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Body weight prediction models of *Macrognathus pancalus* (Hamilton, 1822) from morphometric traits using principal component analysis

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Abstract

In the present study, an attempt was made to evaluate the body weight of barred spiny eel based on morphologic traits. Ten morphometric characters and five meristic counts were measured for 38 specimens, ranging in standard length from 77.80 to 149.60 mm and 2.02 to 17.89 g in weight. All the data sets were standardised using the z-transformation method. The Kaiser-Meyer-Olkin (KMO) test was performed to measure the sample adequacy level, which was found to be 0.85. The significance of the correlation matrix in all traits was tested with Bartlett's test of sphericity, which was found to be significant (χ^2 = 793.360, df = 105, p<0.01). Four of the fifteen principal components (PCs) explained around 85% of the total variation. The first principal component (PC1) contributed 57.52% of the total variation and was represented by significant positive high-loading factors for pre-dorsal (PDL), pre-anal (PAL), and standard length (SL). The second principal component (PC2) explained 10.90% of the total variation and was represented by significant positive high-loading factors for anal fin rays (AFR) and dorsal fin rays (DFR). The third and fourth principal components explained 9.26 and 7.41% of total variation and showed high loading factors for pectoral fin (PFR), and caudal fin rays (CFR), respectively. The estimated communalities ranged from 0.658 for eye diameter (ED) to 0.978 for pre-dorsal fin length (PDL). The species' body weight was predicted using stepwise multiple regression of interdependent morphometric traits and four extracted PCs. Stepwise multiple regression revealed that a combination of three interdependent variables, such as pre-dorsal length (PDL), body depth (BD) and post-orbital length (POL), to be the best to predict the body weight of species based on the coefficient of determinant value (r^2 = 93). Therefore, the study confirms that the species' body weight is function of the three interdependent variables rather than orthogonal variables.

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Introduction

Mastacembelidae has three genera (*Macrognathus*, *Mastacembelus* and *Sinobdella*) with 93 valid species throughout the world (Eschmeyer and Fong, 2023). In Indian waters, the genus *Macrognathus* is represented by only six valid species, *Macrognathus aculeatus*, *Macrognathus aral*, *Macrognathus guentheri*, *Macrognathus malabaricus*, *Macrognathus morehensis*, and *Macrognathus pancalus* (Jayaram, 2010). *Macrognathus pancalus,* known as barred spiny eel, inhabits slow and shallow waters of rivers, estuaries, and other freshwater habitats (Talwar and Jhingran, 1991). It is a bottom-living species with ecological importance due to its predaceous nature and mainly subsists on aquatic insects, crustaceans, and annelids (Serajuddin and Ali, 2005). In Bihar, the species has huge demand due to its delicious taste, and it fetches very high market prices (US$ 6-7 per kg). It is also gaining importance in ornamental fisheries due to its medium size and bright colouration. However, the species' natural population in the local fish market

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is dwindling due to juvenile overfishing and the implementation of non-scientific fishing gear for their harvesting. *M. pancalus* is considered as a species of Least Concern due to limited evidence of threats, and the exact status of the species population needs to be updated (IUCN, 2023).

Principal component analysis (PCA) is a multivariate statistical technique dealing with the reduction of a set of observable variables and accounts for maximum portion of the variance with minimum number of composite variables. It reduces the dimensionality of data and overcomes the problem of multicollinearity among predictor variables. It represents the number of components based on the total variance in the data. First principal component (PC1), which explains the maximum percentage of variation in the whole data set which is subjected to the allometric size of the fish, whereas the second and third principal components (PC2 and PC3) most often lack correlation to size and are the most informative (Delling *et al.,* 2000). PCA is a tool used to examine the size and shape of an animal's body, offering insights into its evolutionary significance and the complex growth process (Sadak *et al.,* 2006; Salako, 2006). Morphometric traits have been used to predict animal body weight because of the existence of phenotypic associations among them (Topai and Macit, 2004). Morphometric traits are easy and low-cost measurements and are genetically correlated with body weight, therefore they can be used as indirect selection for body weight (Oliveira *et al.,* 2021). Body measures and weight are crucial selection factors for improving animal production, that have a significant impact on farmer profitability (Ajafar *et al.,* 2022; Atta *et al.,* 2024). In aquaculture, precise morphometric analysis and weight estimation are helpful for grading procedures, monitoring the health of animals, finding desirable features for selective breeding, forecasting harvest yields and optimising feeding (Saleh *et al.,* 2024).

