Indian J. Fish., 70 (4): 28-37, 2023
doi:10.21077/ijf.2023.70.4.122152-03
Available online at: epubs.icar.org.in/index.php/IJF

Population dynamics of the freshwater mussel *Parreysia cylindrica* Annandale and Prashad, 1919 from the Western Ghats, India

Malathi Shettigar and Seetharamiah Thippeswamy*
Department of Environmental Science, Mangalore University, Mangalagangothri, Mangaluru-574 199, Karnataka, India

*Correspondence e-mail:
stswamy1990@gmail.com

Keywords:
Age and growth, Allometry, Bivalve mollusc, Condition index, Karnataka, Life-history variables

Received : 15.06.2022
Accepted : 13.09.2023

Abstract

Morphometric and length-weight relationships, condition index, age and growth, mortality, exploitation and lifespan of freshwater mussel *Parreysia cylindrica* Annandale and Prashad, 1919 inhabiting the Malthi River, a tributary of the river Tunga, in Thirthahalli Taluk were studied. The calculated linear equations of length-breadth and length-width of mussels were L = 1.6869 + 0.4688 B and L = - 2.9198 + 0.4687 W and respectively. The estimated b values of length-breadth relationship ranged between 0.4285 and 0.4991 whereas for length-width relationship the values fluctuated between 0.4006 and 0.4776. The estimated equations of length-total weight, length-wet weight, length-shell weight and length-dry weight were $W = 0.000046L^{3.279}$, $W = 0.000046L^{3.194}$, $W = 0.00005L^{3.461}$ and $W = 0.000021L^{3.332}$, respectively. Monthly average values of condition index varied from 5.07 to 11.97. High values of condition were noticed during March to May and low values from October to February. The estimated asymptotic length was 56.97 mm and maximum length recorded in the field was 50.2 mm. The growth coefficient and theoretical time at zero length were 0.53 y^{-1} and -0.0376 y, respectively. The growth performance index was 3.236. The total, natural and fishing mortality rates were 2.00, 0.99 and 1.01 y^{-1} respectively and exploitation rate was 0.505. The lifespan was estimated to be 5 years and 8 months.

Introduction

Bivalve molluscs such as oysters, mussels and clams are widely distributed globally in marine and freshwater environments and some of them are exploited commercially. Freshwater bivalves are found in various inland aquatic environments of the Indian subcontinent. Due to their burrowing and filter-feeding nature, they take part in energy transfer and act as bio-depositors in the aquatic ecosystems. Bivalve molluscs are considered as models of natural ageing (Ziuganov *et al*., 2000) and have been subject materials for studies on growth and life span (Wilbur and Owen, 1964; Ansell *et al*., 1972; Cerrato, 1980; Thippeswamy and Joseph, 1991; Strahl *et al*., 2007; Moss *et al*., 2016). In India, these inland aquatic resources are not commercially exploited for human consumption except by tribal populations in some pockets of north-east India (Ramakrishna and Dey, 2007) and some species are used for freshwater pearl production. The genus *Parreysia* belongs to the family Unionidae of class Bivalvia and comprises 20 species from the Indian sub-continent (Preston, 1915; Ramakrishna and Dey, 2007). *Parreysia cylindrica* is rarely distributed in the rivers of the Western Ghats of India and is a holotype from the river Venna from Upper Krishna watershed at Medha in the Krishna River basin of Maharashtra (Annandale and Prashad, 1919). Information on various aspects of freshwater bivalve biology such as condition index of *Parreysia corrugata* (Ramesha and Thippeswamy, 2009a; Malathi and Thippeswamy, 2011) and *P. favidens* (Thippeswamy *et al*., 2014), allometric relationships of *Lamellidens corrianus* (Desai and Borkar, 1989), *L. marginalis* (Agrawal, 1976; Suryawanshi and Kulkarni, 2014a; Pradhan *et al*., 2020; Sarma *et al*., 2022), *P. corrugata* (Ramesha and Thippeswamy, 2009a; Malathi and Thippeswamy, 2011; Suryawanshi and Kulkarni, 2014b) and *P. favidens* (Thippeswamy *et al.*, 2014), age and growth of *P. corrugata* (Malathi and Thippeswamy, 2013) and *L. marginalis* (Nahar *et al.,* 2019) and mortality of *P. corrugata* (Malathi and Thippeswamy,

2013) is available from the Indian sub-continent. However, there is a lack of biological data on *P. cylindrica* which is endemic to the Western Ghats of India. Therefore, the present study was carried out on population dynamics of *P. cylindrica* from the river Malthi, a tributary of the river Tunga of the sub-basin of river Tungabhadra of Krishna river system in the Western Ghats of Karnataka. The data generated in this investigation will form the primary biological data of *P. cylindrica*, which will be useful from the ecological point of view and also for management and conservation of freshwater bivalve resources inhabiting the Western Ghats, one of the global hotspots of biological diversity.

Materials and methods

The freshwater bivalve *P. cylindrica* was sampled at monthly intervals from the river Malthi at Kalmane (13º39'11"N; 75º10'52"E) in Shimoga District between March 2007 and June 2008. The mussels were collected manually from the riverbed, brought to laboratory under refrigerated condition and subsequently subjected to morphometric measurements. The total sample size was 547; sampling size was purely dependent on the availability of mussels at the time of sampling. Samples could not be collected during June to September 2007 due to monsoon flooding.

Allometry and condition index

The length (maximum distance from front to rear ends of the shell), breadth (maximum distance between the dorsal and ventral margins of the shell) and width (maximum distance between the outer surfaces of two shell valves) of individual mussels were determined precisely to 0.05 mm using vernier calipers and subsequently the weights of individual organisms were recorded. The mussels were opened and the whole soft body removed, blotted and weighed individually. Shell weight of mussels was estimated individually. The entire soft tissue was dried at 60°C for 2 days and dry weight of the mussels was individually determined precisely to 0.001 g. Morphometric relationships between length and breadth and length and width of *P. cylindrica* were calculated (Pauly, 1983) using the formula, Y = a + bX, where 'a' is the intercept and 'b' is an exponent. Length-weight relationships (LWR's) were calculated (Pauly, 1983) with the formula $W = aL^b$, where 'a' is the intercept and 'b' is an exponent. After logarithmic transformation of data with the least square linear regression statistic, $\text{Log}_{10} W = \text{Log}_{10} a + b\text{Log}_{10} L$, the relationships between length and total weight, length and wet weight, length and dry weight and length and shell weight for the entire study period and also for different months were established. The shell cavity volume was estimated individually and index of condition of individual mussels was calculated following the mathematical equation (Baird, 1958):

$$\text{Condition index} = \frac{\text{Dry tissue weight}}{\text{Shell volume}} \times 100$$

Growth and mortality

Mussels belonging to all size ranges collected were clubbed into different class intervals following Herbert Sturges's rule (Sturges, 1926). The length distribution for each month and also for the entire period was established with the help of length frequency analysis. Modal growth pattern and monthly growth rate were determined from modal progression analysis (Devaraj, 1983). Settlement and recruitment of mussels into the population were estimated based on mean shell length and presence of young mussels in the sample. Settlement time of mussels was evaluated by backward extrapolation of the modal growth lines for different broods. The growth variables for the von Bertalanffy growth function (VBGF) (von Bertalanffy, 1938) namely asymptotic length (L_∞) and growth coefficient (K) were determined using FiSAT program (Gayanilo *et al*., 1996). The K-scan routine was carried out to evaluate a dependable projection of the K value. The value of theoretical time at zero length (t_0) was assessed using the least square method (Bagenal, 1955). The length frequency data was subjected to Electronic Length Frequency Analysis (ELEFAN-1) (Pauly and David, 1981) in the FiSAT programme to fit the VBGF curve for length-at-age $L_t = L_\infty [1 - e^{-K(t-t0)}]$. The estimated values of L_∞ and K were used to calculate growth performance index (GPI) or Phi-prime (Φ') value (Pauly and Munro, 1984). The life span was estimated as per Pauly (1983). The total mortality (Z) was ascertained by the length-converted catch curve method. Natural mortality (M) was established using Pauly's empirical equation (Pauly, 1980) and fishing mortality (F) Fishing mortality was obtained by F = Z-M. Exploitation rate (E) was estimated (Gulland, 1965, 1983) using the statistic, E = F/Z.

