Chapter 3

MORPHOMETRY

3.1. INTRODUCTION

In the analysis of population variations, geographic variation aims at description and summarisation of patterns of variation and covariation of characteristics of organisms distributed over an area. Such analyses are generally applied to species populations to study the variations of diverse characters. Most frequently, the characters employed for such studies are morphological but a more recent trend has been the utilisation of bio-chemical genetics and such other characters.

The basis for studies in geographic variation rest on the existence of population of comparable organisms at a number of localities with a set of characteristics observed for each organism sampled. Geographic variation studies may be univariate or multivariate. A univariate study considers only one character at a time, irrespective of other characters, while in multivariate study, one investigates not only the geographic variation of each character separately but also the covariation of all the characters together. Recent studies have tended to emphasize multivariate techniques (Sokal and Thomas, 1968; Thomas, 1968 a, b). Furthermore, attempts at explaining the pattern of variation in terms of underlying causes, frequently require a multivariate approach.

3.2. REVIEW OF LITERATURE

In any attempt to understand and measure the causes of fluctuations in the abundance of a species, it is imperative that the number and identity

of any sub-sets of species be established. The reason for this is obvious to any rational management plan in as much as each sub-set of the population or species may have a characteristic distribution and characteristic vital statistics. Saila and Flowers (1969) conducted a detailed analysis of morphologic measurements from geographically separated samples of the American lobster, Homarus americanus. The results of the study showed that definite profile differences were greater between inshore and offshore groups within geographically separated samples of both inshore and offshore lobsters.

A review of the statistical methodologies for comparison of morphological data has been provided by Royce (1957) and an explanation of multivariate technique is given by Kendall (1957). Jolicoeur and Mosimann (1960) are of the view that the shape of organisms may be affected by fluctuations in the external environment. Organisms occur in a more or less distinct or discrete population can be defined as stocks and such populations of a species would have one or more common characteristics depending on the type of environment of domicile (Kulkuhn, 1981). The existence of two or more unit stocks can be satisfactorily demonstrated by applying any one of the following techniques such as biochemical, immunological serological,behavioural, morphometric, electrophoretic etc.

Morphological variation studies by Schmidt (1917 a, 1918) in Zoarces viviparous collected from sixty one different locations demonstrated that the characters were heritable and were found to have direct environmental influence. Studies on morphological variations among organisms are plentiful (Boulva, 1972; Abidi et al., 1978; Choudhary and Dwivedi, 1981; Beacham, 1985). Morphometric technique has been successfully used for stock separation

in several species of fishes including Salmo villosus (Sharp et al., 1978), Salvelinus malma (Morrow, 1980) and Corregonus species (Ihssen et al., 1981; Todd et al., 1981). The main advantage of this technique is that it effectively isolates shape differences than most other traditional methods (Ihssen et al., 1981).

Geographical variations in morphological characters were observed in the genus Nematocelis (Crustacea : Euphausidae) (Gopalakrishnan, 1974); isopod Sphaeroma ruoicauda (Heath, 1975); Western Atlantic population of Gammarus oceanicus segerstrale (Amphipoda) (Croker and Gable, 1977); the dwarf cray fish (Chambers et al., 1979) and Pontinella dara (Flemi-nger and Hulseman, 1974).

Morphological differences were employed to delineate intraspecies variations in several marine and freshwater species of prawns (Lindenfelser, 1980; Morgan, 1982). Morphological relationships between Penaeus semisulcatus Metapenaeus and Parapenaeopsis stylifera was demonstrated by Farmur (1986). Several investigators have utilised electrophoresis and morphometry as valuable tools in the identification of different stocks of population and species (Kasinathan et al., 1972; Mickevich and Johnson, 1976; Salmon et al., 1979; Dando et al., 1979; Davidson et al., 1985; Samuel, 1987). Several environmental factors like salinity, temperature, oxygen, food, etc. are found to produce differences in prawn species (Johnson, 1960; Choudhary, 1971; Venkataramiah et al., 1975) with reference to morphometry.

Several workers have opined that among molluscs, the variations in environmental factors can influence the structure of organism (New

Combe, 1935, 1950; New Combe et al., 1938; Swan, 1953). Studies on the dimensional relationship among lamellibranchs by Galtsoff (1931) and Hamai (1934a,b) indicated that animals of different origin show variations in the ratio of their dimensions. Morphometric studies in Meretrix casta collected from two localities was the topic of scientific enquiry by Durve and Dharmaraja (1965). The results demonstrated the influence of environmental conditions on the extent of variation in their relationship. Measurements of shell dimension and their interrelationships in bivalve molluscs have been put to detailed study by several workers (Hamai, 1934a,b; 1935a,b; Abraham, 1953; Holme, 1961; Shafee, 1976; Mohan, 1980; Mohan and Damodaran, 1981; Nair and Nair, 1985; Mohan et al., 1986).

