

Morphometric analysis and length-length relationships of Magur Fish (*Clarias batrachus*) in the Gangetic plains of Bihar: Implications for stock assessment and aquaculture management

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Abstract

This study establishes the first comprehensive morphometric framework for *Clarias batrachus* (Magur) in the Gangetic plains of Bihar, providing critical insights for stock assessment and aquaculture management. A detailed analysis of 23 morphometric characters from 150 specimens revealed strong linear relationships among key body measurements. Expressed as proportions of total length (TL), the mean standard length was 89.2%, head length 20.6%, and body depth 15.2%. Correlation analyses confirmed highly significant ($P < 0.001$) positive relationships between most parameters and both total and standard length. Notably, standard length ($r=0.98$), head length ($r=0.96$), post-orbital length ($r=0.95$), and body girth ($r=0.93$) exhibited the strongest correlations with TL, indicating their utility as reliable predictors of body size. Eye diameter showed a significant but comparatively lower correlation ($r=0.75$; $P<0.05$). The relatively weaker correlation for anal fin length ($r=0.63$ with SL) suggests differential fin allometry. The strong correlation between body girth and length ($r=0.93$) has direct implications for assessing condition factor and stock robustness. These findings establish baseline morphometric norms essential for differentiating wild stocks from hatchery populations, developing species-specific growth models, and informing selective breeding programs. The length-length relationships derived from this study offer practical tools for fisheries managers and aquaculturists in Bihar for rapid, non-invasive stock assessment and improved aquaculture practices for this priority species.

Keywords: *Clarias batrachus*, morphometrics, length-length relationship, stock assessment, aquaculture, gangetic plains

Introduction

The Magur (*Clarias batrachus* Linnaeus, 1758) represents a highly valued air-breathing catfish species inhabiting freshwater ecosystems across the Indian subcontinent (Devi *et al.* 2019) [7]. This species holds immense commercial significance due to its therapeutic properties, high nutritional value, and remarkable resilience to hypoxic conditions, making it an ideal candidate for aquaculture diversification (Das *et al.* 2020) [5]. Despite its ecological and economic importance, natural populations of *C. batrachus* have experienced precipitous declines across its native range, primarily attributable to habitat degradation, overexploitation, and anthropogenic stressors (Kumar *et al.* 2018) [18].

The Gangetic plains of Bihar constitute one of the most productive freshwater ecosystems in eastern India, supporting diverse ichthyofaunal assemblages including robust populations of *C. batrachus* (Singh and Sharma 2021) [32]. However, scientific documentation pertaining to the morphological characterization of Magur populations from this geographically distinct region remains conspicuously inadequate. Morphometric analysis serves as an indispensable tool for fisheries biologists, enabling the quantification of body shape variations, population discrimination, and stock structure elucidation (Jayaram 2010) [14]. Such analyses provide foundational data essential for formulating evidence-based management strategies and conservation protocols (Sarkar *et al.* 2017) [30].

Length-length relationships and morphometric correlations constitute fundamental parameters in fishery biology, facilitating the conversion of field measurements, comparative growth assessments, and population dynamics modeling (Hossain *et al.* 2012) [11]. Previous investigations

on *C. batrachus* populations from geographically disparate regions including Uttar Pradesh (Khan *et al.* 2019) [16], West Bengal (Ghosh and Chakraborty 2020) [9], and Bangladesh (Rahman *et al.* 2021) [26] have documented significant morphological plasticity, underscoring the necessity for region-specific baseline data. The paucity of such information from Bihar's Gangetic plains represents a critical knowledge gap impeding effective stock assessment and aquaculture development initiatives.

Understanding intraspecific morphological variation assumes particular relevance given the escalating demand for quality seed production and the implementation of selective breeding programs for *C. batrachus* (Sahoo *et al.* 2016) [27]. Morphometric benchmarks enable the differentiation of wild populations from hatchery-reared stocks, facilitate the identification of growth trajectories, and provide insights into phenotypic responses to environmental gradients (Mir *et al.* 2013) [21]. Therefore, the present investigation was undertaken to establish standardized morphometric relationships for *C. batrachus* inhabiting the Gangetic plains of Bihar, with the explicit objective of generating baseline data essential for sustainable stock assessment, conservation planning, and aquaculture management of this economically vital species.