Results and discussion

Morphometric relationship

The linear regression equations between length and breadth and length and width were L = 1.6869 + 0.4688 B and L = - 2.9198 + W, respectively (Fig. 1). The results indicate a directly proportional relation of breadth and width with length However, many individuals of the same length showed variation in breadth and width and these variations accounted for shape difference. Thus, proportionate variation in the shell dimensions accounted for maintaining its shape. Such observations have been reported in bivalve mollusks (Thippeswamy and Joseph, 1992; Hemachandra and Thippeswamy, 2008) and also in higher groups (Jolicoeur and Mosimann, 1960).

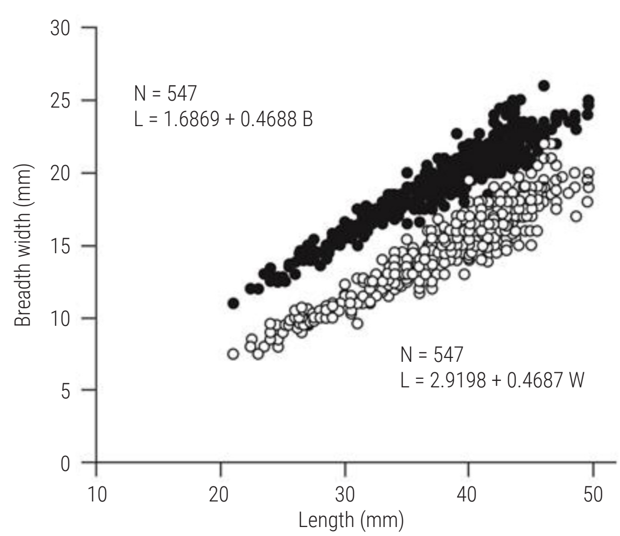

Fig. 1. Bivariate scatter diagram of length-breadth (dark circles) and length-width (open circles) relationships of *P. cylindrica*

Similar linear relationships between length and breadth and length and width have been reported in freshwater mussels such as *P. corrugata* (Agrawal, 1980; Ramesha and Thippeswamy, 2009a; Malathi and Thippeswamy, 2011; Suryawanshi and Kulkarni, 2014b) and *P. favidens* (Thippeswamy *et al*., 2014) from India.

The b values of the length-breadth relationship ranged between 0.4285 in June 2008 and 0.4991 in Nov 2007 whereas the values for length-width relationship varied between 0.4006 in January 2008 and 0.4776 in March 2007 (Fig. 2). The b value of length and breadth relationship in the present study was lower than that of freshwater bivalves reported from the Indian sub-continent whereas for length and width relationship it was higher than that of many freshwater bivalves (Table 1). Such variations in dimensional relationships could be due to the environmental conditions in different habitats influencing shell dimensions. Size of mussels is largely affected than their shape due to variation in environmental conditions (Wilbur and Owen, 1964). Therefore, shape generally provides more precise information on morphometric relationships rather than

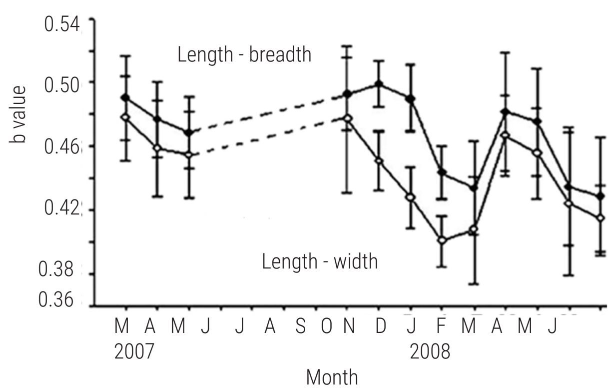

Fig. 2. Monthly variability in the b-values of length-breadth and length-width relationships of *P. cylindrica*

size. Probably, shape is restrained by the genetic compositions of species whereas size is managed by surrounding environmental variables (Malathi and Thippeswamy, 2011; Thippeswamy *et al*., 2019).

Length-weight relationship (LWR)

The estimated nonlinear relationships of length-total weight, length-wet weight, length-shell weight and length-dry weight were $W = 0.000046L^{3.279}$, $W = 0.000046L^{3.194}$, $W = 0.00005L^{3.461}$ and $W = 0.000021L^{3.332}$, respectively (Fig. 3). The study indicated enhanced weight with increase in length and thus, age. However, individuals of the same age showed variation in weight and these differences could be due to gonadal phenology, larval development and surrounding environment including river flow (Ramesha and Thippeswamy, 2009a; Malathi and Thippeswamy, 2011; Thippeswamy *et al*., 2019). The equilibrium constant or b-values in bivalve molluscs generally vary from 2.5 to 4.5 (Wilbur and Owen, 1964) and when b-value is equal to 3, the LWR is said to be isometric (Carlander, 1977).

The b-values of length-total weight relationship varied between 2.596 in April 2008 and 3.348 in October 2007 (Fig. 4a). For length-wet weight relationship the values ranged from 2.384 in April 2007 to 3.353 in November 2007 (Fig. 4b). The b-values ranged between 1.404 in March 2007 and 3.934 in November 2007 for length-dry weight relationship (Fig. 4c) and between 2.288 in March 2008 and 3.606 in December 2007 for length-shell weight relationship (Fig. 4d).

Monthly b-values of all LWR's showed similar trend through the whole period of present investigation. Higher b-values were noticed during November 2007-February 2008 which suggested that growth in weight was higher during these months. In bivalve molluscs, the gonadal growth and maturation precede with increased bulk of soft body which contributes to increased tissue weight. Seasonal shifts noted in the b-values of LWR's could be due to the onset of spawning. The values of LWR's of freshwater bivalves from the Indian sub-continent are given in Table 1.