3.3. MATERIALS AND METHODS

3.3.1. SPECIMENS AND STUDY AREA

Details of the selected specimens and the study area have been described earlier (vide pages, Chapter 2).

3.3.2. COLLECTION AND CONDITIONING OF SPECIMENS

The selected animals namely Villorita cyprinoides, Crassostrea madrasensis and Perna viridis were collected from their respective habitats, using van Veen grab and other suitable devices. They were then transported to the laboratory in polyethylene carbuoys of 50 l capacity containing water from the site of collection. The animals were sorted out using vernier calipers and maintained under laboratory conditions for 48 h in aerated habitat water so as to clear them off their faeces.

3.3.3. METHODS

The various morphometric dimensions of the selected specimens were measured out using vernier calipers. All measurements were corrected upto the nearest 0.1 mm. The weight of each specimen was determined using a chemical balance. The morphometric dimensions chosen for each species were based on previous studies (Mohan, 1980; Nair and Nair, 1985; Mohan et al., 1986). Statistical analysis of the data were carried out and the results presented elsewhere.

a) Villorita cyprinoides

1. Length : The greatest dimension along the antero-posterior axis of the valves.
2. Height : The maximum distance between the hinge and the opposite end of the shell.
3. Depth : Greatest distance between the outer surfaces of the two valves, when they were closed.
4. Shell volume : The volume of water occupied by the shell, determined using displacement method.
5. Total weight of the organism.
6. Weight of the wet shell without flesh.
7. Weight of the flesh.
8. Weight of the dry shell.

b) Crassostrea madrasensis

1. Height : Maximum distance recorded from hinge to the opposite side of the shell.

2. Length : Greatest dimension of the antero-posterior axis of the valves.
3. Depth : Maximum distance between the two valves at a point where the axis of the other two dimensions crossed.
4. Shell volume.
5. Total weight of the organism.
6. Weight of the wet shell without flesh.
7. Weight of the flesh.
8. Weight of the dry shell.

c) Perna viridis

1. Length : The maximum distance along the long axis of the valves.
2. Height : Mean distance along the short axis of the valves.
3. Depth : Maximum thickness between the two valves when they were closed.
4. Shell volume.
5. Total weight of the organism.
6. Weight of the wet shell without flesh.
7. Weight of flesh alone.
8. Weight of the dry shell.

3.4. RESULTS

The present study has focused on the extent of variation in the shell characteristics of selected populations of the three species - V. cyprinoides, C. madrasensis and P. viridis. The data obtained had been analysed using various statistical procedures in testing for significance. The results are outlined in Tables 2a-j, 3a-h, 4a-h, 5a-h and 6a-c.

The matrix of correlation (Snedecor and Cochran, 1967) relating the

Table 2 a-e Villorita cyprinoides. Matrix of correlation coefficient among seven morphometric variables of individuals from stations 1 to 5.

2a. Stn. 1

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.000						
Hgt	0.7706	1.0000					
Dpt	0.4821	0.4437	1.0000				
Svl	0.5125	0.3532	0.1958	1.0000			
Twt	0.4980	0.5631	0.3108	0.3493	1.0000		
Fwt	0.1676*	0.1680*	0.2111	0.2821	0.4392	1.0000	
SdWt	0.4700	0.5257	0.2848	0.3093	0.9671	0.2840	1.0000

* Not significant at 5% level

2b. Stn. 2

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.0000						
Hgt	0.7098	1.0000					
Dpt	0.4280	0.5421	1.0000				
Svl	0.6475	0.5422	0.2625	1.0000			
Twt	0.6916	0.6543	0.6821	0.4751	1.0000		
Fwt	0.2954	0.2939	0.1149*	0.2175	0.4726	1.0000	
SdWt	0.6887	0.6468	0.6329	0.4774	0.9718	0.2419	1.0000

* Not significant at 5% level

Len : Length Hgt : Height Dpt : Depth Svl : Shell Volume

Twt : Total Weight Fwt : Flesh Weight SdWt : Shell dry weight

2c. Stn. 3

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.0000						
Hgt	0.8512	1.0000					
Dpt	0.7284	0.7985	1.0000				
Svl	0.8236	0.8335	0.7119	1.0000			
Twt	0.8011	0.7037	0.6880	0.6665	1.0000		
Fwt	0.6253	0.4656	0.5105	0.5135	0.5166	1.0000	
SdWt	0.5678	0.5512	0.5098	0.4763	0.8658	0.0262*	1.0000

