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Factors influencing shell size and shape in *Donax incarnatus* (Gmelin) inhabiting Panambur sandy beach, Mangalore, India

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The samples of wedge clam *Donax incarnatus* (Gmelin), sediment and seawater were collected for a period of 12 months from Panambur sandy beach, near Mangalore. A total of 2258 individuals of *D. incarnatus* were subjected to analysis. The air (27.5-31.2 ^{o}C), sand (28.5-36 ^{o}C) and seawater (25-32.2 ^{o}C) temperatures showed seasonal fluctuations. The dissolved oxygen (3.29-4.55 ml L^{-1}) and salinity (30.24-34.84 x 10^{-3}) of seawaters showed variations. Fine sand dominated (75.09 to 94.2%) throughout the period of study, followed by medium sand (1.51 to 20.65%). The density (89 to 39446 no. m^{-2}) and biomass (124 to 1892 g. m^{-2}) of wedge clams showed marked variations during breeding season. Principal component analysis of biological variables and environmental parameters showed six components which together accounted for 90.39% of total variance. The component 1 (dissolved oxygen, density, biomass, wet weight, dry) accounted for 24.02% of total variance followed by component 2 (air, water and sediment temperatures, salinity and *b* values of length-breadth and length-dry weight relationships) for 20.64% of total variance and component 3 (mean shell length, mean shell breadth, mean shell width) for 17.27% of total variance. The rest of the variance of 28.46% was accounted for component 4 (medium sand, fine sand, very fine sand), component 5 (coarse sand, *b* value of length-wet weight relationship, *b* value of length-width relationship) and component 6 (silt & clay). The hierarchical cluster analysis produced a dendrogram with six sub-groups of clusters. The temporal variability of six factor scores was delineated using factor analysis.

[**Keywords**: Allometry; Morphometry; Length-weight; Biotic and abiotic variables; Multivariate statistical analysis; Karnataka]

Introduction

Bivalve mollusks occupy an important position in the marine food web as most of them have very high conversion efficiencies. The recent interest in bivalves in developing countries reflects the fact that oysters, mussels and clams are the most promising potential species for production of protein rich sea food for satisfying the animal protein requirements of the world. Among clams, many species of the family Donacidae have been reported from Indian coasts. Several aspects of biology of *D. cunneatus*[1-2], *D. faba*[3-4], *D. incarnatus*[5-8], *D. scortum*[9] and *D. speculum*[5] have been studied by earlier workers. The wedge clam *D. incarnatus* occurs in dense patches along the Mangalore coast[7]. Thippeswamy and Joseph[8] have examined the bivariate allometric relationship in *D. incarnatus* inhabiting the Panambur sandy beach, near Mangalore using least square regression techniques. In the present study, we examined the influence of ambient environmental and biological factors on allometry and the number of factors that can explain variations in the shell size (length, weight) and shape in the wedge clam *D. incarnatus* (Gmelin) inhabiting the Panambur sandy beach, near Mangalore.

Materials and Methods

Samples of *D. incarnatus* (Gmelin) were collected monthly (March 1984 to February 1985) using randomly placed quadrants (1 m^2, area up to a depth of 10 cm) at Panambur beach (12^{o}57'N, 74^{o}48'E) near Mangalore, west coast of India. Clams were separated by sieving the sand (mesh size 1 mm). A total of 2444 randomly selected clams ranging in size from 3.6 to 26.1 mm shell length were examined for dimensional relationships, 2258 clams for length-wet tissue weight and 1153 clams for length-dry tissue weight relationships. Shell length (maximum antero-posterior distance), breadth or height (maximum distance from the hinge-to-ventral margin) and width (maximum distance between outer edges of two valves) of clams were measured accurately to 0.05 mm, using Vernier calipers. Meat from individual clam was removed, blotted, and weighed, and dry weight of clams were recorded after oven-drying the meat at 60 °C for 2 days. Allometry was examined in morphometric (shell length-shell breadth, shell length-shell width) and length- weight (shell length-wet tissue weight, shell length-dry tissue weight) relationships by using least-square regression techniques. The atmospheric, water and sediment temperatures were recorded at the time of collection of samples. The water quality parameters such as dissolved oxygen and salinity were estimated[10]. For textural analysis of sand, the samples were subjected to grain size analysis[11]. The total weight (g m^{-2}) and population density (no. m^{-2}) of clams were recorded. The data on morphometric (shell length-shell breadth, shell length-shell width) and length-tissue weight (shell length-wet tissue weight, shell length-dry tissue weight) relationships were subjected to least square regression techniques. The data on length-tissue weight (shell length-wet tissue weight, shell length-dry tissue weight) relationships has presented earlier[8]. The *b* values of the above dimensional relationships (length-weight) were used for multivariate statistical analysis along with the data presented in this study. The data on biological (density, biomass, shell length, shell breadth, shell width, wet tissue weight, dry tissue weight, *b* values of dimensional and length-weight relationships) and environmental (air, water and sediment temperatures, dissolved oxygen, salinity, sand fractions) variables were subjected to multivariate statistical analysis[12-13].

