



BIOMETRIC AND MORPHOMETRIC STUDIES OF *Perna viridis* AND *Perna indica*
ALONG THE SOUTHWEST COAST OF INDIA: A STATISTICAL APPROACH

Jayalakshmy KV*¹, Maheswari Nair¹, Dileep kumar R¹ and Vijayan M²

¹National Institute of Oceanography, Regional Centre, Kochi-682018, Kerala, India.

²Central Pollution Control Board, Delhi, India.

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ABSTRACT

The growth indices of the Mussels, *Perna viridis* and *Perna indica* collected from the south west coast of India were examined using statistical methods. The Principal Component Analysis (PCA) and Exploratory Factor Analysis (EFA) separated 2 morphometric gradient groups (spat and adult), indicating the different phenotypic plasticity between them. The factor scores classified *P. indica* as a unimodal, positively skewed leptokurtic population and *P. viridis* as a unimodal, negatively skewed leptokurtic population. The allometry was not static, but simple and ontogenetic since their population was continuously varying. The present study shows that factor analysis is better than principal component analysis for delineating the morphometric characteristics of living organisms.

* Corresponding author

E-mail: kvjayaparam@yahoo.co.in (Jayalakshmy KV)

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1 Introduction

Mussels are bivalve mollusks, attached to rocks or any other hard substratum. The common mussels *P. indica* and *P. viridis* predominantly inhabit along the littoral regions of oceans. Growth patterns of molluscs are important to evaluate their production potential and energy flows through populations (Gaspar et al., 2002). *P. viridis* is a common amphiboreal species in India and its growth is influenced by environmental and climatic conditions. Of the two species, the green mussel, *P. viridis*, is widely distributed both on the east and west coast of India along the inter-tidal zones, while *P. indica* has restricted distribution (Appukkuttan et al., 1987). The *P. indica* shell grows up to 12 cm long and 5cm thick, while for *P. viridis* shell grows up to 23 cm long and 7 cm thick. The European counterpart of the green mussel, which is *Mytilus edulis*, are found in low intertidal estuaries. *P. viridis* is of commercial importance because of rapid growth and abundance. They are indicators of pollution by heavy metal, organo chlorides and petroleum hydrocarbons. It is generally tolerant up to salinity 80 PSU, but also survives at low salinity (www.FAO.Org>FAO home>Fisheries & Aquaculture). The growth characteristics of mussels are important to understand the influence of climatic conditions on their morphometry. Temperature is the main factor influencing their growth and other factors include the habitat like littoral, sub-littoral and estuarine regions (Kulakovskii & Lezin, 2002). In the present study, we examine the statistical tools on the morphological features in the two mussels, which are very common in south west coast of India.

2 Materials and Methods

Thirty samples of the two mussels, *P. indica* and *P. viridis* were collected from two stations, viz. Vizhinjam & Calicut of south west coast of India (Figure 1) and the samples were immediately taken for morphometric measurements. This involves the measurement of Shell Length (LT), Height (HT), Width (WI), Volume (VL), Shell weight (empty shell weight without organism) (WT), Wet weight (weight of the organism alone) (WW), Total weight (weight of shell and organism) (TW) and Dry weight (weight of dried organism) (DW) of the two mussel species. LT, HT and WI were measured in the laboratory using the vernier calipers accurate to 0.01cm. WT, WW, TW and DW were taken using an electrical digital balance accurate to 0.001gm. In addition three different ratios were defined; WI/LT, HT/LT and WI/HT for the two sets of samples to determine whether a simple allometry exists between the size and shape measurements or it is a complex allometry.

2.1 Data analysis

All data subjected to statistical tests were first checked for normality using chi-square test of goodness of fit (Sokal & Rohlf, 1995) applying correction for chi square test and using

the degrees of freedom as $n-p-1$ where n is the no. of classes and p is the number of parameters estimated for fitting normal distribution (Anderson, 2006) and for homogeneity of variances using Bartlett's test (Snedecor & Cochran, 1967; Jayalakshmy, 1998). When these conditions were satisfied parametric tests were used in subsequent analysis otherwise non parametric analogues were used. Pearson correlation coefficient test was used to analyze the correlations between the various characteristics of mussels. Before applying the normality test the data are classified into frequency distribution using Sturge's formula for number of classes (Gupta, 2007) to minimize the error due to grouping and all the distribution parameters including the test of symmetry and kurtosis of the distribution are calculated (Jayalakshmy, 1998; Gupta, 2007) to justify the type of population from which the sampling was done. Ordination of samples by PCA and EFA were applied to compare the two species based on the linear combination of the morphometric measures and then to determine a linear combination to discriminate between the species based on these measures which reflect the similarity of their morphometric measures. In this study both PCA and EFA are applied and the groups of measures obtained are compared between the species to delineate the type of distribution of the population from which the samples are drawn. Factor loadings of factors 1 and 2 are plotted for measures as well as for mussels to compare the sets of measures with that obtained from the PC analysis. As an additional application of EFA, distributions of factor scores for mussels are explored (Goodall, 1954) to designate the type of population from which the species samples are collected. Statistical techniques such as 2 Way ANOVA and student's t test can identify the differences between their characteristics based on allometry. Canonical discriminate analysis is applied to discriminate between the two populations of mussels based on the morphometric measures which are not significantly correlated (Snedecor & Cochran, 1967; Larzen & Marx, 1981; Jayalakshmy, 1998).