* Not significant at 5% level

2d. Stn. 4

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.0000						
Hgt	0.8338	1.0000					
Dpt	0.6612	0.7887	1.0000				
Svl	0.7031	0.7509	0.6131	1.0000			
Twt	0.6462	0.5776	0.6435	0.5764	1.0000		
Fwt	0.2883	0.1412*	0.1570*	0.1578*	0.4250	1.0000	
SdWt	0.6149	0.5819	0.6507	0.5733	0.9669	0.1851*	1.0000

* Not significant at 5% level

2e. Stn. 5

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.0000						
Hgt	0.5966	1.0000					
Dpt	0.5093	0.4769	1.0000				
Svl	0.6231	0.4424	0.3591	1.0000			
Twt	0.7018	0.6387	0.6926	0.5243	1.0000		
Fwt	0.5249	0.4156	0.2764	0.3383	0.5536	1.0000	
SdWt	0.6150	0.5782	0.6929	0.4831	0.9382	0.2488	1.0000

Len : Length Hgt : Height Dpt : Depth Svl : Shell Volume

Twt : Total Weight Fwt : Flesh Weight SdWt : Shell dry weight

various morphometric characters of the three species is given in Tables 2a-j. Except for flesh weight with their length, height and depth, and shell volume with depth, all other correlations were found significant at 1% level for the specimens of V. cyprinoides sampled from station 1 (Table 1a). However, all correlations between the different morphometric variables were found significant ($p \leq 0.01$) with the exception of flesh weight with depth and shell volume, and between shell dry weight and flesh weight of individuals from station 2 (Table 2b). The individuals from station 3 were characterised by significant correlation between the different shell characteristics; the level of significance being 1%. The correlation existing between shell dry weight and flesh weight, however was found not significant (Table 2c). Table 2d depicts the matrix of correlation of the shell characteristics of specimens of V. cyprinoides sampled from station 4. Except for the correlations that existed between shell dry weight and flesh weight and those between flesh weight and the height, depth and shell volume which were statistically not significant, all other correlations depicted high statistical significance ($p \leq 0.01$). It was observed that at station 5, the correlations between the various shell measurements were highly significant at 1% level (Table 2e); no significant correlation existing between shell dry weight and flesh weight.

Table 2f-h illustrate the matrix of correlation of the shell characteristics of C. madrasensis from the three stations. It is evident from Table 2f that the correlations between total weight and shell volume and between flesh weight and length, depth and shell volume and between shell dry weight and shell volume were statistically not significant at 5% level for individuals sampled from station 1. Correlations between depth and height and between shell volume with height and length and between

Table 2 f-h. Crassostrea madrasensis. Matrix of correlation coefficient among seven morphometric variables of individuals from stations 1 to 3.

2f. Stn. 1

	Hgt	Len	Dpt	Svl	Twt	Fwt	SdWt
Hgt	1.0000						
Len	0.5212	1.0000					
Dpt	0.2188	0.5727	1.0000				
Svl	0.2204	0.2520	0.2539	1.0000			
Twt	0.5836	0.4123	0.2562	0.1648	1.0000		
Fwt	0.3298	0.1696*	0.0573*	0.1076*	0.4854	1.0000	
SdWt	0.5120	0.3538	0.2303	0.1292*	0.9783	0.3419	1.0000

* Not significant at 5% level

2g. Stn. 2

	Hgt	Len	Dpt	Svl	Twt	Fwt	SdWt
Hgt	1.0000						
Len	0.6999	1.0000					
Dpt	0.4873	0.4187	1.0000				
Svl	0.4174	0.4874	0.3033	1.0000			
Twt	0.6433	0.6412	0.4498	0.5038	1.0000		
Fwt	0.5709	0.6040	0.3249	0.5493	0.7931	1.0000	
SdWt	0.6590	0.6412	0.4833	0.4833	0.9749	0.7037	1.0000

2h. Stn. 3

	Hgt	Len	Dpt	Svl	Twt	Fwt	SdWt
Hgt	1.0000						
Len	0.5470	1.0000					
Dpt	0.6642	0.5245	1.0000				
Svl	0.5844	0.3463	0.6549	1.0000			
Twt	0.7641	0.4742	0.7392	0.5572	1.0000		
Fwt	0.6725	0.3991	0.6754	0.5550	0.7148	1.0000	
SdWt	0.6929	0.4154	0.6811	0.5018	0.9754	0.5536	1.0000

Hgt : Height Len : Length Dpt : Depth Svl : Shell Volume

Twt : Total Weight Fwt : Flesh Weight SdWt : Shell dry weight

shell dry weight and depth were also not significant at 5% level. All other characters were found to exhibit significant correlation even at 0.1% level. Contrary to the observations at station 1, all correlations between the different morphometric variables of individuals sampled from stations 2 and 3 were highly significant at 1% level.

