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Biological insights into the vulnerable *Hyporhamphus xanthopterus* from Vembanad Lake: Fishery trends and growth parameters

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Abstract

This study examined the fishery characteristics, length-weight relationship (LWR), and condition factor of *Hyporhamphus xanthopterus* (Valenciennes, 1847), from Kumarakam region of Vembanad Lake, Kerala, during 2020-2021. This investigation provides the first sex-wise analysis of length–weight relationships (LWR) and season-wise evaluation of condition factor (Kn) for *H. xanthopterus* population. A total of 657 specimens (304 males and 353 females) were caught employing 18 mm mesh sized gillnets, and measured for total length (TL) and total weight (TW) to estimate growth patterns using the allometric model. Males exhibited isometric growth (b=3.004) (R^2=0.94), while females displayed slightly negative allometric growth (b=2.857) and R^2=0.96. When all the individuals are pooled, the estimated growth exponent b was 2.918 (R^2=0.96). Seasonal analysis of condition factor indicated statistically significant variation, with higher Kn values observed in both males and females during Season 3 (post-monsoon), likely reflecting ecological influences such as food availability, reproductive activity, and environmental stress. These findings highlight distinct sex-specific growth patterns and seasonal physiological shifts, offering valuable insights into the biology and ecological adaptation of *H. xanthopterus*. The baseline data provided here can inform future research, resource management strategies, and biodiversity conservation efforts targeting *H. xanthopterus* and the broader aquatic ecosystem of Vembanad Lake.

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Introduction

Vembanad Lake, part of the Western Ghats, a UNESCO World Heritage Site and global biodiversity hotspot (Myers *et al.,* 2000) is one of Kerala's largest tropical wetland systems and South India's second-largest brackishwater ecosystem. The lake is spread across the districts of Alappuzha, Kottayam, and Ernakulam (Kurup *et al.,* 1990), extending approximately 96 km in length with a surface area of 1,512 km² (Krishna Kumar and Priyadarsanan, 2012). It is considered one of the most productive coastal wetlands in Kerala, supporting a rich array of life forms (Dahanukar *et al.,* 2004). The ecological complexity of Vembanad Lake is further enriched by estuaries, tidal lagoons, swamps, mangroves, and distinct man-made features (Ajay, 2022). Due to its high biodiversity and ecological significance, the lake was designated a Ramsar site in November 2002 (Gardner and Finlayson, 2018) and classified as a critically vulnerable coastal area (Singh, 2016). It plays a vital role in providing essential ecosystem services and serves as a crucial habitat for a wide variety of fauna (Kumar *et al.,* 2024). The construction of the Thanneermukkom Barrage has resulted in the division of the lake into two distinct ecological zones (Kolathayar *et al.,* 2021), a freshwater dominated southern zone and a saltwater dominated northern zone (Ajay *et al.,* 2022).

Hyporhamphus xanthopterus (Valenciennes, 1847) is a freshwater halfbeak belonging to the family Hemiramphidae (Order: Beloniformes). This species is endemic to the freshwater systems of the Western Ghats in India (Talwar and Jhingran, 1991; Jayaram, 2010) and was originally described from Vembanad Lake (Kurup and Samuel, 1980; Collette, 1981). The genus *Hyporhamphus* comprises approximately 38 described species globally, of which nine have been reported from Indian waters (Froese and Pauly, 2025). *H. xanthopterus* typically inhabits shallow, slow-flowing waters with abundant vegetation, including lakes, rivers, and low-salinity estuarine environments (Collette, 2004)

The analysis of length–weight relationships (LWRs) is a fundamental tool in fisheries biology (Chu *et al.,* 2012). LWRs provide essential information for estimating fish weight from length measurements (Bagenal and Tesch, 1978), evaluating growth patterns (Jisr *et al.,* 2018; Mehanna and Farouk, 2021), and assessing fish populations and stock structures (Mehanna and Farouk, 2021). These relationships are also crucial for informing fisheries management and conservation strategies (Gonçalves *et al.,* 1997). A key application of LWRs is in the estimation of fish biomass and production, particularly when accurate direct weight measurements are difficult, time-consuming, or impractical to obtain in field conditions (Froese, 2006). While extensive LWR data are available for many temperate fish species (Sinovcic *et al*., 2004), data for tropical and subtropical species remain limited (Ecoutin *et al.*, 2005). In parallel, condition factors serve as reliable indicators of fish health and well-being within their environments (Gomiero and Braga, 2005), offering insights into habitat quality and environmental suitability (Le Cren, 1951; Guidelli *et al.,* 2011). The condition factor is a quantitative measure reflecting the physiological state of a fish and is influenced by variables such as feeding status, parasitic infection, and reproductive condition (Le Cren, 1951). It plays a significant role in determining growth, reproductive success, and survival potential.

