Evaluating the stock status of 10 croaker species landed along the north-eastern Arabian Sea using the length-based Bayesian biomass approach

Shikha Rahangdale [1,2]*, Pariyappanal Ulahannan Zacharia[1], Rajan Kumar[1] and Vinayakumar Vase[1]

[1]Indian Council of Agricultural Research, Central Marine Fisheries Research Institute, Kerala, Kochi, India, [2]Department of Biosciences, Mangalore University, Mangalagangotri, Karnataka, Mangalore, India

India accounts for nearly 60% of the croakers caught in the Indian Ocean. The north-west (NW) coast of India is the most productive fishing ground for croakers and contributes almost half of the nation's croaker catch. Lesser sciaenids (small- and medium-sized croakers) are the multi-species complex landed by commercial trawlers along the NW coast of India. Despite several notable changes in the fishing pattern in the region, such as the emergence of multi-day fishing and increasing dominance of pelagic trawling, there is no recent assessment of this major demersal fishery group. The present study evaluates the stock status of 10 species of lesser sciaenids forming the commercial fishery in the region using length frequency data collected during 2020−2021. The assessment was made using the length-based Bayesian biomass (LBB) estimation method. The indicators of relative biomass (B/B_0 and B/B_{MSY}) showed that most of the species (seven) are fully exploited, whereas two and one species were found under- and over-exploited, respectively. Excessive juveniles (L_{mean}/L_{opt} and $L_c/L_{c\_opt} < 0.90$) in catches were observed in the case of *Paranibea semiluctuosa*. A sufficient number of larger individuals ($L_{95th}/L_{inf} < 0.90$) in the population were lacking in the case of *Johnius belangerii* and *Otoithes ruber*. However, the study indicated a gradual improvement in stock status for most of the species over previous estimates, which can be attributed to the diversion of trawl fishing efforts towards the pelagic realm.

Introduction

Croakers or sciaenids (family Sciaenidae) are one of the major coastal fishery resources of the tropical and temperate waters (Liting et al., 2022). Furthermore, it is one of the most diverse perciform families in terms of the number of species and distribution. Sciaenids are globally represented by 66 genera and 286 valid species (Froese and Pauly, 2022). Indian waters also have a high α-diversity of sciaenids, with 48 reported species, out of which 34 are considered commercially important (Lal Mohan, 1991). Globally, the croaker fishery has seen a steady rise in commercial landings from approximately 0.25 million metric tons (mmt) in 1950 to over 1.5 mmt during 2003–2018 (www. fao.org/fishery/en/statistics/global-capture-production/query/ en). India is a major marine fishing nation in the Indian Ocean and accounts for 60% of the croaker catches in the Indian Ocean and approximately 10% of the global harvest in 2015–2019 (www.cmfri.org.in/fish-catch-estimates). Many sciaenid stocks across the globe are showing signs of decline. A global assessment, as per the 2001 IUCN Red List criteria, reports 5.6% of these species as threatened and 1.4% as near threatened. The global assessment of species known to form the commercial fishery along the Indian coast shows unknown population status, barring *Protonibea diacanthus* and *Otolithoides biauritus*, for which the populations are known to be declining (Liting et al., 2022; www.redlist.org).

The north-west coast of India forms the most productive sciaenid fishing ground along the Indian coast, contributing over 50% to the total sciaenid landings of the country (www.cmfri. org.in/fish-catch-estimates). Biologically, Indian sciaenid species can be broadly classified into two groups, *viz.*, larger sciaenids and lesser sciaenids (small and medium sized). Two species of large sciaenids along the Indian coast, namely, *Protonibea diacanthus* and *Otolithoides biauritus*, grow to a large size measuring up to 150 cm or more. The lesser sciaenids belonging to the genus *Pennahia*, *Otolithes*, *Nibea*, *Paranibea*, *Atrobucca*, and *Johnius* grow commonly up to a size of 30–60 cm and form a cheap source of protein to the poorer section of the coastal community.

Population dynamics and stock assessment studies play a pivotal role in the formulation of sustainable harvesting strategies for the species. The lesser sciaenids in the study region are mostly landed as a multi-species complex by the trawl fleet of the region, which poses a challenge for the fishery enumerators to record species-specific catch and effort details required for the regular assessment using conventional stock assessment models. Despite the bottleneck in data collection, several studies were carried out in population dynamics and stock assessment of commercially important species of sciaenids from the region (Chakraborty, 1987; Chakraborty, 1993; Chakraborty, 1994; Chakraborty, 1996a; Chakraborty, 1996b; Chakraborty, 1997; Chakraborty et al., 2000; Chakraborty, 2006; Telvekar et al., 2007; Ghosh et al., 2010; Tarkeshwar et al., 2014).

All the above assessments were based on species-specific length frequency (LF) as input and found the stocks either in the state of being fully exploited or over-exploited, but the assessment periods were at least a decade ago and in most cases over two decades ago. Recently, Vase et al. (2019) assessed croakers from Gujarat using the surplus production model with catch and effort for all the species pooled together (croakers as a single group) as input data, undermining species diversity and varying life history traits among different species, especially the larger sciaenids and lesser sciaenids.

