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Morphometric Characterization of Economically Important Populations of Black Tiger Shrimp *(Penaeus monodon)* Natural Broodstocks in Sri Lanka

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ABSTRACT

Purpose: *Presence of morphological heterogeneity and economically superior traits in naturally available brood stock greatly supports yield improvement programs characterizing sub-populations with such traits will provide leverage in doing so. The present study was an attempt to characterise giant tiger shrimp, Penaeus monodon brood stock from Sri Lankan waters to identify whether or not commercially important sub-populations exist based on morphological traits, which can be used for the yield improving P. monodon farming industry in Sri Lanka.*

Research Method: *A total of 495 P. monodon samples were randomly collected from nine areas around the country. Ten selected morphometric traits and the Body Weight (BW) were measured from each. Morphometric measurements were standardized and subjected to multivariate analysis with equation LTs (i)=log10LT(i)[log10 TL(m)/log10 TL(i)]b.*

Findings: *Selected morphological traits were highly correlated with BW showing the highest correlation from hepatic spine width and the lowest correlation by width at the midpoint of the abdominal segment six. In PCA, both PC1 and PC2 accounted for 68.1% of total variation. The scatter plot of PC1 and PC2 indicated that all samples in the nine zones belonged to one population. However, significant variations in BW, standard body length, and abdominal length were observed in different areas and the highest significant BW was recorded in Chilaw, Beruwala, Negombo, and Mullaitivu.*

Originality/Value: *Economically important morphological traits in Penaeus monodon are prominent in a few populations around the country, prompting to selection of individuals from these areas for brood stock improvement programs.*

Keywords: *Morphometric Analysis, Morphological Heterogeneity, Multivariate Analysis, P. monodon, Sri Lanka.*

INTRODUCTION

Penaeus monodon is an important marine invertebrate species used in the aquaculture industry. Morphological traits are of broader use in many biological studies for the identification of stocks and hybrids (Tzeng, 2004; Liasko *et al.*, 2012), and adaptive radiation (Clabaut *et al.*, 2007). Studies of phenotypic and genetic relationships among growth-related traits have been investigated in many finfish and shellfish species, including *Penaeus vannamei* (Perez-Rostro and Ibarra, 2003), *Pangasianodon hypophthalmus* (Sang *et al.*, 2009), *Scophthalmus maximus* (Wang *et al.*, 2010), *Paralichthys olivaceus* (Tian *et al.*, 2011), *Salmo salar* (Haffray *et al.*, 2012), and *Lateolabrax maculatus* (Wang *et al.*, 2016).

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Evaluation of the diversity of morphological features of the wild populations can be used to identify the economically important features, and further developing animals having such identifying features can be used economically and effectively in cultivation to optimize yield and improve profitability (Wang *et al.*, 2016). On the other hand, inbreeding due to the continuous production of offspring within the same featured populations can be prevented. In addition, the introduction of new variants from different geographical locations without evaluating the available stocks may be beneficial as well as detrimental for the remaining stocks in the country. In addition, it may be a barrier to investigating own resources for development.

In Sri Lanka, until 2022, *P. monodon* seed production was entirely dependent on the wild broodstock collected from selected areas within 1340 km of the periphery of the country. In the selection of broodstock for breeding purposes, the only scientific intervention reported so far has been the screening of parental stocks for white spot disease and implementing better management practices to prevent disease contamination. In response to continuously reported shrimp diseases in the shrimp farming industry, SPF *P. monodon* was introduced to Sri Lanka in 2016 (Priyadarshana *et al.*, 2020) as an alternative solution. Additionally, since 2022, the use of native *P. monodon* broodstock for post larvae production was prohibited.

However, no studies have been reported in Sri Lanka to assess the suitability of the native *P. monodon* population as broodstock for industry development. Although the investigation of samples collected from three locations on the east, west, and southern coasts revealed the presence of a morphologically similar population (Munasinghe, 2015), a heterogeneous structure of the *P. monodon* stock in the east and west coasts of Sri Lanka was also reported (Anjani *et al.*, 2020). However, not much consideration has been given to investigating the availability of different morphological traits that can be used to develop the shrimp aquaculture industry.

Therefore, in the present study, we aimed to identify the economically important morphological traits of different populations collected from nine locations representing the whole periphery of the country to investigate the availability of economically effective indicators that could be applied in selective breeding programs of *P. monodon* for the future development of the industry.

MATERIALS AND METHODS

Sampling and Data Collection

In the present study, population samples of *P. monodon* were randomly collected using fish landings from nine areas selected around the country. The selection of the sampling area was designed as much as possible to cover the broodstock collecting areas for the industry. Beruwala, Negombo, Chilaw, Mullaitivu, Pottuvil, and Batticaloa areas represented the main brood stock collecting areas, and Hambantota, Galle, and Jaffna areas were selected to cover the remaining coastal region of the country (Fig. 01). In total, 495 samples (an approximately equal number of males and females) representing 55 samples from each sampling area were collected. All the collected samples were transported to the laboratory by preserving in ice and immediately stored at -20°C until further use.

Morphometric measurements

Variation of the size of morphometric parameters proportionately reflects the body size and net meat weight of shrimps as well as the economic importance of the shrimp harvest (Dai *et al.*, 2023). Therefore, the body weight and the most economically important and reliable ten morphometric traits, which can be used to explain the relationship with the body weight, were used for the analysis. All the specimens were thawed and blotted before taking the measurements. Initially, the body weight (BW) of each specimen was measured using a digital weighing balance (Ohaus). Length measurements of 10 morphological parameters (Lester and Pante, 1992; Tzeng, 2004; Rebello *et al.*, 2014; Sun *et al.*, 2013) reflecting the body size were measured using a digital Vernier caliper (±0.01 mm). The following were measured separately: Abdomen length (ABL) - total length of the abdominal segments one to six along the mid-dorsal line, Standard body length (STBL) - length from the posterior margin of the orbit to the tip of the telson, Carapace length (CL) - length from the posterior margin of the orbit to the posterior edge of the carapace,Depth of the abdomen at the mid-point of the sixth segment (DAB6),Depth of the abdomen between the abdominal segment two and three (DAB2&3),Circumference of the abdomen between the abdominal segment five and six (CIR), Hepatic spine width (HSW),Width at the midpoint of the abdominal segment one (ABSW1),Width at the midpoint of the abdominal segment six (ABSW6),Height of the abdominal segment six at the telson end (ABSH6)(Fig. 02.).

