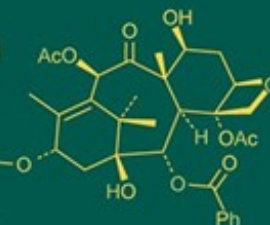
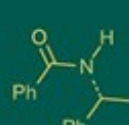
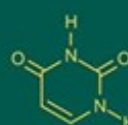


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Length–weight relationship and condition of *Wallago attu* from Pench Reservoir, India

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ABSTRACT

The length–weight relationship and condition of *Wallago attu* were examined using 400 fish sampled from commercial catches in Pench Reservoir, Maharashtra, India, from November to June. Fifty fish were measured each month. Total length ranged from 22.71 to 100.69 cm, and body weight ranged from 56.44 to 5,673.44 g. The pooled relationship was $W = 0.007408L^{2.9043}$, with W in grams and L in centimetres. Length explained 97.98% of the variation in log-transformed weight. The exponent was significantly below 3 (95% confidence interval: 2.8631–2.9454; $p < 0.001$), indicating negative allometry within the sampled length range. Robust and bootstrap confidence intervals supported this result. Mean Fulton's condition factor was 0.5101 ± 0.0844 SD, with monthly means ranging from 0.4839 in February to 0.5268 in January. Neither length-adjusted weight nor the slope of the length–weight relationship differed significantly among sampled months ($p = 0.5626$ and $p = 0.5224$, respectively). These results provide a local reference for the size, mass–length scaling and condition of *W. attu* in sampled commercial catches from Pench Reservoir.

Keywords: Asian sheat catfish, Biometry, Negative allometry, Fulton's condition factor, Monthly variation, Reservoir fishery

1. Introduction

Wallago attu (Bloch & Schneider, 1801), commonly known as the freshwater shark, is a large predatory silurid catfish distributed across South and Southeast Asia (Roberts, 2014) [1]. It is commercially important in Indian freshwater fisheries (Rufus *et al.*, 2015; Kumar *et al.*, 2023) [3, 2]. Inland fisheries contribute to food security and livelihoods, creating a need for reliable biological information on the species represented in local catches (Cooke *et al.*, 2016) [4].

Freshwater fishes face pressures from harvesting and environmental change (Allan *et al.*, 2005) [5]. Regional studies have documented changes in fisheries composition in the Ganges (Montaña *et al.*, 2011) [6], conservation concerns for silurid fishes in the North-East Sundarbans (Patra *et al.*, 2005) [7], and declining fish diversity in the lower Gangetic plains (Parvez *et al.*, 2023) [8]. *Wallago attu* was assessed as Vulnerable on the IUCN Red List in 2019 (Ng *et al.*, 2019) [9]. Local biometric studies provide basic information on the size and condition of this commercially valuable species.

The length–weight relationship (LWR) describes how body mass varies with length. It is widely used to summarize fish biometry and estimate weight from length measurements (Froese, 2006; Froese *et al.*, 2011) [10, 11]. Regression methods provide a quantitative basis for examining this relationship (Ricker, 1973) [12], while the sampled size range and analytical approach influence the resulting estimates (Hayes *et al.*, 1995) [13]. The exponent b describes mass–length scaling: values below, equal to or above 3 correspond to negative allometry, isometry or positive allometry, respectively, with statistical inference based on uncertainty around the estimate.

Published LWRs for *W. attu* differ among water bodies. Rufus *et al.* (2015) [3] reported variation among sampling locations in central Kerala, while Prasad *et al.* (2020) [14] described sex-specific relationships in Bhadar Reservoir. Kumar *et al.* (2023) [2] compared the species across five Indian rivers. These studies provide useful context for evaluating a local relationship in Pench Reservoir, provided that measurement conventions and sampled size ranges are considered.

Condition indices complement LWRs by describing weight relative to length. Fulton's condition factor has a long history in fish biology (Nash *et al.*, 2006) [15], while Le Cren (1951) [16] demonstrated the relevance of reproductive and seasonal variation to fish condition. Because condition indices are influenced by body size and the form of the mass–length relationship, they are most informative when considered alongside the fitted LWR (Bolger *et al.*, 1989; Cone, 1989) [17, 18]. Comparing length-adjusted weight among months provides a complementary assessment of temporal variation.