In India, information on morphometric traits in spiny eels is very scanty. A reliable method for determining body weight using indirect measurements in spiny eel is lacking. Therefore, the present attempt was made to determine the phenotypic correlation of morphometric traits and to establish regression models from them to predict body weight in spiny eel.

Materials and methods

Study area and collection of sample

The Ganga, India's largest freshwater riverine ecosystem, flows for 480 km through Bihar. It holds significant religious value and provides numerous ecological services including drinking water, irrigation, electricity generation, transportation and fishing. In the present study, thirty-eight fresh specimens of *Macrognathus pancalus* were collected at random between January to December 2022 from the Digha Ghat Patipul (25°40'8.4"N; 85°0'18"E) fish landing sites on the southern bank of the river Ganga in Patna District, Bihar (Fig. 1). Fishes were caught with a drag net *Mahajal* (length 150-200 m, width 4-5 m, codend mesh size 10-20 mm) and a conical trap net locally known as *Khairel jal* (length 7-8 m, mouth width 10 m, codend width 1 m, codend mesh size 5-10 mm). Freshly caught specimens were kept in an ice box and brought to the laboratory where they were cleaned with tap water and drained off using filter papers.

Morphometric data

Ten morphometric measurements and five meristic counts were made on each specimen using standard anatomical reference points (Cakmak and Alp, 2010; Duong *et al.,* 2020). Body traits such as standard length (SL), pre-dorsal length (PDL), pre-anal length (PAL), pre-pectoral length (PPL), body depth (BD), head length (HL), eye diameter (ED), post-orbital length (POL) and caudal peduncle length (CPD) were measured in millimeter (mm) with the help of a digital Vernier calliper (Insize–0/150), whereas each specimen's body weight (BW) was determined using a digital weighing balance (Wensar MAB-220). Meristic counts included the number of rays in dorsal (DFR), pectoral (PFR), caudal (CFR) and anal fins (AFR) which were counted using a digital research microscope (Labomed™ Lx 400). The dorsal spines (DS) were counted with naked eye after being separated using a stainless steel needle (Fig. 2).

Statistical analysis

All the morphometric data were standardised using z-transformation to meet the assumptions of the statistical procedure. Pearson

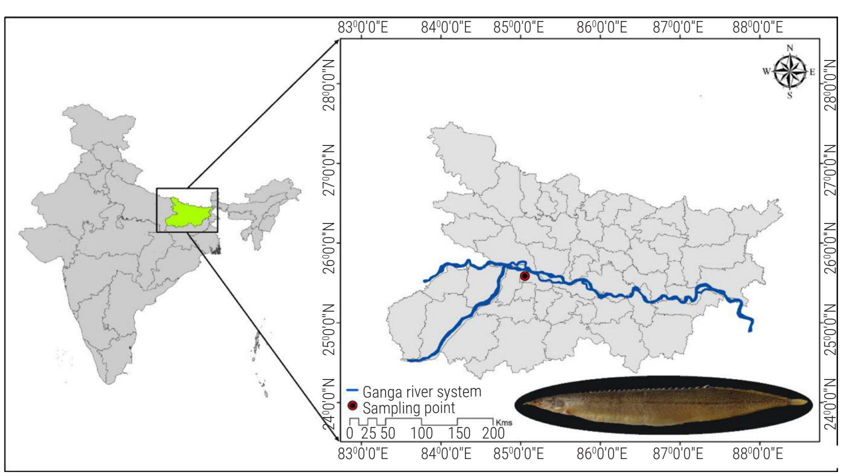

Fig. 1. Map of the study area. Blue line indicates the length of river Ganga along with its tributaries. Red cum black solid dot indicates the location of sampling

