CHAPTER 3

MORPHOMETRY OF 

P. EROSA
3.1 Introduction

Growth is one of the most used measures of an organism's vitality in a given environment. In bivalves, the size is directly related to its age, and this cumulative increase in biomass with respect to time is termed "absolute growth" while the percentage increase in biomass per unit time is "relative growth" (Seed, 1976). As growth represents changes in bivalve size, it is most often measured as shell length, weight, and volume. There may be complications in just measuring single shell parameters, as shell growth may be different from soft body growth due to environmental factors or variations in the reproductive cycle of the bivalve. It is the soft body that carries out the living processes of the animal, not the shell. Thus, allometric relationships are often developed between shell parameters and body weight in order to non-destructively estimate soft body biomass on living bivalves (Dame, 1972). Shell growth is a function of calcium availability in water and, therefore, the amount of water pump across the bivalve tissues, the pH of the internal system, the intermediary metabolism of the animal, and the environmental temperature that controls the rates of most of these processes. Although, shell size is related to soft body tissue mass, it is not a direct measure of body size, because some of the controlling factors are different.

Growth is the three-dimensional process with all dimensions changing over time. The allometric principles of animal morphology have long been recognized, since the concept of allometry was first postulated by Huxley and Tessier (1936). Allometry is the study of the relationship between two measurable variables, or in most general sense, allometry is the study of size and its consequences (Reiss, 1989). Bivalve shell growth and shape are influenced by abiotic (exogenous/environmental) and biotic (endogenous/physiological) factors. A variety of environmental factors are known to influence the shell morphology and relative proportions of many bivalve species, such as latitude (Beukema and Meeha, 1985), depth (Claxton et al., 1998), currents (Fuiman et al., 1999), water
turbulence (Hinch and Bailey, 1988), wave exposure, type of bottom and type of sediment (Claxton et al., 1998). Burrowing behaviour, ability and efficiency also affect the relative growth of the bivalve species (Seed, 1980). Studying growth and establishing allometric relationships are useful information for managing resources and understanding environmental changes. The growth of bivalves is mostly estimated by measuring the shell dimensions or the volume of the animal and also by measuring the shell rings (Deval, 2001).

Despite the existence of studies concerning morphometric aspects of bivalve populations from the Indian coast (Parulekar et al., 1986), currently no information on morphometry of *P. erosa* is available. Worldwide, some morphological aspects of this species are reported by Morton (1976) from Hong Kong mangroves and Gimmin et al. (2004) from the Australian mangroves. Dimensional studies in lamellibranchs reveal that animals coming from different localities have differences in their dimensional ratios. Knowledge of the sex ratio, size at first maturity of a species determines the number and size of individuals that must be held for conditioning and spawning which is very essential for developing aquaculture practises. At present, the *P. erosa* population is subject to a low level of artisanal fishery for local consumption only. Therefore, data on yearly catches are not available. Any future commercial exploitation will need adequate stock management which necessitates the knowledge of the population dynamics that is based on the morphology of the animal. Hence, the present study was undertaken on the morphological aspects of *P. erosa*.

### 3.2 Materials and Methods

The clams were collected from the mangrove habitats along the central west coast of India between Kumta and Ratnagiri in different seasons. In addition, monthly collection of *P. erosa* population at Chorao island was done by hand picking.
randomly from the high tide region (HT). Clams were immediately transported to
the laboratory, where they were analysed for the different morphometric
parameters. Although, the collection of small size group (<30 mm) of clam is
difficult and time consuming, attempts were made to collect the smallest size
clams quantitatively. For this purpose, a marked area of 0.25 m² was sampled by
excavating only top 5 cm sediment layer. All the material was sieved on a 300μm
mesh sieve and preserved in 5% formalin Rose – Bengal solution. However, due
to a wider range of clam size, regular samples do not represent the quantitative
data for all size groups within the population. Most of the individuals collected
however, represent the mean size groups with majority being the matured
specimens (as indicated by their mature gonads).

