Indian J. Fish., 71 (3): 1-7, 2024 doi:10.21077/ijf.2024.71.3.147045-01

Available online at: epubs.icar.org.in/index.php/IJF

Length-based assessment of penaeid shrimp fishery stocks along the north-eastern Arabian Sea

Rajan Kumar*, Gyanranjan Dash, P. T. Sarada, Shikha Rahangdale, Vinayakumar Vase, Vipul Solanki and Jayshree Gohel

Veraval Research Station of ICAR-Central Marine Fisheries Research Institute, Veraval-362 269, Gujarat, India

Abstract

Penaeid shrimps are a key resource in marine fisheries and are of great ecological and economic importance. The north-west (NW) coast of India contributes significantly (~30%) to the penaeid shrimp landings in India. Four species of penaeid shrimps, namely *Parapenaeopsis stylifera*, *Solenocera crassicornis*, *Metapenaeus affinis*, and *M. monoceros,* were assessed using Length-based spawning potential ratio (SPR) based on the length frequency data collected during 2017-21, from commercial trawlers operating in the depth range of 20-100 m along the north-west coast of India bordering the north-eastern Arabian Sea. The current status (2021) of *P. stylifera*, *S. crassicornis* and *M. affinis* was found to be healthy, with a spawning potential ratio of ≥ 0.40. For *M. monoceros*, the SPR was slightly below 0.40 (0.34-35), however, considering the fast growth and short generation time for the resources, the stock status can be considered fair. Significant reduction in fishing pressure (F/M < 1.0) and increase in SPR (>0.40) during COVID-19 affected years (2020-21) were evident. The reduction in fishing hours during the pandemic has allowed the resource to regain the target reference point (TRP) for SPR. Declining catches over the past decade for the group are not due to resource depletion but for the shift in species preference and the diversification of trawls in the region, with bottom trawling giving way to pelagic trawling.

*Correspondence e-mail:
rajan.kumar@icar.gov.in

Keywords:
Sustainability, Spawning potential ratio, COVID-19, Penaeid shrimps

Received : 02.01.2024
Accepted : 17.07.2024

Introduction

Crustaceans are a highly valued marine fishery resource, with penaeid shrimps being particularly in high export demand. India falls among the top shrimp exporters, with an export value of US$2.6 billion in 2018 (Sarada *et al*., 2020). High domestic and export demand has led to extensive fishing for penaeid resources along the Indian coast (Nandakumar and Maheswarudu, 2003). The north-west (NW) coast of India is rich in benthic fisheries resources, including penaeid shrimp owing to the broad continental shelf and perennial productivity (Madhupratap *et al*., 2001; Faruque and Ramachandran, 2014; Solanki *et al*., 2017). The region contributes 30% (~50,000 t) of the total penaeid shrimp landings of the country (CMFRI, 2019) and has a long history of commercial exploitation. The commercial fishery of penaeid shrimps in the region is supported by over 10 species; however, the major contribution is from the genera *Parapenaeopsis, Solenocera* and *Metapenaeus*. *Parapenaeopsis stylifera* (H. Milne Edwards, 1837), *Solenocera crassicornis* (H. Milne Edwards, 1837), *Metapenaeus affinis* (H. Milne Edwards, 1837) and *M. monoceros* (Fabricius, 1798) are the key species in terms of quantity landed under respective genera (Ramamurthy, 1994). Several studies on age, growth, population dynamics and stock assessment have been carried out for these species from other parts of India (Achuthankutty and Parulekar, 1986; Alagaraja *et al*., 1986; Devi, 1987; George *et al*., 1988; Suseelan *et al*., 1989; Sukumaran *et al*., 1993; Rao, 1994; Nandakumar and Srinath, 1999; Sarada, 2002; Pillai *et al*., 2021). However, published reports from the NW coast are limited (Chakraborty *et al*., 1994; Dineshbabu, 2005, 2006; Leena and Deshmukh, 2009), especially in the last decade (Dash *et al*., 2018; Nirmale *et al*., 2021). Further, several of the studies are restricted to the estimation of growth parameters and provide no insight into the stock status of the resource (Dineshbabu, 2005, 2006; Leena and Deshmukh, 2009). The long history of commercial exploitation,

lack of recent assessment and changing fishing patterns in terms of species preference and gear diversification (marginalisation of bottom trawling) in the region (Azeez *et al*., 2021; Rahangdale *et al*., 2022a, b) provide the rationale for the present study.

The prevalence of COVID-19 in 2020 and 2021 has strongly impacted the collection of regular (monthly) length frequency (LF) data from commercial fisheries to apply the conventional length-based stock assessment model recommended for tropical fisheries. However, recently developed tools like Length-based spawning potential ratio (LBSPR) can be applied in such cases using annual LF data and prior information on growth, mortality and maturity parameters (Hordyk *et al.*, 2015a, 2015b) which are often available from commercially important resources. The tool not only facilitates the stock status assessment during data-poor periods but also, provides an opportunity to visualise the impact of pandemic-forced reduction in fishing pressure on the health of the stock. The current study used the LF data from both the pre-pandemic period (2017-19) and the data-poor pandemic period (2020-21), to see the trend in the relative fishing mortality (F/M) and spawning potential ratio (SPR) and evaluate the current stock status of four penaeid shrimp species namely, *P. stylifera, S. crassicornis, M. affinis*, and *M. monoceros*.