The emergence of multi-day trawl fisheries and shifts in species preferences were witnessed along the Indian coast, more so along the NW coast in the last one and half decades, where pelagic trawling emerged as the major component of trawl fishing (Azeez et al., 2021). The changing dynamics of the trawl fishery in the region, especially the change in effective effort spent towards demersal resources, further emphasizes the need for a reassessment of different species under this major demersal fish group.

Several methods have been developed in recent years to cater to the need of data-poor fisheries. One of the popular methods is catch-based CMSY and BSM methods proposed by Froese et al. (2017), which showed wider adoption in tropical fisheries (e.g., Barman et al., 2022). However, for several fisheries that include bycatch species or multi-species fisheries like croakers, the catch and effort estimates for individual species are either absent or not reliable enough. For such fisheries, length-based methods were found more applicable, as LF can be collected fairly accurately. The most popular methods in this category are length-based spawning potential ratio (LB-SPR) (Hordyk et al., 2015) and length-based biomass (LBB) estimation method (Froese et al., 2018). However, the former method needs parameters of the maturity ogive (L_{m50} and L_{m95}) as an input besides LF data. Owing to minimal and simple data requirements, LBB has emerged as a powerful tool for stock status estimation of tropical data-deficient fisheries (e.g., Zhang et al., 2020; Barman et al., 2021; Wang et al., 2021; Raza et al., 2022). In the present study, we opted for the LBB, as reliable estimates for the parameters of the maturity curve were not available for all the species.

Materials and methods

The north-west coast of India, along the north-eastern Arabian Sea, encompasses two maritime states (= provinces), namely, Gujarat and Maharashtra, and has a combined coastline of 2,320 km (Figure 1). The length frequency data analyzed in this study were collected during January 2020 to December 2021 from the commercial trawlers operated from Veraval (070°C 22′52.03″ E; 20°C 54′ 19.23″ N) and Mangrol (070°C 06′ 3.12″ E; 21°C 06′ 27.60″ N) fish landing centers in a participatory mode. The participatory approach to data collection refers to the use of commercial fishing vessels where fishers voluntarily provide
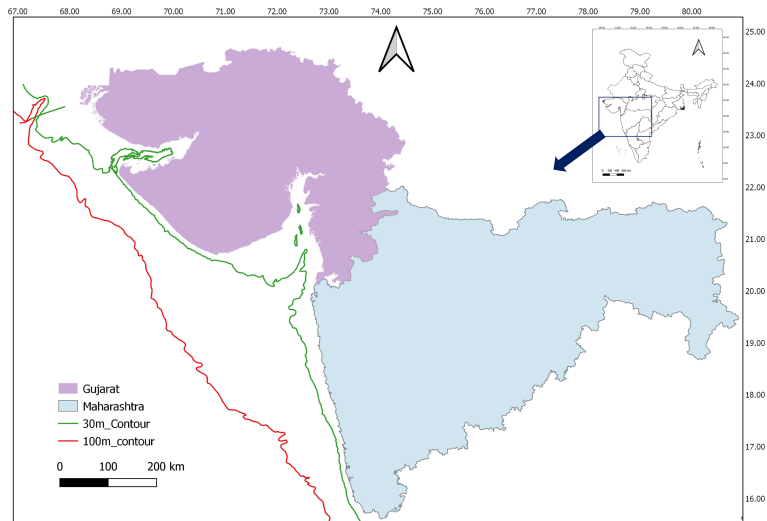
FIGURE 1
The details of the study area and extent of trawling grounds (between 30 and 100 m depth contour).

access to the catch after hauling for collecting scientific data. The LF data were collected monthly from the trawlers except for the ban season (June and July in both years) and during the closure due to coronavirus disease 2019 (COVID-19) (April–May 2020). All the sciaenid specimens caught in a given haul is measured for LF data collection. However, it is worth mentioning that all species are not recorded in all the sampled months. The trawlers were operated in the coastal waters off Gujarat and Maharashtra coast in the depth range of 30–100 m (Figure 1). The length data were collected prior to the sorting of catch of the selected species to ensure that the length composition data are a representative of the catch. Ten croaker species, namely, *Paranibea semiluctuosa* (Cuvier, 1830), *Pennahia anea* (Bloch, 1793), *Johnius belangerii* (Cuvier, 1830), *Johnius macrorhynus* (Lal Mohan, 1976), *Johnius glaucus* (Day, 1876), *Johnius dussumieri* (Cuvier, 1830), *Johnius borneensis* (Bleeker, 1851), *Otolithes ruber* (Bloch & Schneider, 1801), *Otolithes cuvieri* Trewaves, 1974, and *Atrobucca alcocki* Talwar, 1980 comprises most of lesser sciaenid fishery of the region. Furthermore, these species have a sufficient number of specimens over the wider length range in observed samples and hence are selected for the present assessment. For all the specimens, total lengths (TLs) were recorded for incorporation in the length-based Bayesian biomass (LBB) estimation method.

