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Research Article

Study on the Length–Weight Relationship, Condition Factor, and Relative Weight of Six Fishes in the Lower Yarlung Zangbo River, Southwest China

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The lower reaches of Yarlung Zangbo River are one of the most important biodiversity hotspots worldwide. Fishes in the area are of great research value, ecological and fishery value, but little biological information about these fishes is available, restricting the conservation and development of local fish resources. This study aimed to provide basic biological data for these fish by studying the length–weight relationships (LWRs) of six indigenous fish species from the lower Yarlung Zangbo River catchment, Tibet, China. Totally, 1262 specimens belonging to four families, six genera, and six species were collected from 2022 to 2024 using various types of fishing techniques. The LWRs of *Garra yajiangensis*, *Nemacheilus subfusca*, *Creteuchiloglanis kamengensis*, and *Exostoma tenuicaudatum* were reported for the first time to FishBase, except *Neolissochilus hexagonolepis* and *Psilorhynchus homaloptera*. The maximum standard-length information of *G. yajiangensis*, *P. homaloptera*, *N. subfusca*, and *E. tenuicaudatum* was updated to FishBase. The *a* and *b* values calculated from the LWRs ranged between 0.007 and 0.020 and 2.760 and 3.292, respectively. Interspecific and intraspecific variations in LWRs were observed in these fishes. Growth patterns of *N. hexagonolepis* and *C. kamengensis* were isometric, while those of other fishes were strongly allometric. Condition factors of species varied between 1.09 and 1.99, and the relative weight ranged from 99.87 to 104.18. Within species, there were significant temporal and spatial variations of LWRs, condition factor, and relative weight for these fishes, respectively. The findings of this study are essential for the conservation and management of local fish and fisheries.

Keywords: condition factor; length–weight relationship (LWR); lower Yarlung Zangbo River; relative weight

1. Introduction

Length and weight are two basic and important biological metrics to gauge the physiological status and population structure of fishes. The length–weight relationships (LWRs) are fundamental in fish biology, ecology, and fisheries assessment [1, 2]. Many new methods and theories are applied in the LWR research [3]. The LWRs enable the calculation of weight according to the given length and the conversion of the growth-in-length equation to the growth-in-weight equation, facilitating the population biomass and production evaluation in fisheries assessment [4]. Besides, LWRs allow intraspecific or interspecific comparisons of fish biometric, life history, and morphology at different levels [5, 6], contributing to a thorough understanding of the temporal and spatial variations of fish growth [3, 7], and indirectly reflecting the environmental quality of fish habitat [6, 8]. The allometric coefficient *b* derived from LWRs assesses whether increases in body weight are proportional to unit increases in length, providing an insight into species growth patterns [5, 9]. It was reported that the coefficient could also indicate the spawning period and spatial character of fish spawning groups [10].

Condition factor (K) and relative weight (W_r) are additional measurements of LWRs. These two indices indicate the physiological and nutritional status of fish at the individual level, and usually are calculated to gauge the fatness of fish, evaluating fish condition [11]. Condition factor stands as a versatile index in aquaculture, offering valuable insights into the health and dynamics of fish populations and their associated aquatic ecosystems [12, 13]. Relative weight reflects ecological and physiological optimality within a fish population and is recommended for application in the direction comparison of individuals' condition across species or populations. In the ecosystem-based fishery management, identifying variations of fatness can help determine optimal fishing time for the maximum sustainable yield [5, 14].

The Yarlung Zangbo River is located in the highest Qinghai-Tibet Plateau, and the lower reaches of the river are one of the most important biodiversity hotspots worldwide, which are extremely rich in biodiversity [15]. Affected by the unique and diverse physical–geographical plateau environment, fish species distributed in the plateau are undergoing respective special evolution processes under the current global climatic change scenarios [15–17]. Taking the Yarlung Zangbo River, for example, there are significant differences in fish species and fauna composition between the middle–upper reaches and lower reaches [17]. In the lower reaches, there are only fewer primitive taxa of Schizothoracinae, including *Schizothorax integrilabiatus*, *Schizothorax curvilabiatus*, and *Schizothorax molesworthi*, lacking specialized and highly specialized Schizothoracinae fishes. As for the species of Nemacheilidae, fishes that are affiliated to *Triplophysa* are fewer compared to the middle–upper reaches. Besides, fish species belonging to Barbinae and Labeoninae distributed in Tibet occur only in the lower catchment. *Psilorhynchus homaloptera*, the only species of Psilorhynchidae distributed in China, inhabits this area. There are many species of Sisoridae including *Glyptosternum maculatum*, *Pseudecheneis sulcata*, *Parachiloglanis hodgarti*, *Glyptothorax annandalei*, *Glyptothorax cavia*, *Glyptothorax gracilis*, *Exostoma labiatum*, *Exostoma tenuicaudatum*, and so on [16, 17]. Recently, some new species, such as *Garra dengba*, *Garra tibetana* sp. nov., *Garra motuoensis*, and *Garra yajiangensis*, have been found successively in the lower reaches [15, 18–21]. Most of these fish are endemic and highly rare.

These fish are of great research value in the biological evolution and geography. They are an important component of local biodiversity, playing an important role in maintaining the structure and function of the river ecosystem. Besides, they are also the basis of local plateau–featured fisheries [17, 22]. However, little biological information has been published on these species, which further hinders the conservation efforts and fishery development. Furthermore, the increased human activities (such as hydropower project construction, urbanization, and biological invasion), coupled with the global climate change, posed a threat to these fish assemblages [23, 24]. Under this backdrop, we studied the LWRs of six indigenous fish species collected from the lower Yarlung Zangbo River, providing information on LWRs and fatness of these fishes, describing their growth patterns, and identifying the spatiotemporal variations of LWRs and fatness, to expand the biological knowledge of these species and provide basic data for conservation and management.

2. Materials and Methods

2.1. Sample Collection. Sample collections were conducted in the lower reaches of the Yarlung Zangbo River and their tributaries located in the Motuo County, Southwest China (Figure 1; Table 1), from December 2022 to December 2024, followed the methods of Ding et al. [25]. The frequency of sampling during the study period was once per quarter. Fishes were captured using various fishing gears including set nets (mesh size: 1.5 cm; width: 0.5 m; length: 5 m), drift gillnets (mesh size: 3 cm; width: 1 m; length: 10 m), fish cages (mesh size: 0.5 cm; height: 0.4 m; width 0.5 m; length: 4 m), and electrofishing (20 A, 1 V, 3000 W) under the permission of the competent authorities of local fishery administration. All fish specimens were identified to the species level after collection according to the Fishes of Qinghai-Xizang Plateau [16], Fishes and Fish Resources in Xizang, China [17], and Fauna Sinica Osteichthyes Cypriniformes III [26]. The scientific names of all fish species were checked against FishBase [27]. The standard length (SL) (cm) of each fish was measured to the nearest 0.1 cm using a fish measuring board, and body weight (W, g) was measured to the nearest 0.1 g using an electronic balance (Lichen, TD50002A). Fishes were released into the river after the measure. All handling procedures were conducted following the guidelines of the Regulations of Laboratory Animals Administration of China.