Materials and methods

The length frequency (LF) data used in the present study were collected from commercial trawlers operating in the depth range of 20-100 m along the NW coast of India (Fig. 1) bordering the NE Arabian Sea during 2017-21.

The LF data were collected monthly, except for the fishing ban period (June and July) and COVID-19 closure (during 2020-21) separately for males and females. The monthly LF data were pooled and grouped into 5 mm length classes to arrive at annual LF data for the respective years. Length-based spawning potential ratio (LBSPR) was used to evaluate the status of the stock (Hordyk *et al*., 2015a, b). The LBSPR is a steady-state stock assessment approach that estimates stock status indicators such as spawning potential ratio (SPR) and relative fishing mortality (F/M) along with the parameters of a logistic selectivity curve (Hordyk *et al*. 2016; Mora *et al*., 2022). SPR is the proportion of the unfished reproductive potential available in the population at the given level of fishing pressure. It is the ratio of spawning stock biomass under exploitation (SSB_F) and virgin spawning stock biomass ($SSB_{F=0}$) (Hordyk *et al*., 2015a; Nugroho *et al*., 2017; Prince *et al*., 2020).

$$SPR = \frac{SSBF}{SSB_{F=0}}$$

The LBSPR requires length-frequency data as input. Prior information on asymptotic length (L_{inf}), ratio of natural mortality and von Bertalanffy growth coefficient (M/K) and parameters of maturity ogive (L_{m50} and L_{m95}) are the additional inputs for the model. The priors were taken from the available information with the ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), Kochi based on data collected during 2017-19 and are provided in Table 1. The stocks were evaluated based on the categorisation by Palomares *et al*. (2018) and Tosunoglu *et al*. (2022). The LBSPR package available in R was used for the analysis.

Results

Penaeid shrimps (35,936 t) accounted for 21.17% of the total crustacean landings in Gujarat in 2019 (CMFRI, 2019). *P. stylifera* was most dominant with a contribution of 57.8% of the total penaeid shrimp landings followed by *S. crassicornis* with 30.31% of catches. *M. affnis* and *M. monoceros* contributed 4.81 and 0.81% of the landings, respectively along the Gujarat coast (Fig. 2).

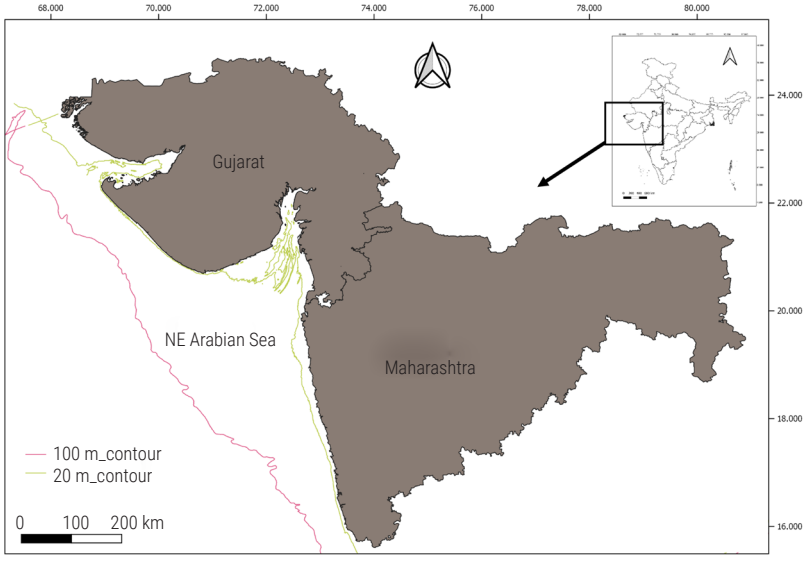

Fig. 1. Study region: LF data from trawlers operating between 20 (green) and 100 m (red) contour lines off the north-west coast of India

Table 1. Priors used for the selected shrimp species landed along the NW coast of India

Species (sex)	L_{∞} (mm)	M/K	L_{m50} (mm)	L_{m95} (mm)
P. stylifera (F)	176	1.58	82.60	136.3
P. stylifera (M)	148	1.61	75.7	108.6
S. crassicornis (F)	144	1.57	70.7	119.5
S. crassicornis (M)	127	1.65	59.8	88.6
M. affinis (F)	208	1.63	108.8	146.6
M. affinis (M)	199	1.67	92.5	117.3
M. monoceros (F)	271	1.61	111.8	149.5
M. monoceros (M)	251	1.64	95.6	119.1

Note: The priors were estimated based on the data available under in-house projects of ICAR-CMFRI (CFD/REC/14 and DEM/RMS/09).

Parapenaeopsis stylifera

The estimated spawning potential ratio (SPR) for *P. stylifera* females ranged between 0.24 (2017) and 0.59 (2020). For the *P. stylifera* male, the values were recorded between 0.27 (2017) and 0.63 (2020) (Table 2; Fig. 3). The relative fishing mortalities (F/M) for female *P. stylifera* were above unity (1.40-2.36) during 2017-19, whereas during 2020 (0.53) and 2021 (0.95), they were below 1. The values of F/M for the males (0.31-1.13) were lower than for females. The F/M were much lower than unity during 2019-21 (Table 3; Fig. 3).