The correlation matrix of shell characteristics of P. viridis from the two selected stations are illustrated in Table 2i and 2j. It is evident from Table 2i that, except for flesh weight with shell dry weight, all other correlations were highly significant at 1% level. On the other hand, with the exception of shell dry weight with height, depth and flesh weight and between depth and height, all other correlations between the various morphometric variables of individuals from station 2 were significant at 1% level.

To compare the various morphological characteristics of organisms inhabiting the different stations, analysis of variance (ANOVA) technique (Snedecor and Cochran, 1967) was employed. The model used was,

$X_{ij} = \mu + \alpha i + \varepsilon_{ij}$ where,

X_{ij} - is the i^{th} morphometric character of the j^{th} specimen

μ - is the overall effect α_i, of the i^{th} morphometric effect

and ε_{ij} - is the random error.

The results of Analysis of Variance of the different morphometric

Table 2 i-j. Perna viridis. Matrix of correlation coefficient among seven morphometric variables of individuals from stations 1 and 2.

2i. Stn. 1

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.0000						
Hgt	0.5081	1.0000					
Dpt	0.5542	0.2124	1.0000				
Svl	0.6105	0.3433	0.6107	1.0000			
Twt	0.6591	0.4452	0.5208	0.4841	1.0000		
Fwt	0.5978	0.3819	0.4868	0.4086	0.8558	1.0000	
SdWt	0.3875	0.2323	0.2407	0.3208	0.6305	0.1861*	1.0000

* Not significant at 5% level

2j. Stn. 2

	Len	Hgt	Dpt	Svl	Twt	Fwt	SdWt
Len	1.0000						
Hgt	0.6148	1.0000					
Dpt	0.5340	0.3329	1.0000				
Svl	0.6745	0.4174	0.4293	1.0000			
Twt	0.6983	0.5727	0.4713	0.5773	1.0000		
Fwt	0.5796	0.4424	0.3311	0.4616	0.8322	1.0000	
SdWt	0.3978	0.3354	0.4042	0.3701	0.6214	0.2222	1.0000

Len : Length Hgt : Height Dpt : Depth Svl : Shell Volume

Twt : Total Weight Fwt : Flesn Weight SdWt : Shell dry weight

Table 3 a-h. Villorita cyprinoides. Analysis of variance (ANOVA) of the different morphometric variables of individuals from stations 1 to 5 along with their corresponding mean values and level of significance.

3a. Length

Source	SS	Df	Mean Sqr	F	Mean Length (cm)
Total	13.314	249	--		3.80
Station	1.462	4	0.366	7.56*	3.80 3.70
Error	11.852	245	0.048		3.73 3.91

* $P \leq 0.01$

3b. Height

Source	SS	Df	Mean Sqr	F	Mean Height (cm)
Total	30.171	249	--		3.63
Station	12.614	4	3.153	44.00*	3.69 3.13
Error	17.557	245	0.072		3.23 3.53

* $P \leq 0.01$

3c. Deptn

Source	SS	Df	Mean Sqr	F	Mean Deptn (cm)
Total	12.119	249	--		2.57
Station	2.162	4	0.540	13.30*	2.68 2.46
Error	9.957	245	0.041		2.42 2.57

* $P \leq 0.01$

3d. Shell volume

Source	SS	Df	Mean Sqr	F	Mean Shell vol. (ml)
Total	1557.222	249	--		10.11
Station	609.199	4	152.300	39.36*	8.28 6.62
Error	948.023	245	3.869		6.90 10.36

* $P \leq 0.01$

3e. Total weight

Source	SS	Df	Mean Sqr	F	Mean Total wt (gm)
Total	3722.610	249	--		19.07
Station	2075.188	4	518.797	77.15*	22.75 14.53 16.87
Error	1647.422	245	6.724		20.75

* $P \leq 0.01$

3f. Shell weight

Source	SS	Df	Mean Sqr	F	Mean Shell wt (gm)
Total	3021.301	249	--		16.09
Station	1627.102	4	406.775	71.48*	19.74 12.20 14.36
Error	1394.199	245	5.691		17.21

