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Assessment of marine fish stocks within India's Exclusive Economic Zone: Status report 2022

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Abstract

India is one of the major fishing nations in the Indian Ocean, with commercial marine fish landings in the country comprising of nearly 1000 species. A comprehensive and periodic assessment of the stocks is crucial for achieving the goals of sustainable fisheries harvest and management. The ICAR-Central Marine Fisheries Research Institute, Ministry of Agriculture and Farmers' Welfare, Govt. of India, is mandated to monitor and assess the marine fisheries resources in the Indian EEZ. In the present study, 135 stocks across 70 species were assessed using monthly length-frequency data. The health status of the stock is projected based on a combination of indicators such as relative biomass or spawning stock biomass (B/B_{msy} or SSB/SSB_0) and relative fishing pressure (F/Fmsy) estimated using a standard length-based dynamic pool model (*i.e.*, Thompson and Bell Model). Based on the comparison of estimated values of indicators against the thresholds, the stocks were classified as sustainable, overfishing, overfished and rebuilding. The study revealed that 91.1% of the assessed fish stocks have a healthy biomass level (stocks under sustainable and overfishing category), 8.2% of stocks are overfished, whereas 0.7% are in the process of rebuilding.

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Introduction

India, with access to both the Arabian Sea and the Bay of Bengal through its long coastline of 8,129 km, is one of the major fishing nations in the Indian Ocean. The country has a vast Exclusive Economic Zone (EEZ) spanning 2.02 million km^2, harbouring a rich biodiversity. This includes 2,275 species of teleosts, 174 species of elasmobranchs, 3,400 species of molluscs, 2,783 species of crustaceans, 936 species of seaweeds, 14 species of seagrasses, 765 species of echinoderms, and 486 species of sponges (Venkataraman and Raghunathan, 2015; Raghunathan *et al*., 2019; Akhilesh *et al*., 2023). Among these, nearly 1,000 species contribute to commercial landings, which are harvested by nearly 30 different fishing craft-gear combinations across different regions of India. In 2020, India was the sixth largest marine capture fisheries producer in the world, contributing about 3.71 million t (5%) to the global marine capture production of 78.79 million t (FAO, 2022). Notably, in 2022, 3.49 million t of marine fish were landed in mainland India, the landing centre value of which was ₹582.47 billion (CMFRI, 2023), supporting livelihoods and ensuring nutritional security for over 28 million stakeholders (DoF, 2021).

The ICAR-Central Marine Fisheries Research Institute (ICAR-CMFRI), India is a leading institute in the Asian region that is actively engaged in tropical marine fisheries research. One of the major mandates of the Institute is to monitor and assess the marine fisheries resources of the EEZ of India to develop sustainable fishery management plans (https://www.cmfri.org.in/mandate). The ICAR-CMFRI has fifty resource and species-specific national working groups (35 finfish and 15 shellfish NWGs) comprised of teams of expert scientists of the institute who dedicatedly focus their research endeavours to assess the stock health status of prioritised species distributed in Indian waters (Muktha *et al.*, 2022). The Institute has been instrumental in assessing and monitoring the status of the finfish and shellfish stocks in the Indian EEZ, which are being periodically published as resource-specific and region-specific research articles in various reputed scientific peer-reviewed journals and also as special publications of the institute (http://eprints.cmfri.org.in/view/subjects/sub7=2E3.html). Nevertheless, a comprehensive and periodic assessment of exploited marine fisheries resources across all the regions to reflect upon the national marine fish stock status of Indian waters, which is very essential to formulate a feasible and holistic fisheries management plan, has been lacking for quite some time. Though periodic assessments are critical, such endeavours are limited to only certain parts of the world (Piddocke *et al*., 2021; NOAA NMFS, 2023). A comprehensive assessment using the data set from 1997 to 2016 was attempted by Sathianandan *et al*. (2021) mainly for the major resource groups (taxa: family/sub-family) in Indian waters; however, the analysis derived its inference from a catch-based surplus production model (biomass dynamic model) that lacks resolution mostly to individual species or stock level. Given that individual species within a broad taxonomic group (family/sub-family) could also show remarkable differences in their life-history traits and resilience (Mohamed *et al*., 2021a, b), grouping them into the higher taxa for ease of assessment may not always accurately reflect the correct stock status. For example, the croakers (Family: Scianidae), a group used by Sathianandan *et al*. (2021) for the analysis is comprised of diverse species-complex that can be broadly categorised into greater sciaenids (*e.g*. larger-sized sciaenids such as *Protonibea diacanthus* and *Otolithoides biauritus*) and lesser sciaenids (small and medium-sized sciaenids that belong to the genus *Pennahia, Otolithes, Nibea, Paranibea, Atrobucca* and *Johnius*) which show considerable variation in their resilience due to heterogeneity in life-history traits such as growth rate, life span, maximum size, size and age at maturity, spawning frequency and relative fecundity, and therefore, resilience (Waggy *et al*., 2006; Rahangdale *et al*., 2022). Similarly, another such broad group in the study of Sathianandan *et al*. (2021) is ‘the sharks’ which includes both oceanic and coastal sharks, the individuals within which show remarkable inter-specific differences in the above-mentioned key life-history strategies (Cortes *et al*., 2000; White *et al*., 2010; Jabado *et al*., 2018; Tyabji *et al*., 2020, Constance *et al*., 2024, https://www.sharkipedia.org).

