





Research Article

Implications for Habitat Suitability Using Length–Weight Relationships and Condition Factors in the Chirchik River, Syr Darya Basin

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Accurate fish growth and condition assessment is central to understanding the ecological health of freshwater ecosystems. Despite severe anthropogenic pressures, ecological and biometric studies of fish populations from heterogeneous habitats of the Chirchik River, a key tributary of the Syr Darya, remain poorly studied. Here, we demonstrate the length–weight relationships (LWRs) and condition factors of five freshwater fish species from the upper and middle parts of the Chirchik River, including two native and three invasive species. Observed positive (*Gymnodiptychus dybowskii*, *Rhodeus ocellatus*, and *Micropercops cinctus*) and isometric growth (*Pseudorasbora parva* and *Cottus jaxartensis*) patterns indicate good habitat and resource conditions in both reaches of the river. Relative condition factor (K_n) values were consistently near 1.0 and did not differ significantly among species, indicating a stable physiological status. In contrast, Fulton's condition factor (K) varied significantly, reflecting marked interspecific differences in body robustness and energy allocation strategies. Taken together, our findings provide vital biometric data for poorly studied and heavily human-impacted rivers of Central Asia, and demonstrate the utility of combined growth and condition metrics as indicators of environmental suitability.

Keywords: anthropogenic pressures; Central Asia; ecological monitoring; fish population health; isometric growth

1. Introduction

The Chirchik River is a major right-bank tributary of the Syr Darya, originating in the western Tien Shan Mountains. It is formed by the outflow of the Charvak Reservoir, which receives water from three major rivers, Pskem, Chatkal, and

Koksu, and is further fed by the Ugam River, its principal right tributary [1, 2]. These four major mountainous and foothill rivers and streams form the upper Chirchik River system, while the flat areas around the Qibray and Zangiota Districts of Tashkent represent the middle section. The lower section flows downstream into the Syr Darya. As the largest

tributary of the Syr Darya, the Chirchik River harbors 39 fish species, of which 22 species are invasive. Its upper reaches are home to several native and endemic taxa. In contrast, the middle reaches are increasingly dominated by non-native species, reflecting a strong gradient of anthropogenic impact and ecological filtering [3].

Freshwater fishes are among the most affected aquatic organisms under the anthropogenic pressures, suffering from water pollution (59%), dam construction (46%), and introduction of invasive species (33%) [4]. The Chirchik River is one of the most highly human-impacted drainage systems in Central Asia, especially from invasive species, urban pollution, and water diversion [5–7]. These pressures can disrupt trophic structures and energy flow, alter habitat quality, and reduce fish growth rates and condition [8]. In this context, biometric indices such as length–weight relationships (LWRs), the relative condition factor (K_n), and Fulton’s condition factor (K) offer a valuable role to assess growth patterns, energy allocation, and population health, for both marine and freshwater fishes [9–12]. LWRs of fishes from the Aral Sea Basin, including the Syr Darya River, have been increasingly reported [7, 13–16]. However, such species- and population-specific data from the Chirchik River remain scarce. In particular, the Syr Darya Basin’s endemic species, such as *Cottus jaxartensis* (Berg 1916; [17]), is absent from global biometric databases such as FishBase [18]. The lack of species-specific LWR data consequently limits our understanding of ecological responses to environmental change, hampers assessment of fish biomass, and weakens both invasive species monitoring programs and effective conservation strategies for native fish populations [19–21].

Relying on formalin-stored samples, this study estimates LWRs and condition factors (K_n and K) for five freshwater species from the upper and middle reaches of the Chirchik River, including two native (*Gymnodiptychus dybowskii* and *C. jaxartensis*) and three invasive species (*Rhodeus ocellatus*, *Pseudorasbora parva*, and *Micropercops cinctus*). The primary objectives are to (i) provide the first biometric data for the Syr Darya endemic species and invasive species and (ii) evaluate the utility of biometric indices as indicators of fish health and potential environmental suitability. Our findings indicate that the two species *P. parva* and *C. jaxartensis* demonstrate isometric growth, whereas the three species *G. dybowskii*, *Rhodeus ocellatus*, and *Micropercops cinctus* exhibit positive allometric growth patterns. The K_n were consistently close to 1, indicating a stable physiological conditions among species; meanwhile, the K varied significantly, suggesting interspecific differences in energy allocation. Taken together, these results illuminate that both the upper and middle reaches of the Chirchik River may serve as relatively favorable habitats. By filling critical data gaps in global fish databases, this study contributes novel biometric information on Central Asian ichthyofauna and provides a valuable baseline for the long-term monitoring of invasive species and the conservation of native fishes in the Chirchik River drainage within the Syr Darya Basin.

