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Population dynamics of *Macrobrachium rosenbergii* (De Man, 1879) from the Narmada Estuary, west coast of India

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Abstract

In the current study, population characteristics of *Macrobrachium rosenbergii* (De Man, 1879) were assessed from the Narmada Estuary during January to December 2019. The length-weight relationships were established as W = 0.0085 $L^{3.085}$. The length groups 150-159 and 170-179 mm accounted for most of the commercial *M. rosenbergii* catch. Different growth parameters were estimated as L_{∞} = 288.75 mm, K = 0.46 yr^{-1} and t_0 = -0.71 y. Annual mortality coefficients for mortality (Z, M and F) were estimated at 1.43, 0.57 and 0.86, respectively. The exploitation rate (E) reached 0.60, marginally surpassing the optimal value of 0.50. The recruitment pattern of *M. rosenbergii* showed that the species follows two recruitment patterns, one from January to February and the major recruitment from May to August. The maximum sustainable yield (*MSY*) was estimated at 267.05 t, if the recommended length at first capture (L_c = 137.91 mm TL) is maintained throughout the capture periods. The relative yield per recruit (Y/R) analysis indicated that the present exploitation rate (0.72) already exceeded the maximum fishing pressure (E_{max} = 0.68), indicating that the stock is already in the decline stage at the present level of fishing pressure.

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Introduction

The freshwater prawn fishery plays an important role in the socio-economic status of the fisher population of India and is mainly confined to *Macrobrachium rosenbergii*. The genus *Macrobrachium* comprises decapod crustaceans with a global distribution, commonly found in tropical and subtropical waters (Freire *et al.,* 2012; Taddei *et al.,* 2017). The most economically important species under the genus include *M. rosenbergii* (De Man, 1879), *M. carcinus* (Linnaeus, 1758), *M. acanthurus* (Wiegmann, 1836), *M. amazanicum* (Heller, 1862) and *M. malcolmsonii* (Milne-Edwards, 1844). Giant freshwater prawn is distributed in tropical and subtropical areas of the Indo-Pacific region, including India (Kumar, 2001). A total of 40 species are represented in Indian waters under the genus *Macrobrachium* (Jayachandran and Joseph, 1992). Along the West coast of India, the species is reported from the lower stretches of Narmada and Tapti, Thana Creek (Maharashtra) and the backwaters of Kerala. The species also forms a lucrative fishery in the Hooghly Estuary (Rao, 1969).

Estimating population parameters serves to offer guidance on the best way to utilise aquatic living resources, such as fish and shrimp, and to sustain those resources (Sparre and Venema, 1998). To generate quantitative forecasts about responses of fish populations to various management options, a range of statistical and mathematical models is used (Sparre and Venema, 1998). It is necessary to evaluate how various environmental changes affect the biological and physical characteristics of a fish species, family, or group using various population parameter models (Beverton and Holt, 1957; Whitfield and Elliott ,2002; Portner and Peck, 2010; Belamino *et al.,* 2024; Jana *et al.,* 2024).

The study of population dynamics is very important as it is useful for the estimation

of growth, mortality and recruitment patterns thereby enhancing our understanding of population production rates (Chung and Woo, 1999; Bhakta *et al.*, 2020; 2022). Thus, it provides useful information on the age at first maturity, spawning frequency, individual and stock responses to changes in the habitat, recruitment success, stock structure which, in turn, influence population dynamics.

Sporadic studies have been carried out on population dynamics of freshwater prawns in the Indian context, namely the age and growth of *M. rosenbergii* by Rajyalakshmi (1964); Kurup *et al.* (1992); Harikrishnan (1997); Harikrishnan and Kurup (1997); Pillai *et al.* (2017); *M. idella* by Kurup *et al.* (1992); *M. malcolmsonii* by Khan *et al.* (2009) and *M. vollenhovenii* by Nwosu and Wolfi (2006). A few studies are also available on the length-weight relationship of various freshwater prawns that were investigated by researchers like Rao (1967), Arana-Magallon and Ortga-Salas (2005), Udoinyang *et al.* (2016) in *M. rosenbergii*, Kadir *et al.* (1987) in *M. rude*, Natarajan *et al*. (1988) in *M. idae*, Singh and Srivastava (1991) in *M. birmanicum*.

