Turk. J. Fish.& Aquat. Sci. 23(4), TRJFAS22465
https://doi.org/10.4194/TRJFAS22465

Turkish Journal of FISHERIES and AQUATIC SCIENCES

RESEARCH PAPER

Stock Assessment of Sin Croaker *Johnius dussumieri* (Cuvier, 1830) Fishery by Different Production Model Approach from Tamil Nadu, Southeast Coast of India

Rajendran Abinaya[1], Moosambikandy Sajeevan[1,*]

[1]Kerala University of Fisheries and Ocean Studies, Faculty of Fisheries, Department of Fisheries Resource Management, Kochi, 682506, Kerala, India.

How to Cite

Abinaya, R., Sajeevan, M. (2023). Stock Assessment of Sin Croaker *Johnius dussumieri* (Cuvier, 1830) Fishery by Different Production Model Approach from Tamil Nadu, Southeast Coast of India. *Turkish Journal of Fisheries and Aquatic Sciences*, *23(5)*, *TRJFAS22465.* https://doi.org/10.4194/TRJFAS22465

Article History
Received 23 August 2022
Accepted 17 October 2022
First Online 28 October 2022

Corresponding Author
Tel.: +919769586759
E-mail: sajeevanfsi@gmail.com

Keywords
Biological reference points
Fishery management
Overexploitation
Sin croaker fishery
Surplus production models

Abstract

The present study aims to analyze the exploitation status of the sin croaker *Johnius dussumieri* (Cuvier, 1830) fishery from Tamil Nadu, India waters. Annual catch and effort data were reconstructed from 2001 to 2020 and analyzed with different surplus production models using Catch and Effort Data Analysis (CEDA), Catch-based MSY (CMSY) and the Bayesian state-space implementation of the Schaefer production Model (BSM). The result of biological reference points such as maximum sustainable yield (MSY), relative stock size (B/B_{MSY}) and relative exploitation rate (F/F_{MSY}) from CEDA was 1,746 metric tonnes (MT), 0.93 and 1.11 respectively. However, CMSY and BSM models estimated MSY, B/B_{MSY} and F/F_{MSY} at 1,650 MT, 0.74 and 1.28 respectively. Hence, it can be inferred that the sin croaker fishery of Tamil Nadu, which was healthy during its initial stage distorted to overfishing status. Therefore, the present study recommends a reduction in fishing efforts and the implementation of conservation measures for better management and sustainable exploitation of the fishery.

Introduction

Fishes of the Family Sciaenidae includes 70 genera and 298 species distributed in the Atlantic, Indian and Pacific oceans (Nelson, 2006). Sciaenids, also known as croakers, grunters and jewfishes are small to medium-sized demersal marine fishes (Mohanraj et al., 2003). Croakers are the largest group within sciaenids with annual landing of 780 thousand metric tonnes (MT) in 2009, most of which were reported from the western Indian Ocean and North West Pacific (FAO 2011). The Indian Ocean is home to 48 sciaenid species from 27 different genera. Some species are restricted to deep water, coastal regions, estuaries and freshwater areas, while others have a broad geographical distribution range (Lal, 1991). Sin croaker *Johnius dussumieri* (Cuvier, 1830), is one of the commercially important sciaenid species of India, accounting for 13% of the sciaenid fishery in Tamil Nadu (CMFRI, 2018). The fish has been documented to occur on both the east and west coasts of India. They were mainly caught from Maharashtra and the Gulf of Mannar coast (MPEDA, 2021). Sciaenid fish resources have grown in importance in recent years due to the adoption of trawling and trawl by-catch primarily consists of juveniles (Sivadas et al., 2019). The great demand for juveniles from fish oil companies lead to a steady flow of income to the fishermen. This resulted in targeted fishery in the Gulf of Mannar and Nagapattinam (Sivadas et al., 2019). Several scientists studied the sciaenid fishery along the Indian coast

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

(Ghosh et al., 2010; Manojkumar, 2011; Santhoshkumar et al., 2011; Bhakta et al., 2020; Sabbir et al., 2021; Barman et al., 2022). However, no study has been conducted on the sustainability status of the sin croaker fishery from Tamil Nadu waters. The annual landings of all fishes belonging to the Family Sciaenidae were presented as croakers. Information on the annual landings and effort of sin croaker was not available. Hence, the present study reconstructed catch and effort data of sin croaker fishery along the Tamil Nadu coast.