3 Results and Discussion

P. indica collected from Vizhinjam ranged in length from 3.05 to 6.65cm (Figure 2 a-h, Table 1a) while for *P. viridis* collected from Calicut measured 2.43 to 10.6cm in length (Figure 3 a-h, Table 1b). Shell height of *P. indica* varied between 1.87 and 3.20cm whereas for *P. viridis* it was 1.44 to 4.47cm. Shell width varied over a narrow range (1.05 – 1.95cm) for *P. indica* while for *P. viridis*, it was higher (0.87 – 3.3cm). Shell volume of *P. indica* was only (1/4th) (1.5 to 5ml) of that of *P. viridis* (0.52 – 22ml). Mussel wise variation for volume was double in the case of *P. viridis* (C.V.% = 92.98) compared to *P. indica*. Shell weight for *P. indica* ranged over 1.25 to 7.07gm whereas it was 1.55 to 33.1gm for *P. viridis*. Mussel wise variability of shell weight for *P. viridis* was nearly 3 times of that of *P. indica* with shell wet weight ranging over 1.28-4.26gm. In the case of *P. viridis* the range for shell wet weight was 1.18 to 22.8gm, nearly 5 times of that of *P. indica*, being nearly 3 times bigger than *P. indica*. Dry

shell weight varied in the range 0.11 – 1.65 gm for *P. indica* and 0.03 – 3.62gm for the other species. Normal distribution (Jayalakshmy, 1998) fitted for the two species showed that observed measurements do (Table 1a) adhere to follow Normal probability density function ($P>0.05$) for all measures except wet weight and total weight in the case of *P. indica* and except height and wet weight in the case of *P. viridis* (Table 1b) ($P<0.05$). Invariably for all shape measures (length, height, width and volume), *P. viridis* showed higher significance and higher deviation from normality compared to *P. indica* where as for size measures it was vice-versa (Figure 2 and 3). Blay (1989) has studied the length distribution of 5 populations of the fresh water bivalve *Aspatharia sinuate* in Nigeria.

Q-Mode factor analysis (Gooddall, 1954) when applied for *P. indica* after row normalization and varimax rotation to simple structure (Kaiser, 1958), delineated only one significant factor with eigen value, λ , 29.58 explaining about 49.79% variability forming the differential factor group and this factor contains all the mussels from one to 19 and the factor 2 with eigen value 0.2933, explaining about 49.79% of the total variance, constituted by the individuals from 20 to 30 (Figure 4b). The factor 1 contained individuals of lower values for all parameters, where as factor 2 contained mussels with higher values for all parameters, thus (Harman, 1967) grouping the

mussels into spat- small mussels and adult -large mussels. But spat mussels are observed to explain the same amount of variations observed in the morphometric characteristics as that by the adult mussels collected from Vizhinjam implying that *P. indica* spat animals are ecologically equally efficient as their adults.

PCA applied has also divided the 30 mussels into two PC's with Eigen values 29.58 and 0.293 respectively and each explaining 49.79% of variance. PC1 and PC2 plotted for *P. indica* has divided the 30 mussels into two groups. One with 19 mussels which are big shaped big sized (adults) mussels and the second with 11 mussels which are small shaped and small sized (spat) ones (Figure 4a). EFA has also grouped the mussels exactly in the same manner as obtained from PCA. But the EFA has given a clear cut demarcation between mussels based on their size and shape for both the species and this uniqueness has been materialized only due to varimax rotation to simple structure. Also all measures are observed to be significantly correlated with factor1 and factor 2 loadings ($r>0.901$, $P<0.001$) except VL ($r=0.891$, $P<0.01$) and HT($r=0.736$, $P<0.01$) which are moderately correlated and it is clearly depicted in the plot of factor loadings also (Figure 4 a-d).

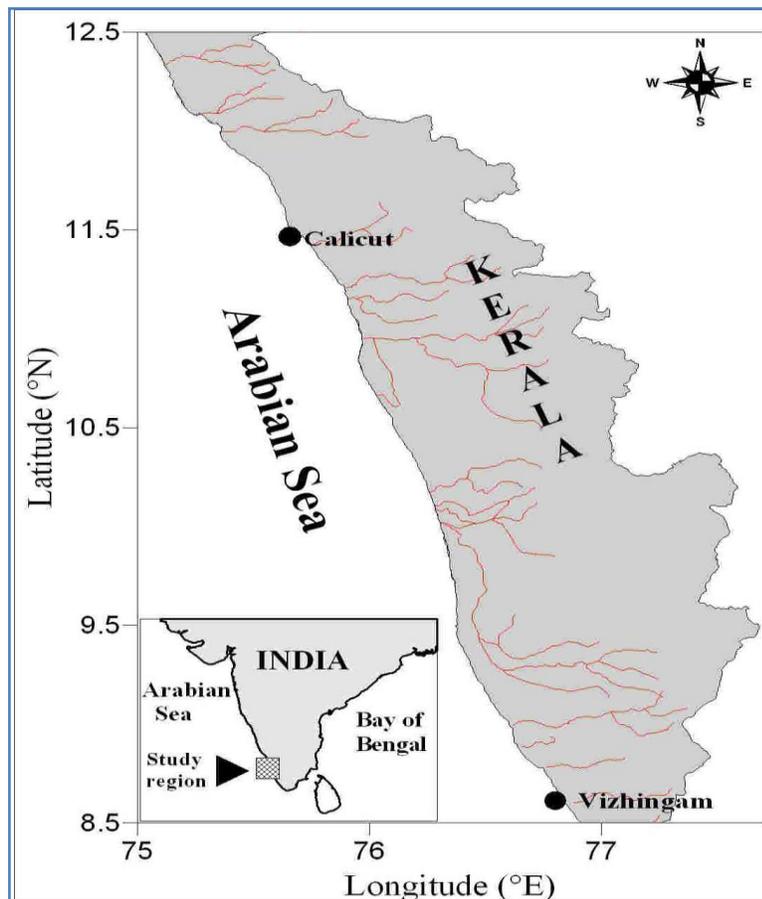


Figure 1 Study region showing station locations.

Table 1 Distribution of shell measurements of *Perna indica* and *Perna viridis*.