To address existing gaps in stock status assessments and the dire necessity for a decision support tool, a multi-disciplinary approach was pursued by the scientific team at ICAR-CMFRI. This approach utilised length-based micro-analytical dynamic pool models fully integrated with biology-based information to facilitate precautionary decisions. It also aimed to provide a synoptic overview on the stock status of major commercially important marine finfish and shellfish resources in India. The primary aim of this study is to evaluate and offer a comprehensive depiction of the status of marine fish stocks of both national and regional importance under the currently prevalent fisheries management regime in the country. Further, it seeks to identify the species that require immediate attention and suggest appropriate corrective measures to alleviate the impact of fishing on the resource.

Materials and methods

Defining the study area

The coastline of India is distributed across nine maritime states and four union territories (UTs). While there is a multitude of diversity in the marine capture fisheries sector of the country, the neighbouring states share many similarities. For instance, the fishing areas and geographical spread of a species/stock considerably overlap the administrative boundaries of the neighbouring states. Considerable similarities are also evident in the harvest and consumption patterns including gears and crafts deployed, duration of voyage, technological advancements and market demand for the fishery resources among neighbouring states.

Considering all these, the Indian coastline was divided into regional assessment zones *viz.,* (1) the North-east region encompassing the states of West Bengal and Odisha (NE); (2) the South-east region encompassing the states of Andhra Pradesh and Tamil Nadu, including the UT of Puducherry (SE); (3) the South-west region encompassing the states of Kerala, Karnataka and Goa (SW) and (4) the North-west region encompassing the states of Maharashtra and Gujarat including the UT of Daman & Diu (NW) (Fig. 1). The UT of Lakshadweep and the UT of Andaman and Nicobar Islands form other two distinct regional assessment zones owing to the completely different ecosystems (oceanic Island vs. coastal) and prevailing fisheries. However, the present study excludes the stocks from the UT of Andaman and Nicobar Islands due to insufficient data.

In the present assessment, a total of 70 species (49 finfish species and 21 shellfish species) segregated into 135 stocks (96 finfish stocks and 39 shellfish stocks) were evaluated for their status. The region-wise stocks evaluated were as follows: (1) North-east (NE) region - 16 stocks (8 finfish stocks and 8 shellfish stocks), (2) South-east (SE) region - 39 stocks (29 finfish stocks and 10 shellfish stocks); (3) (SW) South-west region - 41 stocks (29 finfish stocks and 12 shellfish stocks); (4) North-west (NW) region - 37 stocks (28 finfish stocks and 9 shellfish stocks) and (5) Lakshadweep - 2 finfish stocks.

Data acquisition

The species/stocks considered for the current assessment of the stock status were prioritised based on the following criteria: (i) those with a high contribution to the total marine fish landings in the region; (ii) that hold considerable economic importance in the region; (iii) with more vulnerable life history traits and (iv) for which adequate data are available, including length frequency data for most part of the year, reproductive biology and monthly catch data

Species-wise length-composition data and specimens for biological investigations were collected at fortnightly intervals from January 2017 to December 2022. The length and maturity stages were recorded based on species/group-specific standard maturity scales. The National Marine Fishery Resources Data Centre (NMFDC) of

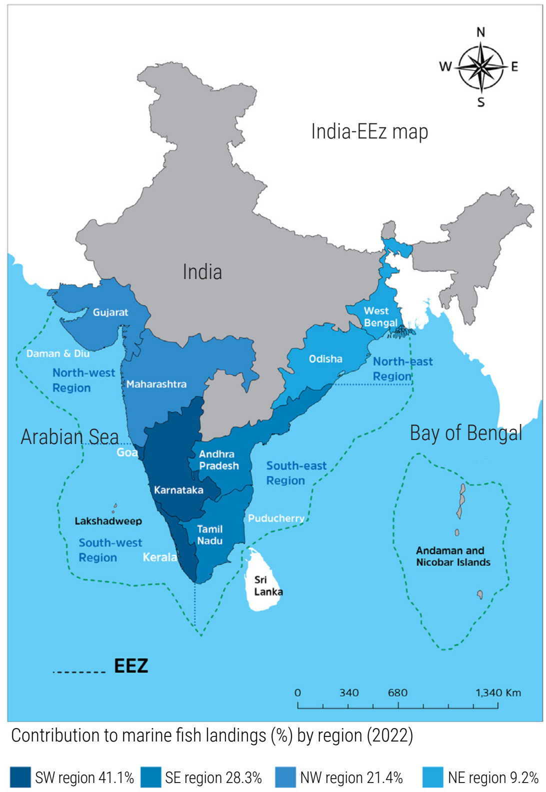

Fig. 1. Demarcation of different zones adopted for regional assessment in the present study.

ICAR-CMFRI collects marine fish landings and effort data (resource-wise, gear-wise and zone-wise) through a multistage stratified random sampling protocol where optimum stratification was done over space and time to ensure adequate data coverage over the extended geographical spread of the Indian coastline (Fig. 2) (Srianth *et al*., 2005; Kuriakose and Sathianandan, 2019).