LBB is a recently developed approach to access data-limited (data-poor) fisheries, which uses length frequency data (either single year or time series) as input and applies a Bayesian Monte Carlo Markov Chain (MCMC) method to estimate indicators of stock status (Froese et al., 2018). The method uses a pre-specified set of priors, but users can manually incorporate priors for asymptotic length (L_{inf}), length at first capture (L_c), and relative

natural mortality (M/K) from local studies. The L_{inf} priors were estimated from the median maximum length rather than the absolute maximum length. The M/K prior is set as 1.5, and L_c is estimated from the catch curve generated from the input LF data. However, for the present studies, default priors were used, as they broadly corroborate with the earlier estimates from the region (Supplementary Tables S1, S2). The details of the LBB method and underpinned formulas are given in Froese et al. (2018). Even so, some of the key assumptions of this method are detailed here. A major assumption of the LBB method is that the size progression in the species was as per von Bertalanffy's growth function (von Bertalanffy, 1938; Beverton and Holt, 1957). von Bertalanffy's growth function has been criticized for its application in the case of invertebrates and large-bodied organisms like marine mammals and elasmobranchs. However, its applicability in teleosts as in the present case is fairly acceptable (Hernandez-Llamas and Ratkowsky, 2004; Liu et al., 2021). The function is given by

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

where L_t is the length at age t, L_{inf} denotes the asymptotic length, K is the growth coefficient (per year), and t_0 is the age at zero length. Another major assumption of the method relevant to the present study is regarding gear selectivity, which is of trawl type. Due care has been taken to meet the assumption by restricting the LF data collection using a conventional trawl net. The selectivity function is:

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

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. Relative biomass at maximum sustainable yield (B_{MSY}/B_0) and relative fishing mortality (F/M) are the major stock status indicators estimated using this method. The stock is under-exploited if $B/B_{MSY} > 1.2$, fully exploited if $0.8 \leq B/B_{MSY} \geq 1.2$, and over-exploited where $B/B_{MSY} < 0.8$. The over-exploited stocks have relative fishing mortality (F/M) of over 1.2. The fully exploited and under-exploited stocks have F/M values of 0.8–1.2 and <0.8,

respectively (Palomares et al., 2018; Amorim et al., 2019). The ideal value of L_{mean}/L_{opt} and L_c/L_{c_opt} should be unity. The significant prevalence of excessive juvenile fishing or growth overfishing is indicated by L_{mean}/L_{opt} and L_c/L_{c_opt} values of < 0.9. The presence of large-sized specimens in the population is known to provide resilience to the stock, which is indicated by the value of L_{95th}/L_{inf}. The value of L_{95th}/L_{inf} lower than 0.9 is an indicator of a lesser number of larger individuals in the population. The LBB analysis with single-year data gives two graphical outputs (Figure 2).

FIGURE 2
Graphical output **(A–J)** of the LBB method for the length-frequency data of the 10 studied sciaenid species landed along the NW coast of India.
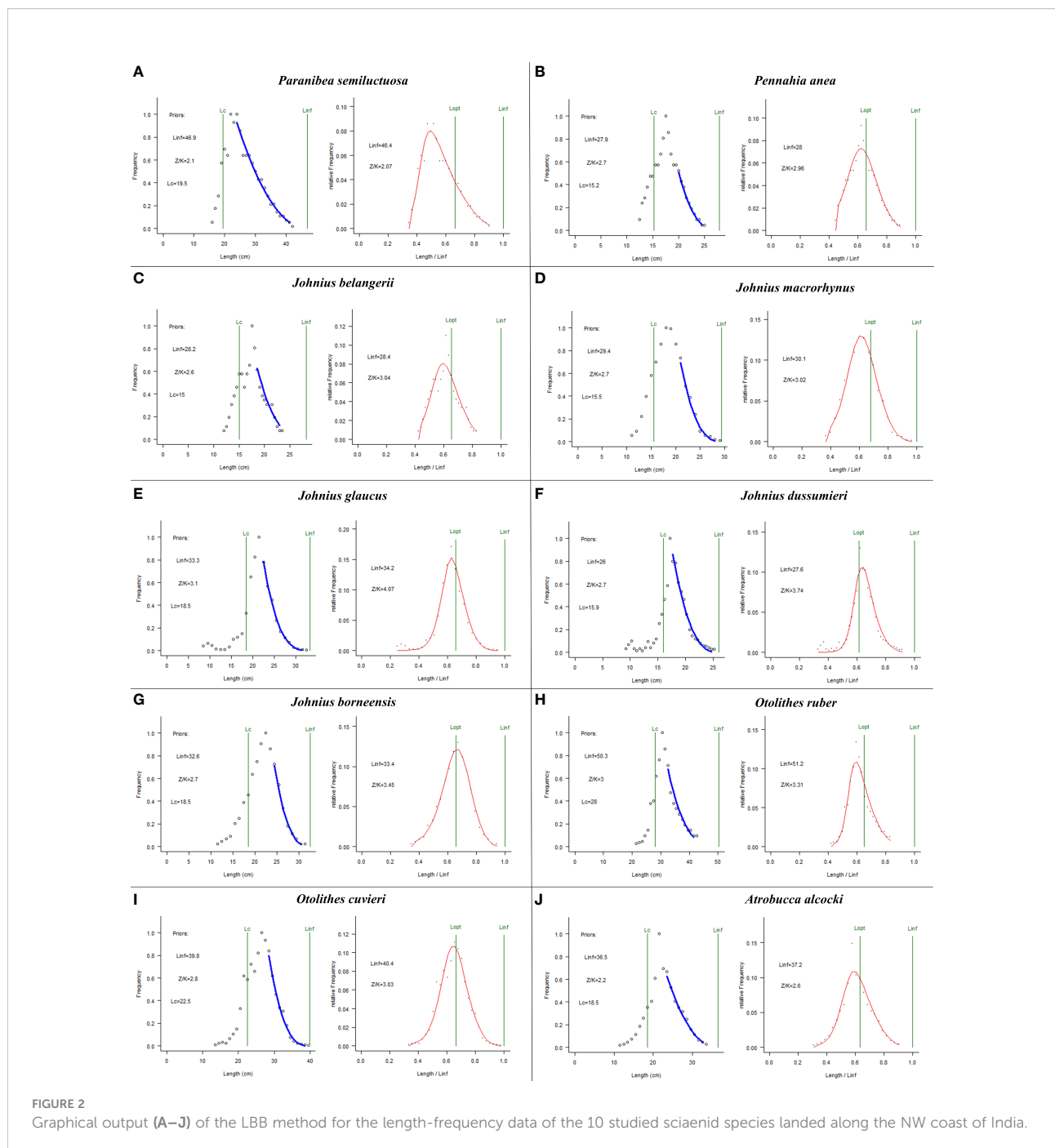
The left one shows the aggregated LF data and the defaults prior used in the study, whereas the right one shows the LF data for the estimated year with estimates of L_{inf}, Z/K, and L_{opt}. All the analysis presented here was done using R code (LBB_33a. R), downloaded from http://oceanrep.geomar.de/44832/ following the guidelines provided in the new user guide of the code.