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This study examined the biometry of *W. attu* sampled from commercial catches in Pench Reservoir, Maharashtra, India. The objectives were to describe the sampled length and weight distributions, estimate the pooled LWR and evaluate allometry, and summarize condition and monthly variation in length-adjusted weight. The results provide a local biometric reference for comparison with other freshwater records of the species.

2. Materials and methods

2.1. Sampling and measurements

The study was conducted at Pench Reservoir, also known as Kamthikhairi Reservoir, in Nagpur district, Maharashtra, India (21.4608° N, 79.1903° E). Located on the Pench River near Parshivni, approximately 54 km north of Nagpur, the reservoir is surrounded by forested hills. It was constructed for irrigation and supplies water to Nagpur and Bhandara districts.

Sampling was conducted weekly from November 2022 to June 2023 at three locations: Pench Dam, Parshivni fish market and Mayo fish market. A total of 400 *Wallago attu* specimens were examined, comprising 50 specimens per month over the eight-month sampling period.

The dataset contained month, total length and body weight. Records were screened for missing values, nonpositive measurements and exact duplicates. Observations with externally studentized residuals exceeding 3 in absolute value were examined and retained because no measurement error was established. Analyses used pooled measurements because sex and maturity were not recorded. Pooled summaries describe the eight equally represented monthly samples.

2.2. Length–weight relationship

The LWR was fitted by ordinary least squares after base-10 logarithmic transformation (Froese, 2006) [10]:

$$\log_{10}W = \log_{10}a + b\log_{10}L + \varepsilon.$$

The coefficient a was obtained by back-transforming the fitted intercept. The exponent b and its 95% confidence interval were used to de-

scribe allometry. Departure from isometry was tested as $t = (b - 3)/SE(b)$, with $n - 2$ degrees of freedom. R^2 refers to the log-transformed model. The back-transformed equation represents the fitted log-scale relationship; no correction for arithmetic mean prediction was applied (Hayes *et al.*, 1995) [13].

Residuals were examined graphically and with the Shapiro–Wilk test. Slope inference was also assessed using HC3 heteroscedasticity-robust standard errors (MacKinnon *et al.*, 1985) [19] and 5,000 paired bootstrap resamples of individual fish, with a percentile confidence interval and random seed 20260925 (Efron, 1979) [20]. Analyses treated individual fish as independent observations; fishing-trip identifiers were unavailable for assessing clustering.

2.3. Condition and monthly comparisons

Fulton's condition factor was calculated as $K_F = 100W/L^3$, with weight in grams and length in centimetres (Nash *et al.*, 2006) [15]. Length, weight and condition were summarized by month and for the pooled sample. Condition was interpreted in relation to the fitted LWR (Bolger *et al.*, 1989; Froese, 2006) [17, 10].

Nested linear models compared log-transformed weight as a function of log-transformed length, length plus month, and length with a month interaction. The month term tested differences in length-adjusted weight; the interaction tested differences in slope. Analyses were performed in R 4.5.2 (R Core Team, 2025) [21], with a significance level of 0.05.

3. Results

3.1. Size and condition

All 400 records contained positive length and weight measurements, with no missing values or exact duplicates. Total length ranged from 22.71 to 100.69 cm (mean $\pm$ SD: 61.50 $\pm$ 22.06 cm), and weight ranged from 56.44 to 5,673.44 g (1,601.56 $\pm$ 1,427.48 g). Monthly summaries are presented in Table 1.

Mean K_F was 0.5101 $\pm$ 0.0844 SD, with a median of 0.5075 and a range of 0.2764–0.7404. The 95% confidence interval for the mean was 0.5018–0.5184. Monthly means ranged from 0.4839 in February to 0.5268 in January (Table 1; Figure 1).