Solenocera crassicornis

The maximum F/M for female *S. crassicornis* was recorded in 2017 (1.57) which reduced to 1.07 in 2021. A similar trend was also evident in male *S. crassicornis* with maximum (1.15) and minimum (0.81) values recorded during 2017 and 2021 respectively (Table 3; Fig. 3). The SPR for *S. crassicornis* female ranged between 0.34 (2018) and 0.42 (2021). The SPR values for male *S. crassicornis*

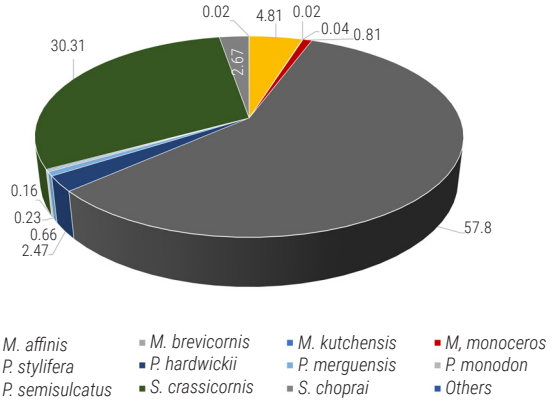

Fig. 2. Estimated catch composition of penaeid shrimps along the Gujarat coast during 2018-19 (pooled for two years) [based on commercial landings at major fishing harbours of Gujarat]

were similar to their female counterparts, with minimum (0.29) and maximum (0.39) values recorded during 2019 and 2021, respectively (Table 2; Fig. 3).

Metapenaeus spp.

M. affinis had the maximum recorded SPR of 0.48 and 0.46 during 2021 for females and males, respectively. The lowest recorded values were 0.30 (females) and 0.28 (males) during 2018. The highest fishing pressure (F/M) was recorded in 2017 (1.86) for females and in 2019 (1.94) for male *M. affinis*. The lowest value of 0.85 and 0.88 was recorded during 2019 for females and males, respectively (Tables 2, 3; Fig. 4).

Both *M. monoceros* females and males had the highest SPR of 0.49 and 0.41 respectively during 2019. The lowest SPRs for both males

Table 2. Estimated spawning potential ratio (SPR) for the selected shrimp fishery along the NW coast of India

Species (Sex)	2017	2018	2019	2020	2021
P. stylifera (F)	0.24 (0.18 - 0.29)	0.32 (0.25 - 0.39)	0.42 (0.33 - 0.51)	0.59 (0.46 - 0.73)	0.44 (0.35 - 0.52)
P. stylifera (M)	0.27 (0.21 - 0.33)	0.35 (0.23 - 0.46)	0.51 (0.33 - 0.68)	0.63 (0.38 - 0.88)	0.55 (0.39 - 0.71)
S. crassicornis (F)	0.38 (0.31 - 0.45)	0.34 (0.26 - 0.43)	0.35 (0.25 - 0.45)	0.37 (0.30 - 0.45)	0.42 (0.33 - 0.51)
S. crassicornis (M)	0.35 (0.28 - 0.43)	0.31 (0.18 - 0.43)	0.29 (0.21 - 0.38)	0.33 (0.21 - 0.45)	0.39 (0.28 - 0.50)
M. affinis (F)	0.36 (0.31 - 0.40)	0.47 (0.39 - 0.55)	0.30 (0.25 - 0.35)	0.38 (0.34 - 0.43)	0.48 (0.41 - 0.55)
M. affinis (M)	0.35 (0.31 - 0.40)	0.45 (0.37 - 0.52)	0.28 (0.23 - 0.33)	0.37 (0.32 - 0.42)	0.46 (0.38 - 0.53)
M. monoceros (F)	0.37 (0.32 - 0.41)	0.27 (0.21 - 0.33)	0.29 (0.25 - 0.32)	0.49 (0.39 - 0.60)	0.34 (0.29 - 0.40)
M. monoceros (M)	0.36 (0.31 - 0.42)	0.27 (0.20 - 0.34)	0.28 (0.24 - 0.33)	0.41 (0.31 - 0.51)	0.35 (0.29 - 0.41)

Table 3. Estimated relative fishing mortality (F/M) for the selected shrimp fishery along the NW coast of India

Species (Sex)	2017	2018	2019	2020	2021
P. stylifera (F)	2.36 (1.51 - 3.21)	2.03 (1.22 - 2.84)	1.40 (0.80 – 2.00)	0.53 (0.22 - 0.84)	0.95 (0.59 - 1.31)
P. stylifera (M)	1.13 (0.85 - 1.41)	1.04 (0.50 - 1.58)	0.62 (0.16 - 1.08)	0.31 (0.10 - 0.63)	0.42 (0.16 - 0.68)
S. crassicornis (F)	1.57 (1.06 - 2.08)	1.33 (0.79 - 1.87)	1.28 (0.68 - 1.88)	1.14 (0.76 - 1.52)	1.07 (0.63 - 1.51)
S. crassicornis (M)	1.15 (0.75 - 1.55)	1.01 (0.48 - 1.54)	1.08 (0.69 - 1.47)	1.00 (0.49 - 1.51)	0.81 (0.44 - 1.18)
M. affinis (F)	1.86 (1.45 - 2.27)	0.99 (0.65 - 1.33)	1.72 (1.29 - 2.15)	1.42 (1.09 - 1.75)	0.85 (0.59 - 1.11)
M. affinis (M)	1.67 (1.29 - 2.05)	1.02 (0.69 - 1.35)	1.94 (1.39 - 2.49)	1.45 (1.08 - 1.82)	0.88 (0.60 - 1.16)
M. monoceros (F)	1.09 (0.87 - 1.31)	2.45 (1.58 - 3.32)	1.49 (1.22 - 1.76)	0.62 (0.38 - 0.86)	1.31 (0.99 - 1.63)
M. monoceros (M)	1.09 (0.82 - 1.36)	2.37 (1.33 - 3.41)	1.39 (1.09 - 1.69)	0.81 (0.47 - 1.15)	1.20 (0.86 - 1.54)