2. Materials and Methods

2.1. Field Sampling. To evaluate growth patterns and body condition factors of fishes, three field surveys were conducted between April 2022 and April 2023 in the upper and middle sections of the Chirchik River, Syr Darya Basin, Uzbekistan (Table 1; Figure 1). The specimens of two native species of *G. dybowskii* (Kessler, 1874) and *C. jaxartensis*-Berg, 1916 and three invasive species of *Micropercops cinctus* (Dabry de Thiersant, 1872), *Rhodeus ocellatus* (Kner, 1866), and *Pseudorasbora parva* (Temminck and Schlegel, 1846) were collected using seine and trammel nets. After capture, individuals were immediately anesthetized with MS-222, fixed in 4% formalin for one week, and transferred to 70% ethanol for long-term preservation.

2.2. Data Analysis. Species identification was based on the studies of Berg (1949), Seraliev and Peng (2021), and Sideleva (2021) [17, 22, 23]. Each specimen was measured to the nearest 0.1-cm total length (TL) using a digital caliper and weighted to the nearest 0.01-g total weight (W). LWRs were calculated using the allometric power function as

$$W = aTL^b, \quad (1)$$

where W is the total weight (g), TL is the TL (cm), a is the intercept, and b is the slope. This relationship was linearized by log-transformation for regression analysis [24] as

$$\log(W) = \log(a) + b * \log(TL). \quad (2)$$

The regression parameters a and b , along with their 95% confidence intervals (CIs) and coefficient of determination (r^2) were estimated for each species. We performed a Student’s t -test to evaluate whether b significantly differed from the isometric value of 3.0 (null hypothesis $H_0: b = 3$), which indicates equal growth in length and weight, simultaneously. If b value is greater than 3, it indicates that allometric growth is positive (weight increases faster than length); meanwhile, if b is less than 3, it shows that the allometric growth is negative, and the fish becomes slimmer [24, 25].

In order to assess body condition, the relative condition factor (K_n) and Fulton’s condition factor (K) were calculated for each individual as [9, 26]

$$K_n: \quad K_n = \frac{W}{aTL^b}, \quad (3)$$

which measures the deviation of an individual’s observed weight from its predicted length-specific weight based on the LWR.

$$K: \quad K = 100 \times \frac{W}{TL^3}, \quad (4)$$

which can be estimated by dividing the observed weight by an expected weight dependent on the individual fish’s length. It is a widely used index in fisheries, assumes isometric growth, and enables comparison across populations regardless of LWR parameters.

TABLE 1: Sampling sites, dates, and coordinates for five fish species from the Chirchik River, Syr Darya Basin, Uzbekistan.

Species	Family/order	Sampling site	Sampling date	Coordinates
<i>Gymnodiptychus dybowskii</i> (Kessler, 1874)	Cyprinidae/Cypriniformes	Upper Chirchik River	9/4/2023	41°42'06.8"N 70°08'59.0"E
<i>Rhodeus ocellatus</i> (Kner, 1866)	Acheilognathidae/Cypriniformes	Middle Chirchik River	17/4/2022	41°14'06.9"N 69°19'52.8"E
<i>Pseudorasbora parva</i> (Temminck and Schlegel, 1846)	Gobiomidae/Cypriniformes	Middle Chirchik River	17/4/2022	41°14'06.9"N 69°19'52.8"E
<i>Micropercops cinctus</i> (Dabry de Thiersant, 1872)	Odontobutidae/Gobiiformes	Middle Chirchik River	17/4/2022	41°14'06.9"N 69°19'52.8"E
<i>Cottus jaxartensis</i> Berg, 1916	Cottidae/Perciformes	Upper Chirchik River	10/4/2023	41°40'05.1"N 70°02'48.1"E