(a) Distribution of shell measurements of <i>Perna indica</i>									
Parameters	Mean	Std	CV%	Inter quartile range	β_1	Test1	β_2	Test2	Calculated value of $\chi^2_{(2)}$
Length	4.979	0.8901	17.88	0.712	0.1443	0.3226	2.093*	2.342*	0.1944
Height	2.685	0.337	12.55	0.2358	-0.0333	-0.0744	2.4105	2.695*	2.3333
Width	1.6077	0.2365	14.71	0.1961	-0.1429	-0.3196	2.1524	2.4065*	2.5774
Volume	2.6333	1.1442	43.45	0.9046	0.7008	1.5677	2.2174	2.4792*	0.1917
Weight	4.1473	1.6176	39.07	1.3095	0.3604	0.8058	1.8371	2.054*	2.6705
Wet wt.	2.8013	1.0443	37.28	0.9558	0.4507	1.0077	1.5794	1.7658	15.3095*
Total wt.	6.9337	2.6138	37.70	2.1256	0.4901	1.0959	1.6858	1.8848	11.379*
Dry wt.	0.5693	0.3256	57.19	0.154	1.3243	2.9613*	5.2334	5.8511*	4.0657
(b) Distribution of shell measurements of <i>Perna viridis</i>									
Parameters	Mean	Std	CV%	Inter quartile range	β_1	Test1	β_2	Test2	Calculated value of $\chi^2_{(2)}$
Length	5.7053	2.2623	39.65	1.9756	1.194	2.6699*	3.426	3.8304*	4.0536
Height	2.7380	0.7919	28.92	0.6972	0.4990	1.1177	1.8088	2.0223*	6.75*
Width	1.8153	0.6483	35.71	0.5988	0.5069	1.1334	1.9195	2.1461*	3.9821
Volume	6.0167	5.5948	92.99	2.8907	1.2279	2.7457*	3.6712	4.1045*	2.6389
Weight	8.446	8.5398	101.11	9.5439	0.4542	1.0157	1.8918	2.115*	2.5635
Wet wt.	7.3613	5.4538	74.09	4.0459	1.0763	2.4066*	3.4212	3.825*	7.6727*
Total wt.	15.6413	13.740	87.85	7.7978	1.1652	2.6054*	3.4694	3.8789*	3.8259

+ - Tabled value of $\chi^2_{(2)}=5.99$, * - Calculated value of corrected (expected frequency < 5 were clubbed together with adjacent frequencies) $\chi^2_{(2)} > 5.99$, P<0.05.

Table 2 Showing the significance of skewness and kurtosis of the factor score distribution of *Perna indica* and *Perna viridis*.

Factor score	(a) <i>Perna indica</i>						(b) <i>Perna viridis</i>					
	β_1	Test ₁	β_2	Test ₂	No.of modes	Remarks	β_1	Test ₁	β_2	Test ₂	No.of modes	Remarks
Factor 1	1.1402	2.5496*	3.7914	0.8848	1	PSLD	-1.8869	-4.2193**	5.7698	3.0967**	1	NSLD
Factor 2	1.4859	3.3225**	5.7146	3.0350**	1	PSLD	-1.7314	-3.8705**	5.6163	2.9251**	1	NSLD
Factor 3	-0.5269	-1.1782	2.7294	-0.3025	2	NSPD	0.4253	0.9509	3.9528	1.0653	1	PSLD
Factor 4	0.4444	0.9936	2.9048	-0.1064	1	PSPD	0.0824	0.1833	1.7193	-1.4319	2	PSPD
Factor 5	-0.3023	-0.6759	2.8290	-0.1912	1	NSPD	-1.2882	-2.8806**	4.8325	2.0488*	1	NSLD
Factor 6	-0.6309	-1.4107	3.0858	0.0959	1	NSLD	-0.8784	-1.9642	4.2044	1.3466	1	NSLD
Factor 7	-0.1725	-0.3856	3.0609	0.0681	1	NSLD	-0.2555	-0.5713	2.4811	-0.5802	1	NSPD
Factor 8	2.2175	4.9584**	9.5807	7.3574**	1	PSLD	0.4236	0.9471	2.6154	-0.4300	1	PSPD

PSLD- positively skewed leptokurtic distribution, NSLD- negatively skewed leptokurtic distribution, PSPD – positively skewed platykurtic distribution, NSPD- negatively skewed platykurtic distribution.