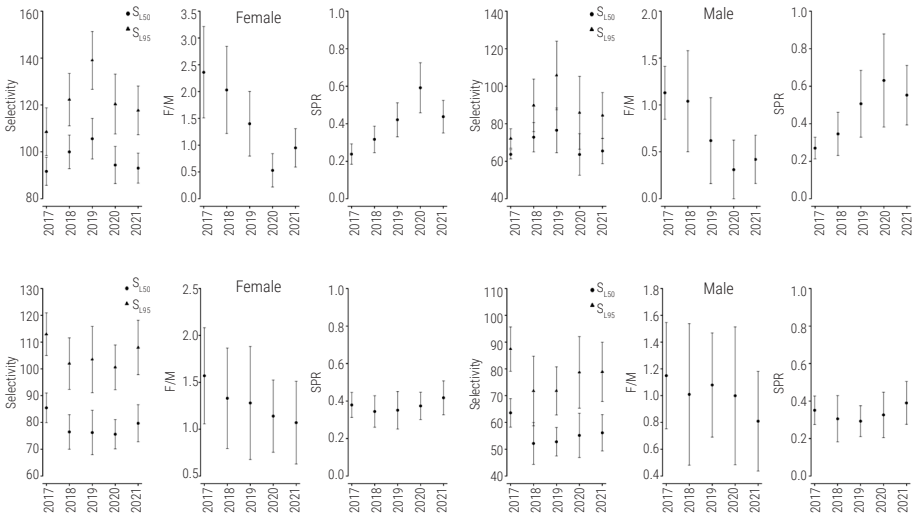

Fig. 3. Graphical output (2017-21) of LBSPR for *P. stylifera* and *S. crassicornis*

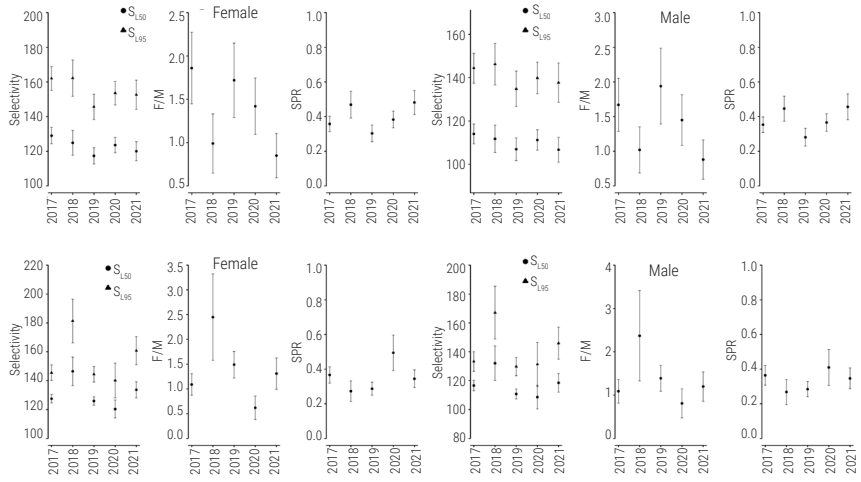

Fig. 4. Graphical output (2017-21) of LBSPR for *M. affinis* and *M. monoceros*

and females were observed during 2018, with a common value of 0.27. The relative fishing mortalities for *M. monoceros* were highest during 2018 (F/M > 2 for both males and females). The lowest estimated values of F/M for males (0.81) and females (0.62) were during 2020 (Table 2, 3; Fig. 4).

Discussion

North-west coast of India, characterised by wide continental shelves, is a rich fishing ground for shrimp resources. The region accounted for 27.79% (54,092 t) of the total penaeid shrimp landings of India (194,618 t) in 2019. Gujarat alone contributed 18.46% of the total national penaeid shrimp landings (CMFRI, 2019). The most abundant resources in the region are *Parapenaeopsis* spp., *Solenocera* spp., *Metapenaeus affinis* and *M. monoceros* (Ramamurthy, 1994). *P. stylifera* and *S. crassicornis* are the most dominant species under the respective genus and form the bulk of the fishery in the region (Fig. 2). Penaeid shrimps have high economic (Bondad-Reantaso, 2012) and ecological importance through prey-predator interactions (Mohamed *et al*., 2008; Vase *et al*., 2021) and need periodic assessment for sustainable management (Watson and Restrepo, 1995). However, several of the species with significant commercial landings have not been assessed in recent times from Indian waters in general and the NW coast of India in particular (Table 4). In addition, the prevalence of COVID-19 in 2020-21 has also impacted data collection for several months and limited the use of the traditional length-based stock assessment approach.