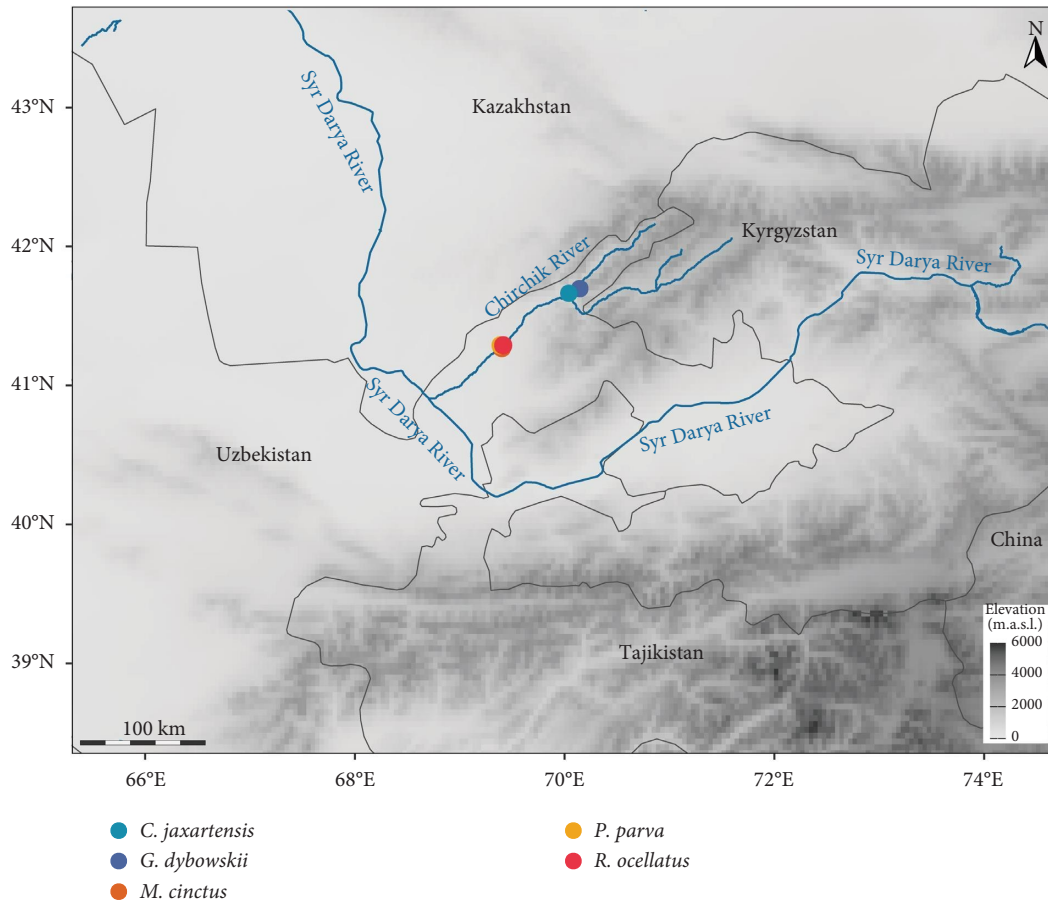


FIGURE 1: Sampling map of the five studied fish species from the Syr Darya Basin. *C. jaxartensis* (teal-colored point) and *G. dybowskii* (navy-colored point) represent upper-reach species, whereas *M. cinctus* (orange-colored point), *P. parva* (golden-yellow point), and *R. ocellatus* (red-colored point) represent middle-reach species.

The K_n and K are widely used proxies for assessing fish health and body condition, with K_n reflecting relative somatic well-being compared to expected weight-at-length, and K indicating absolute body robustness. These condition factors fluctuate in response to environmental variables such as temperature, food availability, and predator presence [15, 27]. Descriptive statistics (minimum, maximum, mean, and SD) were estimated for both K_n and K across species. One-way analysis of variance (ANOVA) was applied to test for differences in condition factors among species, followed by Tukey's honestly significant difference (HSD) post hoc test. All statistical analyses and visualizations were performed using Microsoft Excel 2021 and R V.4.3.2 [28].

3. Results

3.1. Sampling. Sampling sites, dates, and geographic coordinates for each species are given in Table 1 and Figure 1. A total of 233 fish specimens belonging to five species, five families, and three orders were collected from the upper and middle parts of the Chirchik River between 2022 and 2023. These included two native species, *G. dybowskii* and *C. jaxartensis*, and three invasive species, *R. ocellatus*, *P. parva*, and *M. cinctus*. Among these, *P. parva* was the most abundant species ($n = 91$), followed by *R. ocellatus* ($n = 68$).