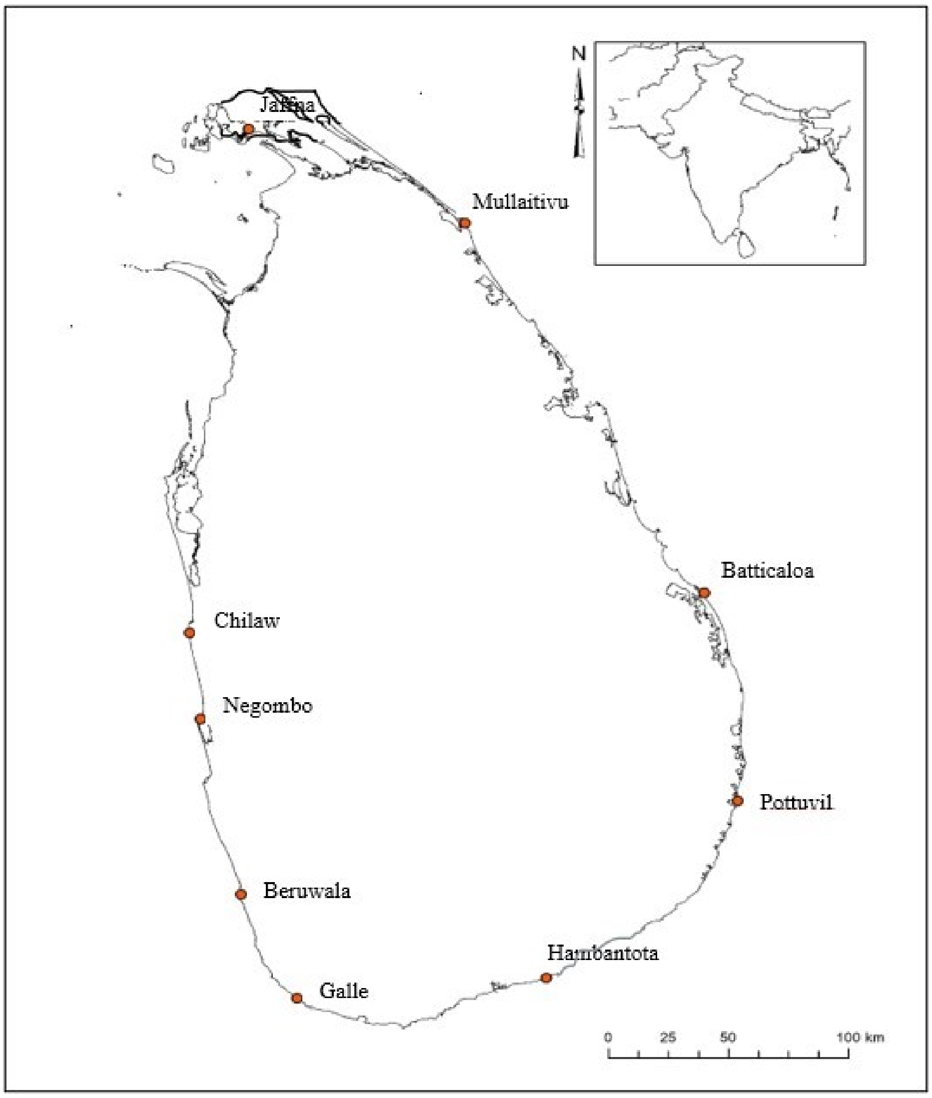

Figure 1: Sample-collecting areas of *P. monodon* for the study.

Statistical analysis

Before the multivariate analysis, all the morphometric characteristics were standardized according to the equation:

$$LT_s(i) = \log_{10} LT(i) \left[\frac{\log_{10} TL_m}{\log_{10} TL(i)} \right]^b$$

(Doherty and McCarthy, 2004; Fernando and Amarasinghe, 2011; Senar *et al.*, 1994), where $LT_s(i)$ is the standardized measurement of the i^{th} shrimp, $LT(i)$ is the length of the measured character of the i^{th} shrimp, TL_m is the arithmetic mean of the standard length (CL) for all shrimp samples, and $TL(i)$ is the standard length of each specimen. CL is used as the reference parameter due to its high accuracy as a single parameter to explain the variation of body weight (Daud and Ang, 1995; Chandra *et al.*, 1997) and its ease, speed, and reliability for length measurement (Mariappan and Balasundaram, 2004). The value of the parameter b was estimated for each character using the allometric growth equation:

$$M = aL^b$$

where the coefficient b was evaluated as the slope of the regression of $\log_{10} LT$ on $\log_{10} TL$ using all shrimp in each group (Ferrito *et al.*, 2007; Sun *et al.*, 2013).

Descriptive statistics, including mean, standard error of the mean, standard deviation, coefficient of variation, minimum, and maximum values of all measurements for nine populations, were recorded. Correlation analysis was used to identify the relationship between morphometric variation and body weight among individuals. PCA was used to identify the morphological variables that contributed substantially to the morphological variation. Cluster analysis was performed using the computed PC1 and PC2 values to observe whether the morphological features supported the cluster formation or not.

Among the tested parameters, which contributed to the highest correlation matrix to BW, STBL and ABL were considered the most economically important parameters. Therefore, further analysis of BW, STBL, and ABL was performed using graphical illustrations

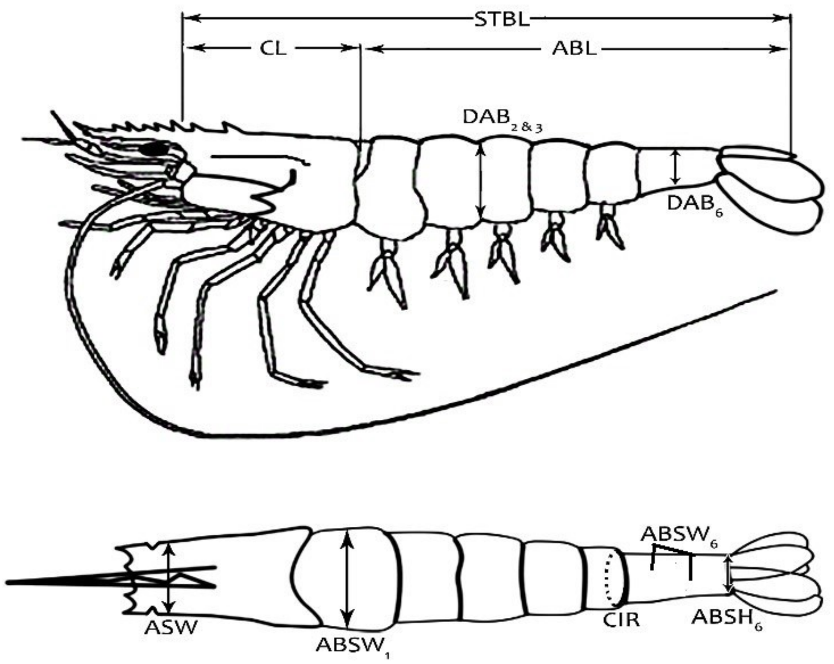

Figure 2: Morphometric parameters taken from each specimen of the *P. monodon* for the study: Abdomen length (ABL), Standard Body Length(STBL), carapace length (CL), depth of the abdomen at the mid-point of the sixth segment (DAB6), depth of the abdomen between the abdominal segment two and three (DAB2&3), the circumference of the abdomen (CIR), hepatic spine width (HSW), width at the midpoint of the abdominal segment one (ABSW1), width at the midpoint of the abdominal segment six (ABSW6) and the height of the abdominal segment six at the telson end (ABSH6).

of nine areas together and pairwise area T-test analysis to test whether the means of BW, STBL, and ABL differed significantly with 95% confidence intervals between each pair of the populations. All statistical analyses were carried out using MINITAB 17 software.