Following the field collection, the bivalves were kept in running water overnight
to allow any sediment to be cleared from the mantle cavity and gut. Then, the
intact clams were washed, blotted dry and then left for a short- time (10-15
minutes) in air to allow the shell surface to dry before being measured and
weighed. The morphometric variables recorded were total length, width and
height, total weight of the whole specimen and wet and dry weight of the soft
parts. The measurements were done as total length (TL) (maximum distance on
the anterior-posterior axis), height (maximum distance on the dorsal-ventral axis,
across the shell middle axis), and width (maximum distance on the lateral axis,
between both valves of the closed shell). All variables were measured to the
nearest 0.01 mm with a vernier caliper. Total weights (TW) to the nearest 0.01 g
were determined after drying the shell with paper towels. Sex is determined based
on the colour of the gonads. The gonad is black in females and creamy white in
males. The wet tissues were blotted and their weights were measured to the
nearest 0.01 g with a Mettler PB602-S electronic balance. The dry weights were
recorded after drying the tissue in the oven at 60°C to a constant weight for 72
hours. The volume of mantle fluid was measured after draining the fluid in a
beaker.
3.2.1 Growth measurements

Following a particular cohort by measuring size frequency distribution through time is a common technique among population ecologists. In this method, a given year class is followed, and the change in the average size of the mode is equivalent to average growth. The ultimate length or the asymptotic length ($L_\infty$) attained by *P. erosa* was determined by the Ford Walford plot (Ford, 1933; Walford, 1946). The size frequency distribution was calculated for 10 mm length intervals.

3.2.2 Size at first maturity

To estimate the theoretical size at first maturity, data on TL and TW was subjected for correlation analysis and on the basis of break in a regression line discerned by inspection of a scattergram of LT/TW data (Ingole et al., 1998).

3.2.3 Sex ratio

The ratio of males to females was determined from microscopic examination of the gonadal smear. Clams were deemed sexually mature if gametes were present. A chi-square goodness of fit test was used to test the hypothesis that there was an equal representation of male and female mud clams in the population.

3.2.4 Morphometric relationship

The estimation of the morphometric relationships between the shell dimensions (length, width and height) and total weight, soft tissue wet weight and soft tissue dry weight were independently evaluated using log transformation of the equation (Ricker, 1973):
Where, \( Y \) is total weight (g), or soft tissue weight (wet or dry weight) in grams, and \( X \) is one of the dimensions (length, width or height) in millimeters, \( a \) is the intercept (initial growth coefficient); \( b \) is the slope (relative growth rate of variables). The length to total weight relationship was evaluated separately for males and females as well as for clams collected during the different seasons. So also the allometric relationship between clams collected from different locations were separately estimated. The parameters \( a \) and \( b \) of the morphometric relationships were estimated by linear regression analysis (least squares method), and the association degree between variables was calculated by the determination coefficient (\( r^2 \)). Additionally, the 95\% confidence limits of \( b \) and the significance level of \( r^2 \) were also estimated. An F-test was applied to test whether the slopes of the regression lines were significantly different from zero. The difference in the mean size between different sites as well as males and females was tested using an analysis of variance (ANOVA). Differences between regression lines of males and females, and of seasons were tested using the two-tailed Student’s t-test and ANOVA (Fowler et al., 2000). Routine regression and ANOVA was done using the Statistica version 5.5 (Statsoft, 1999).

3.3 Results

3.3.1 Structural Morphology

3.3.1.1 The Shell

The mangrove clam, \( P. eros a \) possesses a massive shell and is infaunal, inhabiting the landward fringe in the thick mangrove forest (Plate 3.1). The shell of \( P. eros a \) is large, thick, and dark in colour externally and white internally (Plate 3.2). The largest specimen found in Chorao Island, measured 102 mm in length, 98 mm in width and 54 mm in height. The clam’s shell is plump and globular, the valves
Plate 3.1: Mangrove clam *P. erosa* in *Avicennia* roots

Plate 3.2: Shell valves of *P. erosa* (external and internal view)
being thick and heavy. Majority of the clams have their umbonal beaks heavily corroded (Plate 3.3) while living. The shell is aragonitic. According to Taylor and Brand (1975), the shell of all corbiculids is similar in composition. Smaller, younger clams possess a more rounded shell. The shell is equi-valve with left and right valves being symmetrical and has similar weights (Fig. 3.1a). The shell valve margins meet through the entire length, except for a small gap mid-posteriorly. In the left valve, there are three cardinal teeth and two lateral teeth, one anterior and one posterior. In the right valve, there are three cardinals and two anterior and a single posterior tooth (Fig. 3.1b and 3.1c). The hinge teeth are stout, which, lock the shell tightly when the valves are united. The shell possesses a pallial line but there is no pallial sinus. The umbones are prominent and are near the anterior end. Most of the variability in form is apparently related to the differences in the height of the umbones. The shell interior is white. Young shells are dark green, but the colour disappears with age and older individuals are stained black.

