fish resources and diversity of this region are experiencing serious threats. Basic biological information on most fishes in the river is limited, restricting the conservation of local fish resources. This study aimed to provide estimates of length–weight relationships (LWRs) for six fish species from the lower Yarlung Zangbo River catchment, Tibet, China. From 2023 to 2024, 4034 specimens belonging to two families, five genera, and six species were collected using various types of fishing techniques. The LWRs of five species, namely *Schizothorax curvilabiatus*, *Schizothorax molesworthi*, *Pseudecheneis sulcata*, *Parachiloglanis hodgarti*, and *Exostoma labiatum* were reported for the first time to FishBase, except *Garra tibetana*. The *b* values calculated from the LWRs ranged between 2.738 and 3.172, and the r^2 values for all LWRs estimates ranged from 0.931 to 0.989. Sexual variations of LWRs were observed in *S. molesworthi* and *P. sulcata*; seasonal variations were detected in *S. curvilabiatus*, *S. molesworthi*, *G. tibetana*, *P. sulcata,* and *P. hodgarti*; and geographical differences were discovered in *S. molesworthi*, *G. tibetana*, *P. sulcate*, *P. hodgarti,* and *E. labiatum*. Additionally, this study updated information for FishBase by providing a new record of maximum standard length for *S. curvilabiatus*, *S. molesworthi*, *G. tibetana*, and *P. hodgarti* and a new record of total length for *P. sulcata*. The findings of this study are essential for the management and conservation of locally indigenous fish and fisheries.

Keywords: length–weight relationship (LWR); spatiotemporal variations; growth pattern; conservation of fishes; the Yarlung Zangbo River

Key Contribution: This study provides information on the LWRs of six indigenous fish species from the lower Yarlung Zangbo River, describing their growth patterns and identifying the spatiotemporal variations of LWRs to expand the biological knowledge of these species and provide basic data for conservation.

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1. Introduction

Length and weight are two basic biological indicators for fish individuals and their populations, and they reflect the physiological status and population structure of fish species. They are also important indexes showing life-history traits of fish [1,2]. The length–weight relationships (LWRs) are fundamental in fish life-history research, allowing for the calculation of weight from length, or vice versa, and thereby determining population biomass [3–5]. The LWRs provide information on fish growth patterns, facilitate population production evaluation, and enable biometric and morphological comparisons at different levels [6,7]. In fisheries research, LWRs are considered an integral part of fish stock assessment models and used as a fundamental tool in resource assessment and management [6,8,9]. Many studies have shown that the length–weight relationship of fishes is affected by factors such as sex, season, geography, and environmental conditions, leading to different heterogeneity of parameter values in the relationship [2,7,8].

The power function with the expression of BW = a SL^b has been demonstrated to be the most reasonable mathematical expression describing the LWRs of fish [8,10]. The parameter "*b*", which is defined as an allometric factor, can effectively reflect the growth pattern of fish and can also reflect the environmental quality of the fish habitat indirectly [7,11]. However, many factors, such as sex, developmental phases, stomach fullness, season, and environmental conditions, will affect the relationship between length and weight, which leads to different heterogeneity of parameter values in the relationship [12–15]. Thus, to increase the reliability of the description of fish growth patterns based on the average *b* value, these factors should be considered.

The Yarlung Zangbo River is located in the highest Qinghai–Tibet Plateau. The unique and diverse natural environment in the Qinghai–Tibet Plateau breeds the unique biodiversity in the river [16–18]. The lower reaches of this river are one of the most important biodiversity hotspots worldwide, being extremely rich in biodiversity [19]. The indigenous fish fauna of the lower reaches of the river are mainly *Schizothorax integrilabiatus* (Wu et al., 1992), *Schizothorax curvilabiatus* (Wu & Tsao, 1992), and *Schizothorax molesworthi* (Chaudhuri, 1913), which belong to Schizothoracinae; *Garra tibetana* Gong, Deng, Wang & Liu, 2018 that belong to Labeoninae; and *Aborichthys kempi* Chaudhuri, 1913 and *Nemacheilus subfuscus* (McClelland, 1839) that are affiliated with Nemacheilidae. There are many fish species of Sisoridae, including *Glyptosternum maculatum* (Regan, 1905), *Pseudecheneis sulcata* (McClelland, 1842), *Parachiloglanis hodgarti* (Hora, 1923), *Glyptothorax annandalei* Hora, 1923, *Glyptothorax cavia* (Hamilton, 1822), *Glyptothorax gracilis* (Günther, 1864), *Exostoma labiatum* (McClelland, 1842), *Exostoma tenuicaudatum* Tamang, Sinha & Gurumayum, 2015, etc. [16,17]. And in recent years, some new species, such as *Garra dengba* Deng, Cao & Zhang, 2018, *Garra tibetana* Gong, Deng, Wang & Liu, 2018, *Garra motuoensis* Gong, Freyhof, Wang, Liu, Liu, Lin, Jiang & Liu 2018, and *Garra yajiangensis* Gong, Freyhof, Wang, Liu, Liu, Lin, Jiang & Liu 2018, have been found successively in the lower reaches [20–23]. Most of the fish species are endemic and highly rare.

Additionally, the lower Yarlung Zangbo River area is situated in the transitional zone from the Tibetan Plateau to the Indian peninsula, having a humid subtropical climate with a high-altitude gradient and containing huge hydro-energy [24]. The future development of water resources, coupled with global climate change, will inevitably have a profound impact on the biodiversity of the region, especially on fish resources [19,25]. Recently, influenced by factors such as habitat degradation, overfishing, hydropower development, and biological invasion, the fish resources in the Yarlung Zangbo River have declined dramatically [26]. Despite this, research on fishes of the lower Yarlung Zangbo River is still limited, and some basic biological information is scarce, which further hinders the fishery conservation efforts and development. Therefore, it is very necessary to explore fish biology, population dynamics, and fish diversity in this area to implement conservation and management measures for the protection of local fish assemblages. This study provides information on the LWRs of six fish species from the lower Yarlung Zangbo River, describing their growth patterns and identifying the spatiotemporal variations of LWRs to expand the biological knowledge of these species and provide basic data for conservation.