RESULTS AND DISCUSSION

The mean, standard error, and coefficient of variation (CV %) of each morphometric characteristic of *P. monodon* according to the sample collection areas are given in Table 01. Mean BW and STBL varied from 37.8–119.0 g to 138.7–198.5 mm, respectively, in the nine sample collection areas. The coefficient of variation (CV %) describes the varying degrees within and among populations. Except for BW, all morphological traits in the nine populations recorded CV values less than 20%, varying between 6% for ABL in Batticaloa and 17.7% for both CL and DAB2&3 in Batticaloa and Galle areas, respectively. Higher CV values for BW, varying from 19.6% for samples collected from the Batticaloa area to 44.1% for the samples collected from the Galle area, were recorded. Except for the Batticaloa area, all other areas indicated CV values higher than 20%. A high percentage of CV values indicated a proportionally higher contribution of environmental variance to morphological variability (Mamuris *et al.*, 2005; Han *et al.*, 2015) and suggested that collected samples from each population consisted of a phenotypically heterogeneous group (Ferrito *et al.*, 2007).

Investigating correlations between selected traits of economic importance constitutes an essential component of a profit-oriented aquaculture industry. In aquaculture production systems based on hatchery-bred seeds, body weight is mostly considered as a main indicator to select the parental stocks for breeding purposes as well as to produce quality seeds to obtain a high yield from farming (Zhao *et al.*, 2014; Wang *et al.*, 2015). The relationship between morphological traits with the body weight of the farmed species was investigated in different studies, and body weights were found to be highly correlated with various other morphological traits (Perez-Rostro and Ibarra, 2003; Trong *et al.*, 2013; Wang *et al.*, 2016).In this study, ten morphological traits had a significant contribution ($P < 0.05$) to body weight, with a correlation coefficient ranging from 0.967 for HSW to 0.881 for ABSW6 (Table 02). Two morphological traits, HSW

Table 1: Descriptive statistics of morphometric variables and the body weight of *P. monodon* collected from nine different areas.

Variable	Statistic	Chilaw	Batticaloa	Beruwala	Hambantota	Negombo	Jaffna	Galle	Mullaitivu	Pottuvil
BW	Mean ± S.E.	100.4±4.6	55.7±1.5	112.7±6.4	38.9±1.5	106.3±6.1	37.8±2.0	56.1±3.3	119.0±6.6	49.7±1.9
	CV (%)	33.9	19.6	42.3	28.2	42.4	39.3	44.1	41.1	28.5
STBL	Mean ± S.E.	188.3±2.8	157.0±1.4	192.9±3.8	140.1±1.6	190.0±3.2	138.7±2.3	154.5±3.3	198.5±3.1	151.5±1.8
	CV (%)	10.9	6.6	14.5	8.3	12.6	12.4	15.8	11.7	9.0
CL	Mean ± S.E.	57.6±1.1	43.9±0.5	60.0±1.4	40.1±0.5	57.5±1.2	39.8±0.8	45.0±1.0	61.4±1.3	43.2±0.6
	CV (%)	13.6	7.7	17.7	10.1	15.3	15.4	16.7	16.0	10.0
DAB6	Mean ± S.E.	24.1±0.3	20.1±0.2	24.4±0.5	17.7±0.2	24.7±0.4	17.4±0.3	20.0±0.4	25.7±0.4	19.6±0.3
	CV (%)	9.9	7.6	14.0	9.3	13.4	14.3	16.0	11.7	9.7
DAB2&3	Mean ± S.E.	30.2±0.5	26.0±0.3	32.0±0.6	23.5±0.3	31.4±0.6	23.2±0.5	26.2±0.6	33.3±0.6	25.2±0.3
	CV (%)	11.7	8.1	14.1	9.1	13.9	14.7	17.7	13.5	10.0
CIR	Mean ± S.E.	67.8±0.9	54.7±0.5	66.6±1.2	47.5±0.7	69.3±1.1	47.6±1.0	54.7±1.1	69.5±1.2	52.3±0.7
	CV (%)	9.7	7.3	13.3	10.4	12.2	15.7	15.5	12.7	10.0
HSW	Mean ± S.E.	25.4±0.4	20.8±0.2	27.2±0.6	18.4±0.2	26.3±0.5	18.8±0.3	21.0±0.4	27.7±0.6	20.0±0.3
	CV (%)	11.8	7.7	16.1	8.7	15.0	12.5	14.9	16.3	9.9
ABL	Mean ± S.E.	111.7±1.6	95.9±0.8	118.5±2.2	86.5±1.0	113.2±1.8	84.9±1.5	96.4±2.2	117.2±1.7	95.6±1.2
	CV (%)	10.5	6.0	13.6	8.4	11.7	12.9	17.1	11.0	9.4
ABSW1	Mean ± S.E.	26.2±0.4	22.4±0.2	27.3±0.6	19.6±0.3	27.0±0.5	18.7±0.4	21.9±0.5	28.0±0.6	21.3±0.3
	CV (%)	12.2	7.0	15.2	9.7	14.8	13.9	16.4	15.9	9.6
ABSW6	Mean ± S.E.	17.0±0.3	11.8±0.1	14.8±0.3	10.6±0.2	16.2±0.3	10.5±0.2	11.9±0.3	15.2±0.3	11.3±0.1
	CV (%)	12.3	6.6	15.5	10.8	13.6	13.8	17.3	13.1	9.5
ABSH6	Mean ± S.E.	14.9±0.3	12.2±0.1	14.9±0.3	11.0±0.2	15.2±0.3	10.7±0.2	12.2±0.3	15.5±0.3	12.0±0.2
	CV (%)	12.6	7.8	13.5	10.7	13.8	14.1	16.0	13.2	9.9

and ABSW1, that showed a high correlation with body weight were related to the body width of the shrimps. Previous studies have also reported a high positive genetic correlation of body weight with width-type morphological traits, including the cephalothorax and sixth segment (Shin *et al.*, 2023).

However, only by using correlation coefficients between morphometric traits and body weight might not adequately explain all aspects of their relationships and the investigation of the causality of these relationships (Falconer and Mackay, 1996) and, many statistical methods have been employed to develop a suitable index for better selection. Therefore, the morphological data of samples collected from different locations were subjected to PCA to test for the contribution of morphological features to the

Table 2: Correlation matrix between morphometric characters and body weight of *P. monodon*.

Variable	BW	STBL	CL	DAB6	DAB2&3	CIR	HSW	ABL	ABSW1	ABSW6
STBL	0.958									
CL	0.941	0.967								
DAB6	0.947	0.979	0.947							
DAB2&3	0.940	0.962	0.939	0.961						
CIR	0.925	0.960	0.935	0.965	0.938					
HSW	0.967	0.973	0.961	0.965	0.958	0.943				
ABL	0.929	0.967	0.940	0.955	0.954	0.939	0.948			
ABSW1	0.957	0.976	0.951	0.966	0.959	0.949	0.966	0.955		
ABSW6	0.881	0.918	0.903	0.909	0.867	0.928	0.890	0.882	0.898	
ABSH6	0.921	0.948	0.928	0.951	0.931	0.936	0.937	0.922	0.940	0.901

Pearson correlation coefficients (p<0.05).