* $P \leq 0.01$

3g. Flesh weight

Source	SS	Df	Mean Sqr	F	Mean Flesh wt (gm)
Total	291.677	249	--		3.00
Station	50.901	4	12.725	12.95*	2.66 2.17 2.44
Error	240.776	245	0.983		3.46

* $P \leq 0.01$

3h. Shell Dry weight

Source	SS	Df	Mean Sqr	F	Mean Shell Dry wt (gm)
Total	2212.797	249	--		15.89
Station	1784.547	4	446.137	76.53*	20.06 12.28 14.31
Error	1428.250	245	5.830		17.56

* $P \leq 0.01$

variables of individuals of V. cyprinoides, C. madrasensis and P. viridis from the selected stations are outlined in Tables 3a-h, 4a-h and 5a-h. Wherever significant difference in mean was observed, the least significant difference at 1% level was calculated; the means are separated and presented along with the tables.

The length of V. cyprinoides from the five stations was subjected to 'ANOVA'. Depicting statistically significant variation between stations ($p \leq 0.01$), the individuals from station 5 showed higher mean length (Table 3a) when compared with those from the other stations. Notwithstanding the significant variations in height observed between stations at 1% level, the 'ANOVA' revealed that individuals from stations 1 and 2 had higher mean height than their counterparts from other stations (Table 3b).

Tables 3c,e,f and h illustrate the 'ANOVA' of depth, total weight, shell weight and shell dry weight of V. cyprinoides from the five stations. The results indicated statistically significant variation between stations ($p \leq 0.01$); the highest mean depth, total weight, shell weight and shell dry weight being characteristic to individuals from station 2. Table 3d outlines the 'ANOVA' of the shell volume of specimens of V. cyprinoides. When compared with other stations, individuals from station 1 and 5 recorded the highest mean shell volume and the observed difference between stations were statistically significant ($p \leq 0.01$). 'ANOVA' of the flesh weight showed significant variation between stations at 1% level and the highest mean flesh weight was depicted by individuals from station 5 (Table 3g).

Tables 4a-h illustrate the analysis of variance (ANOVA) of different

Table 4 a-h. Crassostrea madrasensis. Analysis of variance (ANOVA) of the different morphometric variables of individuals from stations 1 to 3 along with their corresponding mean values and level of significance.

4a. Height

Source	SS	Df	Mean Sqr	F	Mean Height (cm)
Total	19.125	149	--		6.78
Station	0.638	2	0.319	2.41	6.66
Error	19.487	147	0.133		6.64

4b. Length

Source	SS	Df	Mean Sqr	F	Mean Length (cm)
Total	12.691	149	--		4.81
Station	0.365	2	0.182	2.18	4.74
Error	12.326	147	0.084		4.69

4c. Depth

Source	SS	Df	Mean Sqr	F	Mean Depth (cm)
Total	11.657	149	--		2.92
Station	0.364	2	0.182	2.37	3.00
Error	11.293	147	0.077		2.88

4d. Shell Volume

Source	SS	Df	Mean Sqr	F	Mean Shell vol. (ml)
Total	811.549	149	--		12.54
Station	41.545	2	20.772	3.97	13.53
Error	770.004	147	5.238		12.32

4e. Total weight

Source	SS	Df	Mean Sqr	F	Mean Total wt (gm)
Total	3617.563	149	--		50.43
Station	133.625	2	66.813	2.83	49.86
Error	3473.938	147	23.632		48.20

4f. Shell Weight

Source	SS	Df	Mean Sqr	F	Mean Shell wt (gm)
Total	3071.828	149	--		39.14
Station	333.500	2	166.750	8.95*	37.57
Error	2738.328	147	18.628		35.50

* $P \leq 0.01$

4g. Flesh weight

Source	SS	Df	Mean Sqr	F	Mean Flesh wt (gm)
Total	367.983	149	--		12.12
Station	17.682	2	8.841	3.71*	12.92
Error	350.301	147	2.383		12.74

* $P \leq 0.01$

4h. Shell Dry weight

Source	SS	Df	Mean Sqr	F	Mean Shell Dry wt (gm)
Total	3541.657	149	--		37.23
Station	215.391	2	107.695	4.76*	37.76
Error	3326.266	147	22.628		35.00

* $P \leq 0.01$

morphometric variables of C. madrasensis from the three stations. Tables 4a, b, c, d and e explain the 'ANOVA' of height, length, depth, shell volume and total weight and no significant difference was observed between the three stations under study. Table 4f gives the 'ANOVA' of shell weight of C. madrasensis and specimens from stations 1 and 2 had higher mean shell weight when compared to the third station. The 'ANOVA' of flesh weight as explained in Table 4g revealed significant difference between stations at 1% level; stations 2 and 3 depicting higher mean flesh weight than those from station 1. Table 4h gives the 'ANOVA' of shell dry weight of C. madrasensis from the three stations. Here also, statistically significant difference was observed at 1% level. Individuals from station 3 had comparatively low shell dry weight.