Results and Discussion

Environmental variables

The environmental variables such as air, seawater and sediment temperatures, salinity and dissolved oxygen of seawaters recorded at Panambur sandy beach are presented in Figure 1. The variation in the air temperature followed a clear-cut seasonal pattern. The air temperature ranged from 27.5 (July) to 31.2 °C (May). The drop in the air temperature coincided with the peak of the south-west monsoon and the rise in temperature from October onwards coincided with the decrease in rainfall and the onset of post-monsoon; thus, the seasonal pattern was due to the fluctuation in the incoming solar radiation. Seawater temperature fluctuated between 25 (August) to 32.2 °C (May). During the monsoon period, the sea surface water temperature was low when compared to other seasons. In the present study, the seasonal changes in water temperature closely followed the air temperature. Generally, high sand temperature recorded during the pre- and post-monsoon periods

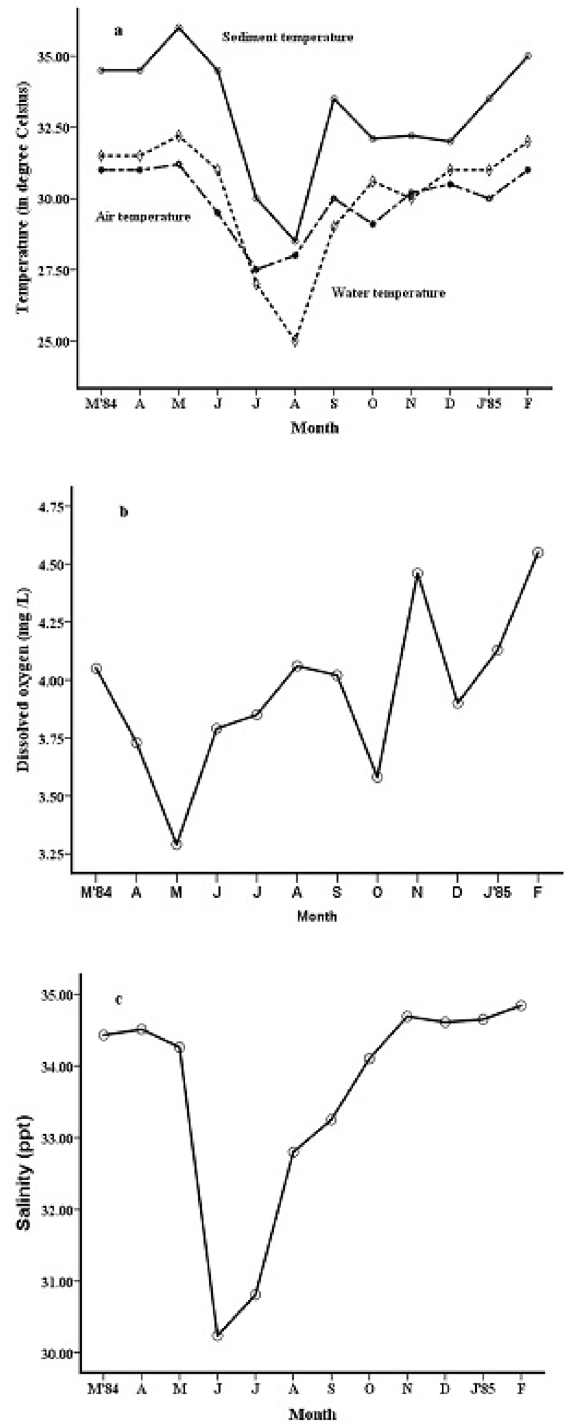

Fig. 1 — Temporal variability in air, water and sediment (a) temperatures, (b) dissolved oxygen (c) and salinity at the study area