Research on length-weight relationships (LWRs) in halfbeak species remains relatively limited. Existing studies have primarily focused on various genera, including *Chriodorus* (Bonilla-Gomez *et al.*, 2014), *Euleptorhamphus* (Thomas et al., 2025), *Hemiramphus* (Mohamad *et al.,* 1997; Tabassum *et al.,* 2015; Mehanna *et al.,* 2019; Natan *et al.*, 2019; Balukh *et al.,* 2021; Shahul Hameed *et al.,* 2021; Talakua *et al.,* 2023; Umasangadji *et al.,* 2023; Thomas *et al.,* 2025), *Hyporhamphus* (Fowler *et al.,* 2008; Yousuf *et al.,* 2013; Jaafour *et al.,* 2015; Karna *et al.,* 2017, 2020; Hasan *et al.,* 2020; Ranjit *et al.,* 2020; Roshni and Renjithkumar, 2022;Ramulu *et al.,* 2022; Alam *et al.,* 2023; Thomas *et al.,* 2025), *Oxyporhamphus* (Thomas *et al.,* 2025), and *Rhynchorhamphus* (Thomas *et al.,* 2025). Despite this growing body of work, comprehensive biological and morphological data for halfbeak species in Indian waters remain scarce. This lack of detailed information poses challenges for effective stock assessment and ecological studies, particularly for endemic and vulnerable species such as *H. xanthopterus*.

H. xanthopterus is currently classified as "Vulnerable" (VU D2) on the updated IUCN Red List (IUCN, 2024) due to a range of anthropogenic threats (Venkataraman *et al.,* 2013), making it a species of significant conservation concern. Globally, approximately fifteen studies have examined the length–weight relationship (LWR) in species of the genus *Hyporhamphus*. Within India, this number is considerably lower, with only four documented studies. At a finer geographic scale, research from Kerala is particularly limited, with merely three available studies. Notably, only two of these pertains to *H. xanthopterus* from Kerala waters (Varghese, 2005; Roshni and Renjithkumar, 2021, 2022), and this study does not provide sex-specific analyses of the length–weight relationship.

This evident paucity of region-specific and sex-disaggregated data underscores a significant gap in the existing literature. Comprehensive fishery-related data are also extremely limited. Given the species' vulnerable status, there is an urgent need to understand its LWR and other key biological parameters within its natural habitat. Accordingly, this study aims to investigate the fishery characteristics, length–weight relationship, and condition factor of *H. xanthopterus*, providing critical data to support its effective management and conservation.

Materials and methods

Sample collection

Fish samples were collected from Vembanad Lake (9°35'59.9"N; 76°25'25.1"E) (Fig. 1), located within the Western Ghats region of India. Monthly sampling spanned from January 2021 to December 2021, covering four distinct seasons: Season 1 - Winter (December-February), Season 2 - Summer (March-May), Season 3 - Monsoon (June-August), and Season 4. Post-monsoon (September-November). Specimens were obtained through local artisanal fisheries employing gill nets '*Murash vala*' with a mesh size of 18 mm. A total of 658 individual fish were collected for the study, comprising 305 males and 353 females. For each specimen, total length (TL) was measured to the nearest cm, and total weight (TW) was recorded in grams using a precision balance, in accordance with the methodology of Fischer (2014).

Length-weight relationship (LWR) and condition factor

The length-weight relationships (LWRs) for the studied species were determined using the equation:

