CHAPTER V

ALLOMETRIC RELATIONSHIPS IN MUSSELS
INTRODUCTION

Allometry is described as the study of relationship between increase of one body parameter to the other. Earlier, several authors, have applied the concept of allometric growth to mussels (Coe, 1946; Mason, 1957; Seed, 1968; 1973; Parulekar et al., 1973; Ansari et al., 1978; Mohan, 1980; Parulekar et al., 1982; Borrero and Hilbish, 1988) however, this concept allows only two parameters to be compared at any one time.

It is known that animals changing their body proportions may also change their shapes. Allometric relationship provides an important information regarding comparative growth of various body parameters. A proper understanding of allometry in shell and soft tissue of bivalves is essential to define the growth of a species. The use of regression analysis to explain such relationship between various morphometric characters has been considered suitable (Gould, 1966; Brown et al., 1976). The morphometric characters and their allometric relationships are to a large extent, influenced by age, local environmental conditions and the population density of the species (Hickman, 1979; Schaefer et al., 1985).

The present study was taken up primarily in terms of expressed interests in commercial exploitation of the green mussel P. viridis L. Here, an attempt is made to describe the seasonal changes in allometric growth relationship of different morphological parameters with reference to length as dependent variable of known size animals from a raft grown population under
continuous submergence in a subtidal estuarine biotope.

RESULTS

The data on morphological parameters were treated for regression analysis after transforming to logarithms in order to get an exponential equation form. Computation of r value (correlation coefficient) was done using computer programme. The best fits were fitted for normal data as shown in figures (25a to 33d). Transformed data was used only to get an exponential equation.

The relationship is expressed, either linear or exponential depending upon its relevance or application. The equations for different relationships along with r values are given in the respective figures. Data was coupled for different collections and was grouped depending upon size categories. This data was treated for regression analysis to see if there exists any significant differences in allometric relationship with different growth rates. Efforts were made to compare these relationships with those for complete period of study.

TOTAL WEIGHT-SHELL LENGTH RELATIONSHIP:

The total weight-shell length relationship is depicted in Figs. 25a to 25d for different growth phases during the study period. Total weight increase with shell length displayed an ascending order. In smaller sized mussels (<40 mm), usually the growth in terms of weight was fast, but in the present study, during initial stages of growth after transplanting mussel seed
Fig. 25. Shell length-total weight relationship during different seasons and for complete period of study in raft-grown mussels P. viridis L.
from natural rocky shore to subtidal ecosystem, the increase in weight was of reduced magnitude. The weight increment upto a length of 40 mm size was only to the tune of about 3.0 gms. In medium size group (40-60 mm) the rate of increase in weight in shell length was much higher when compared to smaller sized mussels. The increase in weight in this size range was upto 8.0 gms, which was much higher than the growth increment observed in the initial growth period. As the mussels became older attaining size of 60 mm and above, the rate of increase in weight slightly reduced as compared to medium size group (about 6.0 gms).

An exponential relationship was noticed for the initial growing period upto a size of 55 mm. During next growth period, linear relationship was exhibited, whereas in the last stages of growth, when mussels attained a size of 70 mm and above, no specific relationship within these parameters was observed, although a linear fit was fitted with low value of determination.

**TOTAL WEIGHT-SHELL HEIGHT RELATIONSHIP:**

The total weight-shell height relationship is shown in Figs. 26a to 26d. In the present study, the rate of increase in weight was very low as compared to height in the initial period of growth. The increase in height upto 18.0 mm reflected only an increase of about 4.0 gms in weight. During next growing phase, increment in height upto 15.0 mm resulted in rapid advancement in weight upto an increase of about 12.0 gms. However, towards the end of the growing period, weight did not show any marked increase (Fig. 26d).
Fig. 26. Shell height-total weight relationship during different seasons and for complete study period in raft-grown mussels *P. viridis* L.
Generally, in these parameters, for the period of study, exponential relationship was observed. When considered separately, with different growth phases, during the initial period, it showed an exponential relation. In the next size group (20-35 mm height), the weight exhibited linear relationship. In the final stages of growth, no specific relationship could be observed, although regression equation of first order could be fitted (Fig. 26d).

