Turk. J. Fish.& Aquat. Sci. 23(SI), TRJFAS22189
https://doi.org/10.4194/TRJFAS22189

Turkish Journal of FISHERIES and AQUATIC SCIENCES

RESEARCH PAPER

Assessing Low Value Crustacean Bycatch Species Using Length Based Bayesian Biomass (LBB) Method, a Tool for Data Poor Fish Stock Assessment

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How to cite

Kumar, R., Dineshbabu A.P., Rahanglade, R., Vase, V.K., Gohel, J., Solanki, V. (2023). Assessing Low Value Crustacean Bycatch Species Using Length Based Bayesian Biomass (LBB) Method, a Tool for Data Poor Fish Stock Assessment. *Turkish Journal of Fisheries and Aquatic Sciences*, *23(SI)*, *TRJFAS22189.* https://doi.org/10.4194/TRJFAS22189

Article History
Received 05 July 2022
Accepted 29 November 2022
First Online 23 December 2022

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Keywords
Arabian Sea
Sustainability
Trawl fishery
LBB
Bycatch

Abstract

The majority of tropical fish stocks lack sufficient data for conventional fish stock assessment, making them data-poor fisheries. The status of stock assessment is even more dismal for the low value fishes or crustaceans landed by the trawlers in a significant quantity. Crustaceans like non-edible small crabs (*Charybdis* spp) and stomatopods form a significant component of the low-value bycatch landed along the northwest coast. Despite the high ecological importance of these groups and the recent declining trend in catches (2007-19), no attempts so far have been made to evaluate the stock status of these groups from the study region. As reliable time series catch and effort data for the individual species are not available, a recently developed length-based approach, LBB (Length Based Bayesian Biomass) estimation method is adopted for the present study. Two of the evaluated stocks, *Charybdis hoplites* and *Miyakella nepa* were found abundant (B/B_{MSY}>1.1), whereas *Oratosquillina interrupta* (B/B_{MSY}=0.94) was found slightly overfished. The sufficient number of larger individuals were found lacking in all three species (L_{95th}/L_{∞}<<1.0). A higher incidence of juveniles in catches was estimated for *C. hoplites* and *O. interrupta* (L_{mean}/L_{opt}<<1.0).

Introduction

The bulk of the global fish stocks lack formal reference limits for harvest management (Froese et al., 2012) as they lack sufficient data to be incorporated into conventional stock assessment models to arrive at stock status. In developing countries, it is believed that only 5-10% fall in to the category of having sufficient data for conventional assessment (Costello et al., 2012). Of late, legal frameworks in several parts of the world like the USA, Australia, New Zealand and the European Union (Froese et al., 2017) and increasing consumer demand for sustainably managed seafood (McClenachan et al., 2016) necessitates more and more stocks to be assessed, which also includes non-commercial but ecologically important resources having significant bearing the overall sustainability of marine fisheries (Baran, 2002; Link, 2007). Several methods have been developed to address the issue of the assessment of data-limited fishery. A comprehensive review of data-limited methods along with proposal of new approaches has been presented by Carruthers et al. (2014). A more recent review (ICES, 2014; Rosenberg et al., 2014) has found the approach proposed by Martell and Froese (2013) promising to overcome the bottlenecks in the assessment of data-poor fisheries, especially in tropical waters. Further, Froese et al. (2017) improved upon the method proposed by Martell and Froese (2013)

Published by Central Fisheries Research Institute (SUMAE) Trabzon, Türkiye

addressing some of the lacunae in the previous approach. CMSY (Monte Carlo method) and BSM (Bayesian state-space implementation of the Schaefer production model) since their inception (Froese et al., 2017) gained wide popularity and applied to several fisheries (e.g., Ji et al., 2019; Liang et al., 2020; Zhai et al., 2020; Nisar et al., 2021; Barman et al., 2022). However, this method also has limited application, especially in the tropical continental ecosystem, where time series catch data segregated up to individual species are lacking in most of the multi-species complexes. Another important data most often believed to be available is the effort spent in hours of fishing or number of units operated. Catch and effort together provide the proxy for the abundance of the resource used in surplus production models. However, quantifying effort in a multi-gear scenario with varying catchability poses a challenge to arrive at representative effort indices. Several statistical manipulations have been proposed to arrive at standardized effort (Maunder and Starr, 2003; Stamatopoulos and Abdallah, 2015; Varghese et al., 2020), but to quantify the time series effort when a single gear itself undergoes diversification as happening with the trawl fishery of India. The trawl operation can have subcomponents like pelagic trawling, column trawling, and bottom trawling (Azeez et al. 2021), each having a drastically different catchability for a given resource. The lack of time series data on effort spent by these sub-components of trawl makes effort data non-reliable for its incorporation in surplus production models, including BSM. The inability of catch and abundances based methods (Martell and Froese, 2013; Carruthers et al. 2014; Froese et al., 2017) to address the assessment needs of all the data limited fishes, has led to the development of length-based methods. The two most popular length based methods for data-limited fisheries are Length based spawning potential ratio (LB-SPR) and Length Based Bayesian Biomass estimation (LBB) method (Hordyk et al., 2015; Froese et al., 2018). The former requires life history traits (e.g. information from maturity ogive) in addition to the representative length frequency (LF) from the population. The latter is even simpler in data requirement as requires only LF (one or more year). However, it needs priors which can be calculated from input LF or can be manually provided, if robust informations are available. The LBB for its simple data requirement, even for a shorter study duration, makes it suitable for data deficient fisheries where reliable catch and effort data are not available. Also, in the case of species having lower commercial values (low-value bycatch species), these methods could provide viable means for evaluating their status. Owing it its flexibility and very simple data requirement, the method has gained popularity among fishery researches or organizations dealing with fish stock assessment (e.g., Wang et al., 2020; Zang et al., 2020; Kindong et al., 2020; Al-Mamun et al., 2021; Raza et al., 2021, Rahangdale et al., 2022a).