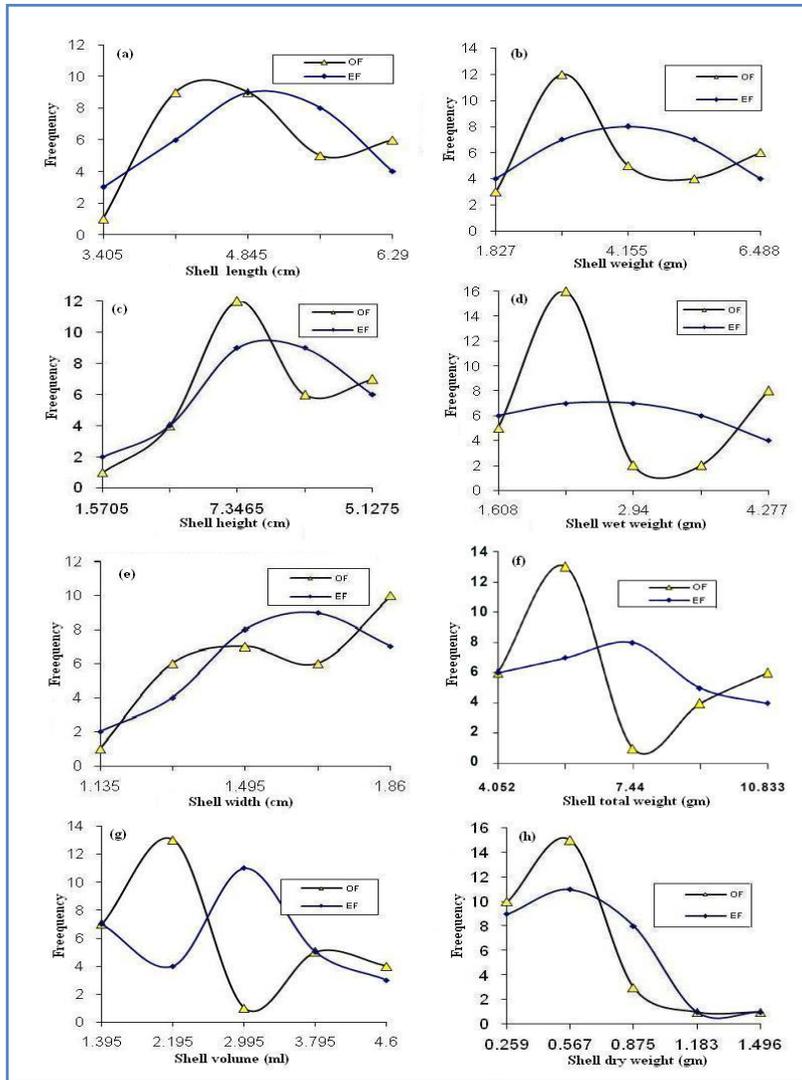


Figure 2 Normal distribution fit to the morphometric measures (a) shell length, (b) shell weight, (c) shell height, (d) shell wet weight, (e) shell width, (f) shell total weight, (g) shell volume, (h) shell dry weight for *Perna indica*.

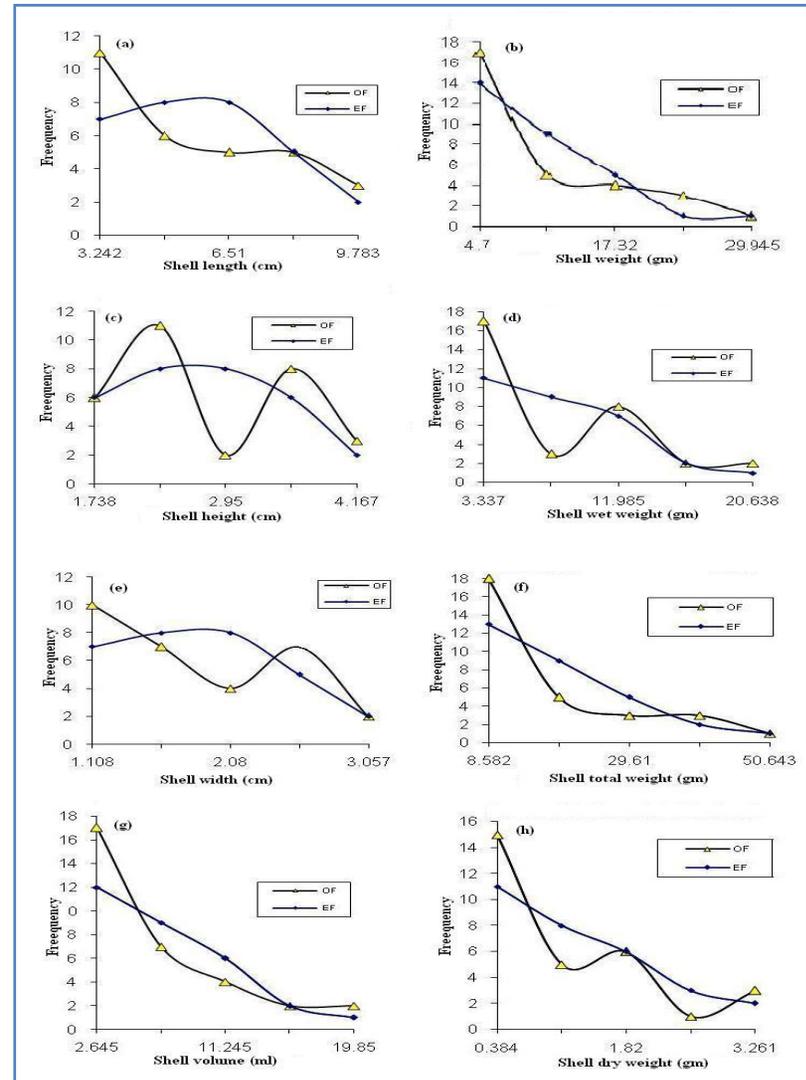


Figure 3 Normal distribution fit to the morphometric measures (a) shell length, (b) shell weight, (c) shell height, (d) shell wet weight, (e) shell width, (f) shell total weight, (g) shell volume, (h) shell dry weight for *Perna viridis*.