3.3.1.2 The Siphons

The siphons of *P. erosa* (both inhalant and exhalant) are very short (Plate 3.4). The inhalant siphon bears a crown of 20-30 tentacles. Surrounding the tentacles is an outer circllet of small papillae at the base of the siphon. The exhalant siphon is somewhat conical and much smaller than the former on. This siphon does not possess the tentacular crown but is surrounded by the papillae, which run as two parallel rows, one on each mantle lobe. The papillae progressively shorten and soon terminate. The siphons and the mantle margins are deeply pigmented in *P. erosa* and hence, it is difficult to observe the siphons in fully open form. The siphons rarely open out fully except when immersed in water and are held between the borders of the valve.
Fig. 3.1a: *P. erosa*, Shell valve (External view)

Fig. 3.1b: *P. erosa*, interior view of the left shell valve

Fig. 3.1c: *P. erosa*, interior view of the right shell valve
Fig 3.1b. Interior view of left shell valve

PA  Posterior adductor muscle (or scar)
PPR Posterior pedal retractor muscle (or scar)
PLT Posterior lateral tooth
POL Posterior outer ligament layer
PIL Posterior inner ligament layer
U  Umbo
CT  Cardinal tooth
ALT Anterior lateral tooth
APR Anterior pedal retractor muscle or scar
AA  Anterior adductor muscle (or scar)
PL  Pallial line

Fig 3.1c. The hinge plate of right shell valve

ALT  Anterior lateral tooth
P    Periostracum
E    Eroded region of shell
CT  Cardinal tooth
U    Umbo
AIL  Anterior inner ligament layer
PIL  Posterior inner ligament layer
POL  Posterior outer ligament layer
PLT Posterior lateral tooth
Plate 3.3: *P. erosa* with heavily corroded umbo

Plate 3.4: *P. erosa* with extended inhalant and exhalant siphon
3.3.1.3 The pedal gape

The pedal gape (Plate 3.5) extends ventrally from the inhalant siphon to the anterior adductor muscle. Through the gape the large creamish white muscular foot can protrude. When they are not covered by water, the shell valves gape slightly, and when the animal is removed from the burrow, they close tightly together. When they close (usually happen, if disturbed), a jet of water is often ejected from the pedal gape.

3.4 Size variation of *P. erosa* along the west coast of India

The size of *P. erosa* in the present study, varied from 1.5 to 102 mm and the adults are usually not >102 mm, with majority of clams between 70 to 80 mm (Plate 3.6). The frequency of clams observed in the different size classes recorded is summarized in figure 3.2. Statistically significant differences in the size classes recorded from different locations during the study were observed (F=4.564, df=55, p=0.000942) and at all sites, clams represented the mean size classes except for Kalbadevi and Terekhol where only smaller and medium size classes were found. Location-wise details of morphometric measurement of *P. erosa* population are given in table 3.1. Maximum total weight, volume of mantle fluid, wet and dry weight was observed in the clams with the maximum total length (largest) and the lowest values for the above mentioned parameters were observed in the clams with minimum total length (smallest). However, this trend was not consistent with all the different size classes since some specimens with large sizes did not always show maximum total weight, wet weight and dry weight.

3.5 Population Structure

The size of *P. erosa* ranged from 1.5 to 102 mm. There was no significant difference in the mean size of the monthly samples (F=1.988, df=25, p>0.05; Table 3.2), as well as the different size classes recorded for one year did not show
Table 3.1: Location-wise details of morphometric measurements (range) of *P. eros* population collected during the present study

<table>
<thead>
<tr>
<th>Location</th>
<th>Length (mm)</th>
<th>Total weight (g)</th>
<th>Wet weight (g)</th>
<th>Dry weight (g)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Malvan</td>
<td>31.7-72.1</td>
<td>11.05-190.16</td>
<td>1.16-15.63</td>
<td>0.18-2.35</td>
</tr>
<tr>
<td>Kumta</td>
<td>37-92.9</td>
<td>9.4-197.8</td>
<td>1.84-43.4</td>
<td>1.09-8.02</td>
</tr>
<tr>
<td>Singuerim</td>
<td>56.48-94.72</td>
<td>60.95-265.73</td>
<td>9.14-29.13</td>
<td>1.32-5.22</td>
</tr>
<tr>
<td>Shirgao</td>
<td>56.4-81.9</td>
<td>51.4-151.4</td>
<td>6.02-21.73</td>
<td>0.95-4.56</td>
</tr>
<tr>
<td>Terekhol</td>
<td>42.5-60.3</td>
<td>21.12-49.3</td>
<td>3.03-10.59</td>
<td>0.58-2.02</td>
</tr>
<tr>
<td>Chorao</td>
<td>33.74-102.2</td>
<td>13.4-205</td>
<td>1.08-45.2</td>
<td>0.89-8.54</td>
</tr>
<tr>
<td>Kalbadevi (Single clam)</td>
<td>59.8</td>
<td>48.63</td>
<td>4.76</td>
<td>0.67</td>
</tr>
</tbody>
</table>