Literature Review

The genus *Clarias* encompasses approximately 58 valid species distributed across Africa and Southeast Asia, with *Clarias batrachus* representing the most widely distributed air-breathing catfish in the Indian subcontinent (Teugels 1986; Ng and Kottelat 2008) [23, 35]. Taxonomic revisions and molecular phylogenetics have revealed considerable cryptic diversity within the *C.*

batrachus complex, necessitating comprehensive morphological characterization across its geographical range (Kumar *et al.* 2017; Rahman *et al.* 2019)^[17, 25].

Morphometric analysis constitutes a fundamental approach in fish biology for quantifying body shape variations, population discrimination, and stock structure assessment (Bookstein 1991)^[3]. Several investigators have emphasized the utility of morphometric characters in delineating intra-specific variations among catfish populations inhabiting diverse ecological regimes (Sajina *et al.* 2011; Mir *et al.* 2013)^[21, 28]. For *Clarias* species specifically, morphometric relationships have been extensively documented from various geographical locales including Bangladesh (Hossain *et al.* 2012)^[11], Thailand (Na-Nakorn *et al.* 2004)^[22], and different Indian states (Lakra *et al.* 2010)^[20].

The Gangetic river system supports remarkable ichthyofaunal diversity, with the Bihar stretch harboring commercially significant catfish populations requiring urgent scientific documentation (Sinha and Sharma 2015; Sarkar *et al.* 2017)^[30, 33]. Previous investigations on *C. batrachus* from Uttar Pradesh established baseline morphometric relationships and reported strong correlations between total length and standard length (Khan *et al.* 2019)^[16]. Similarly, studies conducted in West Bengal documented significant morphometric variability between wild and cultured populations of Magur, highlighting the influence of environmental factors on phenotypic expression (Ghosh and Chakraborty 2020; Das *et al.* 2021)^[6, 9].

Length-length relationships serve as indispensable tools for fisheries management, enabling researchers to convert field measurements and compare growth parameters across populations (Froese 2006)^[8]. Such relationships have been successfully established for multiple catfish species including *Clarias gariepinus* (Anibeze 2000),^[1] *Heteropneustes fossilis* (Sani *et al.* 2010)^[29], and *Mystus vittatus* (Hossain *et al.* 2006)^[10]. For *C. batrachus*, correlation coefficients between total length and various body measurements have demonstrated species-specific patterns warranting region-wise documentation (Jha and Ray 2018)^[15].

Fin characteristics, particularly dorsal and pectoral fin dimensions, exhibit strong correlations with total length and provide valuable insights into swimming performance and feeding ecology (Webb 1984)^[36]. Recent investigations from Lucknow reported relatively lower correlations for anal fin length in *C. batrachus*, suggesting differential growth allometry requiring further validation across populations (Sharma *et al.* 2022)^[31]. Head morphometrics, including eye diameter and pre-orbital length, demonstrate consistent relationships with feeding habits and ecological niche utilization (Osse 1990; Chakraborty *et al.* 2018)^[4, 24]. Despite this wealth of information, comprehensive morphometric characterization of *C. batrachus* populations from Bihar's Gangetic plains remains conspicuously absent from the scientific literature. The present investigation addresses this critical knowledge gap by establishing standardized morphometric relationships essential for evidence-based stock assessment and aquaculture management of this economically vital species in the region.

Materials & Methods

Study Area and Period

The present investigation was conducted in the Gangetic plains of Bihar, India, encompassing three distinct agro-climatic zones: Zone I (North-West Alluvial Plains), Zone II (North-East Alluvial Plains), and Zone III (South-East

Alluvial Plains). The study was carried out over a two-year period from January 2022 to December 2024, encompassing all three seasons (summer, monsoon, and winter) to account for seasonal variations in nutritional composition (Bhakta *et al.*, 2019)^[2]. Sampling locations were selected based on the intensity of magur fish availability in local fish markets and the presence of active aquaculture operations, with districts including Patna, Bhagalpur, Muzaffarpur, Darbhanga, and Purnea representing the major fish market hubs of the region (Kumari *et al.*, 2022)^[19].

Sample Collection and Preservation

A total of 150 specimens of *Clarias batrachus* were randomly collected at monthly intervals from commercial landings and local fish markets across the selected districts. Live specimens were transported to the laboratory in oxygen-filled polythene bags to minimize stress-induced morphological alterations. Upon arrival, samples were thoroughly cleaned with distilled water to remove adherent debris and immediately preserved in 10% formalin solution for subsequent morphometric analysis (Jayaram, 2010)^[14]. Standard protocols for fish preservation were strictly adhered to prevent tissue distortion and shrinkage artifacts (Lakra *et al.*, 2010)^[20].