Results

The present study evaluates the stock status of 10 commercially important croaker species landed along the north-west coast of India (Table 1). The output of the LBB analysis shows a reasonable fit for the length frequency (LF) data of these 10 species (Figure 2; Supplementary Tables S1, S2). Values for B/B_0 ranged from 0.27 to 0.59, whereas the B/B_{MSY} ranged from 0.74 to 1.60. F/M and F/K ranged from 0.30 to 1.60 and 0.56 to 2.50, respectively. The detailed results of the analysis were grouped by genus and are presented below.

Genus *Paranibea*

The fishery in the region is by the single species, *P. semiluctuosa*. The stock is categorized as under-exploited (F/M = 0.37, B/B_0 = 1.60, and B/B_{MSY} = 0.59). However, the L_{mean}/L_{opt} and L_c/L_{c_opt} were below unity (<0.90), indicative of truncated length structure and higher fishing pressure on juveniles than optimum. The L_{95th}/L_{inf} was estimated at 0.90 (<1.0), indicating a lower number of larger individuals in the population (Figure 2A, Table 2).

Genus *Pennahia*

Pennahia anea is the only species under the genus that supports commercial fishery in the region. The stock falls in the category of being fully exploited (F/M = 0.89, B/B_0 = 0.41, and B/B_{MSY} = 1.10). The values for L_{mean}/L_{opt} and L_c/L_{c_opt} were either equal to unity or above it, which shows no excess fishing pressure on juveniles. However, the L_{95th}/L_{inf} was estimated much below unity (0.83), indicating the absence of larger specimens in the populations (Figure 2B, Table 2).

Genus *Johnius*

The present survey recorded nine species of the genus *Johnius* in the commercial catches, but the significant contribution comes only from five species, *viz.*, *J. belangerii*, *J. macrorhynus*, *J. glaucus*, *J. dusumieri*, and *J. borneensis*. The LF data of the above-mentioned five species were analyzed using the LBB approach, which revealed overfished status for *J. glaucus* (F/M = 1.60, B/B_0 = 0.27, and B/B_{MSY} = 0.74) and fully exploited status for other four species (B/B_{MSY} = 0.91–1.10). For all the five species, there were no signs of excessive juveniles in catches (L_{mean}/L_{opt} = 0.98–1.10 and L_c/L_{c_opt} = 0.99–1.20). However, with *J. belangerii*, there was an issue of lack of enough larger individuals in the population (L_{95th}/L_{inf} << 1.0) (Figures 2C–G, Table 2).

Genus *Otolithes*

The two members of genus *Otolithes*, namely, *O. cuvieri* and *O. ruber*, contribute significantly to the catches of croakers in the region. LBB analysis put both the species in the category of being fully exploited (B/B_{MSY} = 0.97-1.10, F/M = 1.10, and B/B_0 = 0.39–0.56). For both the species, the indicators of the sub-optimal size of harvest (L_{mean}/L_{opt} and L_c/L_{c_opt}) are in proximity to the recommended ideal of unity. Nonetheless, in the case of *O. ruber*, there appears to be a lack of enough larger individuals in the population as L_{95th}/L_{inf} << 1.0 (0.83) (Figures 2H, I; Table 2).

TABLE 1 Basic information and priors for the 10 croaker species landed along the north-east Arabian Sea.