2. Materials and Methods

2.1. Sample Collection

Sample collections were conducted in the lower reaches of the lower Yarlung Zangbo River catchment located in Motuo County, Tibet, including 14 tributaries (Table 1, Figure 1). Fishes were captured using a combination of drift gillnets (20–40 m long, 1 m high, and mesh size 1–5 cm) and trap nets (20 m × 50 cm × 50 cm, mesh size 1–3 cm) from August 2023 to October 2024, with the permission of the competent authorities of local fishery administration. After being caught, all fish specimens were identified to the species level according to the Fishes of Qinghai-Xizang Plateau [16], Fishes and Fish Resources in Xizang, China [17], and China Zoography (Osteichthyoidea: Cypriniformes) [27]. All scientific names were checked against FishBase [28]. The total length (TL, cm) and standard length (SL, cm) of each fish were measured to the nearest 0.1 cm using a fish measuring board, and body weight (BW, g) was measured to the nearest 0.1 g using an electronic balance (Lichen, TD50002A). Most fishes were released into the wild after being measured. All handling procedures were conducted in compliance with the Regulations of Laboratory Animals Administration of China.

Table 1. Sampling information for six fish species in the lower Yarlung Zangbo River catchment, Tibet, China, from 2023 to 2024.

Fish Species	Sample Size															Sum
	S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15	
Schizothorax molesworthi (A)	56	30	299	70	13	53	31	360	71	59	135	138	56	57	36	1464
Schizothorax curvilabiatus (B)	440	-	-	2	-	-	-	1	-	-	-	1	-	-	-	444
Garra tibetana (C)	34	-	-	21	12	206	19	15	92	6	43	103	19	38	20	628
Parachiloglanis hodgarti (D)	18	6	3	42	21	46	9	2	31	12	106	44	14	20	15	389
Pseudecheneis sulcata (E)	216	3	-	18	40	56	8	39	13	37	152	31	40	33	32	718
Exostoma labiatum (F)	6	-	-	-	2	9	18	-	155	14	130	6	12	6	33	391
Sum	770	39	302	153	88	370	85	417	362	128	566	323	141	154	136	

Abbreviation list: A, B, C, D, E, and F are code names for *Schizothorax molesworthi*, *Schizothorax curvilabiatus*, *Garra tibetana*, *Parachiloglanis hodgarti*, *Pseudecheneis sulcata*, and *Exostoma labiatum*, respectively; S1, the mainstream of the Yarlung Zangbo River; S2, Ganong River; S3, Jinzhu Zangbo River; S4, Ximo River; S5, Haguo River; S6, Xigong River; S7, Jiaga River; S8, Deergong River; S9, Baimaxilu River; S10, Gongqu River; S11, Lingongri River; S12, Baimaxiri River; S13, Xiri River; S14, Danmoanong River; S15, Lugong River; -, means no specimens were captured. The same below.

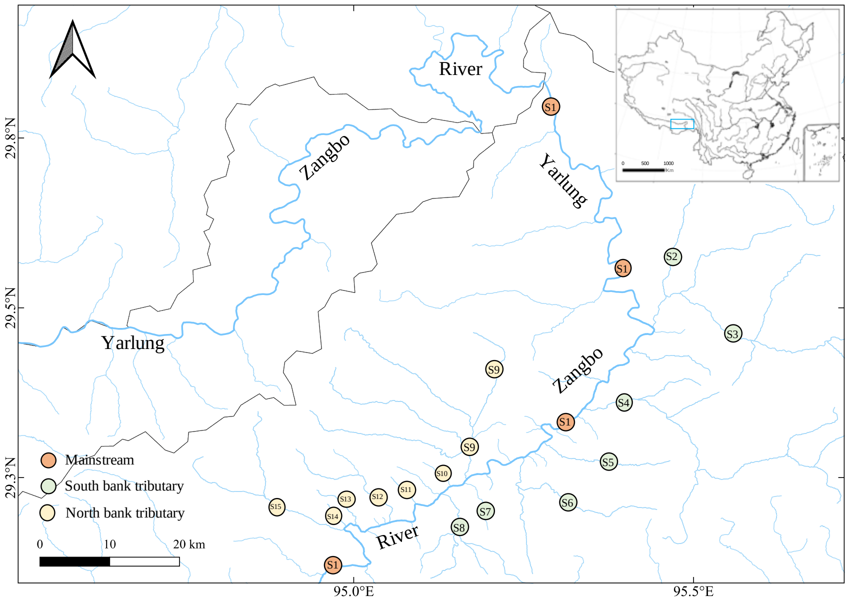

Figure 1. Study area and sampling sites in the lower Yarlung Zangbo River catchment. Information on codes is provided in Table 1.

2.2. Statistical Analysis

Measurements of standard length and body weight were logarithmically transformed first, and then linear regression was used to determine the length–weight relationships (LWRs) using the following logarithmic power function. Furthermore, total length–standard length relationships (LLRs) were established using linear regression analysis. Equations were as follows:

$$lg\ \mathrm{BW} = lg\ a + b \times lg\ \mathrm{SL}, \quad (1)$$

$$\mathrm{TL} = \alpha + \beta \times \mathrm{SL} \quad (2)$$

where (1) is for LWRs and (2) is for LLRs. BW is the body weight (g), TL and SL are the total length and standard length (cm), respectively, the parameter a is the intercept of the regression, and b is the allometric coefficient. α and β were constant and slope, respectively. The coefficient of determination (r^2) calculated from the regression analysis was used to evaluate the fitting degree of the LWR estimate. The 95% confidence intervals (CIs) of parameters a and b were estimated.

Covariance analysis (ANCOVA) was used to test variations of LWRs among seasons, stocks (that is, fishes distribute in different tributaries), and sexes (sex determination was conducted on individuals that were sampled for an ongoing artificial breeding study; other samples were released into the wild). Further, Tukey's post hoc test was employed to explore specific differences among different populations. Comparisons were conducted among populations with a sample size of 30 or more for each species. Growth patterns were analyzed by comparing the b value with the expected value of 3 using a t-test according to Pauly [10]. 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.