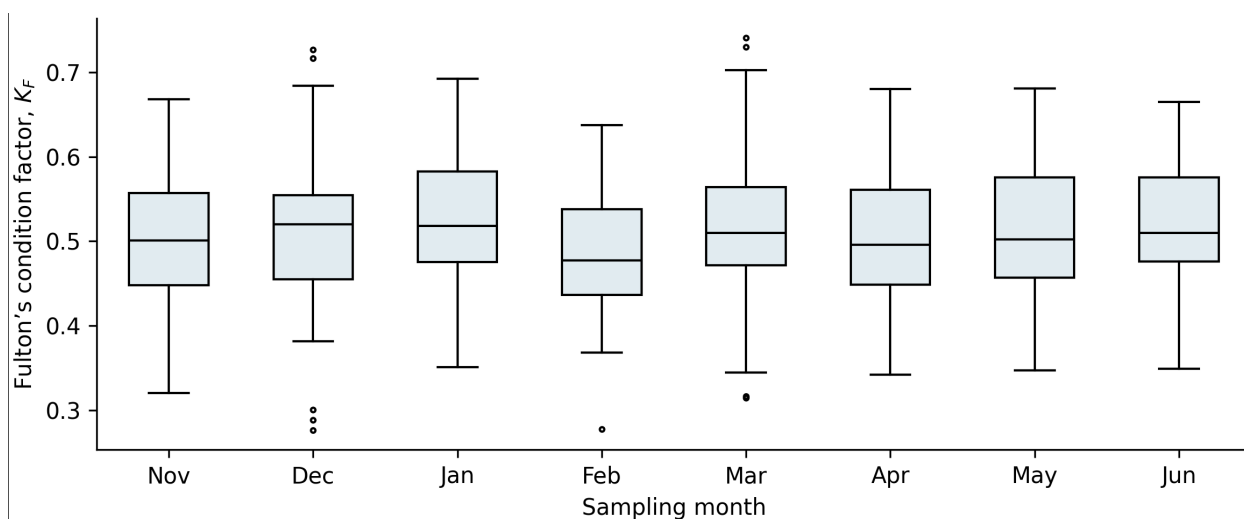


Figure 1. Fulton's condition factor by sampled month ($n = 50$ per month). Boxes show the interquartile range, horizontal lines indicate medians, whiskers extend to observations within 1.5 interquartile ranges, and points indicate observations beyond the whiskers.

3.2. Length–weight relationship

The pooled relationship was $\log_{10}W = -2.130313 + 2.904267 \log_{10}L$, equivalent to $W = 0.007408L^{2.9043}$ (Figure 2). The model explained 97.98% of the variation in log-transformed weight. The slope differed significantly from 3 ($t = -4.5755$, $df = 398$, $p = 0.00000636$),

indicating negative allometry. Its conventional 95% confidence interval was 2.8631–2.9454 (Table 2).

Residuals departed from normality in the Shapiro–Wilk test ($W = 0.9791$, $p = 0.0000155$). Both the HC3 interval (2.8653–2.9432) and the paired-bootstrap interval (2.8646–2.9429) excluded 3. Three observations exceeded the studentized-residual threshold and were retained, as specified in the screening procedure.