2.2. Statistical Analysis. Logarithmic transformation was conducted on the raw measurements of SL and body weight before regression. Then, the linear regression was used to determine the LWRs using the following logarithmic power function (equation (1)). Due to statistical constraints, only populations represented by at least 30 individuals and with a relatively wide size range were considered for the estimation of LWRs. Fulton′s condition factor (equation (2)) and relative weight (equation (3)) were used to assess the growth condition of these fishes. Equations were as follows:

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

$$\mathrm{K} = \frac{100\,\mathrm{W}}{\mathrm{SL}^3}, \quad (2)$$

$$W_r = \frac{100\,\mathrm{W}}{\left(a\,\mathrm{SL}^b\right)}, \quad (3)$$

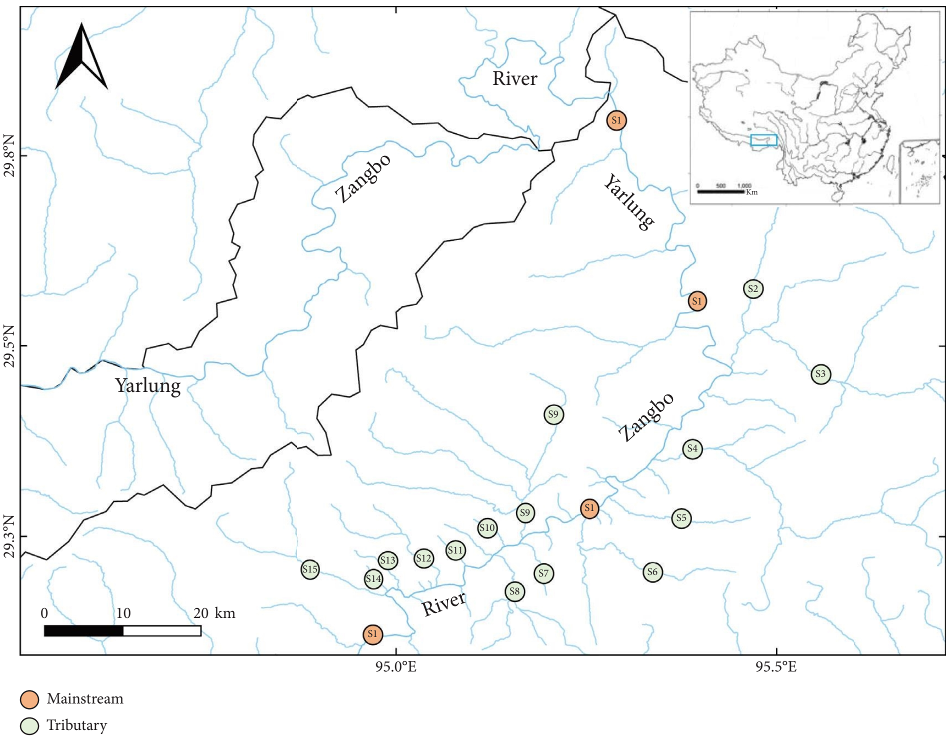

Figure 1: Sample sites of fishes in the lower Yarlung Zangbo River catchment, Southwest China, from 2022 to 2024. S1: the mainstream of the Yarlung Zangbo River; S2: Ganong River; S3: Jinzhu Zangbo River; S4: Ximo River; S5: Haguo River; S6: Xigong River; S7: Jiaga River; S8: Deergong River; S9: Baimaxilu River; S10: Gongqu River; S11: Lingongri River; S12: Baimaxiri River; S13: Xiri River; S14: Danmoanong River; S15: Lugong River.

where W is the body weight (g), SL is the SL (cm), the parameter a is the intercept of the regression, and b is the allometric coefficient. K is the Fulton's condition factor, and W_r is the relative weight. 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 interval (CI) of parameters a and b was estimated.

Covariance analysis (ANCOVA) was used to test the spatial and temporal variations of LWRs. The spatiotemporal differences were based on different seasons and tributaries, respectively. One-way ANOVA was performed to detect the variations in Fulton′s condition factor (K) and relative weight (W_r) among different populations. The LSD post hoc test was employed to explore specific differences among different populations further. Growth patterns were analyzed by comparing the b value with the expected value of 3 using a t-test according to Pauly. If the value is different from 3 significantly, the growth pattern is considered isometric, otherwise, growth is allometric, including positive ($b > 3$) and negative ($b < 3$) [28]. 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. LWR. In total, 1262 specimens belonging to four families, six genera, and six species were collected in this study. The six species were *G. yajiangensis*, *Neolissochilus hexagonolepis*, *P. homaloptera*, *Nemacheilus subfusca*, *Creteuchiloglanis kamengensis*, and *E. tenuicaudatum*. *P. homaloptera* accounted for the highest proportion with the percentage of 44.1%, followed by *N. hexagonolepis*. The sample size and size range of SL and W of each species are listed in Table 2. Maximum standard-length information of four fish species, that is, *G. yajiangensis*, *P. homaloptera*, *N. subfusca*, *E. tenuicaudatum*, were updated to FishBase [27]. The LWRs for four species were reported for the first time to FishBase, with the exception of *N. hexagonolepis* and *P. homaloptera*. The overall LWR parameters a and b and their 95% CI; coefficient of determination, r^2; and growth pattern of these six fish species are listed in Table 2. All the LWRs were significant ($p < 0.05$), and the LWR estimates for all species fit well and are highly reliable with all r^2 greater than 0.925. The overall mean values of b for each fish species ranged from 2.760 for *E. tenuicaudatum* to 3.292 for *N. subfusca*, and the estimated values of parameter a ranged between 0.007 for *N. subfusca* and 0.020 for *N. hexagonolepis*. According to the Pauly t-test, *N. hexagonolepis* ($t = 0.738$) and *C. kamengensis* ($t = 0.909$) manifested an isometric growth pattern with the estimated b value not significantly different from the expected value of 3 (all $p > 0.05$). Growth patterns of *G. yajiangensis* and *N. subfusca* were positive allometric with the b values significantly greater than the theoretical value of 3, respectively (all $p < 0.05$). Differently, growth patterns of *P. homaloptera* ($t = 3.287$) and *E. tenuicaudatum* ($t = 6.580$) were negative allometric with all b values less than 3 significantly (all $p < 0.05$).