Table 3.2: Results of ANOVA between months on (a) mean length and (b) size classes of *P. eros* at Chorao island

<table>
<thead>
<tr>
<th>Source of Variation</th>
<th>SS</th>
<th>df</th>
<th>MS</th>
<th>F</th>
<th>P-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a) Mean length</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Month</td>
<td>88.03</td>
<td>1</td>
<td>88.026</td>
<td>1.988</td>
<td>0.1713</td>
</tr>
<tr>
<td>Residual</td>
<td>1062.45</td>
<td>24</td>
<td>44.269</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(b) Size class</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Month</td>
<td>23.18</td>
<td>12</td>
<td>1.932</td>
<td>0.010</td>
<td>1</td>
</tr>
<tr>
<td>Residual</td>
<td>25912.83</td>
<td>130</td>
<td>199.329</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Fig 3.2: Size-wise distribution of adult *P. erosa* in the mangroves along the central west coast of India
Plate 3.5: *P. erosa* with foot extended through pedal gape

Plate 3.6: Size variation in adult *P. erosa*
Morphometry of *P. erosa*

A significant variation in different months (F=0.0096, df=142, p>0.05; Table 3.2). The sex of all adult clams could be determined based on gonadal state. Sexes are separate in *P. erosa* with no incidence of hermaphroditism at Chorao island, although reported only in a single specimen from the Hong Kong mangroves (Morton, 1985). The gonads were not developed in the small specimens (<30mm). The indication of few sperms in males and developing ova in females were within the size class of 30.1-40 mm shell length. Sexually ripe clams were found in all sizes above 35 mm. In a year class, males are always smaller than female. Sexes are identifiable at TL of > 35 mm (Fig. 3.3). The smallest sized clam with identifiable sex, a male specimen recorded in this study was 35.3 mm shell length. Thus, sex differentiation takes place at the size of 30.1-35 mm and sexual maturation could occurred around 40 mm sizes when the clams are ~5 months old. If the individuals of the first year class begin their life as benthic recruitee in around July, they can grow upto 40.1-50 mm in December (Fig 3.4).

The TL of the clams ranged from 3.83 mm to 102 mm for females and from 3.6 mm to 9.4 mm for males. Mean TL for males and females was 65.8±6.5 SD mm and 69.5±6.8 SD mm, respectively (Fig. 3.5). No significant difference was found in the mean TL of males and females (F=1.988, p=0.171, df=25). The largest was a female with 102 mm TL, observed in March 2005. Most of the individuals were in size classes larger than 40.1 – 50 mm and the most dominant size class was 70.1-80 mm (Fig. 3.6). Eventhough, females outnumbered males in most of the months (Fig 3.7), the overall sex ratio for male to female, was not significantly different from the theoretical 1:1 ratio (χ²=2.1, df=1, p=0.1743).

The data on sex ratio in relation to length presented in figure 3.8 showed that, both male and female clams at Chorao mangroves were most abundant in the 60.1-70 mm shell-length class, however, males were dominant in the smaller length groups and females dominated in the larger length groups. In females, the length group 70.1 – 80 mm was the most dominant whereas the dominant size group for male was 50.1–60 mm. The 100.1-110mm size group was represented...
Fig. 3.3: Regression of soft tissue weight of *P. erosa* on shell length

\[ y = 0.002x^2 + 0.0624x - 0.4238 \]

\[ R^2 = 0.4472, n=479 \]
Fig 3.4: Size frequency distribution of *P. erosa* in different months at Chorao island, Goa
Fig 3.5: Mean length of males and females of *P. erosa* in different months

Fig 3.6: Percentage of *P. erosa* observed in different size classes at Chorao Island
Fig 3.7: Percentage of male and female *P. erosum* in different months

Fig 3.8: Percentage of male and female *P. erosum* in different length groups
Morphometry of *P. erosa* only by females. However, at all length intervals, the numbers of males and females are not significantly different (*χ^2*=14.78, df=7, *p>*0.05). Thus, the null hypothesis of independence between sex and length can be accepted for *P. erosa*. Seasonal variations in the sex ratio were apparent for females from February to July and for males from August to January. The sex ratio for *P. erosa* did not show significant variation over 12 months of study period (*χ^2*=32.67, df=11, *p>*0.05). However, Chi-square test on monthly ratio revealed that the sex ratio bias for male was significant only in January (*χ^2*= 7.41, df=1, *p*=0.0063) and for females in March and April (*χ^2*=6.277, df=1 *p*=0.0123; *χ^2*=4.05, df=1, *p*=0.0442, respectively). At the Chorao island, *P. erosa* is therefore a gonochoristic bivalve.