Scientific Name	Common Name	Length Range (mm)	Priors					
			L_{inf} (cm)	Z/K	M/K	F/K	L_C (cm)	Alpha
Paranibea semiluctuosa	Half-mourning croaker	162–428	46.1	2.1	1.5	0.58	19.9	32.3
Pennahia anea	Donkey croaker	126–252	27.9	2.7	1.5	1.19	15.6	17.8
Johnius belangerii	Belanger's croaker	119–237	28.2	2.6	1.5	1.11	15.3	24.4
Johnius macrorhynus	Big snout croaker	108–294	29.4	2.7	1.5	1.15	15.8	17.7
Johnius glaucus	Pale spotfin croaker	83–326	33.3	3.1	1.5	1.63	18.9	25.4
Johnius dussumieri	Sin croaker	93–254	26.0	2.7	1.5	1.16	16.3	44.4
Johnius borneensis	Sharpnose hammer croaker	114–317	32.6	2.7	1.5	1.23	18.9	17.3
Otolithes ruber	Tigertooth croaker	214–429	50.3	3.0	1.5	1.54	28.6	39.2
Otolithes cuvieri	Lesser tigertooth croaker	133–393	39.8	2.8	1.5	1.25	22.9	22.3
Atrobucca alcocki	Blackmouth croaker	116–336	36.5	2.2	1.5	0.71	18.9	26.7

TABLE 2   Fishery status of 10 croaker species landed along the north-east Arabian Sea assessed using the length-based Bayesian biomass (LBB) method.

Scientific Name	L_{mean}/L_{opt}	L_c/L_{c_opt}	L_{95th}/L_{inf}	B/B_0	B/B_{MSY}	F/M	F/K	Z/K
Paranibea semiluctuosa	0.87	0.83	0.90	0.59	1.60	0.37	0.56	2.10
Pennahia anea	1.00	1.10	0.89	0.41	1.10	0.89	1.40	2.90
Johnius belangerii	1.00	1.00	0.83	0.40	1.10	0.90	1.40	3.10
Johnius macrorhynus	0.98	0.99	0.96	0.34	0.91	1.10	1.60	3.10
Johnius glaucus	1.00	1.00	0.95	0.27	0.74	1.60	2.50	4.00
Johnius dussumieri	1.10	1.20	0.91	0.40	1.10	0.97	1.80	3.70
Johnius borneensis	1.10	1.20	0.94	0.36	0.98	1.20	1.90	3.40
Otolithes ruber	0.99	1.00	0.83	0.35	0.97	1.10	1.70	3.30
Otolithes cuvieri	1.00	1.10	0.98	0.39	1.10	1.10	1.50	3.00
Atrobucca alcocki	1.00	1.10	0.90	0.56	1.60	0.48	0.84	2.60

Genus *Atrobucca*

The fishery in the region is supported by a single species, *A. alcocki*, which is currently being assessed as under-exploited (B/B_{MSY} = 1.60, F/M = 0.48, and B/B_0 = 0.56). L_{mean}/L_{opt} and L_c/L_{c_opt} were estimated at 1.0 and 1.10, respectively. The value of L_{95th}/L_{inf} was lower than unity (0.9), but not below the recommended cutoff value of 0.9, indicating a fair representation of larger individuals in the population (Figure 2J; Table 2).

Discussion

The north-west coast of India along the north-eastern Arabian Sea has a coastline of 2,320 km (Figure 1). The region is known for its wide continental shelf, benthic productivity, and rich demersal fishery resources. The north-west coast of India is the richest fishing ground for the croakers along the entire Indian coastline, with a contribution of 50.9%–57.3% of the total croaker landings of the country (NMFDC, 2022). The region has over 20 reported species of croakers, but the commercial fishery in the region is supported by 12 species, 2 of which belong to larger sciaenids (L_{max}> 100 cm) of the genus *Protonibea* (*P. diacanthus*) and *Otolithoides* (*O. biauritus*). The rest of the species belong to the lesser sciaenid (L_{max}<< 100 cm) group of genus *Johnius*, *Pennahia*, *Otolithes*, *Atrobucca*, and *Paranibea*. The larger sciaenids have a major share of landings coming from large mesh gill nets, and larger individuals' catches are also sporadic; hence, the LF data are not filling the assumption of trawl type selection and thus were not included in the present study. For the rest of the 10 species, the bulk of the commercial catches are from trawls with smaller codend mesh size (20 mm), ensuring a good representation of the natural population in the samples, resulting in the asymmetric patterns in LF data (Figures 2A–I) as recommended by Froese et al. (2018).

Paranibea semiluctosa is one of the coastal croaker species available along the north-west of India in depths shallow than 50 m. Despite being a coastal species, it has not attracted commercial trawlers in the past, as being not preferred for local consumption either in fresh or salt-dried form. The species has a blackish body and soft texture, which is not preferred for domestic consumption. However, in recent years, the resource is being landed in significant quantity, especially at Veraval and Mangrol fish landing sites of Gujarat for preparing fish powder out of it. The establishment of several fish meal plants in recent years in the region has led to the harvest of several non-conventional resources, which includes *P. semiluctosa*. Since the species in the past had not been exploited in significant quantities, there were no assessments for this species. The present finding has categorized the species as under-exploited with B/B_{MSY} >> 1.2 (Tables 2, 3), which can be attributed to the very recent history of its commercial exploitation. Since the end use of the current catch is to prepare fish powder or meal out of it, there is currently no economic preference for larger individuals. Hence, all fish sizes are landed. However, it is advisable to increase the size of harvest (L_c/L_{c_opt}<< 1.0) to ensure the long-term sustainability of the resource.

