Acta Ichthyologica et Piscatoria 54, 2024, 27–36 | DOI 10.3897/aiep.54.114014

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Relations between morphological traits and body weight of shortbelly eel, *Dysomma anguillare* (Actinopterygii: Anguilliformes: Synaphobranchidae), from coastal waters of Zhoushan, East China Sea, determined by multivariate analyses

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https://zoobank.org/14728E68-E38F-4B9A-BD32-DABBAD698B52

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Academic editor: Sanja Matić-Skoko ♦ **Received** 11 October 2023 ♦ **Accepted** 5 December 2023 ♦ **Published** 31 January 2024

Citation: Zhu Z, Yang T, Wang S (2024) Relations between morphological traits and body weight of shortbelly eel, *Dysomma anguillare* (Actinopterygii: Anguilliformes: Synaphobranchidae), from coastal waters of Zhoushan, East China Sea, determined by multivariate analyses. Acta Ichthyologica et Piscatoria 54: 27–36. https://doi.org/10.3897/aiep.54.114014

Abstract

The shortbelly eel, *Dysomma anguillare* Barnard, 1923, is an essential component in the food chain of the marine ecosystem and plays an important role in nearshore fisheries and biodiversity in the East China Sea. In order to provide theoretical support for fishery resource assessment and sustainable utilization of *D. anguillare*, an important bycatch in the offshore area of China, the relations between morphological traits and body weight were investigated based on the measurement of 28 metric traits for the first time. The correlation analysis showed that 25 morphological traits were significantly ($P < 0.05$) correlated with the logarithm of body weight ($\lg X_0$), in which the correlation coefficient of the total length (X_1) was the largest with the extremely high significance ($P < 0.01$). The optimum multiple regression equation of morphological traits was constructed after deleting redundant independent variables: $\lg X_0 = 0.367 + 0.003X_1 + 0.010X_7 - 0.010X_8 + 0.011X_{10} + 0.042X_{14} + 0.006X_{15} + 0.024X_{19} - 0.004X_{23}$. The total length ($X_1$) had the highest positive direct relation with $\lg X_0$ (0.699), which was in accordance with the results of determinate coefficient analysis, while the indirect effect of body height (X_7) through lower jaw length (X_{19}) to $\lg X_0$ was the greatest. The gray correlation analysis indicated that body length (X_2) and distance from snout to dorsal fin origin (X_{22}) were the most closely related to body weight. The comprehensive comparison showed that X_1, X_2, and X_{22} should be used as the ideal morphometric traits for measuring the body weight of *D. anguillare*, and the conclusions obtained from this study will provide valuable references for fishery resource management of this commercial fish species.

Keywords

body weight, *Dysomma anguillare*, gray relational analysis, morphological traits, path analysis

Introduction

The shortbelly eel, *Dysomma anguillare* Barnard, 1923, belonging to the order Anguilliformes and family Synaphobranchidae, is a demersal fish species that is widely distributed in the tropical Indian and western Pacific oceans (Nelson et al. 2016). In China, *D. anguillare* mainly inhabits the nearshore waters and estuaries of the South China Sea and the southern East China Sea (Chen and Zhang 2015). As one of the few widespread species of the genus *Dysomma*, it is also an important bycatch during bottom trawling off the southeastern coasts of China (Zhang 2010). Gradual research progress on ecology, population structure, and molecular genetics of this fish species has been made in recent years (Zhang and Tang 2003; Du et al. 2018; Wang et al. 2019; Yang et al. 2022), but fundamental information on fishery resources biology is still very limited. Ascertaining the biological and genetic backgrounds of target species is the prerequisite and basis for scientific fishery management and biodiversity conservation (Gulland and Carroz 1969).

Body weight is an essential trait for growth and a direct reflection of production performance, which is correlated with various morphological traits. By analyzing the relations between the morphological traits and body weight of economic fishes, ichthyologists can provide reliable suggestions for population resource assessment and the optimum catchable size (William 2011). However, body weight is susceptible to genetic variation, pleiotropy, and the complicated changing environment, and it is inconvenient and imprecise to determine their body weight while fish are still alive. Therefore, the measured values available from other morphological traits are needed to acquire the body weight indirectly.

Recently, published studies have already demonstrated that the correlations between morphological traits and body weight can be clarified by multivariate analysis in many aquatic animals, such as fishes (He et al. 2017; Uiuiu et al. 2017; Yang et al. 2020), crustaceans (Ma et al. 2013; Jiang et al. 2017; Zou et al. 2017), cephalopods (Chen et al. 2012), gastropods (Zhao et al. 2014), and bivalves (Zhang et al. 2018; Guo et al. 2021). Until now, however, there have been no reports on the morphology of *D. anguillare.* Existing research results of the trophic niche and population dynamics of *D. anguillare* have shown a sign of resource decline in the East China Sea since 2018 (Du et al. 2018; Yang et al. 2022), which might be related to the long-term fishing pressure, as well as climate change. In practice, understanding the correlation between morphological traits and body weight of fishery species contributes to formulating mesh size and minimum landing allowable catch size, and then helps to maintain the proper population size to achieve sustainable utilization of the fishery resources. Thus, in this study, correlation analysis, regression analysis, path analysis, determination analysis, and gray correlation analysis were comprehensively applied to characterize the morphological traits and ascertain their effects on the body weight of *D. anguillare*. The main purpose of this study was to fill the gaps of basic biological data on *D. anguillare* and to better understand the dominant shape traits that influence body weight, to lay a foundation for sustainable exploitation and utilization of commercial eels in the future.

