Population dynamics of the Asian green mussel *Perna viridis* (L.) from St. Mary’s islands off Malpe, India

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Size range of mussels in the population varies from 6.1 to 133.2 mm. Von Bertalanffy growth equation for length was $L_t = 136.9 [1-e^{-0.42(t+0.38)}]$. Growth performance index ($\Phi$) was estimated as 3.896. Total mortality ($Z$) of the regime was 1.18 year$^{-1}$. Natural mortality ($M$) and fishing mortality ($F$) rates were 0.42 year$^{-1}$ and 0.76 year$^{-1}$ respectively. Total mortality based on mean size in the sample for the whole population ranged from 0.5380 (October 2005) to 2.2492 (December 2004). Cohort size was reduced by 50% within 6 months after settlement. Maximum and minimum densities of mussels were 5,404 no.m$^{-2}$ (December 2004) and 1,744 no.m$^{-2}$ (October 2005) respectively and the average was 3,105 no.m$^{-2}$. Biomass (total weight) of mussels varied from 8,910 g.m$^{-2}$ (November 2004) to 37,745 g.m$^{-2}$ (December 2005) at the study site during the study period. Average biomass was 22,754 g m$^{-2}$. Biomass values (total weight, wet weight, dry weight and shell weight) increased with the increasing growth of mussels. Specific production ($C$) ranged from 0.0488 (June 2005) to 0.1318 (January 2005). High specific production was recorded during post-monsoon season and low values during pre-monsoon season. Maximum length recorded ($L_{max}$) was 133.2 mm.

[Keywords: Population dynamics, *Perna viridis*, Coconut Island, Karnataka]

Introduction

Asian green mussel *Perna viridis* (L.) is a native to the tropical waters of Indo-Pacific region and in its native range is an important aquaculture species. Mussel's are widely distributed and contribute to a considerable fishery along the south west coast of India and are a cheap source of protein. Marine mussels have been cultured experimentally with good success in varying environmental conditions in India. Considerable amount of data on age and growth of subtidal mussels is available from Chennai coast of Tamil Nadu, Calicut coast of Kerala, Panaji and Vengurla and Dona Paula coasts of Goa and Ratnagiri region of Maharashtra. *P. viridis* is widely distributed in the intertidal and subtidal rocky areas along Karnataka coast, but there is a dearth of information on the population ecology of *P. viridis* inhabiting the intertidal regions of India. Knowledge of growth parameters and production are essential for the understanding of the ecology and productivity of eatable green mussel, *P. viridis* inhabiting rocky beds of an island. It is crucial to support future aquaculture or exploitation activities and management. Present study consists the population dynamics of *P. viridis* from the intertidal rocky shore at St. Mary’s Islands off Malpe in Udupi district of Karnataka state.

Materials and Methods

Mussels were sampled from the intertidal region at Coconut Island (13º21’58”N, 74º42’58”E) of St. Mary’s Islands, a group of 4 small islands spread over a distance of 4 km parallel to mainland off Malpe, near Udupi. Among St. Mary’s Islands, the northern most island, i.e. the Coconut Island, is about 2.59 km$^2$ in area and about 230 m in width and is composed of basalt rocks which have crystallized and split into hexagonal mosaic. This is an uninhabited island and tourists regularly visit the island for recreation.

Mussels were collected from 1 m$^2$ area at monthly intervals between December 2004 and December 2005. Sampling was carried out at daytime during low tide. Mussels were separated...
from associated organisms, counted and weighed. Afterwards, the mussels were individually measured for shell length (maximum anterior-posterior distance) using Vernier caliper. Tissue of individual mussels was removed, blotted, dried at a constant temperature of 60 °C for 2 days and weighed accurately to 0.001 g. At the time of sampling, water temperature was recorded.

The data on shell length was analysed using the FiSAT software. Population parameters, namely asymptotic length \((L_\infty)\) and growth coefficient \((K)\) of the von Bertalanffy Growth Function (VBGF) were estimated by means of ELEFAN-1. K-scan routine was conducted to assess a reliable estimate of the \(K\) value. Theoretical time when an animal has zero length \((t_0)\) was calculated using the least square method. The data were then grouped into 10 mm shell length intervals.