The length-frequency data from samples were extrapolated to monthly estimates by multiplying with the raising factors derived from catch data for a given species (if available) collected by the NMFDC of ICAR-CMFRI, Kochi.

Assessing the key life history traits and exploitation status

Asymptotic length and growth rate (L_∞ and K)

The life-history characteristics (L_∞ and K) for a given stock were estimated using the raised or raw length-frequency data through a direct electronic length frequency analysis (ELEFAN) for the selected species (Pauly and David, 1981; Pauly and Morgan, 1987). The growth was modeled by fitting the von Bertalanffy’ growth function (von Bertalanffy, 1938) on the available length-frequency data using the genetic algorithm (ELEFAN_GA) and simulated annealing algorithm (ELEFAN_SA) routines of TropFishR and then evaluating the performance of the fit using Rn-score as a criterion (Mildenberger *et al*., 2017; Schwamborn *et al*., 2019).

Natural mortality (M)

Natural mortality (M) was estimated from the key life history traits (L_∞ and K) integrating the effect of water temperature (T) using Pauly’s empirical formula (Pauly, 1980):

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

where, L_∞ is the asymptotic length in cm; K is the VBGF growth coefficient in yr^{-1} and T is the water temperature in °C.

The empirical equation of Then *et al*. (2015) was used for non-shoaling pelagic fishes

$$M = 4.118 \times K^{0.73} \times L_\infty^{-0.33}$$

Exploitation parameters (Z, F and E)

The instantaneous total mortality rate (Z) was estimated following the length-converted linearised catch curve method (Pauly, 1983) using the ‘catchCurve’ routine in the ‘TropFishR’ package (Mildenberger *et al*., 2017; Schwamborn *et al*., 2019). The annual fishing mortality rate (F) was calculated by subtracting M from Z (*i.e.*, F= Z-M) and the current exploitation rate (E_{curr}) was computed using the formula E= F/Z (Ricker, 1975). The fishing mortalities, biomass and yield for each length class as well as annual recruitment were assessed by performing a length-based cohort analysis (L_{cohor}) following Jones (1984). The analysis was performed using the virtual population analysis (VPA) routine with ‘analysis type’ set to cohort analysis (CA) in the TropFishR package (Mildenberger *et al*., 2017; Schwamborn *et al*., 2019).

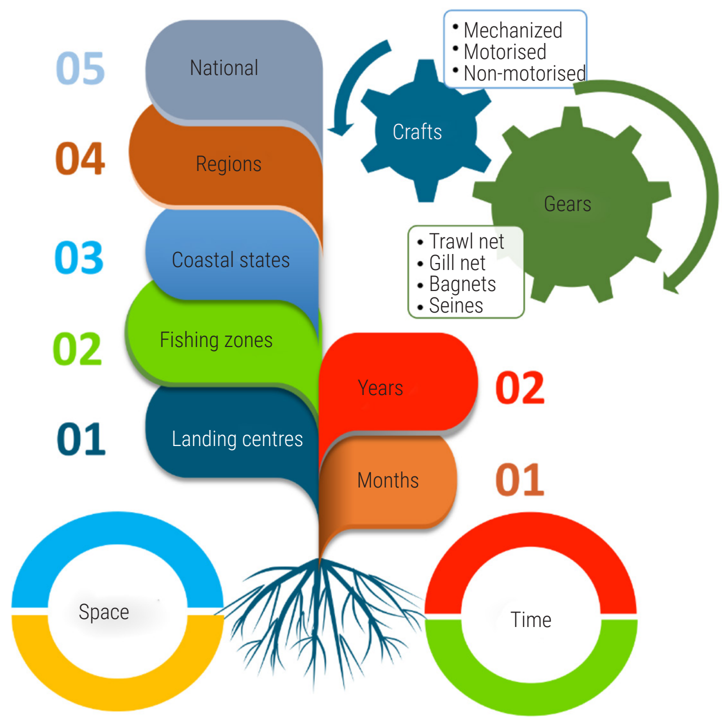

Fig. 2. Schematics of multistage stratified random sampling approach, where optimum stratification is done over space and time to collect catch and effort data from different marine fisheries in India

Length at recruitment (L_r), Length at capture (L_{C50}) and Length at maturity (L_{m50})

The mid-length of the smallest length class caught during the study period was taken as length at recruitment (L_r). The length at which 50% of the individuals in a population become vulnerable to the fishing gear (*i.e.,* L_{C50}) was estimated by performing a logistic regression with the probability of capture of sequential length classes calculated from the backward extrapolation of the regression line of the descending limb of the length-converted catch curve (Pauly, 1984). The analysis was performed using the 'catchCurve' routine with 'calc_ogive' logic set to TRUE in the 'TropFishR' package (Mildenberger *et al*., 2017; Schwamborn *et al*., 2019).

