Indian J. Fish., 68(4): 22-29, 2021
DOI: 10.21077/ijf.2021.68.4.104825-03

Fishery and biology of *Paphia malabarica* (Dilwyn, 1817) off Karapad Bay, south-east coast of India

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ABSTRACT

The fishery, biology, growth and mortality of the short neck clam *Paphia malabarica* (Dilwyn, 1817) was studied from Karapad Bay of Thoothukudi District from January 2013 to December 2019. The annual exploitation of *P. malabarica* in this bay was between 7.5 t (2016) and 82.5 t (2019) with an average of 22.3 t. The average catch per unit effort (CPUE) was estimated as 17.5 kg person^{-1} day^{-1}. The male clams were dominant in most of the months except during March, June and October. Chi-square test indicated that, the sex ratio between males and females (1:0.9) was not significantly different. The size at first maturity (L_m) was estimated as 21 mm for *P. malabarica* in this bay. High percentage (>65%) of mature females was observed between September and December and this pattern suggests spawning season during this period with peak spawning during November. The clam size in the fishery ranged between 24.2 and 55.4 mm (average 39.3 mm) and around 75% of the total catch belonged to 33-41 mm size group. The asymptotic length (L_∞) and growth coefficient (K) were estimated as 55.6 mm and 1.1 respectively. *P. malabarica* attained a length of 37, 49.5 and 53.5 mm at first, second and third year respectively. The t_{max} was found to be 2.7 year and the growth performance index (Ø') was found to be 1.53. Total mortality (Z), natural mortality (M) and fishing mortality (F) were estimated as 4.36, 2.64 and 1.72 year^{-1} respectively. The assessment revealed that 95.8% of the exploited catch is above the optimum length (L_{opt}) of 30 mm. The exploitation rate (E) and exploitation ratio (U) were 0.394 and 0.389, respectively and the maximum sustainable yield (MSY) of *P. malabarica* was 104.8 t which shows the present catch was 21% below the MSY. The above results indicate scope for expansion of the fishery of the species in Karapad Bay.

Keywords: Age, Biology, Population, Stock assessment, Short neck clam

Introduction

India is endowed with rich molluscan resources all along the coast and there exist sustenance and commercial fishery in the inshore waters, bays and estuaries along the east and west coasts. Bivalve resources comprising of clams, cockles, oysters and mussels are distributed throughout the Indian coast and are exploited by the local fisher groups for their sustenance and livelihood. Among the exploited bivalve resources of India, clams and cockles contribute 73.8% catch due to their wide distribution and abundance (Mohamed and Venkatesan, 2017). Since time immemorial, bivalves, except pearl oysters have been exploited commercially either for food or for shell (Kripa and Appukuttan, 2003).

Most of the commercially important clam species belonging to the families Arcidae, Veneridae, Tridacnidae, Solenidae and Donacidae are being exploited along the Indian coast by local fishers including fisherwomen. The members of the family Veneridae represent the most important exploited group along the Indian Coast, particularly in southern states. Among venerid clams, *Meretrix, Marcia* and *Paphia* are the commercially important genera. Among these, the yellow foot clam, *Paphia malabarica* (Dilwyn, 1817), having wider distribution, along the south-west and south-east coasts of India forms an important bivalve resource in many estuaries, backwaters and coastal waters and is exploited for local consumption as well as for exports (Thomas and Nasser, 2009). The fishery of *P. malabarica* has been reported from Mulky Estuary (Rao, 1988), Ashtamudi Estuary (Appukuttan, 1993; Appukuttan *et al.,* 2002) and Dharmadom Estuary (Thomas *et al*., 2003). The reproductive biology of *P. malabarica* from Dharmadom Estuary (Thomas, 2013), Mulky (Rao, 1988) and Ashtamudi estuaries (Appukuttan, 1993) were the few studies from south-west coast of India. The length-weight

relationship of this clam was reported by Mohite and Mohite (2010) from the Kalbadevi and Kajali estuaries of Ratnagiri coast and Thomas (2013) from Dharmadom Estuary. Detailed study on population dynamics of *P. malabarica* was carried out by several authors from west coast (Rao, 1988; Appukuttan *et al.,* 1999; Thomas and Nasser, 2009; Mohite and Mohite, 2010), but information on fishery, population dynamics and reproduction of the above species is lacking along the east coast of India. Considering the lack of relevant information about this species from south-east coast of India, an attempt was made to study the fishery, biology, growth, longevity and mortality of *P. malabarica* from the Karapad Bay, Tamil Nadu, south-east coast of India.