and the low values during the south-west monsoon period. The fluctuation in sand temperature ranged from 28.5 (August) to 36 (May) °C (Figure 1a). Oxygen is vital for all living beings and plays a very important role in the intertidal region. The monthly fluctuation of dissolved oxygen of sea surface water in the present study ranged from 3.29 (February 1985) to 4.55 mg L^{-1}(May 1984) (Figure 1b). It is well documented[14] that the surface water contains only about 4 mg L^{-1} in the tropics, while the concentration went up to 8 mg L^{-1} at the poles. Intertidal regions at times receive large quantities of freshwater from the adjacent land through streams and rivers. In the present study, the salinity declined greatly during monsoon period (30.24 x 10^{-3}). The salinity values of seawater were high during the pre-monsoon period with the highest values of 34.84 x 10^{-3} (February) (Figure 1c).

The data on sand structure at Panambur sandy beach is presented in Figure 2 and the data revealed that the sand was composed of varying fractions of coarse sand (1,000 to 500 µm), medium sand (500 to 250 µm), fine sand (250 to 125 µm), very fine sand (125 to 63 µm), and silt & clay (<63 µm). The fine sand (75.09-94.2%) dominated and was uniform throughout the period of study, followed by medium sand (1.51 to 20.65%). Very fine sand (0.41% to 3.33%) and coarse sand (1.12% to 4.72%) fractions represented only in small quantities. Therefore, it is assumed that the wedge clam *D. incarnatus* is successful in colonizing the fine sand (250 to 125 µm) beach at Panambur. Degioranni and Moueza[15] also reported that *D. trunculus* colonized the fine moving sediment in which the grain size remained identical throughout the year in the Bay of Bou-Ismail in Algeria.