Table 1. The b-values of morphometric and length-weight relationships of freshwater mussels inhabiting the Indian subcontinent (L: Length; B: Breadth; W: Width; TW: Total weight; SW: Shell weight; WW: Wet weight; DW: Dry weight)

Species	L-B	L-W	L-TW	L-WW	L-DW	L-SW	Location	Habitat	Source
Lamellidens corrians	-	-	2.6775	2.8919	2.8946	2.552	Rajshali, Bangladesh.	Lake	Mondol *et al.* (2016)
L. marginalis	-	-	2.6084	-	-	-	Nanded District, Maharashtra		Suryawanshi and Kulkarni (2014b)
L. marginalis	0.475	0.3163	2.9066	2.7377	2.7849	2.918	Rajshahi District, Bangladesh.	Lake at Rajshahi University	Nahar *et al.* (2019)
L. marginalis	-	-	2.712	-	-	-	Bhubaneswar, Odisha	Farm, CIFA, ICAR	Pradhan *et al.* (2020)
L. marginalis	-	-	-	-	3.856	-	Patna	Low lying areas	Sarma *et al.* (2022)
L. marginalis	-	-	2.75	-	-	-	Ratargul Swamp, Bangladesh	Freshwater swamp	Hossain *et al.* (2022)
Parreysia corrugata	0.585	0.333	2.777	2.885	2.832	2.802	Hosmata, near Subhramanya, Karnataka	River Kempuhole	Rameha and Thippeswamy (2009a)
P. corrugata	0.603	0.432	2.666	2.669	2.937	-	Kalmane near Tirthahally, Shimoga District	Malthi river tributary of river Tunga	Malathi and Thippeswamy (2011)
P. corrugata	-	-	3.5489	-	-	-	Nanded District, Maharashtra	Naigaon Lake	Suryawanshi and Kulkarni (2014a)
P. corrugata	-	-	3.2631	-	-	-	Nanded District, Maharashtra		Suryawanshi and Kulkarni (2014b)
P. favidens	0.5985		3.2371	3.6763	2.9182	-	River Burhi Gandak, Bihar	River Burhi Gandak	Begum and Sinha (2000)
P. favidens	0.599	0.440	2.785	2.599	2.499	-	Chikamagalur, Karnataka	River Bhadra,	Thippeswamy *et al.* (2014)
P. cylindrica	0.4688	0.4687	3.0266	2.624	2.439	2.899	Kalmane, near Tirthahally, Karnataka	Malthi river, tributary of river Tunga	Present study

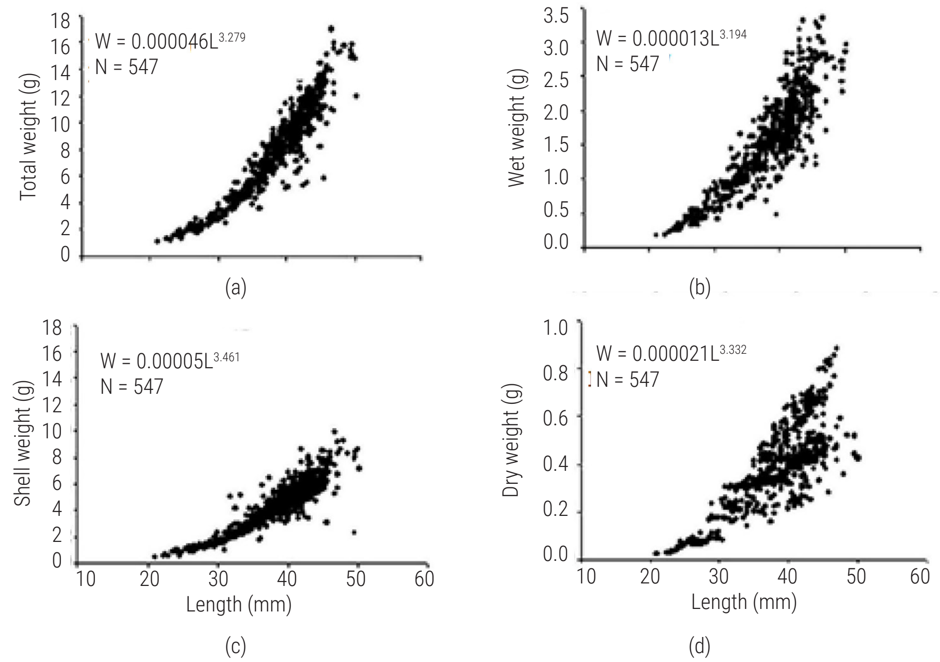

Fig. 3. Length-total weight (a), length-wet weight (b), length-shell weight (c) and length-dry weight (d) relationships of *P. cylindrica*

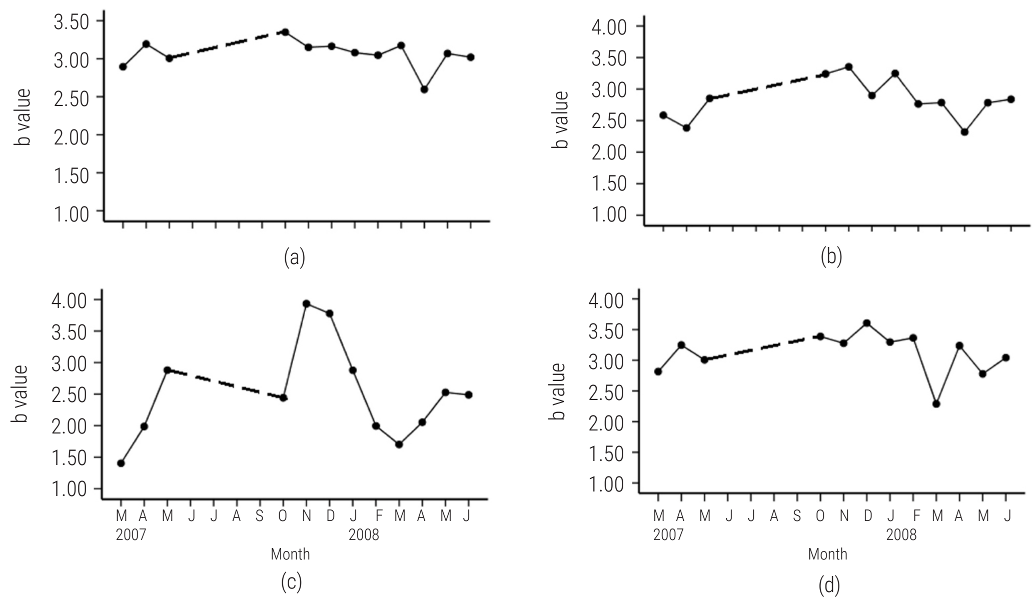

Fig. 4. Monthly variability in the b-values of length-total weight (a), length-wet weight (b), length-dry weight (c) and length-shell weight (d) relationships of *P. cylindrica.* Dotted line indicates no sampling from June to September due to river flooding by the south-west monsoon

Condition index

Condition index relates to the wellbeing of an organism and is an important measure of the physiological conditions of bivalve molluscs; it varies in response to ambient environmental conditions. The index of condition is generally species-specific, differs within bivalve groups such as oysters, mussels, clams and cockles and differs from habitat to habitat within geographical locations (Zeng and Yang, 2021). Monthly mean values of condition index fluctuated between 5.08 in January 2009 and 11.97 in May 2008 (Fig. 5). Three peaks were distinct in March 2007, May 2007 and May 2008 when condition index values >8.74 were noticed. The condition reached its lowest level in January 2008 and thereafter gradually increased to the maximum peak in May 2008. The monthly distribution of condition index of *P. cylindrica* (Fig. 6) suggests the occurrence of spawning activities in the population somewhere during June to January. Similar observations have been reported on freshwater mussels such as *P. corrugata* (Ramesha and Thippeswamy, 2009a; Malathi and Thippeswamy, 2011) and *P. favidens* (Thippeswamy *et al*., 2014) from the Western Ghats regions of Karnataka. However, in the present study, this could not be confirmed due to

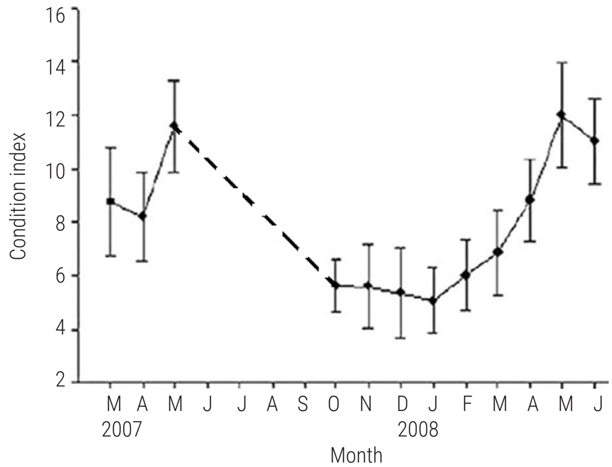

Fig. 5. Monthly variations in mean condition index in *P. cylindrica*. Vertical bars represent the standard deviation, dotted line indicates no sampling from June to September due to river flooding by the south-west monsoon

lack of samples during June to September 2007 because of riverine flooding.