Table 3: Eigenvalues and percentage of principal component.

PC	1	2	3	4	5	6	7	8	9	10
Eigenvalue	4.8831	1.9239	0.9697	0.6440	0.5887	0.4222	0.3394	0.1599	0.0474	0.0218
Proportion	0.488	0.193	0.097	0.064	0.059	0.042	0.034	0.016	0.005	0.002
Cum. %	0.488	0.681	0.778	0.842	0.901	0.943	0.977	0.993	0.998	1.000

configuration of the variance. In the correlation matrix, both first principal component (PC1) and second principal component (PC2) together (eigenvalues > 1) accounted for 68.1% of the total variation, representing 48.8% variation from PC1 and 19.3% variation from PC2 (Table 03).

Eigenvectors of PC1 show that PC scores of six morphological traits, viz., STBL, ABL, DAB6, DAB2&3, HSW, and ABSW1 were positively contributed, proportions varying from +0.150 for the ABSW1 to +0.437 for the STBL while loading negatively by BW, CIR, ABSW6, and ABSH6 with a proportion varying from -0.025 for the CIR to -0.409 for the BW. In the eigenvectors of PC2, eight morphological traits, viz., BW, ABL, DAB6, DAB2&3, CIR, ABSW1, ABSW6, and ABSH6 positively contributed varying proportions from 0.137 for DAB6 to 0.491 for ABSH6. HSW and STBL negatively contributed with proportions of -0.072 and -0.078, respectively for the total variation (Table 04).

Cluster analysis was performed to investigate the formation of separate clusters based on measured morphometric traits using the computed PC1 and PC2 scores. Although all the samples appeared to belong to one population, the scatter plot showed positive and negative loadings belonging to certain areas, suggesting area-wise separation of the population (Figure 03). A large population that represents several areas as a whole can exhibit an admixture of morphological traits, making all of those areas appear as a single population. However, when each area is considered separately, different morphological characteristics can be identified. Therefore, although the nine areas were initially considered as one population, further pairwise in-depth investigation revealed differences in morphological characteristics in different locations considered for the study. Confirmatory evidence supporting the formation of separate clusters was recorded previously when only two areas were considered(Anjani *et al.*, 2020).

Production enhancement is one of the main goals in the aquaculture field, and body weight (BW) is a highly concerning feature in selecting parental stocks to obtain a better harvest. The BW has been reported as highly correlated with many morphological traits, and BW can be used to predict meat weight accurately (Perez-Rostro and Ibarra, 2003; Trong *et al.*, 2013; Wang *et al.*, 2016; Dai *et al.*, 2023). The shrimp body mainly consists of the cephalothorax, abdomen, and tail parts. Concerning the body length parameters, STBL represents the length of the cephalothorax, abdomen, and tail part length along the mid-dorsal line together, and ABL represents the total length of the abdominal segments one to six along the mid-dorsal line. The abdomen represents about 90% of the total shrimp meat. In a shrimp body, meat represents 48% of the total animal, the cephalothorax 39%, the exoskeleton 11%, and the tail 2.3% (Andriantahina *et al.*, 2012; Dang *et al.*, 2018; Shin *et al.*, 2023). Therefore, the present study mainly considered the BW, STBL, and ABL to explain the variation among the nine areas,

Table 4: Factors loading of PCA for each morphometric variable.

Variable	PC1	PC2
BW	-0.409	0.233
STBL	0.437	-0.078
ABL	0.259	0.436
DAB6	0.361	0.137
DAB2&3	0.375	0.182
CIR	-0.025	0.337
HSW	0.436	-0.072
ABSW1	0.150	0.483
ABSW6	-0.288	0.324
ABSH6	-0.083	0.491

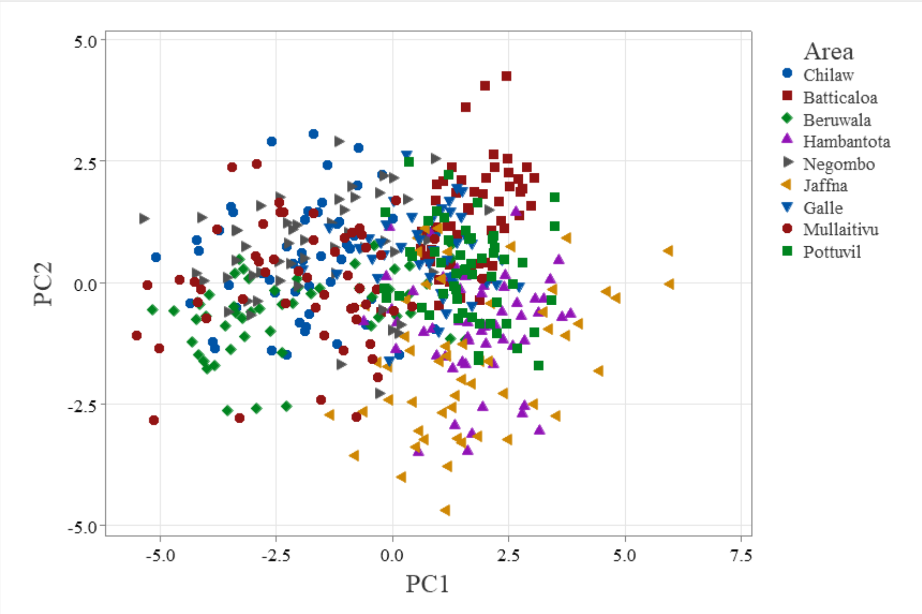

Figure 3: Scatter plot of PC1 and PC2 of PCA for samples collected from nine sample-collecting areas.

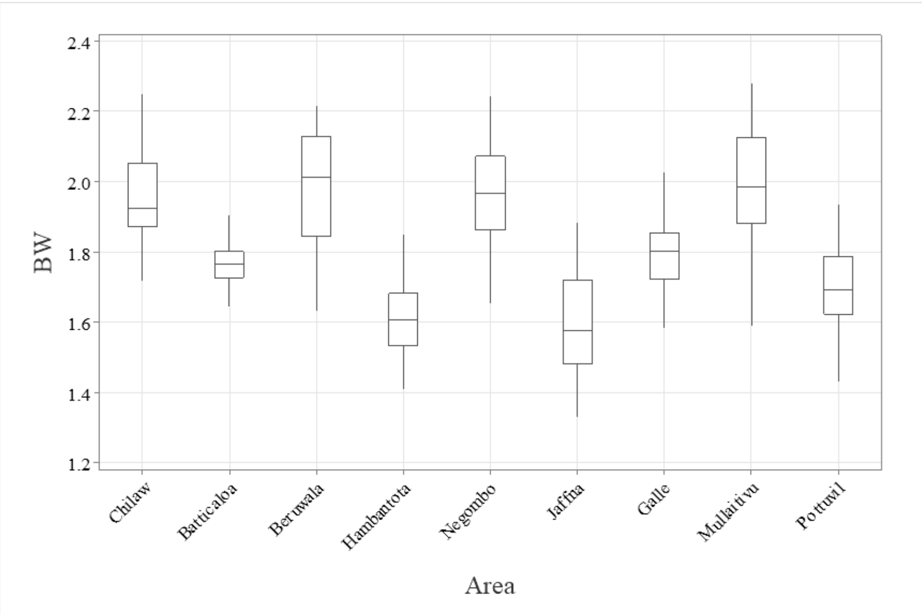

Figure 4: Box plot of standard body Weight (BW) of *P. monodon* samples collected from nine sample-collecting areas.

focusing on the economic importance.