TLs of specimens ranged from 2.17 cm (*R. ocellatus*) to 18.69 cm (*G. dybowskii*); meanwhile, total weights ranged from 0.08 g (*R. ocellatus*) to 68.32 g (*G. dybowskii*). Summaries of biometric data, LWR parameters, and growth patterns for each species are provided in Table 2.

3.2. LWRs. LWRs were statistically significant across all species, with coefficients of determination (r^2) ranging from 0.963 to 0.992, confirming that the model accurately matches the observed data (Figures 2(a), 2(b), 2(c), 2(d), and 2(e); Table 2). The slope parameter (b) varied between 2.795 and 3.394 (Figure 2(f)), whereas the intercept (a) ranged from 0.0054 to 0.0248. Student's t -tests comparing b to the isometric value of 3 demonstrated substantial positive allometric growth in *G. dybowskii* ($b = 3.206$, $p < 0.001$), *R. ocellatus* ($b = 3.394$, $p < 0.001$), and *M. cinctus* ($b = 3.285$, $p = 0.010$). In contrast, growth in *P. parva* ($b = 3.061$, $p = 0.165$) and *C. jaxartensis* ($b = 2.795$, $p = 0.091$) did not deviate significantly from isometry and hence were classed as statistically isometric (Table 2).

3.3. Condition Factors. Overall statistics for the K_n and K are presented in Table 3. The mean K_n values of five studied species fluctuated from 0.996 (*P. parva*) to 1.010

TABLE 2: Descriptive statistics and parameters of the length–weight relationship of five fish species in the Chirchik River, Syr Darya Basin, Uzbekistan.

Species	Status	<i>n</i>	TL (cm)		W (g)		Length–weight relation parameters				GT	<i>p</i> (<i>t</i> -test) <i>b</i> compared to 3
			Min–Max	Min–Max	<i>a</i>	<i>b</i>	<i>r</i> ²	95% CI of <i>a</i>	95% CI of <i>b</i>			
<i>G. dybowskii</i>	E	28	7.77–18.69	3.56–68.32	0.005	3.21	0.99	0.0041–0.0072	3.091–3.322	+A	< 0.001	
<i>R. ocellatus</i>	I	68	2.17–5.83	0.08–3.21	0.006	3.39	0.97	0.0047–0.0073	3.248–3.540	+A	< 0.001	
<i>P. parva</i>	I	91	4.11–9.45	0.52–6.89	0.007	3.06	0.98	0.0057–0.0080	2.974–3.148	I	0.165	
<i>M. cinctus</i>	I	22	2.90–5.56	0.26–2.25	0.007	3.29	0.98	0.0054–0.0099	3.076–3.494	+A	0.010	
<i>C. jaxartensis</i> *	E	24	9.08–14.34	14.03–42.87	0.025	2.80	0.96	0.0136–0.0450	2.554–3.036	I	0.091	

Note: E, endemic fish species; I, invasive fish species; *n*, number of individuals; W, total weight; Min, minimum; Max, maximum; *a*, intercept; *b*, slope; *r*², coefficient of determination; +A, positive allometric growth; I, isometric growth.

Abbreviations: CI = confidence interval; GT = growth type; TL = total length.

*The first reported LWR value.

(*R. ocellatus*), with standard deviations below 0.08 for most species (Figure 3(a)). Two species, *G. dybowskii* and *R. ocellatus*, had higher than 1.0 mean K_n values; meanwhile, it was slightly below 1.0 in *P. parva* and *M. cinctus*. Furthermore, the cold-water Chatkal sculpin *C. jaxartensis* had exactly 1.0 average value. In contrast, K average values showed significant interspecific variability; the lowest value was observed in *P. parva* (0.762), while the highest value was documented in *C. jaxartensis* (1.495) (Table 3; Figure 3(b)). In addition, *R. ocellatus* and *M. cinctus* had higher average K values (1.074 and 1.111, respectively) than that of *G. dybowskii* (0.893). One-way ANOVA analysis did not show statistically significant interspecific variations in K_n ($F_{4,228} = 0.21$, $p = 0.93$; Table 4); however, significant variations were observed in K ($F_{4,228} = 191.29$, $p < 0.001$; Table 4). Similarly, Tukey's HSD post hoc test confirmed no significant pairwise variations in K_n (all adjusted $p > 0.92$), whereas most species pairs exhibited significant differences in K (Table S1).