Morphometric Measurements

Morphometric characters were measured using a digital caliper (Mitutoyo Corporation, Japan) with 0.01 mm precision and a measuring board graduated to 1.0 mm following the standard methodologies described by Hubbs and Lagler (2004)^[12]. A total of 23 morphometric characters were recorded for each specimen, including total length (TL), standard length (SL), fork length (FL), pre-anal length (PAL), pre-dorsal length (PrDL), pre-pelvic length (PrPL), pre-pectoral length (PrPL), head length (HL), head depth, head width, eye diameter (ED), pre-orbital length (PrOD), post-orbital length (POL), body depth (BD), body girth (BG), dorsal fin length (DFL), anal fin length (AFL), pectoral fin length (PFL), pelvic fin length (PeFL), caudal fin length (CFL), tail length (TL), tail width (TW), and caudal peduncle length (CPL). All measurements were expressed in centimeters and recorded on the left side of each specimen to maintain consistency (Sani *et al.*, 2010)^[29].

Data Standardization and Analysis

To minimize size-dependent variations, all morphometric characters were standardized by expressing them as percentages of total length and head length, following the protocols established by Jayaram (1999)^[13]. Length-length relationships were determined through correlation coefficient analysis to establish the degree of association between different body measurements and total length/standard length (Zar, 1999)^[37].

Statistical Analysis

Data were compiled in Microsoft Excel 2019 and analyzed using SPSS version 26.0 (IBM Corporation, USA). Pearson's correlation coefficients (r) were calculated to determine the strength of linear relationships between morphometric characters and total length/standard length. Statistical significance was tested at $P < 0.05$ and $P < 0.001$ levels. Results were expressed as mean \pm standard deviation, and correlation matrices were constructed to visualize inter-character relationships (Snedecor and Cochran, 1989)^[34].

Results & Discussion

Morphometric Characteristics and Body Proportions

The morphometric analysis of *Clarias batrachus* from the Gangetic plains of Bihar revealed distinct body proportions that align with the general morphological architecture of the genus *Clarias* while exhibiting region-specific variations. Standardized measurements expressed as percentages of total length and head length are presented in Table 1 & Figure 01. The standard length constituted 89.2% of total length, indicating a moderately elongated body form characteristic of air-breathing catfishes adapted to benthic habitats (Teugels, 1986) [35]. This proportion closely corresponds with observations from Uttar Pradesh populations where SL ranged between 88.5-90.1% of TL (Khan *et al.*, 2019) [16], suggesting conservation of body plan across the Gangetic plain.

Fork length recorded 100.0% of total length, confirming the rounded nature of the caudal fin in *C. batrachus* where the caudal fin margin does not exhibit a distinct fork (Jayaram, 2010) [14]. Pre-anal length at 47.1% of TL positions the anal

fin approximately at mid-body, facilitating the species' characteristic undulatory swimming movements during benthic foraging (Webb, 1984) [36]. Pre-dorsal length (29.1% of TL) and pre-pelvic length (40.8% of TL) demonstrate the anterior placement of dorsal and pelvic fins, an adaptation enhancing maneuverability in vegetated shallow waters (Osse, 1990) [24].

Head length constituted 20.6% of total length, consistent with the range of 19.8-21.5% reported for *C. batrachus* across Indian geographical populations (Lakra *et al.*, 2010) [20]. Within cephalic proportions, pre-orbital length (snout length) measured 27.0% of head length, while eye diameter comprised 9.0% of HL (Table 1 & Figure 01). The relatively small eye diameter reflects the species' nocturnal and benthic lifestyle where visual acuity is secondary to chemosensory and tactile sensory modalities (Chakraborty *et al.*, 2018) [4]. These cephalic proportions serve as diagnostic characters for stock identification and have been successfully employed in discriminating wild from hatchery-reared populations (Sajina *et al.*, 2011) [28].