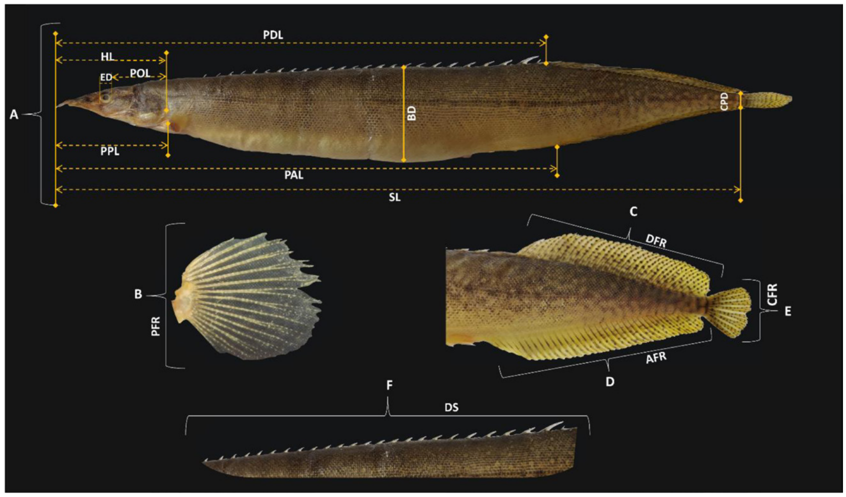

Fig. 2. a: Nine morphological measurements; b: Pectoral fin rays; c: Dorsal fin rays; d: Anal fin rays; e: Caudal fin rays and f: Dorsal spines of *M. pancalus*

correlation among different biometric traits was estimated and data were generated from the correlation matrix used for principal component analysis (PCA). Kaiser Meyer-Olkin (KMO) measures sampling adequacy for each variable and for overall variables. KMO values greater than 0.80 can be considered meritorious, indicating that component or factor analysis will be helpful in these variables (Kaiser, 1970). Bartlett's test of sphericity was performed to check whether the data set could be factored (Bartlett, 1951). Eigenvalues greater than one are considered for the extraction of the components. Varimax rotation method was employed in the rotation of the factor matrix to enhance the interpretability of the factor analysis. To predict the body weight of barred spiny eel based on morphometric traits and their principal components, a stepwise multiple regression procedure was carried out using the general linear model. The following model was used: $Y = a + b_1X_1 + b_2X_2 + b_3X_{3......}\ b_nX_n + e$, where *Y* is the body weight, *a* is the intercept, *b* is the regression coefficient, *X* is the morphometric trait, or principal component and *e* is the random error. The goodness of fit of the regression model was determined using a coefficient of determinant R^2. All the data analysis was performed using the SPSS statistical software (2001).

Results

Table 1 shows the descriptive statistics of various morphometric traits where the coefficients of variation were found to be the lowest for the dorsal spine (4.01%) and the maximum for body weight (41.28%). Table 2 shows the phenotypic correlation analysis where the estimated correlation coefficients ranged from -0.006 (PPL and CFR) to 0.993 (SL and PDL) among the various traits. A total of 120 correlations were established, where 53 correlations (BW with SL, PDL, PAL, PPL, BD, HL ED, POL, CPD, DFR; SL with PDL, PAL, PPL, BD, HL ED, POL, CPD, DFR; PDL with PAL, PPL, BD, HL ED, POL, CPD, DFR; PAL with PPL, BD, HL ED, POL, CPD, DFR; PPL with BD, HL ED, POL, CPD; BD with HL, ED, POL, CPD, DFR; HL with ED, POL, CPD; ED with POL, CPD; POL with CPD, DFR; CPD with DFR; and DFR with AFR) were statistically significant positive ($p<0.05$, $p<0.01$), while 16 correlations were non-significant negative (SL with CFR, PFR; PDL with CFR, PFR; PAL with CFR; PPL with CFR, AFR; BD with DS, AFR; HL with CFR, AFR; ED with CFR, AFR; POL with CFR and DS with CFR, PFR). An exploratory factor analysis was performed using PCA for fifteen morphological traits and the KMO measure of sample adequacy estimated was 0.848. Significance of the correlation matrix was tested with Bartlett's test of sphericity (χ^2 = 793.360, df = 105, $p<0.01$) for all traits, which was found to be significant. Varimax rotation with Kaiser normalisation was used for rotation of principal components. Eigenvalue of the total variance and rotated components in barred spiny eel fish are presented in Table 3.