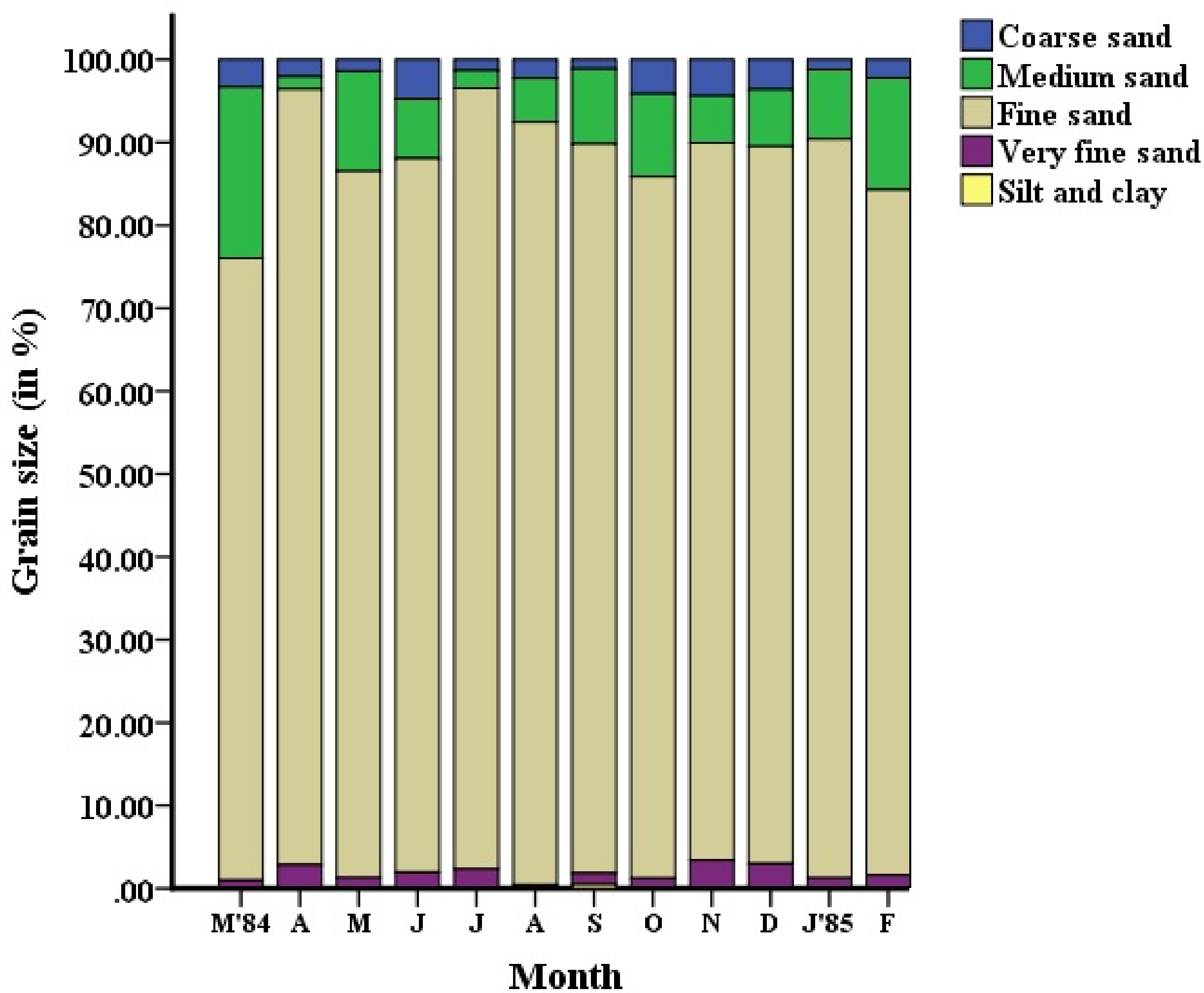

Fig. 2 — Temporal variability in grain size of sediment at the Panambur sandy beach during the study period

Biological variables

The values of density (no. m^{-2}), biomass (g m^{-2}) and *b* values of dimensional relationships of *D. incarnatus* are presented in Figure 3. The density of the population of *D. incarnatus* varied from 89 (April 1984) to 39446 no. m^{-2} (January 1985) (Figure 3a), whereas the biomass (shell-on-wet weight basis) from 124 (April 1984) to 1892 g. m^{-2} (January 1985) (Figure 3b). In the present study, two peak densities of clams recorded during November 1984 to February 1985 and July 1984 to August 1984 the former being larger. The maximum density (39446 no. m^{-2}) of *D. incarnatus* observed for the first time in the present investigation compared to that of earlier works. The clams form a solid bed in the surf zone of sandy shore. However, these beds are subject to the chance of drifting by waves and tides resulting in a new bed formation. The maximum biomass was recorded during January 1985 when more number of small-sized clams occurred in the population. The lowest biomass was recorded during October (25.97 g m^{-2}) when less number of small-sized clams was found in the population. The biomass values were high during November to February and an additional peak during August was also noticed. Thus, the data on biomass revealed that the maximum value on wet weight basis was recorded for the first time of this species in the present study. The *b* values of length-breadth and length-width relationships are presented in Figure 3c. The monthly *b* values of length-breadth relationship ranged from 0.443 (April'84) to 0.791 (July '84) whereas the *b* values of length-width relationships ranged from 0.25 (March'84) to 0.451 (November'84). In shell dimensional relationships, the values of intercept and slop indicate variations in different morphological traits because populations inhabit different habitats where environmental variables are different. However, in allometric length-weight relationships, the value of *b* represents relative growth in weight as compared with length.