Crustaceans, especially the non-edible crabs (*Charybdis* spp) and stomatopods, are key ecological species landed in significant quantity along the Indian coast by the trawlers as a low-value bycatch (LVB) or trash (Sukumaran, 1988; Dineshbabu et al., 2012; Pillai et al., 2014; Dineshbabu et al., 2018, Kumar et al., 2019). Smaller demersal crabs are known to be the major diet component of several demersal fishery resources (Philip, 1998; Xue et al., 2005; Abdurahiman et al., 2010). The most important demersal crab in terms of its ubiquitous distribution along the eastern Arabian Sea is *Charybis hoplites* (Wood-Mason, 1877) (Dineshbabu et al., 2018). Further, it is also the major crab species featuring in the bycatch landings of the trawlers along the Indian coast (Dineshbabu et al., 2012; Pillai et al., 2014). Despite its high ecological importance and significant fishing mortality (bycatch and discards), no attempt to date has been made to assess its stock status.

Stomatopods are specialized marine crustaceans broadly categorized in to two groups, smashers and spearers (Ahyong, 2001). The latter, owing to their less aggressive nature, are known to form large aggregation (Caldwell and Dingle, 1975) and are among the most abundant crustaceans in the tropical continental ecosystem, regularly featuring the landings of bottom trawlers (Antony et al., 2010). The trawlers operating along the Indian coast are known to land large quantities of stomatopods and a significant quantity also goes as discards, especially the ones caught by multi-day trawlers (Menon, 1996; Dineshbabu et al., 2012). Several studies on the diversity and distribution of stomatopods have been carried out (e.g., Manning, 1995; Ahyong, 2001, 2002, 2004; Ahyong and Kumar, 2018), but the studies on population dynamics (e.g. Abello and Martin, 1993; James and Thirumilu 1993; Kaiser et al., 2021) are limited and on stock status are almost absent.

The north-west (NW) coast of India, along the northeastern Arabian Sea, is known for the rich fishing ground for predatory demersal resources. The sustained productivity of the northern Arabian Sea throughout the year has ensured the availability of demersal resources in the region for commercial harvest (Parulekar et al., 1982). The geo-morphology-induced high productivity in the region coupled with easy access to rich fishing grounds owing to wide continental shelves (shallow depth over an extensive area) has permitted the rapid development of trawl fisheries in the region since its introduction in the 1960s. The development at a rapid pace raised fears about the sustainability of the trawl fisheries of the state and the region is currently having the issue of overcapacity (Pravin et al., 1999). Sathianandan et al. (2021) found that the North West Coast (NW) of India is the most exploited coastal zone along the Indian coast, with 54.2% of assessed stocks falling into the 'overexploited' category. This can be attributed to the largest trawl fleet (43%) along the entire Indian coastline (CMFRI, FSI and DoF, 2020), which also means higher landings of the bycatch components. The present study focuses on the low-value bycatch crustacean species with significant landings along the NW coast of India for stock status evaluation. The LBB approach was adopted for the present study for the lack of reliable and species-specific time series catch and effort data, which is not the constraint for the selected method (Froese et al., 2018).

Materials and Methods

Study Area

The study area comprises of the coastal waters of Gujarat and Maharashtra located along the northeastern Arabian Sea. The two maritime states of the country has a combined coastline of 2320 km and has the widest shelf area along the entire Indian coastline (Figure 1). The two major fishing harbour Veraval (070^{0}22’52.03’’ E; 20^{0}54’19.23’’ N) and Mangrol (070^{0}06’3.12’’ E; 21^{0}06’27.60’’ N) fishing harbour of Gujarat were selected for the collection of the data.

Data Collection

The length frequency data (LF) used for the present study were collected from commercial trawlers operated from the selected fishing harbour. The fishing operation was restricted to the depth range of 20-100 m. The three crustacean species viz. *Charybdis hoplites* (Wood-Mason, 1877), *Miyakella nepa* (Latreille, 1828), and *Oratosquillina interrupta* (Kemp, 1911) were found to have a significant contribution towards the low-value catch landings of the trawl operation and are included in the present assessment. The carapace width (CW) was recorded for the crab (*C. hoplites*) and total length (TL) for stomatopods (*M. nepa* and *O. interrupta*). All the primary data were collected in a participatory mode with fishers and lengths were recorded before the sorting of the data to ensure that the LF reflects the original population structure of the stocks.

Data Analysis Framework

Two of the recently developed and widely adopted approaches for the assessment of data-limited fishers are CMSY (Froese et al., 2017) and Length based Bayesian biomass estimation (LBB) approach (Froese et al., 2018). The former method requires time series catch and reliance as input to arrive at stock status. However, in tropical continental fishers as in the present case, the catch data segregated up to individual species over a longer temporal scale are rarely available. The presence of similar-looking congeners in multi-species fisheries makes the species-specific catch enumeration by field surveyors a challenging task. Hence, the CMSY approach probably could be applied in several fisheries of the region, owing to lack of suitable data. LBB provides an alternate analytical framework to access data-limited (or data-poor) fisheries using length-frequency data (either single year or time series) as input. It applies a Bayesian Monte Carlo Markov Chain (MCMC) routine to estimate indicators of stock status (Froese et al., 2018). The method requires a set of priors for asymptotic length (L_∞), length at first capture (L_C), and relative natural mortality (M/K). The method gives users the option to opt for the default prior or to provide a robust