3. Results

3.1. Across-Species Variation in Length–Weight Relationships

In total, 4034 specimens belonging to two families, five genera, and six species were collected in this study. The six species were *S. curvilabiatus*, *S. molesworthi*, *G. tibetana*, *P. sulcate*, *P. hodgarti*, and *E. labiatum*. The sample size and size range of *SL* and *W* of these six species are listed in Table 2. Standard length and body weight varied but were limited to the size of the fishes that were recruited to our sampling gears. Maximum standard-length information of four fish species, namely *S. curvilabiatus*, *S. molesworthi*, *G. tibetana*, and *P. hodgarti*, were updated to FishBase. The maximum total length for *P. sulcata* was 22.60 cm in this study, which was also a new record for FishBase [28].

The LWRs for five species were reported for the first time to FishBase, with the exception of *G. tibetana*. The overall length–weight relationship parameters *a*, *b*, and their 95% confidence interval; coefficient of determination r^2; and the growth patterns of these six fish species can be seen in Table 2, and LLRs of TL and SL are given in Table 3. All the length–weight relationships were significant ($p < 0.05$), and all of the relationships between length and weight had a coefficient of determination (r^2) greater than 0.90, indicating that the LWR estimates for all species fit well and are highly reliable. The overall mean values of *b* for the studied six fish species ranged from 2.738 for *P. hodgarti* to 3.172 for *E. labiatum*, and the estimated values of parameter *a* ranged between 0.010 for *E. labiatum* and 0.024 for *S. curvilabiatus*. According to the results of the *t*-test, the *b* value of *E. labiatum* was significantly greater than the theoretical value of 3 ($t = 4.828$, $p < 0.05$), indicating that the growth pattern of this fish was positive allometric [10]. Different from *E. labiatum*, the growth patterns of *S. curvilabiatus* ($t = 8.764$), *G. tibetana* ($t = 7.382$), and *P. hodgarti* ($t = 6.914$) were negative allometric, with all *b* values significantly less than 3 (all $p < 0.05$). Among all fish species in this study, *S. molesworthi* ($t = 0.120$) and *P. sulcata* ($t = 0.103$) manifested an isometric growth pattern with a *b* value not significantly different from 3 (all $p > 0.05$). In addition, all LLRs were highly significant ($p < 0.05$), and all coefficients of determination values were >0.90.

Table 2. Descriptive statistics and estimated parameters of LWR (*lg* BW = *lg a* + *b lg* SL) for six fish species sampled in the lower Yarlung Zangbo River, Tibet, China, from 2023 to 2024. (SL, cm; BW, g).

Family	Species	*n*	Standard Length		Body Weight		*a*	95% CI of *a*	*b*	95% CI of *b*	r^2	Growth Pattern
			Range	Mean ± S.E.	Range	Mean ± S.E.						
Cyprinidae												
	Schizothorax molesworthi *	1464	2.50~**32.50**	10.34 ± 0.11	0.20~688.40	28.82 ± 1.27	0.017	0.016~0.018	2.999	2.976~3.022	0.989	I
	Schizothorax curvilabiatus *	444	3.50~**34.00**	15.79 ± 0.31	1.30~448.00	91.81 ± 4.55	0.024	0.022~0.026	2.858	2.826~2.890	0.986	N
	Garra tibetana	628	3.00~**13.50**	7.90 ± 0.08	0.30~35.27	9.40 ± 0.23	0.023	0.021~0.025	2.836	2.792~2.879	0.963	N
Sisoridae												
	Parachiloglanis hodgarti *	389	2.50~**8.90**	5.43 ± 0.06	0.20~6.58	2.00 ± 0.06	0.017	0.015~0.019	2.738	2.664~2.813	0.931	N
	Pseudecheneis sulcata *	718	3.20~19.00	10.31 ± 0.12	0.32~94.10	19.00 ± 0.69	0.013	0.012~0.014	3.002	2. 964~3.040	0.971	I
	Exostoma labiatum *	391	2.90~9.00	652 ± 0.06	0.43~11.40	4.13 ± 0.11	0.01	0.008~0.011	3.172	2.101~3.242	0.953	P

Abbreviation list: *, newly recorded LWR to FishBase; *n*, sample size; S.E., standard error; bold, new maximum record of standard length to FishBase; *a* and *b*, regression parameters; CI, confidence interval; r^2, coefficient of determination; I, isometric growth; N, negative allometric growth; P, positive allometric growth.

Table 3. Descriptive statistics and estimated parameters of LLR (TL = α + β SL) for six fish species from the lower Yarlung Zangbo River, Tibet, China.

Family	Species	Parameters			
		n	α	β	r^2
Cyprinidae					
	Schizothorax molesworthi	1464	0.496	1.201	0.988
	Schizothorax curvilabiatus	444	0.318	1.226	0.994
	Garra tibetana	628	0.102	1.202	0.988
Sisoridae					
	Parachiloglanis hodgarti	389	0.534	1.066	0.954
	Pseudecheneis sulcata	718	0.461	1.166	0.985
	Exostoma labiatum	391	0.104	1.174	0.939

3.2. Within-Species Variation in Length–Weight Relationships

Sexual differences in LWRs were observed in *S. molesworthi* and *P. sulcata*. For *S. molesworthi*, the value of the allometric coefficient *b* of females was significantly greater than that of males (ANCOVA, $F = 5.176$, $p < 0.05$) (Figure 2A). And for *P. sulcata*, the value for females was statistically lower than that for males ($F = 19.227$, $p < 0.05$) (Figure 2E). There were no sexual differences in LWRs observed in *S. curvilabiatus* (Figure 2B), *G. tibetana* (Figure 2C), and *E. labiatum* (Figure 2F) (all $p > 0.05$). Sexual differences in LWRs in *P. hodgarti* were not analyzed because of the small sample size. The parameters *a* and *b* of LWRs calculated based on gender for six fishes are listed in Table 4. Further, the standard length and body weight distributions of these six fishes, based on gender, were analyzed (Figure 3) to compare their body size between sexes. There were some differences in individual body size between sexes.

Table 4. Estimated parameters *a* and *b* of LWR based on gender for six fish species from the lower Yarlung Zangbo River, Tibet, China.