$W = a \times L^b$

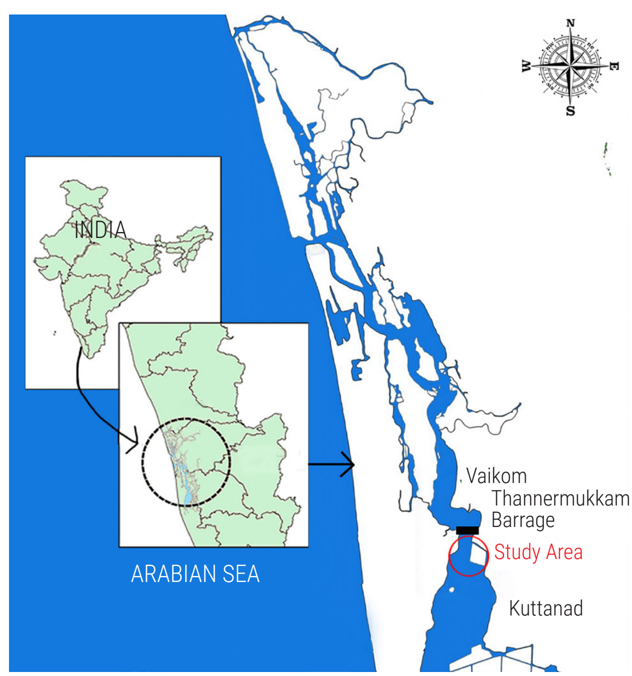


Fig. 1. Location map of Vembanad Lake, Kerala, India, indicating study area

where W is the weight, L is the length, and a and b are parameters estimated through nonlinear regression. The significance of deviation of b from the isometric value (b=3) was tested using Student's t-test, calculated as: t = b-3/Sb, where b is the regression coefficient of the length-weight relationship and Sb is the standard error of b (Snedecor, 1941; Snedecor and Cochran, 1967). Based on the value of b and its statistical significance, growth patterns were classified as: isometric (b = 3); positive allometric growth (b>3) and negative allometric (b<3).

ANCOVA was employed to assess the effects of total length (TL) and sex on total weight (TW). The interaction term between TL and sex was included to test for differences in slopes of the LWR between males and females. Residuals from the ANCOVA model were examined for normality using the Shapiro-Wilk test. Levene's test was applied to evaluate the homogeneity of variances across sex groups. To address the non-normality of residuals observed in initial analyses, square root transformation was applied to the weight data (Perk *et al.,* 2018). This transformation aims to stabilise variance and meet the assumptions of the ANCOVA model.

The relative weight condition factor (k_n) was estimated as $k_n = W/W_c$, where W_o is the observed total weight of fish and W_c is the calculated (or predicted) total weight of respective fish estimated using the length–weight relationship:

$W_c = aL^b$ (Le Cren, 1951; Ragheb, 2023)

According to Fulton (1902), a condition factor of 1.6 implies excellent condition, 1.4 denotes good and well-proportioned fish, 1.2 reflects fair condition, 1.0 indicates- a long and thin fish in poor condition, and 0.8 represents extremely poor condition. Descriptive statistics for Kn were computed for each season to provide an overview of central tendency and variability across seasons. To statistically compare Kn among the four seasons, the non-parametric Kruskal-Wallis test was employed, suitable for comparing more than two independent groups without requiring assumptions of normality. *Post-hoc* pairwise comparisons were subsequently conducted using Dunn's test with Bonferroni correction to identify specific seasonal differences (Kassambara, 2019). Effect sizes were quantified using partial eta-squared (η^2) to determine the magnitude of observed differences, interpreted according to established guidelines where η^2 values of 0.01, 0.06, and 0.14 typically indicate small, medium, and large effects, respectively (Cohen, 1988). All statistical analyses were conducted using R software (version 4.0.3), utilising the tidyverse, ggpubr, rstatix, dplyr, and ggplot2 packages.

Results

Fishery

H. xanthopterus is a freshwater halfbeak species considered endemic to the backwaters of Kerala, India, specifically the Vembanad and Ashtamudi lakes and their interconnected riverine systems. Locally known as "*Murash*," this species supports a notable artisanal fishery (Fig. 2b). The primary method, "Murash fishing," employs specialised gillnets called "*Murash Vala*." These nets, originally white ("Vaishali nets"), were dyed green, reportedly to attract halfbeaks by mimicking phytoplankton. Typically, long and narrow, these floating nets can extend up to 1 km in length and 1 m in width. Mesh sizes of 18 mm and 16 mm are predominantly used for targeting adult and sub-adult *H. xanthopterus*. However, juveniles are incidentally caught in smaller 12 mm mesh nets, although the use of this mesh size is banned due to its impact on juvenile fish populations, its persistence is anecdotally reported. Despite widespread fishing in the region, relatively few fishers specifically target this species (Fig. 2c).