The giant freshwater prawn forms a commercially important fishery in the Narmada Estuary, but no published data is available on its stock assessment from this region. A few studies are available on the growth parameters of *M. rosenbergii* in reservoir conditions (Harikrishnan, 1997; Harikrishnan and Kurup, 1997). In this context, an attempt has been made to study the growth, mortality and certain population characteristics of *M. rosenbergii,* which will be useful for long-term sustainable management of this high-value species in the Narmada Estuary.

Materials and methods

Sampling sites and collection of samples

Length frequency data were collected monthly from five selected landing centers, namely Sisodra, Jhanor, Bharuch, Bhadbhud and Mehegam, from the Narmada Estuary, a west-flowing river in India, from January to December 2019 (Fig. 1). The specimens were caught by monofilament gillnet (mesh size - 20-60 mm), hook and line and bagnet (10 mm cod-end mesh size) from those landing sites. Freshly collected prawn samples were transported in a plastic-insulated box after being preserved in ice and then brought to the laboratory. At the laboratory, the total length (TL) of the prawn specimens was measured from the tip of the rostrum to the tip of the telson to the nearest 0.1 mm using a measuring board, and weight was noted to the nearest 0.01 g accuracy using an electronic balance. The total catch of the species on the sampling day was noted, The collected length-frequency data were grouped into 10 mm class intervals for estimation of growth parameters and other population parameters.

Population parameters

The von Bertalanffy growth parameters such as asymptotic length (L_0) and growth coefficient (K) were estimated by pooling the sample using the ELEFAN I module of FiSAT-II software version 1.2.2 (Gayanilo *et al.*, 1996 and 2005). The age at zero length (t_0) was calculated from Pauly's (1979) empirical equation:

$$\log_{10}(-t_0) = -0.3922 - 0.275 \log_{10} L_{\infty} - 1.038 \log_{10} K$$

where L_α is the asymptotic length, *K* is the growth coefficient.

Growth performance index *(φ')* for *M. rosenbergii* population in terms of length growth was computed using the index of Pauly and Munro (1984):

$$\varphi' = \text{Log}K + 2 \text{ Log } L_{\infty}.$$

The lifespan ($_{max}$) of the species was estimated by the equation given by Pauly (1983) as:

$$t_{max} = 3/K + t_0$$

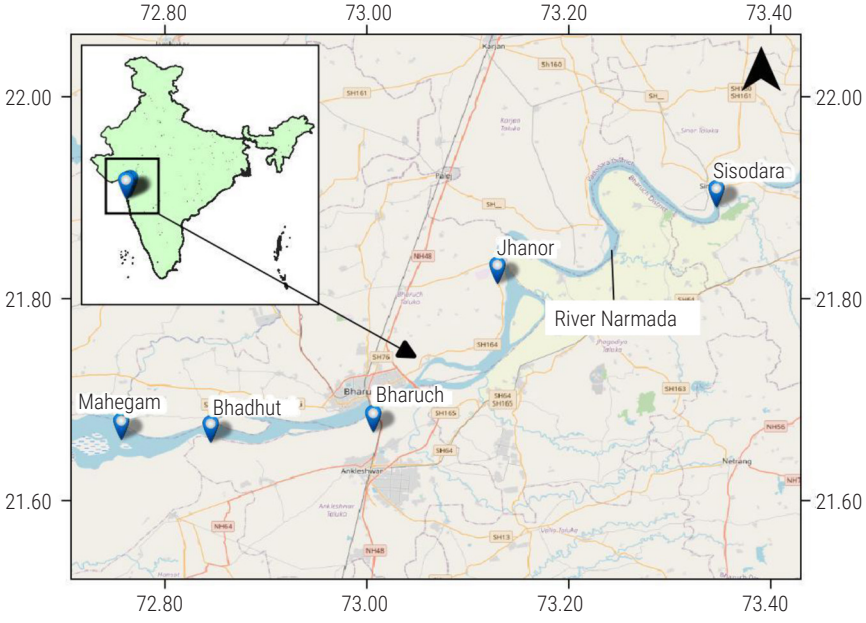

Fig. 1. Map showing the collection sites of *M. rosenbergii* from Narmada Estuary

Mortality parameters

The total mortality (Z) was calculated from the length converted catch curve method (Pauly, 1983) using FiSAT software, and the natural mortality was estimated by Pauly's (1980) empirical formula:

$\ln(M) = -0.0152-0.279 \ln (L_{\infty}) + 0.6543 \ln(K) + 0.463 \ln(T)$

Fishing mortality (F) was estimated by subtracting the instantaneous rate of natural mortality (M) from the instantaneous rate of total mortality (Z), i.e., F = Z - M. The exploitation rate (E) was estimated as F/Z.