Table 1: Sampling information of fish species collected in the lower Yarlung Zangbo River catchment, Tibet, China, from 2022 to 2024.

Species	Sample size		S1	S2	S3	S4	S5	S6	S7	S8	S9	S10	S11	S12	S13	S14	S15
	Number	Ratio (%)															
Cyprinidae																	
Garra yajiangensis	83	6.6	73	–	–	–	–	6	–	–	–	–	–	3	–	–	1
Neolissochilus hexagonolepis	227	18.0	90	–	–	–	1	2	18	–	–	30	3	7	8	68	–
Psilorhynchidae																	
Psilorhynchus homaloptera	556	44.1	120	–	–	46	129	61	15	24	2	–	5	52	53	29	20
Nemacheilidae																	
Nemacheilus subfusca	111	8.8	30	–	–	1	4	2	58	2	–	–	–	–	–	12	2
Sisoridae																	
Creteuchiloglanis kamengensis	118	9.4	2	3	110	1	–	–	–	–	2	–	–	–	–	–	–
Exostoma tenuicaudatum	167	13.2	12	–	–	3	9	101	12	1	3	–	10		4	12	–

Note: –, means no specimens were captured. 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.

Descriptive statistics and estimated parameters of LWRs for the six fish species based on seasons and stocks are listed in Tables 3 and 4, respectively. Seasonal differences of LWRs were observed in five species according to the ANCOVA, except for *C. kamengensis*, for which 95% individuals were collected in summer. For *P. homaloptera*, seasonal variations of LWRs mainly showed between summer and other seasons (ANCOVA, $F = 7.55$, $p < 0.05$). Growth patterns of this fish were positive allometric in summer ($t = 4.010$), while in other seasons, they were negative allometric. As for *N. hexagonolepis*, these seasonal differences of LWRs existed in spring and summer and spring and winter ($p < 0.05$). Growth patterns of *N. hexagonolepis* were negative allometric in spring ($t = 2.419$) and autumn ($t = 2.034$), while in summer ($t = 1.083$) and winter ($t = 1.375$), they were isometric, respectively. Differences in LWRs for *N. subfusca* were observed in pairwise comparison among three seasons ($p < 0.05$), except winter, because of the small sample size. Growth patterns of this fish were negative allometric in spring ($t = 1.702$), positive in summer ($t = 3.341$), and isometric in autumn ($t = 0.034$). Though seasonal differences of LWRs and growth patterns for *G. yajiangensis* and *E. tenuicaudatum* were compared, these estimations and comparisons were tentative due to limited sample size (less than 30) and size range in some seasons.

Geographical variations of LWRs and growth patterns were observed in *P. homaloptera*, *N. hexagonolepis*, and *N. subfusca* on the premise of 30 individuals at least in the population analyzed. For *P. homaloptera*, the difference in LWRs mainly showed between the mainstream of the Yarlung Zangbo River and other tributaries (that is, S4, S5, S6, S12, and S13), Tributary S5, and other rivers. According to growth patterns, the growth of *P. homaloptera* was isometric in S1, S5, and S13, while it was negative allometric in S4, S6, and S12. As for *N. hexagonolepis*, there were no significant differences in LWRs between stocks ($p > 0.05$), but the growth patterns varied, which manifested positive allometry in the mainstream and isometry in the tributary. Similar results were observed in *N. subfusca*.

3.2. Condition Factor (K). The overall mean value of condition factors of each fish species varied between 1.09 and 1.99 (Table 5). The factor varied in different seasons for five fish species with the exception of *C. kamengensis* (Figure 2) due to small sample size in some seasons. For *P. homaloptera*, condition factors in spring and summer were significantly higher than those in autumn and winter ($F = 14.776$, $p < 0.05$), with no significant differences observed within respective groups (Figure 2, *Ph*). Similar variations among seasons were observed in *G. yajiangensis* ($F = 9.128$, $p < 0.05$; Figure 2, *Gy*). The condition factor of *N. hexagonolepis* in spring was significantly higher than that in summer and winter but not differing from autumn (Figure 2, *Nh*). For *N. subfusca*, the condition factor in spring was significantly higher than that in summer and autumn, while no significant differences were detected between summer and winter (Figure 2, *Ns*). As for *E. tenuicaudatum*, condition factor in winter was the lowest, not significantly different from that of autumn but statistically lower than that in spring and summer (Figure 2, *Et*).

Variations of condition factors among different rivers were observed in *P. homaloptera*, *N. hexagonolepis*, and *E. tenuicaudatum*. For *P. homaloptera*, this difference manifested mainly between tributaries on two banks (Figure 1; Figure 3, *Ph*), while fewer differences were detected among tributaries within each bank. Except for Tributary S5, there were no significant differences between mainstream and all other tributaries (all $p > 0.05$). As for *N. hexagonolepis* (Figure 3, *Nh*), the factors of Tributary S7 and Tributary S10 were significantly larger than those of S1 (the mainstream) and S14 (all $p < 0.05$), while no statistical differences existed in each group (all $p > 0.05$). Condition factors of *E. tenuicaudatum* varied in different geographical populations (Figure 3 *Et*). The largest condition factor was observed in S7 ($K = 1.39$), followed by S14 ($K = 1.25$), while the lowest was tested in the mainstream ($K = 1.02$). No significant geographical differences were observed in *N. subfusca* (Figure 3 *Ns*) (all $p > 0.05$). Geographical variations of condition factor for *G. yajiangensis* and *C. kamengensis* were not

Table 2: Descriptive statistics and estimated parameters of LWR ($lg\ W = lg\ a + b\ lg\ SL$) for fishes sampled in the lower Yarlung Zangbo River, Tibet, China, from 2022 to 2024.