The length at which 50% of the individuals in a population become mature (*i.e.*, L_{m50}) was estimated by performing a logistic regression with the probability of maturity of sequential length classes. The proportions of such mature individuals in sequential length classes were regressed using the following logistic formula (Ashton, 1972):

$$p_{TL} = \frac{\exp^{[a+b(TL)]}}{(1+\exp^{[a+b(TL)]})}$$

where, P_{TL} is the extrapolated probability of capture at length *TL*, *a* and *b* are the estimated coefficients of the logistic equation and *TL* is the total length of the species in cm. L_{m50} was estimated as the negative ratio of the coefficients (-*a/b*). The analysis was performed using the generalised linear model 'glm' routine with binomial distribution and 'link' set to 'logit'.

Length-weight relationship (LWR)

The relationship between length and weight (LWR) for each species was established using the power law (Le Cren, 1951):

$$W = a(L)^b$$

where, *W* is the body weight in 'g'; *L* is the total length/standard length/carapace length/dorsal mantle length in 'cm'; *a* and *b* are model parameters.

Simulating the impact of fishing on yield and biomass

The information from L_{cohor} was used in a length-based Thompson and Bell model (1934) to simulate the effect of different levels of fishing pressure (F) on the annual yield (Y), biomass (B) and spawning stock biomass (SSB). The analysis was performed using the 'predict_mod' routine with a model type set to 'ThompBell' in the TropFishR package (Mildenberger *et al*., 2017; Schwamborn *et al*., 2019). The fishing mortality and biomass levels required to produce the maximum sustainable yield, *i.e.*, F_{msy} and B_{msy} were determined from the simulated yield and biomass projections and these were further used to quantify the relative fishing mortality (F/F_{msy}) and relative biomass (B/B_{msy}) prevalent at the current exploitation scenario. In cases where the estimated F_{msy} or F_{max} from the length-based Thompson and Bell model were unrealistic (the yield curve flattens), the F_{msy} was fixed at M (Froese *et al*., 2018) and relative biomass was recalculated to project the status of the stock.

Stock status characterisation and health assessment

Region-wise data compilation and analysis on prioritised species were done by working groups (Muktha *et al*., 2022) for respective resources, constituted by ICAR-CMFRI. The stock status indicators estimated were compared with pre-defined sets of criteria or thresholds to determine the current health status of a given stock.

Different sets of criteria/thresholds were used to categorise the finfish and shellfish resources into different exploitation/health status categories. In general, tropical shellfish resources have higher resilience than finfish resources and hence thresholds are marginally relaxed for shellfish resources.

Finfish stock categorisation criteria

Criteria and threshold values for categorising the stock status of finfish resources are shown in Table 1. All the finfish stocks with a B/B_{msy} above 1 when F/F_{msy} was below 1 were considered sustainable, whereas those with F/F_{msy} above 1 were considered to be subjected to overfishing. All the finfish stocks with a B/B_{msy} below 1 and with F/F_{msy} above 1 were considered overfished, whereas those with an F/F_{msy} below 1 were considered rebuilding stocks. Any stock with a B/B_{msy} less than 0.3 was considered a collapsed stock.

Shellfish stock categorisation criteria

Criteria and threshold values for categorising the stock status of shellfish resources are shown in Table 2. Considering the very high stock regeneration capacity of shellfish resources, a 20% downward allowance in B/B_{msy} ($B/B_{msy} > 0.8$) and a 20% upward allowance in the F/F_{msy}, *i.e.,* < 1.2 for categorising the sustainable stock and >1.2 for categorising the stock subjected to overfishing, were used as criteria. Furthermore, a 20% downward allowance in B/B_{msy} ($B/B_{msy}<0.8$) and a 20% downward allowance in the F/F_{msy}, *i.e.,* >0.8 for overfished and <0.8 for categorising the rebuilding status, were used as criteria for assessing the stock health status of shellfish resources. Any stock with a B/B_{msy} less than 0.3 was considered to have collapsed. When information on relative spawning stock biomass (SSB/SSB_0) was available, it was used for categorising shellfish stocks. Retention of 25% SSB of virgin stocks ($SSB/SSB_0 > 0.25$) is considered sustainable.

Table 1. Criteria and threshold values for categorising the stock status of finfish resources

Category	Relative biomass (B/B_{msy})	Relative fishing mortality (F/F_{msy})
Sustainable	> 1.0	< 1.0
Overfishing	> 1.0	> 1.0
Overfished	< 1.0	> 1.0
Rebuilding	< 1.0	< 1.0
Collapsed	< 0.3	-

Table 2. Criteria and threshold values for categorising the stock status of shellfish resources

Category	Relative biomass (B/B_{msy})	Relative fishing mortality (F/F_{msy})
Sustainable	> 0.8	< 1.2
Overfishing	> 0.8	> 1.2
Overfished	< 0.8	> 0.8
Rebuilding	< 0.8	< 0.8
Collapsed	< 0.3	-

Bayesian state-space implementation of the Schaefer production model (BSM) was used to assess the short-lived cephalopod and *Acetes* stocks, which requires catch and effort data or an indicator of biomass or relative abundance (*e.g.,* catch per unit of effort) to predict stock status (Froese *et al*., 2017, 2018).

Validation and management recommendations

Deliberations were held among NWG members on specific fishery resources, other experts and stakeholders to verify the findings of the analysis and derive implementable solutions to address the resource/stock-specific issues. For the species/stocks under distress, optimum care was taken to re-examine the findings and to prepare viable and effective management strategies for their revival/recovery.