H. xanthopterus (Fig. 2d, e) is a schooling species exhibiting increased activity during the evening, likely influenced by reduced boat traffic. Year-round, fishing success is significantly affected by weather conditions such as wind speed and water currents. The peak fishing season occurs from December to May. During the rainy season (June–August), fishing declines sharply due to excessive weed growth, leading fishers to target Karimeen (*Etroplus suratensis*) as an alternative. Catches notably increase following the monsoon, benefiting from freshwater runoff, and also when the Thannermukkom saltwater barrage opens (Fig. 2a), allowing saltwater influx. Fishing operations typically involve two individuals using a small engine-powered boat with 18 mm mesh nets. Commencing in the evening, fishers use torches to locate fish, often jumping at the surface, and anchor their boat with bamboo poles. The floating nets are strategically deployed based on environmental conditions, a process termed "*Vala neetti virikkuka*." Nets are retrieved and inspected approximately one hour later before being reset, a cycle repeated 4-5 times per night with 90 to 120 min intervals. Captured fish are stored in ice-filled boxes. Common bycatch includes, false white sardine, catfishes, and garfish. Fishing concludes in the morning upon returning to the mainland. Fishers registered with the local association (Sangam) deliver their catch, receiving payment (₹200-400) based on daily availability and demand, before the association sells the fish locally with a minimal profit margin (Fig. 2).

Length-weight relationship (LWR)

Detailed information on sample size, total length (TL) and total body weight (TW) ranges (in cm and g, respectively)**,** length–weight relationship (LWR) parameters such as "a" and "b" with their 95% confidence intervals, and the coefficient of determination (r^2) is provided in Table 1. The LWR values for males, females, and pooled data are presented**.** A scatter diagram illustrating the length–weight relationship of *H. xanthopterus***,** with males, females and pooled depicted separately, is shown in Fig. 3. The estimated b values for both males and females fall within the typical biological range (2.5-3.5) commonly observed in length–weight relationships, indicating normal growth patterns.

For male specimens, the allometric model estimated the intercept a at 0.0025 and the exponent b at 3.0047. Both parameters were highly significant (p<0.001), indicating a strong allometric relationship between TL and TW (Table 1). The exponent b being not significantly different from 3 suggests an isometric growth pattern, where weight increases proportionally with the cube of body length. In females, the intercept a was estimated at 0.004083, and the exponent b at 2.8573. Both parameters were also highly significant (p<0.001), indicating a good fit of the model to the data (Table 1). The exponent b, being slightly below 3, suggests a pattern of slightly negative allometric growth (Table 1).

Fig. 2. Fishery of *H. xanthopterus* from Vembanad Lake, Kerala. (a) Thannermukkom Barrage; (b) Artisanal fishery; (c) Murash net (gillnet); (d) and (e) *H. xanthopterus* (Murash)

Table 1. Descriptive statistics and estimated parameters of length–weight relationships of *H. xanthopterus* from Vembanad Lake, Kerala

Sex	N	TL	TW	a	95% of CL of a	b	95% of CL of b	t value	p value	Allometric growth	R^2 value
Male	304	10.7-26.1	3-56.7	0.00254	0.00178-0.00361	3.00472	2.8881-3.1225	51.05	<0.0001	Isometric	0.94
Female	353	10.8-26.3	3 - 50	0.00408	0.00305-0.00544	2.85725	2.7631-2.9521	58.299	<0.001	Negative	0.96
Pooled	657	10.7-26.3	3-56.7	0.003351	0.00267-0.00419	2.917869	2.8439-2.9923	76.655	<0.01	Negative	0.96

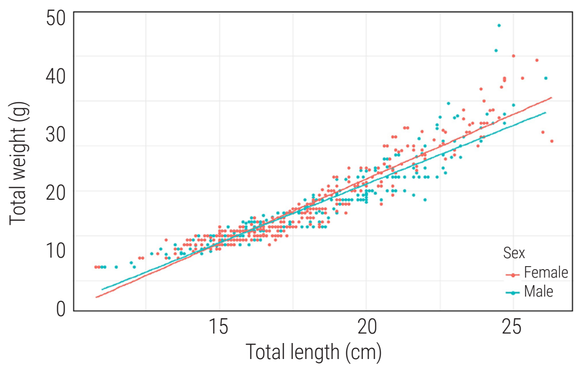
An ANCOVA was conducted to assess the effect of sex on log-transformed total weight (log TW), with for log-transformed total length (log TL) included as a covariate. The interaction between sex and log TL was included to test the assumption of homogeneity of regression slopes. The covariate, log TL, had a significant effect ($p<0.001$), indicating that body length strongly predicts body weight. After accounting for log TL, there was also a significant main effect of sex on log TW ($p=0.003$), suggesting that males and females differ in body weight independent of body length. Importantly, the interaction between sex and log TL was not significant ($p=0.456$), indicating that the assumption of homogeneity of regression slopes was met. This indicates that the relationship between log TL on log TW does not differ significantly between sexes.