Materials and methods

A total of 85 specimens of *Dysomma anguillare* were collected by trawling in the coastal waters of the Zhoushan Archipelago, East China Sea in October 2022. Frozen fish individuals were transported to the Fishery Ecology and Biodiversity Laboratory (FEBL) of the Zhejiang Ocean University of China for further analysis. The body weight (X_0), was obtained by an electronic balance to the nearest 0.01 g, and the measurable characters were determined by a digital vernier caliper and a ruler with the accuracies of 0.01 mm and 1 mm, respectively. Twenty-seven measurable parameters are depicted in Fig. 1.

Microsoft Excel 2019 was used for calculating the path coefficients and determination coefficients. Multivariate analyses such as correlation analysis, regression analysis, and path analysis are conducted to reveal the direct and indirect effects of morphological traits on body weight by using SPSS 26.0 software (Field 2005).

Kolmogorov–Smirnov test (K–S test) and Shapiro–Wilk test (S–W test) are two commonly used normal test methods, and are suitable for statistical analysis with large samples ($n > 50$) and small samples ($n \leq 50$), respectively (Shapiro and Wilk 1965; Tikhomirov 1993). The P-value lower than the significance level of 0.05 implies the null hypothesis is rejected and it is assumed that the data is non-normally distributed (Tong 1990). Only data meeting the normal distribution can be used for the subsequent correlation analysis and regression analysis, and conversion can be applied if the raw data cannot satisfy the condition.

Correlation analysis can be performed through the software SPSS 26.0 after confirming the normal distribution of the data. It can be distinguished whether the two morphological traits are related to the analysis of the significance level (Singh and Chaudhary 1979). The two morphological traits are related or extremely related if the significance is at 0.05 level ($P < 0.05$) or at 0.01 level ($P < 0.01$), respectively. Otherwise, they have no relation ($P > 0.05$).

The aim of multiple regression analysis is to find out the linear relation between body weight and the related morphological traits. After removing the morphological traits unrelated to the body weight based on correlation analysis, the effects of morphological traits on the body weight are studied by stepwise multiple regression analysis (Wittink and Heights 1988). The significance test (T-test) is performed on the partial regression coefficient (B), or non-standardized regression coefficient for each independent variable to verify the validity of the established regression equation. Furthermore, the F-test is used to check the significance of the multiple regression equation.

The path analysis reflects the effects of the independent variables on the dependent variable, and it can be divided into parts: the direct effects of each trait on body weight and the indirect effects of each trait on body weight through other traits (Sheng and Wu 1999). These two effects can be assessed by the direct and indirect path coefficients, respectively. The direct path coefficient, also named the path coefficient, is the same as the standardized regression coefficient obtained directly from multiple regression analysis. And the indirect path coefficient ($P_{X_iX_j}$) can be calculated from the formula [1] below.

