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Mathematical analysis of morphological traits and their effects on body weight in the red crab (*Charybdis feriata*)

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The red crab (*Charybdis feriata*) is one of most important fishery resource in China. In the present study, 17 morphological traits and body weight of *C. feriata* were first measured and 18 traits were characterized, and then, the effects of morphological traits on body weight were estimated by statistical methods including correlation coefficients, determination coefficients, path coefficients and regression equations. All correlation coefficients between each morphological trait and body weight reached an extremely significant level (*P*<0.01). Determination and path coefficients analysis revealed the real correlation between the independent variables and the dependent variable. Significant path coefficients were found between three morphological traits (stemum width, X_8; meropodite length of pereopod 3, X_{16}; meropodite length of pereopod 4, X_{17}) and body weight, suggesting these three traits were the key factors directly influencing body weight. Multiple correlation index (R^2) between the above three morphological traits and body weight was of 0.977, which indicated that the main independent variables influencing body weight had been found. Finally, a best-fit linear regression equation was established as $Y = 13.078 X_8 + 7.048 X_{16} - 4.902 X_{17} - 576.635$, which provided an ideal model for better understanding of the feature of morphological traits and body weight of *C. feriata*.

Key words: *Charybdis Feriata*, morphological traits, correlation analysis, path analysis, regression analysis.

INTRODUCTION

Morphological trait is an essentially basic index for artificial breeding and seedling propagation. Body weight is a direct reflection of production performance, so it is always one of the main target traits for selection in aquaculture (Liu et al., 2004; Dong et al., 2007). However, the measurement of body weight not only needs special weighing apparatus, but also needs certain operating environmental condition. In contrast, it is easier to

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accurately measure the morphological traits. Recently, published literatures have already showed that the correlation between morphological traits and body weight can be clarified by multivariate analysis and path analysis in *Penaeus vannamei* (Liu et al., 2004), *Eriocheir sinensis* (Geng et al., 2007), *Micropterus salmoides* (He et al., 2009), *Charybdis japonica* (Song et al., 2010) and *Scylla paramamosain* (Ma et al., 2013). Accordingly, the goal of selective breeding could be reached through selection of morphological traits.

The red crab (*Charybdis feriata*) is a large size marine crab with high economic value, mainly distributed in coastal regions of southeastern sea of China (Wu, 2002; Yu et al., 2005; Huang, 2006). It is very popular in consuming market due to the growth speed, survival rate and flesh flavor. In the last decades, studies on *C. feriata* mainly focused on fisheries resources (Abello and Hispano, 2006; Sakthivel and Fernando, 2012), reproduction biology (Parado-Estepa et al., 2007; Josileen, 2011), and molecular phylogeny (Ma et al., 2015). Recently, multivariate analysis has been widely applied to scheme optimization of aquaculture and estimation of production (Liu et al., 2004; Song et al., 2010; Geng et al., 2007; Wang et al., 2008a; Gao et al., 2008; Yang et al., 2011; Deng et al., 2012). However, little information is available on the feature of morphological traits and their effects on body weight of *C. feriata* that has severely limited the understanding of growth characteristics and further studies such as conservation genetics and artificial selective breeding for *C. feriata.*

The morphological traits and body weight of *C. feriata* are important selective criteria for artificial selection and reproduction, of which, in practice, body weight is considered an essential trait for growth performance. Therefore, the purpose of this study was to characterize the morphological traits, and determine their effects on body weight of *C. feriata*, so that it could lay a foundation for better understanding of the morphological traits and body weight, and provide meaningful information for artificial selective breeding for *C. feriata*.

MATERIALS AND METHODS

Samples

Twenty-seven wild adults of *C. feriata* were randomly purchased from Tanmen Port Market, Hainan Province of China in November 2012. All of them were brought to Qionghai Research Center for measurement and analysis.