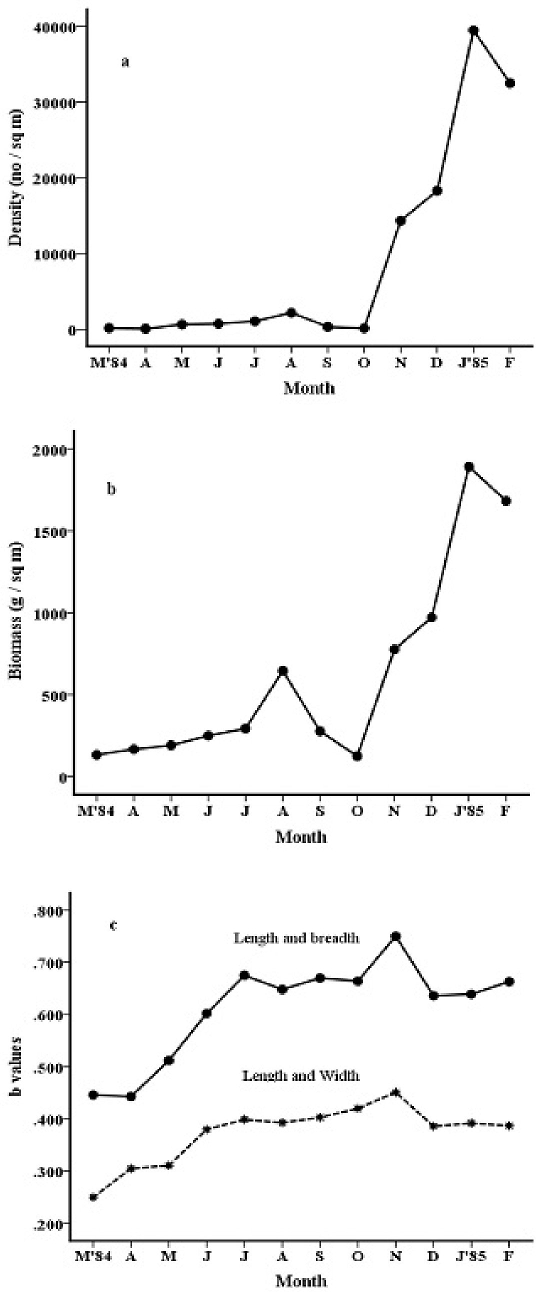

Fig. 3 — Temporal variability in (a) density, (b) biomass and (c) *b* values dimensional relationships of *D. incarnatus* from the Panambur sandy beach

Multivariate statistical analysis

Cluster analysis uses as its base the proximities or distances between cases in the process of organizing them and aligns the cases along two or sometimes more dimensions. In hierarchical cluster analysis, the cases are placed in groupings or clusters based on their proximities. Principal components and factor analysis comprise a family of exploratory data analysis procedures that are used to identify a relatively small number of dimensions (components or factors) underlying a relatively larger set of variables; and these procedures represent ways to consolidate into a small number of synthesizing constructs information that is dispersed among several variables[16]. The application of these techniques to delineate the influence of environmental and biological factors on the shell size (length, weight) and shape in bivalve mollusks, such as *Perna viridis*[17] and *Parreysia corrugate*[18-19] have been reported.

Hierarchical cluster analysis (HCA) – HCA produced two major groups (Fig. 4) which revealed that the similar groups of variables clustered within each subgroup. The group *A* clustered most of the biological variables and one abiotic variable (fine sand) whereas group *B* clustered most of the environmental variables and biological variables like dimensional variables (mean length, mean breadth, mean width). The major group *A* is divided into two sub-groups *A1* and *A2* (*b* values of length-breadth, length-wet weight relationships). The sub-group *A1* consisted of biomass, wet weight, density, dry weight, dissolved oxygen and *b* value of length-width and fine sand. Another major group *B* is divided into two *B1* and *B2*. The sub-groups *B1* is further divided into to two subgroups such as *B1a* that clustered with mean length, mean breadth, mean width, very fine sand and *B2b* clustered with only coarse sand. The sub-group *B2* is also further divided into *B2a*, which clustered with water temperature, sediment temperature, air temperature, salinity and medium sand, and *B2b* clustered with only silt & clay.

Principal component analysis (PCA) and Factor analysis (FA) – PCA and FA are performed on the biological data of *D. incarnatus* and environmental variables at Panamur beach revealed six components

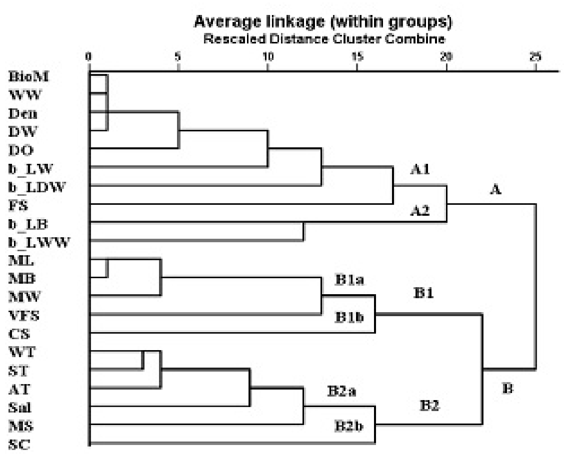

Fig. 4 — Hierarchical cluster dendrogramme of environmental and biological variables of *D. incarnatus* inhabiting the Panambur beach. Abbreviations: DO, dissolved oxygen; Sal, salinity; WT, water temperature; AT, air temperature; ST, sediment temperature; CS, coarse sand; MS, medium sand; FS, fine sand; VFS, very fine sand; SC, silt and clay; ML, mean length; MB, mean breadth; MW, mean width; BioM, biomass; Den, density; b_LB, *b* value of length-breadth; b_LW, *b* value of length-width; WW, wet-weight; DW, dry-weight; b_LWW, *b* value of length wet-weight; b_LDW, *b* value of length-dry weight.