Materials and methods

The study was based on samples collected from the Karapad Bay of Tamil Nadu, south-east coast of India (Fig. 1). Karapad Bay is influenced by freshwater inflow from a rivulet of river Thamaraparani with tidal amplitude of 1 m. The catch data was collected from January 2013 to December 2019 from the commercial landings and shell traders. Catch per unit effort (CPUE) was estimated as kg person^{-1} day^{-1}. Length-weight measurements were taken between 2013 and 2019. Monthly samples of *P. malabarica* were collected during January 2016 to December 2017 that was used for analysing reproductive biology. A total of 2,201 numbers of *P. malabarica* specimens were used for biology, age, growth and mortality studies. Fresh gonad smears were observed under microscope for assessing gonadal development stages as per Narasimham (1988). Chi-square test was followed to find out the significance of sex ratio. Size at maturity (L_m) was estimated by fitting the logistic model to the proportion of mature clam in the 1 mm size categories (King, 1995).

Total length (distance between the anterior and posterior extremities of the shell in a direction parallel to the ventral margin) was measured to the nearest of 0.01 mm using a digital caliper. The total weight was recorded by an electronic balance to the nearest of 0.01 g. Length frequency data were analysed using FiSAT II software package (Gayanilo *et al.,* 2005). For calculating the length frequency, the data was grouped into 3 mm class intervals. The length frequency distribution in the sample was raised to the total number of clams exploited on the sampling day and subsequently raised for a month (Appukuttan *et al.,* 1999).

For estimation of von Bertalanffy growth parameters, the month-wise length composition data for two years were pooled and grouped with 3 mm class intervals.