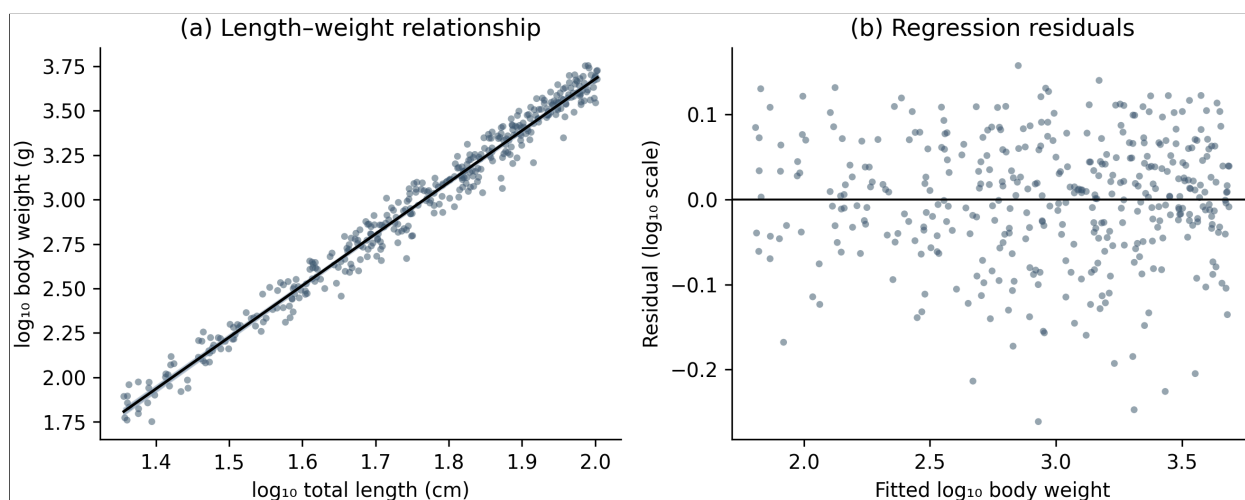


Figure 2. Pooled length–weight relationship of *Wallago attu* ($n = 400$). (a) Base-10 log-transformed observations, fitted regression and 95% confidence band for the fitted mean on the log scale. (b) Residuals against fitted values.

3.3. Monthly comparisons

Adding month to the length-only model did not significantly improve the fit ($F = 0.8302$, $df = 7, 391$; $p = 0.5626$). The log-length $\times$ month interaction was also nonsignificant ($F = 0.8799$, $df = 7, 384$; $p =$

0.5224). Thus, no significant monthly differences in length-adjusted weight or slope were detected during the sampled period.

Table 1. Monthly size and condition summaries for *Wallago attu* from Pench Reservoir.

Month	n	Length range (cm)	Mean weight (g)	K_F , mean $\pm$ SD
Nov	50	22.71–99.72	1,717.88	0.5031 ± 0.0800
Dec	50	22.97–100.45	1,447.34	0.5116 ± 0.0969
Jan	50	24.80–97.81	1,394.33	0.5268 ± 0.0782
Feb	50	24.48–100.64	1,938.37	0.4839 ± 0.0776
Mar	50	22.78–100.09	1,432.87	0.5185 ± 0.0924
Apr	50	22.94–100.69	1,833.78	0.5059 ± 0.0871
May	50	26.10–95.69	1,499.25	0.5103 ± 0.0831
Jun	50	26.22–100.14	1,548.68	0.5206 ± 0.0759
Pooled	400	22.71–100.69	1,601.56	0.5101 ± 0.0844

*All months contain 50 sampled fish. $K_F = 100W/L^3$, with W in grams and L in centimetres.

Table 2. Pooled length–weight regression and sensitivity of slope inference ($n = 400$).

Statistic	Estimate	95% confidence interval
a (g, cm convention)	0.007408	0.006267–0.008756
b	2.904267	2.863134–2.945400
SE(b), conventional	0.020923	—
R^2 , log scale	0.979762	—
Residual standard error, $\log_{10}$ scale	0.072539	—
b, HC3 inference	2.904267	2.865330–2.943204
b, paired bootstrap	2.904267	2.864550–2.942908

*The bootstrap interval is based on 5,000 paired resamples of individual fish. Isometry was tested against $b = 3$.

4. Discussion

4.1. Length–weight scaling and regional comparisons

The pooled exponent of 2.9043 indicates negative allometry in the sampled *W. attu*: body weight increased slightly less than the cube of total length. The departure from 3 was modest but supported by conventional, robust and bootstrap confidence intervals. The strong log-linear relationship provides a concise description of mass–length scaling across the observed size range. This interpretation follows the distinction between the biometric relationship and individual changes through time described by Froese (2006) [10].