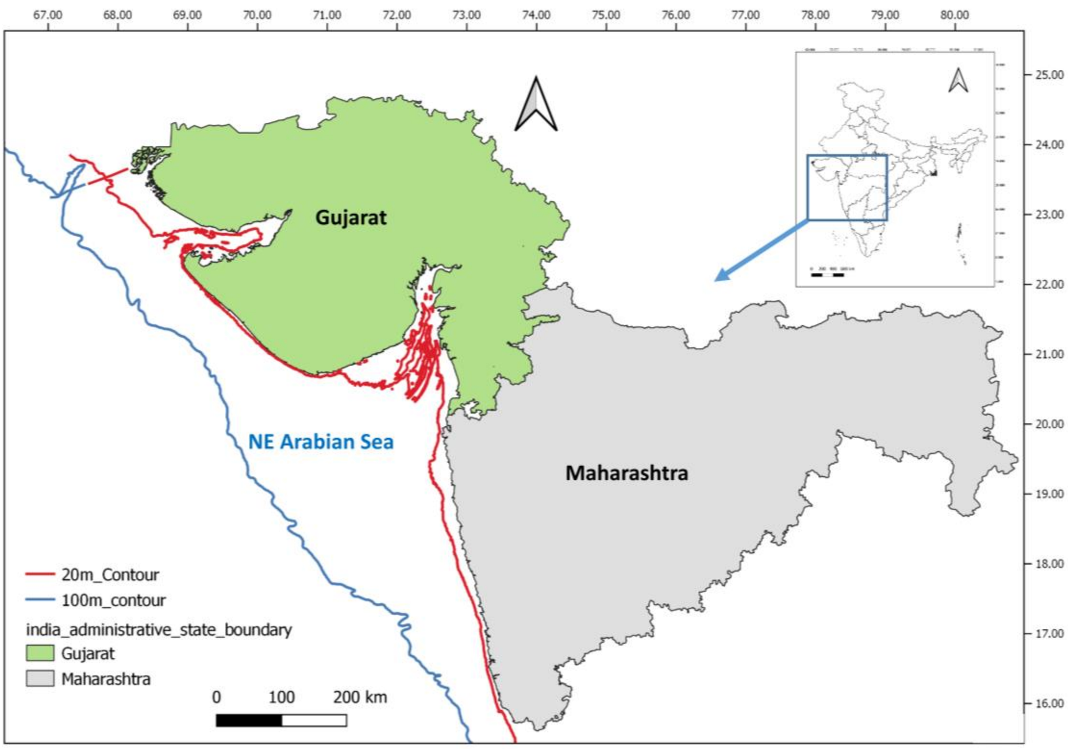

Figure 1. The study area comprising of the coastal waters of Gujarat and Maharashtra, the two maritime state (~ provinces) of India along NE Arabian Sea.

estimate of priors for a local study, in case they are available. For the present study, default priors (Table 1) were opted, as they were found suitable for the species under investigation. The details of the LBB method are elaborately illustrated in Froese et al. (2018). However, some of the key equations used in this method are detailed here.

LBB can be applied to length frequency (LF) data of aquatic fishes or invertebrates, provided the growth in length follows von Bertalanffy growth function (von Bertalanffy, 1938; Beverton and Holt, 1957) as:

$$L_t = L_\infty\left[1 - e^{-K(t-t_0)}\right]$$

where L_t is the length at age t, L_∞ denotes asymptotic length, K is the growth coefficient (per year) and t_0 is the theoretical age at zero length. LBB depends on the catch curve to arrive at growth, mortality, and selectivity attributes. The selectivity follows trawl type selection given by:

$$S_L = \frac{1}{\left[1 - e^{-\alpha(L-L_c)}\right]}$$

where S_L indicates the proportion of individuals of length L retained by the gear and α (alpha) is the steepness of the selection ogive. The relative fishing mortality, F/M, an indicator of fishing pressure, is estimated as a product of F/K and M/K estimated by LBB. The length of the fish corresponding to the maximum biomass of the cohort (L_{opt}) and the mean length at first capture, which maximizes catch and biomass (L_{c_opt}) can be estimated with prior estimates of L_∞, M/K, and F/K.

$$L_{opt} = L_\infty\left(\frac{3}{3+\frac{M}{K}}\right)$$

$$L_{c\_opt} = \frac{L_\infty\left(2+3\frac{F}{M}\right)}{\left(1+\frac{F}{M}\right)\left(3+\frac{M}{K}\right)}$$

The yield per recruit (Y'/R) and catch per unit effort per recruit ($CPUE'/R$) (Beverton and Holt, 1966) can be calculated once the estimates of L_c/L_{inf}, F/K, M/K, and F/M are available (Froese et al., 2018). The CPUE is known to be proportional to the biomass of the exploited portion of the population.

$$\frac{CPUE'}{R} = \frac{Y'/R}{F/M} = \frac{1}{1+F/M}\left(1-\frac{L_c}{L_\infty}\right)^{\frac{M}{K}}\left(1 - \frac{3\left(1-L_c/L_\infty\right)}{1+\frac{1}{M/K}} + \frac{3\left(1-L_c/L_\infty\right)^2}{1+\frac{2}{M/K}} - \frac{3\left(1-L_c/L_\infty\right)^3}{1+\frac{3}{M/K}}\right)$$

The relative biomass in the exploited phase of the population, baring the fishing activities (F=0) can be calculated as:

$$\frac{B'_0>L_c}{R} = \left(1-\frac{L_c}{L_\infty}\right)^{\frac{M}{K}}\left(1 - \frac{3\left(1-L_c/L_\infty\right)}{1+\frac{1}{M/K}} + \frac{3\left(1-L_c/L_\infty\right)^2}{1+\frac{2}{M/K}} - \frac{3\left(1-L_c/L_\infty\right)^3}{1+\frac{3}{M/K}}\right)$$