4. Discussion

This study provides the LWRs, K_n , and K estimates for five species, including an endemic and poorly known species (*C. jaxartensis*, first time) from the Syr Darya drainage in Uzbekistan, thereby contributing to the ichthyological baseline of Central Asia and addressing a gap in global databases such as FishBase. Beyond their descriptive values, these results show how native endemics and invasive species differ in their growth patterns and body condition dynamics, providing information about ecological adaptations and possible management issues. Such data are particularly valuable given the region's rich but understudied freshwater biodiversity, as recently highlighted by Rozimov et al. [29], who also highlighted the need for integrative research on the mitochondrial genome of endemic fishes in the Tien Shan and surrounding areas.

The slope (*b*) of the LWR is a key indicator of fish growth type, with the theoretical value of 3.0 representing isometric growth [9], and expected biological values typically ranging between 2.5 and 3.5 [24]. Variability in *b* can be attributed to environmental (e.g., water temperature and habitat structure), biological (e.g., gonadal maturation, diet, stomach fullness, and growth stage), and

anthropogenic factors (e.g., gear type, size range, and sample size) [30, 31]. All slope values in this study were within the expected biological range. Although cold-water, fast-flowing, and high-altitude mountain fishes show negative allometric growth patterns [19, 32, 33], the native species, *G. dybowskii* presented significant positive allometric growth in this study ($b = 3.206$). This pattern suggests faster weight gain than length and may indicate favorable conditions in cold, high-oxygen mountain streams in the upper Chirchik River, particularly in Aksarsay Stream (Ugam-Chatkal National Park), where the absence of predators or competitors may enhance the growth patterns. In comparison, *C. jaxartensis* had a slope value ($b = 2.795$) that was lower than the isometric value, which suggests negative allometric growth. However, the 95% CI for *b* (2.554–3.036) included 3.0, and the deviation from isometry was not statistically significant ($p = 0.091$). Consequently, *C. jaxartensis* is regarded as demonstrating isometric growth in the current study, and analogous trends have been documented in other cold-water fishes such as *Iskandaria kuschakewitschi* and *Triplophysa ferganaensis* from the upper Syr Darya drainage [15]. The wide CI and diminished precision for *C. jaxartensis* may be partially linked to the limited sample size ($n = 24$) or habitat heterogeneity within the Pskem-Charvak system. Future studies should consider season, sex, maturity, and gut fullness of *C. jaxartensis* populations from the Ugam River, a fast-flowing right tributary of the Chirchik River, to better understand intraspecific variability in growth patterns. The invasive species displayed a different pattern. Both *R. ocellatus* ($b = 3.394$, 95% CI: 3.248–3.540) and *M. cinctus* ($b = 3.285$, 95% CI: 3.076–3.494) showed substantial positive allometric growth, indicating that individuals gain weight faster than they increase in length. The positive growth patterns of two invasive species in the middle reaches of the Chirchik River may be associated with slower-moving waters, warmer temperatures, and sufficient food availability [34]. Compared to regional data [15], two invasive species also demonstrated similar growth dynamics with close *b* values; meanwhile, *P. parva* demonstrated isometric growth in this study. The observed isometric and positive allometric growth patterns of the five studied fishes clearly indicate the suitable habitat in both the upper and middle reaches of the Chirchik River.