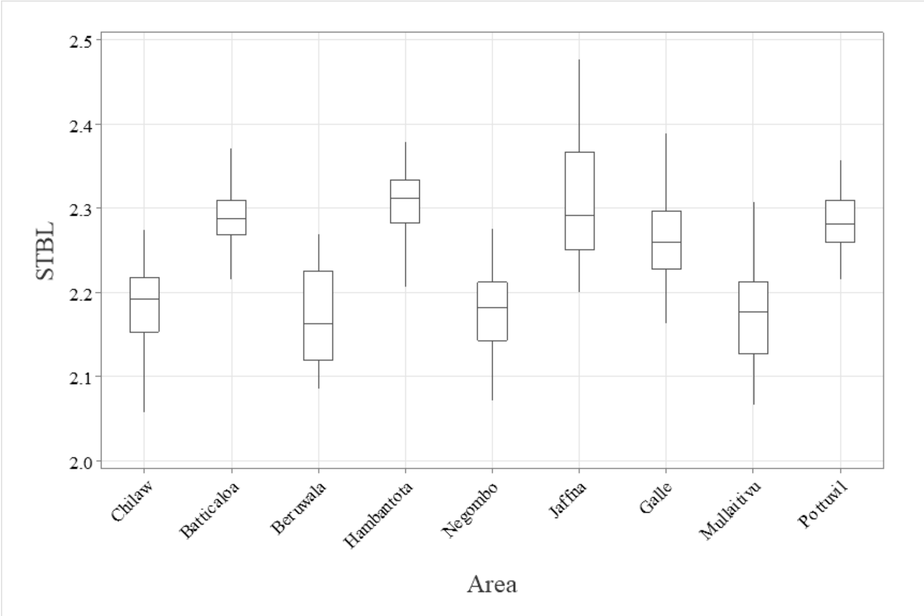

Figure 5: Box plot of standard body length (STBL) of *P. monodon* samples collected from nine sample-collecting areas.

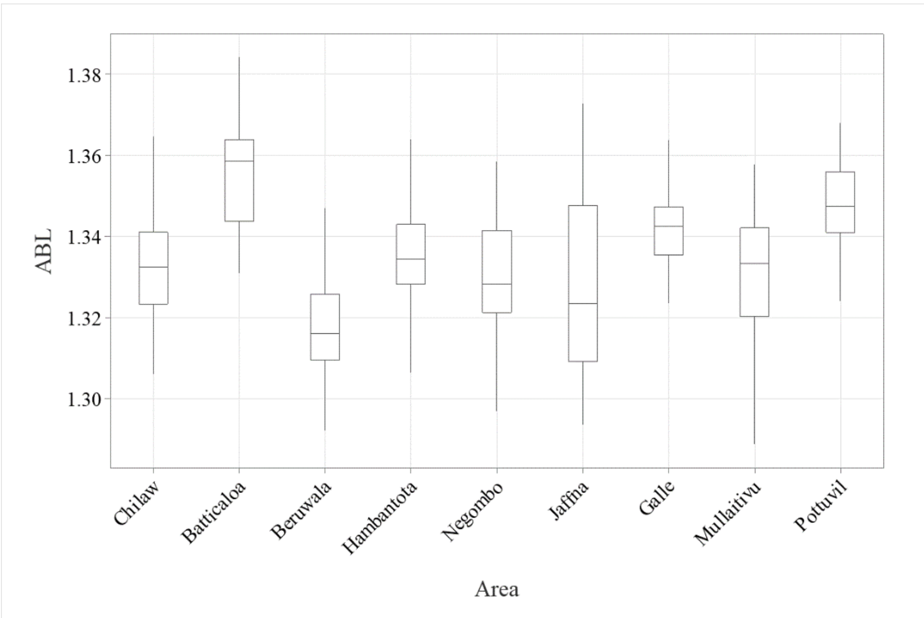

Figure 6: Box plot of abdominal length (ABL) of *P. monodon* samples collected from nine sample-collecting areas.

The box plot examines the median and behavior of data points for each trait, and it was indicated that the samples collected from Chilaw, Beruwala, Negombo, and Mullaitivu have relatively higher BW compared to the other five areas of Batticaloa, Hambantota, Jaffna, Galle, and Pottuvil (Figure 04). The box plot of the STBL shows the opposite behavior of the BW, indicating the highest STBL in Batticaloa, Hambantota, Jaffna, Galle, and Pottuvil areas (Figure 05), and relatively higher ABL was recorded only from Batticaloa and Pottuvil areas (Figure 06).

For the justification of these results, two-sample T-tests were performed using standardized data for 36 pairwise combinations between nine areas. The mean difference, T value, and probability value for the BW, STBL, and ABL are separately indicated in table 05, and the mean of the BW and morphological traits of STBL and ABL and the 95% confidence interval (CI) of the mean for each area are indicated in table 06.Of the 36 pairwise combinations of the BW of the nine populations, there were no significant differences ($p>0.05$) of the BW reported in the pairwise combinations of T-tests in Beruwala-Mullaitivu, Negombo-Mullaitivu, Chilaw-Mullaitivu, Beruwala-Negombo, Chilaw-Beruwala, and Chilaw-Negombo areas. The highest standardized means of body weight were recorded as 1.992, 1.974,

Table 5: Mean difference, T value, and P value for the BW, STBL, and ABL for 36 pairwise area combinations.