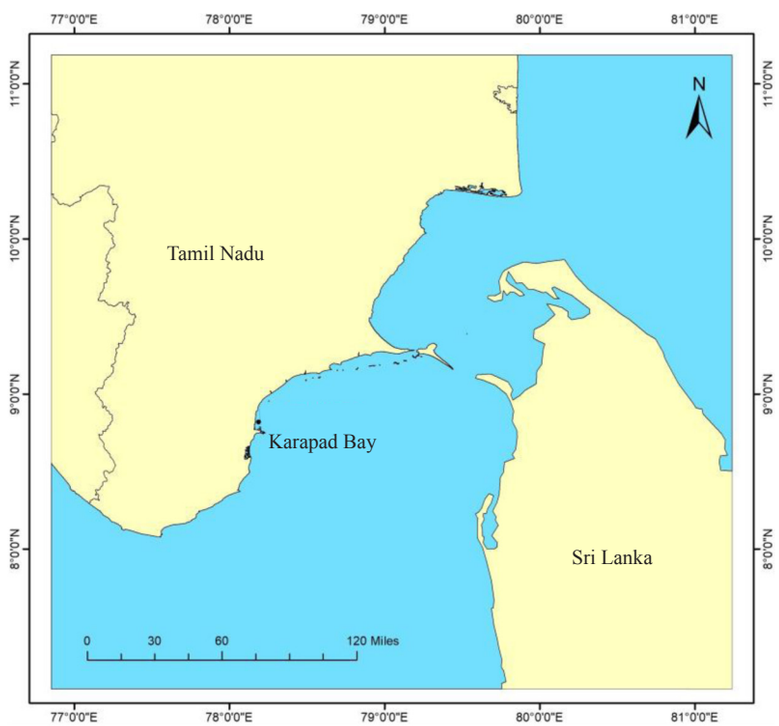

Fig. 1. Map showing study area

Growth coefficient (K) and asymptotic length (L_∞) of the von Bertalanffy growth function (VBGF) were estimated by ELEFAN (Bertalanffy, 1934; Pauly, 1986) and the Powell-Wetherall plot (Gayanilo *et al.,* 2005). The VBGF was fitted to a growth-curve estimate using non-linear square estimation procedures. The inverse von Bertalanffy growth equation (Sparre and Venema, 1992) was used to envisage lengths at various ages. The VBGF was fitted to estimates of the length at curve using non-linear estimation procedure and the VBGF is defined by the equation: $L_t = L_\infty [1\text{-}e^{-K\,(t - t_0)}]$, where L_t is the mean length at age t, L_∞ is the asymptotic length, K is the growth coefficient, t is the age and t_0 is the hypothetical age at which the length is zero. Growth performance index was applied to compare different estimations of growth parameters, the empirical equation of growth performance, $Ø' = \log_{10} K + 2 \log_{10} L_\infty$, of Pauly and Munro (1984) was used. Longevity (t_{max}) was calculated as $t_{max} \approx 3/ K + t_0$ (Pauly, 1980). Total mortality (Z) was determined by the length converted catch curve method using total annual length frequency distribution of catch. Natural mortality rate (M) was estimated using Pauly's (1980) formula, $\log M = -0.0066 - 0.279 \log L_\infty + 0.6543 \log K + 0.4634 \log T$. The fishing mortality (F) was calculated using the relationship F = Z - M where, Z is the total mortality, F is the fishing mortality and M is the natural mortality. The exploitation rate (E) was estimated as F/Z (Pauly, 1980). Exploitation ratio (U) was given by $U = F / Z * (1 - e^{-Z})$. The optimum length at capture was calculated using the formula $L_{opt} = 3L_\infty/(3 + M/K)$ (Beverton, 1992) . The maximum sustainable yield (MSY) was estimated by following equation MSY=Z(Y/F) 0.5 (Gulland, 1979).

Results

The clam, *P. malabarica* is exploited from Karapad Bay from the shallow area during the low tide period throughout the year except during unfavourable environmental conditions. The depth of the fishing area ranges from 1 to 1.5 m during high tide period. The clams were collected by men, women and children during the low tide period from shallow areas by digging the substratum using a sharp metallic plate and the collected clams were stored in net bags. At Karapad Bay, clam resources are mainly supported by five major species, *P. malabarica, Meretrix casta, M. meretrix, Marcia opima* and *Gafrarium pectinatum*. Until 2018, the harvested clams were marketed to the lime, poultry industries and shrimp farms through middle men for ₹5 kg^{-1}. From 2019 onwards, the exploited clams, particularly *P. malabarica* and *M. casta* were exported to the Kerala market for edible purpose and the price of the clams increased to ₹25 kg^{-1}. The fishery trend of *P. malabarica* from 2013 to 2019 is given in Fig. 2 which shows sharp increase in the catch during 2019 due to increased demand for this species in Kerala market. The total exploitation of *P. malabarica* ranged between 7.5 t (2016) and 82.7 t (2019). The estimated average annual catch of *P. malabarica* was 22.3 t (2013-2019) with the catch per unit effort of 17.5 kg $person^{-1}$ day^{-1}. The average total clam catch of all the five species is estimated as 68.5 t in which *P. malabarica* contributes 33% in Karapad Bay.

The sex ratio of *P. malabarica* showed that male population was slightly dominant over females in most of the months except during March, June and October. The estimated sex ratio for *P. malabarica* was 1:0.9 (Table 1). Chi-square test indicated that, the sex ratio between males and females was not significantly different. Indeterminate stage was observed from January to April and June to September. The mature clams were observed from 17 mm size onwards. Around 15% of the clams were in mature condition at 19 mm size; 41.7% of clams were found to be mature at 20 mm size and 50% were mature when the animal attains 21 mm size, which is considered as the size at first maturity of *P. malabarica* from this region.

Females with maturing gonadal stage were observed between February and October. In February, 25% of the

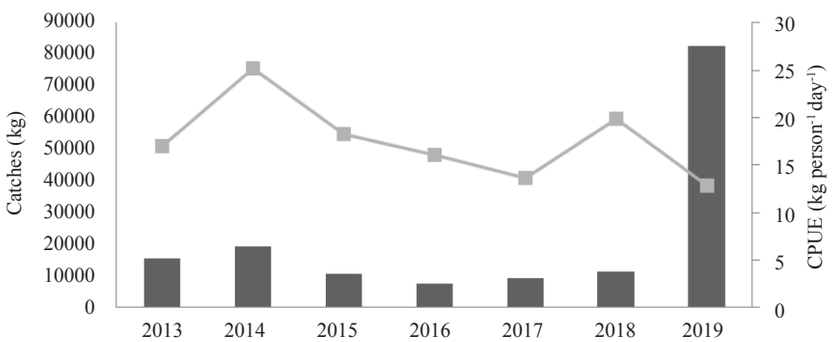

Fig. 2. Catch and catch per unit effort (CPUE) of *P. malabarica* from Karapad Bay