### 3.6 Growth

The length frequency distribution showed that, there was an appreciable modal shift in length of cohorts with time (Fig 3.4). The small newly recruited clams appeared during July to October 2004 at Chorao mangrove mudflat. An analysis of size frequency distribution shows that, the mode at 50.1-60 mm in July 2004 progressively moves to 60.1-70 mm in August, indicating an increase of 10 mm. In March, this mode is shifted to 100.1-110 mm (Fig. 3.4) showing a monthly growth rate of about 4 mm. However, this mode is not traceable after March. In July 2004, a mode appears at 0-10 mm and this is traceable through November – December, 2004 upto January 2005 reaching a size of 60.1-70 mm, thus attaining an average monthly increase of 10 mm during the first year of recruitment. In February 2005, the mode at 60.1-70 mm does not change, but then moves to 70.1-80 mm in March 2005 (Fig. 3.4), indicating a monthly increase of 5 mm. In April 2005, the mode at 70.1-80 mm does not change and only in July 2005 was shifted to 80.1-90 mm (Fig. 3.4), thus showing a monthly growth of 3.3 mm. This indicates that, during the first year, the growth rate is faster, but as clams attains maturation, growth rate decreases. The clam can grow upto 100 mm in approximately 4 years. The asymptotic or the ultimate length that can be attained
by *P. erosa* in Chorao mangrove mudflat, was estimated as L∞=120 mm (Fig 3.9).

### 3.7 Morphometric relationships

In all the allometric relationships of *P. erosa*, all the slopes of the regression lines are significantly different from zero. The estimated coefficients of the length-weight relationship and other statistical details are summarized in (Table 3.3). Shell length, shell width and shell height showed a strong correlation with total weight (Fig 3.10 to 3.12). At least 83% of the variation in the latter is accounted for the variation in shell dimensions. Among the shell dimensions, shell length is the best estimator of total weight with $r^2$ of 95%. However, when applied to soft tissue weights, the correlation of shell dimensions are not so strong ($r^2$ values of 46-47%) and with dry tissue none of these shell variables is a good predictor ($r^2$ values of 21-27%).

The differences in total weight of male and female during the different seasons were estimated using only the shell length since the length showed a comparatively stronger correlation than the width and height (Fig 3.13; Table 3.4). The slope for male’s regression line is found to be significantly higher than the females ($t=2.9315, df=587, p<0.01$). The slopes are constantly higher during the monsoon season (Table 3.4), indicating more variability in total weight than that of the summer season. The slope of the female’s regression line during post-monsoon season is significantly lower than for the monsoon season ($t=3.0637, df=139, p<0.001$; Fig. 3.14 and 3.15), while the slopes for the males do not differ significantly ($t=1.2716, df=223, p>0.05$; Fig. 3.16 and 3.17). Combined data for both sexes showed a significantly different slope ($t=-2.7890, df=364, p<0.001$), for clams collected during the summer season than the clams collected in the monsoon season (Fig 3.18 and 3.19). However, when contrasting the two sexes collected in the same season, the result is not significant (summer: $t=2.2845,$
Table 3.3: Morphometric relationship of shell dimensions with total weight and soft tissue weight of *P. erosa*