Yield per recruit analysis

The relative yield per recruit (*Y'/R*) and biomass per recruit (*B/R*) were estimated using the selection ogive procedure (Gulland, 1969) as a function of exploitation level (*E*) through FiSAT II.

Virtual population analysis

The length structured virtual population analysis (*VPA*) was carried out from the relevant information produced by the methods of Thompson and Bell (1934) and Gulland (1969). The inputs for the *VPA* analysis of the species were taken from the estimated values of L_{∞}, *K, M, F, a* (constant of length-weight relationship) and *b* (exponent value).

Results

Length-frequency data of 512 specimens of *M. rosenbergii* were collected and analysed from January to December 2019 for the stock assessment study. The size of the specimens ranged from 62 to 270 mm and 2.7 to 224.1 g, respectively. The average length of the specimens ranged from 157.59±41.09 mm (mean±SD) and the average weight was estimated at 45.80±35.89 g, respectively. From the length-frequency data, it was revealed that length groups 150-159 (17.38%) and 170-179 mm (12.50%) dominated the commercial catches of *M. rosenbergii* in the Narmada Estuary (Fig. 2).

Population parameters

$W = 0.0085\ L^{3.085}$ was defined as the length-weight relationship, where *a* = 0.0085 and *b* = 3.085. According to the results of the ELEFAN technique using the FiSAT programme, the growth parameters L_{∞} and *K* were estimated to be 288.75 mm and 0.46 yr^{-1}, respectively (Fig. 3) and the value for t_0 was determined to be -0.71 yr. If not subjected to fishing activities, *M. rosenbergii* could grow up to 288.75 mm in the Narmada Estuary, according to the asymptotic length value. It was determined that the estimated growth performance index was 4.58. The super-imposed growth curves from the length-frequency showed the existence of seven growth curves (Fig. 3), which indicated the presence of seven cohorts or size groups of *M. rosenbergii* in the Narmada Estuary.

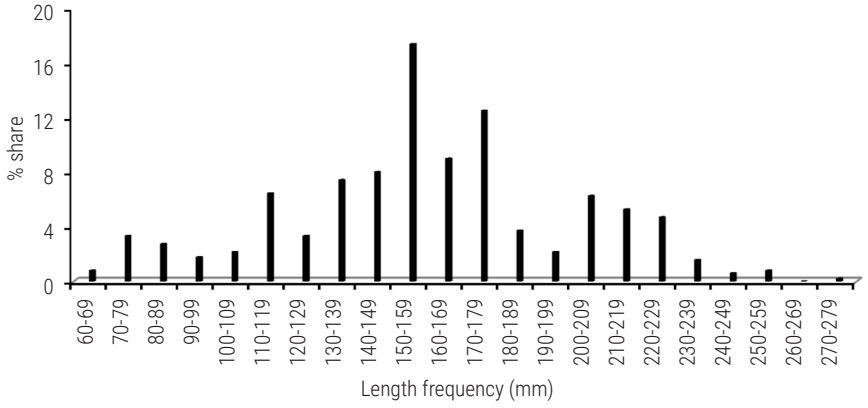

Fig. 2. Length-frequency distribution of *M. rosenbergii* collected from the Narmada Estuary during the study period