(with an eigen values >1), which together accounted for 90.29% of total variance. The eigen vectors more than 0.4 of correlation coefficient were considered[12-13] to extract the significant variables in each principal component. The component 1 with five positive variables (dissolved oxygen, density, biomass, wet weight, dry weight) accounted for 24.02% of total variance, followed by component 2 with six variables (air temperature, water temperature, sediment temperature, *b* value of length-breadth, *b* value of length-dry weight, salinity) for 20.64% of total variance and component 3 with three variables (mean shell length, mean breadth and mean width) for 17.27 % of total variance. The component 4 (medium sand, fine sand, very fine sand), component 5 (coarse sand, *b* value of length-width, *b* value of length-wet weight) and component 6 with only silt & clay together accounted for 28.46% of total variance. In component 2, *b* value of length-breadth and *b* value of length-dry weight showed negative correlation among all other associated variables whereas in component 4, the medium sand showed negative values. In rest of the components all variables showed positive correlations.

Principal component plots of component 1 and component 2 (Fig. 5a) showed five possible groupings of variables. Group 1 composed of positive variables (density, biomass) with high positive correlation on the component 1 axis and low correlation on component 2 axis whereas dry weight and dissolved oxygen showed high negative correlation on component 1 axis and low correlation on component 2 axes. However, salinity and *b* value of length-width showed medium positive correlation on both the axes of component 1 and component 2. Group 2 consisted of variables such as water temperature, air temperature, sediment temperature showed high correlation on component 2 axis and low correlation on component 1 axis. Group 3 with medium sand, mean length, mean breadth, very fine sand, silt & clay, coarse sand, mean weight and fine sand showed low correlation on both the axes 1 and 2. Group 4 included the *b* value of length-wet weight with low negative correlation on both exes of component 1 and component 2. Group 5 consisted of negative variables such as *b* value of length-dry weight and length-breadth with positive correlation on component 1 axis and negative correlation on component 2 axis.

Principal component plot of component 1 and component 3 (Figure 5b) showed five possible

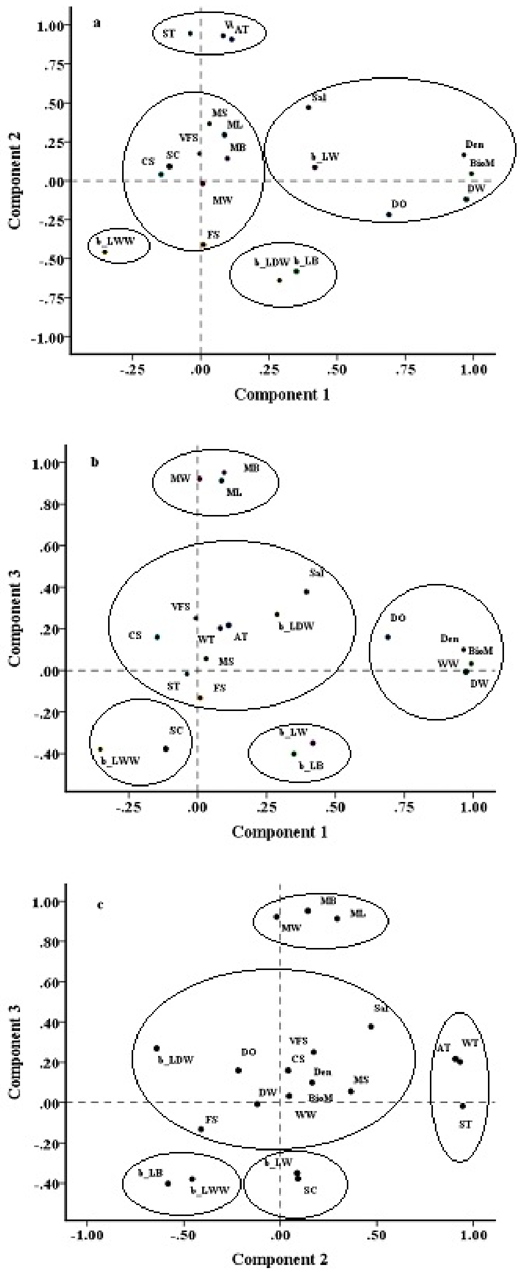

Fig. 5 — Principal component plots between component axis 1 and component axis 2 (a), component 1 and component 3 (b) and component 2 and component 3 (c). Abbreviations: DO, dissolved oxygen; Sal, salinity; WT, water temperature; AT, air temperature; ST, sediment temperature; CS, coarse sand; MS, medium sand; FS, fine sand; VFS, very fine sand; SC, silt and clay; ML, mean length; MB, mean breadth; MW, mean width; BioM, biomass; Den, density; b_LB, *b* value of length-breadth; b_LW, *b* value of length-width; WW, wet-weight; DW, dry-weight; b_LWW, *b* value of length wet-weight; b_LDW, *b* value of length-dry weight.