Species	Sex	n	a	95% CI of a	b	95% CI of b	r^2
Schizothorax molesworthi (A)	F	159	0.016	0.013~0.018	3.031	2.982~3.080	0.990
	M	139	0.017	0.012~0.022	2.991	2.880~3.102	0.954
Schizothorax curvilabiatus (B)	F	67	0.021	0.013~0.030	2.888	2.756~3.019	0.968
	M	55	0.016	0.008~0.024	2.994	2.822~3.165	0.959
Garra tibetana (C)	F	56	0.027	0.015~0.039	2.780	2.590~2.969	0.941
	M	55	0.034	0.021~0.048	2.675	2.498~2.853	0.945
Parachiloglanis hodgarti (D) +	F	16	0.068	−0.040~0.176	2.071	1.227~2.914	0.664
	M	12	0.051	−0.038~0.139	2.199	1.332~3.065	0.762
Pseudecheneis sulcata (E)	F	66	0.016	0.009~0.023	2.901	2.733~3.070	0.949
	M	93	0.011	0.006~0.016	3.077	2.902~3.253	0.930
Exostoma labiatum (F)	F	128	0.011	0.007~0.015	3.104	2.932~3.276	0.910
	M	47	0.010	0.004~0.016	3.174	2.835~3.512	0.888

Abbreviations list: +, tentative estimation due to limited sample size; F, female; M, male.

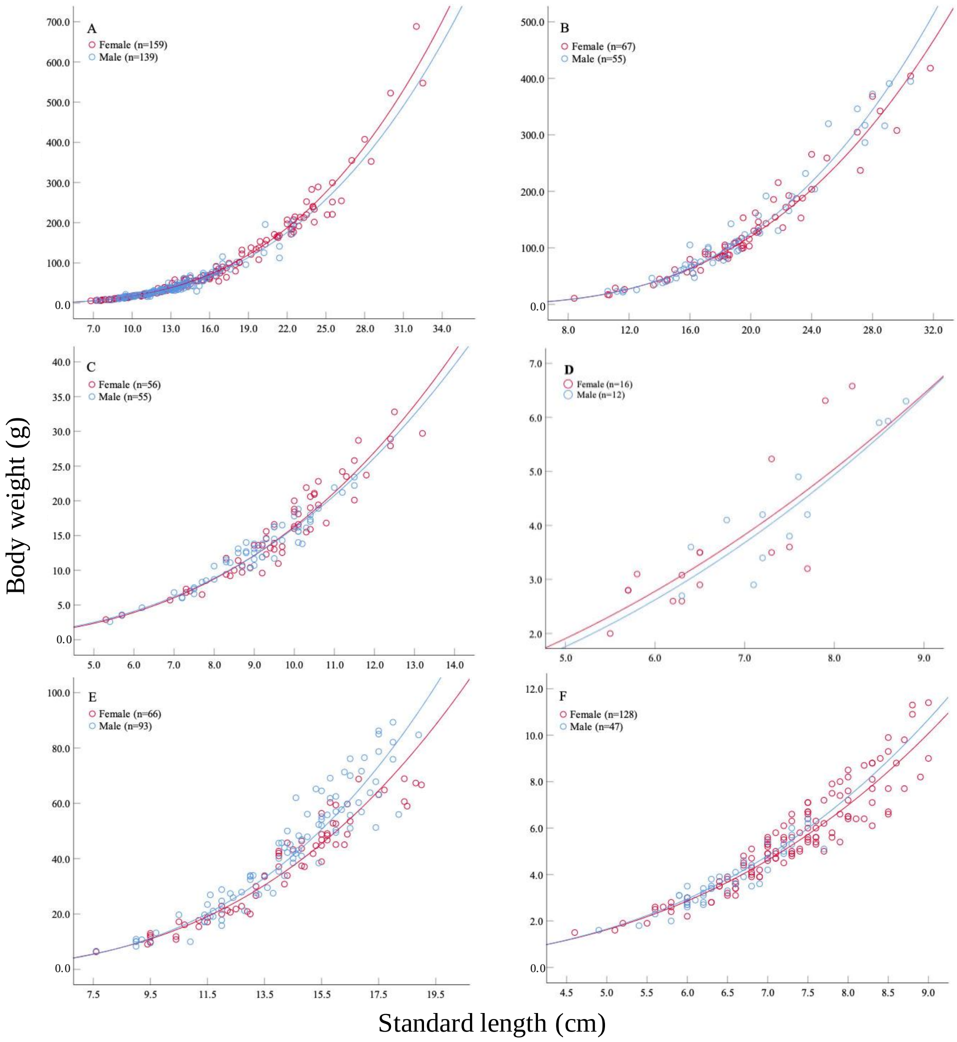

Figure 2. Sexual variations of length–weight relationships for (**A**) *Schizothorax molesworthi*; (**B**) *Schizothorax curvilabiatus*; (**C**) *Garra tibetana*; (**D**) *Parachiloglanis hodgarti*; (**E**) *Pseudecheneis sulcata*; (**F**) *Exostoma labiatum* sampled in reaches of the lower Yarlung Zangbo River, Tibet, China.

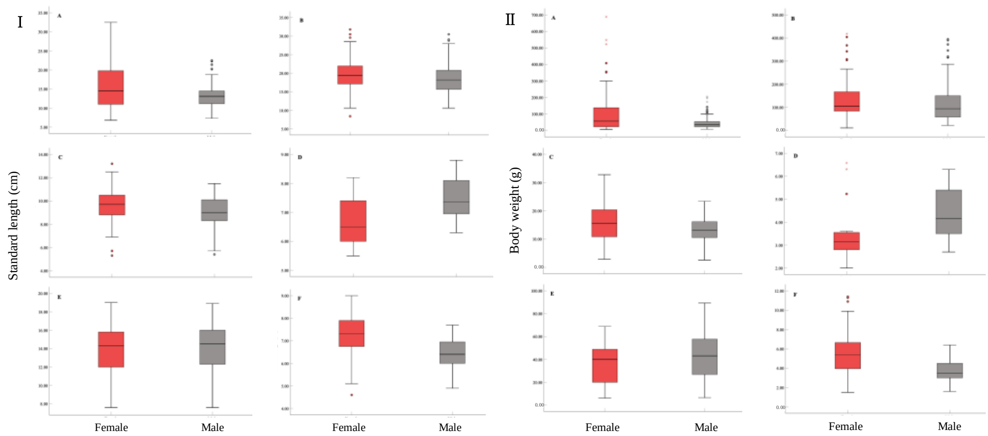

Figure 3. **S**tandard length (Ⅰ) and body weight (Ⅱ) distributions based on genders for (**A**) *Schizothorax molesworthi*; (**B**) *Schizothorax curvilabiatus*; (**C**) *Garra tibetana*; (**D**) *Parachiloglanis hodgarti*; (**E**) *Pseudecheneis sulcata*; and (**F**) *Exostoma labiatum* sampled in reaches of the lower Yarlung Zangbo River, Tibet, China.