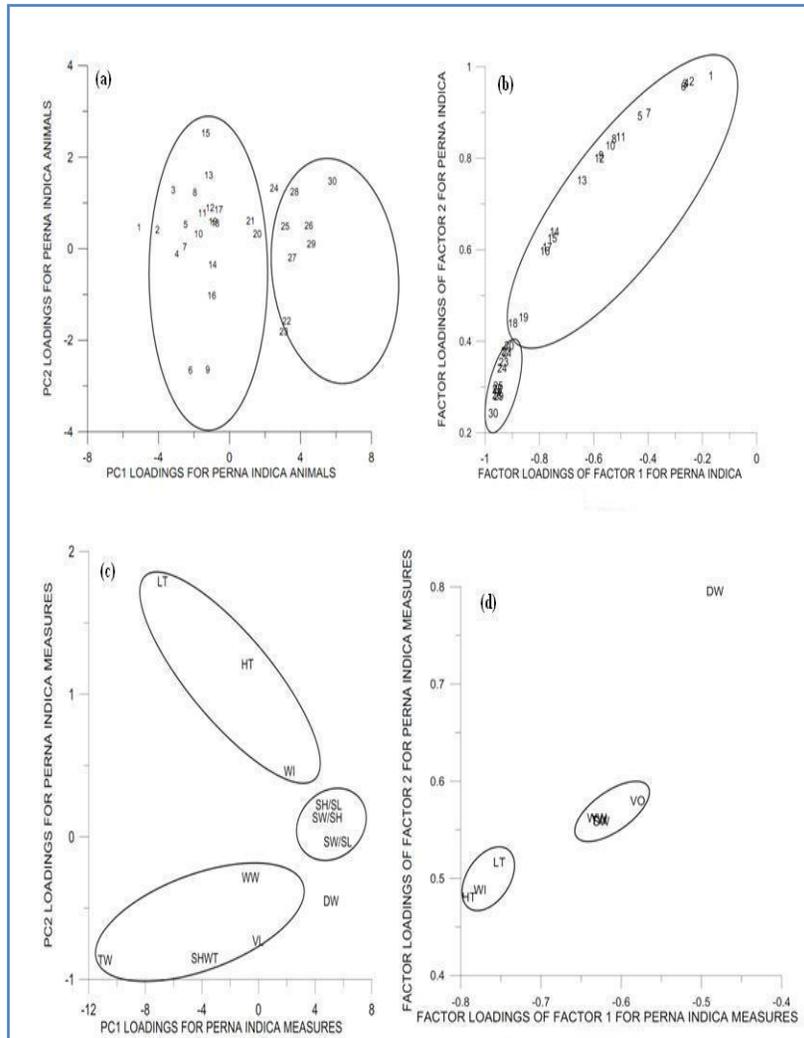


Figure 4 Principal component loadings for PC1 and PC2 of *Perna indica* (a), Factor loadings for factors 1 and 2 of *Perna indica* (b), Principal component loadings for PC1 and PC2 of morphometric measures of *Perna indica* (c) and -Factor loadings for factors 1 and 2 of morphometric measures of *Perna indica* (d).

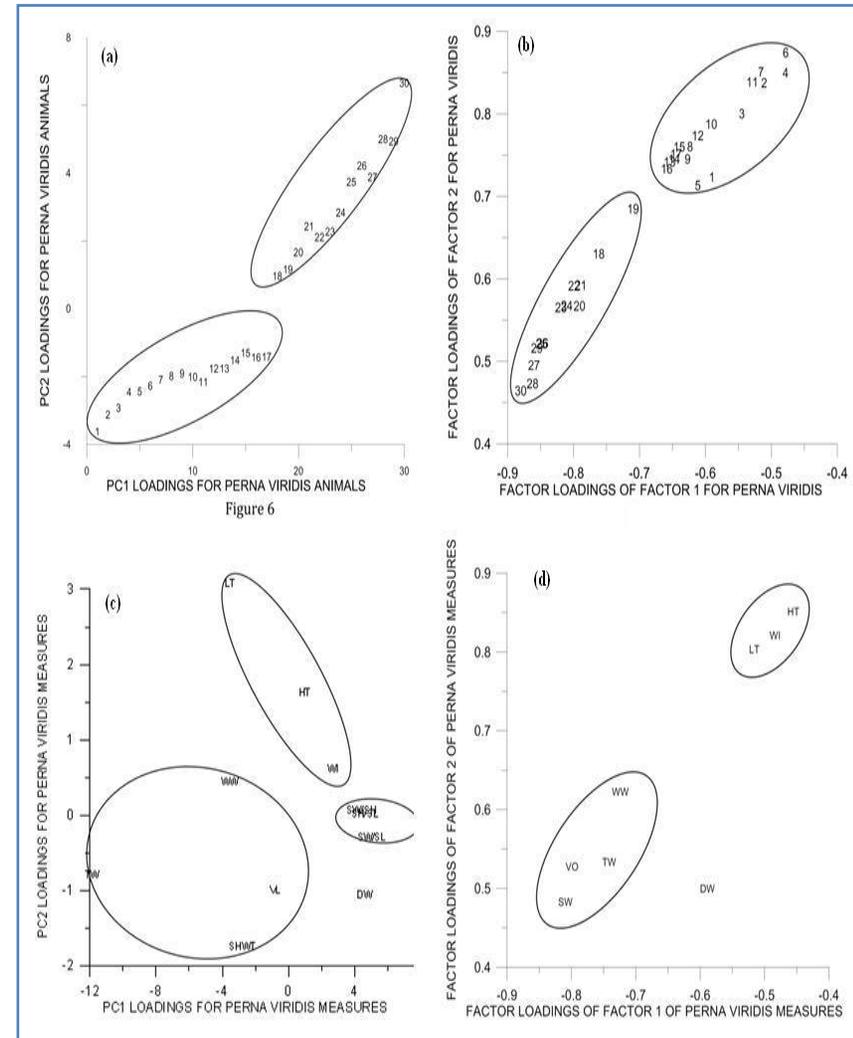


Figure 5 Principal component loadings for PC1 and PC2 of *Perna viridis* (a), Factor loadings for factors 1 and 2 of animals of *Perna viridis* (b), Principal component loadings for PC1 and PC2 of morphometric measures of *Perna viridis* (c) and Factor loadings for factors 1 and 2 of morphometric measures of *Perna viridis* (d).

R-mode factor analysis applied on *P. indica* resulted in three factors of which only factor 1 is statistically significant ($\lambda > 1$) explaining a total of 99.61% of total variance with highest Eigen value 7.76, explaining about 44.26% of the variability in the mussel distribution (Figure 4d). All loadings of the first factor were negative with moderate loadings for LT, HT, WI, WT, WW and TW and almost approximately equal loadings for first three measures. Second factor has all positive factor loadings with almost same factor loading for all measures

except for DW for which this factor has highest loading with Eigen value, 0.1410 and explains about 33.07% of the variability among mussels. This analysis further stresses the fact that to describe *P. indica*, the morphometric measures including DW are highly essential and additional measures are also required explaining this mussel because the total variance explained by the factors 1 and 2 is less than 100 by a value of 22.67% which is not negligible.