Pennahia anea catches in the region are being utilized both in fresh and salt-dried form. The salt-dried form is traded to the north-eastern and southern states of India for domestic consumption. In recent years, a portion of the catches is also converted into fish mince by surimi-based processing plants. The species has been previously assessed from the region using 3-year LF data collected during the early 1990s, which categorized the species as fully exploited and recommended no further increase in the fishing effort (Chakraborty, 1996a). The current assessment (B/B_{MSY} = 1.10 and F/M = 0.89) corroborates the earlier findings and discourages any further escalation of fishing effort (Tables 2, 3).

The genus *Johnius* is having the maximum α-diversity in the region. As many as five species are known to contribute

TABLE 3 Comparison of present findings with the previous assessment made along the north-west coast of India along north-eastern Arabian Sea

Scientific Name	Previous assessment			Current study
	Assessment method (period)	Assessment result	Reference	
Paranibea semiluctuosa	————	————	————	Under-exploited
Pennahia anea	Length Cohort & Thompson and Bell Model (1990–1992)	Fully exploited	Chakraborty (1996a)	Fully exploited
Johnius belangerii	————	————	————	Fully exploited
Johnius macrorhynus	Length converted catch curve (1989–1993)	Fully exploited	Chakraborty (1994)	Fully exploited
Johnius glaucus	Length converted catch curve (1990–1994)	Over exploited	Chakraborty et al. (2000)	Over-exploited
Johnius dussumieri	Length converted catch curve (1989–1994)	Over-exploited	Chakraborty (1996b)	Fully exploited
	Length converted catch curve (2003–2005)	Over-exploited	Telvekar et al. (2007)	
	Length converted catch curve and Thompson and Bell Model (2009–2011)	Over-exploited	Tarkeshwar et al., (2014)	
Johnius borneensis	Length converted catch curve (1979–1984)	Fully exploited	Chakraborty (1993)	Fully exploited
	Length converted catch curve (1990–1994)	Over-exploited	Chakraborty et al. (2000)	
Otolithes ruber	————	————	————	Fully exploited
Otolithes cuvieri	Yield per recruit (1979–1984)	Fully exploited	Chakraborty (1987)	Fully exploited
	Length converted catch curve (1990–1994)	Fully exploited	Chakraborty et al. (2000)	
	Length converted catch curve (1993–1995)	Over-exploited	Manojkumar (2007)	
Atrobucca alcocki	————	————	————	Under-exploited

For length converted catch curve, F/Z of<0.4 is under-exploited, 0.4–0.6 as fully exploited, and over 0.6 as over-exploited.

significantly to the commercial croaker landings, the bulk of which comes from the trawl operated within 50 m depth. *Johnius belnagerii* has not been assessed earlier from the region, despite significant contribution to the commercial catches. The current status of the stock is fully exploited (B/B$_{MSY}$ = 1.10 and F/M = 0.90). *J. macrorhynus* is presently assessed as fully exploited, which is in line with the findings of Chakraborty (1994) who, based on exploitation ratio as an indicator, also categorized the species as being fully exploited. The two closely resembling species, both in size and external appearance, *J. glaucus* and *J. borneensis*, have contrasting stock status. The former falls into the category of over-exploited (B/B$_{MSY}$ = 0.74 and F/M = 1.60), while the latter is a fully exploited resource. *Johnius glaucus* in the past has also been assessed as being over-exploited (Chakraborty et al., 2000), whereas *J. borneensis* was a fully exploited resource in 1979–1984 (Chakraborty, 1993) and an over-exploited resource in 1990–1994 (Chakraborty et al., 2000). The current assessment of the stock indicates an improvement in the status over the recent past assessment made two and a half decades ago. The three very similar-sized species, namely, *J. macrorhynus*, *J. glaucus*, and *J. borneensis*, with yellow-tinged bodies have similar utilization patterns. A portion of the catch goes to the domestic market either in fresh or salt-dried form. A significant amount enters the export market as fish mince or whole frozen form in the trade name of "Yellow croaker". Because

of similar appearance, especially *J. glaucus* and *J. borneensis*, which can be differentiated only based on gill raker's size and appearance and teeth pattern in the lower jaw, are often misidentified in the field, leading to erroneous catch data. *Johnius glaucus* possibly has much more restricted distribution, being dominant only along the NW coast of India, unlike *J. borneensis*, which is more abundant along the Indian coast, something that has made it more vulnerable to the fishing pressure than its look-alike congener *J. borneensis*. *Johnius dussumieri* is one of the most abundant croaker species in the region. However, owing to its relatively smaller size, it is mostly consumed locally in salt-dried form. A small fraction will also go towards fish powder and fish mince production by fish meal and surimi-based plants, respectively. The species was assessed as over-exploited in 1989–1994 (Chakraborty, 1996b), 2003–2005 (Telvekar et al., 2007), and 2009–2011 (Tarkeshwar et al., 2014) in different studies conducted along the NW coast of India. The stock status seems to have improved over the years, as the stock has been categorized as fully exploited in the present investigation (Tables 2, 3).