Similarly, Table 5a-h represent the results of analysis of variance (ANOVA) of different morphometric characters of P. viridis sampled from the two selected stations. No significant difference between stations at 1% level was observed as far as the morphometric characters concerned.

The multiple regression of total weight on different parameters were worked out for all stations of the three test species using the mathematical model,

$Y = b0 + b1X1 + b2X2 + b3X3 + b4X4 + b5X5 + b6X6$, where,

Y is the total weight,

and X1, X2, X3, X4, X5 and X6 are the different variables.

The coefficient of multiple correlation (R^2) was highly significant

Table 5 a-h. Perna viridis. Analysis of variance (ANOVA) of the different morphometric variables of individuals from stations 1 and 2 along with their corresponding mean values and level of significance.

5a. Length

Source	SS	Df	Mean Sqr	F	Mean Length (cm)
Total	1.288	99	--		4.68
Station	0.002	1	0.002	0.17	
Error	1.286	98	0.013		4.67

5b. Height

Source	SS	Df	Mean Sqr	F	Mean Height (cm)
Total	0.278	99	--		1.99
Station	0.000	1	0.000	0.17	
Error	0.278	98	0.003		1.99

5c. Depth

Source	SS	Df	Mean Sqr	F	Mean Depth (cm)
Total	1.457	99	--		1.65
Station	0.009	1	0.009	0.61	
Error	1.448	98	0.015		1.63

5d. Shell Volume

Source	SS	Df	Mean Sqr	F	Mean Shell vol. (ml)
Total	19.249	99	--		5.55
Station	0.004	1	0.004	0.02	
Error	19.245	98	0.196		5.54

5e. Total weight

Source	SS	Df	Mean Sqr	F	Mean Total wt. (gm)
Total	117.667	99	--		7.43
Station	0.042	1	0.042	0.03	
Error	117.625	98	1.200		7.39

5f. Shell weight

Source	SS	Df	Mean Sqr	F	Mean Shell wt. (gm)
Total	11.861	99	--		3.07
Station	0.008	1	0.008	0.06	
Error	11.853	98	0.121		3.08

5g. Flesh weight

Source	SS	Df	Mean Sqr	F	Mean Flesh wt (gm)
Total	51.848	99	--		4.01
Station	0.128	1	0.128	0.24	
Error	51.720	98	0.528		4.08

5h. Shell Dry weight

Source	SS	Df	Mean Sqr	F	Mean Shell Dry wt (gm)
Total	11.451	99	--		3.00
Station	0.115	1	0.115	0.99	
Error	11.336	98	0.116		3.07

in all the stations. This indicates that the variable taken into account explains a significant part of the variability in the data. The fitted multiple regressions and the corresponding R^2 values are given below.

a) V. cyprinoides

Stn. 1

$$Y = 0.8034 + 0.1356\ X1 + 0.0089\ X2 + 0.0219\ X3 + 0.0935\ X4 - 0.0311\ X5 + 0.01970\ X6$$

$R^2 = 0.5597$; N = 100.

Stn. 2

$$Y = 0.0815 + 0.0393\ X1 - 0.0143\ X2 + 0.1855\ X3 - 0.0772\ X4 + 0.0994\ X5 + 0.2124\ X6$$

$R^2 = 0.7362$; N = 100

Stn. 3

$$Y = 0.8284 + 0.1668\ X1 + 0.0028\ X2 - 0.0026\ X3 - 0.0111\ X4 + 0.0403\ X5 + 0.1892\ X6$$

$R^2 = 0.9487$; N = 100.

Stn. 4

$$Y = 0.8336 + 0.1635\ X1 + 0.0038\ X2 + 0.0197\ X3 - 0.0178\ X4 + 0.0200\ X5 + 0.1869\ X6$$

$R^2 = 0.82234$; N = 100.