Results and discussion

A total of 135 stocks across 70 species of finfish and shellfish were assessed during the present study, out of which 86.7% of the stocks were found sustainable and 4.4% were transitioning towards overfishing. The rest of the stocks were either overfished (8.2%) or under the rebuilding state (0.7%) (Fig. 3). At present, 91.1% of the assessed stocks (stocks under sustainable and overfishing category) were found healthy. Among finfish, 96 stocks of 49 species were analysed and 90.6% of them were found in a healthy state. All the five regions studied were found to have most of the stocks in a healthy state (Fig. 4). A relatively lower (75%) percentage of healthy stocks was recorded along the NE region of India, but this could be due to the lower number of stocks (8) analysed along the coast. Analysis of more stocks from the region in the future is recommended to get a better picture of the extent of exploitation of finfish resources in the region. The Kobe plot showing the distribution of current relative biomass (B/B_{msy}) and relative fishing pressure (F/F_{msy}) is presented in Fig. 5. A closer look at the plot shows that several stocks are very close to the intersection of the threshold lines and hence are susceptible to change in stock status soon, if due measures are not in place. It is likely that the reduction in fishing pressure during the last two years (2020 and 2021) due to COVID-19 has played a significant role in improving the biomass of several resources.

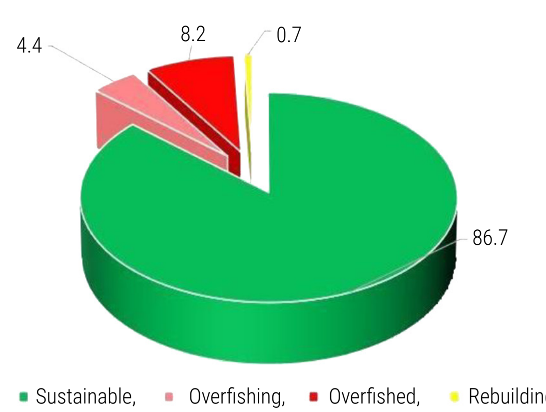

Fig. 3. Overall stock status of marine finfish and shellfish resources in the Indian EEZ

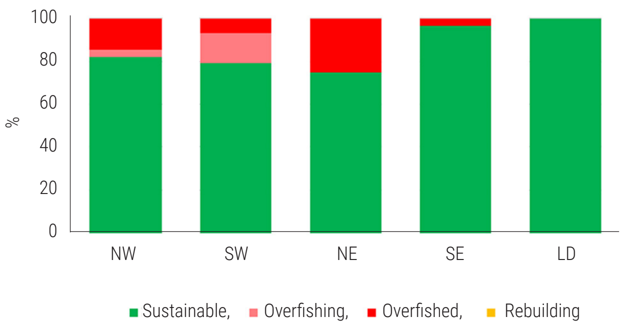

Fig. 4. Stacked bar chart showing region-wise stock status of finfish resources in the Indian EEZ

Among the 39 assessed stocks of shellfish of 21 species, 92.3% were found healthy. All the assessed stocks along the east coast of the Indian EEZ were found healthy. Along the SW region of the Indian coast, 91.7% of the assessed stock was found healthy compared to 77.8% along the NW region of India (Fig. 6). The Kobe plot (Fig. 7) indicated that four stocks, two along the NW region and one each along the SW and SE regions, fall in the quadrants, which need focused attention as far as monitoring and assessment are concerned. The region-wise details of individual stocks and their present exploitation or health status can be referred from CMFRI (2023) (Supplementary data/table: http://eprints.cmfri.org.in/17173/, Page no. 8-14).

The present assessment exercise identified 12 stocks (regional management units) across eight species, that need priority in fisheries monitoring, assessment and management programmes (Table 3).

The catfish *P. layardi* has unique life history traits such as low fecundity, spawning migration to shallow waters and buccal incubation by males, which renders it vulnerable to the impacts of fishing. The species has a low fecundity (Dan, 1977), carries out shoreward migration for breeding purposes when they are caught by dolnetters and purse seiners (Polara *et al*., 2002; Nair *et al*., 2007). With the larger males getting size-selected by commercial fisheries (Raje and Vivekanandan, 2008), there were several indications of the stock of this species being under threat along the NW coast of India. To conserve the stock of this species along the NW coast, an immediate cessation of fishing in spawning grounds and seasons is recommended, along with size-based conservation tools (CMFRI, 2023).

The grouper *E. diacanthus* exhibits protogynous hermaphroditism, where mature males are found only in larger size classes. The juveniles of this grouper species have been fished indiscriminately along the west coast of India, with several reports of "heavy landings of juveniles" documented even as far back as 1995 (Zacharia *et al*., 1995) and similar reports have continued since then (Chavan and Sundaram, 2005, Sawant *et al*., 2006, Sivakami and Seetha, 2006). The mean size of the juveniles landed ranged from 11.0 to 24.0 cm TL, which is far smaller than the size at which sex transition occurs in this species, which has been reported to be in the 27-30 cm size class, when males convert to females (Rao and Krishnan, 2007). Not surprisingly, excess fishing pressure on the stock of *E. diacanthus* along the SW coast of India was indicated as early as 2002 (Manojkumar, 2005). To sustain the stocks of *E. diacanthus* along the west coast, strict implementation of minimum legal size (MLS) has been recommended, along with regulation of fishing in spawning grounds (CMFRI, 2023).