Out of fifteen principal components (PCs), four PCs were extracted based on Kaiser criterion and the components having eigenvalues greater than 1 were only retained (Table 3). The scree plots also showed that the extracted four components had eigenvalues up to bent elbow (Fig. 3).

Table 1. Descriptive statistics of various morphometric traits of *M. pancalus* (*n* = 38)

Traits	Minimum	Maximum	Mean ± SE	SD	CV (%)
Morphological					
BW	2.02	17.89	8.43 ± 0.56	3.48	41.28
SL	77.80	149.60	115.89 ± 2.44	15.06	13.00
PDL	55.30	107.70	83.12 ± 1.78	10.97	13.20
PAL	53.20	100.60	79.22 ± 1.64	10.10	12.74
PPL	15.90	28.20	23.68 ± 0.45	2.76	11.66
BD	8.70	19.80	15.73 ± 0.44	2.74	17.39
HL	15.70	27.30	22.85 ± 0.42	2.56	11.22
ED	1.60	2.80	2.25 ± 0.04	0.25	11.27
POL	7.10	12.80	10.84 ± 0.21	1.27	11.74
CPD	1.70	3.50	2.63 ± 0.07	0.44	16.73
Meristic					
DS	23.00	27.00	24.68 ± 0.16	0.99	4.01
DFR	32.00	39.00	35.13 ± 0.27	1.65	4.69
CFR	11.00	15.00	12.84 ± 0.13	0.79	6.15
PFR	14.00	19.00	17.00 ± 0.18	1.14	6.70
AFR	34.00	41.00	38.05 ± 0.28	1.71	4.49

SE: Standard error; SD: standard deviation; CV: Coefficient of variation

Table 2. Correlation coefficients among body weight and various morphometric traits of *M. pancalus*

	BW	SL	PDL	PAL	PPL	BD	HL	ED	POL	CPD	DS	DFR	CFR	PFR	AFR
BW	1														
SL	0.939**	1													
PDL	0.947**	0.993**	1												
PAL	0.927**	0.989**	0.990**	1											
PPL	0.833**	0.888**	0.894**	0.901**	1										
BD	0.920**	0.904**	0.905**	0.900**	0.839**	1									
HL	0.854**	0.924**	0.924**	0.931**	0.979**	0.847**	1								
ED	0.448**	0.579**	0.565**	0.601**	0.534**	0.425**	0.624**	1							
POL	0.826**	0.917**	0.915**	0.926**	0.885**	0.836**	0.929**	0.625**	1						
CPD	0.832**	0.823**	0.836**	0.821**	0.757**	0.806**	0.786**	0.436**	0.777**	1					
DS	0.108	0.093	0.135	0.104	0.019	-0.043	0.01	0.029	0.034	0.137	1				
DFR	0.401*	0.451**	0.408*	0.413**	0.219	0.331*	0.279	0.211	0.334*	0.463**	0.193	1			
CFR	0.117	-0.013	-0.003	-0.013	-0.006	0.119	-0.048	-0.259	-0.081	0.078	-0.170	0.059	1		
PFR	0.014	-0.021	-0.014	0.015	0.011	0.095	0.023	0.028	0.115	0.135	-0.239	0.187	0.061	1	
AFR	0.040	0.106	0.068	0.083	-0.094	-0.01	-0.05	-0.067	0.026	0.041	0.187	0.517**	0.007	0.139	1

* $p<0.05$; ** $p<0.01$

Table 3. Total variance explained by different components in the principal component analysis

Components	Initial eigen value			Extraction sums of squared loadings			Rotation sums of squared loadings		
	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %	Total	% of variance	Cumulative %
1	8.627	57.515	57.515	8.627	57.515	57.515	8.470	56.469	56.469
2	1.635	10.899	68.414	1.635	10.899	68.414	1.743	11.618	68.087
3	1.388	9.256	77.670	1.388	9.256	77.670	1.275	8.499	76.586
4	1.111	7.409	85.080	1.111	7.409	85.080	1.274	8.494	85.080
5	0.653	4.352	89.432						
6	0.525	3.503	92.935						
7	0.416	2.777	95.712						
8	0.213	1.423	97.135						
9	0.194	1.291	98.426						
10	0.100	0.669	99.095						
11	0.074	0.492	99.587						
12	0.042	0.278	99.865						
13	0.010	0.066	99.931						
14	0.007	0.048	99.979						
15	0.003	0.021	100.000						