Species	Sample size		Standard length (SL, cm)			Body weight (W, g)			*a*	95% CI of *a*	*b*	95% CI of *b*	r^2	Growth pattern
	n	Ratio (%)	Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max						
Cyprinidae														
*Garra yajiangensis**	83	6.6	15.47 ± 1.65	9.6	18.9#	76.22 ± 24.23	15.0	141.5	0.012	0.006~0.018	3.185	2.997~3.374	0.933	P
Neolissochilus hexagonolepis	227	18.0	7.63 ± 4.12	2.9	22.5	18.42 ± 8.43	0.33	214.0	0.020	0.017~0.023	2.973	2.901~3.045	0.967	I
Psilorhynchidae														
Psilorhynchus homaloptera	556	44.1	6.81 ± 1.62	2.8	12.7#	4.13 ± 2.72	0.1	18.2	0.014	0.012~0.016	2.887	2.818~2.956	0.925	N
Nemacheilidae														
*Nemacheilus subfusca**	111	8.8	5.54 ± 0.98	2.7	8.3#	2.26 ± 1.23	0.1	6.8	0.007	0.006~0.006	3.292	3.138~3.445	0.943	P
Sisoridae														
*Creteuchiloglanis kamengensis**	118	9.4	12.27 ± 2.75	4.5	17.8	31.25 ± 6.88	1.5	79.1	0.013	0.010~0.016	3.049	2.942~3.157	0.965	I
*Exostoma tenuicaudatum**	167	13.2	7.14 ± 2.94	2.9	13.9#	5.46 ± 3.73	0.3	21.6	0.017	0.014~0.019	2.760	2.688~2.833	0.972	N

Note: *a* and *b*, regression parameters; r^2, coefficient of determination; P, positive allometric growth; I, isometric growth; N, negative allometric growth.
Abbreviations: CI, confidence limits; *n*, number; S.D., standard deviation.
*Newly recorded LWR to FishBase.
#New maximum record of standard length to FishBase.

Table 3: Estimated parameters of LWR based on seasons for fishes sampled in the lower Yarlung Zangbo River.

Species	Season	Sample size		a	95% CI of a	b	95% CI of b	r^2	Growth pattern
		n	Ratio (%)						
Garra yajiangensis	Spr.	42	50.6	0.017	0.004~0.031	3.063	2.778~3.348	0.922	I
	Sum.	11^+	13.3	0.012	−0.011~0.034	3.210	2.487~3.933	0.918	I
	Aut.	11^+	13.3	0.005	0.001~0.024	3.465	2.908~4.021	0.957	I
	Win.	19^+	22.9	0.009	0.004~0.014	3.253	3.045~3.460	0.985	N
Neolissochilus hexagonolepis	Spr.	49	21.6	0.028	0.021~0.034	2.867	2.756~2.978	0.983	N
	Sum.	109	48.0	0.016	0.011~0.020	3.088	2.926~3.249	0.931	I
	Aut.	33	14.5	0.027	0.017~0.037	2.831	2.660~3.001	0.974	N
	Win.	36	15.9	0.018	0.015~0.020	3.051	2.975~3.127	0.995	I
Psilorhynchus homaloptera	Spr.	52	9.4	0.023	0.013~0.034	2.672	2.435~2.909	0.911	N
	Sum.	161	29.0	0.007	0.002~0.009	3.322	3.164~3.481	0.915	P
	Aut.	305	54.9	0.017	0.014~0.019	2.785	2.700~2.869	0.933	N
	Win.	38	6.8	0.017	0.009~0.024	2.804	2.576~3.033	0.945	N
Nemacheilus subfusca	Spr.	30	27.3	0.019	0.010~0.027	2.798	2.555~3.041	0.952	N
	Sum.	48	43.6	0.006	0.003~0.009	3.469	3.186~3.753	0.930	P
	Aut.	32	29.1	0.012	0.006~0.017	2.995	2.697~3.293	0.933	I
Creteuchiloglanis kamengensis	Sum.	112	95.0	0.013	0.010~0.017	3.047	2.942~3.152	0.968	I
Exostoma tenuicaudatum	Spr.	66	39.5	0.022	0.016~0.028	2.639	2.496~2.782	0.955	N
	Sum.	14^+	8.4	0.030	0.009~0.052	2.516	2.161~2.871	0.952	N
	Aut.	25^+	15.0	0.017	0.008~0.026	2.670	2.337~3.003	0.923	I
	Win.	62	37.1	0.015	0.013~0.017	2.809	2.745~2.873	0.992	N

Note: Spr., spring; Sum., summer; Aut., autumn; Win., winter; a and b, regression parameters; r^2, coefficient of determination; P, positive allometric growth; I, isometric growth; N, negative allometric growth.
Abbreviations: CI, confidence limits; n, number.
$^+$Tentative estimation due to small size range; estimations of small sample size (≤ 10 individuals) were not listed.

Table 4: Estimated parameters of LWR based on tributaries for fishes sampled in the lower Yarlung Zangbo River.

Species	Site	Sample size		a	95% CI of a	b	95% CI of b	r^2	Growth pattern
		n	Ratio (%)						
Garra yajiangensis	S1	73	87.95	0.012	0.006~0.018	3.184	2.990~3.377	0.938	I
Neolissochilus hexagonolepis	S1	90	43.69	0.016	0.013~0.019	3.082	3.004~3.160	0.986	P
	S7	18^+	8.74	0.051	0.011~0.090	2.517	2.043~2.991	0.888	N
	S10	30	14.56	0.132	0.012~0.253	1.927	1.388~2.466	0.657	N
	S14	68	33.01	0.018	0.011~0.025	2.979	2.771~3.188	0.925	I
Psilorhynchus homaloptera	S1	120	21.86	0.012	0.009~0.015	2.985	2.861~3.109	0.951	I
	S4	46	8.38	0.019	0.005~0.033	2.793	2.409~3.177	0.830	I
	S5	129	23.50	0.009	0.006~0.012	3.057	2.891~3.222	0.913	I
	S6	61	11.11	0.021	0.008~0.034	2.683	2.353~3.013	0.818	I
	S7	15^+	2.73	0.014	0.004~0.024	2.940	2.547~3.334	0.952	I
	S8	24^+	4.37	0.018	0.007~0.029	2.771	2.460~3.081	0.940	I
	S12	52	9.47	0.025	0.013~0.037	2.585	2.354~2.815	0.910	N
	S13	53	9.65	0.011	0.006~0.017	3.041	2.796~3.285	0.924	I
	S14	29^+	5.28	0.026	0.015~0.036	2.529	2.269~2.788	0.937	N
	S15	20^+	3.64	0.016	0.006~0.026	2.794	2.480~3.109	0.951	I
Nemacheilus subfusca	S1	30	30.00	0.005	0.003~0.008	3.481	3.208~3.754	0.961	P
	S7	58	58.00	0.010	0.006~0.014	3.126	2.892~3.361	0.928	I
	S14	12^+	12.00	0.018	0.006~0.031	2.742	2.343~3.142	0.959	I
Creteuchiloglanis kamengensis	S3	110	93.22	0.013	0.010~0.017	3.047	2.942~3.153	0.968	I
Exostoma tenuicaudatum	S1	12^+	8.16	0.010	0.001~0.020	2.968	2.406~3.529	0.933	I
	S6	101	68.71	0.017	0.014~0.019	2.760	2.692~2.828	0.985	P
	S7	12^+	8.16	0.012	−0.013~0.037	3.070	1.705~4.436	0.715	I
	S11	10^+	6.80	0.004	0.0002~0.087	3.574	1.780~5.368	0.725	I
	S14	12^+	8.16	0.019	0.002~0.036	2.767	2.281~3.254	0.941	I

Note: a and b, regression parameters; r^2, coefficient of determination; P, positive allometric growth; I, isometric growth; N, negative allometric growth.
Abbreviations: CI, confidence limits; n, number.
$^+$Tentative estimation due to small size range; estimations of small sample size (≤ 10 individuals) were not listed.