Otolithes cuvieri is the predominant species under the genus *Otolithes* along the west coast of India. The status of the species has been analysed several times in the past along the west coast of India using approaches such as yield per recruit, length converted catch curve and length-based Bayesian Biomass (LBB) approach. The species was previously found to be either fully exploited (Chakraborty *et al*., 1987; Chakraborty *et al*., 2000; Rahangdale *et al*., 2022) or overexploited (Manojkumar, 2007). The present findings place the species under the overfished category from both the NW and SW coasts of India and advocate management measures such as the implementation of MLS and avoidance of spawning ground during the peak spawning months of April to June and December along the NW coast of India (Chakraborty *et al*., 2000; Telvekar *et al*., 2005; Sandhya *et al*., 2014).

Table 3. List of the stocks identified for prioritisation in the fisheries management program

Sl. No.	Species/common name	Region	Major fishery	Status
1.	*Plicofollis layardi* Thinspine sea catfish	NW	Purse seine/ gill net/ trawl	Overfished
2.	*Otolithes cuvieri* Lesser tigertooth croaker	NW SW	Trawl Trawl	Overfished Overfished
3.	*Otolithes ruber* Tigertooth croaker	NE SE	Trawl Trawl	Overfished Overfished
4.	*Epinephelus diacanthus* Spinycheek grouper	NW SW	Trawl Trawl	Overfished Overfished
5.	*Rhinobatos lionotus* Smoothback guitarfish	NE	Trawl	Overfished
6.	*Rhizoprionodon oligolinx* Grey sharpnose shark	NW	Trawl	Overfished
7.	*Thenus unimaculatus* Shovel-nosed lobster	NW SW	Trawl Trawl	Overfished Overfished
8.	*Uroteuthis (Photololigo) duvaucelii* Indian squid	NW	Trawl	Rebuilding

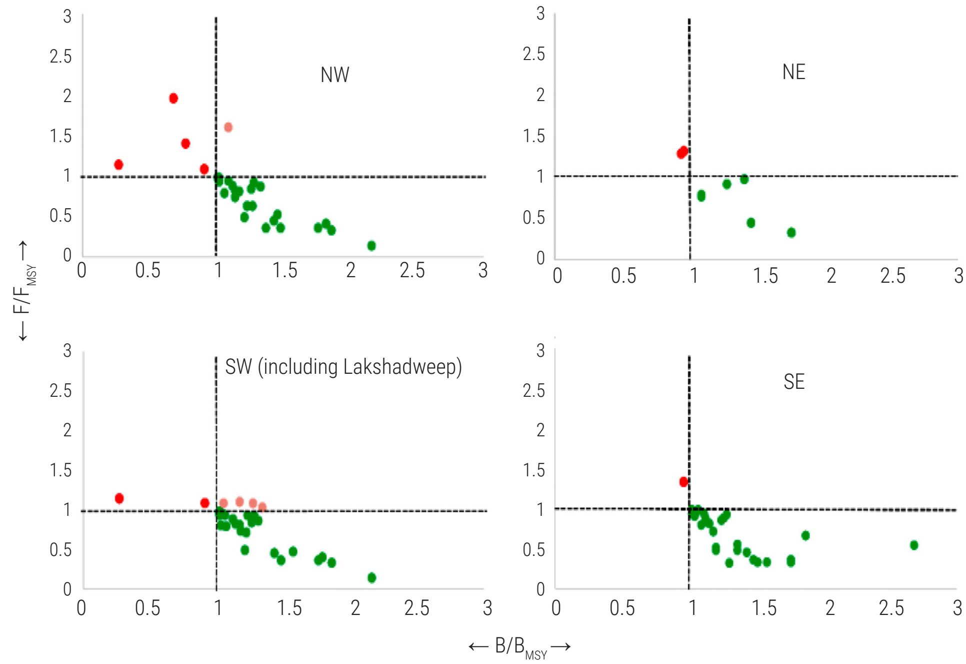

Fig. 5. Region-wise Kobe plot depicting the distribution of relative biomass and fishing pressure against the thresholds for finfish resources

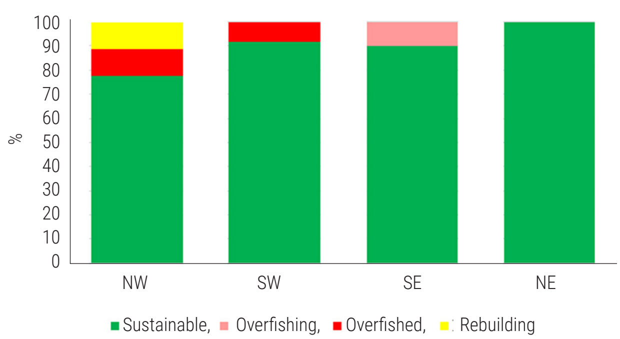

Fig. 6. Stacked bar chart showing region-wise stock status of shellfish resources in the Indian EEZ