A valid estimation on biological reference points (BRPs) of fishery resources is a prerequisite for fishery management. Catch, effort and catch per unit effort (CPUE) data are the primary input data for the conventional surplus production models (SPMs). The conventional SPMs use abundance data at a reasonably consistent rate resulting in an effort that reflects a catch in subsequent years (Coppola & Pascoe, 1998). It combined several population dynamics components into a simple model as well as project management reference points such as the maximum sustainable yield (MSY) or biomass giving MSY (B_{MSY}) or fishing mortality giving MSY (F_{MSY}) (Pincin & Wilberg, 2012). Henceforth, the present study analyzed the sustainability status of sin croaker fishery through various SPMs using reconstructed catch and effort data from 2001 to 2020.

Materials and Methods

Data Sources

Historical annual catch and effort data for sin croaker fishery were reconstructed using published sources such as the fisheries handbook (DADF, 2009, 2012), central institute reports (CMFRI, 2010, 2011, 2012a, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020), Tamil Nadu policy notes (GOT, 2004, 2005, 2006, 2010, 2011, 2012, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020), scientific dissertation (Bhathal, 2014) and other related government documents (MOA, 2001; CMFRI, 2006, 2012b) outlining Bhathal (2014). The total catch and fishing effort of the species were expressed as catch weight in MT and Horsepower (HP) days. Bhathal (2014) provided catch data for the Tamil Nadu sin croaker fishery from 2001 to 2005. From 2006 to 2020, landing data for the sin croaker fishery was reconstructed by converting group-wise croaker landing data (DADF, 2012; CMFRI, 2013, 2014, 2015, 2016, 2017, 2018, 2019, 2020) to species level based on composition of croaker landings (MOA, 2001).

The main variables for the reconstruction of fishing effort were vessels with and without an engine; the total number of vessels, total power (HP units), fishing days, and crew size. The fishing effort of the vessel with an engine such as motorized and mechanized fishing units (craft and gear combination) was estimated separately as the product of number of vessels, total power (HP units), and fishing days (Bhathal 2014). In the case of the vessel without an engine (non-motorized vessels), the product of number of vessels, crew size, average daily energy output equivalent to HP of a south Asian male (Karim, 1985; Dalzell et al., 1987) and fishing days were estimated separately for fishing units in HP days. Following Bhathal (2014), the effort of a vessel without an engine was reconstructed using an average crew size of eight from 2001 to 2020. The average engine power of vessels with an estimated number of fishing days for each gear in the given time was used to determine the vessels with engine's fishing effort. The number of fishing days in a year was computed based on six fishing days each per week. Downtime and spiritual vacation days were deducted from the total number to determine the fishing days. Sin croakers were caught by gillnets, liners and hand lines, trawl nets and other gears, which took an average of 216, 75, 240 and 228 fishing days, respectively. Fishing efforts estimated for each fishing unit were summed up to find out the total fishing effort and presented in tabular form against time series data of catch. To address differences in the catchability coefficient of fishing gears, crew size and HP of the engine was taken as crucial component for effort estimation of the vessel without an engine and vessel with an engine, respectively. Standardization of effort was carried out following Bhathal (2014) and Abinaya & Sajeevan (2022).