Considering all individuals together, the combined model estimated the intercept a at 0.00335, and the exponent b at 2.918, both statistically significant ($p<0.001$). Although the relationship between TL and TW was strong and consistent, the exponent b being slightly less than 3 indicates a pattern of negative allometric growth, where increases in length result in less-than-proportional increases in weight (Table 1).

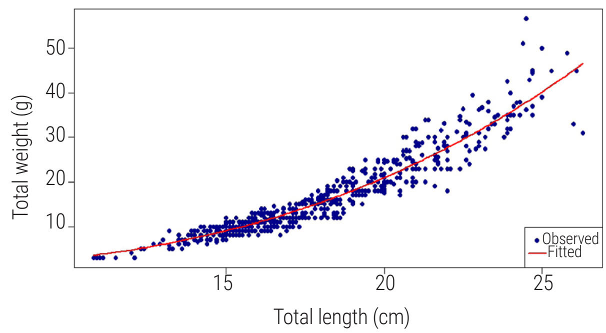
Condition factor

The analysis of the condition factor Kn across four seasons with respect to males revealed significant differences in its distribution. Kruskal-Wallis test revealed a statistically significant difference in Kn among the four seasons ($\chi^2 = 12.5$, $df = 3$, $p=0.005$), indicating that at least one seasonal group differed from the others. Descriptive statistics indicated that the mean Kn was highest in Season 3 (mean = 1.06, SD = 0.137) and lowest in Season 2 (mean = 0.973, SD = 0.104). Median values also suggested some seasonal variation, with the widest spread observed in Season 4. *Post hoc* comparisons using Dunn's test with Bonferroni correction identified a statistically significant difference in Kn between Season 2 and Season 3 ($p.adj< 0.004$), with Season 3 showing higher condition values. No other pairwise comparisons were statistically significant after adjustment (Table 2).

These findings show that seasonal variation in condition factor exists, with individuals in Season 3 exhibiting significantly better condition compared to those in Season 2. However, differences among other seasonal groups were not statistically significant after correction for multiple testing. The partial eta-squared (η^2) value was 0.0317,



(a)



(b)

Fig. 3. Scatter diagram showing length-weight relationship of *H. xanthopterus*- (a) Male (green); Female (red) and, (b) Pooled

indicating that approximately 3.17% of the variance in Kn is explained by the seasonal variable, *i.e.* a small effect size. (Table 2 and 3).

In females, the Kn showed significant variation across seasons (Table 2). Season 3 exhibited the highest mean Kn value (mean = 1.06, SD = 0.150), while Season 4 had the lowest (mean = 0.917, SD = 0.123). Median reflected similar patterns, with a notably lower median in Season 4 (0.910) compared to the other seasons. Kruskal–Wallis test indicated a statistically significant difference in Kn among the four seasons (χ^2 = 12.5, df = 3, p <0.005). The effect size was moderate (η^2 = 0.118), indicating that approximately 11.2% of the variance in Kn is explained by the seasonal variable (Table 2 and 3).

Post hoc pairwise comparisons using Dunn's test with Bonferroni correction revealed significant differences (Table 3). Notably, Season 4 had significantly lower Kn values compared to Seasons 1, 2, and 3. No significant differences were observed between Seasons 1 and 2 or between 1 and 3 (Fig. 4). These results suggest that individuals in Season 4 had significantly lower condition factors compared to the other seasons, possibly reflecting seasonal variation in environmental or physiological conditions that affect fish health or energy reserves. Despite these trends, the small effect size suggests that although seasonality contributes to variation in Kn, other unexamined factors such as food availability, reproductive status, or habitat quality may also have a substantial impact on Kn variability.

Discussion

Length and weight data are fundamental to fishery research and management, providing critical biological and ecological insights

Table 2. Descriptive statistics of condition factor (K) for both male and female *H. xanthopterus* across seasons from Vembanad Lake, Kerala

Season	Sex	*n*	Min	Max	Median	Mean	SD
Summer (1)	Male	90	0.736	1.33	0.968	1.01	0.138
	Female	96	0.666	1.28	0.995	0.995	0.129
Monsoon (2)	Male	81	0.724	1.22	0.965	0.973	0.104
	Female	94	0.732	1.25	0.999	0.998	0.104
Post-monsoon (3)	Male	71	0.794	1.33	1.05	1.06	0.137
	Female	69	0.792	1.38	1.060	1.060	0.150
Winter (4)	Male	62	0.659	1.50	0.979	1.00	0.170
	Female	94	0.629	1.20	0.910	0.917	0.123