Table 5: Condition factors (K) and relative weight (W_r) for fish species sampled in the lower Yarlung Zangbo River.

Species	Number	K			W_r		
		Mean ± S.D.	Min	Max	Mean ± S.D.	Min	Max
Garra yajiangensis	83	1.99 ± 0.20	1.60	2.39	99.87 ± 9.69	82.17	120.44
Neolissochilus hexagonolepis	227	1.97 ± 0.46	0.31	4.39	103.85 ± 23.63	16.27	226.74
Psilorhynchus homaloptera	556	1.16 ± 0.24	0.34	2.36	102.45 ± 20.37	27.25	203.62
Nemacheilus subfusca	111	1.20 ± 0.17	0.51	1.61	104.18 ± 14.91	54.31	143.58
Creteuchiloglanis kamengensis	118	1.49 ± 0.22	0.83	2.12	101.37 ± 15.26	57.90	144.49
Exostoma tenuicaudatum	167	1.09 ± 0.25	0.63	2.16	100.52 ± 19.13	52.46	179.27

Abbreviation: S.D., standard deviation.

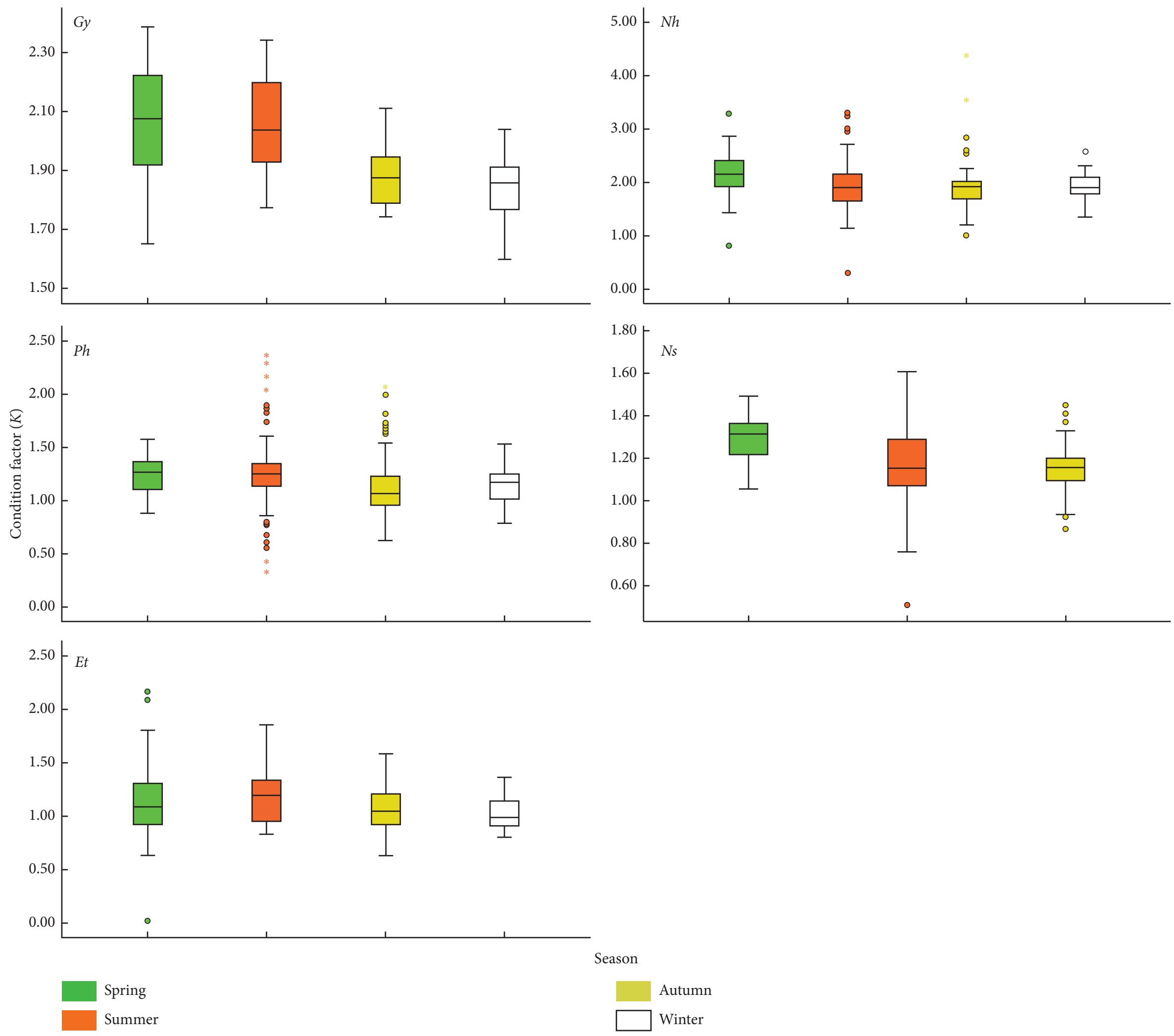

Figure 2: Seasonal variations of condition factors (K) for fishes collected in the lower Yarlung Zangbo River. *Gy*: *Garra yajiangensis*; *Nh*: *Neolissochilus hexagonolepis*; *Ph*: *Psilorhynchus homaloptera*; *Ns*: *Nemacheilus subfusca*; *Et*: *Exostoma tenuicaudatum*.

analyzed, because the great majority of specimens of these two species were obtained in one single river.