<table>
<thead>
<tr>
<th>Relationship</th>
<th>n</th>
<th>a</th>
<th>b±SE</th>
<th>r²</th>
<th>F*</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Total weight (g)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length vs Total weight</td>
<td>594</td>
<td>-3.404</td>
<td>2.937±0.0535</td>
<td>0.8357</td>
<td>3010.971</td>
</tr>
<tr>
<td>Width vs Total weight</td>
<td>594</td>
<td>-3.483</td>
<td>3.035±0.558</td>
<td>0.8332</td>
<td>2958.9</td>
</tr>
<tr>
<td>Depth vs total weight</td>
<td>594</td>
<td>-2.162</td>
<td>2.591±0.047</td>
<td>0.833</td>
<td>2953.77</td>
</tr>
<tr>
<td><strong>Wet Soft tissue weight (g)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length vs wet weight</td>
<td>455</td>
<td>-2.899</td>
<td>2.172±0.1075</td>
<td>0.4238</td>
<td>407.9</td>
</tr>
<tr>
<td>Width vs wet weight</td>
<td>455</td>
<td>-2.874</td>
<td>2.199±0.1109</td>
<td>0.414</td>
<td>392.6</td>
</tr>
<tr>
<td>Depth vs wet weight</td>
<td>455</td>
<td>-1.936</td>
<td>1.889±0.0948</td>
<td>0.4169</td>
<td>396.7</td>
</tr>
<tr>
<td><strong>Dry soft tissue weight (g)</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Length vs dry weight</td>
<td>455</td>
<td>-2.131</td>
<td>1.946±0.1674</td>
<td>0.247</td>
<td>211.3</td>
</tr>
<tr>
<td>Width vs dry weight</td>
<td>455</td>
<td>-2.74</td>
<td>1.758±0.1320</td>
<td>0.213</td>
<td>103.1</td>
</tr>
<tr>
<td>Depth vs dry weight</td>
<td>455</td>
<td>-2.166</td>
<td>1.188±0.1624</td>
<td>0.275</td>
<td>187.9</td>
</tr>
</tbody>
</table>

Table 3.4: Morphometric relationship of shell weight with total weight of female and male *P. erosa* during different seasons

<table>
<thead>
<tr>
<th>Sex</th>
<th>Season</th>
<th>n</th>
<th>a</th>
<th>B±SE</th>
<th>r²</th>
<th>F</th>
</tr>
</thead>
<tbody>
<tr>
<td>Male</td>
<td>Monsoon</td>
<td>79</td>
<td>-3.868</td>
<td>3.200±0.081</td>
<td>0.952</td>
<td>1557.7</td>
</tr>
<tr>
<td>Male</td>
<td>Postmonsoon</td>
<td>146</td>
<td>-3.5</td>
<td>2.979±0.120</td>
<td>0.809</td>
<td>610.1</td>
</tr>
<tr>
<td>Male</td>
<td>Premonsoon</td>
<td>41</td>
<td>-2.816</td>
<td>2.629±0.250</td>
<td>0.738</td>
<td>109.1</td>
</tr>
<tr>
<td>Female</td>
<td>Monsoon</td>
<td>52</td>
<td>-3.856</td>
<td>3.201±0.102</td>
<td>0.951</td>
<td>977.4</td>
</tr>
<tr>
<td>Female</td>
<td>Postmonsoon</td>
<td>89</td>
<td>-2.668</td>
<td>2.531±0.1569</td>
<td>0.744</td>
<td>253.1</td>
</tr>
<tr>
<td>Female</td>
<td>Premonsoon</td>
<td>70</td>
<td>-1.924</td>
<td>2.119±0.2347</td>
<td>0.545</td>
<td>81.4</td>
</tr>
<tr>
<td>Male + Female</td>
<td>Monsoon</td>
<td>131</td>
<td>-3.861</td>
<td>3.199±0.063</td>
<td>0.952</td>
<td>2541.9</td>
</tr>
<tr>
<td>Male + Female</td>
<td>Postmonsoon</td>
<td>235</td>
<td>-3.2</td>
<td>2.817±0.096</td>
<td>0.785</td>
<td>852.7</td>
</tr>
<tr>
<td>Male + Female</td>
<td>Premonsoon</td>
<td>111</td>
<td>-2.111</td>
<td>2.226±0.173</td>
<td>0.602</td>
<td>164.9</td>
</tr>
</tbody>
</table>
**Fig 3.9:** The asymptotic length of *P. erosa* estimated for Chorao Island population

\[ y = 2.9373x - 3.4046 \]

\[ R^2 = 0.8357, \; n=594 \]

**Fig 3.10:** Shell length and total weight relationship of *P. erosa*
Fig 3.11: Width and total weight relationship of P. erosa

$$y = 3.0353x - 3.4832$$
$$R^2 = 0.833, \ n=594$$

Log total weight (g)

Log width (mm)

Fig 3.12: Depth and total weight relationship of P. erosa

$$y = 2.5917x - 2.1624$$
$$R^2 = 0.833, \ n=594$$

Log total weight (g)