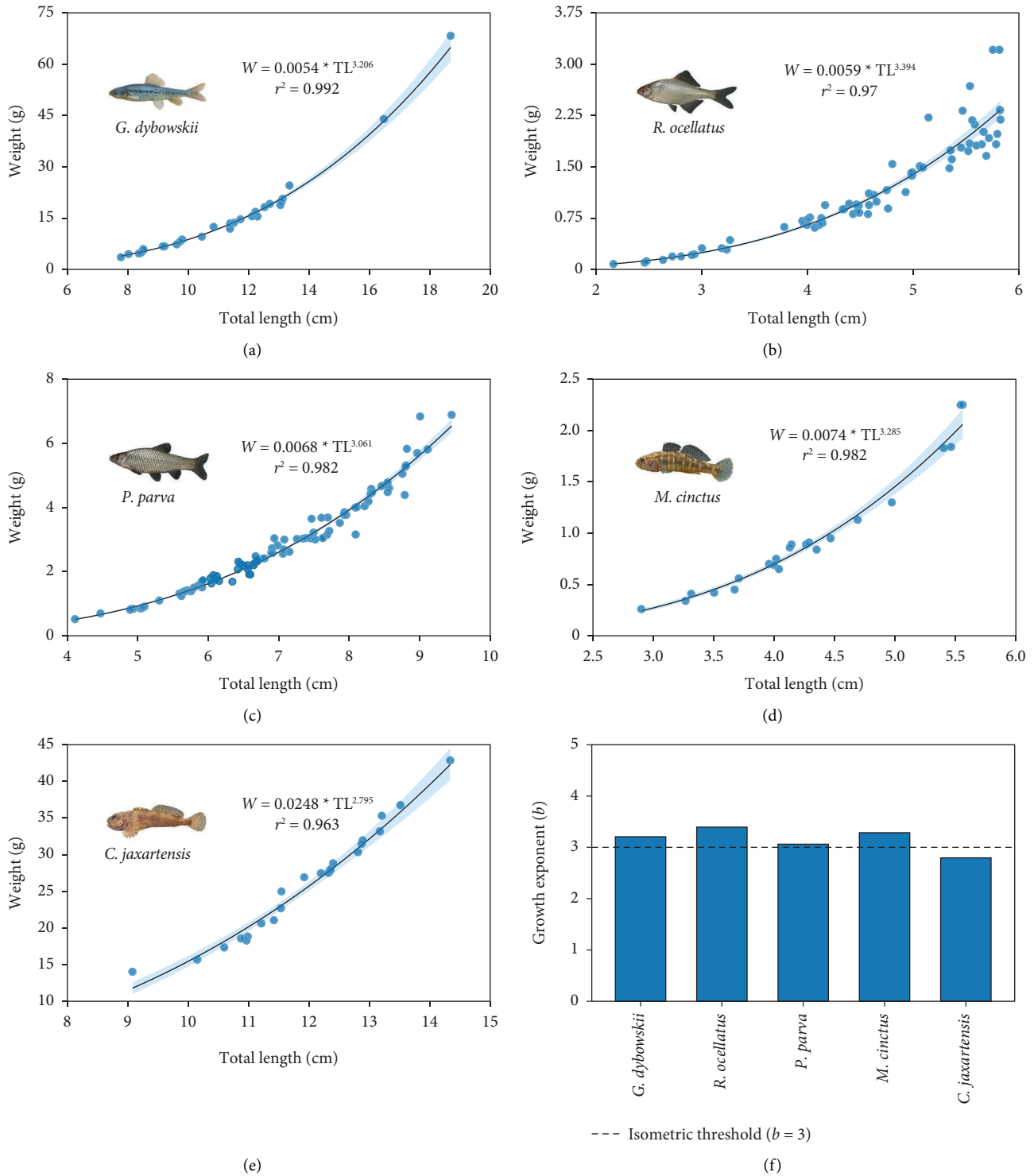


FIGURE 2: Length–weight relationships (LWRs) for five fish species from the Chirchik River: (a–e) Species-specific LWRs results for the two species and three invasive species. Each plot shows observed data (blue points), fitted regression curves (black lines), and 95% confidence intervals (light-blue ribbons). The estimated length–weight equations and coefficients of determination (r^2) are presented within each plot. (f) Growth exponent (b) by species, with a dashed horizontal line at $b = 3$ indicating the isometric threshold; values above and below 3 denote positive and negative allometric growth, respectively. Credit: Photo of *Micropercops cinctus* by Murdojon Rakhmonov.

A notable outcome of this study is the contrast between K_n and K . Mean K_n values across species were tightly clustered around 1.0, with low standard deviations,

indicating that most individuals maintained balanced weight-for-length ratios under current environmental conditions. Slightly elevated mean K_n values in *G. dybowskii*

TABLE 3: Summary statistics for relative condition factor (K_n) and Fulton's condition factor (K) across five fish species.