**TOTAL WEIGHT-SHELL WIDTH RELATIONSHIP:**

Total weight-shell width relationships are shown in Figs. 27a to 27d for the complete data of the study period. During early stages of growth, increase in weight with corresponding shell width followed similar pattern of variation as that of shell height and showed an increase of only about 4.0 g with shell width progression upto 15.0 mm. In the succeeding phase of growth, the shell width increased from 15.0 to 30.0 mm, while, weight showed sharp rise upto an increment of about 11.0 g in this size range. For the remaining part of the study, no noteworthy increase in total weight with corresponding shell width increase was observed.

A linear relationship was observed during the initial period of growth in total weight and shell width. During the next phase of growth, the relationship observed was exponential, suggesting that increase in weight was of higher magnitude in shell width range of 5.0 - 15.0 mm, whereas during the final stages of growth, non-linear relationship was observed. The same data,
Fig. 27. Shell breadth–total weight relationship in different seasons and for complete study period in raft-grown green mussel *P. viridis* L.
considered for complete period of investigation showed an exponential relationship (Fig. 27a).

**SHELL HEIGHT-SHELL LENGTH RELATIONSHIP:**

Shell height-shell length relationship for different growing periods and for complete period of investigation are depicted in Figs. 28a to 28d. Shell height with reference to shell length was constant and proportionate throughout the period of study. However, the rate of increase in height in small sized mussels (<40 mm) was at a much increased rate. In large sized category of mussels (>50 mm) the growth in shell height per unit time decreased but was not significant. In the mussels of 35-45 mm size group, the shell height increment did not show an ascending order. In the mussels of size group 70-75 mm, the shell height was observed to be equal to shell width. The ratio of shell width/shell length was found to vary from 0.22 to 0.50. The higher values of shell height/shell length ratio were noticed in the initial period of growth. As the mussel size increased, these values were observed to be low, which indicate less increase in shell height with corresponding increase in shell length. However, during the complete period of study, the ratios did not show much variations indicating proportionate increase in shell height when compared to increasing shell length.

The shell height/shell length relationship was observed to be linear for complete period of study. When considered separately, with varying growing stages upto a size of 70 mm, the observed relationship was also linear, however, towards the end
Fig. 28. Shell length-height relationship in different seasons and for complete study period in raft-grown mussels *P. viridis* L.
of the growing period, no specific relationship could be seen from the regression plot (Fig. 28d).

**SHELL WIDTH-SHELL LENGTH RELATIONSHIP:**

The variations in shell width with shell length are shown in Figs. 29a to 29d. A corresponding increase in shell width and shell length was observed to be of an increasing order i.e. as mussels grew older the increment per unit time was more in shell width as compared to younger mussels. In the initial stages of growth when these mussels were small and growth was relatively faster, the shell width did not increase in proportion with shell length. The rate of increase of shell width in small sized mussels was moderate, whereas, in large sized mussels (>60 mm) the increase in shell width was at faster rate and uniform upto the termination of the experiment. The ratio of shell width/shell length in the present study ranged from 0.27 to 0.66. The changes in the ratio of shell width/shell length did not show much variations. The ratio was found to increase as mussel growth advanced.

An exponential curve was fitted for the above parameters for the total period of study (Fig. 29a). However, for different growing period, when considered separately, the relationship was observed to be linear for all size groups.

**SHELL WEIGHT-SHELL LENGTH RELATIONSHIP:**

Figs. 30a to 30d represent relationship between shell weight and shell length. The variations in shell weight with reference
Fig. 29. Shell length-breadth relationship during different seasons and for complete study period in raft-grown mussels *P. viridis* L.
Fig. 30. Shell length-shell weight relationship during different seasons and for complete study period in raft-grown mussels _P. viridis_ L.
to shell length indicate that the increase in shell weight was of very low magnitude up to a size of about 30 mm. In next size category (30-60 mm), the increase in shell weight with shell length showed steep rise. The increment in shell weight in this size category was about 7.0 g. In this size group, the increase in shell weight was observed to be uniform with growth, except at a size of 60 mm where a sudden increase in shell weight in relation to shell length was observed. However, the increase in shell weight was only up to the order of about 4.0 g. In larger size group (>70 mm) the corresponding shell weight was observed to be very high, attaining a shell weight of about 12.0 g.