$$P_{X_iX_j} = r_{X_iX_j} \times P_{X_j} \quad [1]$$

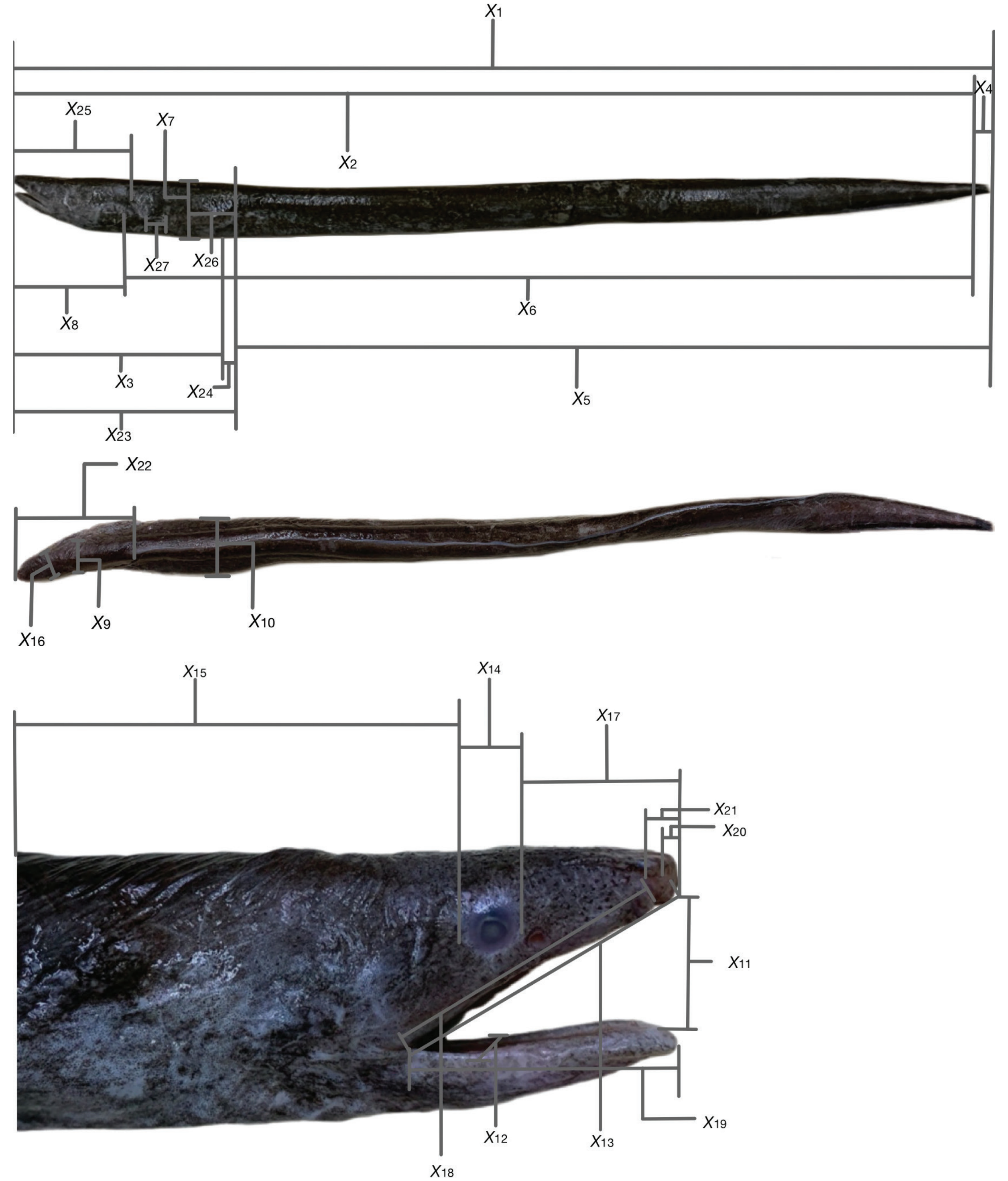

Figure 1. Diagrams of morphometric measurements of *Dysomma anguillare.* (**A**) Lateral view (**B**) Dorsal view (**C**) Head view. Abbreviations: X_1 = total length, X_2 = body length, X_3 = anal length, X_4 = tail length, X_5 = postanal length, X_6 = trunk length, X_7 = body height, X_8 = head length, X_9 = head breadth, X_{10} = body width, X_{11} = oral fissure height, X_{12} = oral fissure width, X_{13} = oral fissure length, X_{14} = eye diameter, X_{15} = head length after eye, X_{16} = interocular distance, X_{17} = snout length, X_{18} = upper jaw length, X_{19} = lower jaw length, X_{20} = distance from snout to anterior nostril, X_{21} = distance from snout to posterior nostril, X_{22} = distance from snout to dorsal fin origin, X_{23} = distance from snout to anal fin origin, X_{24} = distance from the anal fin origin to the anus, X_{25} = distance from the first aperture of lateral line to snout, X_{26} = distance from dorsal fin origin to anal fin origin, X_{27} = pectoral fin length.

The coefficient of determination (CD) is a measure of how well a linear regression model fits the data and is calculated as the square of the correlation between the dependent variable and the predicted values from the regression model (Nagelkerke 1991). The determination coefficient (d_{X_i}) shows the direct effects that the independent variables have on the dependent variables, while the co-determination coefficient ($d_{X_iX_j}$) shows the indirect effects accordingly. The determination coefficient and co-determination coefficient are concluded from the following formulas [2] and [3], respectively (Wright 1921).

$$d_{X_i} = P_{X_i}^2 \qquad [2]$$

$$d_{X_iX_j} = 2 \times r_{X_iX_j} \times P_{X_i} \times P_{X_j} \qquad [3]$$

In the above three formulas, $r_{X_iX_j}$ means the correlation coefficient between morphological traits X_i and X_j. P_{X_i} and P_{X_j} mean the direct path coefficients of the morphological traits X_i and X_j on body weight, respectively.