Lower values of condition index in the post-monsoon (October-January) and higher values in the pre-monsoon (February-May) were recorded in the present study. Seasonal changes in condition index could be due to the interaction of environmental factors, food availability and reproductive activity. In bivalves, gonadal development and growth occur before the onset of spawning which results in fattening and increased meat yield (Thippeswamy and Joseph, 1988; Ramesha and Thippeswamy, 2009a). In many bivalves, gonadal and somatic growth and tissue irrigation are the primary underlying variables responsible for fattened appearance. The gonad makes up a great chunk of the visceral mass and hence gonadal growth before spawning results in higher total weight of the soft tissue. Following spawning, the gonads shrink and there is a decrease in the total body weight, and thus the condition index too decreases. Several studies have established correlation between changes in annual reproductive activities and seasonal gonadal phenology (Patil and Bal, 1967; Nagabhushanam and Lohgaonker, 1978; Begum and Munshi, 1996) and condition (Zeng and Yang, 2021).

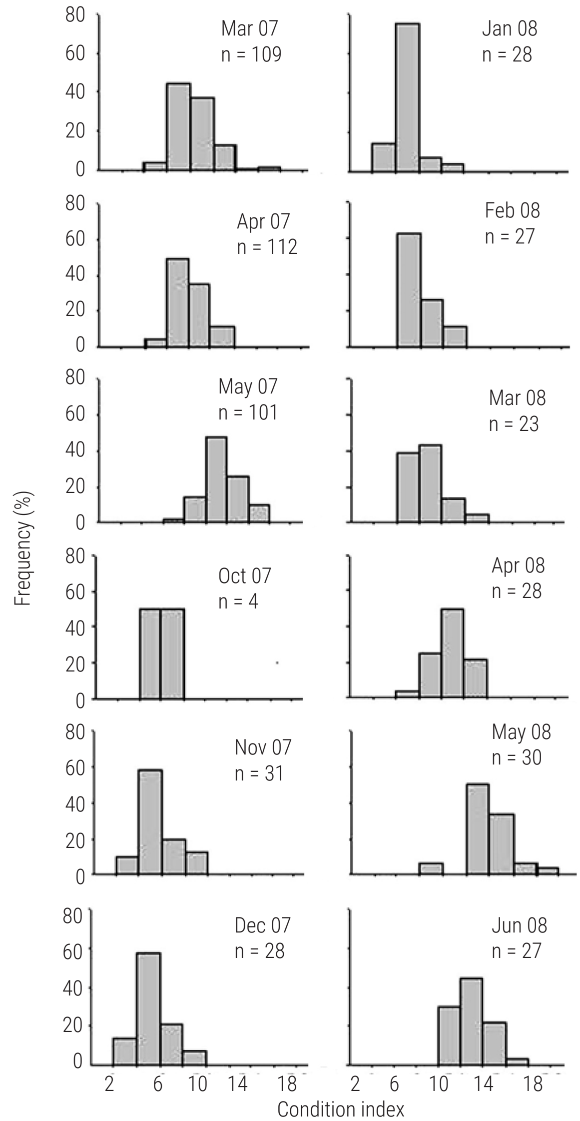

Fig. 6. Monthly percentage frequency distribution of condition index in *P. cylindrica*

Age and growth

Length frequency

The length-frequency distribution of the sampled mussels (Fig. 7) indicated shell length range from 21 to 51 mm with one major peak at 41 mm and five minor peaks at 21, 27, 32, 45 and 47 mm. The mean shell length recorded during the study period was 38.6 mm. Entry of young mussels (<24 mm) into the population was in November-December (Fig. 8), indicating the breeding period of adult mussels and/or metamorphosis and settlement of larvae during September-October.

Recruitment

The modal growth curves showing the differential rate of growth and size ranges of *P. cylindrica* (Fig. 9) indicated the presence of mussels of <1 year class to 5-year class.

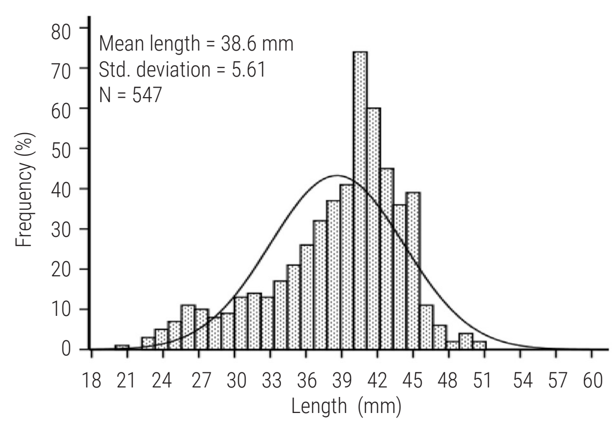

Fig. 7. Length frequency (%) distribution of *P. cylindrica*

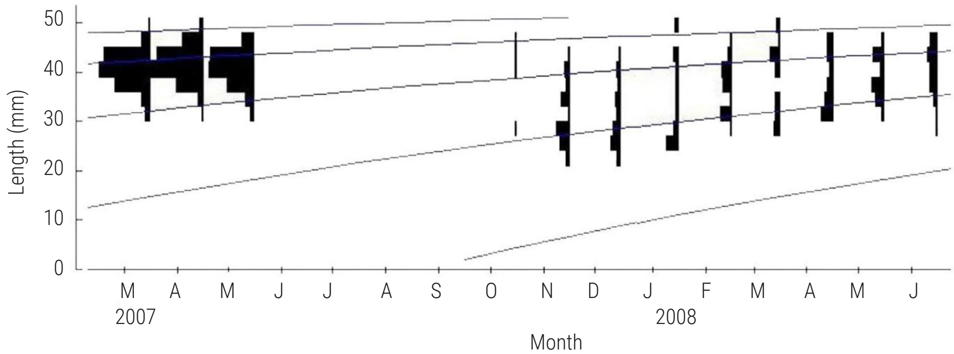

Fig. 8. Length frequency distribution with growth curves of *P. cylindrica* superimposed using ELEFAN-I