Table 3. Comparative assessment of condition factor (K) in both male and female *H. xanthopterus* by season from Vembanad Lake, Kerala

Group	*Sex*	n_1	n_2	Statis tic	*p*.adj	Significance
Season 1 to Season 2	Male	90	81	-1.36	1.000	Not significant
	Female	96	94	0.0666	1.000	Not significant
Season 1 to Season 3	Male	90	71	2.17	0.179	Not significant
	Female	96	69	2.56	0.0635	Not significant
Season 1 to Season 4	Male	90	62	-0.583	1.000	Not significant
	Female	96	94	-4.22	0.000147	***
Season 2 to Season 3	Male	81	71	3.40	0.00406	**
	Female	94	69	2.48	0.0780	Not significant
Season 2 to Season 4	Male	81	62	0.660	1.000	Not significant
	Female	94	94	-4.26	0.000121	***
Season 3 to Season 4	Male	71	62	-2.54	0.0669	Not significant
	Female	69	94	-6.41	8.92e-10	****

Season 1 - Winter (December-February), Season 2 - Summer (March-May), Season 3 - Monsoon (June-August), and Season 4 - Post-monsoon (September-November)

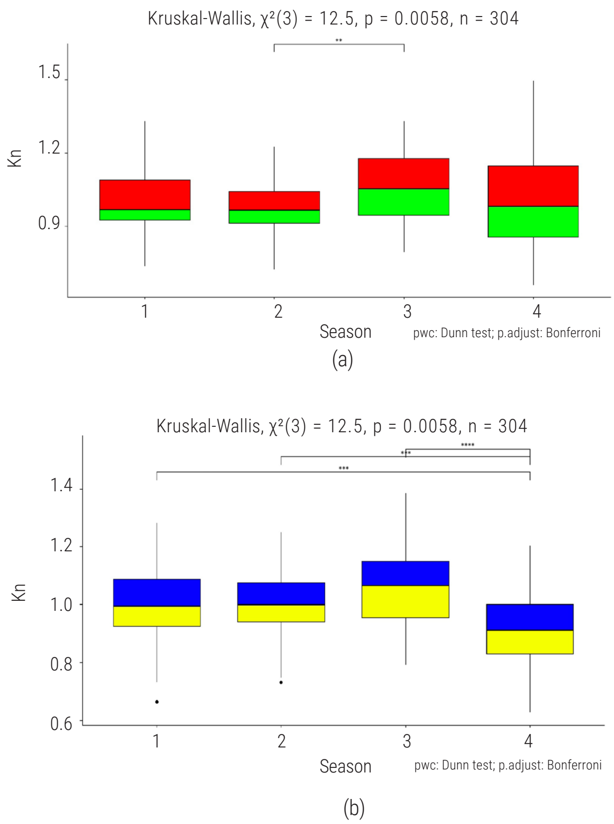


Fig. 4. Seasonal comparison of condition factor (K) of *H. xanthopterus* from the Vembanad Lake, Kerala- (a) Male, and (b) Female

as emphasised by Anderson and Neumann (1996). Although *Hyporhamphus* species have been extensively studied globally (Hossain *et al.,* 2006; Wang *et al.,* 2012; Cota-Gómez *et al.,* 2013; Yousuf *et al.,* 2013; Jaafour *et al.,* 2015; Palla *et al.,* 2018; Hasan *et al.,* 2020; Alam *et al.,* 2023; Cruz-Sánchez *et al.,* 2024), research specific to Indian waters remains limited (Karna *et al.,* 2017, 2020; Manoharan *et al.,* 2018; Ranjit *et al.,* 2020; Ramulu *et al.,* 2022; Thomas *et al.,* 2025). Furthermore, investigations on *Hyporhamphus xanthopterus* are scarce (Roshni and Renjithkumar, 2021), with no published research on seasonal variation in condition factor from Indian waters. The present study addresses this knowledge gap by providing the first comprehensive analysis of the length-weight relationship (by sex) and condition factor (by season) for *H. xanthopterus* in Indian waters.