The gray system theory (GST) was first proposed by a Chinese scholar, professor Julong Deng in 1982, and it has become an effective tool for studying the uncertainty of a small sample and limited information (Deng 1982). As an important part of GST, gray relational analysis (GRA) or gray box analysis utilizes the correlation order to express the relations of various factors, and it is suitable for solving problems with complicated interrelations between multiple factors and variables (Kuo et al. 2008). According to this theory, body weight (X_0) and 27 morphological traits (X_1–X_{27}) of *D. anguillare* are taken as a gray system, with the former as reference data and the latter as comparative data. For comparison purposes, the dimensionless treatment method in formula [4] is applied to solve the problem of dimensional inconsistency among different traits. Formula [5] is used to calculate the correlation coefficients between X_i and X_0, while formula [6] is used to obtain the correlation degree between X_i and X_0.

$$X_i'(K) = \frac{X_i(K) - \overline{X_i}}{S_i} \qquad [4]$$

$$\xi i\,(K) = \frac{minVi(K) + \rho\, maxVi(K)}{Vi(K) + \rho\, maxVi(K)} \qquad [5]$$

$$\gamma_i = \frac{1}{n}\sum\nolimits_{k=1}^{n} \xi i\,(K) \qquad [6]$$

In the formula [4], $X_i'(K)$ is the dimensionless data, $X_i(K)$ is the original data, $\overline{X_i}$ is the mean value of X_i, and S_i is the standard deviation of X_i. In the formula [5], $Vi\,(K)$is the absolute difference between X_i and X_0 at a point K that denotes as $Vi\,(K) = |X_0'(\mathrm{K}) - X_i'(K)|$, ρ is the gray resolution coefficient (ρ = 0.5), as well as *max Vi* (*K*) and *min Vi* (*K*) represent the absolute values of the secondary maximum difference and the secondary minimum difference, respectively. In the formula [6], γ_i is the correlation degree between X_i and X_0, and n is the sample size ($n = 85$).

Results

Descriptive statistics of morphometric traits. The statistical data on 28 morphometric parameters of *Dysomma anguillare* are shown in Table 1. The coefficient of variation (CV) is a normalized measure of dispersion of a probability distribution. The CV of X_4 (50.61%) was the greatest, followed by X_{11} (46.68%) and X_0 (40.12%), but the CV of X_{13} (11.00%) was the lowest. The standard deviation (SD) ranged from 0.57 to 48.46, showing an obvious fluctuation in the total length of different samples.

Normal distribution test and correlation analysis. In the K–S test and S–W test, the *P*-value lower than the significance level of 0.05 implies the null hypothesis is rejected and it is assumed that the data is non-normally distributed (Tong 1990). The logarithmic conversion was performed on the body weight to satisfy the normal distribution (Zhan et al. 2019), and the converted data were subjected to the K–S test considering the sample size of this study. The results showed the significance value was 0.100, which followed the normal distribution and could be used for regression analysis subsequently. Phenotypic correlations of 27 morphological traits (X_i) and logarithmic body weight ($\lg X_0$) were analyzed. As shown in Suppl. material 1, 21 morphological traits measured in this study had extremely significant correlations with $\lg X_0$ ($P < 0.01$), and four (X_4, X_{12}, X_{20}, and X_{27}) were significantly correlated with $\lg X_0$ ($P < 0.05$). Only two morphological traits including X_{11} and X_{25} did not correlate with $\lg X_0$ ($P > 0.05$), indicating that these traits were stable and not affected by environment or growth stage. The correlation coefficients ranged from –0.603 (X_{11} versus X_{20}) to 0.996 (X_1 versus X_2), which suggested that the total length (X_1) was strongly associated with the body length (X_2). While the oral fissure height (X_{11}) was the least relevant with distance from the snout to the anterior nostril (X_{20}).

Table 1. The descriptive statistics of phenotypic parameters for *Dysomma anguillare* from the East China Sea.

Trait	*N*	Value			Standard deviation (SD)	Coefficient of variation (CV) [%]
		Min.	Max.	Mean		
X_0	68	27.20	145.50	63.54	25.49	40.12
X_1	85	301.00	557.00	396.55	48.46	12.22
X_2	85	296.00	540.00	388.00	46.82	12.07
X_3	85	38.20	82.00	61.53	9.04	14.69
X_4	85	3.50	38.60	8.56	4.33	50.61
X_5	84	218.00	461.00	334.79	45.37	13.55
X_6	84	261.80	533.88	345.09	47.22	13.68
X_7	84	12.30	32.30	19.22	3.81	19.83
X_8	85	34.20	65.60	49.10	7.42	15.11
X_9	82	6.10	16.50	9.39	1.76	18.71
X_{10}	85	7.00	23.60	14.22	3.67	25.79
X_{11}	68	6.08	33.60	14.01	6.54	46.68
X_{12}	68	3.20	11.70	6.32	1.79	28.35
X_{13}	68	15.58	24.90	19.60	2.16	11.00
X_{14}	85	2.10	5.30	3.46	0.57	16.46
X_{15}	84	22.60	47.70	35.12	0.63	16.44
X_{16}	85	5.10	14.80	8.07	1.83	22.71
X_{17}	84	6.60	20.80	10.50	1.97	18.81
X_{18}	84	8.40	30.00	18.99	2.89	15.22
X_{19}	84	12.00	26.30	16.63	2.45	14.74
X_{20}	84	1.70	5.00	2.47	0.57	23.12
X_{21}	84	6.00	13.00	8.65	1.05	12.08
X_{22}	84	32.10	63.00	44.37	5.62	12.68
X_{23}	84	44.70	94.20	70.96	10.90	15.37
X_{24}	84	5.40	11.30	8.66	1.17	13.51
X_{25}	84	10.76	87.18	31.81	8.24	25.92
X_{26}	85	11.20	32.40	23.68	4.06	17.15
X_{27}	84	5.20	32.78	9.49	2.79	29.43

N = number of measurements. X_0 is the body weight. All other variables are morphometric characters defined in Fig. 1.