From the regression plots (Figs. 30a to 30d), it was observed that the above parameters exhibited curvilinear relationship during the period of study, indicating that shell weight increases relatively faster as compared to shell length. In the present study, during initial period of growth up to a size of 55 mm, the mussels, exhibited exponential relationship which became linear during next phase of growing period. However, during the time of termination of experiment, no specific relation was noticed.

MEAT WEIGHT-SHELL LENGTH RELATIONSHIP:

The relationship in these parameters is shown in Figs. 31a to 31d. Meat weight increment followed an ascending order with shell length. In small sized mussels (<40 mm), the increase in meat weight with shell length was low as compared to other size groups. In medium sized mussels (40-60 mm) the increment in meat
Fig. 31. Shell length–meat weight relationship in different seasons and for complete study period in raft-grown mussels *P. viridis* L.
weight was higher as compared to smaller size groups. The growth increment in medium size group was about 4.0 g. The increase in meat weight with shell length in this size group was uniform. In large sized mussels (>60 mm) the meat weight was observed to increase with shell length and was up to the tune of 4.5 g, the increment in meat weight being higher than the medium size group. During the period of investigation, the increase in meat weight was found to follow consistent pattern with the shell length.

During the complete period of study, the regression analysis between above parameters was observed to be of an exponential nature. A curvilinear relationship was recorded in the initial period of growth up to a size of 50 mm and as the growth advanced, up to 75 mm size, linear relationship persisted (Figs. 31b to 31d). Mussels, during rest of the growing period showed neither linear nor exponential relationship.

**DRY MEAT WEIGHT-SHELL LENGTH RELATIONSHIP:**

Dry meat weight-shell length relationship for the different growth phases and for the complete period of study are shown in Figs. 32a to 32d. The changes in dry meat weight with reference to shell length was not found to follow any uniform pattern. The dry meat weight increased gradually with increase in shell length attaining maximum value (3.5 g) at a size of about 55 mm. In a size group of 65 mm, a second peak value (2.5 g) in dry meat weight was observed. In general, the dry meat weight in large sized mussels decreased and was found to be low as compared to their respective shell length group.
Fig. 32. Shell length dry meat weight relationship in different seasons and for complete study period in raft-grown green mussel P. viridis L.
The relationship of above mentioned parameters, was reported to be of an exponential order for total period of study. During initial period of growth, an exponential relationship was observed, whereas, no specific relationship during remaining part of the study could be observed. However, the regression plots (Figs. 32c and 32d) indicate fitted regression equation of first order with very low significance.

**SHELL VOLUME- SHELL LENGTH RELATIONSHIP:**

The variations in shell volume-shell length relationship during the period of study are depicted in Figs. 33a to 33d. Shell volume increase with respect to shell length upto a size of 40 mm was of very low order registering only an increase of 3 cm. In large sized mussels (>40 mm) the shell volume was found to increase at much faster rate. The mussels of 70 mm size group showed steep increase in shell volume from the earlier size group i.e. upto a tune of about 6 cm. For the present study, increase in shell volume in relation to shell length was observed to follow an uniform pattern.

The shell volume-shell length showed an exponential relationship for the study period. In the beginning of the growth period, an exponential relationship was observed upto a size of 50 mm, whereas during the remaining part of growth period, the relationship was linear. However, the degree of determination of linearity was not the same.
Fig. 33. Shell length-volume relationship during different seasons and for complete study period in raft-grown mussels *P. viridis* L.
DISCUSSION

The concept of allometry was first postulated by Huxley and Tessier (1938) and since then it has been extensively applied to many bivalves like *Mytilus californianus* (Coe and Fox, 1942; Fox and Coe, 1943), *Mytilus edulis* (Genovese, 1961; Hancock, 1965b; Seed, 1968), *Perna canaliculus* (Hickman, 1979), *Perna viridis* (Shafee and Sundaram, 1975; Ansari *et al.*, 1978; Mohan, 1980; Parulekar *et al.*, 1982). These studies suggest that allometric relationships in bivalves play an important role in understanding comparative morphometrics and emphasize the care that must be exercised in using different bivalve population. However, the use of this concept is somewhat limited and has been criticised by some authors (Holme, 1961; Wilbur and Owen, 1964). Although, knowingly that the changes in the form of an animal cannot be described satisfactorily by such relationships, they are, however, useful in comparison of shell dimension of animals of known size within a locality which is a primary concern of this study. An understanding of the allometric relationships in shell and soft body characters is therefore essential to fully understand the growth of a species. The use of regression analysis to define such relationships has been considered most suitable (Gould, 1966; Brown *et al.*, 1976).