Measurement of morphological traits and body weight

A total of 17 morphological traits were measured by using a vernier caliper (accurate to 0.001 mm). These traits included body height (BH, X_1), carapace length (CL, X_2), carapace width (CW, X_3), internal carapace width (ICW, X_4), carapace width at spine 6 (6CW, X_5), carapace frontal width (FW, X_6), posterior carapace width (PWC, X_7), stemum width (SW, X_8), abdomen width (AW, X_9), fixed finger length of the claw (PL, X_{10}), fixed finger height of the claw (PD, X_{11}), fixed finger width of the claw (PW, X_{12}), dactylus length of the claw (DL, X_{13}), meropodite length of the claw (ML, X_{14}), meropodite length of pereopod 2 (2PML, X_{15}), meropodite length of pereopod 3 (3PML, X_{16}), and meropodite length of pereopod 4 (4PML, X_{17}). Body weight (Y) was measured using an electronic scale (accurate to 0.001 g).

Statistical analysis

The mean value and standard deviation of each trait were calculated using the software SPSS version 18.0. The coefficient of variation (CV) of each trait was estimated using the following formula: CV = (standard deviation/mean) × 100%. Path analysis was carried out as described by Du and Chen (2010). Correlation analysis and multiple regression analysis were also performed using SPSS 18.0. Multiple regression equation was constructed as follows: $Y = b_0 + b_1X_1 + b_2X_2 + b_3X_3$, where Y is the dependent variable, X_1, X_2 and X_3 are the independent variables, b_0 is the constant, and b_1, b_2, and b_3 are the partial regression coefficients for Y. The determination coefficient was calculated using the alternative formulas: $d_i = P_i^2$ and $d_{ij} = 2r_{ij} \times P_i \times P_j$, where d_i is the effect of a single trait i on body weight, d_{ij} is the effect of traits i and j on body weight, P_i is the path coefficient of the single trait i to body weight, r_{ij} is the correlation coefficient between traits i and j, and P_j is the path coefficient of the single trait j to body weight.

RESULTS

Correlation relationships of 18 traits

The statistics of measured data of 17 morphological traits and body weight are listed in Table 1. Among 18 traits, the largest standard deviation (SD = 83.097) was detected in body weight, while the lowest one was present in morphological trait PW. The coefficient of variation of body weight was also the largest one (CV = 29.38%), whereas the lowest one was observed in morphological trait PWC.

The correlation coefficients of 18 traits in *C. feriata* are shown in Table 2. All phenotypic correlations between morphological traits and body weight reached an extremely significant level ($P < 0.01$) which indicated that the conduction of correlation analysis between morphological traits and body weight is practically meaningful. The size order of correlation coefficients (r) were as follows: $X_8Y > X_5Y > X_4Y > X_3Y > X_7Y > X_1Y > X_{10}Y > X_6Y > X_{16}Y > X_2Y > X_{12}Y > X_{17}Y > X_{14}Y > X_{15}Y > X_9Y > X_{11}Y > X_{13}Y$. Moreover, significant correlations were identified between morphological trait-pairs what suggested the existence of linear correlation among these traits.

Path analysis of morphological traits on body weight

Path coefficient of each morphological trait on body weight was calculated based on the principle of path

Table 1. The descriptive statistics of morphological traits and body weight in *C. feriata*.

Trait	Mean value	Standard deviation	Coefficient of variation (%)
BW (g)	282.819	83.097	29.382
BH (mm)	45.290	5.057	11.167
CL (mm)	73.302	9.513	12.978
CW (mm)	114.549	11.123	9.710
ICW (mm)	107.104	10.670	9.962
6CW (mm)	107.158	10.393	9.698
FW (mm)	39.683	3.729	9.398
PWC (mm)	37.563	3.467	9.231
SW (mm)	58.516	5.582	9.540
AW (mm)	42.523	9.051	21.284
PL (mm)	92.066	11.394	12.376
PD (mm)	28.315	3.706	13.090
PW (mm)	19.687	3.015	15.315
DL (mm)	45.691	7.404	16.205
ML (mm)	57.608	7.693	13.354
2PML (mm)	41.397	5.035	12.163
3PML (mm)	38.825	3.994	10.287
4PML (mm)	36.616	3.681	10.053

analysis. After a test of significance, three morphological traits including SW, 3PML and 4PML were retained, because their path coefficients reached a significant level (0.879, 0.339 and -0.217). Besides, those morphological traits with insignificant path coefficients were removed in the next analysis. Path coefficients reflected the direct influence of independent variables on dependent variables. Of the retained morphological traits, trait SW had the biggest direct influence on body weight, while 4PML had the negative effect on body weight.