Nirmale *et al*. (2021) assessed the *P. stylifera* stock from different localities of Maharashtra along the NW coast of India using LF data collected during 2014-16 and estimated relative fishing mortalities in the range of (F/M = 0.85-2.03, Table 4), which is comparable to the estimates of F/M (1.04-2.36) in the initial period (2017 -18) of the present study (Table 2; Fig. 3). The catch trend of the genus

Table 4. Previous studies on growth and mortalities of selected penaeid shrimp species from Indian waters

Reference	Species (Sex)	Area	Study duration	L_{inf} (mm)	K (Yr^{-1})	F/M
Achuthankutty and Parulekar (1986)	*P. stylifera* (F)	Goa	1981-82	139.7	1.08	
	P. stylifera (M)	Goa	1981-82	99.2	2.38	
Alagaraja *et al*. (1986)	*P. stylifera* (F)	Kerala	1981-82	134	2.4	
	P. stylifera (M)	Kerala	1981-82	130	2.28	
Suseelan *et al*. (1989)	*P. stylifera* (F)	Kerala	1983-87	135	1.19	
	P. stylifera (M)	Kerala	1983-87	108	1.05	
Chakraborty *et al*. (1994)	*P. stylifera* (F)	Maharashtra	1987-91	140.8	2.15	1.13
	P. stylifera (M)	Maharashtra	1987-91	119.2	1.45	2.73
Sarada (2002)	*P. stylifera (*F)	Kerala	1987-92	132	2.28	
	P. stylifera (M)	Kerala	1987-92	111.8	2.48	
Dineshbabu (2005)	*P. stylifera* (F)	Gujarat	1995-2000	147-149	1.41-1.87	
	P. stylifera (M)	Gujarat	1995-2000	120-145	1.43-1.59	
Pillai *et al*. (2021)	*P. stylifera* (F)	Kerala	2011-19	131	1.10	2.57
	P. stylifera (M)	Kerala	2011-19	117	1.25	3.16
Nirmale *et al.,* 2021	*P. styifera* (M + F)	Maharashtra	2014-16	128-142	1.20-1.80	0.85-2.03
Chakraborty *et al*. (1994)	*S. crassicornis* (F)	Maharashtra	1987-91	139	2.00	2.01
	S. crassicornis (M)	Maharashtra	1987-91	92	1.50	1.13
Achuthankutty and Parulekar (1986)	*M. affinis* (F)	Goa	1981-82	202.6	0.89	
	M. affinis (M)	Goa	1981-82	156.8	1.73	
Chakraborty *et al*. (1994)	*M. affinis* (F)	Maharashtra	1987-91	188.8	1.47	1.62
	M. affinis (M)	Maharashtra	1987-91	151.5	1.50	0.65
Leena and Deshmukh (2009)	*M. affinis* (F)	Maharashtra	1999-2000	195.3-240.0	1.26-2.50	
	M. affinis (M)	Maharashtra	1999-2000	152.6-204.6	1.09-2.37	
Dash *et al*. (2018)	*M. affinis* (F)	Gujarat	2012-15	204.75	1.70	1.86
	M. affinis (M)	Gujarat	2012-15	185.5	1.90	1.59
Lalitha Devi (1987)	*M. monoceros* (F)	Andhra Pradesh	1980-82	216.2	0.99	1.98
	M. monoceros (M)	Andhra Pradesh	1980-82	208.4	0.97	3.40
George *et al*. (1988)	*M. monoceros* (F)	Karnataka	1980s	225	1.80	1.50
	M. monoceros (M)	Karnataka	1980s	190	1.88	5.67
Sukumaran *et al*. (1993)	*M. monoceros* (F)	Indian coast	1985-89	210	1.80	1.54-2.33
	M. monoceros (M)	Indian coast	1985-89	180	1.80	1.85-2.45
Chakraborty *et al*. (1994)	*M. monoceros* (F)	Maharashtra	1987-91	219.5	1.40	1.38
	M. monoceros (M)	Maharashtra	1987-91	180.5	1.35	1.32
Rao (1994)	*M. monoceros* (F)	Andhra Pradesh	1974-1977	207.3	1.62	0.79-1.56
	*M. monoceros (*M)	Andhra Pradesh	1974-1977	178.4	1.68	1.04-1.86
Nandakumar and Srinath (1999)	*M. monoceros* (F)	Kerala	1991-93	204	1.80	2.00
	M. monoceros (M)	Kerala	1991-93	170	1.50	2.29
Dineshbabu (2006)	*M. monoceros* (F)	Gujarat	1996-99	228	1.80	
	M. monoceros (M)	Gujarat	1996-99	184	2.00	

Parapenaeopsis along the Gujarat coast showed a declining trend since 2017 (Fig. 5). However, the present study showed an improving status of the stock during the same period. The decreasing catch, especially during 2017 -19, could hence be attributed to the diversion of fishing effort towards pelagic resources like ribbonfishes and cephalopods (Azeez *et al*., 2021; Rahangdale *et al*., 2022a, b)

The coastal mud shrimp, *S. crassicornis*, has an established fishery along the NW coast of India since long and bulk of the landings come from a depth of less than 40 m (Dineshbabu, 2003, 2013). The species is the second most dominant penaeid shrimp species (30.31%) in commercial catches of Gujarat (Fig. 2). Except for 2021 (female *S. crassicornis*), the SPR was below the TRP of 0.40, but never below the limit reference point of 0.20. Unlike *P. stylifera*, the SPRs are more or less uniform throughout the study period and are similar for both the sexes. Marginal improvements in SPRs were observed during 2020-21, which could be because of a reduction in fishing pressure due to COVID-19 restrictions. The estimated F/M was 0.81-1.57, mostly close to unity for most of the years, making them a fully exploited resource. No recent assessment of the species has been done from the study region. An estimate for the period 1987-91, from the Maharashtra coast (Chakraborty *et al*., 1994) categorised the resources as over-exploited (F/M = 1.13-2.01, Table 4). Trawl diversification in the region led to improvement in stock status.