3.3. Relative Weight (W_r). In general, the overall mean value of the relative weight of each fish species was about 100, ranging from 99.87 to 104.18 (Table 5). Seasonal variations were observed in five fish species, except *C. kamengensis* (Figure 4) due to small sample size in some seasons. The factor of *P. homaloptera* (Figure 4, *Ph*) was lowest in autumn, not significantly different from that in winter, but significantly lower than spring and summer ($p < 0.05$). There was no statistical difference between spring and summer. For *N. hexagonolepis* (Figure 4, *Nh*), the factor in spring was significantly higher than that in summer and winter ($p < 0.05$). The lowest relative weight of this fish was observed in summer. As for *G. yajiangensis* (Figure 4, *Gy*), the relative weight in spring and summer was approximately,

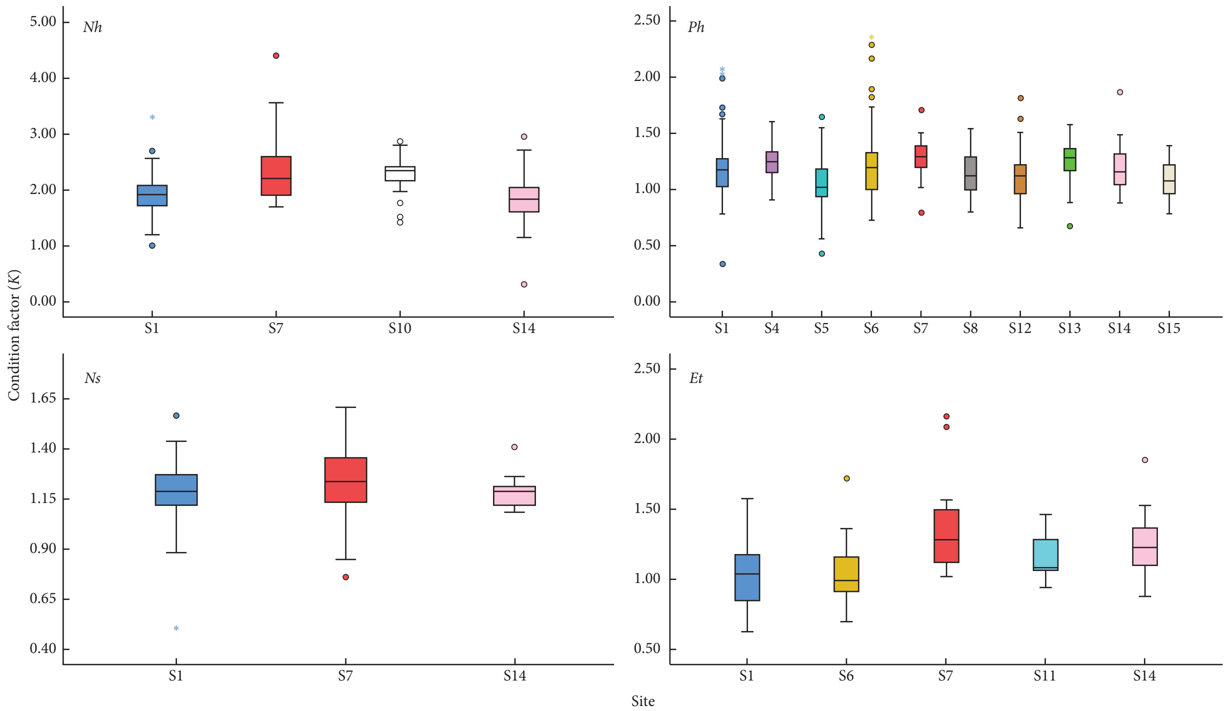

Figure 3: Geographical variations of condition factors (K) for fishes collected in the lower Yarlung Zangbo River. *Nh*: *Neolissochilus hexagonolepis*; *Ph*: *Psilorhynchus homaloptera*; *Ns*: *Nemacheilus subfusca*; *Et*: *Exostoma tenuicaudatum*. S1: the mainstream of the Yarlung Zangbo River; S4: Ximo River; S5: Haguo River; S6: Xigong River; S7: Jiaga River; S8: Deergong River; S10: Gongqu River; S11: Lingongri River; S12: Baimaxiri River; S13: Xiri River; S14: Danmoanong River; S15: Lugong River.

statistically higher than those in autumn and winter ($p < 0.05$). Similar results were detected in *E. tenuicaudatum* (Figure 4, *Et*). No seasonal differences were observed in *N. subfusca* ($p > 0.05$).

In terms of geographical stock, except *G. yajiangensis* and *C. kamengensis*, the relative weight of each fish species varied in different rivers (Figure 5). For *P. homaloptera* (Figure 5, *Ph*), the index of stocks in River S5 was the lowest, statistically different from that of other stocks ($p < 0.05$). No differences were observed among stocks with the relative weight larger than 100 ($p > 0.05$) for this fish. The difference in relative weight for *N. hexagonolepis* manifested mainly between River S14 and other rivers (Figure 5, *Nh*). As for *N. subfusca*, the relative weight in different rivers was all larger than 100 (Figure 5, *Ns*). Significant difference was only detected between stocks in the mainstream and River S7 ($p < 0.05$). For *E. tenuicaudatum*, there were considerable differences among different stocks (Figure 5, *Et*), existing mainly among the mainstream (S1), River S7 and other rivers.

4. Discussion

LWR and condition factor are basic biological data that are necessary to comprehend life history and stock assessment of fish [5]. They are also important to understand fishing pressure and environmental conditions, which are essential for population conservation and fishery management planning [29]. However, information on these biological features of fishes from the lower Yarlung Zangbo River remains deficient. The results of this study will help fill current gaps regarding the biology and growth pattern of these species.

The LWRs of different fishes were different, and hence the differences in parameters calculated from the relationship [1, 30]. The allometric coefficient b with the expected range of $2.5 < b < 3.5$ reflected the heterogeneity of growth and related to the body shapes of the respective fish species [5]. In the present study, the overall mean b values for each fish species were 2.760–3.292, within the expected range. The b value of *N. hexagonolepis* in this study was less than that of published data on FishBase, while that of *P. homaloptera* was larger than published [27], and the value of *C. kamengensis* was larger than that of the populations from Drung River [31]. These differences indicated intraspecific differences among different stocks. Besides, the interspecific difference of this b value for fishes belonging to the same genus was general. For example, the value of *G. yajiangensis* was larger than that of *Garra tibetana*, another species of the *Garra* genus distributed in the same area [25], and was also larger than *G. pingi pingi* from Chishui River [32] and *Garra orientalis* from Nujiang River [33]. The b value of *E. tenuicaudatum* was less than that of *Exostoma labiatum* [25], a fish species equally belonging to the *Exostoma* genus and distributed in the same area.