Table 1. Month-wise distribution of male and female of *P. malabarica* (January 2016-December 2017)

Month	Male (Nos.)	Female (Nos.)	% Male	% Female	Sex ratio	Chi-square value
Jan	99	83	54	46	1:0.8	1.406
Feb	96	91	51	49	1:0.9	0.133
Mar	86	90	49	51	1:1.0	0.091
Apr	96	84	53	47	1:0.9	0.800
May	93	86	52	48	1:0.9	0.273
Jun	89	93	49	51	1:1.0	0.088
Jul	101	91	53	47	1:0.9	0.521
Aug	95	90	51	49	1:0.9	0.135
Sep	98	88	53	47	1:0.9	0.537
Oct	90	101	47	53	1:1.1	0.633
Nov	96	82	54	46	1:0.9	1.101
Dec	97	86	53	47	1:0.9	0.661

clams were in maturing condition and the percentage of maturing clams leaped to 57% in March, 70% in April and 64% in May and thereafter slowly declined in the subsequent months. Mature clams were present throughout the period, and was dominant from September to December with high percentage in November (86%) as this period is being considered as the spawning season of *P. malabarica* in this region. Partially spawned and spent clams started occurring from June onwards and the spent stage was abundant in the population during January (75%) and February (50%) (Fig. 3 and 4).

The size of *P. malabarica* in commercial catch ranged from 24.2 and 55.4 mm with a mean size of 39.3 mm. The weight range of this clam species contributing to the fishery was 3.0-36.4 g with an average of 18.0 g. The maximum contribution to the catches came from length class 33-41 mm (75%) followed by 24-31 mm (10%), 43-49 mm (14%) and 51-55 mm (1.0%) (Fig. 5).

The asymptotic length (L_∞) was 55.6 mm and the growth coefficient (K) value obtained was 1.1 (Fig. 6). According to VBGF, the clam attained a size of 37, 49.5 and 53.5 mm at the end of first, second and third year respectively (Fig. 7). The life span (t_{max}) of *P. malabarica* from Karapad Bay was estimated as 2.72 years and the growth performance index (Ø') was found to be 1.53. The estimated total mortality (Z) by length converted catch curve for *P. malabarica* from Karapad Bay was 4.36 year^{-1} (Fig. 8).

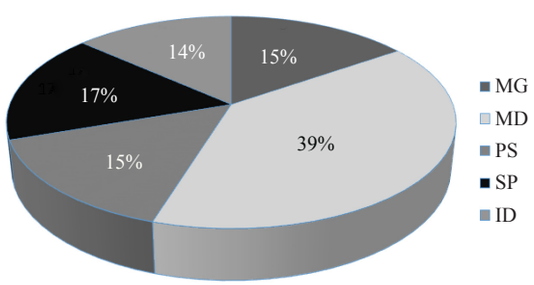

Fig. 3. Percentage composition of maturity stages during the study period (January 2016- December 2017). MG-Maturing; MD-Mature; PS-Partially spent; SP-Spent; ID-Indeterminate

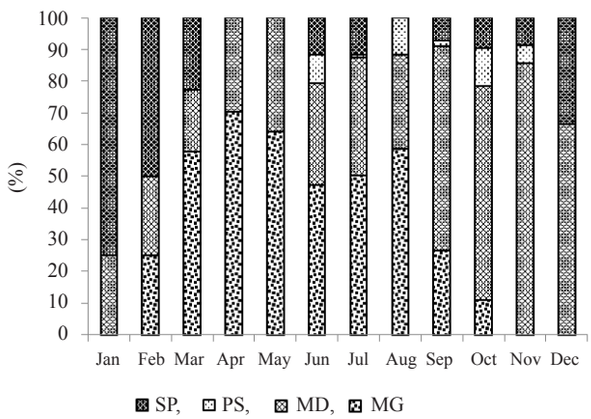

Fig. 4. Month-wise gonadal development stages of female *P. malabarica* (January 2016-December 2017). SP-Spent, PS-Partially spent, MD-Mature, MG-Maturing