Otolithes ruber is the largest of the two major species of genus *Otolithes* reported in the commercial fishery of the country. The species forms a significant fishery along the east coast of India. The stocks from both the NE and SE regions were evaluated as overfished. The recent studies from the Madras and Tuticorin coasts also categorised the stocks as overfished based on the estimated exploitation rate (Chakraborty *et al*., 2000; Santhoshkumar *et al*., 2017). The stock from the northern Bay of Bengal was also evaluated as overfished based on indicators such as B/B_0 and F/M values and the prevalence of sub-optimal-sized fish in commercial catches (Sultana *et al*., 2022). Hence, regulatory measures such as the introduction and implementation of MLS and reduction in fishing pressure during peak spawning season would be necessary to ensure the long-term sustainability of the resource.

The grey sharpnose shark, *Rhizoprionodon oligolinx* is one of the important coastal small/medium-sized sharks landed along the NW coast of India and fetches a good price when landed fresh. The species is preferred both in fresh and dried form by the coastal communities of the region. A major share is transported to southern Indian states, mostly in the salt-dried form. Like most shark species, they are slow-growing and have limited reproductive potential (Purushottama *et al*., 2017a, b), making them susceptible to overfishing. The present assessment places them in the overfished category. The most recent assessment from the region also found it overfished, with an exploitation rate much higher than the optimum (E>0.5) and biomass ($B/B_0 < 0.40$) below the optimum level (Purushottama *et al*., 2017a). Their study also highlighted the higher pressure on sub-optimal-size classes. The introduction and implementation of MLS for the species in the region and the avoidance of pregnant females in catches, especially in November-December and March-April (Purushottama *et al*., 2017b) would be highly effective in improving the stock status.

The smoothback guitarfish *Rhinobatos lionotus* is a small-sized guitarfish with a known distribution range in the northern Indian Ocean. It is often landed as a bycatch of coastal trawl fisheries along the east coast of India. It has been categorised as Critically Endangered in the IUCN Red List (Dulvy *et al*., 2021). The meat is consumed locally in fresh or dried form; the skin is often exported with the dried skin of other batoids, but there is not much species-specific information on the international trade of this species from India. The stock status of this species assessed in this study from the NE region indicated that it is overfished. Like most elasmobranchs, the species exhibits ovovivipary, with a relatively small litter size of 2-7 pups and a size at birth ~15 cm TL; the size at maturity was estimated to be 48.5 cm TGL for females and 40.2 cm TL for males (Sen and Dash, 2020). Due to its high susceptibility to fishing gears in coastal waters, paucity of information on specific biological and population traits and lack of information on the extent of international trade, it is necessary to implement measures to regulate its fishery through strict implementation of MLS, avoiding the capture of gravid females

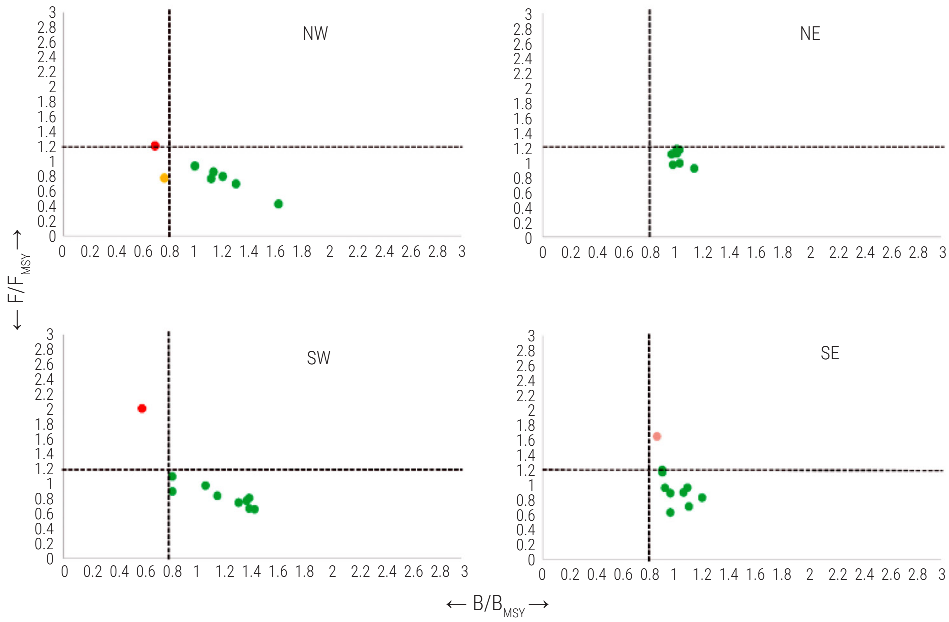

Fig. 7. Region-wise Kobe plot depicting the distribution of relative biomass and fishing pressure against the thresholds for shellfish resources

during the peak breeding season, generating awareness among fishers and other stakeholders and encouraging the release of incidentally caught live individuals back to the sea.