Area	BW			STBL			ABL		
	Mean diff.	T value	P value	Mean diff.	T value	P value	Mean diff.	T value	P value
Chi-Bat	0.186	10.20	0.00	0.106	13.53	0.00	0.024	9.50	0.00
Chi-Ber	0.019	0.67	**0.51**	0.013	1.24	**0.23**	0.014	5.05	0.00
Chi-Ham	0.346	16.48	0.00	0.122	14.47	0.00	0.004	1.46	**0.15**
Chi-Neg	0.009	0.39	**0.70**	0.001	0.12	**0.90**	0.001	0.42	**0.68**
Chi-Jaf	0.367	14.33	0.00	0.124	11.05	0.00	0.005	1.30	0.19
Chi-Gal	0.152	6.82	0.00	0.083	8.51	0.00	0.011	4.52	0.00
Chi-Mul	0.037	1.42	**0.16**	0.014	1.4	**0.17**	0.001	0.24	**0.81**
Chi-Pot	0.252	11.69	0.00	0.101	12.39	0.00	0.017	7.0	0.00
Bat-Ber	0.205	8.29	0.00	0.119	13.58	0.00	0.038	15.39	0.00
Bat-Ham	0.160	9.79	0.00	0.016	2.55	0.01	0.021	8.68	0.00
Bat-Neg	0.195	9.62	0.00	0.107	13.88	0.00	0.026	9.68	0.00
Bat-Jaf	0.181	8.24	0.00	0.018	1.84	**0.07**	0.029	8.62	0.00
Bat-Gal	0.034	1.91	**0.06**	0.023	2.85	0.00	0.013	6.26	0.00
Bat-Mul	0.223	9.83	0.00	0.120	13.94	0.00	0.025	9.37	0.00
Bat-Pot	0.067	3.86	0.00	0.004	0.73	**0.47**	0.008	3.88	0.00
Ber-Ham	0.365	13.61	0.00	0.135	14.52	0.00	0.018	6.98	0.00
Ber-Neg	0.009	0.32	**0.75**	0.011	1.13	**0.26**	0.012	4.47	0.00
Ber-Jaf	0.385	12.63	0.00	0.137	11.52	0.00	0.009	2.59	0.01
Ber-Gal	0.171	6.14	0.00	0.096	9.13	0.00	0.025	10.78	0.00
Ber-Mul	0.019	0.6	**0.55**	0.002	0.14	**0.89**	0.013	4.6	0.00
Ber-Pot	0.270	9.94	0.00	0.114	12.6	0.00	0.03	13.7	0.00
Ham-Neg	0.355	15.57	0.00	0.123	14.79	0.00	0.005	1.87	0.07
Ham-Jaf	0.021	0.86	**0.39**	0.002	0.16	**0.89**	0.009	2.49	0.02
Ham-Gal	0.194	9.36	0.00	0.039	4.54	0.00	0.007	3.22	0.00
Ham-Mul	0.383	15.34	0.00	0.137	14.86	0.00	0.005	1.66	**0.10**
Ham-Pot	0.094	4.73	0.00	0.021	3.03	0.00	0.013	5.92	0.00
Neg-Jaf	0.376	13.87	0.00	0.125	11.23	0.00	0.003	0.95	**0.35**
Neg-Gal	0.161	6.72	0.00	0.084	8.71	0.00	0.012	4.86	0.00
Neg-Mul	0.028	1.01	**0.32**	0.013	1.30	**0.20**	0.00	0.17	**0.88**
Neg-Pot	0.261	11.2	0.00	0.103	12.69	0.00	0.013	7.25	0.00
Jaf-Gal	0.215	8.47	0.00	0.041	3.60	0.00	0.016	4.8	0.00
Jaf.Mul	0.404	13.96	0.00	0.138	11.73	0.00	0.004	1.08	0.28
Jaf.Pot	0.115	4.65	0.00	0.022	2.23	0.03	0.021	6.59	0.00
Gal.Mul	0.189	7.26	0.00	0.097	9.36	0.00	0.012	4.6	0.00
Gal-Pot	0.100	4.69	0.00	0.019	2.2	0.03	0.005	2.91	0.00
Mul-Pot	0.289	11.37	0.00	0.116	12.93	0.00	0.017	6.94	0.00

Chi: Chilaw, *Bat*: Batticaloa, *Ber*: Beruwala, *Ham*: Hambantota, *Neg*: Negombo, *Jaf*: Jaffna, *Gal*: Galle, *Mul*: Mullaitivu, and *Pot*: Pottuvil and p>0.05 values are highlighted.

1.964, and 1.955, respectively for the Mullaitivu, Beruwala, Negombo, and Chilaw areas with the range from 1.923 (Chilaw) to 2.034 (Mullaitivu) of the 95% confidence intervals. The Mullaitivu area recorded the highest average BW, and a previous study also recorded the highest significant average body weight of the farmed *P. monodon* using the post-larvae produced from the broodstock collected from the Mullaitivu area (Ekanayake *et al.*, 2018). The areas of Batticaloa-Galle and Hambantota-Jaffna also did not show a significant difference in the BW, but lower mean body weights were reported from both areas. The remaining 28 pairwise area combinations indicated a significant difference in the BW (p<0.05) between each area displaying the heterogeneity of the population (Table 05 and 06).

Although, there were no significant differences (p>0.05) in the STBL reported in the Mullaitivu-Beruwala, Mullaitivu-Negombo, Mullaitivu-Chilaw, Beruwala-Negombo, Beruwala-Chilaw, and Negombo-Chilaw areas similar to the BW, lower standardized means of STBL were recorded from Chilaw, Negombo, Beruwala, and Mullaitivu areas varied from 2.153 (Mullaitivu) to 2.201 (Chilaw) of the 95% confidence intervals. However, the highest standardized means of

Table 6: Mean and 95% confidence interval (CI) of the mean for the morphological traits of BW, STBL, and ABL for each sample collecting area.

Area	BW		STBL		ABL	
	Mean value	95% CI	Mean value	95% CI	Mean value	95% CI
Chilaw	1.955	1.923-1.987	2.189	2.177-2.201	1.332	1.328-1.336
Batticaloa	1.769	1.751-1.787	2.285	2.278-2.293	1.354	1.350-1.359
Beruwala	1.974	1.927-2.020	2.170	2.154-2.185	1.318	1.313-1.321
Hambantota	1.609	1.582-1.637	2.305	2.295-2.315	1.334	1.330-1.338
Negombo	1.964	1.928-2.009	2.182	2.169-2.196	1.334	1.328-1.339
Jaffna	1.588	1.548-1.628	2.306	2.288-2.324	1.328	1.322-1.335
Galle	1.803	1.772-1.834	2.248	2.237-2.259	1.345	1.342-1.348
Mullaitivu	1.992	1.950-2.034	2.168	2.153-2.184	1.330	1.325-1.335
Pottuvil	1.703	1.674-1.732	2.284	2.275-2.293	1.349	1.346-1.351

STBL were recorded in Jaffna, Hambantota, Batticaloa, Pottuvil, and Galle, with values of 2.306, 2.305, 2.285, 2.284, and 2.248, respectively ranging from 2.237 (Galle) to 2.324 (Jaffna) of the 95% confidence intervals. There were no significant differences in the STBL also observed in Batticaloa-Jaffna, Batticaloa-Pottuvil, and Hambantota-Jaffna, all areas which have higher values of the standardized means of STBL and the remaining 27 pairwise area combinations indicated a significant difference in the STBL ($p<0.05$) between each area displaying the heterogeneity of the population (Tables 05 and 06).