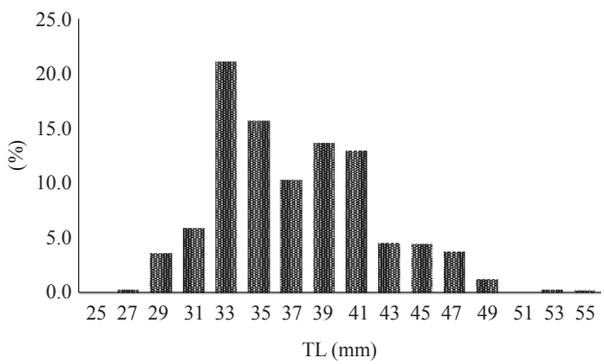

Fig. 5. Percentage length composition of *P. malabarica* from Karapad Bay (January 2013-December 2019)

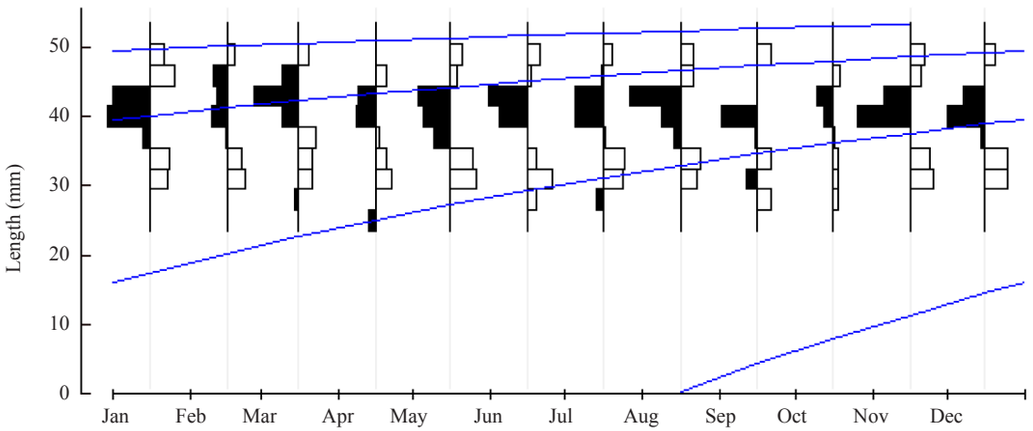

Fig. 6. Estimation of L_∞ of *P. malabarica* using ELEFAN I method

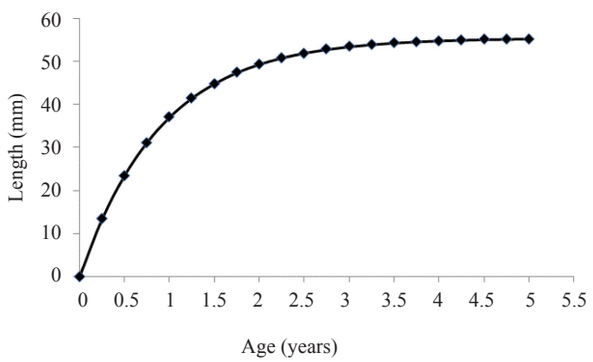

Fig. 7. Estimated VBGF age and growth curve for *P. malabarica*

The estimated natural mortality (M) was 2.64 year^{-1}. The fishing mortality (F) was subsequently calculated as 1.72 year^{-1}. The derived value of exploitation ratio (U) and exploitation rate (E) were 0.38 and 0.39 respectively. The optimum length (L_{opt}) of this species was estimated as 30 mm and 95.8% of the exploited catch was found to be above optimum length. The MSY of *P. malabarica* was estimated as 104.8 t and the present catch was found to be 21% below the MSY. It is evident from the above mentioned indicators that *P. malabarica* is underexploited in Karapad Bay and the level of exploitation level can be further increased.

Discussion

The short neck clam, *P. malabarica* forms a major fishery along the west coast of India mainly in Mulky, Gurupur, Udyavara and Coondapoor estuaries of Karnataka and Azhikkal, Chittari and Ashtamudi estuaries of Kerala (Narasimham, 1991). Comparing to west coast of India, the fishery of *P. malabarica* is lower in east coast of India. In Karapad Bay, *P. malabarica* is a major species than the other clam species. Similarly, *P. malabarica* is the most exploited clam along the south-west coast for local consumption as well as for export (Thomas and Nasser, 2009).