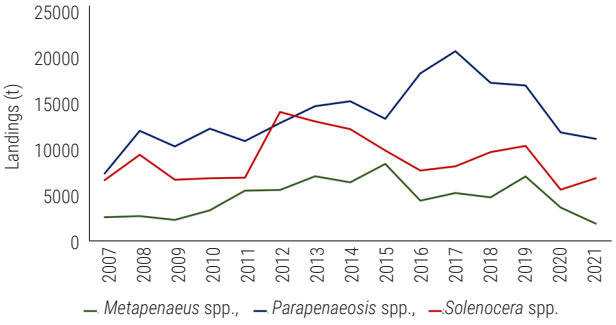

Fig. 5. Time series (2007-21) landings of selected penaeid resources along Gujarat coast [Source: NMFDC of ICAR-CMFRI]

Dash *et al*. (2018) based on the LF data curated during 2012-15, estimated the relative fishing mortality of 1.59 and 1.86 for male and female *M. affinis*, respectively. Even Chakraborty *et al*. (1994) estimated F/M much higher than unity (1.62) for female *M. affnis* from the Maharashtra coast. In the present study, barring the years 2018 and 2021, the estimated F/M was close to 1.5 (Table 3), which corroborates with earlier findings from the region. The F/M has reduced during 2020 and 2021 from the previous year (2019) which is similar to the observation in the other species. The SPR for the species was either close to 0.40 to above it except for the year 2019, when it was 0.30 for females and 0.28 for males (Table 2). Higher F/M and lower SPR in 2019 is concurrent with higher fishing intensity or landings of *Metapenaeus* spp. (Fig. 5). The SPR close to 0.40 despite higher relative fishing mortality (F/M > 1.5) over the years exemplifies the resilience of the resource towards fishing pressure owing to fast growth, multiple recruits per year and short generation time. The higher resilience of the species was also highlighted by the study conducted by Dash *et al*. (2018) along the Gujarat coast. Much wider variation in SPR was observed with *M. monoceros* (0.27-0.49) unlike its congeners *M. affinis*. The SPR of less than 0.30 was observed in 2018-19 which rose to over 0.40 in 2020 when fishing was largely restricted due to the pandemic. The decrease in SPR (0.34-0.35) was recorded in 2021 when fishing activities increased (Table 2). Chakraborty *et al*. (1994) estimated the F/M value of 1.38 and 1.32 for female and male *M. monoceros* during 1987-91 (Table 4). The present estimates of F/M show wider inter-annual fluctuations, ranging with values as high as 2.45 for female *M. monoceros* in 2019 to the lower figure of 0.62.

The current stock status (2021) for most of the resources is above the recommended TRP of 0.40, which is a good indication for the fishery in the region. In 2021, the SPR for *M. monoceros* was marginally below the recommended level, however, considering the high resilience of the species, the stock can be considered to be in a state of fair health.

Although significant variations in SPRs were observed for penaeid shrimp resources over the study period, the values generally remained close to the recommended TRP of 0.40 for most years. These resources are able to sustain higher fishing pressures (F/M > 1.0) owing to their inherent characteristics like fast growth, short generation time, and continuous recruitment. The observed declining trend in the landings is not attributed to resource depletion, but rather to the diversion of trawl ef forts towards pelagic and mid-water species. The reduced fishing pressure during the COVID-19 pandemic (2020-21), had a significant positive impact on stock health, as reflected in the elevated SPR value during those years. Overall, the current status of the stock in the region can be considered fair. The findings of the study can form the basis for scientific management of these resources in the region.

Acknowledgements

The work was supported by the institutional research contingency available to the ICAR-Central Marine Fisheries Research Institute, Kochi, India.

References

Achuthankutty, C. T. and Parulekar, A. H. 1986. Growth of Penaeid prawn in Goa waters. *Indian J. Geo-Mar. Sci.*, 15: 117-120.

Alagaraja, K., George, M. J., Kurup, N. K. and Suseelan, C. 1986. Yield per recruit analysis on *Parapenaopsis stylifera* and *Metapenaeus dobsoni* from Kerala state, India. *J. Appl. Ichthyol.*, 2 (1): 1–11. https://doi.org/10.1111/j.1439-0426.1986.tb00424.x.

Azeez, P. A., Rohit, P., Shenoy, L., Jaiswar, A. K., Raman, M., Koya, K. M., Vase, V. K. and Damodaran, D. 2021. Species composition and spatio-temporal variation of bycatch from mid-water trawlers operating in the Arabian Sea along north-west coast of India. *Reg. Stud. Mar. Sci.,* 43: 101692. https://doi.org/10.1016/j.rsma.2021.101692.

Bondad-Reantaso, M. G., Subasinghe, R. P., Josupeit, H., Cai, J. and Zhou, X. 2012. The role of crustacean fisheries and aquaculture in global food security: Past, present and future. *J. Invertebr. Pathol.*, 110(2): 158-165. https://doi.org/10.1016/j.jip.2012.03.010.