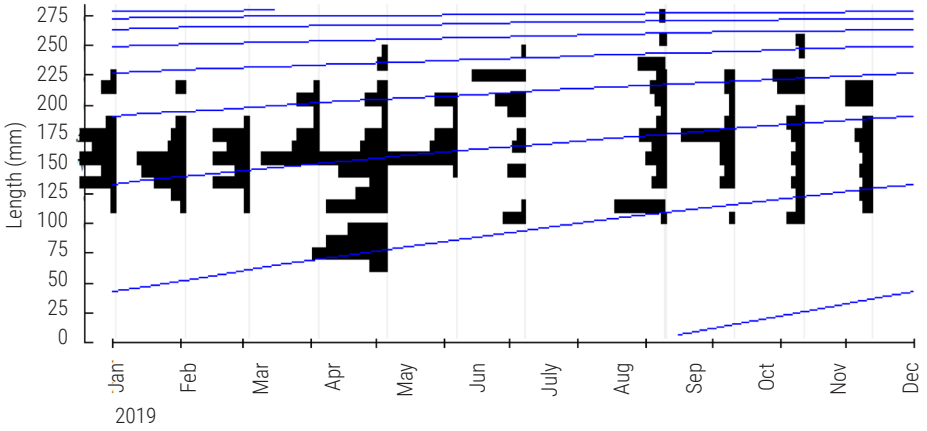

Fig. 3. Growth curve of *M. rosenbergii* from the Narmada Estuary by employing ELEFAN I (L_{∞}= 288.75 and *K* = 0.46 yr^{-1})

Mortality parameters

Using the length-converted catch curve method, the annual mortality rate (*Z*) was calculated by integrating the values of L_∞ and *K*. By using the annual average surface temperature of the Narmada Estuary during the study period as 28.0°C, the estimated value of total mortality (*Z*) was determined to be 1.43, natural mortality (*M*) to be 0.57 and fishing mortality (*F*) to be 0.86. The fishing mortality was found to be a little higher than that of natural mortality. The exploitation rate (*E*) was calculated as 0.60 (Fig. 4), which was observed to be higher than the optimum exploitation rate (0.5). Table 1 provides the estimated population parameters of *M. rosenbergii* from the Narmada Estuary.

Recruitment pattern

The recruitment pattern of *M. rosenbergii* from the Narmada Estuary showed that the species follows two recruitment patterns in a year, once from January to February and the major recruitment from May to August (Fig. 5). It could also be inferred that the spawning of *M. rosenbergii* from the Narmada Estuary starts from May onwards and might continue till August.

Yield per recruit

The relative yield per recruit (*Y'/R*) and biomass per recruit (*B/R*) of *M. rosenbergii* were estimated using the selection ogive procedure of FiSAT-II (Fig. 6). The input data to estimate those were L_c/L_∞ (0.482) and *M/K* values (1.239). From the relative yield per recruit (*Y/R*) analysis, the estimated E_{max}, $E_{0.1}$ and $E_{0.5}$ values were estimated as 0.68, 0.56 and 0.36, respectively. The present estimation showed that the maximum yield could be obtained for *M. rosenbergii* at an *E* value of 0.68. Further, 50% of the biomass could be obtained as yield when *E* = 0.36, as shown in red colour in Fig. 6.

Virtual population analysis

The probability of capture estimated using the selection curves found *M. rosenbergii* length at first capture ($L_c = L_{50}$) to be 137.91 mm (Fig. 7). The input parameters for the *VPA*, were L_α of 288.75 mm, *K* of 0.4697 yr^{-1}, *M* of 0.57 97 yr^{-1}, intercept *a* of 0.085 and regression coefficient *b* of 3.085. According to the *VPA* graph, the 220-230 mm length class seemed to have the highest fishing mortality, at 1.6748 yr^{-1}, followed by the 250-260 mm (1.1753 yr^{-1}) and

Table 1. Population parameters of *M. rosenbergii* from the Narmada Estuary (N = 512)

Parameter	Value
Asymptotic length (L_∞) (mm)	288.75
Growth coefficient (*K*) (yr^{-1})	0.46
Initial condition factor (t_0) (years)	-0.71
Growth performance index (φ')	4.58
Length at first capture (L_c) (mm)	137.91
Total mortality coefficient (*Z*) (yr^{-1})	1.43
Natural mortality coefficient (*M*) (yr^{-1})	0.57
Fishing mortality coefficient (*F*) (yr^{-1})	0.86
M/K value	1.24
Exploitation rate (*E*)	0.60
Exploitation ratio (*U*)	0.72