Thenus unimaculatus is the only species of slipper lobster that forms a fishery of commercial significance. Though the species has commercial value, it is not a targeted fishery resource; rather it is a bycatch of bottom trawl operations. The species, unlike other tropical crustacean resources, is more vulnerable to fishing due to its slower growth and lower reproductive potential. The stocks of the species from the NW and SW coasts are assessed as overfished in the present study, similar to the earlier reports of Radhakrishnan *et al*. (2013) from the SW coast of India. Considering the vulnerability of the resource, the MLS of 150 g for export has already been in place for some time as a regulatory measure. However, additional measures like the release of berried females from November to March (Kagwade and Kabli, 1996a, b; Radhakrishnan *et al*., 2013) and incentives to fishers for releasing females would be introduced to ensure sufficient recruitment and improvement in biomass.

The Indian squid (*U. duvaucelii*) distributed in the shelf waters supports the largest squid fishery in the country, exhibiting fast growth, short life-span and high resilience. The stock was undergoing a state of rebuilding. Over the past few years, there has been relatively lower fishing pressure, likely aided by the pandemic-induced closure, which might have facilitated the recovery. However, it remains crucial to closely monitor the fishing pressure on this resource during its recovery phase. To reduce the fishing pressure on juvenile squid, MLS was set for the Indian squid as a management measure (Mohamed *et al*., 2009; Chellappan *et al*., 2018). Given that these squids are exploited mostly by trawls, implementing input controls such as the diamond mesh cod-end based on size selectivity (Lc_{50}) for *U. duvaucelii* in squid trawls (Madhu *et al*., 2011), which is estimated to be very close to the MLS, as well as maintaining vigilant surveillance of fishing activities are recommended.

Even though the present study covered 135 stocks and over 70 species, there is still a need to increase the number of stocks under a comprehensive assessment program to project the overall health of the fish stocks in the Indian EEZ and also to facilitate the development of a holistic fisheries management and development plan. Incorporating information on stock structure into the assessment and management of fish stocks will ensure the conservation of genetic diversity and biocomplexity in fish populations. Preserving the biocomplexity of fish populations is essential to ensure climatic resilience. Advanced genetic and genomic tools enable accurate identification of stocks/subpopulations along with patterns of local adaptation to habitats. ICAR-CMFRI has undertaken extensive research on the genetic stock structure of several species. So far, the genetic stock structure of 24 species has been delineated using mitochondrial and nuclear markers and this information has been utilised for assessing the stock status of those species in the present study (Muktha *et al*., 2022). Significant genetic differentiation has been detected between the east and west coasts of India, indicating the role of oceanographic and environmental barriers that limit their migration, larval dispersal and subsequent homogenisation of gene pools. Signals of local adaptation have also been observed in widely distributed species such as Indian oil sardine (Sebastian *et al*., 2021). Genetic stock structure information on all the assessed stocks has to be generated for undertaking fish stock assessment and management based on defined stock boundaries. Though information pertaining to genetic fish stock's distribution in space is highly recommended, the geographical features or similarities/dissimilarities in the ecosystem are often used to define stocks for practical assessment purposes in the absence of such information.

Comprehensive and periodic assessment of the fishery resources is a prerequisite for developing a sound fishery management plan. However, it has been practised only in certain parts of the world (*e.g.* NOAA region, https://www.fisheries.noaa.gov/sustainable-fisheries/status-stocks-2022) and barely in the Indian Ocean

Region. In an Indian context, a comprehensive assessment was attempted by Sathianandan *et al*. (2021) covering stock from all the regions of the Indian coastline to depict the status of Indian fish stocks. The present study also attempts to give an overall picture of the fish stocks in the Indian region. However, it largely differs from the attempts of Sathianandan *et al*. (2021) and other global reports (Piddocke *et al*., 2021; NOAA NMFS, 2023) in terms of the input data used. The results presented here are based on monthly length-frequency (LF) data collected from commercial fishing gears, unlike the time series catch or catch rates used in other assessment reports. The LF-based methods have certain advantages, like stock-specific data with fair accuracy (direct involvement of scientific staff against field enumerators or fisher's log books) and minimum influence on data structure due to demand-driven changes in fisheries as long as the fishing method (cod-end mesh size, fishing ground and other factors) remains the same. This LF-based approach would cater to the need for an Indian assessment program owing to multi-species fisheries, where getting species-specific catch/catch rate data over a longer temporal scale with fair accuracy is not easy. On the contrary, the network of research stations/centers of ICAR-CMFRI spanning all the coastal states of India ensures a continuous supply of high-quality species-specific LF data for assessment purposes. The present study provides a comprehensive stock status report for marine fish stocks of Indian EEZ based on LF and other biological inputs like length at maturity data. The study also recommends syncing of both catch and LF data collection to facilitate an integrated approach to fish stock assessment in the future.

Stock assessment of marine fish within the Indian EEZ, based on biological parameters and its reporting is envisaged as a regular, periodic output from the ICAR-CMFRI every 2-3 years, to enable science-based management of marine fish stocks in India. The number of stocks assessed will be incrementally increased to 180 and more in the coming years. The northern Indian Ocean (NIO) is an important region with respect to marine fisheries; and fisheries management in the region can be improved significantly through enhanced collaboration and regional networking for stock assessment, so that, stock assessment reports based on biological inputs for the NIO can be a reality in the near future.

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