Data Analysis

Catch and Effort Data Analysis (CEDA) Software

SPMs integrate catch and effort data or catch and CPUE to estimate biomass and other fishery reference points. The present study used CEDA version 3.0.1 (MRAG, 2016), which performed a regression analysis for three SPMs, namely the Schaefer model (Schaefer, 1954), the Pella-Tomlinson model (Pella & Tomlinson, 1969) and the Fox model (Fox, 1970), each one with three error assumptions, i.e. normal, log-normal, and gamma models. It delivers a variety of BRPs like MSY, B_{MSY} and F_{MSY} to present information on the status of the sin croaker fishery. Schaefer (1954) developed the first surplus production model founded on Graham's past efforts. The logistic population growth model served as a basis for the Schaefer model:

$$dB/_{dt} = \mathrm{rB}(B_\infty - \mathrm{B}) \quad \text{.......... Schaefer (1954)}$$

Following that, Pella-Tomlinson (1969) recognized a generalized production equation:

$$\frac{dB}{dt} = rB({B_\infty}^{n-1} - B^{n-1}) \text{...Pella \& Tomlinson (1969)}$$

And Fox (1970) proposed a Gompertz growth equation:

$$dB/_{dt} = \mathrm{rB}(\mathrm{In}B_\infty - \mathrm{InB}) \text{...Fox (1970)}$$

Where B, fish stock biomass; t, time in a year; r, intrinsic rate of population increase; B_∞, carrying capacity; n, shape parameter.

CEDA requires an initial proportion (IP), which is the ratio of population's starting size to the maximum historical catch. When the starting proportion is zero or close to zero, the fishery begins with an intensively exploited population; when the starting proportion is one or close to one, the fishery begins with a virgin population. Outcomes of CEDA computer application are carrying capacity (K), intrinsic growth rate (r), final biomass (B), catchability coefficient (q), maximum sustainable yield (MSY), replacement yield (R yield), Biomass giving MSY (B_{MSY}) and fishing mortality giving MSY (F_{MSY}). Based on the resilience plot and coefficient of the determination R^2 values, the best fit model was selected for further exploration of the BRPs. The BRPs of the best fit model were analyzed further to understand the exploitation status of sin croaker fishery in Tamil Nadu from 2001 to 2020.

Catch-based MSY (CMSY) and Bayesian State-space Implementation of the Schaefer Production Model (BSM) Models

CMSY and the relevant BSM R-packages (Froese et al., 2017) were used to analyze the catch and CPUE or catch and biomass data through a Markov Chain Monte Carlo method based on the Schaefer function. The key outputs of the model include biomass trends, exploitation rates (F/F_{MSY}), relative stock size (B/B_{MSY}), fisheries intermediate parameters (MSY, r, and k) and BRPs (MSY, F_{MSY}, and B_{MSY}) (Froese et al., 2017).

Simple biomass dynamics in the CMSY and BSM models are expressed in

$$B_{t+1} = B_t + r\,(1- B_t / k)\, B_t - C_t,$$

Where B_t, biomass in year t; $B_{t+1,}$ biomass in the succeeding year; r, intrinsic rate of population increase; k, carrying capacity; $C_{t,}$ catches in year t.

The resilience values of sin croaker fishery was used to provide default parameters to r-ranges. The medium resilience range of croaker fish resources was employed as an input and determined as 0.2 - 0.8 (Froese et al., 2017). Prior biomass ratio to carrying capacity (B/k) at the start and the end of the period, i.e., B_{start}/k and B_{end}/k, were demanded by the CMSY and BSM techniques. The relative biomass at the beginning and end of each time series was set based on the depletion level of the stock. Croaker landings were significantly smaller during the first and last years of the dataset; hence a low prior value for B/k was considered to be acceptable, and the prior beginning and last year relative biomass ranges were implemented at 0.4 - 0.8 and 0.2 - 0.6 (Froese et al., 2017). Sin croaker landings were adjusted by default throughout the intermediate phase, and the program fixed the value of 0.5 - 0.9. Prior ranges for r, k and q values ranged 0.2 - 0.8, 3.15- 50.3 and 1.83e-06 - 7.31e-06, respectively.