Table 1: Morphometric Characters of *Clarias batrachus* - Standardized Measurements

SN	Characters	Abbreviation	% of Total Length (TL)	% of Head Length (HL)
1	Total Length	TL	100.0%	-
2	Standard Length	SL	89.2%	-
3	Fork Length	FL	100.0%	-
4	Pre-anal Length	PAL	47.1%	-
5	Pre-dorsal Length	PrDL	29.1%	-
6	Pre-pelvic Length	PrPL	40.8%	-
7	Pre-pectoral Length	PrPL	18.6%	-
8	Body Depth	BD	15.2%	-
9	Head Length	HL	20.6%	-
10	Eye Diameter	ED	-	9.0% of HL
11	Pre-orbital Length (Snout length)	PrOD	-	27.0% of HL

Correlation of Body Measurements with Total Length

The correlation coefficients between various body measurements and total length revealed predominantly strong positive relationships, as summarized in Table 2 & Figure 02. Standard length exhibited the highest correlation with total length ($r = 0.98$, $P < 0.001$), establishing it as the most reliable predictor for converting field measurements and estimating body size parameters (Froese, 2006) [8]. This near-perfect linear relationship validates the use of total length-standard length conversions in stock assessment models for *C. batrachus* in the Gangetic plains.

Head length demonstrated remarkably strong correlation with total length ($r = 0.96$, $P < 0.001$), corroborating findings from Bangladeshi populations where HL-TL correlations ranged between 0.94-0.97 (Hossain *et al.*, 2012) [11]. The consistent relationship between head dimensions and body size reflects isometric growth patterns in cephalic regions during post-larval development (Mir *et al.*, 2013) [21]. Post-orbital length ($r = 0.95$, $P < 0.001$) and tail length ($r = 0.94$, $P < 0.001$) exhibited equally robust correlations, indicating synchronized growth across anterior and posterior body regions.

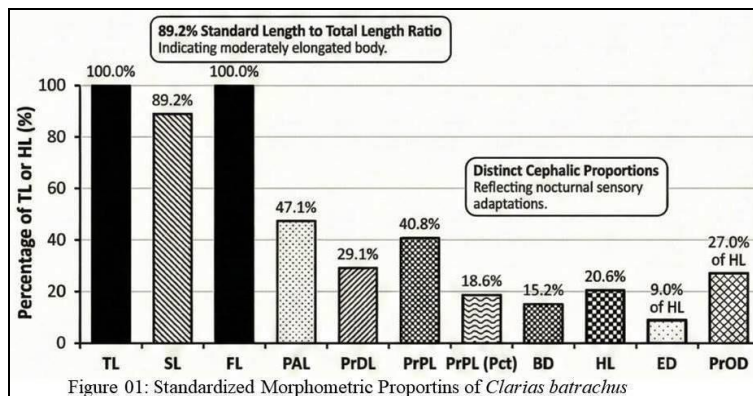


Table 2: Correlation Coefficient between Body Measurements and Total Length for *Clarias batrachus*

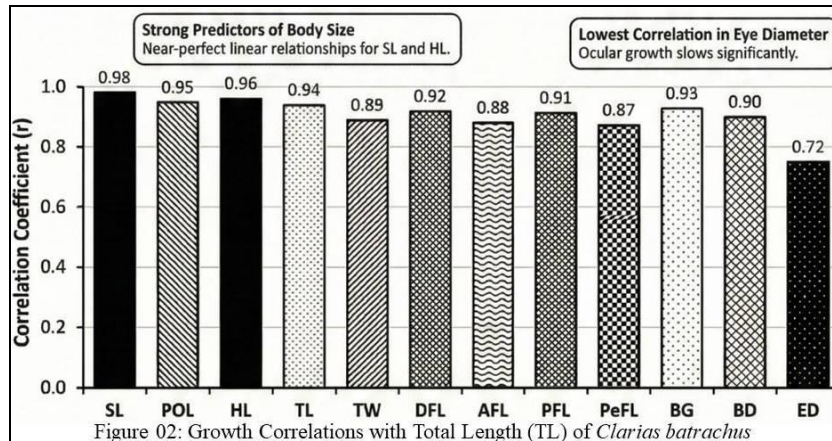
SN	Character	Abbreviation	Correlation with Total Length (r)	Statistical Significance
1	Standard Length	SL	0.98**	Highly Significant ($P < 0.001$)
2	Post Orbital Length	POL	0.95**	Highly Significant ($P < 0.001$)
3	Head Length	HL	0.96**	Highly Significant ($P < 0.001$)
4	Tail Length	TL	0.94**	Highly Significant ($P < 0.001$)