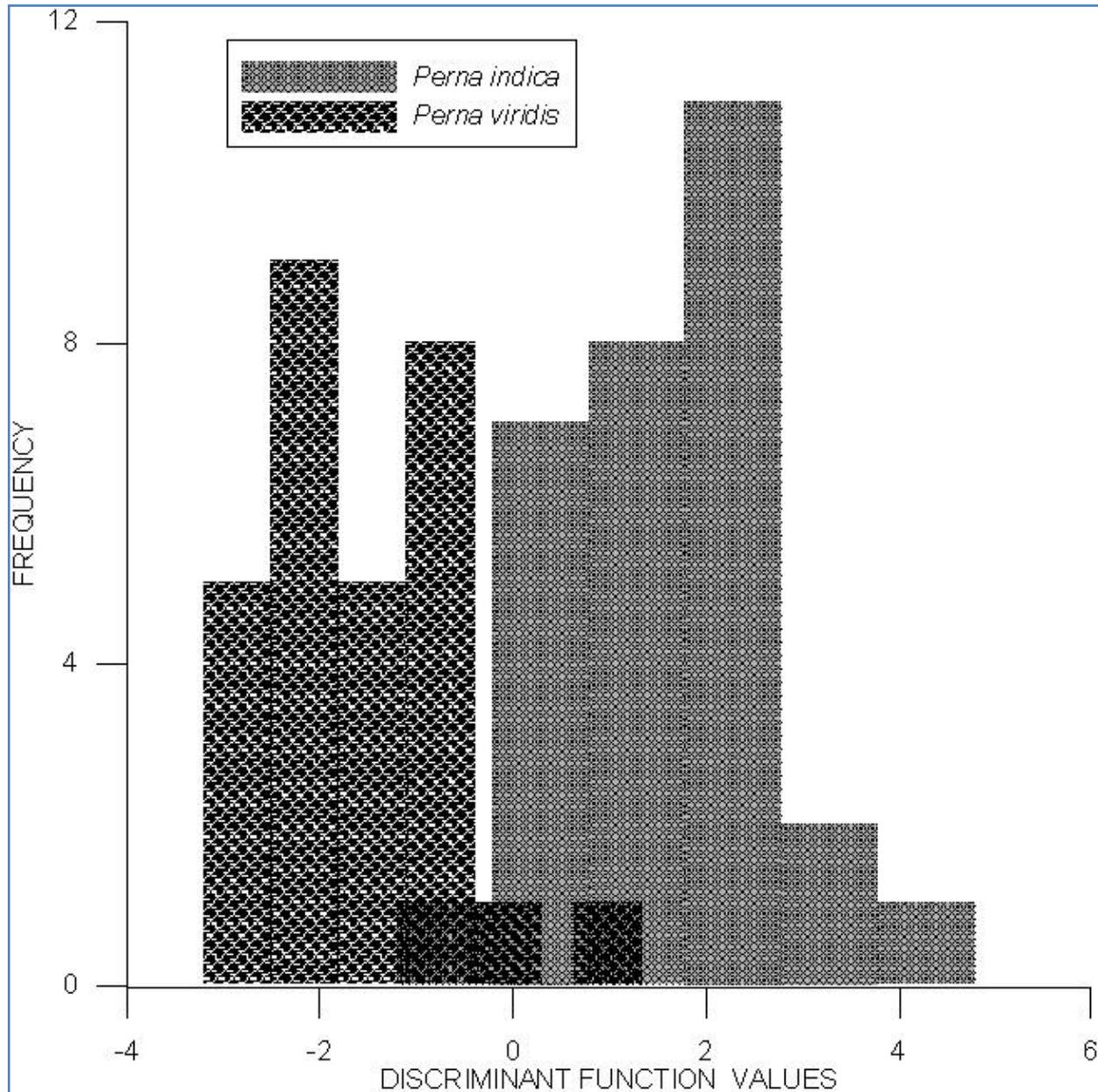


Figure 6 (Canonical Discriminant Analysis (CDA) to discriminate between the species *Perna Indica* and *Perna viridis* based on the biometric and morphometric measures).

Principal component analysis carried out for measures of *P. indica*, resulted in 4 PC's and explained about 97.5% of total variance (Figure 4c). The first PC explained the maximum of the total variation among the samples (88.3%). All of the first component loadings were strongly positive for all morphometric variables except ratio measures, but with almost equal value with respect to all measures. It indicates that PC1 is a measure of shell size due to the high proportion of the explained total variance, Further, it can be concluded that mussel size accounted for most of the variance in the data. Approximately 10.7% of total variance was explained by PC2. Loadings on the PC2 were all positive except that of WI and WW (which are very low values) and DW which has the maximum negative loading on PC2. PC3 explained about 5.9% of total variance in the data. The high positive loading of PC3 was for HT. PC4 had all the loadings negative except that of DW which was the maximum positive for this factor and for HT and TW which were the second maximum and very low values respectively. PC analysis plotted for grouping of measures for *P.indica*, delineated three separate clusters keeping shape measures separated from size measures and all weight measures together with DW as a different entity. Further PCA clustered the ratios in a highly associated manner while the shape measures were grouped in a dispersed pattern, but more associated than the size measures

Q-mode analysis applied on *P. viridis* collected from Calicut, delineated factor1 with Eigen value (λ), 28.56, explaining about 48.72% and constituted by mussels with lower values for all parameters and factor 2 with Eigen value, 0.955 explaining about 48.15% of the variability and constituted by mussels with higher values for all parameters, both together forming the differential factor groups (Figure 5b). This analysis has thus grouped *P. viridis* also based on shell size determined by various weight measurements and shell shape determined by HT and LT, as small sized- small shaped and large sized - big shaped mussels. The plot of PC1 and PC2 obtained from PCA applied for mussels of *P. viridis* has divided the total of 30 individuals into two as small mussels constituting the PC1 and large mussels with larger shape constituting the PC2 (Figure 5a). Factor analysis has also grouped the mussels exactly in the same manner as obtained from PC analysis but with a clear cut characterization for the same reason mentioned earlier (Figure 5b).