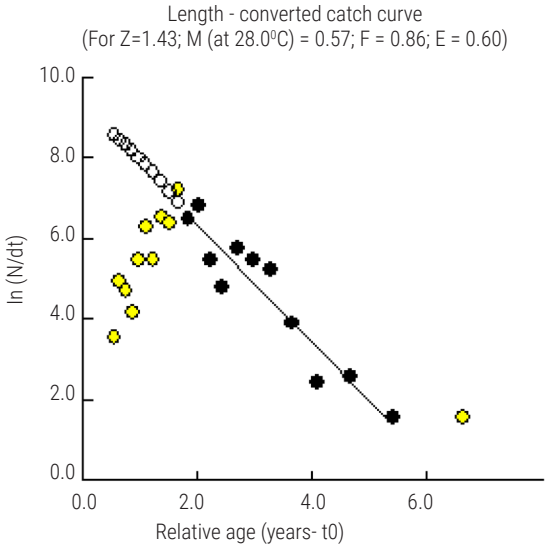

Fig. 4. Length converted catch curve for estimation of *Z* of *M. rosenbergii* from the Narmada Estuary

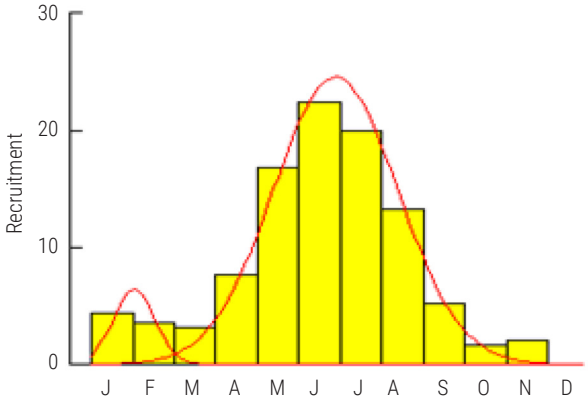

Fig. 5. Recruitment pattern of *M. rosenbergii* from the Narmada Estuary

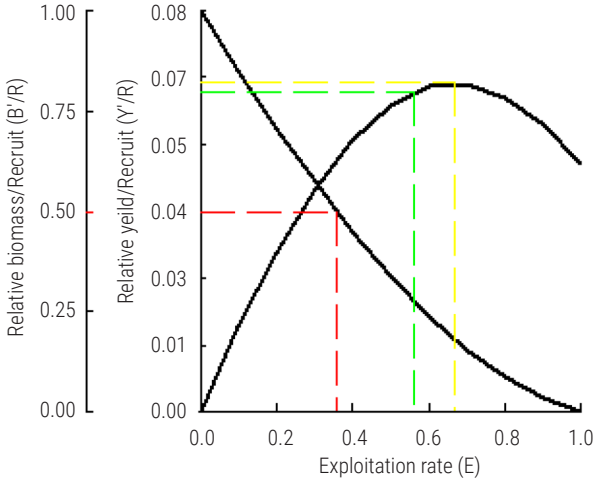

Fig. 6. Relative yield per recruit and relative biomass per recruit model using selection ogive curve for *M. rosenbergii* from the Narmada Estuary

150-160 mm (1.1753 yr^{-1}) length class groups. Smaller length groups, including those between 60 and 70 mm, had a relatively low fishing mortality rate of 0.0335 yr^{-1}. The 60-70 mm length class represented the highest population numbers (1,265,000), and the corresponding fishing mortality was 0.0335 yr^{-1}. Based on the assumption that the terminal fishing mortality was 0.86 yr^{-1}, only 2000 individuals from the highest length class (270-280 mm) were seen. The biomass rose from 4 t in the 60-70 mm length class to a maximum of 38.17 t in the 190-200 mm length class and then gradually fell to a minimum of 3.31 t in the 270-280 mm length class.

The estimated total steady stock biomass (*SSB*) from the length-structured virtual population analysis (VPA) of the FiSAT II was observed to be 373.49 t from the Narmada Estuary. Accordingly, the maximum sustainable yield (MSY) of *M. rosenbergii* was estimated at 267.05 t if the recommended length at first capture (L_c = 137.91 mm TL) is maintained throughout the capture period.