Where $B'_0>L_c$ represents the exploitable fraction ($>L_c$) of unfished biomass (B_0). The index for the relative biomass depletion for the exploited portion of the population (B/B_0) can be estimated as per Beverton and Holt (1966) using the function:

$$\frac{B}{B_0} = \frac{CPUE'/R}{\frac{B'_0>L_c}{R}}$$

A proxy for relative biomass at maximum sustainable yield (B_{MSY}/B_0) can be obtained by fixing parameters $F/M=1$ and $L_c=L_{c\_opt}$ and recalculating expression for Y'/R, $CPUE/R'$, $B'_0>L_c$ $/R$, and B/B_0 (equation 5 to 7). Subsequently, the current relative stock size (B/B_{MSY}) can also be estimated as a ratio of B/B_0 and B_{MSY}/B0, which indicates the stock status (Healthy- $B/B_{MSY}>1.1$; slightly overfished/ fully exploited- $0.8<B/B_{MSY}>1.1$; overfished- $0.5<B/B_{MSY}>0.8$; grossly overfished-$0.2<B/B_{MSY}>0.5$; collapsed- $B/B_{MSY}<0.2$) according to Palomares et al. (2018) and Amorim et al. (2019). The analysis presented here was done using R code (LBB_33a. R), available at http://oceanrep.geomar.de/44832/.

Table 1. Details of primary data and priors used for LBB estimation of the low-value crustacean landed by trawlers operated along NE Arabian Sea.

Species	*C. hoplites*	*M. nepa*	*O. interrupta*
Length range (mm)	13-66 (DW)	41-122 (TL)	42-173 (TL)
Length class interval (mm)	4	5	10
L_∞ (mm)	7.13	14	19.5
M/K	1.5	1.5	1.5
Z/K	2	2.6	2.5
F/K	0.49	1.13	1.04
L_C	2.45	6.88	7.14
Alpha	15.9	16.3	18.9

Results

Charybdis hoplites

C. hoplites is a small-sized non-edible crustacean having an estimated asymptotic length (L_∞) of 7.22 cm CW (Table 2 and Figure 2A). The current biomass was estimated at 45% of the virgin biomass (B/B_0=0.45). The species is currently assessed as healthy or abundant indicated by B/B_{MSY} values of 1.2 (>1.1) and F/M of 0.54 (<<1.0). However, the length-structure of the catch shows a truncated length structure with a higher abundance of juveniles in catches (L_{mean}/L_{opt} and L_C/L_{opt}<<1.0) (Table 2). Though the size range recorded in the present study was between 13 and 66 cm CW, the bulk of the landings (~ 80%) was between 20-44 mm CW (Table 1). Further, a sufficient number of larger individuals in the population is also lacking, as indicated by $L95^{th}/L_\infty$ (=0.89) of less than unity.

Miyakella nepa

M. nepa has been recorded in the size range of 41-122 mm TL (Table 1) and has an estimated asymptotic length of 14.2 cm TL (Table 2 and Figure 2B). The currently estimated biomass was 52% of the virgin biomass (B/B_0=0.52). The stock was found abundant o as B/B_{MSY} (1.50) was higher than 1.10. Also, the relative fishing mortality (F/M=0.53) was much lower than the unity, further emphasizing the healthy status of the stock. The L_{mean}/L_{opt} (0.98) and L_C/L_{opt} (1.10) values were very close to the unity. However, L_{95th}/L_∞ (0.85) was