The von Bertalanffy growth equation was used to find the length at various ages. VBGF was fitted to estimate of length at age curve. VBGF was defined by the equation: \(L_t = L_\infty \left[1 - e^{-K(t - t_0)}\right]\)

\(L_t\) is the length at age \(t\), \(L_\infty\) is the mean asymptotic length, \(K\) is the body growth coefficient, \(t\) is the age and \(t_0\) is the time when \(L_t = 0\). The estimates of \(L_\infty\) and \(K\) were used to estimate the growth performance index \((\Phi')\) using the equation: \(\Phi' = 2 \log_{10} \left(1 - \frac{t_0}{L_\infty}\right) + \log_{10} K\).

Total mortality \((Z)\) was estimated using length converted catch curve method. Natural mortality rate \((M)\) was determined using \(M = K\) approximation. Fishing mortality \((F)\) was estimated using the relationship: \(F = Z - M\). The exploitation level \((E)\) was obtained from the relationship of Gulland: \(E = F / Z\), where \(Z = F / F + M\).

The recruitment pattern of the stock was determined by the backward projection on the length axis of the set of available length–frequency data as described in FiSAT. Recruitment pulse was constructed from a time series of length frequency data to determine the number of pulses per year and the relative strength of each pulse with the input parameters \((L_\infty, K\) and \(t_0)\). Specific production \((C)\) was calculated as per the procedure given by Zaika using the equation: \(C = K / T\), where \(K\) is the growth constant and \(T\) is the maximal life span.

**Results**

A total of 3551 individuals ranging from 6.1 to 133.2 mm size was studied for length frequency distribution. There was a distinct peak in young mussels (<10 mm) evident during December 2004 and August-October 2005 (Fig. 1). During the study period the sampled mussel population showed two distinct size related peaks: a peak at 40-50 mm and then at 90-100 mm.

Examination of sampled mussels revealed a size range up to 140 mm. The mean mussel size was 50.2 mm. Most mussels in the sampled population were <70 mm.

In December 2004 the primary peak was in 10-20 mm size group, which was shifted to 30-40 mm size group during January 2005. Peak remained at the same size during March 2005. Thereafter the peak shifted to 40-50 mm during April 2005 and remained in the same size group during May 2005 also. Mode shifted back to 30-40 mm in June 2005. The majority of mussels was noticed in 50-60 mm from August to December 2005. Again the peak shifted to 50-60 mm size class during August 2005 and remained in the same class till December 2005. However, during August 2005, appearance of primary peak was noticed at 0-10 mm. The newly recruited young mussels during August 2005-September 2005 attained the size of about 30 mm by the end of December 2005. Modal growth curve of P.
**Perna viridis** is presented in Fig. 2. From the modal growth curves for different year broods, the average settlement period was estimated by extrapolating the curves.

![Fig. 2 – Settlement and growth rate (based on modal shell length) of *P. viridis*. Overall size ranges (vertical lines), mean sizes (circles), standard deviation (histograms), modal values (filled circles) and extrapolated values (dotted lines)](image)

The population comprises individuals of <1 and >1 year populations. Growth rate of mussels was almost similar for different brood stocks, which have settled in different years from 1999 to 2005 based on modal shell length (Fig. 2). A perusal of the data presented in Fig. 3 showed that the growth rate of mussels was fast in the early part of life which steadily decreased and continued until death. Sizes attained by *P. viridis* were 48.0 mm, 79.5 mm, 96.0 mm, 107.0 mm, 116.5 mm and 125.0 mm at the end of 1st, 2nd, 3rd, 4th, 5th and 6th years respectively. Average growth rate of *P. viridis* from 1st to 6th years was 45.6 mm, 30.0 mm, 15.6 mm, 10.8 mm, 9.60 mm and 8.40 mm respectively.

![Fig. 3 – Monthly mean growth rate of *P. viridis*](image)

The monthly length frequency distribution with growth curves superimposed using ELEFAN I was obtained. Estimated values of growth parameters such as asymptotic length (*L*_∞) of the VBGF, the growth coefficient (K) and age at birth (t₀) for *P. viridis* were 136.9 mm, 0.42 year⁻¹ and -0.38 year respectively. Computed von Bertalanffy growth curve for length is presented in Fig. 4. The growth performance index (Φ') was 3.8960.