Discussion

The giant freshwater prawn, of considerable economic importance, is found extensively throughout the tropical and subtropical areas of the Indo-Pacific, particularly within the estuarine and riverine systems of India. Grasping the population dynamics of this species is essential for formulating sustainable fishery management strategies, especially in areas such as the Narmada Estuary on the west coast of India, where the prawn underpins local livelihoods through capture fisheries and aquaculture. Investigations into growth parameters, mortality rates, exploitation patterns, and reproductive biology yield essential insights for enhancing harvest practices and preserving natural stocks. Since *M. rosenbergii* is important for both environment and economy, studying its population and how it changes is crucial for ensuring that fisheries in estuarine ecosystems can continue to thrive despite different environmental conditions and fishing activities.

Population parameters

The estimated length-weight relationship in the present study (*a* = 0.0085 and *b* = 3.085) was found to be similar to that of Kunda *et al.* (2008), who observed the *b* value of 3.075 for the specimens collected from rice fields of Mymensingh, Bangladesh. Kurup *et al.* (2000) reported that *b* values varied from 1.53 to 3.50 in different stages of *M. rosenbergii* from the Vembanad Lake of Kerala. In other studies, positive allometric-type growth patterns were reported by several researchers, like Rao (1967) (*b* = 3.19) from Hooghly Estuary; Hossain *et al.* (1987) (*b* = 3.40) from Tetulia River, Bangladesh; Sampaio and Valenti (1996) (*b* = 3.43) from Brazil; Lalrinsanga *et al*. (2012) (*b* = 3.39) from Odisha; Wang (1985) (*b* = 3.26) from Hawaii, USA; Indarjo *et al.* (2021) (b = 0.75 to 2.73) from North Kalimantan Province, Indonesia. Differences in *b* values may be due to the combination of one or more factors such as habitat areas, seasonal variations, degree of stomach fullness, gonadal maturity stages, health condition and length groups of species studied (Tesch, 1971; Yang and Ding, 2016; Bhakta *et al.,* 2019a, b; Borah *et al.,* 2020).

In the present study, the growth parameters L_∞, *K* and t_0 were recorded as 288.75 mm, 0.46 yr^{-1} and -0.71 y, respectively. There are very few reports available on the growth parameters of *M. rosenbergii* from different water bodies in India as well as in neighbouring countries. Harikrishnan and Kurup (1997) reported L_∞, *K* and t_0 values of *M. rosenbergii* as 454.89 mm, 0.98 yr^{-1}, -0.158 and 297.36 mm, 1.366 yr^{-1}, -0.226 for the male and female specimens, respectively, in the Vembanad Lake of India, which were found a little higher than our values. Comparative estimates of different population parameters of *Macrobrachium* spp. studied by different researchers are provided in Table 2.

Mortality parameters

The total mortality (*Z*), natural mortality (*M*) and fishing mortality (*F*) were calculated to be 1.43, 0.57 and 0.86, respectively, with

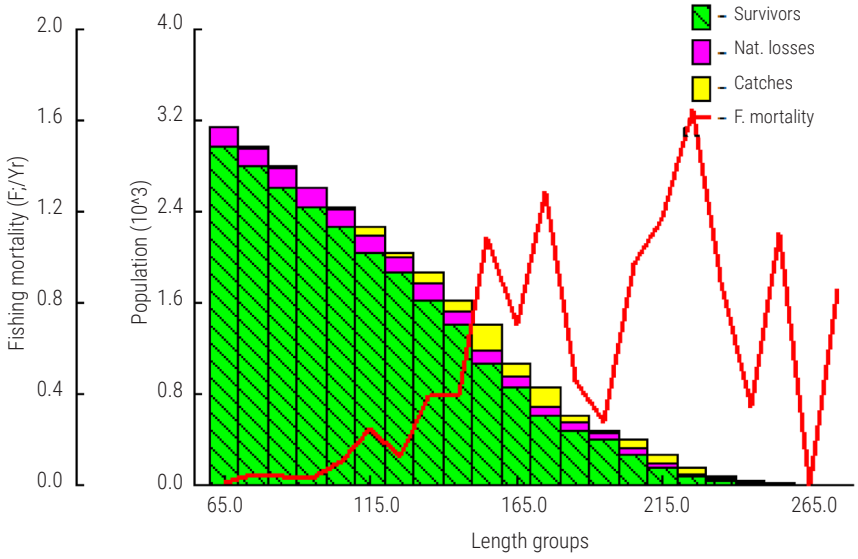

Fig. 7. Length-structured virtual population analysis of *M. rosenbergii* from the Narmada Estuary