The seasonal fluctuation and intergroup variation of the allometric coefficient b can be used to examine the response of fish to environmental changes, reflecting the population dynamics to some degree [2]. Seasonal and geographical variations of the LWRs observed in this

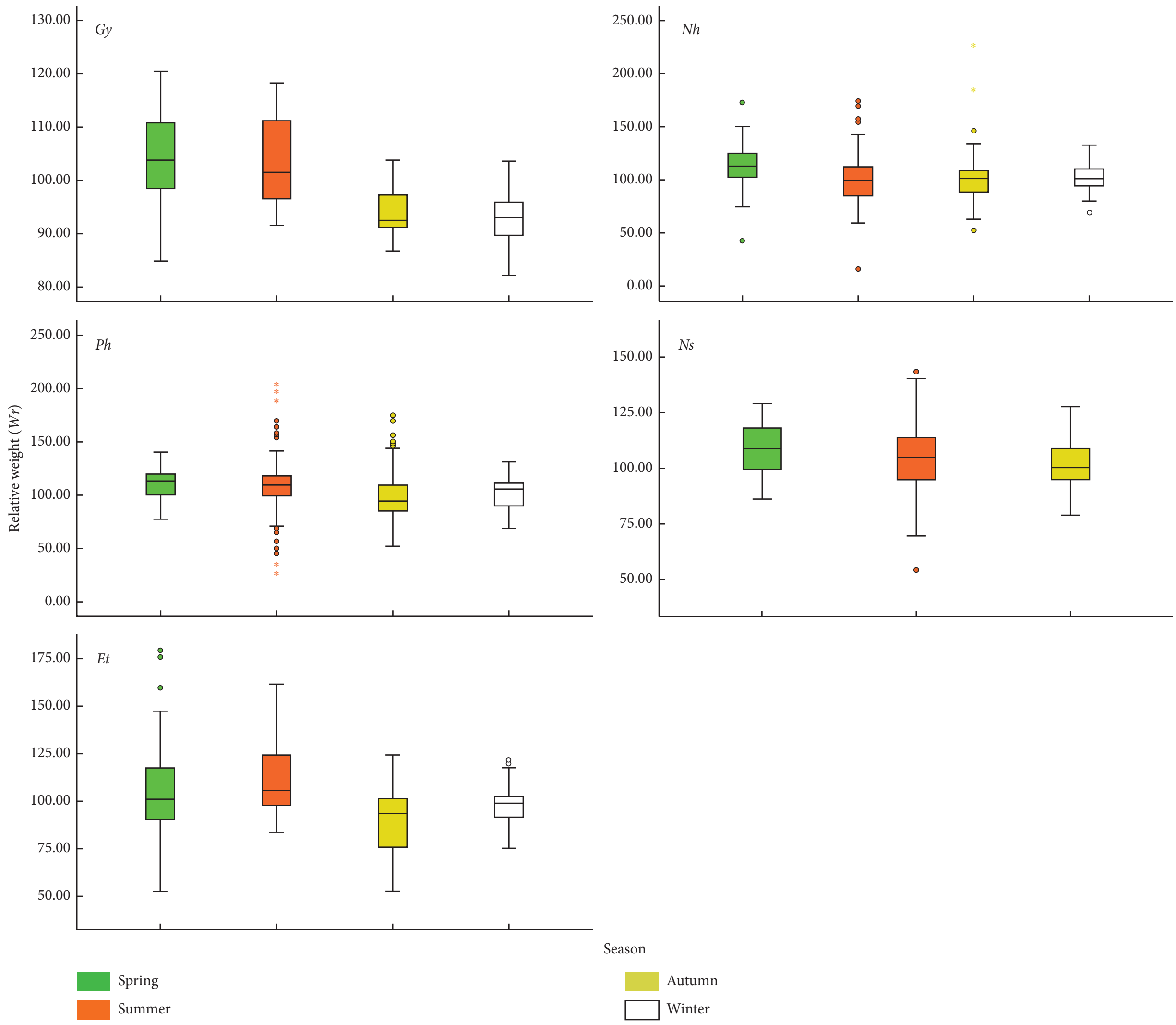

Figure 4: Seasonal variations of relative weight (W_r) for fishes collected in the lower Yarlung Zangbo River. *Gy*: *Garra yajiangensis*; *Nh*: *Neolissochilus hexagonolepis*; *Ph*: *Psilorhynchus homaloptera*; *Ns*: *Nemacheilus subfusca*; *Et*: *Exostoma tenuicaudatum*.

study, to some extent, reflected the variations in growth patterns caused by habitat heterogeneity, reproductive status, feeding intensity, etc. Further analysis indicated that the reproductive time of *E. tenuicaudatum* lasted from late winter to early spring, mainly in April. The *N. subfusca* was a spring-spawning fish with a spawning period mainly in May. *G. yajiangensis* reproduced at the turn of spring and summer and peaked in June. The reproduction of *N. hexagonolepis* was related to flooding, and their spawning occurs in summer, mainly in August. As for *P. homaloptera*, it was an autumn-spawning fish, whose spawning occurs between September and October [23, 34]. The gonad accumulation and evacuation significantly affected weight gain and weight loss of the respective fish species and consequently led to variations of the LWRs for each fish species. This can be verified by other research studies, such as studies on *Pholis fangi* [35] and *Hexagram mosotakii* [36]. Environmental factors, especially water temperature, dissolved oxygen, water-flow velocity, and food resources, will affect not only the growth but also the gonadal development and reproductive activities of fish [7, 14].

Strong positive allometric growth was found in *G. yajiangensis* and *N. subfusca*, while negative allometric growth was observed in *P. homaloptera* and *E. tenuicaudatum*, and isometric growth patterns were detected in *N. hexagonolepis* and *C. kamengensis*. The strong allometric growth of these fishes may relate to the body shapes of the respective fish species on one hand [37]. According to Froese [5], there is a clear and significant increase in the form factor (i.e., median $a_{3.0}$, calculated from log$a$ and b) across fish species from eel-like to elongated, fusiform and short or deep body shapes. This factor is likely to differ between phylogenetic or functional groups of fishes, or between riverine or lacustrine habitats [5, 37]. This can be partially verified by seasonal and geographical comparisons of LWRs in the present study.