The artisanal fishery for *H. xanthopterus* ("*Murash*") in Kerala's backwaters is a seasonally driven activity, strongly influenced by schooling behaviour of the species and environmental factors like weed growth and freshwater influx (Padmakumar *et al.,* 2002). Notably, fishing activity intensifies after the monsoon and with the opening of the Thannermukkom barrage (Kolathayar *et al.,* 2021). The fishers of this particular region have adopted adaptive strategies including the use of green-dyed nets (Mohanan *et al.,* 2022) and evening torches to enhance catch efficiency. However, the continuous use of banned 12 mm mesh nets poses serious threat for juvenile populations (Alagaraja *et al.,* 1986; Silvano *et al.,* 2017). The '*Murash Vala*' (gillnets), operated by two-person teams in engine-powered boats, highlight a specialised and economically structured livelihood. These operations are managed through local associations that regulate both sales and payment, underscoring the delicate balance between traditional fishing practices, ecological sustainability, and socio-economic dynamics in this unique endemic fishery (Jadhav, 2017; Sundar, 2018).

The estimated b values for all species fall within the acceptable range of 2.5–3.5, as outlined by Froese (2006). A comparative review of previously published length weight relationships (LWRs) for other species within the genus *Hyporhamphus* reveals considerable intraspecific variation in the growth exponent b (Table 4). For instance, *H. naos* and *H. quoyi* exhibited higher b values, suggesting a positive allometric growth pattern. Multiple studies on *H. limbatus* and *H. quoyi* have documented a wide range of b values, from 2.02 to 3.84 and 2.6–3.4 43 respectively. These differences may be attributed to broad geographical variation and associated environmental factors (Rahman *et al*. 2021). The majority of *Hyporhamphus* species reported in the literature demonstrated b values close to or slightly above 3.0, such as *H. meeki* (3.01), *H. picarti* (3.17), and *H. unifasciatus* (3.13), indicating near-isometric growth. However, species such as *H. intermedius* (2.866), *H. neglectus* (2.86), and *H. dussumieri* (2.3148) exhibited a lower *b* value, indicating negative allometric growth. Numerous reasons have been suggested as age, season, ontogenic changes, fish feeding, sampling methodologies, taxonomic errors, anthropogenic stressors, variation in gonad weight during various stages of sexual maturity and the productivity of the ecosystems (Sparre and Venema 1998; Moutopoulos and Stergiou 2002; Froese 2006; Hossain *et al*. 2009; Mir *et al.* 2013; Hanif *et al.* 2017; Mehanna and Farouk 2021; Ragheb 2023).

For most common fishes of the tropical and temperate region, 'b' values range from 2.7 to 3.3 (King, 1996). According to Gayanilo and Pauly (1997), 'b' values may range from 2.5 to 3.5. In the present study, the estimated b value for males was 3.00, indicating an isometric growth pattern, where weight increases proportionally with length. In contrast, the b value for females was 2.86, suggesting a slightly negatively allometric growth pattern, which aligns with typical growth dynamics observed in many tropical fish species, suggesting that the length of fish increased more than their weight (Wootton and Wootton, 1990) and the fish became slenderer as they grow (Pauly, 1984). Slight differences are observed for the calculated b values in present study and those reported in previous studies (Roshni and Renjitkumar, 2021) may be attributed to the variation in growth patterns across different populations of the same species or within the same population over time. These differences can result from variations in food availability (Ricker, 1975); water quality (Mommsen,1998); and the biological, temporal, and sampling factors (Mehanna and Farouk, 2021).

The condition factor (K or Kn) is a dynamic and crucial index in fish biology, reflecting feeding intensity, age, and growth rates (Oni *et al.,* 1983). In males, *post hoc* comparisons revealed a statistically significant difference in the condition factor (Kn) between Season 2 (monsoon) and Season 3 (post-monsoon). This variation in the Kn value may be attributed to ecological conditions, nutritional status and reproductive state across different size groups (Nash *et al.,* 2006) with higher Kn values (1.06) observed in Season 3 (post-monsoon), indicating an optimal balance between prey and predator

Table 4. Literature-based compilation of length–weight relationship metrics for *Hyporhamphus* fishes