Of the 36 pairwise combinations of the ABL of the eight populations, no significant differences ($p>0.05$) in the ABL were reported from the Chilaw-Negombo, Chilaw-Mullaitivu, and Negombo-Mullaitivu areas (95% of the confidence intervals of the mean varied from 1.325 (Mullaitivu) to 1.339 (Negombo)); however, compared with BW and STBL, the Beruwala area indicated a significant difference of the ABL ($p<0.05$) with the Chilaw, Negombo, and Mullaitivu areas. Apart from that, Chilaw-Hambantota, Mullaitivu-Hambantota, Chilaw-Jaffna, Mullaitivu-Jaffna, and Negombo-Jaffna areas also did not indicate a significant difference in the ABL varying the 95% confidence intervals of the mean between 1.330 (Hambantota) to 1.335 (Jaffna). The remaining 28 pairwise combinations of areas (with a combination of the Beruwala area) indicated a significant difference in the ABL between each of the areas showing the heterogeneity of the populations (Tables 05 and 06).

As a result of the overall study, graphic illustration and pairwise comparison of the means of BW, STBL, and ABL among the nine populations reported economically important evidence in the selection of parental stocks to obtain benefits in the farming industry. Although the STBL was highest in the Jaffna, Hambantota, Batticaloa, Pottuvil, and Galle areas, the BW of the shrimps in those areas was significantly ($p<0.05$) lower than in the Mullaitivu, Beruwala, Negombo, and Chilaw areas. Therefore, it can be concluded that the shrimp in the Jaffna, Hambantota, Batticaloa, Pottuvil, and Galle areas had proportionately elongated bodies compared to their body weight.In addition, the shrimp in the Jaffna area had the highest STBL, and their low ABL values suggested the presence of an elongated cephalothorax. Further, the Beruwala area shrimps also indicated higher BW within the range of BW of the shrimps in Mullaitivu, Negombo, and Chilaw areas; their significantly ($p<0.05$) lower values of the ABL suggested the presence of fattened animals with shorter lengths. Accordingly, when BW, STBL, and ABL were taken into account as economically important morphological characteristics, the shrimps from the Mullaitivu, Negombo, Chilaw, and Beruwala areas can be used as broodstock for the success of the shrimp farming industry.

CONCLUSION

Using the ten morphometric characters considered in the study as economically significant parameters contributing to the body weight of *P. monodon* wild stocks, multivariate analysis shows no separate cluster formation in the selected broodstock collecting areas, signifying morphological heterogeneity of wild stocks along the coast of Sri Lanka. However, these contributing factors between different localities show significant variation, and abdominal length and standard body length mostly contribute to the economical yield of body weight. Accordingly, Mullaitivu, Negombo, Chilaw, and Beruwala areas are identified as having sub-populations with better morphological traits contributing to the body weight, suggesting prioritizing these broodstock collecting areas for future broodstock improvement programs in Sri Lanka shrimp farming for better economic yield.

Declaration

The authors declare that the research data described in this manuscript has not been published elsewhere.

Conflicts of Interest

The authors declare no conflicts of interest.

REFERENCES

Andriantahina, F., Liu, X., Huang, H., and Xiang, J. (2012). Response to selection, heritability and genetic correlations between body weight and body size in Pacific white shrimp, *Litopenaeus vannamei*. *Chinese Journal of Oceanology and Limnology*, 30(2), 200–205. DOI: http://dx.doi.org/10.1007/s00343-012-1004-3.

Anjani, P. A. D. L., Athula, J. A., Walpita, C. N., and Ruwandeepika, H. A. D. (2020). Morphometric variation analysis of Black Tiger Shrimp (*Penaeus monodon*) bloodstock collected from two sites in Sri Lanka. *Conference Proceedings of 6th International Conference on Dry Zone Agriculture (ICDA 2020)*, 3–4 December 2020. Faculty of Agriculture, University of Jaffna, Sri Lanka. Vol 6, 65p. Retrieved from http://www.conf.jfn.ac.lk/icda2020/.

Chandra, P. K., Rajendran, K. V., Santiago, T. C., Vijayan, K. K., and Rao, L. H. (1997). Reliable criteria for the selection of bloodstock of *Penaeus monodon* Fabricius in genetic improvement programmes. *Indian Journal of Fisheries*, 44(4), 331–336.

Clabaut, C., Bunje, P. M. E., Salzburger, W., and Meyer, A. (2007). Geometric morphometric analyses provide evidence for the adaptive character of the Tanganyikan cichlid fish radiations. *Evolution*, 61, 560–578. DOI: http://doi:10.1111/j.1558-5646.2007.00045.x.

Dai, P., Li, D., Sui, J., Kong, J., Meng, X., and Luan, S. (2023). Prediction of meat yield in the Pacific white leg shrimp *Penaeus vannamei*. *Aquaculture*, 577, 739914. DOI: http://doi.org/10.1016/j.aquaculture.2023.739914.

Dang, T. T., Gringer, N., Jessen, F., Olsen, K., Bøknaes, N., Nielsen, P. L., and Orlien, V. (2018). Emerging and potential technologies for facilitating shrimp peeling: A review. *Innovative Food Science and Emerging Technologies*, 45, 228–240. DOI: http://doi.org/10.1016/j.ifset.2017.10.017.

Daud, S. K., and Ang, K. J. (1995). Selection of bloodstock of tiger prawn, *Penaeus monodon* Fabricius, on the basis of morphometric traits. *Pertanika Journal of Tropical Agricultural Science*, 18, 15–20.

Doherty, D., and McCarthy, T. K. (2004). Morphometric and meristic characteristics analysis of two western Iris populations of Arctic char, *Salvelines alpinus* (L.). *Biology and Environment: Proceedings of the Royal Irish Academy*, 148B(1), 75–85. Royal Irish Academy.

Ekanayake, E. M. H. Y., Athula, J. A., Atapaththu, A. M. D. N. S., and Ranathunga, R. M. N. P. K. (2018). Growth Performance of Black Tiger Shrimp (*Penaeus monodon*) Based on Three Different Brood Stock Collecting Areas Handala, Beruwala, and Mulathivu in Sri Lanka. *Proceeding of the 2nd International Research Symposium of the Uva Wellassa University*, 1–2 February 2018, Uva Wellassa University, Badulla 90000, Sri Lanka. Abstract of papers, 71p.

Falconer, D. S., and Mackay, T. F. C. (1996). *Introduction to Quantitative Genetics*. 4th edn. Longmans Green, Harlow, Essex.

Fernando, G. K. A. W., and Amarasinghe, U. S. (2011). Morphological differentiation of two cichlid species in Sri Lanka using truss networks. *Sri Lanka Journal of Aquatic Science*, 16, 01–10. DOI: http://dx.doi.org/10.4038/sljas.v16i0.6705.

Ferrito, V., Mannino, M. C., Pappalardo, A. M., and Tirano, C. (2007). Morphological variation among populations of *Aphanius fasciatus* Nardo, 1827 (Teleostei, Cyprinodontidae) from the Mediterranean. *Journal of Fish Biology*, 70, 1–2. DOI: http://dx.doi.org/10.1111/j.1095-8649.2006.01192.x.

Haffray, P., Vandeputte, M., Petit, V., and Pincent, C. (2012). Minimizing maternal effect in salmonid families mixed since eyed stages and a posteriori DNA-pedigreed. *Livestock Science*, 150, 170–178. DOI: http://dx.doi.org/10.1016/j.livsci.2012.08.017.