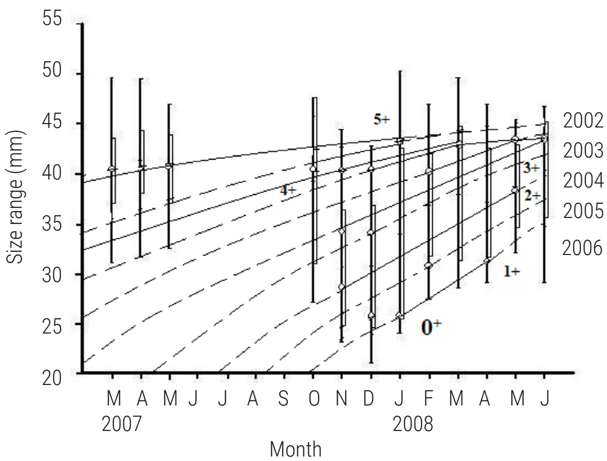

Fig. 9. Recruitment pattern of *P. cylindrica*

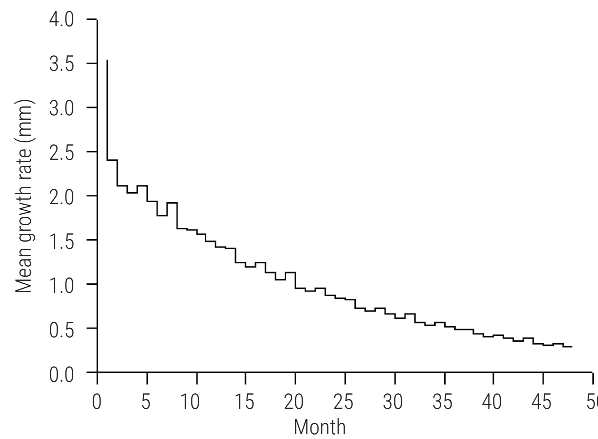

Fig. 10. Monthly mean growth rate of *P. cylindrica*

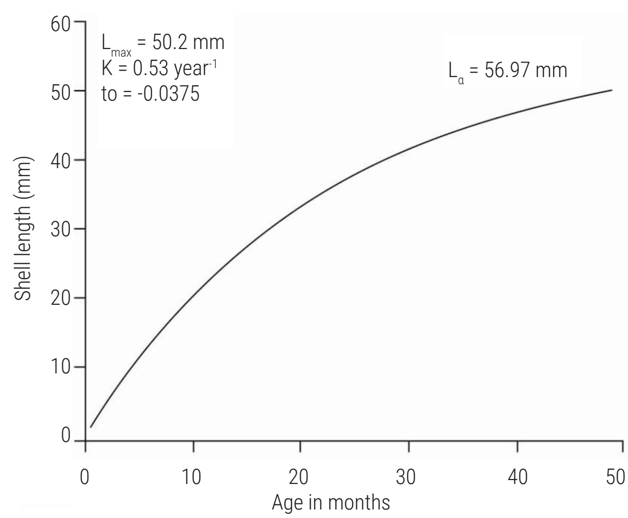

Fig. 11. von Bertalanffy growth curve of *P. cylindrica*

Young mussels after settlement showed faster rate of growth in the first few months. The broodstock of mussels between 2002 and 2006 showed similar growth pattern. The monthly mean growth rate of *P. cylindrica* during the present investigation (Fig. 10) inidicated faster growth rate initially, which subsequently decreased. Newly settled young *P. cylindrica* attained 24, 38, 46 and 50 mm size at the end of 1st, 2nd, 3rd and 4th years, respectively. The mean growth rates of *P. cylindrica* were 2, 1.17, 0.66 and 0.33 mm month^{-1} during 1st, 2nd, 3rd and 4th years, respectively. Similar observations have been observed in other bivalves from the riverine environments of the Western Ghats (Ramesha and Thippeswamy, 2009a, 2000; Malathi and Thippeswamy, 2011; Thippeswamy *et al*., 2014).

Growth parameters

The parameters of VBGF are useful in correlation of growth rates of similar species in different habitats and different species in the same habitat. The von Bertalanffy growth curve for *P. cylindrica* is depicted in Fig. 11 and the calculated equation was Lt = 56.97 [1-e$^{-0.53(t+0.0376)}$). The recorded L_{max} was 50.2 mm. The L_∞ of the VBGF of *P. cylindrica* was estimated to be 56.97 mm which is more than that of the marine mussel *Modiolus auriculatus* from Byndoor intertidal region of Karnataka and less than that of *P. corrugata* and *Perna indica* and *P. viridis* from different marine environs of the Indian sub-continent (Table 2). The K-value of *P. cylindrica* was 0.53 y^{-1} and the t_0 value in the current investigation was -0.0376 y. Table 2 presents a comparison of the corresponding estimates of growth parameters for different species of freshwater and marine mussels inhabiting the Indian sub-continent.

Table 2. Population parameters of freshwater and marine mussels inhabiting the Indian subcontinent. K: Growth constant; L_{∞}: Asymptotic length; t_0: Age at zero length; GPI (Φ'): Growth performance index. GPI values in bold are calculated from the raw data reported by various authors

Species	L_{∞} (mm)	K (year $^{-1}$)	t_0 (year)	GPI (Φ')	Location	Source
Modiolus auriculatus	27.77	0.620	-0.267	2.679	Intertidal rocky shore at Byndoor, Karnataka	Tenjing *et al.* (2016)
Parreysia corrugata	56.7	0.62	0.0304	3.299	River Kempuhole Hosmata near Kadaba, Karnataka	Ramesha and Thippeswamy (2008)
P. corrugata	60.76	0.470	-0.042	3.239	Malthi river at Kalmane, near Tirthahally, Karnataka	Malathi and Thippeswamy (2013)
P. favidens	64.58	1.20	0.0073	3.699	River Seeta at Seetanadi near Hebri, Karnataka	Ramesha and Thippeswamy (2009b)
Perna indica	110.0	0.0954	-	3.062	Coastal waters of Calicut	Kuriakose (1973)
P. viridis	159.5	0.9294	-	4.369	Ennore Estuary, Madras	Shafee (1979)
P. viridis	41.927	0.1518	-0.038	2.426	Intertidal, at Someshwar near, Mangalore	Ramachandra (1980)
P. viridis	62.51	0.1278	-	2.698	Low littoral, at Malpe, Udupi	Ramachandra (1980)
P. viridis	184.6	0.2512	-1.73	3.932	Sub tidal, Kakinada Bay, Andhra Pradesh	Narasimham (1981)
P. viridis	110.0	0.1124	-	3.133	Raft culture, Goa	Chatterji *et al.* (1984)
P. viridis	52.825	0.2025	-0.2384	2.752	Intertidal, at Someshwar, near Mangalore	Thippeswamy (1990)
P. viridis	85.0	0.1014	-0.1153	2.865	Raft culture, Zuari Estuary, Goa	Rivonkar *et al.* (1993)
P. viridis	124.65	0.1075	0.5066	3.223	Moheshkhali , Bay of Bengal, Bangladesh	Kamal and Khan (1998)
P. viridis	194.3	0.56	-	2.325	Intertidal at Cox's Bazaar, Bangladesh	Amin *et al.* (2005)
P. viridis	136.5	1.30	-	2.380	Naf river coast, Bangladesh	Khan *et al.* (2010)
P. viridis	75.4	1.51	-	3.934	Intertidal, at Mukka, near Mangalore	Thejasvi (2016)
P. viridis	117.5	0.28	-	3.587	Sub tidal, at Amdalli, near Karwar	Thejasvi (2016)
P. viridis	136.9	0.420	-0.380	3.896	Intertidal, at St. Mary's Islands, Malpe near Udupi	Hemachandra *et al.* (2017)
P. viridis	162.75	0.87	-0.7025	4.363	Sub tidal bed of Ye Estuary, Myanmar	Nwe *et al.* (2020)
Parreysia cylindrica	56.97	0.53	-0.0376	3.236	Malthi River at Kalmane, near Tirthahally, Karnataka	Present study