Otolithes cuvieri, the most abundant species of the genus, has been assessed several times in the past from the region. It was categorized as fully exploited in 1979–1984 (Chakraborty, 1987) and 1990–1994 (Chakraborty et al., 2000). However, the most recent assessment made during 1993–1995 (Manojkumar, 2007)

put it in the category of being over-exploited (Table 3). This shows the gradual decline in the status of the resource from 1979 to 1995, which coincides with the period of trawl expansion in the region. However, the present assessment put the species in the category of being fully exploited, which is an improvement over the last assessment of 1993–1995, almost 25 years ago. The congener, *O. ruber*, has similar stock status in the present findings but seems to lack enough larger individuals in the population ($L_{95th}/L_{inf} << 1.0$) (Tables 2, 3). The reason could be the higher fishing pressure on larger individuals by gillnet or hook and line operators, which also contribute significantly towards the landings of this species. *Otolithes ruber* has not been assessed against the indicators of sustainability from the study region. The two species form the most prized species among the lesser sciaenids. The species are consumed in the domestic market in fresh or salt-dried form. The fair share of the catches enters the export market as whole frozen fish in the common trade name of "Silver Croaker".

The sole member of genus *Atrobucca*, *A. alcocki*, is probably the most recent addition to the commercial croaker fishery of the NW coast of India. Earlier, it was being landed in relatively smaller quantities as bycatch or else discarded back to the Sea due to its lower price. The distribution of this species is restricted to the northern Arabian Sea and is a relatively deeper water species (>70 m), unlike other species of croakers (Froese and Pauly, 2022). The species' appearance in commercial catches in significant amounts in recent years is because of the expansion of the fishing ground by multi-day trawlers and the establishment of fish meal plants that consume the catch as raw materials. The species as of now is not going for human consumption owing to its soft textured and blackish-tinged body and mouth. The quality of catch landed is also poor, since there is no economic incentive for bringing premium quality fish to the shore. The species was not assessed earlier from the study region; however, an assessment was made from the northern Arabian Sea

(Pakistan waters), which may be accessing the common stock, as it is a deeper water species. Memon et al. (2016), using LF data collected in 2008–2009, categorized the stock as fully exploited (E = 0.53) using length converted catch curve and over-exploited using yield per recruit models. However, the estimates were questionable for the very low value of K (0.18 per year), which otherwise is much higher for tropical teleosts. The current assessment of the species being under-exploited (Table 2, 3) seems more reasonable due to its very recent history of commercial exploitation in the region.

Most of the species assessed earlier in 1985–1995 were either fully exploited or over-exploited, and it was recommended to maintain the current fishing effort or even reduce the same (Chakraborty, 1987; Chakraborty, 1993; Chakraborty, 1996a; Chakraborty, 1996b; Chakraborty et al., 2000; Manojkumar, 2007). The species during the current assessment either show the same status (*P. anea*, *J. macrorhynus*, and *J. glaucus*) or improvement compared to the recent past assessment (*J. dussumieri*, *J. borneensis*, and *O. cuvieri*). This is contrary to the fact that the trawl effort (trawl being the major contributor to the trawl landings) has increased significantly over the year both in numbers of vessels and actual fishing hours. The actual trawl fishing hours for the Gujarat coast (one of the maritime states of the NW coast of India) in 1987–1995 were between 1,840 and 3,510 thousand hours, which has escalated to 8,510 to 10,570 thousand hours in 2015–2018 (Figure 3). Similar escalation of the trawl effort was also observed along the Maharashtra coast (the second maritime states along the NW coast of India). The development was against the general recommendation for fishing effort reduction in previous studies. However, a parallel shift of trawl effort towards pelagic trawling, especially since 2005, has substantially reduced the effective fishing pressure on bottom-dwelling croakers. This shift has contributed to the stable or improving stock status of the croaker resources of the region. Azeez et al. (2021) reported that almost 40%–45% of
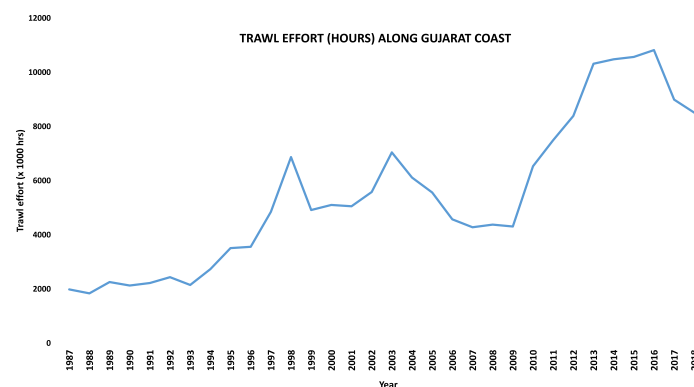

FIGURE 3
Trend in the trawl fishing effort of Gujarat between 1987 and 2018 (source: NMFDC of ICAR-CMFRI).