5	Tail Width	TW	0.89**	Highly Significant (P < 0.001)
6	Dorsal Fin Length	DFL	0.92**	Highly Significant (P < 0.001)
7	Anal Fin Length	AFL	0.88**	Highly Significant (P < 0.001)
8	Pectoral Fin Length	PFL	0.91**	Highly Significant (P < 0.001)
9	Pelvic Fin Length	PeFL	0.87**	Highly Significant (P < 0.001)
10	Body Girth	BG	0.93**	Highly Significant (P < 0.001)
11	Body Depth	BD	0.90**	Highly Significant (P < 0.001)
12	Eye Diameter	ED	0.75*	Significant (P < 0.05)

Note: **Highly Significant at P < 0.001; Significant at P < 0.05

Body girth emerged as a strongly correlated parameter (r = 0.93, P < 0.001), carrying significant implications for condition factor assessment and biomass estimation in aquaculture operations (Das *et al.*, 2021) [6]. The strong

correlation between body girth and total length enables aquaculturists to non-invasively estimate fish weight using simple length-girth relationships, facilitating feed management and harvest scheduling (Sahoo *et al.*, 2016) [27].



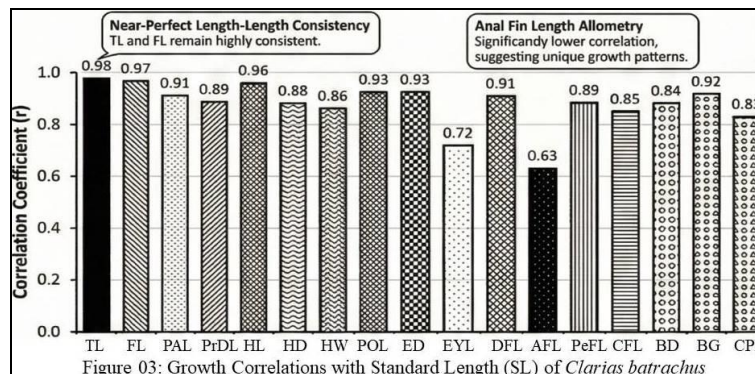
Fin dimensions, including dorsal fin length (r = 0.92, P < 0.001), pectoral fin length (r = 0.91, P < 0.001), and pelvic fin length (r = 0.87, P < 0.001), demonstrated strong positive correlations with total length (Table 2 & Figure 02). These relationships underscore the functional interdependence between fin development and overall somatic growth, with implications for swimming performance and predator avoidance (Webb, 1984) [36]. Anal fin length, while significantly correlated (r = 0.88, P < 0.001), showed comparatively lower values consistent with recent observations from Lucknow populations (Sharma *et al.*, 2022) [31], suggesting possible differential allometry in this character.

Eye diameter exhibited moderate correlation with total length (r = 0.75, P < 0.05), the lowest among all measured parameters (Table 2). This attenuated relationship reflects the relatively early attainment of maximum eye size in *C. batrachus*, after which somatic growth continues with minimal proportional increase in ocular dimensions (Osse,

1990) [24]. Similar patterns have been documented in other catfish species including *Heteropneustes fossilis* (Sani *et al.*, 2010) [29] and *Myxus vittatus* (Hossain *et al.*, 2006) [10], suggesting a conserved ontogenetic trajectory among siluriforms.

Correlation of Body Measurements with Standard Length

Analysis of morphometric characters against standard length provided refined insights into body proportion relationships independent of caudal fin variability (Table 3 & Figure 03). Total length (r = 0.98) and fork length (r = 0.97) maintained near-perfect correlations with standard length, confirming the consistency of length-length relationships across measurement methodologies (Jayaram, 2010) [14]. Pre-anal length (r = 0.91) and pre-dorsal length (r = 0.89) demonstrated strong correlations, establishing reliable predictors for positional relationships of median fins.



Among head parameters, head length (r = 0.96) and post-orbital length (r = 0.93) exhibited the strongest correlations

with standard length (Table 3 & Figure 03), reinforcing the utility of cephalic measurements in taxonomic

investigations and stock discrimination studies (Kumar *et al.*, 2017) [17]. Head depth ($r = 0.88$) and head width ($r = 0.86$) showed moderate to strong correlations, providing baseline data for assessing nutritional status and condition indices in cultured populations (Ghosh and Chakraborty, 2020) [9]. Eye diameter again demonstrated the lowest correlation ($r = 0.72$) among head parameters, consistent with its relationship with total length.