The JAGS tool and the Markov chain Monte Carlo technique measured the various statistical parameters (Plummer, 2003). This provides adequate knowledge about the BRP of the fishery (Nisar et al., 2021). The CMSY and BSM model BRPs and equilibrium yield curve findings were used to compare the results with CEDA to determine the exact situation of the sin croaker fishery in Tamil Nadu from 2001 to 2020.

Results

Historical catch and effort statistics of the sin croaker fishery of Tamil Nadu from 2001 to 2020 are presented in Table 1. As shown in Table 1, the landings of the sin croaker fishery decreased from 2001 to 2005 with minimal fluctuation, followed by an increasing

Table 1. Total catch (in metric tonnes) and effort (in million horsepower days) of the sin croaker fishery in Tamil Nadu from 2001 to 2020

Year	Total catch in metric tonnes	Effort in million horsepower days
2001	1234	54.93
2002	1398	55.49
2003	1181	59.37
2004	1196	63.94
2005	861	58.49
2006	1327	62.91
2007	1387	69.37
2008	1642	65.81
2009	1751	62.23
2010	1700	62.23
2011	1764	75.15
2012	2582	85.58
2013	2679	87.88
2014	2289	82.44
2015	1937	90.00
2016	2738	91.99
2017	2370	107.68
2018	1863	112.82
2019	2025	134.81
2020	1565	99.67

trend from 2005 to 2013, and a decreasing trend with a large-scale variation of the catch was observed during recent years. The reconstructed effort of the sin croaker was increased throughout the study except during 2020 (Table 1). The CPUE of sin croaker in Tamil Nadu from 2001 to 2020 showed an increasing trend from 2005 to 2013. Since 2013, a reduction in CPUE was recorded with a large-scale fluctuation (Figure 1).

CEDA Results

MSY estimated by CEDA computer software for the sin croaker fishery for a wide range of IP values (0.1 to 0.9) is furnished in Table 2. The results obtained from the CEDA package were highly responsive to the input IP values (Table 2) and the present study used an IP value of 0.5 because the initial yield was about 50% of the maximum catch. The catch and effort data were analyzed with CEDA software and the results are shown in Table 3. As seen in Table 3, the values of several intermediates with biological parameters varied depending on the three SPMs. The intermediate parameters of carrying capacity (K) values varied from 28,544 t (Schaefer & Pella-Tomlinson normal) to 40,837 t (Fox log-normal), while the catchability coefficient (q) ranged from 1.01E-09 (Fox log-normal) to 1.51E-09 (Schaefer & Pella-Tomlinson normal) and intrinsic population growth rate (r) estimates fluctuated between 0.13 (Fox normal) and 0.27 (Schaefer & Pella-Tomlinson log-normal).

The BRPs of MSY with the CEDA program varied between 1,074 t (Schaefer & Pella-Tomlinson normal) and 1,924 t (Fox log-normal) and the B/ B_{MSY} ratio ranged between 0.85 (Schaefer & Pella-Tomlinson normal) and 1.30 (Fox log-normal). The variable with the perfect fit was determined based on the high R^2 values of the regression analysis (Table 3) and trends in residual plots (i.e., expected and observed catch/CPUE evenly scattered in a horizontal band; Mohsin et al., 2017). The equilibrium yield curve of sin croaker fishery (Figure 2) for the Schaefer log-normal model illustrated that MSY varied depending on biomass. The parabolic curve demonstrated that yield increased from the virgin population to a peak of MSY (1,746 t) at a B_{MSY} of 16,619 t, then significantly decreased to zero when biomass reached its maximum, i.e., carrying capacity (33,237 t).