groups. Group 1 consisted of biomass, density, wet weight, dry weight, dissolved oxygen with high correlation on axis 1 and low correlation on component 3 axis. Group 2 with mean length, mean breadth, mean width showed high positive correlation with axis 3 and low positive correlation with axis 1. Group 3 included salinity, *b* value of dry weight, air temperature, water temperature, medium sand, very fine sand, coarse sand, fine sand and sediment temperature with low correlation on both axes. In group 4, The *b* value of length-wet weight and silt & clay showed negative correlation on the both axes of component 1 and component 3 with high correlation on axis 3 and low correlation on axis 1. The *b* values of length-width and length–breadth are associated with group 5.

The plot of component axis 2 and component axis 3 (Figure 5c) showed five groups. Group 1 consisted of water temperature, air temperature and sand temperature with high correlation on axis 2 and low correlation on axis 3. The group 2 consisted of mean length, mean breadth, mean width with high correlation on both the component axes 2 and 3. The group 3 (b values of length-dry weight, salinity, medium sand, coarse sand, very fine sand, biomass, wet weight, dry weight, dissolved oxygen) showed low correlation on both the axes od component 2 and component 3. The group 4 consisted of *b* value of length-breadth, *b* values of length-wet weight showed negative values on both axes. The group 5 consisted of silt & clay and *b* value of length-wet weight with positive values on component 2 axis and negative values on component 3.

*Temporal variability of factor scores*__– The temporal variability of factor scores is presented in Figure 6. Among the temporal variability of various factors, Factor 1 (dissolved oxygen, density, biomass, wet weight dry weight) was the highest during March followed by April and subsequently the low values throughout the study period. The high values could be due to increased growth of shell and tissue of clams of previous year and large-sized clams in the population and low values due to the onset of breeding season followed by occurrence of very small-sized clams in the population. The recruitment of clams to the population takes place at several stages indicating a prolonged/staggered breeding period for the population. The differential growth rate and ranges in the size of 0 and 1 year old clams showed that growth rate of juvenile clams was high during the first few months after settlement and was poor during the adult stages at the study site[7]. The environmental factors are