In the current study, the sex ratio of *P. malabarica* stocks in Karapad Bay showed a tenuous predominance of male population. Chi-square test showed that there was no significant difference ($p>0.05$) in the sex ratio of clams and the result was also similar to the observation of Narasimham *et al.* (1998) in *M. meretrix* from the same region. Rao (1988) reported almost equally distributed sex ratio of *P. malabarica* from Mulky Estuary except during August. The sex ratio of *P. malabarica* differed significantly from 1:1 only in the month of May in Dharmadom Estuary, Kerala (Thomas, 2013). The size at first maturity (21 mm) observed in the present study was comparable with earlier reports on this species, Thomas

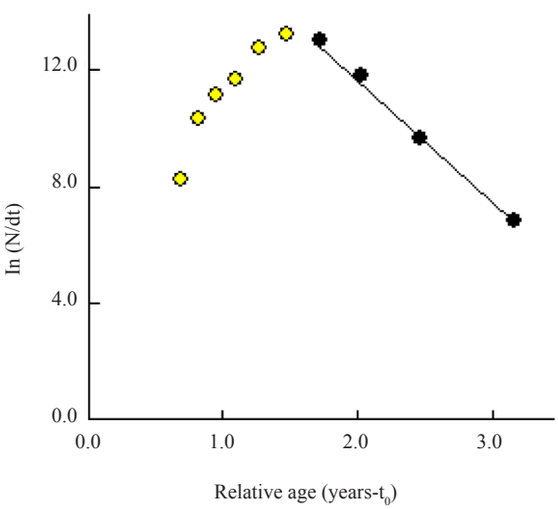

Fig. 8. Length converted catch curve for estimation of total mortality coefficient (Z)

(2013) reported 20 and 22 mm for male and female from Dharmadom Estuary; Mohamed *et al.* (2013) observed 21 mm from Ashtamudi Lake, while Kripa and Appukuttan (2003) recorded 20 mm along west coast of India.

In Indian waters, most of the bivalves have broad spawning period with certain peaks (Kripa and Appukuttan, 2003). In the present study, the spawning season of *P. malabarica* in Karapad Bay was found to be between September and December with peak spawning in November. Similarly, Kripa and Appukuttan (2003) reported that the spawning season of this species was from September to February along the west coast of India. Appukuttan (1993) observed that the breeding season for *P. malabarica* in Ashtamudi Estuary was during October to January with peak period between November and December. Rao (1998) and Thomas (2013) recorded the spawning season of *P. malabarica* from October to February in Mulky and Dharmadom estuaries.

In Karapad Bay, the dominant size group of *P. malabarica* contributing to the fishery was greater than the previous reports from Dharmadom and Ashtamudi estuaries. Thomas (2009) recorded *P. malabarica* in the length range of 31-40 mm contributing maximum to the fishery of Dharmadom Estuary, while Appukuttan (1993) recorded 34-36 mm size group in Ashtamudi Estuary. However, in the present study, the size group of 33-41 mm contributed 75% of total exploitation which was larger than the earlier reports from various estuaries of India. The minimum legal size (MLS) for exploitation of *P. malabarica* is 20 mm (Mohamed *et al*. 2014). The size of *P. malabarica* that occurs in the fishery was found to be above the MLS, which shows that the stock is harvested in a healthy manner.