Growth performance index or Phi-prime index

Growth performance index (GPI) or Phi-prime index is a length and time-based indicator in which K and L_{∞} of VBGF are used to ascertain the growth potential of species. Phi-prime is also used to differentiate the performance of growth of the same species or between the species of the same genus (Mathews and Samuel, 1990). The GPI values for inland and marine mussels from Indian subcontinent are presented in Table 2. The Phi-prime value of *P. cylindrica* in the present study was 3.236, which is more than that of *M. auriculatus*, *P. indica* and *P. viridis* inhabiting certain marine environmentss of the Indian subcontinent (Table 2). Marine mussels are exposed to reduced feeding time during low tide and subjected to anthropogenic activities and also exposed to coastal marine pollution during submersion which probably results in low growth efficiency of intertidal mussels than river mussels. The Phi-prime value of *P. cylindrica* in the present study was less than that of *P. corrugata* from river Malthi, India (Malathi and Thippeswamy, 2013) and *P. viridis* from different coastal habitats of the Indian sub-continent (Table 2).

Reduced flow of water in the river throughout the study period, except during monsoon months, and anthropogenic activities at the study sites probably contributed to relatively low growth efficiency of *P. cylindrica* in the Malthi River.

Mortality and exploitation

The total, natural and fishing mortalities of *P. cylindrica* were 2,0.99 and 1.01 y^{-1}, respectively (Fig. 12). Loss of freshwater mussel populations has been reported worldwide due to predation, parasites, environmental flow and eutrophication. Natural mortality is closely related to age and size since larger species of bivalves generally have less rate of predation pressure. High fishing (1.19 y^{-1}) and low natural (0.90 y^{-1}) mortality rates have been reported for

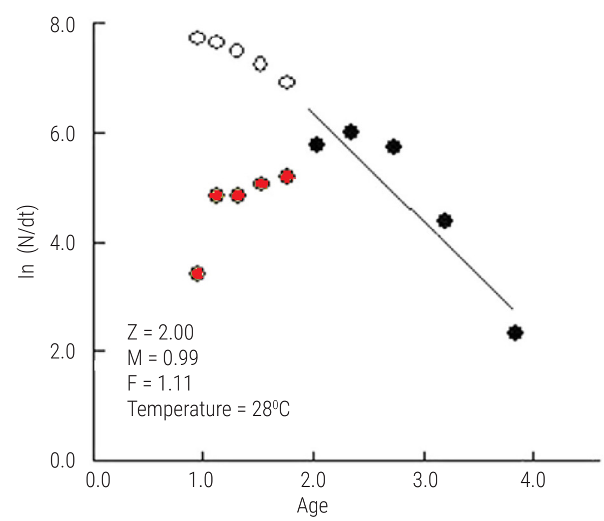

Fig. 12. Length–converted catch curve used to plot probability of capture of each length class of *P. cylindrica* from the river Malthi, the Western Ghats, India

P. corrugata inhabiting the same habitat (Malathi and Thippeswamy, 2013). Removal of mussels during local sand mining activities and exposure to detergents that enter into the river through domestic discharge and washing of clothes and vehicles, coupled with lack of motility, contribute to mortality rates in bivalve populations. Further, the mussel populations in the area are subjected to mortality during the summer season when water flow is almost reduced or restricted to small poundings in the river. Therefore, the stock of *P. cylindrica* in the present investigation is seen to be slightly above optimaly exploited (E=0.505). A slightly higher value of exploitation rate (E = 0.57) for *P. corrugata* was also noticed in this same study area by Malathi and Thippeswamy (2013). These sympatric species are not exploited for human consumption but are used as baits for angling, in the deep waters of river Tunga and river Malthi, in the downstream stretch where a natural barrier at Bhimanakatte Village obstructs the flow of river Tunga, just after the confluence of river Malthi with river Tunga.

Lifespan

A large number of bivalve molluscs have lifespan of more than 150 years, particularly in the temperate region (Abele *et al*., 2008). Therefore, research focus on biogerontological aspects of bivalve molluscs (Ziuganov *et al*., 2000; Abele *et al*., 2009) has increased in the last few decades (Ridgway *et al*., 2011). The maximum life span (MLSP) in bivalves has been documented from 1-2 years in the case of *Donax* spp. (Thippeswamy and Joseph, 1991) to hundreds of years in *M. margaritifera* (Ziuganov *et al*., 2000). Tropical Unionid species like *P. cylindrica* are smaller in size and short-lived in contrast to temperate species. The lifespan of *P. cylindrica* in the present study was about five years and eight months (5.6604 years) which is less than that of *P. corrugata* (6.383 years) from the same habitat (Malathi and Thippeswamy, 2013).

The present investigation provides baseline data on population aspects such as shell morphology, LWR's, condition index, population structure, age and growth, mortality and lifespan of *P. cylindrica* from a tropical riverine system. The data will serve as important information for developing and implementing suitable measures for the sustainable management and conservation of this species which is endemic to the Western Ghats of India. The stock of *P. cylindrica* in its holotype location can be maintained by reducing the indirect anthropogenic pressures on this less known species which could become a potential source of harvest for consumption in fresh or in value-added forms.

Acknowledgements

The first author is grateful to the University Grants Commission (UGC), Government of India, New Delhi for Research Fellowship in Science for Meritorious Students (RFSMS) (No.F.4-3/2007/BSR/11-32/2008/BSR, dated 24.052008) and is thankful to Mangalore University for facilities.

References

Abele, D., Brey, T. and Philipp, E. 2009. Bivalve models of aging and the determination of molluscan lifespans. *Exp. Gerontol*., 44: 307-315. https://doi.org/10.1016/j.exger.2009.02.012.

Abele, D., Strahl, J., Brey, T. and Philipp, E. E. R. 2008. Imperceptible senescence: Ageing in the ocean quahog *Arctica islandica*. *Free Radic. Res*., 42: 474-480. https://doi.org/10.1080/10715760802108849.

Agrawal, H. P. 1976. Observation on correlation between body length and linear growth of the shell in freshwater mussel, *Lamellidens marginalis* (Lamarck). *J. Food Farm Agric*., 7: 19-20.

Agrawal, H. P. 1980. Some observations on the seasonal variation in the gonads of *Indonaia caerulea* (Lea) (Mollusca: Unionidae). *Bull. Zool. Surv. India*, 3(1- 2): 87-92.

Amin, N. S. M., Halim, M. A., Barua, M., Zafar, M. and Arshad, A. 2005. Population dynamics and exploitation level of green-lipped mussel (*Perna viridis*) using FiSAT from the offshore island of Cox's Basar coast of Bangladesh. *Pertanika J. Trop. Agric. Sci*., 28(2): 103-109.

Annandale, N. and Prashad, B. 1919. Some freshwater molluscs from the Bombay Presidency. *Rec. Indian Mus.,* 16: 139-152.

Ansell. A. D., Sivadas, P., Narayanan, B. and Trevallion, A. 1972. The ecology of two sandy beaches in southwest India. 3. Observations on the population of *Donax incarnatus* and *Donax spiculum. Mar. Biol*., 17(4): 318-332. https://doi.org/10.1007/BF00366743.

Bagenal, T. B. 1955. The growth rate of the long rough dab *Hippoglassoides platessoides* (Fabr), *J. Mar. Biol. Assoc. U. K*., 34: 297-311. http://doi.org/10.1017 /S0025315400027673.