![Fig. 4 – von Bertalanffy growth curve of *P. viridis*](image)

The total mortality (Z) of *P. viridis* based on the length converted catch curve was 1.18 year⁻¹. The estimated natural mortality (M) and fishing mortality (F) were 0.42 year⁻¹ and 0.76 year⁻¹ respectively. Instantaneous total mortality (Z) of a cohort was reduced by 50% within 6 months after settlement (Fig. 5) and thereafter the mortality rate was more or less constant. Total mortality based on mean size in the sample for the whole population ranged from 0.5380 (October 2005) to 2.2492 (December 2004). As the mussels attained larger size, the mortality rates steadily reduced and slightly higher mortality rates were observed during November and December 2005.

![Fig. 5 – Instantaneous total mortality of *P. viridis*](image)
Data on temporal variations of population density and biomass (total weight) is presented in Fig. 6. Maximum density of mussels was 5,404 m$^{-2}$ (December 2004) and the minimum density was 1,744 m$^{-2}$ (October 2005). The density of mussels was high during the settlement period (months) with the average density of 3,105 m$^{-2}$. Maximum and minimum biomass of mussels were 37,745 g.m$^{-2}$ (November 2005) and 8,910 g.m$^{-2}$ (December 2004) respectively. Average biomass was 22,754 g m$^{-2}$ during the study period. The increasing trend in the mean values of biomasses such as total weight, wet weight and shell weight of mussels was observed from December 2004 to October 2005 except May 2005 (Fig. 7). During November 2005 the decrease in the mean total weight, wet weight and shell weight was noticed and during December 2005 the mean total weight and shell weight increased further, whereas the decreased average wet weight was recorded. Mean dry weight showed a steady increase from December 2004 to June 2005 and decreased during August 2005. Afterwards it increased gradually up to November 2005 and showed a slight reduction in dry weight during December 2005.

The monthly specific production ($C$), the production in unit time per unit of biomass, of $P. viridis$ is depicted in Fig. 8. Maximum specific production was 0.1318 (January 2005), whereas the minimum value was 0.0488 (June 2005). High values of $C$ were recorded during the post-values during pre-monsoon season.

![Temporal variation in the population density and biomass of $P. viridis$](image1)

![Average values of total weight, wet weight, dry weight and shell weight of $P. viridis$ during the study period](image2)

![Monthly specific production ($C$) of $P. viridis$](image3)

![Relationship between life span ($T$) and specific production ($C$) of $P. viridis$](image4)

Specific production of $P. viridis$ settled in 2004 is given in Fig. 9. The fitted regression was $Y = 0.1668 - 0.015X$ ($r = 0.9473$, $P < 0.001$).

**Discussion**

Both physical and biological processes can influence the settlement pattern of planktonic larvae on morphologically and chemically distinct substrates. Further mussels may re-settle several times on different substrates during their post-larval and juvenile stages. Previous studies have shown that the major intertidal recruitment of mussels on the east coast of India is during August, corresponding to the major
spawning season\textsuperscript{31}. During the present study the spawning and subsequent recruitment took place from August to December 2005.

The freshly settled spat showed faster rate of growth during the first few months and thereafter growth decreased. Rapid growth rate of 6.0-10 mm month\textsuperscript{-1} was reported elsewhere\textsuperscript{32-34}. Ranade et al.\textsuperscript{33} reported that green mussel spat in Ratnagiri waters showed an average growth rate of 7.6 mm month\textsuperscript{-1}. The faster growth rate during post-monsoon (26.4 mm), followed by moderate growth (2.5 mm) during summer and slow growth rate in monsoon (1 mm) from Goa waters have been reported\textsuperscript{35}. Average growth rate of another Perna species (\textit{P. indica}) inhabiting Vizhangam bay of Kerala coast was 35.3 mm\textsuperscript{36}. The faster growth rate in the first six months and decreased growth in the second half of the year has been reported from Kakinada Bay\textsuperscript{37}.