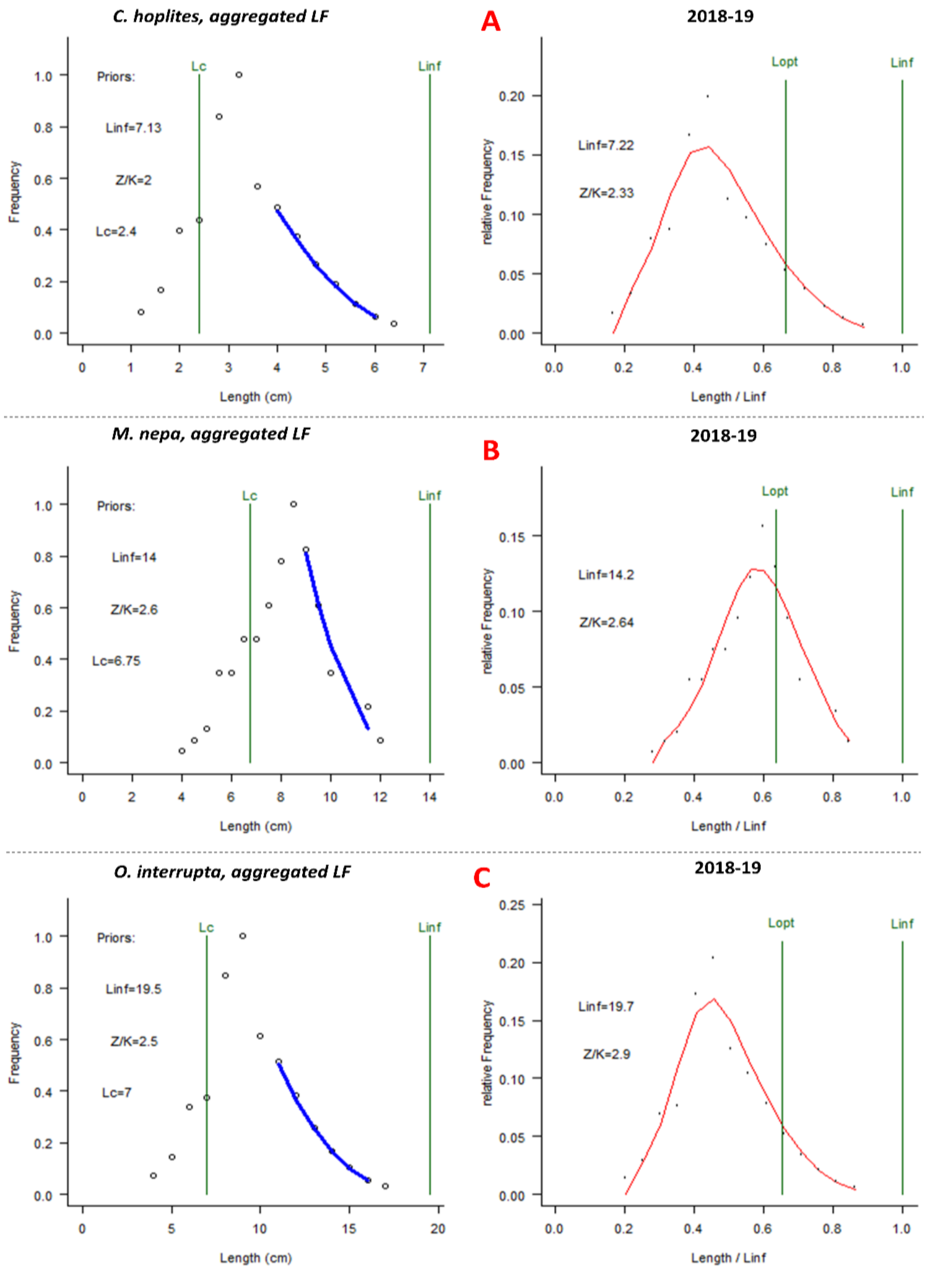

Figure 2. Graphical output LBB analysis of the three species: 2A - *Charybdis hoplites*; 2B – *Miyakella nepa*; 2C – *Oratosquillina interrupta*.

found to be significantly lower than 1 (Table 2), showing a lack of sufficient number of larger individuals in the population.

Oratosquillina interrupta

O. interrupta, a relatively larger stomatopod recorded in the size range of 42-173 mm TL (Table 1) and has theoretical maximum attainable size (L_∞) of 19.7 mm TL (Table 2 and Figure 2C). The stock is characterized as fully exploited (B/B_{MSY}=0.94; F/M=0.83). The indicators of length structure indicates the truncated length structure with higher proportion of smaller specimens (L_{mean}/L_{opt}=0.80; L_C/L_{opt}=0.68) and lack of sufficient number of larger specimens (L_{95th}/L_∞=0.86). The current biomass is estimated around 34% of the virgin biomass (Table 2).

Discussion

Tropical fisheries characterized by multi-species nature have been advocated to be managed through the Ecosystem-based fisheries management (EBFM) approach (Vivekanandan et al., 2003). The approach requires information not only on commercially important fish stocks but also on the ecologically important organism, which play a vital role in the trophic functioning of the marine ecosystem (Dineshbabu et al., 2018). Crustacean owing to their high α-diversity and biomass in the tropical continental shelf ecosystem plays a vital role in prey-predator interaction. Several studies along the eastern Arabian Sea have highlighted the importance of crustaceans in the diet of the commercial fishery resources and hence link the sustainability of the commercial fish stocks to the healthy biomass of crustaceans' prey, which includes low-value crustaceans like small non-edible crabs and stomatopods (Suseelan and Nair, 1969; Thangavelu et al., 2012, Mohamed, 2004; Mohamed and Zacharia, 2009; Vase et al., 2021). Abdurahiman et al. (2010) in thier feeding ecology study along the Arabian Sea, found crabs and stomatopods as a key diet component of demersal predator fish species.

The crab landings of Gujarat over the period of 2007-19 showed a gradual decline with the highest recorded during 2008 (26283 t) and lowest during 2019 (7501 t) (Figure 3). The Catch composition of crab landings of Gujarat during 2019 showed that *Charybdis* spp (multi-species low-value bycatch component) forms the major component, which includes non-edible crabs or juveniles of commercially important crabs. *Charybdis hoplites* were found to be the most dominant component of the multi-species *Charybdis* spp complex (Figure 4). The other species include *C. callianasa, C. omanensis, C. smithii, C. lucifera, C. helleri*, etc. The multi-day trawlers accounted for over 75% of the total crab landings of Gujarat. Dineshbabu et al. (2018) also found *C. hoplites* to be the most dominant component

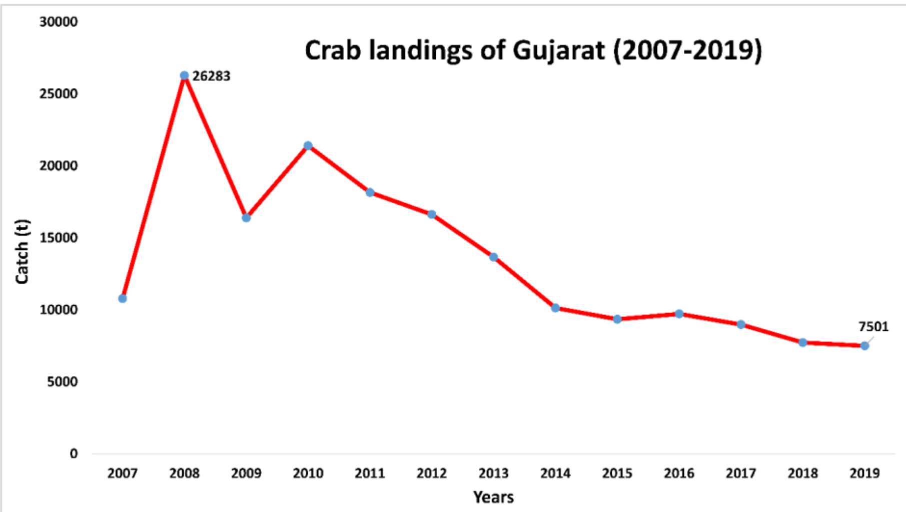

Figure 3. Time series catch data of crabs landed along Gujarat coast during 2007-19 [Source: NMFDC of ICAR-CMFRI].