Multiple regression analysis. The results of stepwise multiple regression analysis are presented in Table 2. When the number of independent variables increased from 1 to 8, the correlation coefficient of each regression model also gradually increased from 0.865 to 0.959. In the meantime, the estimated standard error decreased from 0.083 to 0.050. The results indicated that the accuracy of the regression model kept increasing during the above process. The corrected coefficient of determination reached 0.909, which meant that a 90.9% variation of the dependent variable could be attributed to independent variables. Therefore, these 8 morphological traits (X_1 = total length; X_7 = body height; X_8 = head length; X_{10} = body width; X_{14} = eye diameter; X_{15} = head length; X_{19} = lower jaw length; X_{23}= distance from snout to anal fin origin) brought into the regression equation had a great determining relation with $\lg X_0$. The results of the T-test for each independent variable in the regression equation are shown in Table 3. The non-standardized regression coefficients of 6 variables (X_1 = total length; X_7 = body length; X_8 = head length; X_{10} = body width; X_{14} = eye diameter; X_{19} = lower jaw length) and 2 variables (X_{15} = head length after eye; X_{23} = distance from the first aperture of lateral line to snout) achieved extremely significant level ($P < 0.01$) and significant level ($P < 0.05$), respectively, demonstrating that the established regression equation was valid. Besides, the potential collinearity problems were diagnosed using the variance inflation factor (VIF) test that measured the correlation among independent variables (Wesolowsky 1976). None of the VIF values were above the threshold level of 10, which meant fewer effects of multicollinearity were detected among independent variables (O'Brien 2007). Furthermore, the results of the F-test were also summarized in Suppl. material 2. The F value of 80.447 ($P = 0.000$) declared that the regression equation reached a very significant level ($P < 0.01$), and the independent variable could effectively explain the variation of the dependent variable. That is, the regression equation had statistical significance. Therefore, a multiple regression equation was established as follows: $\lg X_0 = 0.367 + 0.003X_1 + 0.010X_7 - 0.010X_8 + 0.011X_{10} + 0.042X_{14} + 0.006X_{15} + 0.024X_{19} - 0.004X_{23}$.

Table 2. The regression model summary for *Dysomma anguillare* from the East China Sea.

Model	Correlation coefficient (R)	Coefficient of determination (R^2)	Corrected coefficient of determination (Adjusted R^2)	Standard error (SE)
1	0.865[a]	0.748	0.744	0.083
2	0.900[b]	0.810	0.804	0.073
3	0.919[c]	0.844	0.836	0.067
4	0.927[d]	0.860	0.851	0.064
5	0.942[e]	0.888	0.878	0.058
6	0.950[f]	0.903	0.893	0.054
7	0.955[g]	0.912	0.901	0.052
8	0.959[h]	0.920	0.909	0.050

[a] = predictor: (constant), X_{19}
[b] = predictor: (constant), X_{19}, X_1
[c] = predictor: (constant), X_{19}, X_1, X_{14}
[d] = predictor: (constant), X_{19}, X_1, X_{14}, X_{10}
[e] = predictor: (constant), X_{19}, X_1, X_{14}, X_{10}, X_8
[f] = predictor: (constant), X_{19}, X_1, X_{14}, X_{10}, X_8, X_6
[g] = predictor: (constant), X_{19}, X_1, X_{14}, X_{10}, X_8, X_7, X_{23}
[h] = predictor: (constant), X_{19}, X_1, X_{14}, X_{10}, X_8, X_7, X_{23}, X_{15}.
Variables X_1 through X_{23} are morphometric characters defined in Fig. 1.

Path analysis. The path analysis revealed the effects of the independent variable (X_i) on the dependent variable ($\lg X_0$). The results showed that the sum of each indirect relation to body weight was greater than that of the direct effects (Table 4). The direct effects of each trait on $\lg X_0$ in the established regression equation are presented in descending order as: X_1 (total length) > X_8 (head length) > X_{19} (lower jaw length) > X_{10} (body width) > X_{23} (distance from snout to anal fin origin) > X_{15} (head length after eye) > X_7 (body height) > X_{14} (eye diameter), wherein X_8 and X_{23} negatively impacted $\lg X_0$. Among all indirect effects, the indirect effect of X_7 through X_{19} to $\lg X_0$ was in the first place (IP = 0.554), followed by the indirect effect of X_7 through X_1 to $\lg X_0$ (IP = 0.489), while, X_{15} had the least indirect relation with $\lg X_0$ through X_{14} (IP = 0.028). VIF values were between 1.6 and 8.7, lower than the empirical value (VIF = 10), indicating the collinearity effects were eliminated and the analysis results were reliable.