Total weight-shell length relationship suggests that in early stages, growth rate was less. However, for certain size groups, an exponential relationship was recorded, indicating that increase in total weight was at a rapid rate with respect to shell length. The reduced rate of progression during early
period of growth of the transplanted mussels could mainly be due to improper acclimatisation to subtidal ecosystem and to varying environmental conditions prevailing at that time. Earlier, Seed (1968) reported that in some populations of blue mussel, growth increase is not realised until fourth or fifth year of life. In medium size group (40-60 mm), the weight increase was of a high magnitude. The increase in the total weight coincided with higher rate of increase in meat weight suggesting that contribution of soft tissue to the total weight was significant. This could probably be due to increased feeding efficiency and food availability for the raftgrown mussels. Seed (1969) also reported higher contribution of meat weight and stated that this increase in tissue weight occurs through the deposition of fat and glycogen in the tissue. In the case of large size mussels (60-80 mm), rate of increase in total weight decreased with length as compared to medium size group. Earlier studies (Jorgensen, 1976; Hickman, 1979) have reported that, as the mussels grew older, in the later stages of growing period, growth rate decreases with increase in size. In the present study, for different growing periods, varying relationships were observed, suggesting that rate of change in body dimensions does change with different growing periods. The *Perna viridis* L. from Mangalore (west coast of India) was found to exhibit linear relationship in body characters after logarithmic transformation (Mohan, 1980). However, Ansari et al. (1978) reported an exponential relationship in above parameters of the green mussel *P. viridis* L., from Goa, also along the west coast of India.
Considering the importance of shell height to predict other biomass parameter (Dame, 1972; Ansari et al., 1978) a relationship between total weight with shell height and shell width were studied to assess whether any of these parameters play an important role in the morphometric of green mussel. Neither shell height nor shell width was found to be useful in predicting other biomass parameters.

The total weight-shell height relationship showed an exponential trend indicating that increase in total weight was at a low magnitude in the initial stages of growing period. After certain size, the rate of increase in total weight was much faster and linear, indicating proportionate increase in total weight with shell height increment. Seed (1969) reported a linear relation in Mytilus edulis of large and small size categories, whereas, Mohan (1980) noticed non-linear relationship in the green mussel, Perna viridis L.

For the complete study period, total weight-shell width displayed an exponential curve, implying that the total weight increase was not proportionate with the shell width. Ansari et al. (1978) reported an exponential relationship in these parameters of the green mussel Perna viridis L. During different growing periods, considered separately, an exponential relationship was observed. However linear relationship was observed in the size range of 15-35 mm shell width, thus suggesting a change in the growth pattern of body dimensions with advancement of growth. Most of the earlier studies on allometry (Seed, 1968; 1973; Jones et al., 1979; Hickman, 1979) suggest
that such changes in body parameters are likely to occur due to changes in local environmental conditions. Hilbish (1986) demonstrated uncoupled growth in shell and soft tissue in *Mytilus edulis* L. Towards the end of growth period, as seen from Fig. 27d, no relationship of a particular significance was noticed.

The shell height increase with shell length was found to be proportionate and uniform as indicated by linear relationship (Figs. 28a - 28d) except in case of large size mussels. Furthermore, in small sized mussels, the increase was at a higher level and more linear \((r = 0.93)\) as compared to the large size category. The increased rate of height in the initial phase of growth in present study could mainly be attributed to the density of mussels on the rope. Due to increased density of mussels, in the initial period of fast growth, there could have been more scope for height enhancement, thereby suppressing width and length due to competition for space. Seed (1973) and Hickman (1979) have also made similar observations in their experiments on *Mytilus edulis* L. and *Perna canaliculus*, respectively. This type of relationship of shell height-shell length may be density dependent and could be explained by the fact that, such conditions of high density coupled with external factors as in the present study, may lead to reduced growth in shell length and shell width and promote shell height. However, Seed (1968) reported that under such conditions, the shell length and height get reduced and promotes shell width.