Table 2. Stock status of three major bycatch crustacean species landed along NE Arabian Sea based on LBB estimation approach.

Species	*C. hoplites*	*M. nepa*	*O. interrupta*
B/B_{MSY}	1.2	1.5	0.94
B/B_0	0.45	0.52	0.34
F/M	0.54	0.53	0.83
F/K	0.82	0.92	1.3
Z/K	2.4	2.6	2.9
L_{mean}/L_{opt}	0.75	0.98	0.8
L_C/L_{opt}	0.62	1.1	0.68
L_{95th}/L_∞	0.89	0.85	0.86
L_∞	7.22	14.2	19.7
Remarks	Healthy/Abundant	Healthy/Abundant	Fully exploited/ slightly overfished

of the non-edible crabs along the Arabian Sea. They also presented the Spatio-temporal distribution of the species and concluded that, this species shows uniform abundance both in space and time, unlike *C. smithii* which has restricted spatio-temporal availability. The declining catch over the last decade (Figure 3) or so has raised questions over the sustainability of the crab resource in general and non-edible component as particular as no assessment has been made for this bycatch component of trawl landings from the study region. Sathianandan et al. (2021) based on time series catch and effort data categorized the crab fishery (as the entire group) of the region as over-exploited. However, the present study revealed that the stock of *C. hoplites* along NE Arabian was healthy or abundant (B/B_{MSY}=1.20) against the hypothesis of declining (or overfished) status indicated by a drastic drop in landings. The two possible reasons which can be attributed to the decline in landings of crabs over the years, despite the healthy stock abundance, are the increasing duration of fishing voyages and the diversion of trawl effort towards pelagic trawling. The studies conducted by Dineshbabu et al. (2012) found *Charybdis* spp (non-edible) to have high discard rates in multi-day trawlers operated along the eastern Arabian Sea. Continuous Increase in duration of fishing by multi-day trawlers over the last decade has led to more quantum of discards than landings of these low-valued bycatch components as retaining these low-value components (non-edible crabs) over a longer period on-board is not perceived economical by the fishers. Another major shift observed in the trawl fishery of the study region is the

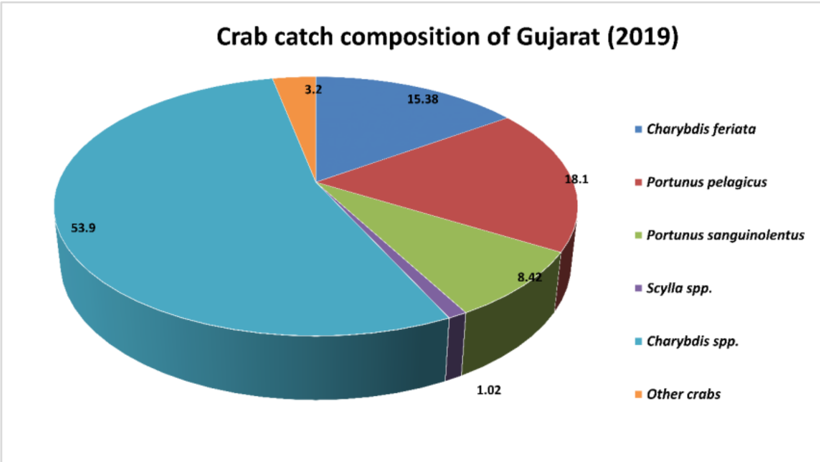

Figure 4. Catch composition of crab landings of Gujarat in 2019 [Source: NMFDC of ICAR-CMFRI].

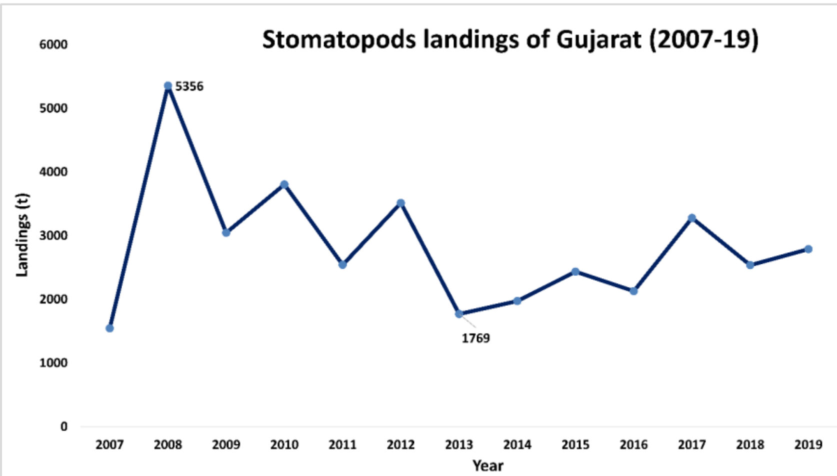

Figure 5. Time series catch data of stomatopods landed along Gujarat coast during 2007-19 [Source: NMFDC of ICAR-CMFRI].

Table 3. Top five fishery resources landed by single day trawlers (MTN) operated along NW coast of India in terms of catch rates in 2019 [Source: NMFDC of ICAR-CMFRI]

Resource	Catch rates (kgs/hrs)
Non-penaeid prawns	105.17
Ribbonfishes	9.74
Croakers	7.79
Penaeid prawns	7.39
Stomatopods	3.47

increasing dominance of pelagic or column trawling for ribbonfishes and cephalopods. Almost 40-45% of the total trawl effort in recent years is towards pelagic trawling for ribbonfishes (Azeez et al., 2021; Rahangdale et al., 2022b) and a fair share must be going towards cephalopod trawling owing to its increasing export demand. This development has led to the marginalization of the bottom trawling, which forms the major means of crustacean harvest. Among non-edible crabs species of the genus *Charybdis*, *C. hoplites* is known to have a benthic preference (Turkay and Spiridonov, 2006), unlike *C. smithii* which forms pelagic or semi-pelagic aggregations (Dineshbabu et al., 2018). Though the stock was found healthy, an excessive harvest of smaller individuals was evident as L_{mean}/L_{opt} (0.75) and L_C/L_{opt} (0.62) were much lower than unity. The pre-dominance of juvenile of *C. hoplites* in commercial landings was also reported by Pillai et al. (2014) trawl fishery of Chennai along the Bay of Bengal coast. They reported a size range of 20-48 mm for the species, which is narrower than our observation, but the bulk of the landings (80%) in the current study were also is a smaller size range of 20-44 mm CW.