Species	N	b	R^2	Growth type	Reference
Hyporhamphus dussumieri	114	2.3148	0.8618	A (-)	Yousuf *et al.* (2013); Pakistan
Hyporhamphus intermedius	103	2.866	0.94	A (-)	Wang *et al*. (2012); China
Hyporhamphus limbatus	352	2.945	.952	A (-)	Karna *et al*. (2017); India
	50	2.84	.950	A (-)	Hasan *et al*. (2020); Bangladesh
	65	3.275	.981	A (+)	Ranjit *et al.* (2020); India
	524	2.02-3.84	.855-.868	A (-) and A (+)	Alam *et al*. (2023); Bangladesh
	251	3.284	.987	A (+)	Thomas *et al.* (2025); India
Hyporhamphus meeki	79	3.01	.852	A (+)	Vega-Cendejas *et al.* (2017); Mexico
Hyporhamphus naos	109	3.4	.93	A (+)	Gomez *et al*. (2013); Mexico
Hyporhamphus neglectus	41	2.86	.824	A (-)	Palla *et al.* (2018); Philippines
Hyporhamphus picarti	52	3.17	.96	A (+)	Jaafour *et al,* (2015); Morocco
Hyporhamphus quoyi	68	2.6	.8531	A (-)	Ramulu *et al.* (2022); India
	146	3.199	0.97	A (+)	Hossain *et al.*(2006); Bangladesh
	101	3.443	.992	A (+)	Thomas *et al.* (2025); India
Hyporhamphus unifasciatus	67	3.13	.94	A (+)	Cruz-Sánchez *et al.*(2024); Mexico
Hyporhamphus xanthopterus	40	3.165	.972	A (+)	Roshini and Renjitkumar (2021); Kerala

populations, and a healthy aquatic environment supporting robust fish growth (Muchlisin *et al.,* 2017; Jisr *et al.,* 2018). No significant differences in Kn were found among Seasons 1, 2, and 4. I Increase in temperatures can enhance fish metabolic activity, promoting digestion and growth. In females, *post hoc* analysis showed lower Kn values in season 4 (winter) compared to those in Seasons 1, 2, and 3, indicateing high predator density or limited prey (Anderson and Newmann, 1996; Muchlisin *et al*., 2010). The highest Kn values in females were recorded in Season 3, which could be associated with increased feeding activity or energy accumulation prior to spawning, suggesting that females were in better physiological condition during this period, likely due to the deposition of energy reserves for gonad development which led to increase in weight (Fawole, 2002). The lower Kn values observed in Season 4 may reflect seasonal fluctuations in resource availability, spawning activity, or environmental stressors such as temperature or salinity (Blackwell *et al.,* 2000).

The observed seasonal variations in relative condition factor (Kn) underscore the influence of temporal factors on its distribution, physiology and ecology. Significant decreases in Kn from Season 1 to Season 3, followed by increases from Season 3 to Season 4, may reflect seasonal changes affecting the underlying processes governing Kn. These fluctuations are complex, influenced by physiological factors such as maturity and spawning, where resource transfer to gonads can lead to weight gain, followed by reduction post-spawning (Brown, 1957) as well as seasonal variations and habitat characteristics (Morato *et al.,* 2001). The small effect size implies that while season contributes to variability in Kn, the condition factor is fundamentally derived from fish length and weight, its interpretation is intrinsically linked to all factors affecting the length-weight relationship (Hamid *et al.,* 2015).

To the best of our knowledge, no previous references dealing with sex wise LWR and condition factor for *H. xanthopterus* were available in the Vembanad Lake ecosystem. This species, endemic to the freshwater zones of Vembanad Lake, has been classified as vulnerable, underscoring the importance of such baseline biological data for species specific conservation. The intercept (a) and slope (b) values calculated in the study on LWRs could be of much use as input data in the prediction model for assessing the standing stock biomass and average biomass of *H. xanthopterus*. These parameters also facilitate yield calculations, thereby informing sustainable management strategies. It is suggested that future research should focuson biodiversity, assessment of stock using prediction models, feeding and reproductive biology, trophic ecology, and broodstock development of this vulnerable freshwater halfbeak species.

H. xanthopterus in Vembanad Lake, a vital Ramsar wetland, warrants particular attention given its vulnerable status. This study provides the first detailed account of the length–weight relationship and condition factor of the species from this ecosystem, revealing predominantly isometric growth in males and slightly negative allometric growth in females, with significant seasonal variation linked to ecological factors such as feeding and reproduction. The non-significant interaction between sex and length in ANCOVA indicates homogeneity of growth patterns, while observed fluctuations in condition factor reflect environmental influences on population health. These baseline insights contribute to improved stock assessment frameworks and data repositories. At the same time, the emerging nature of this fishery necessitates precautionary management, including enforcement of a minimum 18 mm mesh size to limit juvenile bycatch, integration of LWR data into global databases such as FishBase/RFishBase, and the initiation of reproductive studies (*e.g.*, GSI) for robust MSY estimation. Given the ecological sensitivity of this Ramsar-designated system, priority must be placed on ecosystem-based conservation strategies to mitigate pressures from habitat alteration, pollution, and fishing, thereby ensuring the long-term sustainability of both the species and the biodiversity of the lake system.

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