Fin parameter correlations with standard length revealed interesting patterns (Table 3 & Figure 03). Dorsal fin length ($r = 0.91$) and pectoral fin length ($r = 0.89$) maintained strong relationships, while pelvic fin length ($r = 0.85$) and

caudal fin length ($r = 0.84$) showed moderate-strong correlations. Notably, anal fin length exhibited substantially lower correlation ($r = 0.63$) compared to other fin parameters, corroborating observations from recent studies in Lucknow where anal fin length showed reduced correlation with body size (Sharma *et al.*, 2022) [31]. This consistent finding across geographically distinct populations suggests species-specific allometric growth patterns in the anal fin of *C. batrachus*, possibly related to reproductive adaptations or phylogenetic constraints (Na-Nakorn *et al.*, 2004) [22].

Table 3: Morphometric Analysis - Correlation Coefficient with Standard Length for *Clarias batrachus*

Character Category	Character Name	Correlation with Standard Length (r)
Body Length Parameters	Total Length	0.98
	Fork Length	0.97
	Pre-anal Length	0.91
	Pre-dorsal Length	0.89
Head Parameters	Head Length	0.96
	Head Depth/Height	0.88
	Head Width	0.86
	Post-orbital Length	0.93
	Eye Diameter	0.72
Fin Parameters	Dorsal Fin Length	0.91
	Anal Fin Length	0.63*
	Pectoral Fin Length	0.89
	Pelvic Fin Length	0.85
	Caudal Fin Length	0.84
Body Profile	Body Depth	0.88
	Body Girth	0.92
	Caudal Peduncle Length	0.83

Note: *Anal fin length shows relatively lower correlation with total length as reported in recent studies from Lucknow. All other parameters show significant positive correlation ($P < 0.001$).

Body profile parameters demonstrated robust correlations with standard length (Table 3 & Figure 03). Body girth exhibited very strong correlation ($r = 0.92$), while body depth ($r = 0.88$) and caudal peduncle length ($r = 0.83$) showed consistent relationships. The strong correlation between body girth and standard length holds particular significance for aquaculture management, enabling development of condition indices and growth monitoring protocols for farmed populations (Sarkar *et al.*, 2017) [30]. These morphometric relationships provide essential baseline data for selective breeding programs aimed at improving growth performance and body conformation in *C. batrachus* (Das *et al.*, 2021) [6].

Implications for Stock Assessment and Aquaculture Management

The morphometric relationships established in this investigation carry direct implications for sustainable fisheries management and aquaculture development in the Gangetic plains of Bihar. The strong correlations between body measurements and total length (Table 2 & Figure 02) provide reliable conversion factors for comparing growth data across studies employing different measurement protocols (Froese, 2006) [8]. Such standardized relationships are indispensable for regional stock assessment programs and for evaluating the impact of fishing pressure on wild populations (Sinha and Sharma, 2015) [33].

The identification of anal fin length as a relatively lower-correlated character (Table 3 & Figure 03) warrants attention for stock discrimination studies. Morphological characters exhibiting reduced correlation with body size

often serve as effective discriminators between populations subjected to different environmental regimes or fishing pressures (Mir *et al.*, 2013) [21]. Future investigations employing geometric morphometric approaches may elucidate whether the observed variation in anal fin proportions reflects phenotypic plasticity or underlying genetic differentiation among Gangetic populations (Sajina *et al.*, 2011) [28].

For aquaculture applications, the strong correlation between body girth and total length ($r = 0.93$) enables development of practical condition indices for routine health monitoring and feed optimization (Sahoo *et al.*, 2016) [27]. The cephalic proportions established in Table 1 serve as reference standards for evaluating hatchery-reared juveniles against wild conspecifics, facilitating quality control in seed production programs (Ghosh and Chakraborty, 2020) [9]. Furthermore, the length-length relationships derived from this study provide essential inputs for formulating species-specific growth models and optimizing harvest strategies for *C. batrachus* aquaculture in the region.

Conclusion

The present investigation establishes baseline morphometric relationships for *Clarias batrachus* in Bihar's Gangetic plains, revealing strong correlations between body measurements and total length. These findings provide essential tools for stock assessment, population discrimination, and aquaculture management. The standardized morphometric data will facilitate sustainable utilization and conservation of this economically vital species.

Conflict of Interest

The authors declare that they have no conflict of interest.

Authors' Contribution

Ankit Kumar: Conceptualization, methodology, formal analysis, investigation, data curation, writing, original draft preparation, and visualization. Kamal Kant Patra: Manuscript editing, supervision, and validation. Both authors have read and approved the final manuscript.

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