Influence of morphological traits on body weight

According to composition effect, correlation coefficients can be divided into two parts including direct and indirect effects. From Table 3, we can see that three morphological traits showed effects on body weight. Trait SW, which had the largest correlation coefficient on body weight, also had the biggest direct effect (0.879) on body weight, whereas it had the smallest indirect effect (0.103) on body weight. The second biggest direct effect (0.339) on body weight was detected in trait 3PML, whose indirect effect was 0.517. Besides, direct effect of 4PML on body weight was negative (-0.217), but it has the largest indirect effect through other morphological traits (1.026) that has neutralized the negative effect. The multiple correlation coefficient (R^2) was 0.977 (higher than 0.85), indicating that morphological traits SW, 3PML and 4PML were the key factors influencing body weight in *C. feriata*.

Table 4 shows the determination coefficients of morphological traits on body weight. Total sum of single determination coefficient and codetermination coefficient was 0.979; this number was equal to correlation coefficient (0.977) that indicated these three morphological traits are the main traits influencing body weight in *C. feriata*, while other traits had a relatively less influence on body weight. Data from Table 4 also showed that the determination degree of SW, 3PML and 4PML on body weight was 77.30, 11.50 and 4.70%, respectively. Further, SW and 3PML had the biggest codetermination coefficients (48.90%) on body weight.

Establishment of multiple regression equation

According to contribution rates of independent variables on body weight and the significance of standard partial regression coefficients, eight variables with insignificant influence on body weight and six variables (BW, CW, ICW, 6CW, PL and PWC) with colinearity to trait SW were excluded by using gradual regression method. Finally, a best-fit linear multiple regression equation, which took body weight as a dependent variable and SW, 3PML and 4PML as independent variables, was established as follows: $Y = 13.078\ X_8 + 7.048\ X_{16} - 4.902\ X_{17} - 576.635$, where Y is body weight, X_8 is SW, X_{16} is 3PML and X_{14} is 4PML. The data listed in Table 5 indicated that the regression relation has reached an extremely significant level (P < 0.01). Meanwhile, significance tests showed that all partial regression coefficients have reached extremely significant level (P<0.01) (Table 6).

Table 2. The correlation coefficients among trait-pair in *C. feriata*.

Trait	BW (Y)	BH (X_1)	CL (X_2)	CW (X_3)	ICW (X_4)	6CW (X_5)	FW (X_6)	PWC (X_7)	SW (X_8)	AW (X_9)	PL (X_{10})	PD (X_{11})	PW (X_{12})	DL (X_{13})	ML (X_{14})	2PML (X_{15})	3PML (X_{16})	4PML (X_{17})
BW (Y)	1	0.927	0.847	0.972	0.975	0.979	0.861	0.943	0.981	0.765	0.907	0.757	0.825	0.72	0.782	0.774	0.855	0.809
BH (X_1)		1	0.83	0.924	0.919	0.922	0.847	0.938	0.914	0.794	0.82	0.793	0.817	0.659	0.728	0.644	0.747	0.682
CL (X_2)			1	0.865	0.868	0.87	0.768	0.827	0.844	0.697	0.787	0.675	0.747	0.719	0.635	0.659	0.692	0.695
CW (X_3)				1	0.996	0.996	0.885	0.96	0.978	0.812	0.922	0.795	0.838	0.77	0.769	0.742	0.813	0.796
ICW (X_4)					1	0.999	0.889	0.953	0.981	0.804	0.931	0.798	0.85	0.781	0.773	0.751	0.828	0.81
6CW (X_5)						1	0.892	0.954	0.981	0.801	0.931	0.793	0.845	0.775	0.774	0.757	0.835	0.808
FW (X_6)							1	0.853	0.844	0.739	0.82	0.868	0.714	0.701	0.646	0.653	0.77	0.709
PWC (X_7)								1	0.955	0.845	0.859	0.79	0.832	0.674	0.784	0.689	0.748	0.704
SW (X_8)									1	0.803	0.918	0.768	0.85	0.755	0.782	0.748	0.82	0.806
AW (X_9)										1	0.606	0.767	0.611	0.539	0.566	0.377	0.398	0.408
PL (X_{10})											1	0.743	0.877	0.814	0.8	0.807	0.908	0.893
PD (X_{11})												1	0.746	0.718	0.552	0.428	0.587	0.547
PW (X_{12})													1	0.702	0.749	0.669	0.748	0.721
DL (X_{13})														1	0.356	0.497	0.712	0.766
ML (X_{14})															1	0.793	0.732	0.677
2PML (X_{15})																1	0.856	0.779
3PML (X_{16})																	1	0.938
4PML (X_{17})																		1