Factor analysis by R-mode for the morphometric measures of *P. viridis*, resulted in 1 significant factor explaining ($\lambda > 1$) 42.75% of total variance (Figure 5d). The first factor explained only less than half of the total variation among the data measures. All of the first factor loadings are strongly negative and approximately equal with respect to WT, TW, WW and VL. Also second factor has positive loadings for all the measures and with almost high positive loadings for HT, LT and WI for which it has low negative loadings on factor 1. 42.45% of the total variance was explained by the second factor also. The third factor explained only a nominal amount

(14.42%) of the total variance. Also the third factor has very low positive loadings on all variables except DW. Hence it indicates that the first two factors constitute measures of shell size with respect to high proportion of the total variance and form the differential factor groups including all the weight measurements except dry weight. Hence, it could be concluded that the *P.viridis* is almost completely defined by the morphometric measures premeditated at present, which constitute size factor, shape factor and carbon factor. It further emphasizes that no additional characteristics are required to identify this species because almost all of the variability could be extracted from these three factors unlike *P. indica*.

For *P. indica*, Q-mode Factor 2 contained measures which are highly consistent where as factor 1 is that of measures which highly inconsistent (Table 1a) are. In the case of *P. viridis* also the two groups of morphometric measures are those of higher scale of variability forming factor group 1 and lower scale of variability, (Table 1b) forming factor group 2. Also all measures are observed to be significantly correlated with factor1 loadings and factor 2 loadings ($r>0.934$, $P<0.001$) except DW ($r=0.709$, $P<0.01$) and HT($r=0.876$, $P<0.01$) which are only moderately correlated with the factor loadings.

Based on PC analysis carried out for *P. viridis*, 4 PC's are delineated with a total of 97.2% of the total variance in the measures being explained (Figure 5c). PC1 has all positive loadings with approximately same value for all measures. PC2 has high negative loading on WI and very low negative loading on WW and TW whereas PC3 has moderately high negative loading on DW. PC1 explains about 74.6% of the total variance while PC2 explains only 12.9% of the total variance, concluding that mussel size accounted for most of the variance in the data. PCA for *P. viridis* showed ratios to be highly associated than the shape measures and the size measures. Factor loadings of factors 1 and 2 when plotted for *P. viridis* showed a similar pattern as that obtained from PCA but were more closely associated and shape and size more virtually separated. These disparities in these clustering were less for *P. indica*. This may be because the mussel-wise variation was more for the latter species compared to the former (Tables 1a and 1b).

Studies have compared the ratios of several morphometric variables in mussels (Dermott and Munawar 1993; Pathy & Mackie 1993). In general, the disadvantage of this type of analysis is that ratios are not constant within a group that shows allometry at substantial plasticity (Reyment et al., 1984). Simple allometry occurs if the ratio between the specific growth rates of two different characters is constant (Blackstone, 1987). In this study the ratios, WI/LT, HT/LT and WI/HT are almost constants having less variability (Table 1a and Table 1b) indicating simple allometric relationships between the size measures. Factor score distribution when subjected to shape and symmetry, showed that factors 1 and 2 for both the species are significantly skewed, positively for *P.*

indica and negatively for *P. viridis* and amount of Kurtosis in the population appears to be non trivial for factors 2 and 8 for *P. indica* and factors 1, 2 and 5 for *P. viridis*. For both the species factor score distribution is unimodal for all factors except factor 3 for *P. indica* and except factor 4 for *P. viridis*. This indicates that the samples of both the species have been generated from a continuously varying population but not from distinct and discontinuous mussel populations.

Two ways ANOVA has been applied to compare the two species of mussels for the significance of the difference between the measured characteristics. All morphometric variables except that of HT and WI/LT differed significantly between *P. indica* and *P. viridis* at 1% level ($P < 0.01$). Between mussels also the measured variables differed significantly ($P < 0.05$) except that of WI/HT ($P > 0.10$). Student's t test applied to compare the measures also resulted in the same conclusion. Two way ANOVA as well as t test applied for comparing between factor loadings and between mussels showed significant difference ($P < 0.01$) between the 2 species for factors 3 and 4. Difference between the mussels of the 2 species was also highly significant for factors 1, 2 and 3. Factor loadings of the morphometric measures compared between the 2 species showed high difference only for HT but at a lower level of significance ($P < 0.10$). Mussel wise difference was also highly significant between species for all the measures except DW ($P < 0.05$). The morphometric measures could discriminate between the two species with 89% cross validation (Figure 6).

The commonly used parameters to study growth kinetics of bivalves are the shell length and height (Franz, 1993; Zainudin & Tsuchiya, 2007). However, these data may not always reflect the mass of an organism. Factors such as reproduction, population density and habitat are found to influence the tissue growth. The morphometric variations for *P. viridis* are greater than *P. indica*, as the latter are larger in shape. WT and VL varied widely for *P. viridis*, whereas DW and VL varied for *P. indica*. The smaller size of *P. indica* may be attributed to the different environmental conditions (at Vizhinjam and Calicut) and the presence of predators at Vizhinjam (mussels are consumed by fishes like leatherjackets, crabs and starfish). However, mussels growing in spat fall region will be easily subjected to fouling (by barnacles, tunicates, bryozoans, algae, oysters and amphipods), when their growth is inhibited.