Table 1 – Growth parameters, asymptotic length (\(L_\infty\)) and growth coefficient (K) of marine mussel. Growth performance index (\(\Phi'\)) values were calculated using the raw data given by the authors except in case of Al-Bharwani et al.\textsuperscript{50}

<table>
<thead>
<tr>
<th>Species</th>
<th>(L_\infty) (mm)</th>
<th>(K) (year\textsuperscript{-1})</th>
<th>(\Phi')</th>
<th>Habitat</th>
<th>Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>\textit{P. indica}</td>
<td>110.0</td>
<td>0.10</td>
<td>3.0828</td>
<td>Coastal waters of Calicut, India</td>
<td>Kuriakose\textsuperscript{10}</td>
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<td></td>
<td>73.9</td>
<td>0.13</td>
<td>2.8512</td>
<td>Wooden raft, Ubatuba, south east Brazil</td>
<td>Marques et al.\textsuperscript{37}</td>
</tr>
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<td></td>
<td>71.3</td>
<td>0.16</td>
<td>2.9103</td>
<td>Autumn</td>
<td></td>
</tr>
<tr>
<td></td>
<td>72.7</td>
<td>0.19</td>
<td>3.0019</td>
<td>Winter</td>
<td></td>
</tr>
<tr>
<td></td>
<td>73.8</td>
<td>0.11</td>
<td>2.7775</td>
<td>Spring</td>
<td></td>
</tr>
<tr>
<td>\textit{P. perna}</td>
<td>101.2</td>
<td>0.53</td>
<td>3.7347</td>
<td>Texas Gulf of Mexico, Northern jetty, Fish Pass</td>
<td>Hicks et al.\textsuperscript{44}</td>
</tr>
<tr>
<td></td>
<td>96.8</td>
<td>0.82</td>
<td>3.8856</td>
<td>Northern jetty, Mansfield Pass</td>
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<td></td>
<td>89.4</td>
<td>2.14</td>
<td>4.2331</td>
<td>Suspended plastic cage, Penang, Malaysia</td>
<td>Choo&amp;Speiser\textsuperscript{45}</td>
</tr>
<tr>
<td></td>
<td>184.6</td>
<td>0.25</td>
<td>3.9304</td>
<td>Subtidal bed, Kakinada Bay, India</td>
<td>Narasimham\textsuperscript{7}</td>
</tr>
<tr>
<td></td>
<td>110.0</td>
<td>0.1124</td>
<td>3.1336</td>
<td>Raft culture, Goa, India</td>
<td>Chatterji et al.\textsuperscript{12}</td>
</tr>
<tr>
<td></td>
<td>101.9</td>
<td>0.30</td>
<td>3.5411</td>
<td>Victoria Harbour, Hong Kong</td>
<td>Lee (1985)</td>
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<td></td>
<td>112.0</td>
<td>1.00</td>
<td>4.0984</td>
<td>Pole culture, Upper Gulf, Thailand</td>
<td>Tuaycharden et al.\textsuperscript{49}</td>
</tr>
<tr>
<td>\textit{P. viridis}</td>
<td>85.0</td>
<td>0.1014</td>
<td>2.8648</td>
<td>Raft culture, Zuari estuary, Goa, India</td>
<td>Rivonkaret et al.\textsuperscript{50}</td>
</tr>
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<td></td>
<td>102.4</td>
<td>1.50</td>
<td>4.1965</td>
<td>Coastal region, Malacca, Malaysia</td>
<td>Al-Bharwani et al.\textsuperscript{51}</td>
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<tr>
<td></td>
<td>136.9</td>
<td>0.42</td>
<td>3.8960</td>
<td>Intertidal region of Coconut Island of St. Mary’s group of Islands off Malpe, India</td>
<td>Present study</td>
</tr>
</tbody>
</table>

Various factors such as season\textsuperscript{36-38}, population density\textsuperscript{39} and tidal height\textsuperscript{40} affected the growth of marine mussels, \textit{P. viridis} inhabit the coastal waters where the salinity ranges from 16 to 33 ppt (optimum of 27-33 ppt) and temperature from 10 to 35\degree C (optimum of 26-32 \degree C) and known to grow well in turbid and polluted waters\textsuperscript{2,34,41,42}. Mean length of \textit{P. viridis} measured in this study progressively increased from 27.4 mm (December 2004) to 63.5 mm (October 2005) and slowed down afterwards (58.4 mm during November 2005 and 60 mm during December 2005) (Fig. 2). The mean monthly growth rate was high in the first year (3.8 mm month\textsuperscript{-1}) which gradually decreased up to sixth year (0.7 mm month\textsuperscript{-1}) (Fig. 3). This might be due to the high metabolic rate in younger mussels compared to older mussels.