Determination coefficient analysis. In this study, the sum of the determination coefficients was calculated to be 0.920 (Table 5), fulfilling the criterion for screening the main independent variables with this value of no less than 0.850 according to Wang et al. (2021). It was indicated that these eight traits introduced by the model had a great determining relation with $\lg X_0$, which was in consistence with the conclusion of path analysis. X_1 had the largest determinant relation with $\lg X_0$ (0.489), while X_{14} had the least determinant relation with $\lg X_0$ (0.022). X_1 and X_8 had the greatest negative co-determining relation with $\lg X_0$ (–0.475), but the smallest positive co-determi-

Table 3. The results of regression coefficient for *Dysomma anguillare* from the East China Sea.

Variable	Partial regression coefficient (B)	Standard error (SE)	Standardized regression coefficient (β)	T-statistics	P value	Variance inflation factor (VIF)
Constant	0.367	0.064	—	5.758	0.000	—
X_1	0.003	0.000	0.699	6.267	0.000	8.698
X_7	0.010	0.003	0.194	3.314	0.002	2.394
X_8	–0.010	0.002	–0.418	–4.409	0.000	6.288
X_{10}	0.011	0.002	0.227	4.722	0.000	1.613
X_{14}	0.042	0.014	0.149	3.054	0.003	1.661
X_{15}	0.006	0.003	0.199	2.356	0.022	4.981
X_{19}	0.024	0.006	0.303	4.140	0.000	3.747
X_{23}	–0.004	0.001	–0.226	–2.596	0.012	5.320

Variables X_1 through X_{23} are morphometric characters defined in Fig. 1.

Table 4. Effects of eight morphometric traits on body weight of *Dysomma anguillare* from the East China Sea.

Trait	Correlation coefficient (*R*)	Path coefficient (*P*)	Indirect path coefficient (IP)									Variance inflation factor (VIF)
			Total	X_1	X_7	X_8	X_{10}	X_{14}	X_{15}	X_{19}	X_{23}	
X_1	0.825	0.699	1.469		0.212	0.246	0.187	0.121	0.193	0.251	0.259	8.698
X_7	0.771	0.194	2.474	0.489		0.392	0.376	0.380	0.372	0.554	0.400	2.394
X_8	0.571	−0.418	0.549	0.121	0.083		0.098	0.036	0.106	0.096	0.129	6.288
X_{10}	0.553	0.227	0.712	0.140	0.122	0.149		0.046	0.113	0.135	0.147	1.613
X_{14}	0.538	0.149	0.765	0.167	0.227	0.100	0.084		0.061	0.218	0.074	1.661
X_{15}	0.384	0.199	0.642	0.123	0.103	0.138	0.097	0.028		0.113	0.161	4.981
X_{19}	0.865	0.303	0.862	0.187	0.179	0.146	0.135	0.118	0.132		0.151	3.747
X_{23}	0.579	−0.226	0.749	0.170	0.114	0.173	0.129	0.035	0.166	0.132		5.320

Variables X_1 through X_{23} are morphometric characters defined in Fig. 1.

Table 5. Determination coefficients of eight morphometric traits on body weight of *Dysomma anguillare* from the East China Sea.

Trait	X_1	X_7	X_8	X_{10}	X_{14}	X_{15}	X_{19}	X_{23}
X_1	0.489							
X_7	0.190	0.038						
X_8	−0.475	−0.091	0.175					
X_{10}	0.196	0.047	−0.125	0.052				
X_{14}	0.083	0.031	−0.030	0.014	0.022			
X_{15}	0.177	0.041	−0.119	0.045	0.009	0.040		
X_{19}	0.350	0.093	−0.164	0.082	0.047	0.071	0.092	
X_{23}	−0.270	−0.050	0.164	−0.067	−0.012	−0.075	−0.091	0.051
SDC	0.920							
RCD	0.080							
e	0.392							

SDC = sum of determination coefficient, RCD = residual coefficient of determination, *e* = residual factor ($= \sqrt{1 - R^2}$). Variables X_1 through X_{23} are morphometric characters defined in Fig. 1.

nation coefficient appeared between X_{14} and X_{15} (0.009). The residual factor (*e*) was determined to be 0.392, which reflected that perhaps certain factors were not taken into account, and the relation among different traits should be further considered.