Han, Z. Q., Han, G., Wang, Z. Y., and Sui, B. N. (2015). The genetic divergence and genetic structure of two closely related fish species *Lateolabrax maculatus* and *Lateolabrax japonicus* in the Northwestern Pacific inferred from AFLP markers. *Genes and Genomics*, 37, 471–477. DOI: http://dx.doi.org/10.1007/s13258-015-0276-3.

Lester, L. J., and Pante, M. J. R. (1992). Genetics of *Penaeus* species. In Arlo, W. Fast and L. James Lester, (Eds). *Marine Shrimp Culture: Principles and Practices*. Elsevier Science Publishers, 29–52.

Liasko, R., Anastasiadou, C., Ntakis, A., Gkenas, C., and Leonardos, I. (2012). Morphological differentiation among native trout populations in North-Western Greece. *Journal of Biological Research*, 17, 33–43. Retrieved from http://www.jbr.gr.

Mamuris, Z., Apostolidis, S. A. P., Panagiotaki, P., Theodorou, A. J., and Triantaphyllidis, C. (2005). Morphological variation between red mullet populations in Greece. *Journal of Fish Biology*, 52(1), 107–117. DOI: http://dx.doi.org/10.1111/j.1095-8649.1998.tb01556.x.

Mariappan, P., and Balasundaram, C. (2004). Studies on the morphometry of *Macrobrachium nobilii* (Decapoda, Palaemonidae). *Brazilian Archives of Biology and Technology*, 47, 441–449. DOI: http://doi.org/10.1590/S1516-89132004000300015.

Munasinghe, D. H. N. (2015). Morphological and genetic diversity levels of *Penaeus monodon* (Fabricius, 1798) populations in three coastal regions of Sri Lanka. *Indian Journal of Fisheries*, 62(1), 12–17.

Perez-Rostro, C. I., and Ibarra, A. M. (2003). Quantitative genetic parameter estimates for size and growth rate traits in Pacific white shrimp, *Penaeus vannamei* (Boone 1931) when reared indoors. *Aquaculture Research*, 34(7), 543–553. DOI: http://dx.doi.org/10.1046/j.1365-2109.2003.00851.x.

Priyadarshana, S. D. A. M., Athula, J. A., Ranathunga, R. M. N. P. K., Lakmal, J. A. S., and Adikari, A. M. L. W. (2020). Comparative Study on Growth Performance and Profitability of Shrimp Farming Industry in Sri Lanka: Native *Penaeus monodon* vs. Imported Specific Pathogen Free *Penaeus monodon*. *Proceedings of the International Research Conference of Uva Wellassa University*, July 29–30, 2020, 103p. Retrieved on June 25, 2024, from https://www.uwu.ac.lk/wp-content/uploads/2020/proceeding_oct_08.pdf.

Rebello, V. T., George, M. K., Paulton, M. P., and Sathianandan, T. V. (2014). Morphometric structure of the jumbo tiger prawn, *Penaeus monodon* Fabricius, 1798 from southeast and southwest coasts of India. *Journal of the Marine Biological Association of India*, 55(2), 11–15. DOI: http://dx.doi.org/10.1111/j.1365-2109.2012.03210.x.

Sang, N. V., Thomassen, M., Klemetsdal, G., and Gjoen, H. M. (2009). Prediction of fillet weight, fillet yield, and fillet fat for live river catfish (*Pangasianodon hypophthalmus*). *Aquaculture*, 288, 166–171. DOI: http://dx.doi.org/10.1016/j.aquaculture.2008.11.030.

Senar, J. C., Leonart, J., and Metcalfe, N. B. (1994). Wing-shape variation between resident and transient wintering siskins *Carduelis spinus*. *Journal of Avian Biology*, 25(1), 50–54.

Shin, H. S., Chimborazo, M. E. M., Rivas, J. M. E., Lorenzo-Felipe, A., Soler, M. M., Serrano, M. J. Z., and Lopez, J. M. A. (2023). Genetic parameters for growth and morphological traits of the Pacific white shrimp *Penaeus vannamei* from a selective breeding programme in the industrial sector of Ecuador. *Aquaculture Reports*, 31, 101649. DOI: http://doi.org/10.1016/j.aqrep.2023.101649.

Sun, M. M., Huang, J. H., Jiang, S. G., Yang, Q. B., Zhou, F. L., Zhu, C. Y., Yang, L. S., and Su, T. F. (2013). Morphometric analysis of four different populations of *Penaeus monodon* (Crustacea, Decapoda, Penaeidae). *Aquaculture Research*, 45(1), 113–123. DOI: http://doi.org/10.1111/j.1365-2109.2012.03210.x.

Tian, Y. S., Xu, T. J., Liang, Y., and Chen, S. L. (2011). Estimates of genetic and phenotypic parameters for weight and length in *Paralichthys olivaceus* (Temminck et Schlegel). *Acta Oceanologica Sinica*, 30, 58–64. DOI: http://dx.doi.org/10.1007/s13131-011-0161-0.

Trong, T. Q., Mulder, H. A., Van Arendonk, J. A. M., and Komen, H. (2013). Heritability and genotype by environment interaction estimates for harvest weight, growth rate, and shape of Nile tilapia (*Oreochromis niloticus*) grown in river cage and VAC in Vietnam. *Aquaculture*, 384–387, 119–127. DOI: http://dx.doi.org/10.1016/j.aquaculture.2012.12.022.

Tzeng, T. D. (2004). Stock identification of sword prawn *Parapenaeopsis hardwickii* in the East China Sea and Taiwan Strait inferred by morphometric variation. *Fisheries Science*, 70(5), 758–764. DOI: http://dx.doi.org/10.1111/j.1444-2906.2004.00868.x.

Wang, J., Ai, Q., Mai, K., Xu, H., Zuo, R., Xu, W., and Zhang, C. (2015). Effects of dietary ethoxyquin on growth, feed utilization and residue in the muscle of juvenile Japanese seabass, *Lateolabrax japonicus*. *Aquaculture Research*, 46(11), 2656–2664. DOI: http://dx.doi.org/10.1111/are.12420.

Wang, W., Ma, C. Y., Chen, W., Ma, H. Y., Zhang, H., Meng, Y. Y., and Ma, L. B. (2016). Optimization of selective breeding through analysis of morphological traits in Chinese sea bass (*Lateolabrax maculatus*). *Genetics and Molecular Research*, 15(3), 1–11. DOI: http://dx.doi.org/10.4238/gmr.15038285.

Wang, X. A., Ma, A. J., Huang, Z. H., and Zhou, Z. (2010). Heritability and genetic correlation of survival in turbot (*Scophthalmus maximus*). *Chinese Journal of Oceanology and Limnology*, 28(6), 1200–1205. DOI: http://dx.doi.org/10.1007/s00343-010-9014-5.

Zhao, L. Q., He, Y. Y., Yang, F., and Nie, H. T. (2014). Correlation and path analysis of morphological and weight traits in marine gastropod *Glossaulax reiniana*. *Chinese Journal of Oceanology and Limnology*, 32, 821–827. DOI: http://dx.doi.org/10.1007/s00343-014-3290-4.