DISCUSSION

Path analysis and selection of independent variables

Phenotypic correlation coefficient is a synthetical correlation between two morphological traits, which includes direct relation between them and indirect relation through other variables. Correlation analysis cannot comprehensively show the correlation relationship between variables, so the information it provides is only considered as a basis for multivariate analysis (Liu et al., 2004; Gao et al., 2008; Song et al., 2010). In this study, all phenotypic correlation coefficients between each morphological trait and body weight have reached significant or extremely significant level; nevertheless, it does not mean that each morphological trait has important effect on body weight. Similar phenomenon was observed in other animals such as *Strongylocentrotus intermedius* (Chang et al., 2012) and *Scylla paramamosain* (Jiang et al., 2014). This phenomenon is possibly because the interference of other variables was not excluded from the analysis. The essential independent variables which affect on body weight could not be identified only through phenotypic correlation analysis. So it is necessary to conduct path analysis to differentiate the effects of independent variables, and finally find out the main traits influencing body weight in *C. feriata*.

Path analysis can divide the total effects of independent variables on dependent variables into direct and indirect effects (De Rodriguez et al., 2001), and it can fully reflect the relative importance of independent variables on dependent variables. In general, an independent variable could be selected only when its phenotypic correlation coefficient reaches significant level to a dependent variable, otherwise, it should be excluded (Li et al., 2012).

Table 3. The effects of morphological traits on body weight in *C. feriata.*

Trait	Correlation coefficient	Direct effect	Indirect effect ($r_{ij} P_j$)			
			∑	SW	3PML	4PML
SW	0.981	0.879	0.103		0.278	-0.175
3PML	0.855	0.339	0.517	0.721		-0.204
4PML	0.809	-0.217	1.026	0.708	0.318	

Table 4. The determination coefficients of morphological traits on body weight in *C. feriata*.

Trait	SW	3PML	4PML
SW	0.773	0.489	-0.307
3PML		0.115	-0.138
4PML			0.047

Table 5. Analysis of variance of multiple regression equation in *C. feriata*.

Index	d.f.	Sum of squares	Mean squares	F value	*P* value
Regression	3	370708.190	123569.400	708.330	0.000
Residual	96	9071.492	174.452		
Total	99	379779.680			

Table 6. Partial coefficients test in *C. feriata*.

Parameter	Constant	SW (X_8)	3PML (X_{16})	4PML (X_{17})
Partial coefficient	-576.635	13.078	7.048	-4.902
t value	-29.898	23.060	5.200	-3.441
P value	0.000	0.000	0.000	0.000

In this study, the relationship between morphological traits and body weight was estimated. As a result, three independent variables including SW, 3PML and 4PML were found to have significant effects. Moreover, path coefficients are also the partial regression coefficients of standard variables in regression equation. Hence, the independent variables in optimal regression equation are equal to those selected in path analysis (Wang et al., 2008b). In the present study, the independent variables retained in above two analysis processes were the same morphological traits including SW, 3PML and 4PML.