Stn. 5

$$Y = 0.8120 + 0.1746\ X1 - 0.0034\ X2 + 0.0238\ X3 + 0.0135\ X4 - 0.0252\ X5 + 0.1979\ X6$$

R^2 = 0.5367; N = 100. where

X1 = Length, X4 = Shell volume

X2 = Height X5 = Flesh weight

X3 = Depth X6 = Shell dry weight.

b) C. madrasensis

Stn. 1

$$Y = 0.6879 + 0.1947\ X1 + 0.0085\ X2 + 0.0109\ X3 + 0.0511\ X4 + 0.1234\ X5 + 0.2574\ X6$$

R^2 = 0.9445; N = 100.

Stn. 2

$$Y = 0.7441 + 0.2769\ X1 - 0.0274\ X2 - 0.0207\ X3 - 0.0230\ X4 - 0.0830\ X5 + 0.3356\ X6$$

R^2 = 0.8808; N = 100.

Stn. 3

$$Y = 0.6770 + 0.2677\ X1 - 0.0112\ X2 - 0.0215\ X3 + 0.0827\ X4 + 0.0707\ X5 + 0.2497\ X6$$

R^2 = 0.9632; N = 100, where,

X1 = Height X4 = Shell volume

X2 = Length X5 = Flesh weight

X3 = Depth X6 = Shell dry weight

c) P. viridis

Stn. 1

$$Y = 0.4918 + 0.3767\ X1 + 0.0702\ X2 + 0.0193\ X3 - 0.0863\ X4 + 0.5715\ X5 - 0.0305\ X6$$

$R^2 = 0.8644$; $N = 100$.

Stn. 2

$$Y = 0.5029 + 0.4336\ X1 - 0.0209\ X2 - 0.2738\ X3 + 0.1401\ X4 + 0.1257\ X5 + 0.1698\ X6$$

$R^2 = 0.8644$; $N = 100$, where,

X1 = Length
X2 = Height
X3 = Depth
X4 = Shell volume
X5 = Flesh weight
X6 = Shell dry weight

The relative importance of the different parameters in the fitted multiple regression model, for the different species were calculated using the formula, $b_i \sqrt{x_1^2/y^2}$ (Snedecor and Cochran, 1967) and are illustrated in Tables 6a-c.

Table 6a illustrates the relative importance of the different variables of V. cyprinoides. It is evident that in the first four stations, shell dry weight was the most important factor but in station 5, length was found to be more important than the other morphometric parameters. This difference may be explained as due to variations in the hydrological factors, mostly salinity, at station 5 when compared to other stations. Table 6b

Table 6a. Villorita cyprinoides. Relative importance of the different morphometric variables of individuals from stations 1 to 5.

	Stn. 1	Stn. 2	Stn. 3	Stn. 4	Stn. 5
Length (X1)	0.1241	0.0406	0.1661	0.1600	0.2324
Height (X2)	0.0077	-0.0413	0.0021	0.0031	-0.0045
Breadth (X3)	0.0148	0.2020	-0.0021	0.0191	0.0294
Shell vol (X4)	0.0355	-0.0477	-0.0057	-0.0056	0.0088
Flesh wt (X5)	-0.0151	0.0230	0.0171	0.0293	-0.0133
Sh. dry wt. (X6)	0.1847	0.2090	0.1831	0.1763	0.1894

Table 6b. Crassostrea madrasensis. Relative importance of the different morphometric variables of idividuals from stations 1 to 3.

	Stn. 1	Stn. 2	Stn. 3
Height (X1)	0.2129	0.3704	0.3641
Breadth (X2)	0.0065	-0.0337	-0.0128
Depth (X3)	0.0062	-0.0170	-0.0225
Shell vol (X4)	0.0192	-0.0200	0.0743
Flesh wt (X5)	0.0957	-0.0814	0.0629
Sh. dry wt. (X6)	0.2054	0.3090	0.2237

Table 6c. Perna viridis. Relative importance of the different morphometric variables of individuals from stations 1 and 2.

	Stn. 1	Stn. 2
Length (X1)	0.6102	0.7078
Height (X2)	0.0816	-0.0244
Breadth (X3)	0.0282	0.4422
Shell wt (X4)	-0.0945	0.1458
Flesh wt (X5)	0.3970	0.0907
Sh. dry wt. (X6)	-0.0262	0.1393

gives the relative importance of the various morphometric parameters of C. madrasensis. In all the three stations, height was found to be the most important parameter. Similarly, the relative importance of the different variables in the regression model of P. viridis is outlined in Table 6c. In both the stations, length was found to be the most important factor in comparison with other variables.

3.5. DISCUSSION

Morphological characters represent a series of measured variables and represent the synergism between shape and size. Effects of physiological and epigenetic constraints on morphology is directly related to certain environmental parameters such as temperature, salinity and oxygen. The nature of observed variations, however, suggested that morphometric differences are of adaptive significance. Univariate and multivariate analyses have been found to be effective in the analysis of geographic variation with respect to multiple characters. Further, analysis of the data employing the two methods would give a better understanding of the nature of variation within and between populations.