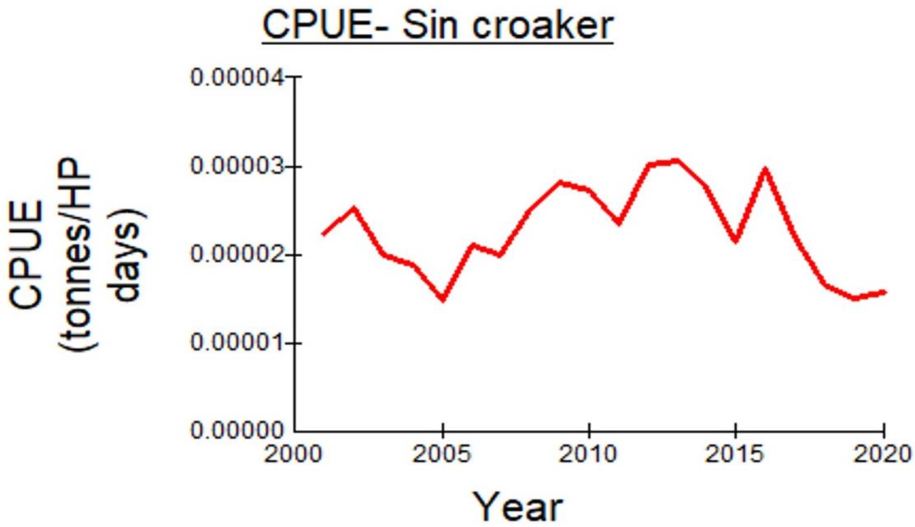

Figure 1. The CEDA computer package predicted the catch per unit effort (CPUE) of sin croaker fishery in Tamil Nadu from 2001 to 2020.

Table 2. Maximum Sustainable Yield (MSY) estimated (expressed in metric tonnes) by CEDA for the sin croaker fishery in Tamil Nadu from 2001 to 2020 using Fox, Schaefer and Pella Tomlinson and their error assumption models (normal, log-normal, and gamma) for a range of initial proportions (0.1 to 0.9)

	Fox model			Schaefer model			Pella Tomlinson model		
IP	normal	log-normal	gamma	normal	log-normal	gamma	normal	log-normal	gamma
0.1	4242	4913	4941	5980	6198	MF	6980	4798	MF
0.2	3991	4741	MF	4656	5479	MF	5656	4479	MF
0.3	3603	3921	3188	3772	4654	MF	3772	3654	MF
0.4	2993	2199	MF	2204	3298	MF	2204	3298	MF
0.5	1806	1924	MF	1703	1746	MF	1703	1746	MF
0.6	1100	1402	MF	1421	1421	MF	1421	1421	MF
0.7	823	632	4941	1212	1131	MF	1212	1131	MF
0.8	502	253	MF	802	831	MF	802	831	MF
0.9	123	131	3188	631	421	MF	631	421	MF

* MF, minimization failure.

CMSY and BSM Results

The annual catch increased from 2001 to 2016 and the 3-year moving average of catch reached a peak in 2013 (Figure 3A). Viable r-k pairs in the shape of triangles showed that medium resilience of 0.2–0.6 makes sense (Figure 3B). The best r-k pairs were discovered by CMSY (blue cross) and BSM (red cross), and their estimated 95 % CI overlapped for both models (Figure 3C). The relative biomass of CMSY and BSM models revealed a decreasing trend of biomass in recent years (Figure 3D). The exploitation rate F/(r/2) of both models signalled an overall upward trend in exploitation through 2019 (Figure 3E). Catch relative to MSY versus biomass relative to unexploited stock size (B/k) showed that 60% of catch estimates from both models were above the equilibrium curve, which inferred that overfishing of the stock and reduction of biomass (Figure 3F).

BRPs of the CEDA and BSM models are furnished in Table 4. As shown in Table 4, MSY values were comparable. The MSY results of the CMSY and BSM models were 1,990 t, (95% CI=1,520 – 2,600 t) and 1,650 t, (95 % CI=1,330 – 2,060 t), respectively. The plots of landings against MSY indicated the over-fished status of sin croakers along the Tamil Nadu coast from 2008 onwards (Figure 4A). Biomass projected by BSM, along with CI (grey color) is depicted in Figure 4B. The horizontal dashed line represents B_{MSY} (68,000 t, 95% CI=51,400 – 89,800 t), and the dotted line represents 50% of B_{MSY}. The solid black line is just above the B/ B_{MSY} line, showing that present biomass exceeds B_{MSY} by a substantial amount.