Confirmation of morphological traits influencing body weight

In both path analysis and determination coefficient analysis, only when total sum of correlation index (R^2) is more than or equal to 0.85, can indicate that the main independent variables have been found (Liu et al., 2011). In this work, the codetermination coefficient of three independent variables (SW, 3PML and 4PML) was 0.977, suggesting 97.7% of variations of body weight in *C. feriata* are determined by these three morphological traits. While the rest 2.30% of variations are caused by undetected factors and the random errors. It also showed that these three morphological traits are the key factors influencing body weight in *C. feriata*. In previous study, two morphological traits (carapace length and fixed finger height of the claw) were determined to have significant direct effects on body weight of *Scylla paramamosain* (Ma et al., 2013). Besides, the key independent variables have been identified to influence body weight in other animals, such as *Pinctada martensii* (Deng et al., 2008) and *Portunus trituberculatus* (Liu et al., 2009).

Selective breeding indexes of quantitative traits

Body weight is one of important target traits in selective breeding, so it is a basic work to quantify the influence of morphological traits on body weight for artificial selective breeding. This research discussed the relationship between quantitative traits of *C. feriata* using length traits. The morphological traits are taken as independent variables, their regression correlation to body weight was extremely significant, therefore it is appropriate to take morphological traits as independent variables in *C. feriata*. Similar researches have been conducted in other marine organisms such as *Eriocheir sinensis* (Geng et al., 2007), *Portunus trituberculatus* (Gao et al., 2008), *Paralichthys olivaceus* (Wang et al., 2008a), *Hucho taimen* (Tong et al., 2011) and *Ctenopharyngodon idellus* (Li et al., 2012). This research suggested that three morphological traits (SW, 3PML and 4PML) are the key factors directly or indirectly influencing body weight in *C. feriata*, and these traits should be the ideal target traits in artificial breeding of *C. feriata*.

Conclusion

In the present study, 17 morphological traits and body weight in *Charybdis feriata* were first characterized, and then three phenotypic traits (SW, 3PML, and 4PML) which played a key role in influencing body weight were identified. It is suggested that these three morphological traits shall have an important potential in artificial selective breeding of *C. ferata*.

Conflict of interests

The authors have not declared any conflict of interest.

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REFERENCES

Abello P, Hispano C (2006). The capture of the Indo-Pacific crab *Charybdis feriata* (Linnaeus, 1758) (Brachyura: Portunidae) in the Mediterranean Sea. Aquat. Invas. 1:13-16.

Chang YQ, Zhang WJ, Zhao C, Song J (2012). Estimates of heritabilities and genetic correlations for growth and gonad traits in the sea urchin, *Strongylocentrotus intermedius*. Aquac. Res. 43:271-280.

Deng PP, Dai XL, Zang WL, Zou WL, Zhang LT, Guo Y, Xia LJ (2012). The effects of morphometric attribute on body in *Macrobrachium rosenbergii*. Jiangsu Agric. Sci. 40 (7):205-211.

Deng Y, Du XD, Wang Q, Fu S (2008). Correlation and path analysis for growth traits in F_1 population of pearl oyster, *Pinctada martensii*. Mar. Sci. Bull. 10:68-73.

De Rodriguez DJ, Angulo-Sanchez JL, Rodriguez-Garcia R (2001). Correlation and path coefficient analyses of the agronomic traits of a native population of guayule plants. Ind. Crop Prod. 14:93-103.

Dong SR, Kong J, Wan CK, Luan S, Zhang TS, Meng XH, WANG RC (2007). Path analysis of effects of morphometric attributes on body weight of *Fenneropenaeus chinensis*. Mar. Fish. Res. 28 (3):15-22.

Du JJ, Chen ZW (2010). Carrying out path analysis by linear regression of SPPS. B. Biol. 45:4-6.

Gao BQ, Liu P, Li J, Chi H, Dai FY (2008). The relationship between morphometric characters and body weight of *Portunus trituberculatus*. Mar. Fish. Res. 29(1):44-50.

Geng XY, Wang XH, Sun JS, Zhang YS (2007). Morphometric attributes to body weight for juvenile crab, *Eriocheir sinensis*. Oceanol. Limnol. Sin. 38(1):49-54.

He XY, Liu XL, Bai JJ, Li SJ, Fan JJ (2009). Mathematical analysis of effects of morphometric attribute on body weight of largemouth bass (*Micropterus salmoides*). J. Fish. China 33(4):597-603.