Table 2. Estimation of L_{∞}, K, and t_0 of freshwater prawn (*Macrobrachium* spp.) studied by different researchers from other water bodies

Species	Author	Region	L_{∞} (mm)	K (yr^{-1})	(φ′)
M. rosenbergii	Valenti *et al.* (1993)	Sao Paulo, Brazil	218	0.10	-
			132	0.14	-
			119	0.18	-
M. rosenbergii	Sampaio and Valenti (1996)	Sao Paulo, Brazil	234	0.24	2.11
			209	0.31	2.14
			184	0.37	2.10
			188	0.28	1.99
M. rosenbergii	Harikrishnan and Kurup (1997)	Vembanad Lake	454.9 (Male)	0.67	3.15
			420 (Male)	0.98	-
			297.4 (Female)	1.37	3.08
			308.0 (Female)	1.1	-
Macrobrachium felicinum	Yakub (2010)	Lower Ogun River, South-west Nigeria	76.45±3.25 mm	1.33±0.7	3.87±0.19
M. macrobrachion			100.26±12.20	0.59±0.2	3.76±0.01
M. vollenhovenii			215.10±16.27	0.2±0.04	3.98±0.04
M. rosenbergii	Present study	Narmada Estuary	288.75	0.46	4.58

exploitation rate (E) of 0.60, suggesting a moderate level of fishing pressure. The reported numbers for *Z*, *M* and *F* in *M. rosenbergii* from Indian waters vary a lot due to different regional and environmental factors, for example, *Z* value ranges from 2.23 to 7.25, *M* from 1.50 to 1.74 and *F* from 0.73 to 5.54, as reported by Harikrishnan (1997) and Khan *et al.* (2009). The observed *E* value indicates that the stock is under fishing pressure, warranting careful monitoring to prevent overexploitation.

The present study found that fishing mortality slightly exceeds natural mortality. The fishing mortality of *M. rosenbergii* in the Narmada Estuary is significantly influenced by the intensity of fishing during peak breeding seasons, the use of non-selective fishing gear, such as fine-meshed bag nets and the inadequate enforcement of fishing regulations.

The exploitation rate of *M. rosenbergii* was reported as 0.702 and 0.763 for the male and female specimens collected from Vembanad Lake in Kerala (Harikrishnan, 1997), which indicated overexploitation of the species. A comparatively low exploitation rate with values of 0.33 and 0.31 was reported by Khan *et al.* (2009) from the Wyra Reservoir in India, which indicated that the monsoon river prawn, *M. malcolmsonii,* from the studied reservoir was under-exploited and there is further scope to increase the fishing. In our study, if we compared the present exploitation rate (0.72) with the optimum level (0.50) as well as the present maximum level of exploitation (E_{max} = 0.68), we could see that there is already overexploitation of the species in the Narmada Estuary.

Recruitment pattern

Singholka *et al.* (1980) observed that the peak recruitment of *M. rosenbergii* was from April to September in Thailand's water bodies. According to Harikrishnan (1997), the peak spawning season of *M. rosenbergii* is during September-October months in Vembanad Lake, Kerala, India. The highest occurrences of *M. rosenbergii* juveniles were reported during the June-September months in the Cochin backwaters of Kerala, which indicates that the species is recruited in the Kerala backwaters during monsoon months (Kumar, 2001). As per Khan *et al.* (2009), for *M. malcolmsonii* from the Wyra Reservoir in India, at least two peaks of spawning were observed, once during June and another during August or October. According to them, from 2003 to 2004, the monsoon river prawn was recruited at Wyra Reservoir in India from June to September. In the present study, it was found that the species had two recruitment patterns in a year: once during January to February and the major recruitment during May to August, which coincides with the monsoon period and resembles other studies.

In the present findings, the phi-prime (φ′) value (4.58) was found to be slightly higher than that of the reports of Harikrishnan and Kurup (1997). As they found, the value of φ′ was 3.15 for males and 3.08 for females of the specimens collected from Vembanad Lake in Kerala, India. In general, the values of phi-prime vary from 2-4 and are constant for a species, family, or similar taxonomic group (Pauly, 1980; Sparre, 1993; Bhakta *et al.* 2019c). The variations of φ′ from one species to another are mainly observed due to different *K* values, variability in environmental conditions, and different fishing intensities (Majumder *et al.,* 2012). The relatively higher φ′ value estimated in the present study indicated that *M. rosenbergii* from the Narmada Estuary follows a steady growth rate.