Seasonal differences in LWRs were observed in five species, with the exception of *E. labiatum* (Table 5; Figure 4F) (ANCOVA, $F = 1.180$, $p = 0.317$). According to the ANCOVA results of seasonal comparisons, the difference for *S. molesworthi* mainly showed between spring and other seasons (all $p < 0.05$) (Figure 4A), while that for *G. tibetana* mainly existed between autumn and other seasons (all $p < 0.05$) (Figure 4C). For *S. curvilabiatus*, seasonal differences in LWRs showed in spring vs. winter ($p < 0.05$) (Figure 4B), and samples from autumn were excluded because of the small sample size ($n = 7$). For *P. hodgarti*, this difference existed in spring vs. summer and summer vs. winter ($p < 0.05$) (Figure 4D), while for *P. sulcata*, except spring vs. autumn and summer vs. winter, seasonal differences showed among all other groups ($p < 0.05$) (Figure 4E).

Table 5. Estimated parameters *a* and *b* of LWR based on season for six fish species from the lower Yarlung Zangbo River, Tibet, China.

Species	Season	*n*	*a*	95% CI of *a*	*b*	95% CI of *b*	r^2
Schizothorax molesworthi (A)	Winter	431	0.017	0.016~0.019	2.974	2.938~3.010	0.984
	Spring	388	0.016	0.013~0.018	3.029	2.959~3.098	0.950
	Summer	540	0.017	0.016~0.018	2.995	2.968~3.022	0.989
	Autumn	106	0.018	0.013~0.023	2.933	2.812~3.054	0.957
Schizothorax curvilabiatus (B)	Winter	138	0.024	0.019~0.029	2.821	2.748~2.893	0.978
	Spring	199	0.024	0.021~0.027	2.875	2.830~2.920	0.988
	Summer +	7	0.053	0.021~0.085	2.611	2.411~2.812	0.996
	Autumn	100	0.018	0.016~0.020	2.949	2.905 ~2.992	0.995
Garra tibetana (C)	Winter	177	0.028	0.024~0.032	2.761	2.691~2.832	0.971
	Spring	172	0.025	0.021~0.029	2.813	2.729~2.897	0.963
	Summer	175	0.021	0.017~0.024	2.887	2.809~2.966	0.968
	Autumn	104	0.025	0.018~0.033	2.767	2.632~2.903	0.941
Parachiloglanis hodgarti (D)	Winter	132	0.017	0.014~0.021	2.743	2.619~2.867	0.936
	Spring	92	0.021	0.013~0.030	2.591	2.357~2.815	0.855
	Summer	105	0.014	0.011~0.016	2.888	2.785~2.991	0.968
	Autumn	60	0.021	0.016~0.026	2.633	2.484~2.782	0.956
Pseudecheneis sulcata (E)	Winter	130	0.018	0.014~0.022	2.869	2.779~3.959	0.969
	Spring	286	0.016	0.013~0.018	2.939	2.882~2.995	0.973
	Summer	213	0.019	0.016~0.022	2.806	2.729~2.884	0.960
	Autumn	91	0.011	0.009~0.013	2.997	2.896~3.098	0.975
Exostoma labiatum (F)	Winter	110	0.008	0.006~0.010	3.312	3.171~3.452	0.953
	Spring	188	0.012	0.009~0.014	3.086	2.968~3.205	0.934
	Summer	69	0.009	0.007~0.012	3.149	2.981~3.318	0.954
	Autumn +	26	0.019	0.013~0.026	2.738	2.536~2.941	0.970

Abbreviations list: +, tentative estimation due to limited sample size.