trawl effort of Gujarat coast was towards pelagic trawling for ribbonfishes and croakers form only a minor bycatch component in them. Furthermore, a significant trawl effort also goes for column trawling of cephalopods, making bottom trawling (a major mode to harvest croakers) a minor component only. This development helped several over-exploited stocks to improve their status. This is supported by the fact that the total croaker catch along the Gujarat coast, which contributed 55% −66.3% of the croaker landings of the NW coast of India (Supplementary Table S3), has either been stable or showing an increasing trend since 2005, whereas the contribution of croakers to total trawl catch was reduced from its peak figure of 26.3% in 1992 to 5%–8.4% in the last 5 years (2015–2019) (Figures 4, 5). On the other hand, the percentage contribution of ribbonfishes and cephalopods are showing an increasing trend, especially since mid-2000s (Figure 5). The average contributions of ribbonfishes and cephalopods to the total trawl landings of Gujarat during the last 5 years (2015–2019) were 18.8% and

12.8%, respectively, against only 6.3% for croakers, indicating significant diversion of trawl effort towards pelagic and column trawling.

Sathianandan et al. (2021) studied 223 stocks all along the Indian coast and found the north-west coast of India as the most exploited zone, with 54.2% of the assessed stocks being overfished. However, they have not included any species of croaker or entire croaker as a group in their assessment from the NW coast of India. Vase et al. (2019) used the catch-based method CMSY with time series of catch (1994–2017) for the entire group as input data to evaluate the status of stocks using the ratio of the current catch (Y_{curr}) and estimated MSY (Y_{curr}/MSY) as an indicator of health. They evaluated croakers as a whole and categorized them as underutilized stock for the state of Gujarat, but the study has undermined the α-diversity of the group with contrasting life history traits. Furthermore, using catch data alone when fishing methods and species preferences have undergone a major change may lead to erroneous estimates,
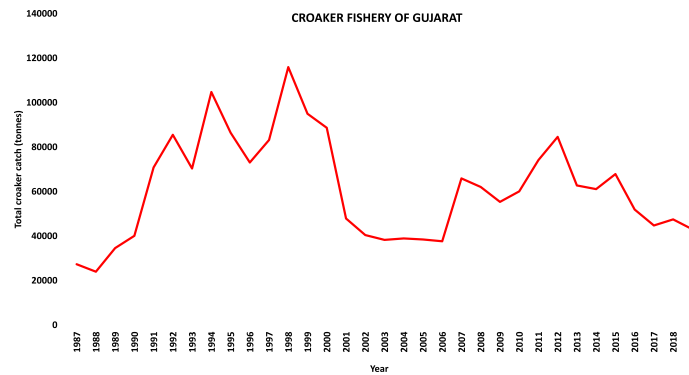

FIGURE 4
Trend in the croaker landings of Gujarat between 1987 and 2018 (source: NMFDC of ICAR-CMFRI).
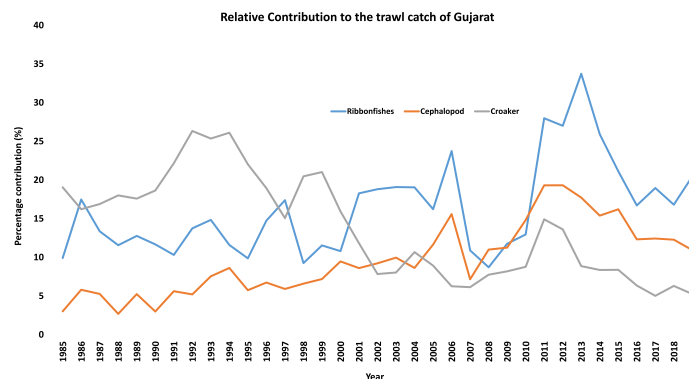

FIGURE 5
Relative contribution of croakers, cephalopods, and ribbonfishes in trawl landings of Gujarat between 1985 and 2018 (source: NMFDC of ICAR-CMFRI).

as catches cannot be taken as a proxy for abundances. The current study hints towards released fishing pressure on croaker stocks in the region, which may help the stock get closer to its pristine status in the coming years. The study also recommends a periodic species-specific assessment to monitor the stock status and also to encourage catch and effort data collection at the species level.

Conclusion

This study provided a stock assessment for 10 croaker species along the northeastern Arabian Sea, four of which have never been assessed in this region before. Two species, *A. alcocki* and *P. semiluctuosa*, have only recently started to be commercially exploited and were, hence, shown to still have healthy status. Among other species, *J. glaucus* is still an over-exploited stock, while the others have the status of being fully exploited. Most of the stocks that were previously assessed as over-fished have improved over the years because of the major diversion of trawl effort towards pelagic and column trawling for ribbonfishes and cephalopods, respectively. The study recommends a periodic species-specific assessment and data collection.

Data availability statement

The original contributions presented in the study are included in the article/Supplementary Material. Further inquiries can be directed to the corresponding author.

Ethics statement

This article does not contain any experimental studies with live animals. Observations were made on dead fishes landed by commercial fishing units and ethical statements are not applicable.

Author contributions

SR has conceptualized the work, analyzed the LF data, and prepared the first draft. RK helped in LF data analysis and manuscript preparation. PZ and VV provided guidance in result interpretation and manuscript correction and improvement. All authors contributed to the article and approved the submitted version.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fmars.2022.952795/full#supplementary-material

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