The extracted four components explained a cumulative percentage of variance of 85.08%. Component matrix and rotated component matrix (with cut-off value, 0.50) of different morphometric traits are presented in Table 4. The extracted first principal component contributed 57.52% of total variation and was represented by significant positive high loading factors for pre-dorsal (PDL), pre-anal (PAL), and standard length (SL). The second principal component explained 10.90% of total variation and was represented by significant positive high loading factors for anal fin rays (AFR) and dorsal fin rays (DFR). Third principal component explained 9.26% of the total variation and was represented by a significant positive high loading factor for pectoral fin rays (PFR). Communalities represent the total variance an original variable shares with all other variables in the analysis across all components. In the present study, it ranged from 0.658 for eye diameter (ED) to 0.978 for pre-dorsal fin length (PDL). High communalities of each trait (>0.60) indicated maximum variability of traits in morphometric evaluation of barred spiny eel (Fig. 4).

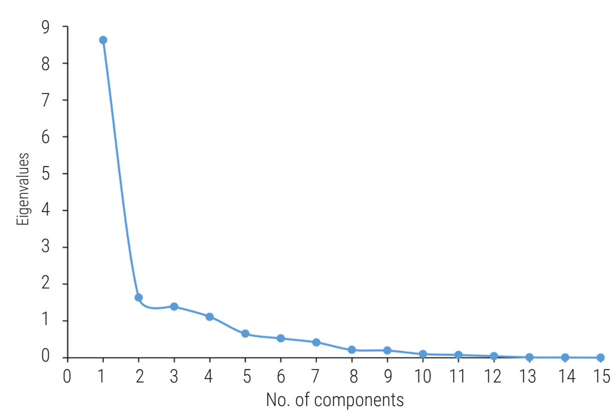

Fig. 3. Scree plot showing principal component number with eigenvalues

Table 4. Component and rotated component matrix (cut-off value, 0.50) of different morphological traits

	Component matric No. of components					Rotated component matric No. of components			
Traits	1	2	3	4	Traits	1	2	3	4
PAL	0.986	-	-0.036	0.021	PDL	0.976*	0.128	-0.083	0.050
SL	0.985	0.034	-0.041	0.046	PAL	0.974*	0.132	-0.039	0.081
PDL	0.985	-	-0.050	0.072	SL	0.971*	0.156	-0.060	0.062
HL	0.955	-0.169	-0.013	-0.049	HL	0.960*	-0.039	0.029	0.138
POL	0.942	-0.071	-	-0.135	BW	0.943*	0.123	-0.064	-0.111
BW	0.939	0.025	0.066	0.180	PPL	0.940*	-0.091	-	0.069
PPL	0.924	-0.209	0.014	0.021	BD	0.933*	0.040	0.084	-0.120
BD	0.919	-0.059	0.189	0.100	POL	0.930*	0.065	0.086	0.185
CPD	0.870	0.107	0.084	0.069	CPD	0.857*	0.205	0.018	-0.053
ED	0.614	-0.172	-0.258	-0.430	ED	0.583*	-0.035	0.085	0.117
AFR	0.054	0.855	-0.041	-0.080	AFR	-0.055	0.859*	-	-0.011
DFR	0.433	0.750	0.0310	-0.064	DFR	0.337	0.800*	0.040	-0.028
DS	0.087	0.370	-0.688	0.304	PFR	0.011	0.303	0.826*	0.051
CFR	-	0.104	0.668	0.624	DS	0.028	0.374	-0.735	0.172
PFR	0.055	0.263	0.588	-0.599	CFR	0.066	-	0.109	-0.911