Growth parameters (\(L_\infty, K, t_0\)) are helpful in comparison of growth rates between and within species inhabiting different habitats. The values of growth parameters of marine mussels varied with different habitats (Table 1). Asymptotic length (\(L_\infty\)) is the maximum theoretical length an organism can attain under the given rate of growth. Highest \(L_\infty\) (184.60 mm) value for \textit{P. viridis} was reported from Kakinada Bay, India\textsuperscript{43}. Lowest value (89.4 mm) was reported from Malaysia\textsuperscript{34}. During the present study the \(L_\infty\) was 136.9 mm. The \(L_{\text{max}}\) (maximum length reached by the mussel of a given stock) was 133.2 mm. The
coefficient $K$ (the rate at which the animal approaches the theoretical maximum) can be used to compare between the growth of related species or same species in varied habitats. The $K$ value (0.42 year$^{-1}$) of $P. viridis$ in the present study was close to the values reported for $P. viridis$ from Kakinada Bay (0.25 year$^{-1}$) and Hong Kong waters (0.3 year$^{-1}$) (Table 1). Highest $K$ value (2.14 year$^{-1}$) was from Malaysia$^{46}$ which is higher than the present study. Because $K$ denotes the rate at which the growth decreases to reach the maximum, lower values of $K$ denote faster rates of growth. The coefficient of growth rate constant could be used as an index of the intrinsic development rate of a species and has importance in intra- and inter-specific comparisons of growth$^{45,46}$.

Phi-prime ($\Phi'$) or growth performance index (GPI) is a length-based index of growth performance. The GPI of the present study was 3.90. This value was lower than that of mussels inhabiting Thailand (4.1) and Malaysia waters (4.2) and very close to the mussels (3.93) of Kakinada waters, India. However the GPI value of the present study was more than that of mussels from temperate regions (Table 1). In the present study the mussels inhabiting the intertidal zone are exposed to atmosphere during low tide and hence are under stress continuously when compared to the subtidal natural population of Kakinada waters and the subtidal cultured mussels of Thailand and Malaysian waters. In spite of adverse conditions of the intertidal zone the growth of mussels is maximum.

Mortality is an important aspect in the population dynamics of mussels$^{46}$ and could vary enormously depending on environmental conditions. Natural mortality was less (0.42 year$^{-1}$) compared to fishing mortality (0.76 year$^{-1}$) of $P. viridis$ in the present study. The exploitation rate is high ($E$ = 0.64) which indicated the over-fishing of $P. viridis$ at the study area. Stock is over fished when the exploitation rate ($E$) is more than 0.5 according to Gulland$^{17}$. However, $Eof$ eared horse mussel, Modiolus auriculatus from Karnataka coast were negligible due to majority of them were small in size in their colony$^{12}$. Total mortality for the whole population ranged from 0.5380 (October 2005) to 2.2492 (December 2004). As the mussels attained larger size, the mortality rates steadily reduced. A slightly high mortality rates were observed in November 2005 and December 2005. This might be due to overcrowding as a result of continued settlement of young mussels and favorable environmental conditions.

In the present study, the average production of 22.75 Kg m$^{-2}$ on a total weight basis and 1.14 Kg m$^{-2}$ on dry weight basis were registered. As may be expected biomass was low when a large number of young mussels settled. Annual production and biomass (wet meat weight) of cultured mussel in Edaiyur back waters of the east coast of India were 47 Kg m$^{-2}$ and 22 Kg m$^{-2}$ respectively$^{31}$. In the present study, during December 2004 the density, biomass on a total weight basis and biomass on dry weight basis were 5,404 ind. m$^{-2}$, 8.91 Kg m$^{-2}$ and 0.33 Kg m$^{-2}$ respectively. High values were recorded in older age groups, indicative of the larger shell size and more flesh present in the mussels. The maximum biomass on the total weight and dry weight was observed during November 2005 (37.745 Kg m$^{-2}$ and 1.98 Kg m$^{-2}$ respectively) when 2,594 ind. m$^{-2}$ was recorded. However, an inverse relationship between density and production was noticed (Fig. 6).

Acknowledgements

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