Chakraborty, S. K., Deshmukh, V. D., Khan, M. Z., Vidyasagar, K. and Raje, S. G. 1994. Estimates of growth, mortality, recruitment pattern and MSY of the important resources from the Maharashtra coast. *J. Indian Fish. Assoc.*, 24: 1-39.

CMFRI 2019. *Annual Report 2019.* ICAR-Central Marine Fisheries Reearch Institute, Kochi, India

Dash, G., Koya, M., Dash, S. S., Sreenath, K. R., Vase, V. K., Pradhan, R. K., Sukhadane, K. S., Divu, D., Solanki, V. and Maheswarudu, G. 2018. Fishery, population dynamics and stock status of Jinga shrimp, *Metapenaeus affinis* (Milne-Edwards, 1837) from Gujarat waters of India. *Indian J. Geo-Mar. Sci.*, 47(11): 2267-2277.

Devi, L. S. 1987. Growth and population dynamics of three penaeid prawns in the trawling grounds off Kakinada. *Indian J. Fish.*, 34(2): 245-264.

Dineshbabu, A. P. 2003. Fishery and some biological aspects of penaeid shrimps along Saurashtra region. *J. Mar. Biol. Ass. India,* 45(2)*:* 195-207.

Dineshbabu, A. P. 2005. Growth of kiddy shrimp, *Parapenaeopsis stylifera* (H. Milne Edwards, 1837) along Saurashtra coast. *Indian J. Fish.*, 52(2): 165-170.

Dineshbabu, A. P. 2006. Length-weight relationship and growth of the speckled shrimp *etapenaeus monoceros* (Fabricus) off Saurashtra. *J. Mar. Biol.l Ass. India*, 48(2): 180-184.

Dineshbabu, A. P. 2013. *Solenocera*. In: *Taxonomy and identification of commercially important crustaceans of India*. ICAR-Central Marine Fisheries Research Institute, Kerala, India.

Faruque, B. M. and Ramachandran, K. V. 2014. The continental shelf of western India. *Geol. Soc. Lond. Mem.*, 41(1): 213-220. https://doi.org/10.1144/M41.15.

George, M. J., Alagaraja, K., Sukumaarn, K. K., Nandakumar, G., Ramamurthy, S. and Telang, K. Y. 1988. The present staus of shrimp trrawling and itss impact on the shrimp stoks of Karnataka coast. In: *Proceedings of the Seminar on Problems and prospects of marine fishing and fish processing in Karnataka.* 19-20 June 1986, College of Fisheries, Mangalore, India.

Hordyk, A., Ono, K., Prince, J. D. and Walters, C. J. 2016. A simple length-structured model based on life history ratios and incorporating size-dependent selectivity: Application to spawning potential ratios for data-poor stocks. *Can. J. Fish. Aquat. Sci.*, 13: 1-13. https://doi.org/10.1139/cjfas-2015-0422.

Hordyk, A., Ono, K., Valencia, S., Loneragan, N. and Prince, J. 2015a. A novel length-based empirical estimation method of spawning potential ratio (SPR), and tests of its performance, for small-scale, data-poor fisheries. *ICES J. Mar. Sci.*, 72(1): 217-231. https://doi.org/10.1093/icesjms/fsu004.

Hordyk, A. R., Ono, K., Sainsbury, K. J., Loneragan, N. and Prince, J. D. 2015b. Some explorations of the life history ratios to describe length composition, spawning-per-recruit, and the spawning potential ratio. *ICES J. Mar. Sci.*, 72: 204-216. https://doi.org/10.1093/icesjms/fst235.

Lalitha Devi, S. 1987. Growth and population dynamics of three penaeid prawns in the trawling grounds off Kakinada. *Indian J. Fish.*, 34(2): 245-264.

Leena, K. and Deshmukh, V. D. 2009. Age and growth of Jhinga prawn *Metapenaeus affinis* Edwards (Decapoda, Penaeidae) in Mumbai waters. *Indian J. Fish.*, 56(1): 1-5.

Madhupratap, M., Nair, K. N. V., Gopalakrishnan, T. C., Haridas, P., Nair, K. K. C., Venugopal, P. and Gauns, M. 2001. Arabian Sea oceanography and fisheries of the west coast of India. *Curr. Sci.*, 81(4): 355-361.

Mohamed, K. S., Zacharia, P. U., Muthiah, C., Abdurahiman, K. P. and Nayak, T. H. 2008. Trophic modelling of the Arabian Sea ecosystem off Karnataka and simulation of fishery yields. *CMFRI Bulletin Vol. 51.* ICAR-Central Marine Fisheries Research Institute,Kochi, India, 140 p.

Mora, P., Figueroa-Muñoz, G., Cubillos, L. A. and Strange-Olate, P. 2022. A data-limited approach to determine the status of the artisanal fishery of sea silverside in southern Chile. *Mar. Fish. Sci*., 35(2): 287-306. https://doi.org/10.47193/mafis.3522022010508.

Nandakumar, G. and Srinath, M. 1999. Stock assessment of *Metapenaeus monoceros* (Fabricus) from Cochin waters, Kerala. *Indian J. Fish.*, 46(3): 221-226.

Nandakumar, G. and Maheswarudu, G. 2013. Penaeid shimps. In: Joseph, M. M. and Jayaprakash, A. A. (Eds.), *Status of exploited marine fishery resources of India*. ICAR-Central Marine Fisheries Research Institute, Kochi, India.