The longevity (t_{max}) value was estimated at 5.81 years for *M. rosenbergii* from the Narmada Estuary. In the Vembanad Lake of Kerala, India, the value of t_{max} for *M. rosenbergii* was reported as 1.97 and 4.27 years for female and male specimens, respectively (Harikrishnan and Kurup, 1997). Khan *et al.* (2009) estimated the t_{max} value of monsoon river prawn *M. malcolmsonii* at 4.76 years (based on Pauly's 1980 formula) in the Wyra Reservoir of India. While the value of t_{max} of giant African river prawn *Macrobrachium vollenhovenii* Herklots 1857 reported the values as 2.42 and 2.40 y for males and females, respectively, in the Cross River Estuary, Nigeria (Nwosu and Wolfi, 2006). In the Lobe River, *Macrobrachium vollenhovenii* has a lifespan of 0.9 years (Gabche and Hockey, 1995); in the Fahe reservoir, it is 3 years (Etim and Sankare, 1998) and in the Cross River Estuary, it is 1.7 years (Enin, 1995). Prawns, being crustaceans, are known for their short lifespans. In the present study, we found relatively higher longevity compared to the other *Macrobrachium* species from different water bodies, which implied

that *M. rosenbergii* inhabiting the Narmada Estuary may live a maximum of 5.81 years indicating a suitable environment for the growth of the species.

Yield per recruit

The relative yield per recruit study based on knife-edge selection was estimated at an E_{max} of 0.68, which was slightly higher than the estimated *E* value of 0.60. Khan *et al.* (2009) observed a similar kind of fishing pressure with an estimated *E* value (0.32) less than that of the E_{max} value (0.48) of *M. malcolmsonii* from the Wyra Reservoir of Andhra Pradesh, India. Further, they have suggested that for the most economical yield, it would be ideal to exploit till an *E* value of 0.41 ($E_{0.50}$) instead of 0.48 (E_{max}). The present study also suggests an exploitation level of 0.36 ($E_{0.50}$), which is less than the present *E* (0.60) level to achieve the *MEY* in the environment studied.

Virtual population analysis

The *VPA* revealed that, in contrast to natural mortality, fishing mortality increases with increasing length class. The highest fishing mortality of 1.6748 yr^{-1} was observed at the 220-229 mm length class, and the lowest was 0.0335 yr^{-1} at 60-69 mm length class. Harikrishnan and Kurup (1997) mentioned in their study that for female *M. rosenbergii*, the highest fishing mortality was observed in the 210–230 mm size group, and in males, it was 230-290 mm in the specimens collected from Vembanad Lake, India.

The virtual population analysis revealed that *M. rosenbergii* inhabiting the Narmada Estuary exhibited slightly high fishing mortality from the 150-159 mm length group onwards. An analysis of the observed length groups in relation to the reported length at first maturity of *M. rosenbergii* is crucial for the effective management of fisheries. The present study found that a notable percentage of individuals fell within the length groups (150-159 mm) that are equal to or below the length at maturity previously documented, specifically 155 mm for females and 175 mm for males, as reported in earlier research from the Hooghly Estuary, India (Rao, 1967). This suggests that a significant portion of the harvested population consists of mature individuals, which is advantageous for sustainability. These comparisons are essential for establishing minimum legal size limits and managing fishing practices to guarantee that individuals can spawn at least once prior to being captured. The *MSY* was estimated at 267.05 t if the recommended length at first capture (L_c = 137.91 mm TL) is maintained throughout the capture periods.

It was found that *M. rosenbergii* in the Narmada Estuary is experiencing overfishing, leading to a gradual decline in its population. At the present level of exploitation, the sustainability of this stock is at risk. Therefore appropriate management measures are essential to ensure long term viability of the species in Narmada Estuary. Recommended management strategies include regulation of fishing efforts through selective fishing, reduction of current fishing pressure and enforcing a total or partial ban on fishing during the peak breeding season of the species.

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