*Values are above cut-off value 0.50

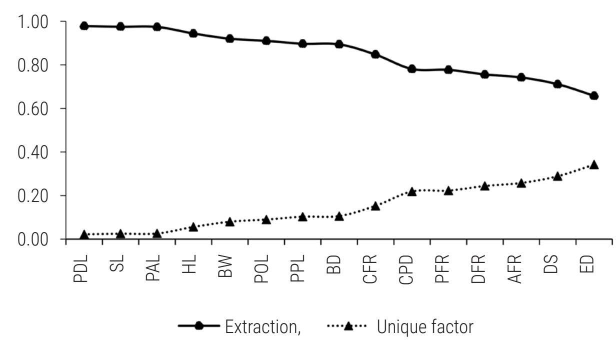

Fig. 4. Communalities and unique factor of various morphometric traits of *M. pancalus*

Table 5. Prediction models to predict the body weight of barred spiny eel based on different interdependent morphometrics

Prediction equation	SE	F	P	R^2	DW
BW = 0.01 + 0.947 PDL	0.32	313.87	0.000	0.897	
BW = 0.01 + 0.631 PDL + 0.350 BD	0.29	199.16	0.000	0.919	
BW = 0.01 + 0.868 PDL + 0.361 BD – 0.271 POL	0.27	153.22	0.000	0.931	1.649
BW = 0.01 + 0.943 PC1	0.34	286.34	0.000	0.889	
BW = 0.01 + 0.943 PC1 + 0.123 PC2	0.32	163.61	0.000	0.903	
BW = 0.01 + 0.943 PC1 + 0.123 PC2 – 0.111PC4	0.30	122.93	0.000	0.916	1.765

SE: standard error; DW: Durbin Watson test

The body weight of the barred spiny eel was predicted from interdependent morphometric traits and their principal components (Table 5). It is observed that three variables *viz,* pre-dorsal length (PDL), body depth (BD) and post-orbital length (POL), are found to be the best predictors of the body weight of the species. Pre-dorsal length accounts for 89.7% of the variation in body weight, combinations of PDL and BD account for 91.9% of the variation in body weight; and combinations of PDL, BD and POL account for 93.1% of the variation in body weight. This result is also evident from highly significant correlation of body weight with PDL (r = 0.947, p<0.01), body depth (r = 0.920, p<0.01) and post-orbital length (r = 0.826, p<0.01), respectively. Prediction of fish body weight from PC1 explained 88.9%, the combination of PC1 and PC2 explained 90.3%, whereas the combination of PC1, PC2 and PC4 explained only 91.6% of variation in the body weight of fish. Hence, it is observed that the combination of pre-dorsal length, body depth and post-orbital length is the best prediction model to predict the body weight of barred spiny eel.

Discussion

In the present study, the maximum size of the barred spiny eel was 14.96 cm and weight was 17.89 g. Body shape of *M. pancalus* is elongated, lateroventrally compressed, tapering towards both ends. Body weight has a maximum coefficient of variation (41.28%), followed by body depth (17.39%) and caudal peduncle depth (16.73%). For the rest of the traits, it was within 11 to 13%. All the meristic counts exhibit an extremely narrow range of coefficients of variation, from 4.01 to 6.70%. It indicates that countable structures are constant within the size range of the specimens. Morphologically, dorsal spines are sharply pointed, originate above the middle of the pectoral fin and are distributed up to the dorsal fin's base. Three spines precede the anal fin; the second is the largest and the last is small and hidden beneath the skin. The caudal fin is almost rounded and distinctly separated from the dorsal and anal fins. The number of dorsal spines and rays in the dorsal, pectoral and anal fins are quite similar to earlier observations, except for caudal fin rays (Hamilton, 1822; Day, 1876; Datta and Srivastava, 1988; Nath and Dey, 2000; Patra and Datta, 2013; Mahfuj *et al.*, 2019). Our estimates show that the number of rays in the caudal fin varied from 11 to 15, while earlier authors reported ranges from 10 to 12. Two possible explanations for these discrepancies are the species' body weight variance, which ranged from 2.02 to 17.89.

Correlation coefficients among the body weight and different morphometric traits of the species revealed that the majority of these traits had a significant correlation. Body weight had higher significant correlations with pre-dorsal length (BW and PDL, 0.947), standard length (BW and SL, 0.939) and pre-anal length (BW and PAL, 0.927), while the lowest phenotypic correlation with pectoral fin rays (BW and PFR, 0.014). Luxinger *et al.* (2018) observed that body weight has the highest significant correlation with body depth (0.93), caudal perimeter (0.89), and standard length (0.88) in *Arapaima gigas*, while Fazazi *et al.* (2019) observed that body weight has the highest correlation with standard length (0.91), pre-anal length (0.90) and pre-dorsal length (0.88) in African catfish. High phenotypic correlations between body weight and other body measurements clearly reveals that these variables or their combination can be used as an effective predictor of body weight of spiny eel.