As mussels grew older, the height increment was stagnant.
whereas in few cases, width was found to be equal to the shell height. Seed (1968; 1973) and Hickman (1979) in their studies on *Mytilus edulis* and *Perna canaliculus* respectively, have also reported similar trend of variation in shell height with shell length. The shell height/shell width ratio was found to follow decreasing trend with the shell length. In large sized mussels (>65 mm) the ratio of shell height/shell width was less than 1, thus highlighting that the increase in shell width was at a faster rate than the shell height during later stages of growth in the present study.

Shell width-shell length relationship in the raftgrown population demonstrated that as mussels grew older, the increment in width per unit length was high. The higher rate of increase of shell width in older mussels was mainly due to increased shell gape in these mussels for feeding. Seed (1973) also reported an increase in shell width with larger shell length categories and further stated that, in *Mytilus edulis* increased tension in older animals lead to more gape of the valves. This increase in gape could be due to increased feeding efficiency coinciding with abundance of food material (present study) at that time. Shell width increase was proportionate with length in the initial stages, indicating that, in early stages of growth, much of the energy gained from ingested food was used for building up of soft tissue (as seen from meat:shell ratio). The ratio of shell width/shell length was increasing and higher in the later stages of growth as compared to shell height, suggesting that as the animals grow older, they become wider and many a time shell width
often exceeds shell height. Seed (1973) made similar observations and stated that as shell length increases beyond a certain limit shell width continues to increase, when increase in height almost ceased. During the course of present study, as well as during different stages of growth, linear relationship of these parameters suggests that, changing growth rates and seasons did not affect the relationship of these parameters. Jones et al. (1979) also reported, no seasonal variations in shell and soft body characters of the limpet, *Patella vulgata* L.

Shell weight and meat weight with shell length showed similar type of relationship for the period of study as well as for changing growth phases (Figs. 30a to 31d). In early stages of growth, an exponential relationship was observed, which indicates that increase in shell and meat was faster in the size range of 30-50 mm size group. Similar curvilinear relationship in *Mytilus edulis* was also reported by Seed (1973). During remaining period of growth, relationship was linear, emphasizing, changing pattern of variation in shell weight with respect to shell length. Seed (1969) stated that during unfavourable environmental conditions, cessation of accretionary growth at shell margin occurs, however, growth of shell in terms of thickness continues, thereby resulting in increased shell weight. Rao (1953) also found that subtidal population of mussels had heavier shells, and this he attributed to longer and continuous submergence, leading to calcium deposition which was directly dependent on time of exposure to the calcium source i.e. sea water. In large sized mussels, no such specific relation was
observed. From this it could be inferred that, in large sized mussels, total weight, shell weight and meat weight cannot be related to shell length or another possibility could be insufficient data to predict any valid relationship between these parameters. Such non-linear relationship in large size green mussels has earlier been observed by Mohan (1980).

The relationship between dry meat weight and shell length was found to be of an exponential order for complete period of study. When considered separately, no specific relationship could be seen except an exponential relationship in early stages of growth. In large size mussels, some low values of dry weight were reported which could mainly be attributed to environmental conditions prevailing at that time. Similar exponential relationship was earlier reported by Ansari et al. (1978) in *Perna viridis*. Shell volume exhibited an exponential relationship with shell length indicating that increase in shell volume with respect to shell length was of higher rate in size group of 50 mm and above. However, Seed (1973) in his experiment on *Mytilus edulis* reported sigmoidal curve for above parameters.

This suggests that the allometric relationship during various stages of growth is important functionally in biology of an organism and practically a predictive tool for ecological investigations. The changes in body dimensions of raft-grown population in the green mussels during different stages of growth indicate that the relationship could indirectly be influenced by population density, feeding efficiency at different size groups, food availability and local environmental conditions prevailing
at that particular time. Non-linear growth due to change in
direction of body dimensions also play an important role in
determining allometric relationships of the raftgrown green
mussel population.