Baird, R. H. 1958. Measurement of condition in mussel and oyster. *ICES J. Mar. Sci.*, 23: 249-257. https://doi.org/10.1093/icesjms/23.2.249.

Begum, S. and Munshi, J. S. D. 1996. Reproductive cycle in *Parreysia favidens* (Benson): A freshwater bivalve of Kosi River. *Rec. Zool. Surv. India*, 95(3-4): 287-297.

Begum, S. and Sinha, A. K. 2000. Length-weight relationship of *Parreysia favidens* of freshwater drainage system of Burhi Gandak, north Bihar (India). *Rec. Zool. Surv. India*, 98(3): 61-66. https://doi.org/10.26515/rzsi/v98/i3/2000/159660.

Carlander, K. 1977. *Handbook of freshwater fishery biology*. Iowa State University Press, Ames, USA. 770 p.

Cerrato, R. M. 1980. Demographic analysis of bivalve populations. In: Rhoads, D. C. and Lutz, R. A. (Eds.), *Skeletal growth of aquatic organisms: Biological records of environmental change,* Plenum Press, London, UK, pp. 417-465.

Chatterji, A., Ansari, Z. A., Ingole, B. S. and Parulekar, A. H. 1984. Growth of green mussel *Perna viridis* L. in a seawater circulation system. *Aquaculture*, 40: 47-55. https://doi.org/10.1016/0044-8486(84)90215-1.

Desai, P. V. and Borkar, M. R. 1989. A study of allometric relationship in *Lamellidens corrianus. Indian J. Fish.*, 36: 180-182.

Devaraj, M., 1983. *Fish population dynamics. CIFE Bulletin No.* 3(10), ICAR-Central Institute of Fisheries Education, Mumbai, India, 90 p.

Gayanilo, F. C., Sparre P. and Pauly, D. 1996. *The FAO-ICLARM stock assessment tools (FiSAT) users guide*, *FAO Computerized Bioinformation Series, Fisheries*, Food and Agriculture Organisation of the United Nations, Rome, Italy, 126 p.

Gulland, J. A. 1965. Estimation of mortality rates. In: Cauhing, P. H. (Ed.), *Key papers on fish populations*. IRL Press, Oxford, UK, pp. 231-241.

Gulland, J. A. 1983. *Fish stock assessment: A manual of basic methods*. Wiley, New York, USA, 223 p.

Hemachandra, Tenjing, S. Y. and Thippeswamy, S. 2017. Population dynamics of the Asian green mussel *Perna viridis* (L.) from St. Mary's Islands off Malpe, India. *Indian J. Geo Mar. Sci*., 46(2): 1659-1666.

Hemachandra and Thippeswamy, S. 2008. Allometry and condition index in the green mussel *Perna viridis* (L.) of St Mary's Islands off Malpe, near Udupi, India, *Aquac. Res*., 39(16): 1747-1758. https://doi.org/10.1111/j.1365-2109.2008.02051.x.

Hossain, M. A., Hussain, M., Sarker, T. R., Saha, S. and Mohammed, M. I. M. M. 2023. Reproductive and morphometric traits of freshwater mussel *Lamellidens marginalis* and associated hydrology in the Ratargul freshwater Swamp Forest, Bangladesh. *Egypt. J. Aquat. Res*., 49(2): 161-170. https://doi.org/10.1016/j.ejar.2022.11.004.

Jolicoeur, P. and Mosimann, J. E. 1960. Size and shape variation in the painted turtle, a principal component analysis. *Growth,* 24: 339-354.

Kamal, D. and Khan, Y. S. A. 1998. Growth of the green mussel, *Perna viridis* (Linn. 1758), from Moheshkhali Channel of the Bay of Bengal, Bangladesh. *Pakistan J. Mar. Sci*., 7(1): 45-55.

Khan, A. A. M., Assim, Z. B. and Ismali, A. 2010. Population dynamics of the green-lipped mussel, *Perna viridis* from the offshore waters of Naf River coast, Bangladesh. *Chiang Mar. J. Sci.,* 37(2): 344-354.

Kuriakose, P. S. 1973. *Studies on the Mytilidae of the Indian coasts*. Ph. D. Thesis, University of Kerala, India.

Malathi, S. and Thippeswamy, S. 2011. Morphometry, length-weight and condition in *Parreysia corrugata* (Mullar 1774) (Bivalvia: Unionidae) from river Malthi in the Western Ghats, India. *Int. J. Biol. Sci*., 2(1): 43-52.

Malathi, S. and Thippeswamy, S. 2013. Population ecology of freshwater mussel *Parreysia corrugata* (Mullar 1774) from River Malthi, tributary of River Tunga, in the Western Ghats, India. *Recent Res. Sci. Technol*., 5(4): 20-26.

Mathews, C. P. and Samuel, M. 1990. Using the growth performance index (Φ') to choose species for aquaculture: An example from Kuwait. *Aquabyte*, 3(2): 1-4.

Mondol, M. R., Nasrin, F. and Nahar, D. A. 2016. Length-weight relationships, condition index and sex ratio of mussel *Lamellidens corrianus* (Lea, 1834) in a Freshwater Lake, Northwest Bangladesh. *Croatian J. Fish.*, 74: 172-178. https://doi.org/10.1515/cjf-2016-0025.

Moss, D. K., Ivany, L. C., Judd, E. J., Cummings, P. W., Bearden, C. E., Kim, W. J., Artuc, E. G. and Driscoll, J. R. 2016. Life span, growth rate, and body size across latitude in marine Bivalvia, with implications for Phanerozoic evolution. *Proc. R. Soc. B*., 283: 20161364. https://doi.org/10.1098/rspb.2016.1364.

Nagabhushanam, R. and Lohgaonker, A. L. 1978. Seasonal reproductive cycle in the mussel, *Lamellidens carrianus*. *Hydrobiologia,* 61: 9-14. https://doi.org/10.1007/BF00019019.

Nahar, D. A., Islam, M. R., Islam, M. S., Jasmine, S. and Mondol, M. M. R. 2019. Growth pattern of freshwater bivalve mollusk *Lamellidens marginalis* (Lamarck, 1819) from the northwest Bangladesh. *J. Biol. Sci*., 27: 121-132. https://doi.org/10.3329 /jbs.v27i 0.44677.

Narasimham, K. A.1981, Dimensional relationships and growth of green mussel *Perna viridis* in Kakinada Bay, *Indian J. Fish*., 28: 240-248.

Nwe, W. W., Aye, Z. M., Oo, N. N. and Myint, M. N. 2020. Population parameters of green mussel, *Perna viridis* (Linnaeus, 1758) from Ye estuary, Mon coastal area, Myanmar. *Int. J. Sci. Res. Publ*., 10(12): 309-314. http://dx.doi.org/10.29322/IJSRP.10.12.2020.p10830.

Patil, V. Y. and Bal, D. V. 1967. Seasonal gonadal changes in adult freshwater mussel, *Parreysia favidens* var. *marcens* (Benson). *Proc. Indian Acad. Sci., Sect. B,* 65(1): 26-33.

Pauly, D. 1980. On the interrelationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. *ICES J. Mar. Sci*., 39(2): 175-192. https://doi.org/10.1093/icesjms/39.2.175.

Pauly, D. 1983. Some simple methods for the assessment of tropical fish Stocks. *FAO Fish. Tech. Pap.,* 235. Food and Agriculture Organisation of the United Nations, Rome, Italy, pp. 1-52.