The Pench exponent was close to the Gomti River value of 2.92 reported by Kumar *et al.* (2023) [2]. However, their Gomti estimate was statistically compatible with isometry, whereas the Pench confidence interval excluded 3. Their pooled five-river exponent was 3.05, with positive allometry reported for Hooghly and Pampa samples. These comparisons show that similar point estimates may receive different classifications depending on their precision (Table 3).

Rufus *et al.* (2015) [3] reported b values of 2.6647 at Edathua, 2.8784 at Payippad and 3.5335 at Parumala, with a pooled central Kerala estimate of 3.2550. The Pench estimate falls within this regional range. Negative allometry was supported at Edathua, while Payippad was compatible with isometry. Together with the five-river study, these

findings demonstrate variation in the observed LWR of *W. attu* among sampling locations.

The equation should be applied within the observed range of 22.71–100.69 cm using total length in centimetres and weight in grams. Reporting these conventions together with sample size, parameter estimates and confidence intervals facilitates comparison with other

studies (Froese *et al.*, 2011) [11]. Regression interpretation also depends on the purpose of the analysis and the sampling design (Ricker, 1973; Hayes *et al.*, 1995) [12, 13]. The present equation describes the pooled commercial-catch sample and provides a reference for subsequent measurements made using comparable methods.

Table 3. Selected published length–weight exponents for *Wallago attu* and the present estimate.

Water body / sample	b	Inference reported for $b = 3$	Reference
Pench Reservoir, pooled	2.9043	Negative allometry	Present study
Gomti River	2.92	Compatible with isometry	Kumar <i>et al.</i> (2023)
Yamuna River	2.98	Compatible with isometry	Kumar <i>et al.</i> (2023)
Hooghly River	3.64	Positive allometry	Kumar <i>et al.</i> (2023)
Pampa River	3.58	Positive allometry	Kumar <i>et al.</i> (2023)
Five rivers, pooled	3.05	Compatible with isometry	Kumar <i>et al.</i> (2023)
Edathua, central Kerala	2.6647	Negative allometry	Rufus <i>et al.</i> (2015)
Payippad, central Kerala	2.8784	Compatible with isometry	Rufus <i>et al.</i> (2015)
Parumala, central Kerala	3.5335	Positive allometry	Rufus <i>et al.</i> (2015)
Central Kerala, pooled	3.2550	Positive allometry	Rufus <i>et al.</i> (2015)

*Published estimates are provided for descriptive comparison. Compatibility with isometry indicates that the source did not reject $b = 3$.

4.2. Condition and monthly variation

Mean K_F in Pench was 0.5101. For comparison, Rufus *et al.* (2015) [3] reported a pooled central Kerala mean of 0.57 ± 0.12 SD, while Table 2 of Kumar *et al.* (2023) [2] gave river-specific values of 0.43–0.47. These values place the Pench observations in a regional context. Direct comparisons should nevertheless account for the length range and composition of each sample, because condition indices can vary with body size (Bolger *et al.*, 1989; Cone, 1989) [17, 18].

For the fitted relationship $W = aL^b$, Fulton's factor follows $K_F = 100aL^{b-3}$. The Pench exponent therefore implies a fitted length dependence of $L^{-0.0957}$. This explains why condition was interpreted alongside the LWR rather than against a fixed numerical threshold. The approach is consistent with the interpretation of mass–length scaling and condition discussed by Froese (2006) [10].

Although descriptive monthly means differed, the length-adjusted analyses detected no significant month effect or difference in slope. The pooled equation therefore provides a useful summary of the observations from November to June. Le Cren (1951) [16] showed that reproductive changes can contribute to seasonal variation in condition; sex and maturity information would allow such effects to be examined in future sampling. The present monthly comparisons apply to the observed period and sampled catches, rather than a complete annual cycle.

5. Conclusion

Wallago attu sampled from commercial catches in Pench Reservoir exhibited a strong LWR and negative allometry, with $b = 2.9043$. Mean Fulton's condition factor was 0.5101, and no significant differences in length-adjusted weight or slope were detected among the sampled months. The equation and monthly summaries provide a local reference for the biometry and condition of the species over the observed size range.

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