Gray relational analysis. The mean values of gray relational coefficients between different morphological traits and body weight were different, ranging from 2.466 to 396.522 (Table 6). Meanwhile, the standard deviation of the correlation coefficient of each morphological trait was calculated to analyze the dispersion degree among samples. The gray correlation degree represented the mean value of the relational coefficient between X_i and lgX_0, and it was sorted from the largest to the smallest in order: X_2 (body length) > X_{22} (distance from snout to dorsal fin origin) > X_{18} (upper jaw length) > X_5 (postanal length) > X_{23} (distance from snout to anal fin origin) > X_7 (body height) > X_8 (head length) > X_{17} (snout length) > X_1 (total length) > X_{20} (distance from snout to anterior nostril) > X_{26} (distance from dorsal fin origin to anal fin origin) > X_6 (trunk length) > X_9 (head breadth) > X_{25} (distance from the first aperture of lateral line to snout) > X_4 (tail length) > X_{24} (distance from the anal fin origin to the anus) > X_{21} (distance from snout to posterior nostril) > X_{16} (interocular distance) > X_{15} (head length after eye) > X_{10} (body width) > X_{19} (lower jaw length) > X_{12} (oral fissure width) > X_3 (anal length) > X_{27} (pectoral fin length) > X_{13} (oral fissure length) > X_{14} (eye diameter) > X_{11} (oral fissure height).

Discussion

The linear body measurements have been widely applied to evaluate body demission to an animal's overall body size, and the prediction of body weight using morphometric features is very practical in aquaculture breeding programs and fishery management (Gjedrem 2005; William 2011). Herein, the relation between 27 morphological traits and the body weight of *Dysomma anguillare* was first established. In the case of morphological traits, the CV values for tail length (X_4) varied greatly, compared with those measured for other morphological traits. Unlike the standard deviation that must always be considered in the context of the mean of the data, the CV provides a relatively simple and quick tool to com-

Table 6. The gray relational coefficients and gray relational degrees of each trait of *Dysomma anguillare* from the East China Sea.

Traits	Gray relational coefficient			Gray correlation degree	Gray correlation order
	Min.	Max.	Mean ± SD		
X_1	301.000	557.000	396.552 ± 48.460	0.918	9
X_2	296.000	540.000	388.004 ± 46.824	0.937	1
X_3	38.200	82.000	61.531 ± 9.039	0.893	23
X_4	3.500	38.600	8.560 ± 4.332	0.907	15
X_5	218.000	461.000	334.792 ± 45.375	0.936	4
X_6	261.800	533.880	345.091 ± 47.220	0.909	12
X_7	12.300	32.300	19.220 ± 3.810	0.925	6
X_8	34.200	65.600	49.099 ± 7.419	0.921	7
X_9	6.100	16.500	9.389 ± 1.756	0.908	13
X_{10}	7.000	23.600	14.225 ± 3.668	0.897	20
X_{11}	6.080	33.600	14.014 ± 6.541	0.840	27
X_{12}	3.200	11.700	6.323 ± 1.792	0.894	22
X_{13}	15.580	24.900	19.600 ± 2.155	0.883	25
X_{14}	2.100	5.300	3.461 ± 0.570	0.865	26
X_{15}	0.000	47.700	34.711 ± 6.890	0.900	19
X_{16}	5.100	14.800	8.070 ± 1.833	0.900	18
X_{17}	6.600	20.800	10.496 ± 1.974	0.920	8
X_{18}	8.400	30.000	18.994 ± 2.892	0.936	3
X_{19}	12.000	26.300	16.629 ± 2.452	0.894	21
X_{20}	1.700	5.000	2.466 ± 0.570	0.915	10
X_{21}	6.000	13.000	8.655 ± 1.045	0.901	17
X_{22}	32.100	63.000	44.370 ± 5.625	0.937	2
X_{23}	44.700	94.200	70.956 ± 10.903	0.925	5
X_{24}	5.400	11.300	8.661 ± 1.170	0.904	16
X_{25}	10.760	87.180	31.809 ± 8.244	0.908	14
X_{26}	11.200	32.400	23.679 ± 4.062	0.909	11
X_{27}	5.200	32.780	9.491 ± 2.794	0.888	24

Variables X_1 through X_{27} are morphometric characters defined in Fig. 1.

pare different data series (Field 2005). For the majority of Anguilliformes species, it is difficult to measure the tail length (total length) precisely because the extended dorsal fin and anal fin are usually connected to the caudal fin. Perhaps it was the main reason for the greatest variation of this phenotypic feature in the study. Furthermore, all the CVs were larger than 10%, which indicated there were individual differences in growth rate and it was an important prerequisite for size-selective fishing.

The correlation analysis results showed that 25 traits were positively correlated with the logarithm of body weight, except for the oral fissure height (X_{11}) and distance from the first aperture of the lateral line to the snout (X_{25}). The top 3 phenotypic correlation coefficients of morphological traits were lower jaw length (X_{19}), total length(X_1), and body height (X_7), which were quite different from other bony fishes, such as *Larimichthys polyactis* (Bleeker, 1877) (see Liu et al. 2016), *Lates calcarifer* (Bloch, 1790) (see Yang et al. 2020), and *Amphiprion ocellaris* Cuvier, 1830 (see Wang et al. 2021), implying that the relation between morphological traits and body weight of different fishes was species-specific, and it might be also related to the living environment and whether the research object was a cultivated species.