Huang PM (2006). The amount distribution and biological characteristics of *Charybdis feriatus* in the southern part of East China Sea. J. Fujian Fish. 1:23-25.

Jiang W, Ma HY, Ma CY, Li SJ, Liu YX, Qiao ZG, Ma LB (2014). Characteristics of growth traits and their effects on body weight of G_1 individuals in the mud crab (*Scylla paramamosain*). Genet. Mol. Res. 13(3):6050-6059.

Josileen J (2011). Captive spawning, hatching and larval development of crucifix crab, *Charybdis feriatus* (Linnaeus, 1758). J. Mar. Biol. Assoc. India 53(1):35-40.

Li XY, Bai JJ, Fan JJ, Yu LY, Liang XF (2012). The relationship between morphological characters and body weight of *Ctenopharyngodon idellus*. J. Shanghai Fish. Univ. 21(4):535-541.

Liu CL, Chang YM, Liang LQ, Xu LH, Liu JL, Chi BJ, Wu XG (2011). Correlation and path analyses of phenotypic traits and body mass of transgenic carp with growth hormone gene of salmon. Chin. J. Appl. Ecol. 22(7):1893-1899.

Liu L, Li J, Gao BQ, Liu P, Dai FY, Pan LQ (2009). Correlation of growth traits of *Portunus trituberculatus* at the different ages and its impact on body weight. J. Fish. China 33:964-971.

Liu XL, Wu CG, Zhang ZH, Huang H, Li B, Zhang YF, Sun CB, Xiang JH (2004). Mathematical analysis of effects of morphometric attributes on body weight for Penaeus vannamei. Acta Ecol. Sin. 24(4):857-862.

Ma H, Ma C, Li C, Lu J, Zou X, Gong Y, Xia L (2015). First mitochondrial genome for the red crab (*Charybdis feriata*) with implication of phylogenomics and population genetics. Sci. Rep. 5:11524.

Ma HY, Ma CY, Ma LB, Xu Z, Feng NN, Qiao ZG (2013). Correlation of growth-related traits and their effects on body weight of the mud crab (*Scylla paramamosain*). Genet. Mol. Res. 12(4):4127-4136.

Parado-Estepa FD, Quinitio ET, Rodriguez E (2007). Seed production of *Charybdis feriatus* (Linnaeus). Aquac. Res. 38:1452-1458.

Sakthivel K, Fernando A (2012). Brachyuran crabs diversity in Mudasal Odai and Nagapattinam coast of south east India. Arthropods 1(4):136-143.

Song CN, Li J, Liu P, Gao BQ, Chen P (2010). Effects of morphometric traits on body weight in mud crab *Charybdis japonica*. J. Dalian Ocean Univ. 25(4):365-369.

Tong GX, Kuang YY, Xu LX, Liu B, Yin JS (2011). Mathematical analysis of effects of morphometric attributes on body weight in Taimen *Hucho taimen*. Chinese J. Fish. 24(2):31-36.

Wang K, Liu HJ, Liu YX, Gu XM (2008a). Mathematical analysis of effects of morphometric attributions on body weight for *Paralichthys olivaceus*. J. Shanghai Fish. Univ. 17(6):655-660.

Wang XA, Ma AJ, Xu K, Lei JL, Yang Z, Qu JB (2008b). Relationship between morphometric attributes and body weight of juvenile turbots *Scophthalmus maximus*. Acta Zool. Sin. 54(3):540-545.

Wu GF (2002). Biological characteristic of main commercial crabs and their space-time distribution in minding north fishing ground. Mod. Fish. Inform. 17(3):16-18.

Yang CM, He T, Liu XL, Huang H, Xiang JH (2011). Stepwise regression analysis of morphometric attributes on body weight of *Penaeus vannamei*. Acta Agr. Boreali-Occidentalis Sin. 20 (2):15-20.

Yu CG, Song HT, Yao GZ (2005). Fishery biology and quantity distribution of *Charybdis feriatus* in the middle south of East China Sea. J. Zhanjiang Ocean Univ. 25(3):24-28.