In the present study, the Kaiser-Meyer-Olkin (KMO) measure of sample adequacy estimated was 0.848, which is much better than the acceptable value of 0.50 for sample adequacy (Kaiser, 1974). Bartlett's test of sphericity was employed to assess the correlation matrix's significance, and it was found significant for all morphological traits. It suggests that the correlation matrix is not an identity matrix and provides sufficient support for the data factor analysis's validity. Therefore, the Varimax rotation method was employed to maximise high and low-value factor loadings simply for better inspection and interpretation of the data. Four of fifteen principal components (PCs) were extracted based on the Kaiser criterion and the components had eigenvalues greater than 1. First principal component (PC1) explained 57.52% of the total variation and had significantly high loading factors for pre-dorsal (0.976), pre-anal (0.974), and standard length (0.971). On the other hand, the second component (PC2), which comprised 10.90% of the total variation, had a significantly higher loading factor for anal fin rays (0.859) and dorsal fin rays (0.800). However, the third component retained significantly high loading factor for pectoral fin rays (0.826) with 9.27% of the total variation. PC1, which shares the maximum percentage of the total variation, represents the allometric size factors, whereas PC2 and PC3 most often lack correlation with size and are taxonomically more informative. The current findings are consistent with earlier observations made on *Salmo marmoratus* and *Salmo trutta*, where they also revealed that PC1 contributed the largest portion of the total variation and was characterised by a high loading value for body size, while fin measurements were highly loaded on PC2 and PC3, explaining most of the variation not related to size (Delling *et al.,* 2000). Another observation on *Oreochromis niloticus* and *Lates niloticus* also reveals that PC1 shares the highest proportion of the total variation (75.23%), with high loading factors for total length (0.917), standard length (0.895) and body weight (0.669). At the same time, the second and third PC had high loading factors for the dorsal (0.944) and caudal fin (0.819), respectively (Yakubu and Okunsebor, 2011). Based on the result and their comparison with earlier reports., it was found that most morphological traits are highly correlated with body size, which appeared to reflect in the first PC, while fins appeared independently in the remaining components of PCA.

Further, the species' body weight was predicted using interdependent morphometric traits and four extracted components of PCA. In this study, the combination of pre-dorsal length (PDL), body depth (BD), and post-orbital length (POL) was found to be the best predictors of body weight of species based on the coefficient of determinant value (r^2 = 93). However, use of different morphological traits to predict body weight should be considered carefully due to multicollinearity, which has been associated with unstable regression estimates (Ogah, 2010). A combination of different principal components (such as PC1, PC2 and so on) would provide a better estimator for predicting body weight rather than individual morphometric traits (Valsalan *et al.,* 2020) because PCA was able to break the multicollinearity among the interdependent morphometric traits. However, no studies are available to determine the body weight of spiny eel using principal component analysis. Hence, the findings of this study will serve as the first benchmark to determine the body weight of *M. pancalus* based on the principal component analysis of body measures.

All the morphological traits correlate significantly and positively with the body weight, while meristic counts do not correlate with dorsal fin rays. Meristic counts also have a narrow range of coefficients of variation within the size range of the species. The Kaiser-Meyer-Olkin (KMO) measure of sample adequacy estimated was found to be very good (>0.80). Based on the eigenvalue (>1), four components were extracted, of which the first principal component shares the maximum amount of total variation with significant high loading factors for PDL, PAL, and SL. Communalities of all the morphological traits were found satisfactory and were above 0.60. Body weight prediction models were developed through stepwise regression of morphological traits and the four components of the PCA. Of the fifteen traits, PDL, BD and POL are the best predictor variables to predict the species' body weight based on the coefficient of determinant value (r^2 = 93). Our findings are based on a limited sample size. Hence, for greater accuracy of the results, further studies are needed with a large data set.

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