The influence of biological environment is stronger since there is a habitat difference in the proportion of LT to TW (Black, 1977; Lewis & Bowman, 1975). Similarly, the intra specific variation is found between the two populations of *C. karachiensis* from the Gulf of Oman and the Arabian Gulf and has been attributed to the difference in the habitats. The intra specific variations between the two species in WI/LT, WI/HT and HT/LT ratios could be due to the difference in the habitat and size between the species. Alternatively, a difference in the

morphometric character (Emam, 1994) explains the difference in the habitats of the two regions.

The distribution of measures for the two species generally adhered to the probable normal density function except WW and TW for *P. indica* and except HT and WW for *P. viridis*. For all shape measures (LT, HT, WI and VL), *P. viridis* invariably showed greater significance and higher deviation from normality compared to *P. indica*, whereas it was vice-versa for size measures (Figure 2 and 3). Both PCA and EFA are data reduction techniques. But the limitations for PCA are its rigidity of dissimilarity measure and weak distance preservation. The first problem is solved by Gower (1966) extending the PCA to Principal Coordinate Analysis (PCOA) or classical scaling. In this method the set of variables in higher dimensions are reduced to linear combinations of these variables. PCA is used when the variables are highly correlated to reduce the number of variables which account for most of the variance observed.

Factor analysis is used to identify the underlying constructs in data that cannot be directly measured. This method has been used to identify factor structure without imposing any preconceived structure on the outcome (Angel & Fasham, 1974; Child, 1990). EFA provides a distribution pattern for the population from which the sample is collected. It is observed that Q-Mode analysis in EFA (Harman, 1967) grouped the mussels into 2 distinct classes of small and large sizes, but there was uniform variation in their morphometric characteristics. R mode analysis for *P. indica* reveals that other morphometric measures are highly essential since the total variance explained by factors 1 and 2 are < 100 . However *P. viridis* is completely defined by the morphometric measures of size, shape and carbon factor, emphasizing the better prediction of this procedure.

The PCA has divided the 30 mussels (*P. indica*) into two groups (PC1, PC2) of big size (19 mussels) and small size (11 mussels). Factor analysis has also grouped the mussels exactly in the same manner. But EFA has distinguished mussels based on their size and shape through varimax rotation to simple structure. There was also significant correlation between factor 1 and factor 2 loadings ($P < 0.001$) except for volume and height, which were moderately correlated. The total variance of morphometric data for zebra mussel (*Dreissena polymorpha*) was explained by the shell size alone (Trichkova et al., 2008), whereas both shape and size contributed to the total variance in the present study.

Taxonomical studies on quagga mussel (*Dreissena bugensis*) did not yield any nucleotide difference, suggesting that the profundal form of the quagga mussel is a phenotype and not a separate species (Claxton et al., 1998). In contrast, the second and third PCs of the morphometric variables including length, width, height and weight separated the epilimnetic and profundal forms of the quagga mussel irrespective of the

depths (Mackie, 1991). This is due to the fact that *D. bugensis* shows plasticity in shell morphology with respect to depth, whereas *D. polymorpha* does not.

All morphometric variables except for HT and W/LT differed significantly between *P. indica* and *P. viridis*. Between mussels also the measured variables differed significantly except for WI/HT. Student's t test also gave the same result. The growth rate of mussels may vary intra or inter-specifically depending on a number of factors including tides, seasons (Sutherland, 1970), food availability (Parry, 1977), maturation (Kay & Magruder, 1977) and eventually lead to different proportions and longevities (Branch, 1981).

The results obtained by EFA and PCA were in broad agreement with each other except in grouping of mussels. FA providing distribution patterns for the measures are useful for modeling studies. Unlike cluster analysis, FA does not impose a hierarchical structure on the data and the allometry between the measures is simple and ontogenetic, since the mussel population vary based on the factor scores (Cock, 1966). PCA and cluster analysis do not consider rotation to simple structure. The varimax rotation to simple structure (Goodall, 1954) has the advantage that the factor loading matrix (Morrison, 1978) determined from an interspecific coefficient matrix would be that each species would have high loadings on only a few factors (usually one) and its loadings on the other factors would be near zero.

This makes the division of the variables into groups of associated variables simpler than if no rotation had been carried out. FA is better than PCA in this study for delineating the morphometric measures which uniquely defined the mussel population. This study further strengthens the fact that separate allometric relationships between length, height and width for spat larval and adult stages are essential to predict the corresponding size of the mussel.

Taxonomic characteristics have higher potential, while quantitative analysis provides morphological characters in an objective manner. Multivariate analysis can identify independent characters for separating morphological forms (Dodson & Lee, 2006). The growth and shape of shells are influenced by abiotic (environmental) and biotic (physical) factors (Miguel et al., 2002).

Abiotic factors include geographical location (Beukema & Meehan, 1985), depth (Claxton et al., 1998), shore level (Franz, 1993), tides (Dame, 1972), currents, (Furman et al., 1999), turbulence (Bailey & Green, 1988), waves (Akester & Martel, 2000), type of bottom (Claxton et al., 1998), sediment texture (Newell & Hadeu, 1982) and burrowing behavior (Eagar, 1978). In this study, the mussels taken from two different environments were found to be varying by size and shape and hence, other factors are also to be included to further identify their morphometric behavior.

Summary

Two mussels, *P. indica* and *P. viridis* collected from Southwest coast of India were subjected to morphometric studies using statistical techniques on shape and size growth parameters. PCA and EFA separated 2 morphometric gradient groups justifying the different phenotypic plasticity between the spat and adults of the two mussels. The population distribution of *P. indica* was unimodal positively skewed and leptokurtic whereas that of *P. viridis* was also unimodal and leptokurtic but negatively skewed. The growth allometry was simple and ontogenetic but not static since the population was continuously varying. Further this study revealed that EFA is a better tool than PCA for delineating the morphometric characteristics of living organisms.

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