The results on univariate and multivariate analysis of the shell measurements revealed that variations did exist between populations of the three species the extent of variation although different in the three species. The difference in shell characters observed in respect of V. cyprinoides may in part be attributed to the changes in climate correlated with the latitudinal and longitudinal changes. Wilson and Summers (1966) found a clinal variation in relative width of the shell of Zoila friendi (Cowrie) around the southern

coast of Australia from Shark Bay in Western Australia to Southern Australia and deduced that water temperature was probably the environmental factor producing this cline. Similar observations on the effect of temperature on growth have been made by Barnes and Healy (1965, 1969) in some common cirripeds in which measurements of scuta and terga were found to be correlated with environmental temperature.

The variations in morphometric characteristics observed during the present study could possibly be due to changes in habitat salinity which was significantly different in the selected stations and may have exerted a major influence on the organism as a whole and shell characteristics in particular. It may be noted here that, the substratum of V. cyprinoides from stations 1, 2 and 3 was muddy in nature while those from stations 4 and 5 was sandy. Univariate analysis of the data revealed that variations did occur in the shell characteristics, among and between populations from stations of both sandy and muddy substrata (Table 3a-h). It has been suggested that the similarity of animals found on similar substrata is possibly not related to the substratum itself and it may be due to the food sources available or to a number of other factors as well. Further, it is reported that sites with similar substrata may offer similar food sources or other conditions (Phillips et al., 1973). The present results however, do not support the above contention.

In the case of C. madrasensis, despite the similarity in substratum, significant variations were observed at 1% level in the shell characteristics, especially with regard to shell weight, flesh weight and shell dry weight (Tables 4f, g and h), among the three selected stations. On the other

hand, in P. viridis, no significant variation in shell characters was evident, despite the similarity in substratum as evidenced by both univariate and multivariate analyses (Table 5a-h). Here also, the effect of substratum on shell characteristics seems doubtful.

Kitching et al. (1968) found that Nucella lapillus found on the open coast had a larger body weight, length and width of aperture and area of foot than in a sheltered area. Further, it was found that animals on the open coast had greater powers of adhesion under rough weather conditions. Moore (1936) found that an increase in mussels (Mytilus) in the food of Nucella lapillus tended to produce a fatter shell with a more open spiral and wider aperture. It was therefore assumed that food could play a significant role in causing the variation in shell characteristics of different populations. Further, studies on the development of Dicathais by Phillips et al. (1973) revealed that food may be particularly important as one of the selective forces of the habitat defining its development especially the shell characteristics. Although the study revealed a possible relationship between food and shell shape, it was suggested that what part of the food was more important at each of the selected sites is difficult to determine. They further pointed out that no single factor, but rather a combination of factors is the 'selective force' at any site. Moreover, since all geographic variations result from the adaptation of a local population to its 'environment', the clinal change in shell shape may be interpreted as a phenotypic expression caused by a change in local conditions. The marginal variations in morphometric characters observed among the different populations of C. madrasensis and V. cyprinoides may perhaps be explained on the basis of the above facts.

Phillips et al. (1973) further observed distinct differences in the structure of the shell between the two populations studied. They opined that among the factors which may have influenced these differences, the most important one would probably be the slight changes in the genetic condition of these populations over a long period of geographic separation. Moreover, majority of the phenotypic variability or morphovariance observed among areas would be due to the fact that structural gene evolution (measured by electrophoresis) proceeded independently at a different rate from evolution at more complex phenotypic level (King and Wilson, 1975; Wilson et al., 1974). Besides these, the rate of protein evolution appears to be proportional to time (Ayala, 1976). This is probably the reason why some morphovariance is noticed in specimens from different areas, although biochemically they may appear to belong to the same species. Perhaps the above interpretations may offer another possible explanation for the observed variations in morphometric characters of the different populations of V. cyprinoides, C. madrasensis and P. viridis in the present study.

It is therefore felt that, among the three species under study, V. cyprinoides represents a species of high phenotypic plasticity as evidenced from the present results. Since V. cyprinoides have a wide geographic distribution, they are more likely to produce locally adapted populations or ecophenotypes than the other two species. The results of the present study further indicate that any studies on morphometric variables of individuals of a population and to relate it with population variation has serious limitations. It may however be used in conjunction with other genetic studies and may be useful in bringing out the extent of such variations among populations as a result of environmental influence.