Log Height (mm)
Fig 3.13: Relationship of shell length and total weight of males and females of *P. erosa* in different seasons
Fig. 3.14: Shell length and total weight relationship of female *P.erosa* during monsoon

\[
y = 3.2017x - 3.8567 \\
R^2 = 0.9513, n=52
\]

Fig. 3.15: Shell length and total weight relationship of female *P.erosa* during post- monsoon

\[
y = 2.5315x - 2.6688 \\
R^2 = 0.7342, n=69
\]
**Fig. 3.16**: Shell length and total weight relationship of male *P. erosa* during monsoon

\[ y = 2.9792x - 3.5001 \]

\[ R^2 = 0.8091, n=146 \]

**Fig. 3.17**: Shell length and total weight relationship of male *P. erosa* during post-monsoon

\[ y = 3.2004x - 3.8684 \]

\[ R^2 = 0.9529, n=79 \]
Fig. 3.18: Shell length and total weight relationship of male and female *P. erosa* during monsoon

\[ y = 3.1996x - 3.8614 \]
\[ R^2 = 0.9517, n = B1 \]

Fig. 3.19: Shell length and total weight relationship of male and female *P. erosa* during pre-monsoon

\[ y = 2.2265x - 2.1119 \]
\[ R^2 = 0.6022, n = 111 \]
df=233, p>0.05, monsoon: t=0.0077, df=129, p>0.05). Furthermore, when the results of the length to total weight relationship between different locations were compared, it was seen that there exist no significant difference (F=2.25093, df=34, p>0.05, n=35).

3.8 Discussion

3.8.1 Growth in Size

From the size frequency distribution it appears that the growth is very rapid in the initial phase i.e. in the size group of 0-10 mm to 50.1-60 mm. The rate is approx. 10 mm during first 5-6 months after recruitment. Thereafter, the growth rate decreases to a monthly average of only 3.3 mm (Fig. 3.4), mainly due to the maturing gonads. Most of the published information on the growth of bivalves suggests that, young bivalves grow quite rapidly in size, and the growth rate is decreased as the animal grows. This suggests the possibility of a decreased growth rate in the older individuals as an effect of size as well as age. It is seen from the figure 4 that, individuals of 0-10 mm size group recruited in July of 2004, attains a size of 40-50 mm in December 04 and grew to a size of 60 mm in the first six months, showing an average growth of 10 mm per month. During the next six months the clam grew by 20 mm with a monthly average growth of 3.3 mm and attained a length of 80-90 mm at the age of one year. It appears that, the growth from 60-80 mm is comparatively faster as it grows with an average rate of 5 mm per month. After this length, the clams grow at rates of 2.5 mm per month. Thus, it can be concluded that *P. erosa* grew at a very fast rate during its early life and the rate was considerably retarded in the later period of life (Fig. 3.4). The decreased growth observed from April to July could probably be due to the allocation of more energy in the gamete production than the shell growth because gametogenesis in *P. erosa* starts around 40 mm size.
Morphometry of *P. erosa*

and attains its peak during 6-8 months of age around 50-70 mm shell length (Fig. 3.3).

In the present study, the growth parameters of *P. erosa* could not be estimated, as the asymptotic length \( (L_\infty) \) was calculated based on the monthly data, which was biased towards the mean size and the smaller and larger sizes were poorly represented. Such problems arise due to the difficulty in sampling the smaller population which was done by handpicking and is very well explained by a statement of Ralph and Maxwell (1977): “according to Knight (1968) and Theisen (1973), very misleading values of \( L_\infty \) are obtained by using data that does not cover the whole or most of a species growth”.