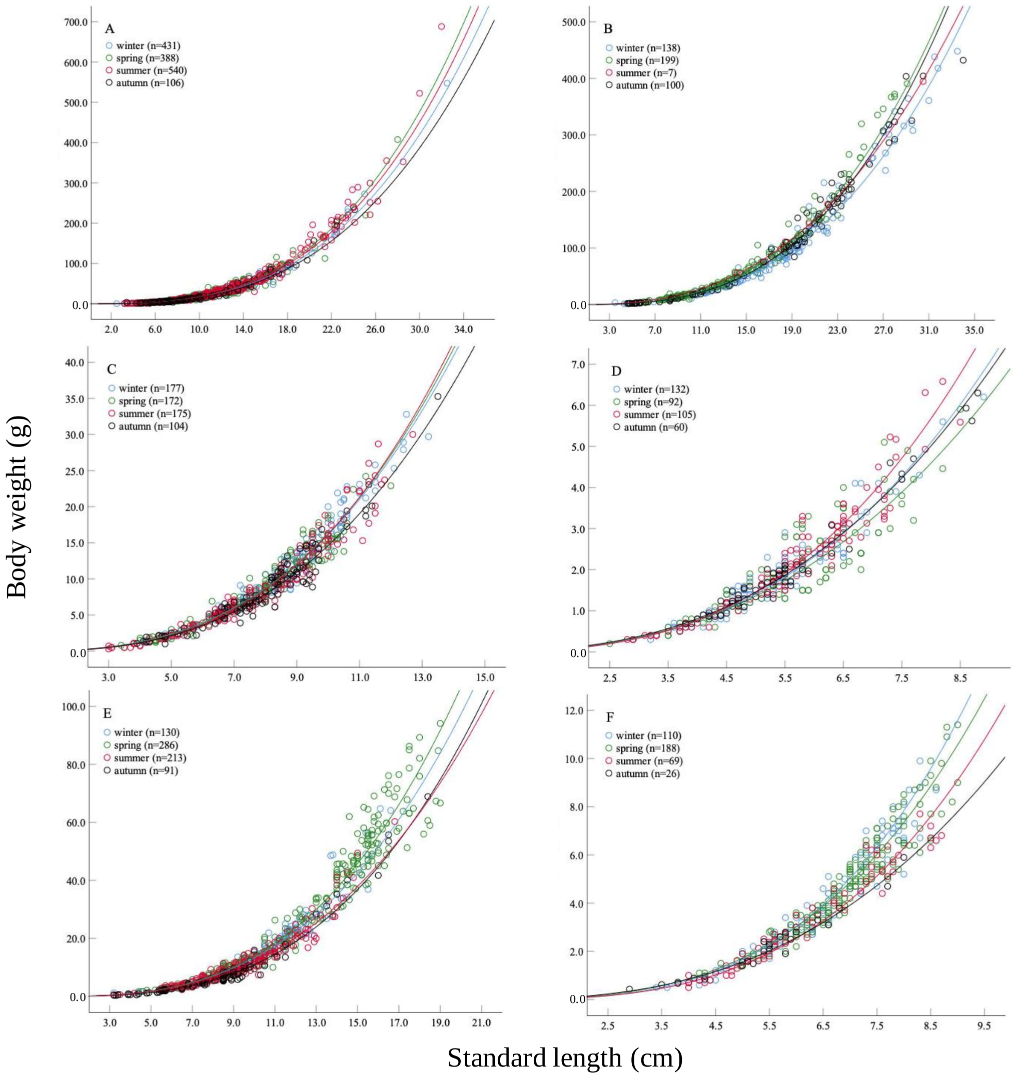

Figure 4. Seasonal variations of length–weight relationships for (**A**) *Schizothorax molesworthi*; (**B**) *Schizothorax curvilabiatus*; (**C**) *Garra tibetana*; (**D**) *Parachiloglanis hodgarti*; (**E**) *Pseudecheneis sulcata*; and (**F**) *Exostoma labiatum* sampled in reaches of the lower Yarlung Zangbo River, Tibet, China.

Geographical differences in LWRs were compared among populations with a sample size of 30 or more for each species (Table 6; Figure 5). And because *S. curvilabiatus* analyzed in the present study was mainly obtained in the mainstream of the Yarlung Zangbo River (Table 1), geographical differences for this species were not compared (Figure 5B). LWR differences in geographical populations were observed in all five other species. For *S. molesworthi*, the difference mainly showed between the mainstream of the Yarlung Zangbo River and its tributaries. Additionally, geographical differences were observed among almost all tributaries on the south bank, while there were fewer differences observed in tributaries on the north bank (Table 7, Figure 5A). Similar results were observed in *P. sulcata* (Table 8, Figure 5E). However, for *G. tibetana* and *P. hodgarti*, the geographical differences mainly existed among populations from tributaries on the north bank (Figure 5C, D), respectively. The difference for *E. labiatum* mainly existed between tributary 15 and other tributaries (all $p < 0.05$) (Figure 5F).

Table 6. Estimated parameters *a* and *b* of LWR based on tributary for six fish species from the lower Yarlung Zangbo River, Tibet, China.

Species	River	*n*	*a*	95% CL of *a*	*b*	95% CL of *b*	r^2
Schizothorax molesworthi (A)	S1	56	0.016	0.012~0.019	3.024	2.942~3.107	0.990
	S2	30	0.028	0.012~0.044	2.772	2.548~2.997	0.958
	S3	299	0.017	0.015~0.018	3.001	2.964~3.038	0.988
	S4	70	0.012	0.009~0.015	3.143	3.039~3.247	0.982
	S6	53	0.026	0.021~0.031	2.815	2.722~2.907	0.987
	S7	31	0.019	0.012~0.026	2.966	2.764~3.167	0.972
	S8	360	0.018	0.017~0.020	2.916	2.872~2.961	0.979
	S9	71	0.011	0.008~0.015	3.199	3.063~3.335	0.969
	S10	59	0.019	0.012~0.026	2.997	2.833~3.160	0.959
	S11	135	0.023	0.018~0.027	2.920	2.838~3.002	0.962
	S12	138	0.018	0.015~0.022	2.964	2.881~3.046	0.974
	S13	56	0.023	0.016~0.030	2.825	2.691~2.958	0.971
	S14	57	0.015	0.010~0.020	3.027	2.864~3.190	0.962
	S15	36	0.020	0.014~0.026	2.921	2.789~3.052	0.983
Garra tibetana (C)	S1	34	0.026	0.019~0.033	2.742	2.599~2.885	0.980
	S6	206	0.018	0.015~0.022	2.946	2.860~3.032	0.957
	S9	92	0.024	0.018~0.030	2.812	2.687~2.937	0.957
	S11	43	0.024	0.014~0.034	2.844	2.652~3.037	0.956
	S12	103	0.029	0.023~0.034	2.748	2.659~2.837	0.974
	S14	38	0.046	0.026~0.066	2.485	2.271~2.699	0.939
Parachiloglanis hodgarti (D)	S4	42	0.024	0.018~0.031	2.541	2.388~2.694	0.966
	S6	46	0.022	0.012 ~0.031	2.613	2.349~2.877	0.900
	S9	31	0.013	0.008~0.018	2.892	2.653~3.130	0.961
	S11	106	0.020	0.015~0.025	2.607	2.466~ 2.748	0.928
	S12	44	0.016	0.011~0.020	2.800	2.625~2.974	0.962
Pseudecheneis sulcata (E)	S1	216	0.010	0.009~0.011	3.091	3.037~3.145	0.983
	S5	40	0.007	0.001~0.014	3.166	2.787~3.546	0.883
	S6	56	0.014	0.010~0.018	2.950	2.820~3.080	0.974
	S8	39	0.012	0.007~0.017	3.088	2.885~3.292	0.962
	S10	37	0.019	0.012~0.027	2.859	2.686~3.031	0.970
	S11	152	0.013	0.010~0.016	2.979	2.880~3.078	0.959
	S12	31	0.016	0.008 ~0.024	2.898	2.675~3.121	0.961
	S13	40	0.013	0.006~0.019	3.021	2.805~3.237	0.955
	S14	33	0.025	0.015~0.036	2.643	2.456~2.830	0.964
	S15	32	0.017	0.007~0.026	2.924	2.687~3.161	0.955
Exostoma labiatum (F)	S9	155	0.015	0.011~0.019	2.971	2.837~3.106	0.926
	S11	130	0.011	0.008~0.014	3.099	2.970~3.228	0.946
	S15	33	0.016	0.007~0.025	2.861	2.548~3.174	0.918

Table 7. Pairwise comparison of LWRs between tributaries for *Schizothorax molesworthi*.