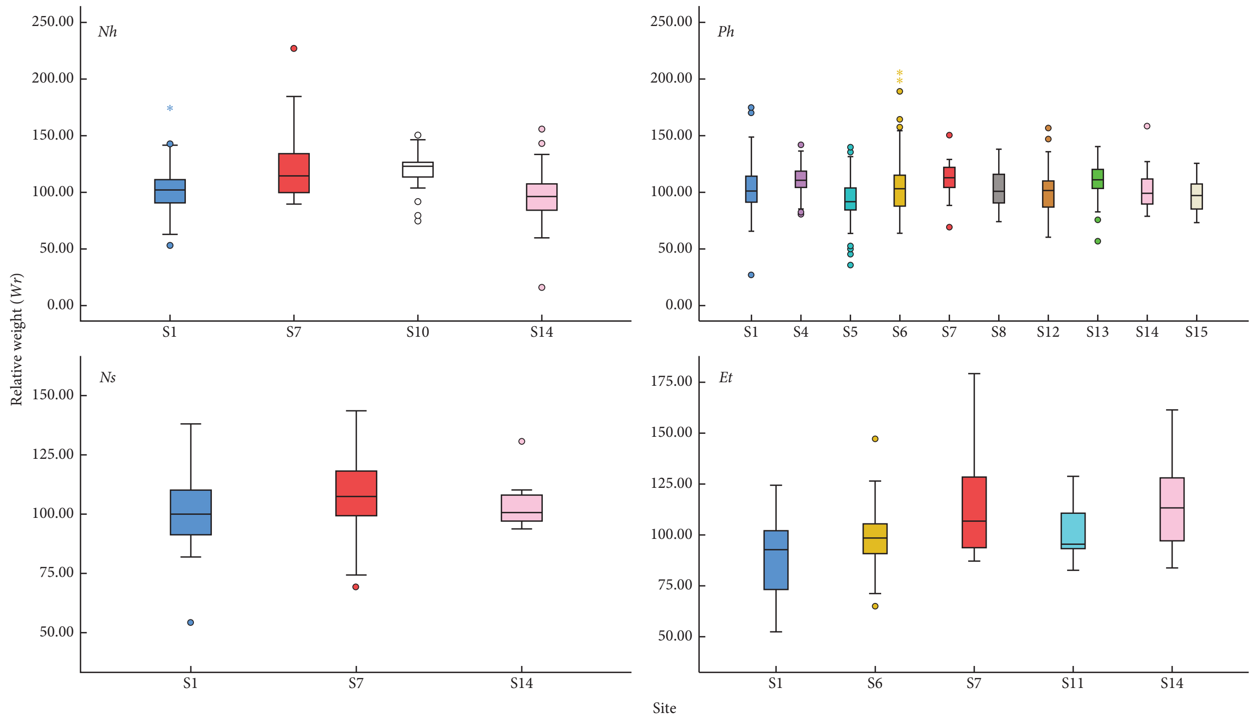

Figure 5: Geographical variations of relative weight (W_r) for fishes collected in the lower Yarlung Zangbo River. *Nh*: *Neolissochilus hexagonolepis*; *Ph*: *Psilorhynchus homaloptera*; *Ns*: *Nemacheilus subfusca*; *Et*: *Exostoma tenuicaudatum*. S1: the mainstream of the Yarlung Zangbo River; S4: Ximo River; S5: Haguo River; S6: Xigong River; S7: Jiaga River; S8: Deergong River; S10: Gongqu River; S11: Lingongri River; S12: Baimaxiri River; S13: Xiri River; S14: Danmoanong River; S15: Lugong River.

The condition factor (K) reflects the energy and nutritional status of fish at the individual level [38]. It is usually used to assess the fullness, nutritional status, and the effect of environmental variability on fish [39]. Some research pointed out that many factors will affect the index, gender, sexual maturity, breeding period, and external environmental conditions for instance [14]. In the present study, the differences in condition factors among the six fish species were in relation to the diverseness of the reproductive season for the respective fish species [23, 34]. This can be demonstrated by the seasonal variations of condition factor (K) for each fish species, and further analyses showed that many fish were collected around their breeding season (Table 3). The stages of gonad development at the sampling time and their sample size will result in different *K* values. On the other hand, every fish species sample was composed of individuals inhabited different tributaries. The habitat heterogeneity, including physical and chemical environments and food resources supply, will impact the growth and reproduction of fish and finally result in the differences of the *K* value [40] Besides, *G. yajiangensis* and *N. hexagonolepis* are of great value for fishery development [34]. According to Haberle et al. [41], the body length, body weight, and average condition factor increased with an increase in fishing pressure but decreased with an increase in population abundance [6, 14]. Fishing pressure could also affect the condition factors of *G. yajiangensis* and *N. hexagonolepis*, respectively.

The relative weight (W_r) is another practical index for the assessment of freshwater fish condition, which reflects ecological and physiological optimality within the fish population [42]. If the index was less than 100, it may indicate problems, such as low prey availability or high predation pressure [43]. In this study, the mean relative weight of each fish species was above 100 (the index of *G. yajiangensis* was slightly lower than 100) (Table 5), indicating a balance between prey availability and predator density of these fish populations in their habitat. However, there were seasonal and geographical variations of relative weight for the six fish species, and the trends of the variations were consistent with the condition factor (K). This may relate to reproductive activities for respective fish species and external environmental conditions.

It can be speculated that the different spawning periods of these six fishes in the lower Yarlung Zangbo River were the main reason for the spatiotemporal variations of LWRs, condition factor, and relative weight. Apart from genetics, environmental conditions play an important role in the determination of the breeding season. In the present study, the study area, lower Yarlung Zangbo River reaches, is located in the transitional zone from the Tibetan Plateau to the Indian peninsula, having a humid subtropical climate with a high-altitude gradient [23]. Influenced by the altitude, variable climate types, and environmental factors (e.g., pH, velocity, river width, substrate types, etc.), the community structure and density and diversity indices of phytoplankton, periphytic algae, and benthic macroinvertebrates exhibited significant temporal and spatial variation, respectively [44, 45]. Consequently, the biomass of food organisms varied among seasons and tributaries, further influencing the food availability and quality of fish, resulting in growth and reproduction variations of fish that inhabit here ultimately.

5. Conclusions

Overall, the present study provides basic biological background regarding LWR and its associated parameters or indexes of six fish species distributed in the lower Yalung Zangbo River. The results showed that, there were significant temporal and spatial variations of LWRs, condition factors, and relative weights for these fishes affected by spawning periods and high environmental heterogeneity, and the growth patterns of these fishes were also different. However, restricted to the investigation conditions, other factors that will affect the LWRs and the associated parameters or indexes were not evaluated in the present study, such as gender, reproductive stage, intestinal fullness, size ranges, fishing gears, fishing intensity, and specific environmental factors and so on. Further research involving more factors that affect fish growth is required to increase the reliability of the description of fish growth patterns and conditions. Long-term ecological studies are also necessary to reveal the life history traits for these fishes in the lower Yarlung Zangbo River. These biological and ecological information is of great value for the conservation of local fish and the establishment of local fishery management.

Data Availability Statement

The data that support the findings of this study are available from the corresponding author upon reasonable request.

Conflicts of Interest

The authors declare no conflicts of interest.

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