### 3.8.2 Morphometric relationships

The results on the allometric relationship show a strong linearity between shell dimensions and total weight, with poor relationships between shell dimensions and the soft tissue. This indicates that the soft tissue of *P. erosa* does not change much although the clams grow steadily. The lack of a strong correlation between shell size and meat tissue for *P. erosa* is different from that reported for other bivalves but the \( b \) value for the length – weight relationships is within the range observed for other bivalves such as *Mytilus edulis* (Rodhouse et al., 1984), *Chamelea gallina* (Deval, 2001). Nevertheless, similar findings were observed in the study of allometric relationship in *P. erosa* from Australian mangroves (Gimmin et al., 2004), but the \( r^2 \) for the shell dimensions and wet weight of the soft tissue were very low compared to the values observed in the present study. These differences may be related to the particular ecological characteristics of the different areas. Further, some disagreements on the species morphometric relationships may be a consequence of distinct hydrological and sedimentological features between different geographical areas (Gaspar et al., 2002). The higher determination coefficients in shell dimensions and total weight relationship than
shell dimensions and soft tissue, reveals that growth in *P. erosa* in terms of total weight, is less variable than growth in soft tissue. Factors such as the reproductive state of the animal (Rueda and Urban, 1998) and physical as well as biological variables of the habitat (Thorarinsdottir and Johannesson, 1996) are known to affect the growth of bivalves and can change the allometry between the shell and flesh. It is seen that fully-grown shell of *P. erosa* make the clams heavier, either because of increased shell mass or a higher amount of water or mantle fluid inside the shell. The amount of mantle fluid could be related to the species survival strategies and may vary seasonally depending upon the reproductive state of *P. erosa*. The large thick shell constitutes excellent characteristics to inhabit the extremely adverse conditions of the mangroves. *P. erosa* is found in the high zones of the mangrove forest, which is emersed for long periods of time. The clams are potentially exposed to dessication and a wide range of salinities as well as starvation since these clams are filter feeders. To protect the body against adverse environmental conditions and predators, they need thick valves that can be closed tightly. The need for thicker and heavier shells than normal has been reported for bivalves inhabiting periodically dry zones (Seed, 1968).

The need for strong shells and a high capacity to live in adverse conditions might direct more energy to shell growth than the growth of the soft tissue. According to Currey (1998), investment in the shell, limits the growth of an individual. In addition, a low rate of flesh tissue growth is useful for survival of the animals exposed to prolonged emersion. During the periodic emersion, the clams need to maintain a sufficiently large volume of water inside the shell to create a watery environment for survival of the body tissue (Seed, 1968; Ansari et al., 1978). If the soft tissue continues to grow and occupy a large part of the space inside the shell, then there would not be enough water to support the metabolic needs of the increased tissue.
The higher slope values for the regression line in males than females probably indicate that males gained more weight with increase in length, indicating a better condition than females. The $b$ values for the shell length and total weight relationship of the clams in the monsoon season (Fig. 3.18) were significantly different to those during the summer season (Fig. 3.19). This probably could be because the clams spawn during the monsoon season. Variation in the value of $b$ to some extent is due to the proportion of shell mass. In conclusion, only shell dimensions are not good estimators for the biomass production of *P. erosa*. Nevertheless, the allometric relationship between shell length, shell width and shell height to total weight can be used to monitor the growth of this species in the natural population.

3.8.3 Size at first maturity:

The theoretical size at first maturity for *P. erosa* at Chorao mangroves as seen from figure 3.3, is in agreement with the observed size of smallest egg bearing female (40 mm). However, the mean size of egg bearing female may vary with time during the reproductive season, either due to the growth of females or due to the entry of newly maturing females. Moreover, the growth rate can significantly alter the size at first maturity (Ingole et al., 1998). Since the physical inspection did not show the presence of matured eggs in females below 40 mm TL, maturation in female *P. erosa* at Chorao occurs around ca.40 mm TL. However, males being smaller than females mature at smaller size, ~35 mm length.

3.8.4 Sex ratio

At Chorao island the male: female ratio in *P. erosa* conforms to 1:1 in all months barring few exceptions. According to Fisher (1930), in gonochoric species, selection acts on the sex ratio of the offspring in order to equalize the contribution of both sexes to the fitness of their parents, favouring at the population level an
overall sex ratio of 1:1. Although, prevalence of females is a general rule (Ponurovsky and Yakovlev, 1992), in the present study, the males prevailed in most of the months. The male domination reported here is in general agreement with previously reported sex ratios for different bivalve species (Amaro, 2005). Although, there was no statistically significant difference in the male: female ratios throughout the entire shell length size distribution analyzed, males generally prevailed in the smaller size classes (Fig. 3.8). Several authors have also noted, males to dominate in small size classes with females often becoming more prevalent as size/age increases (e.g. P. zelandica, Gribben and Creese, 2003; Gribben et al., 2004). Males typically dominate protandric bivalve species in the first year (Alan et al., 2004) whereas older age classes are generally equal. The sex ratio of P. erosa at Chorao island were equal over the size range of collected clams. Although, females prevailed in the largest size class and males in the smallest size class recorded, there is insufficient data to conclude that the ratio is biased towards a particular sex. If females dominate larger size classes, then harvesting larger clams may specifically target females, seriously compromising the sustainability of local populations. Hence, to make a full assessment of the sexual development of P. erosa, mud clams will have to be collected over the entire size/age range for several populations.