Pauly, D. and David, N. 1981. ELEFAN-I BASIC program for the objective extraction of growth parameters from length–frequency data. *Meeresforschung*, 28: 205-211.

Pauly, D. and Munro, J. L. 1984. Once more on the comparison of growth in fish and invertebrate. *Fishbyte,* 2: 1-21.

Pradhan, S., Saurabh, S., Padhi, N., Kumar, T., Kumarn, R., Mohanty, U. L. and Sundaray, J. K. 2020. Length-weight, width-weight and height-weight relationships of cultured freshwater pearl mussel *Lamellidens marginalis* (Lamarck, 1819). *Indian J. Fish.,* 67(1): 157-160. https://doi.org/10.21077/ijf.2019.67.1.78687-18.

Preston, H. B. 1915. *The fauna of British India including Ceylon and Burma - Mollusca* (*Freshwater Gastropoda and Pelecypoda*). Taylor and Francis, London, UK, 244 p.

Ramachandra, 1980. *Studies on the biology of green mussel Perna viridis (Linnaeus*). M. F. Sc. Thesis, University of Agricultural Sciences, Bangalore, India,102 p.

Ramakrishna and Dey, A. 2007. *Handbook of Indian freshwater molluscs*. Zoological Survey of India, Kolkata, India, 399 p.

Ramesha, M. M. and Thippeswamy, S. 2008, Population ecology of the Unionid mussel *Parreysia corrugata* (Mullar) from the river Kempuhole, a tributary of river Nethravathi, Western Ghats, India, In: *Book of Abstracts, 8th Indian Fisheries Forum,* 22-26 November 2008, Kolkata, Asian Fisheries Society, Indian Branch, Mangalore, India, p.38.

Ramesha, M. M. and Thippeswamy, S. 2009a. Allometry and condition index in the freshwater bivalve *Parreysia corrugata* (Muller) from river Kempuhole, India. *Asian Fish. Sci.,* 22: 203-213. https://doi.org/10.33997/j.afs.2009.22.1.019.

Ramesha, M. M. and Thippeswamy, S., 2009b, Population dynamics of the freshwater mussel *Parreysia favidens* (Benson) (Bivalvia: Unionidae) from the river Seeta, Western Ghats, India. In: *Book of Abstracts, National conference on current trends in environmental science and sustainable development*, 27-28 November 2009, University of Mysore, Mysore, India, p. 32.

Ridgway, I. D., Richardson, C. A. and Austad, S. N. 2011. Maximum shell size, growth rate, and maturation age correlate with longevity in bivalve molluscs. *J. Gerontol*., 66A: 183-190. https://doi.org/10.1093/gerona/glq172.

Rivonkar, C. U., Sreepada, R. A. and Parulekar, A. H. 1993. Growth parameters in the cultured green mussel *Perna viridis* L. from the Zuari Estuary, Goa. *Indian J. Mar. Sci*., 22: 72-74.

Sarma, K., Ahirwal, S. K., Kumar, A. and Narayan, D. 2022. Biological parameters, culture potential and nutritional quality of freshwater mussel *Lamellidens marginalis* (Lamarck, 1819). *Indian J. Fish*., 69(3): 51-58. https://doi.org/10.21077/ijf.2022.69.3.119345-07.

Shafee, M. 1979. Ecological energy requirements of the green mussel, *Perna viridis* Linnaeus from Ennore Estuary, Madras. *Oceanol. Acta*, 2: 69-74.

Sturges, H. 1926. The choice of a class interval. *J. Amer. Statist. Assoc.,* 21: 65-66.

Suryawanshi, A. V. and Kulkarni, A. N. 2014a. Comparative studies of length-weight relationship of *Parreysia corrugate* (Muller) and *Lamellidens marginalis* (Lamarck), from Nanded region, Maharashtra (India). *Indian J. L. Sci.,* 3(2): 77-80.

Suryawanshi, A. V. and Kulkarni, A. N. 2014b. Length-weight, length-height, and height-weight relationship of *Parreysia corrugata* (Muller) from Nanded region. *Indian J. Appl. Pure Biol*., 29(1): 133-137.

Strahl, J., Philipp, E., Brey, T., Broeg, K. and Abele, D. 2007. Physiological aging in the Icelandic population of the ocean quahog *Arctica islandica. Aquat. Biol.*, 1(1): 77-83. https://doi.org/10.3354/ab00008.

Tenjing, S. Y., Thippeswamy, S., and Narasimhaiah, N. 2016. A first study on growth, mortality and survivorship of the eared horse mussel, *Modiolus* *auriculatus* (Krauss, 1848) from India. *Indian J. Geo-Mari. Sci*., 45(2): 323-332.

Thejasvi, A. 2016. *Ecological studies of the green mussel Perna viridis from intertidal region of Mukka and sub tidal region of Karwar along Karnataka Coast, India*. Ph. D. Thesis, Mangalore University, Karnataka, India.

Thippeswamy, S. 1990. *Community ecology of the green mussel, Perna viridis (L.) island microhabitat*. Ph. D. Thesis, University of Agricultural Sciences, Bangalore, India.

Thippeswamy, S. and Joseph, M. M. 1988. Seasonable variability in the condition of the wedge clam *Donax incarnates* (Gmelin). In: Joseph, M. M. (Ed.), *Proceedings of the first Indian fisheries forum*, 04-08 December 1987, Asian Fisheries Society, Indian Branch, Mangalore, India, pp. 247-249.

Thippeswamy, S. and Joseph, M. M., 1991. Population selection strategies in the wedge clam, *Donax incarnatus* (Gmelin) from Panambur beach, Mangalore. *Indian J. Mar. Sci.*, 20: 147-151.

Thippeswamy, S. and Joseph, M. M., 1992. Allometry in the wedge clam, *Donax incarnatus* (Gmelin) from Panambur beach, Mangalore. *Indian J. Mar. Sci*., 21: 161-163.

Thippeswamy S., Joseph, M. M., Shubharekha, B. and Malathi, S. 2019. Factors influencing the shell size and shape in *Donax incarnatus* (Gmelin) inhabiting the Panambur sandy beach, Mangalore. *Indian J. Mar. Geo Sci*., 48(4): 475-483.

Thippeswamy, S., Malathi, S. and Anupama, N. M. 2014. Allometry and condition index in the freshwater bivalve *Parreysia favidens* (Benson, 1862) from river Bhadra, India. *Indian J. Fish*., 61(4): 47-53.

von Bertalanffy, L. 1938. A quantitative theory of organic growth (Inquiries on growth laws, II). *Hum. Biol*., 10: 81-213.

Wilbur, K. M. and Owen, G. 1964. Growth. In: Wilbur, K. M. and Yonge, C. M. (Eds.), *Physiology of mollusca*. Academic Press, New York, USA, pp. 211-242.

Zeng, Y. and Yang, H., 2021. Review of molluscan bivalve condition index calculations and application in Northern Quahogs *Mercenaria mercenaria, Aquac. Res*., 52(1): 23-36. https://doi.org/10.1111/are.14866.

Ziuganov, V., Miguel, E. S., Neves, R. J., Longa, A., Fernandez, C., Amaro, R., Beletsky, V., Popkovitch, E., Kaliuzhin, S. andJohnson, T. 2000. Life span variation of the freshwater pearl shell: A model species for testing longevity mechanisms in animals. *AMBIO*, 29: 102-105. https://doi.org/10.1579/0044-7447-29.2.102.