Stomatopods are another group of crustaceans which are ubiquitously distributed in the tropical marine ecosystem, have high ecological importance and forms significant component of bottom trawl harvest (Caldwell et al., 1989, Mohamed, 2004; Antony et al., 2010). Several species of stomatopods in different parts of the world forms seafood of high commercial importance (Abello and Martin, 1993; Arshad et al., 2015; Kaiser et al., 2021). However, along the Indian coast, they historically form one of the major components of single-day bottom trawl landings and discard from multi-day trawlers (Kurup et al., 1987; Sukumaran, 1988; James and Thirumilu, 1993, Menon et al., 1996; Dineshbabu et al., 2012; Kumar et al., 2019). The stomatopods landings of Gujarat have a declining trend during 2008-13. However, a gradual increase in landings since 2013 is evident in the catch trend (Figure 5). The gear contributing to the stomatopod fishery of Gujarat are multi-day trawlers (MDTN, 45.70%), mechanized dolnetters (MDOL, 38.86%) and single day trawlers (MTN, 15.44%). It is worth mentioning here that the effort spent by MTN in hours is only 1.2% of MDTN and 5.4% of trawlers. Despite the low share in total effort

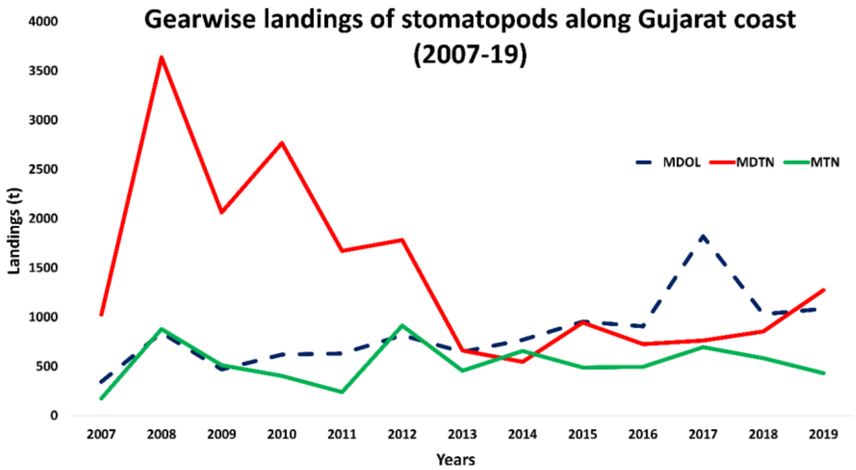

Figure 6. Gearwise landings of stomatopods along Gujarat coast during 2007-19 (MDOL- mechanized dolnets; MDTN – multi-day trawlers; MTN – single day trawlers) [Source: NMFDC of ICAR-CMFRI].

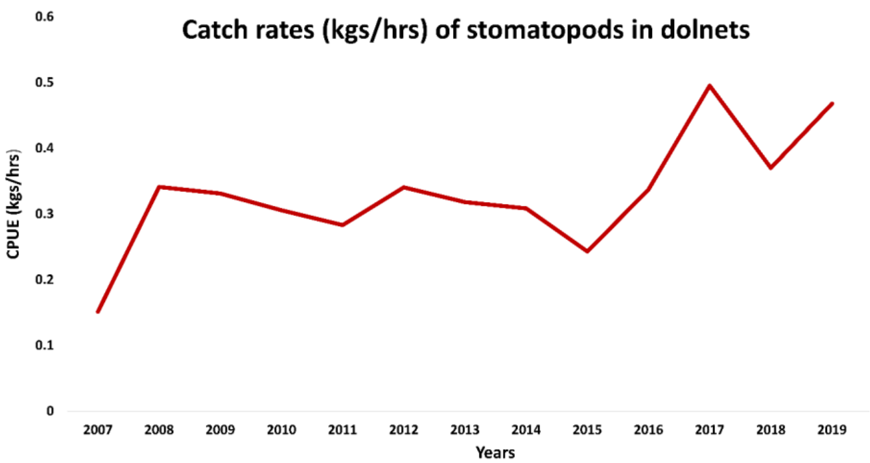

Figure 7. Time series (2007-19) catch per unit effort realized for stomatopods in mechanized dolnets of Gujarat [Source: NMFDC of ICAR-CMFRI].