Seed and Brown (1978) stated that in nature, bivalves reveal a broad range of growth rates and these growth rates reflect survival strategy of the species to a certain extent. The asymptotic length (L_∞) of VBGF was 55.6 mm and the growth coefficient (K) value obtained was 1.1 year^{-1} (Fig. 3 and 4). The growth parameters such as L_∞ and K from the present study were compared (Table 2) with the values obtained by other researchers from different estuaries of west coast of India such as Mulky by Rao (1988), Ashtamudi by Appukuttan *et al.* (1999), Dharmadom Estuary by Thomas (2009), Shirgaon and Bhatye estuaries of Maharastra by Mohite and Mohite (2009). The growth coefficient of *P. malabarica* obtained in the present study was slightly lower than that observed in Mulky Estuary and tenuously higher than the values obtained for clams of Dharmadom, Ashtamudi, Shigaon and Bhatye estuaries. The value obtained at Mulky Estuary was higher than the values obtained in all other estuaries. At par with the work of Rao (1988), the present findings were comparable with most of the earlier estimates. The minor variation was obvious owing to variation in the prevailing ecological ambience. The t_{max} value of *P. malabarica* from the present study was higher than the values obtained by Mohite and Mohite (2009) from two different estuarine environments (2.2 and 2.4 years). The estimated life span of this clam from Dharmadom Estuary was 2.5 to 3 years (Thomas, 2009) which was comparable to the estimated life span of 2.7 years in the present study. The growth of *P. malabarica* during the present study was lesser than the reports of Rao (1988) who recorded the growth of *P. malabarica* as 36.3 mm in 6 months, 43.1 mm in 9 months and 48.1 mm in 1 year from the Mulky Estuary, along the west coast of India. Thomas (2009) reported a length of 35.5 mm at the end of the first year and 49.6 mm in the second year. Kripa and Appukuttan (2003) predicted a length of 43.1 mm length at the end of first year for *P. malabarica* from west coast. Appukuttan *et al.* (1999) observed slower growth of 30, 38 and 41 mm length in the first, second and third year respectively. Similarly, Mohite and Mohite (2009) found slower growth in *P. malabarica* and reported a growth of 30 and 29 mm at Bhatye and Shirgaon estuaries of Ratnagiri coast respectively at the end of first year and 39 mm in both estuaries during the subsequent year.

Thomas (2009) reported the total mortality (Z), natural mortality (M) and fishing mortality (F) of *P. malabarica* from Dharmadom Estuary as 4.65, 1.82 and 2.83 respectively and Appukuttan *et al.* (1999) in Ashtamudi Estuary reported as 2.11, 1.17 and 0.94 respectively. In the present study, it was 4.36, 2.64 and

Table 2. Comparison of L_∞, K and Ø' values of *P. malabarica* with other estuaries

Study area	L_∞ (mm)	K (Yr^{-1})	Ø'*	Reference
Mulky Estuary, Karnataka	59.0	1.425	1.695	Rao (1988)
Ashtamudi Lake, South Kerala	44.4	0.839	1.218	Appukuttan *et al.* (1999)
Dharmadom, North Kerala	59.0	0.92	1.505	Thomas (2009)
Shirgaon, Maharastra	44.58	0.8322	1.218	Mohite and Mohite (2009)
Bhatye, Maharashtra	43.487	0.9649	1.261	Mohite and Mohite (2009)
Karapad Bay, Tamil Nadu	55.6	1.1	1.53	Present study

* The growth performance index (Ø') values were calculated from the L_∞ and K values of the respective studies

1.73 which differs from the previous reports. This was in agreement with Pauly (1983), who indicated that the natural mortality is influenced by several biological and environmental factors and is difficult to get an accurate estimate. The yield is optimised when the value of fishing mortality is equal to natural mortality (Devaraj and Vivekanandan, 1999; Gulland, 1965). In the present study 'F' value was lower than the 'M' value that indicates scope for expansion of fishery.

The findings of the present study portrayed the status on the fishery and population of *P. malabarica* at Karapad Bay, south-east coast of India. The study detailed the growth rate of *P. malabarica* estimated from Karapad Bay which was found to be in line with the estimates of previous studies. The present study revealed that the clam catch in Karapad Bay fluctuated between 2013 to 2019 and sudden peak in the fishery was recorded in 2019 due to increased demand in Kerala market. The result of the present study unveiled that the size of *P. malabarica* occurring in the fishery was above minimum legal size and 95.8% of the catch is above L_{opt} which shows that the stock is being exploited in a sustainable manner. The estimated value of exploitation rate (E) and exploitation ratio (U) were below the optimum level and the annual catch of *P. malabarica* was 21% below the MSY. It is inferred that the *P. malabarica* stock is underexploited in Karapad Bay and the current exploitation pattern indicates scope for further expansion of the *P. malabarica* fishery in the region. This preliminary work on *P. malabarica* would help us to understand the present status of this pivotal clam species.

Acknowledgements

The authors are very much thankful to the Director, ICAR-CMFRI, Kochi, for constant encouragement. In addition, thanks are due to the Scientist-in-Charge, Tuticorin Regional Station of ICAR-CMFRI, Thoothukudi, for continued support and encouragement during the period of research.

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Date of Receipt : 14.09.2020
Date of Acceptance : 08.12.2021