Sample River	S1	S2	S3	S4	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
S1		**	**	**	*	ns	**	**	**	**	**	**	*	**
S2	**		*	**	**	**	**	**	**	*	**	*	**	*
S3	**	*		**	**	**	ns	ns	*	ns	*	ns	**	ns
S4	**	**	**		ns	*	*	ns	ns	*	ns	ns	ns	ns
S6	*	**	**	ns		ns	**	ns	ns	**	ns	*	ns	*
S7	ns	**	**	*	ns		**	**	**	**	**	**	ns	**

S8	**	**	ns	*	**	**		ns	ns	ns	ns	ns	**	ns
S9	**	**	ns	ns	ns	**	ns		ns	ns	ns	ns	ns	ns
S10	**	**	*	ns	ns	**	ns	ns		ns	ns	ns	ns	ns
S11	**	*	ns	*	**	**	ns	ns	ns		*	ns	**	ns
S12	**	**	*	ns	ns	**	ns	ns	ns	*		ns	ns	ns
S13	**	*	ns	ns	*	**	ns	ns	ns	ns	ns		*	ns
S14	**	*	ns	ns	*	**	ns	ns	ns	ns	ns	*		ns
S15	**	*	ns	ns	*	**	ns	ns	ns	ns	ns	ns	*	

Abbreviations list: ns means no difference; * means significant difference; ** means extremely significant difference.

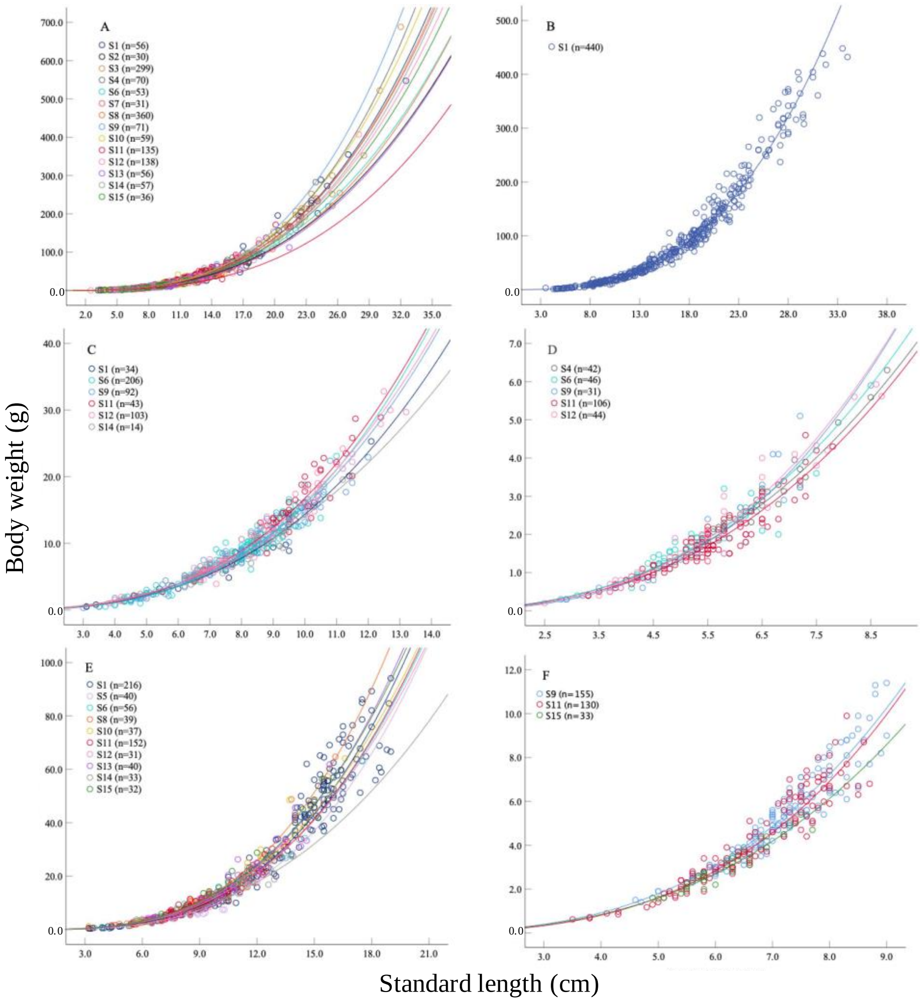

Figure 5. Geographical variations of length–weight relationships for (**A**) *Schizothorax molesworthi*; (**B**) *Schizothorax curvilabiatus*; (**C**) *Garra tibetana*; (**D**) *Parachiloglanis hodgarti*; (**E**); *Pseudecheneis sulcata*; and (**F**) *Exostoma labiatum* sampled in reaches of the lower Yarlung Zangbo River, Tibet, China.

Table 8. Pairwise comparison of LWRs between tributaries for *Pseudecheneis sulcata.*

Sample River	S1	S5	S6	S8	S10	S11	S12	S13	S14	S15
S1		**	**	ns	ns	**	**	**	**	**
S5	**		ns	**	**	ns	ns	ns	ns	ns
S6	**	ns		**	**	ns	ns	ns	ns	ns
S8	ns	**	**		ns	**	**	**	**	**
S10	ns	**	**	ns		**	**	*	**	*
S11	**	ns	ns	**	**		ns	ns	ns	ns
S12	**	ns	ns	**	**	ns		ns	ns	ns

S13	**	ns	ns	**	*	ns	ns		ns	ns
S14	**	ns	ns	**	**	ns	ns	ns		ns
S15	**	ns	ns	**	*	ns	ns	ns	ns	

Abbreviations list: ns means no difference; * means significant difference; ** means extremely significant difference.