Species	K_n Min	K	K_n Max	K	K_n Mean	K	K_n SD	K
<i>G. dybowskii</i>	0.904	0.758	1.148	1.046	1.009	0.893	0.063	0.068
<i>R. ocellatus</i>	0.755	0.671	1.449	1.685	1.010	1.074	0.157	0.199
<i>P. parva</i>	0.772	0.597	1.204	0.936	0.996	0.762	0.074	0.057
<i>M. cinctus</i>	0.848	0.909	1.128	1.321	0.997	1.111	0.079	0.105
<i>C. jaxartensis</i>	0.913	1.386	1.189	1.875	1.000	1.495	0.058	0.097

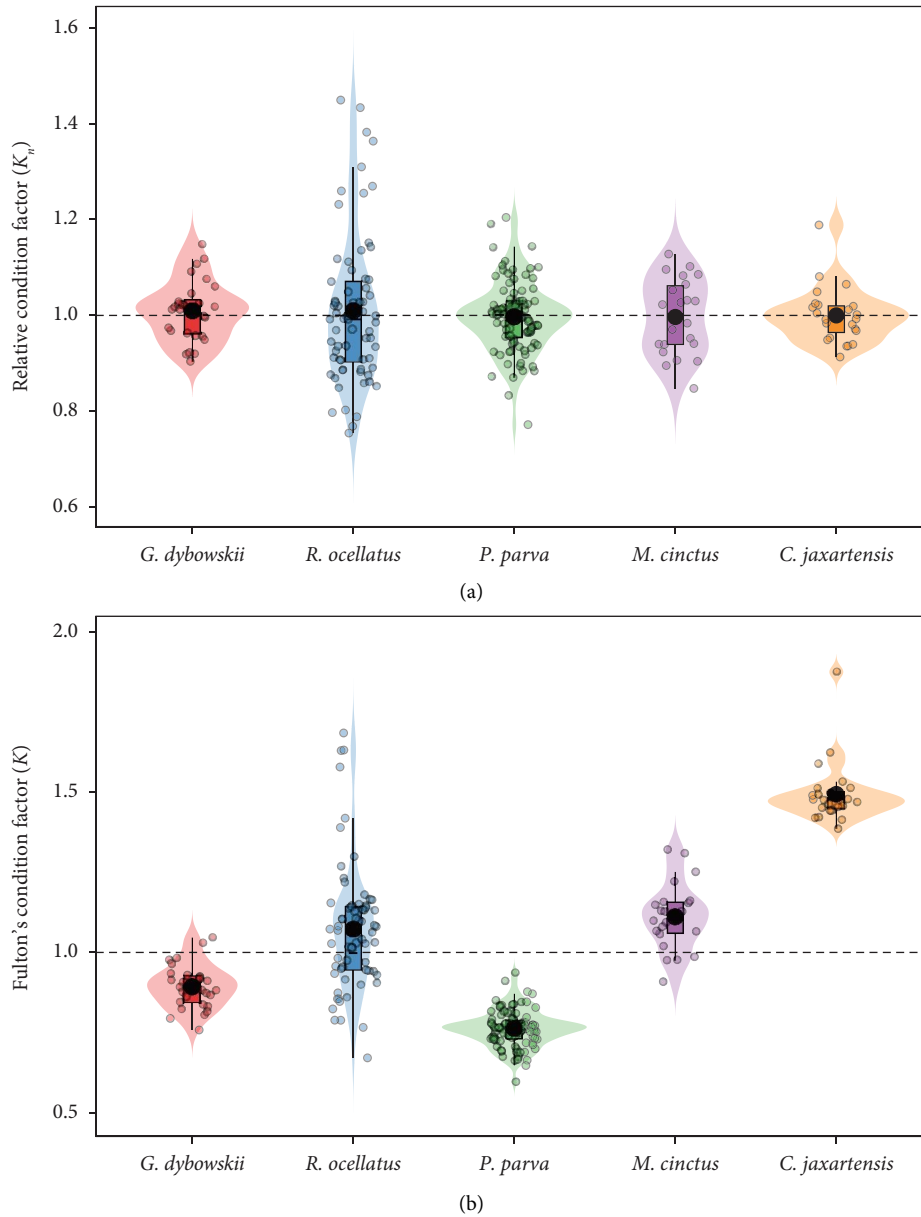


FIGURE 3: Condition factors of five fish species from the Chirchik River: (a) relative condition factor (K_n) and (b) Fulton's condition factor (K). Dashed horizontal lines represent the expected reference value of 1.0 for both indices. No significant differences were found among species for K_n ($p = 0.93$), while K differed significantly ($p < 0.001$). Violin plots show the full distribution, boxplots indicate interquartile ranges, and bold points represent mean values.