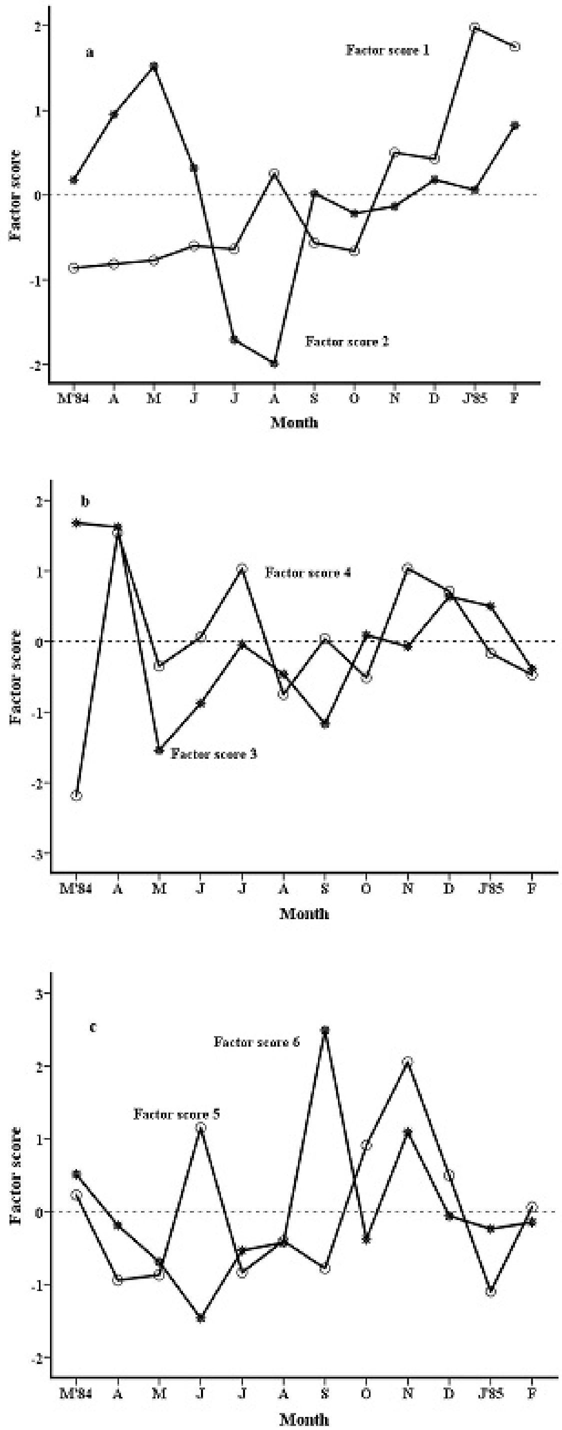

Fig. 6 — Temporal variability of scores of (a) Factor 1 and Factor 2, (b) Factor 3 and (c) Factor 4 and Factor 5 and Factor 6 during the study period

known to influence the shell form in bivalves[20-21]. Factor 2 (air temperature, water temperature, sediment temperature salinity, and *b* value of length-breadth and length-width) showed maximum during the monsoon and pre-monsoon season with peak value during May and followed by low values during monsoon and pre-monsoon seasons. The high values of Factor 2 could be due to the increased contribution by each component of Factor 2 during the pre-monsoon season (summer). The clams maintain their non-linear (*b* value of dry weight) pattern from spat stage onwards at the present study site; however, *b* values of dry weight are different, on monthly basis, indicating the variation in index of condition[22] and reproductive cycle[23]. In allometric length-weight relationship, the equilibrium constant, *b* value, the variations of which from the hypothetical unity suggest physiological deviations in condition. The value of *b* represents relative growth in weight as compared with length. In bivalves, where gonadal growth and maturation result in increasing bulkiness of soft body and consequent high body weights, such sudden shifts in *b* valves indicate onset of maturation and gonadal growth[23]. High condition index of *D. incarnates* in the same habitat[22] is just prior to spawning due to the increase in the total bulk of the gonad which forms the major part of the visceral mass.

Factor 3 (mean length, mean breadth, mean width) showed maximum during the pre-monsoon season, with peak value during April, followed by post-monsoon and monsoon periods. The high values of Factor 3 could be due to the increased contribution by each component of Factor 3 during May and also during the pre-monsoon season. For species like the one studied here, shape is probably of major adaptive significance because of the importance of rapid burrowing in the surf beaten intertidal sandy shore where ambient environmental factors fluctuate significantly. Thus, the size of clams is more affected than their shape by fluctuations of ambient environment. Probably, shape is controlled by its genetics and size by ambient environment and coupled with its population selection strategies[7]. Size may also influence life-history evaluation through up and down migration with tides and/or burrowing behaviour of clams. Factor 4 (medium sand, fine sand, very fine sand) showed that the height value was during April followed by the lowest value during March and subsequently more or less similar variations throughout the study period. A study from the same site[8] reported that short individuals are light and long individuals are heavy (*b* value of length-dry weight), as reported elsewhere in higher organisms[24], thus clearly pointing out that as age increases the weight of clams also increases. The values of weights could be due to physiological conditions[22] and variations in environmental factors in air temperature-27.5 (July) to 31.2 ^{o}C (May), water temperature-25 (August) to 32.2 ^{o}C (May) and sand temperature-28.5 (August) to 36 (May) ^{o}C. It is well-acknowledged that weights and lengths of organisms have shown to be highly correlated with life history measures in cross-taxonomic comparisons[25-26].

Factor 5 (coarse sand, *b* value of length-width) showed two major peaks with maximum, during the post-monsoon (November) and monsoon (June) seasons. This could be due to the faster rate of percolation/movement of water in the coarse sand and retain/movement of water inside the shell of live clams. Thus the allometric relationship, as in the present study, the *b* value of length-wet weight describe rates for a wide range of metabolic processes and over a wide range of organisms' size and types has important ecological implications[27]. Factor 6 (silt & clay) showed maximum during September followed by November. Factor 3 showed more or less similar pattern of variation with Factor 1. Thus the shell (shape, size) and fine sand have similar relationship thus indicating major adaptive significance of rapid burrowing in the surf beaten intertidal sandy shore where ambient environmental factors fluctuate significantly. The biological data on development, genetics, tidal migration, specific production, energy budget and inter- and intra–specific competition is warranted to understand the ecological aspects, in depth, of this wedge clam.

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