Nirmale, V. H., Metar, S. Y., Chogale, N. D., Pawar, R. A., Sawant, B. T., Gitte, M. J., Meshram, S. J., Sadawarte, R. K., Bondre, R. B. and Yadav, B. M. 2021. Growth and mortality of Kiddy shrimp, *Parapenaeopsis stylifera* (H. Milne Edwards, 1837) along the coast of Maharashtra. *Reg. Stud. Mar. Sci.*, 48: 102030. https://doi.org/10.1016/j.rsma.2021.102030.

Nugroho, D., Patria, M. P., Supriatna, J. and Adrianto, L. 2017. The estimates spawning potential ratio of three dominant demersal fish species landed in Tegal, north coast of Central Java, Indonesia. *Biodiversitas*, 18(2): 844-849. https://doi.org/10.13057/biodiv/d180258.

Palomares, M. L., Froese, R., Derrick, B., Nöel, S. L., Tsui, G., Woroniak, J. and Pauly, D. 2018. A preliminary global assessment of the status of exploited marine fish and invertebrate populations. *A report prepared by the Sea Around Us for OCEANA,* The University of British Columbia, Vancouver, Canada.

Pillai, S. L., Maheswarudu, G., Baby, P. K., Radhakrishnan, M., Ragesh, N. and Sreesanth, L. 2021. Using length data to derive biological reference points for kiddi shrimp *Parapenaeopsis stylifera* (Milne Edwards, 1837) from the south-eastern Arabian Sea, India. *Aquat. Living Resour.*, 34: 8. https://doi.org/10.1051/alr/2021003.

Prince, J., Creech, S., Madduppa, H. and Hordyk, A. 2020. Length based assessment of spawning potential ratio in data-poor fisheries for blue swimming crab (*Portunus* spp.) in Sri Lanka and Indonesia: Implications for sustainable management. *Reg. Stud. Mar. Sci.*, 36: 101309. https://doi.org/10.1016/j.rsma.2020.101309.

Rahangdale, S., Kumar, R., Vase, V. and Zacharia, P. U. 2022a. Estimation of maximum sustainable yield for lesser sciaenids fishery of North-Eastern Arabian Sea using Surplus Production Model with environmental effects. *J. Ichthyol.*, 62(4): 632-640. https://doi.org/10.1134/S0032945222040208.

Rahangdale, S., Zacharia, P. U., Kumar, R. and Vase, V. 2022b. Evaluating the stock status of 10 croaker species landed along the north-eastern Arabian Sea using the length-based Bayesian biomass approach. *Front. Mar. Sci.*, 9: 952795. https://doi.org/10.3389/fmars.2022.952795.

Ramamurthy, S. 1994. Penaeid prawn fisheries of the northwest coast of India. *J. Mar. Biol. Ass. India*, 36(1&2): 205-215.

Rao, G. S. 1994. Mortality rates and stock assessment of *Metapenaeus monoceros* along Kakinada coast. *J. Mar. Biol. Ass. India,* 36(1&2): 1-18.

Sarada, P. T. 2002. Fishery, biology and population dynamis of *Parapenaeopsis stylifera* at Calicut. *Indian J. Fish.*, 49(4): 351-360.

Sarada, P. T., Maheswarudu, G., Dineshbabu, A. P., Lakshmi, P. S., Saleela, K. N., Chakraborty, R. D., Dash, G., Divipala, I., Rajkumar, M., Kumar, R., Ratheesh, K. R., Josileen, J. and Laxmilatha, P. 2020. Pesent status and trend of marine prawn fishery in India. In: *Book of Abstracts, Marine Ecosystems Challlenges and Ortunities (MECOS 2).* Marine Biological Association of India, Kochi, India.

Solanki, H. U., Bhatpuria, D. and Chauhan, P. 2017. Applications of generalised additive model (GAM) to satellite-derived variables and fishery data for prediction of fishery resources distributions in the Arabian Sea. *Geocarto Int*., 32(1): 30-43. https://doi.org/10.1080/10106049.2015.1120357.

Sukumaran, K. K., Deshmukh, V. D., Rao, G. S., Alagaraja, K. and Sathianandan, T. V. 1993. Stock assessment of penaeid prawn *Metapenaeus monoceros* Fabricus along Indian coast. *Indian J. Fish.*, 40(1&2), 20-34.

Suseelan, C,, Rajan, K, N,, and Nandakumar, G. 1989. The Karikkadi fishery of Kerala. *Mar. Fish. Info. Serv. T & E Ser.*, 102: 4-8.

Tosunoglu, Z., Senbahar, A. and Demirel, N. 2022. Length based assessments for European Pilchard *Sardina pilchardus* and European Anchovy *Engraulis encrasicolus*, in the İzmir Bay, Aegean Sea. *Turkish J. Fish. Aquat. Sci.*, 23 (SI): TRJFAS21901. https://doi.org/10.4194/TRJFAS21901.

Vase, V. K., Koya, M. K., Dash, G., Dash, S., Sreenath, K. R., Divu, D., Kumar, R., Rahangdale, S., Pradhan, R. K., Azeez, A. and Sukhdhane, K. S. 2021. *Acetes* as a keystone species in the fishery and trophic ecosystem along north-eastern Arabian Sea. *Thalassas*, 37(1): 367-377. https://doi.org/10.1007/s41208-020-00276-y.

Watson, R. A. and Restrepo, V. R. 1995. Evaluating closed season options with simulation for a tropical shrimp fishery. In: *ICES Mar. Sci. Symp.,* 199: 391-398.