4. Discussion

Length–weight relationships (LWRs) of different fishes were different; hence, the differences in parameters were calculated from the relationship [29]. The variation in this *b* value reflected the heterogeneity of growth and related to the body shapes of the respective fish species [6]. According to the results of this study, the overall mean values of the allometric coefficient *b* for the six studied fish species were 2.738 to 3.002, within the expected range of 2.5 to 3.5 [6]. Strong allometric growth patterns were observed in *S. curvilabiatus*, *G. tibetana*, *P. hodgarti,* and *E. labiatum* in this study, indicating that the weight growth of these fishes was in the "different" dimension as the cube of length. Negative allometric growth patterns of *S. curvilabiatus*, *G. tibetana*, and *P. hodgarti* may relate to their relatively elongated body shapes [16,17], and the growth in length was faster than that of weight for these fishes accordingly. While the positive allometric growth pattern of *E. labiatum* was probably due to a large number of samples (exceeding 75%) being collected in winter and spring, when they were just at the gonad accumulation period [17], and the growth in weight was faster than that of length for this fish.

The LWRs of fish were influenced by many factors, such as sex, season, geography, and environmental conditions, thus leading to varying heterogeneity in the parameter values within this relationship [30–32]. In the present study, sexual differences in LWRs were detected in *S. molesworthi* and *P. sulcata* (Table 4; Figure 3A, E). Further analysis showed that the significant sexual differences in the LWRs for these two species could be associated with the individual size difference between sexes. The body size of the female *S. molesworthi* (Figure 3A) was larger than that of the male, while the size of the male *P. sulcata* was larger than that of the female (Figure 3E). Sexual differences were also observed in other fish species [11,13,33].

Seasonal variations in the LWRs were observed in many fish species [2,11,30,34,35]. These variations may relate to differences in the life history stage, gonad developmental phases, and stomach fullness of fishes at the time [36,37]. In the present study, for *S. molesworthi*, spring was the fattening season; a large amount of food intake resulted in more weight gain than in other seasons. Additionally, according to the wild investigation, the breeding period of *S. molesworthi* lasted from May to October; energy obtained could have been spent on gonad development, not on length and weight. However, the spawning type of this species is not yet clear. As for *S. curvilabiatus*, with a breeding time mainly in winter, from December to January of the next year, reproductive activities coupled with food scarcity in winter accounted for the lower weight growth in winter than in spring and autumn, respectively. The seasonal variations in the LWRs for *G. tibetana* and *P. hodgarti* were probably associated with the gonad developmental phases of the respective fish species. The breeding season for *G. tibetana* was concentrated in summer [17]; when the investigation was conducted in the autumn, many individuals had not recovered from the breeding, leading to less weight growth in autumn. For *P. hodgarti*, the reproductive season was mainly in summer [27], and the gonad accumulation resulted in more weight gain in this season.

Geographical differences in LWRs within species were general in many fishes [14,38]. Because the growth of fish is affected by external environmental factors, such as water temperature, dissolved oxygen, water-flow velocity, food resources [11,35,39], and so on. Usually, these factors are spatial variations that would result in variations in growth patterns for fishes in different rivers. In the present study, geographical differences in LWRs for each fish species were observed from the results of comparison among mainstream and tributaries, except for *S. curvilabiatus*. The variations among geographical populations could relate to the environmental factors of the respective habitats. Firstly, located in the Qinghai–Tibet Plateau and affected by geographical conditions, there were prominent spatiotemporal variations among water bodies of the lower Yarlung Zangbo River [40]. This variation could result in spatiotemporal variations of water quality and food supply accordingly [41,42], affecting the growth of the fish distributed there and ultimately resulting in within-species geographical differences in LWRs. Additionally, according to geographical location, distances among tributaries on the south bank were farther than that of tributaries on the north bank (Figure 1), which may cause more environmental heterogeneity among tributaries on the south bank. This is why LWR variations were different between the two banks for *S. molesworthi* and *P. sulcata*. However, specific environmental variables were not detected in this study; further studies are needed to confirm the environment–growth relationship.

5. Conclusions

The present study provides a basic understanding of the LWRs of six fish species distributed in the lower Yalung Zangbo River, Tibet, China. The LWRs for five species are published herein for the first time for FishBase. New records of maximum standard length for four species and total length for *P. sulcatawere* were recorded. Sexual differences in LWRs were observed in two fish species: *S. molesworthi* and *P. sulcata*. Seasonal differences were observed in five species, except for *E. labiatum*. And with the exception of *S. curvilabiatus*, geographical differences in LWRs were observed in all other species. According to the overall mean *b* values, the growth patterns of *S. molesworthi* and *P. sulcata* were isometric, and those of *S. curvilabiatus*, *G. tibetana*, and *P. hodgarti* were negative allometric, while *E. labiatum* had positive allometric growth. However, other factors that will affect the LWRs and the associated parameters were not evaluated in the present study, such as size ranges, reproductive stage, fishing gears, fishing intensity, and water condition. Further research involving more factors that affect fish growth is required to increase the reliability of the description of fish growth patterns and to provide additional valuable information for local fish conservation and fishery management.

S. molesworthi and *S. curvilabiatus* are important economic fishes of local fisheries; our results will be useful for future fisheries research evaluating their population dynamics. Additionally, these fishes in the lower Yarlung Zangbo River are important in maintaining local biodiversity and aquatic food webs. We suggest that further studies concentrate on long-term fish resources monitoring; community and population dynamics analysis; and environment–fishery resources relationship evaluations. Based on this research, scientific fishery resource management should be conducted to ensure that the river has sustainable fishery production while supporting important ecological service functions.

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Data Availability Statement: Data are contained within the article and available from the corresponding author upon reasonable request.

Conflicts of Interest: The authors declare that Dongya Zhang was employed by the company Power China Beijing Engineering Corporation Limited. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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