Only using correlation coefficients can't adequately explicate all aspects of the relations among all variables and will be misleading when investigating causal effects (Falconer and Mackay 1996). Conversely, path analysis can effectively compensate for these shortcomings because of providing an algorithm to understand the direct, indirect, and total effect of one variable on another in a hypothesized model, and can therefore accurately reflect the relative importance of the results (Baloch et al. 2001). Our results showed that total length (X_1) was estimated to have the largest direct relation with the body weight, which was consistent with the results of *Misgurnus anguillicaudatus* (Cantor, 1842) (see Wang et al. 2011), *Anguilla reinhardtii* Steindachner, 1867 (see An et al. 2012), and *Lethenteron reissneri* (Dybowski, 1869) (see Ma et al. 2018). The phenotypic traits occupying a large geometric space for organisms are just the primary factors that cause changes in body weight (Chen and Liu 2022). The energy obtained by feeding mainly provides an increase in body length and body weight. The ample geometric space for longitudinal growth will be conducive to accumulate nutrients such as lipids and proteins, conforming to the regular growth pattern of rod-shaped fishes.

The conclusion of determinant coefficients analysis generally agreed with that of path analysis, with total length (X_1) having the largest determinant relation with the body weight. The total coefficient of determination was higher than the critical value of 0.850, which manifested that 92% of the variation came from eight independent variables, and the selected morphological traits could reflect the variation of body weight to a large extent. The multiple regression equation constructed based on these 8 parameters reached a very significant level ($P < 0.01$), reconfirming the accuracy of prediction to the body weight through morphological traits aforesaid. Nevertheless, the correlation coefficients of the retained eight morphological traits disaccorded with their direct effects on body weight, indicating that correlation analysis could not bespeak the true relations among variables (An et al. 2013). Moreover, the larger residual factor insinuated that some other morphometric traits acting on body weight still had not been found. In future studies, it is necessary to take both the external and internal characteristics into consideration.

GST is proved to be useful for dealing with poor, incomplete, and uncertain information (Deng 2005). Compared to conventional mathematical statistics such as correlation analysis, regression analysis, and path analysis, this geometry-based method does not require strict compliance with certain statistical laws or linear relations among objects. Nowadays, it has been widely applied in the fields of industry, agriculture, finance, and environmental science (Wang et al. 2000; Pai et al. 2007; Lai et al. 2009; Zhang and Qi 2011; Xia et al. 2016), and has gradually been used in quantitative analysis of morphological traits in *Paralichthys olivaceus* (Temminck et Schlegel, 1846) (see Liu et al. 2014), *Pinctada fucata* (Gould, 1850) (see Tan et al. 2015), *Siganus guttatus* (Bloch, 1787) (see Huang et al. 2019), and *Trachysalambria curvirostris* (Stimpson, 1860) (see Zhang and Cheng 2022). In the presently reported study, the gray correlation degree showed that X_2 and X_{22} had equal importance to the body weight. The results of the path analysis and gray correlation analysis were not exactly the same for how to determine the importance of independent variables. The former focused on the direct and indirect relations between dependent and independent variables, but the latter only brought independent variables into consideration (Wright 1921; Deng 2005). Consequently, a combination of two methods needed to be adopted to identify the key factors influencing the target traits.

Conclusion

In the presently reported study, a multivariable statistic method including correlation analysis, regression analysis, path analysis, and gray correlation analysis was applied to evaluate the morphological influence on body weight for *Dysomma anguillare* in the coastal waters of China for the first time. Integrated research findings suggested that the three metric traits representing the longitudinal growth of the fish body could be regarded as suitable indicators for formulating mesh size and minimum landing allowable catch size during the fishery resource management of *D. anguillare*.

Certainly, the correlations between the morphological traits of fishes and their body weight were also related to growth stage, sex, habitat environment, nutritional condition as well as genetic regulation. Hence, we should comprehensively deliberate the influence of multiple factors and increase the sample size as much as possible to make the results more reliable.

Acknowledgments

We are grateful to Dr Wei Meng and Dr Rijin Jiang of Zhejiang Marine Fisheries Research Institute for sample collection. This research was funded by the Technology Planning Project of Zhoushan (No. 2022C41022), the Innovation and Entrepreneurship Training Program for College Students (No. 202310340056), and the Science and Technology Innovation Project of College Students in Zhejiang Province (No. 2023R411005).

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Supplementary material 1

Correlation analysis of morphological traits for *Dysomma anguillare*

Authors: Ziyan Zhu, Tianyan Yang, Sige Wang

Data type: docx

Link: https://doi.org/10.3897/aiep.54.114014.suppl1

Supplementary material 2

Variation analysis of multiple regression equations

Authors: Ziyan Zhu, Tianyan Yang, Sige Wang

Data type: docx

Link: https://doi.org/10.3897/aiep.54.114014.suppl2