spent, the contribution of MTN to stomatopod landings (15.44%) is very high. Stomatopod forms one of the major components of single-day trawl landings taking the 5th position in terms of realized catch rates (kgs/hrs) during 2019 (Table 3). Three species were recorded in the commercial catches viz. *Miyakella nepa*, *Oratosquillina nepa*, and *Harpiosquilla harpax. M. nepa* was the most dominant species in commercial catches (70%), followed by *O. interrupta* (22%) and *H. haprax* (8%). Former two species are assessed in the present study and they presented contrasting stock statuses. *M. nepa*, the most common species along the Indian coast (James and Thirimilu, 1993; Pillai et al., 2014; Kumar et al., 2019) found fairly abundant (B/B_{MSY}=1.5) with existing fishing effort well below the optimum (F/M=0.53). The existing relative biomass (B/B_0=0.52) was also found above the threshold level of 0.40 (Froese et al., 2018). The size range observed in the present study (41-122 mm TL) was wider than what was observed from the Chennai coast (48-115 mm TL, Pillai et al., 2014). Unlike *C. hoplites*, excessive fishing pressure on juveniles was not evident, which is also a good sign for *M. nepa* stock. On the contrary, *O. interrupta* stock was found to be in the category of fully exploited or slightly over-fished (B/B_{MSY}=0.94). The existing relative fishing mortality (F/M=0.83) is also in the proximity of unity. The size structure of the catch is also skewed with a higher incidence of juveniles (L_{mean}/L_{opt} and L_C/L_{opt}<1). The present level of biomass (B/B0=0.34) was also found below the recommended level of 0.40 (Froese et al., 2018), which significantly compromises the resilience of the stock. The general decline in the stomatopod landings (2008-2013) can be attributed to the reasons like increasing discards and marginalization of bottom trawling by multi-day trawlers leading to the lower landings of stomatopods by MDTN, whereas the declining trend in not evident in MTN and MDOL stomatopod catches (Figure 6) Catch per unit effort from trawlers may not be indicative of the abundance of stomatopods, as efforts are increasingly spent towards pelagic realm, which is not the natural habitats of stomatopods. However, the time series of catch rates (CPUE) from the dolnets can be considered as proxy for the abundance of stomatopods in the fishing ground, as these fishing methods have undergone minimal changes in modes operandi. The CPUE over 2008-2013 (Figure 7), showed no signs of decline, conflicting with the trend presented in the total stomatopod landings (Figure 5). However, in recent years, there is an increasing demand for stomatopods from the animal feed industry. The landings from MDOL have increased (by reducing the discard component) in response to increasing demand, leading to higher landings of this resource in recent years. Another major unknown in the case of these crustacean stocks is the quantum of onboard discard, especially from the multi-day trawlers and their post-release fate. However, Jayasankar (2006) has demonstrated that stomatopods show higher survival among discarded organisms from the trawls, which could potentially be the reason for the stock to survive the wrath of the largest trawl fleet of India (Gujarat alone accounts for 1/3rd of total trawl operated along Indian coast) (CMFRI, FSI and DoF, 2020).

The presence of a sufficient number of larger individuals in the population provides resilience to the stocks against higher fishing pressure and bestows a buffer against environmental fluctuations (Xu et al., 2013; Le Bris et al., 2015). For all the three evaluated stocks, there seems a lack of a sufficient number of larger individuals (L_{95th}/L_∞<<1.0), which do not present a healthy sign for long-term sustainability when climate change in the Arabian Sea is real and a force to reckon with (Piontkovski and Al-Oufi, 2015). Link (2007) opined that several non-commercial species can be "Keystone species" in an ecosystem and declining stock status of these groups can lead to irreversible damage to the entire ecosystem. Heavy exploitation of these groups undermining their scientific management may have a detrimental impact on the productivity of an otherwise rich continental shelf ecosystem (Baran, 2002). Hence, periodic monitoring and assessment of these ecologically important organisms landed in significant quantity are recommended to ensure the long-term sustainability of the marine fishiness of the NE Arabian Sea.

Conclusion

The present study is the first attempt in the Indian context and among a few global attempts to evaluate the stock status of non-edible portunid crab and stomatopods. The tropical multi-gear and multi-species fisheries are often considered data-poor. The data became even scarcer when we think of low-value bycatch (LVB) components. The catch data for the LVB component are seldom segregated up to species level, making species-specific assessment using conventional methods almost impossible. The present study applied an LBB approach which uses only LF data as input, which can be collected with a fair degree of accuracy. The present estimate found *C. hoplites* and *M. nepa* in a state of abundance, whereas *O. interrupta* was found fully exploited. Although *M. nepa* stock is abundant, escalating the fishing pressure towards this resource is not-recommended as similar species (*O. interrupta) having* common fishing ground and mostly similar catchability falls under the category of fully exploited. Any increase in an effort towards the harvest of *M. nepa* could potentially endanger the sustainability *O. interrupta* and hence a "status quo" is recommended as far as stomatopod fishery is concerned. Allowing a sufficient number of larger specimens in the population is also recommended, which can be achieved by returning larger specimens (terminal length groups) back to the sea. This measure would not be an economic compromise as there does not exist any price preference for a larger specimen. A better utilization scheme must be formulated for these species, especially stomatopods, which already are prized seafood commodities in various parts of the world. The present study advocates periodic assessment of these species of high ecological importance and develops a specific data collection framework to assure the availability of quality data for scientific evaluation.

Ethical Statement

The study does not involve any live animals and human subjects and ethical statements are not applicable.

Funding Information

The work is supported by the institutional research contingency available to the Indian Council of Agricultural Research-Central Marine Fisheries Research Institute, Kochi, India.

Author Contribution

First Author: Conceptualization, Data Curation, Formal Analysis, Methodology, Writing - original draft; Second Author: Conceptualization, Formal Analysis, Methodology, Writing -review and editing; Third and Fourth Author: Formal Analysis, Methodology Writing - review and editing; and Fifth and Sixth Author: Data Curation, Formal Analysis.

Conflict of Interest

The authors declare that they have no known competing financial or non-financial, professional, or personal conflicts that could have appeared to influence the work reported in this paper.

Acknowledgements

The authors express their gratitude to the Dr. A. Gopalakrishnan, Director, ICAR-CMFRI, Kochi and Dr. Divu D., Scientist-In-Charge, Veraval Regional Station of ICAR-CMFRI for providing all the facilities for carrying out this work. The authors are also thankful to NMFDC of ICAR-CMFRI for catch data required to conclude the study. We are also grateful to all the fishers of Gujarat for allowing us to take length frequency from commercial catches.

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