and *R. ocellatus* (> 1) may reflect localized advantages such as favorable habitat conditions, abundant food resources, or reduced interspecific competition [35]. In contrast, the

slightly lower values in *P. parva* and *M. cinctus*, although still within the healthy range, could indicate subtle ecological pressures such as competitive stress or predation risk from

TABLE 4: Results of one-way ANOVA for relative condition factor (K_n) and Fulton's condition factor (K) among five fish species sampled from the Chirchik River.

Condition	Term	Df	Sum sq	Mean sq	F value	Pr (> F)
K_n	Species	4	0.009	0.002	0.214	0.930
K_n	Residuals	228	2.448	0.011	NA	NA
K	Species	4	11.863	2.966	191.285	1.24E-71
K	Residuals	228	3.535	0.016	NA	NA

large piscivores present in the system, including *Silurus glanis*, *Channa argus*, and *Opsariichthys bidens* in the sampling site [36]. The mean K_n of exactly 1.0 in *C. jaxartensis* reflects a physiologically balanced population, possibly linked to its benthic niche specialization and reduced trophic overlap with other taxa. The narrow variability in K_n values, combined with the absence of statistically significant interspecific differences, supports the interpretation that fish communities in the upper and middle reaches of the Chirchik River are currently ecologically stable and not subject to major nutritional or energetic stress. In contrast to the relative condition observed in K_n , K revealed considerable variation among species (Table 4), reflecting marked differences in body form and energy allocation strategies. As an indicator of somatic plumpness, K is highly sensitive to interspecific differences in morphology, energy reserves, and ecological adaptations [9, 24, 37]. The comparatively low K values observed in *P. parva* likely reflect a more streamlined body shape or occupation of habitats with limited resources. In contrast, the notably high K values in *C. jaxartensis* and *M. cinctus* point to more robust body forms, potentially adapted to benthic life strategies and adaptation to structurally complex microhabitats [38]. The strong interspecific contrasts in K suggest long-term morphological divergence by ecological partitioning within the Chirchik River system [34, 39]. These patterns are clearly reflected in the visual comparison of K_n and K (Figures 3(a) and 3(b)), where relative condition remains stable, yet body robustness diverges significantly among species. These findings highlight the importance of employing both K_n and K together to assess not only the short-term physiological condition but also deeper morphological and ecological differentiation among fishes in diverse river ecosystems. However, it should be noted that our study presents several limitations that future studies should address. These include formalin-stored samples, sex and maturity determination, and gut fullness. In addition, seasonal and extensive geographical sampling may enhance accurate conclusions and enable insightful understandings of fish growth dynamics.

5. Conclusions

This study provides an integrated assessment of LWRs, relative condition factor (K_n), and Fulton's condition factor (K) for five native and invasive fish species from the Chirchik River, a right-bank tributary of the Syr Darya Basin in Uzbekistan. The substantial positive allometric growth

patterns observed in *G. dybowskii*, *R. ocellatus*, and *M. cinctus* demonstrate rapid weight gain relative to length, likely indicating suitable environmental conditions, abundant food resources, or lower interspecific competition. In contrast, the isometric growth patterns of *P. parva* and *C. jaxartensis* suggest balanced energy allocation. K_n values showed no statistically significant interspecific differences, whereas K values varied substantially among species, with *C. jaxartensis* displaying the highest body robustness and *P. parva* the lowest. These differences, further confirmed by Tukey's HSD tests, highlight distinct species-specific adaptations and habitat use. The narrow range and near-unity mean K_n values across species indicate that the sampled populations are in stable physiological condition. Overall, this work offers valuable baseline data for monitoring fish health and ecological stability in the Central Asian river systems and supports future conservation and management efforts in the Chirchik River ecosystem.

Data Availability Statement

The data presented in this study are available upon reasonable request from the corresponding author.

Conflicts of Interest

The authors declare no conflicts of interest.

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Supporting Information

Additional supporting information can be found online in the Supporting Information section. (*Supporting Information*)

Table S1: Tukey's HSD post hoc test results for both relative condition factor (K_n) and Fulton's condition factor (K).

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