The exploitation plots are projected using CMSY and the BSM approach showed that present fishing mortality exceeds F_{MSY} or F/F_{MSY} value crossed one after 2012 (Figure 4C). The correlation between B/B_{MSY} and F/F_{MSY} showed that the estimated F/F_{MSY} was less than

Table 3. The results of the CEDA software with an initial proportion of 0.5 for sin croaker fishery in Tamil Nadu from 2001 to 2020

Model	K	q	r	MSY	R^2	B	B_{MSY}	F_{MSY}
Fox (normal)	35352	1.25E-09	0.14	1806	0.46	15335	13005	0.14
Fox (log-normal)	40837	1.01E-09	0.13	1924	0.52	19666	15023	0.13
Fox (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF
Schaefer (normal)	28545	1.51E-09	0.24	1703	0.51	12160	14272	0.12
***Schaefer (log-normal)**	**33237**	**1.23E-09**	**0.27**	**1746**	**0.55**	**15434**	**16619**	**0.11**
Schaefer (Gamma)	MF	MF	MF	MF	MF	MF	MF	MF
Pella- Tomlinson (normal)	28545	1.51E-09	0.24	1703	0.51	12160	14272	0.12
Pella-Tomlinson (log-normal)	33237	1.23E-09	0.27	1746	0.55	15434	16619	0.11
Pella-Tomlinson (Gamma)	MF	MF	MF	MF	MF	MF	13005	0.14

*: the best fit model, MF: minimization failure, K: carrying capacity, q: catchability coefficient, r: intrinsic population growth rate, MSY: maximum sustainable yield, R^2: coefficient of determination, CV: coefficient of variation, B: current biomass, B_{MSY}: stock biomass giving MSY, F_{MSY}: fishing mortality rate giving MSY.

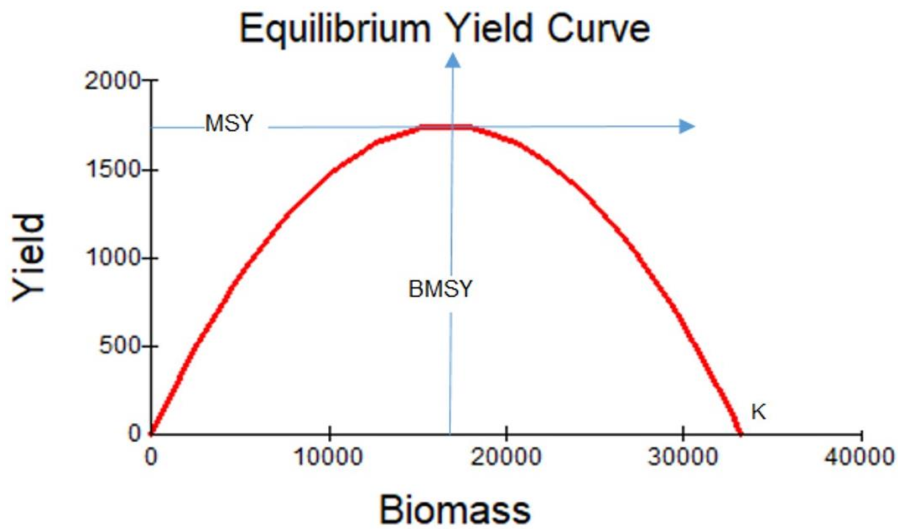

Figure 2. The projected equilibrium yield curve of the sin croaker fishery in Tamil Nadu with the Schaefer log-normal model (initial proportion= 0.5) from 2001 to 2020.

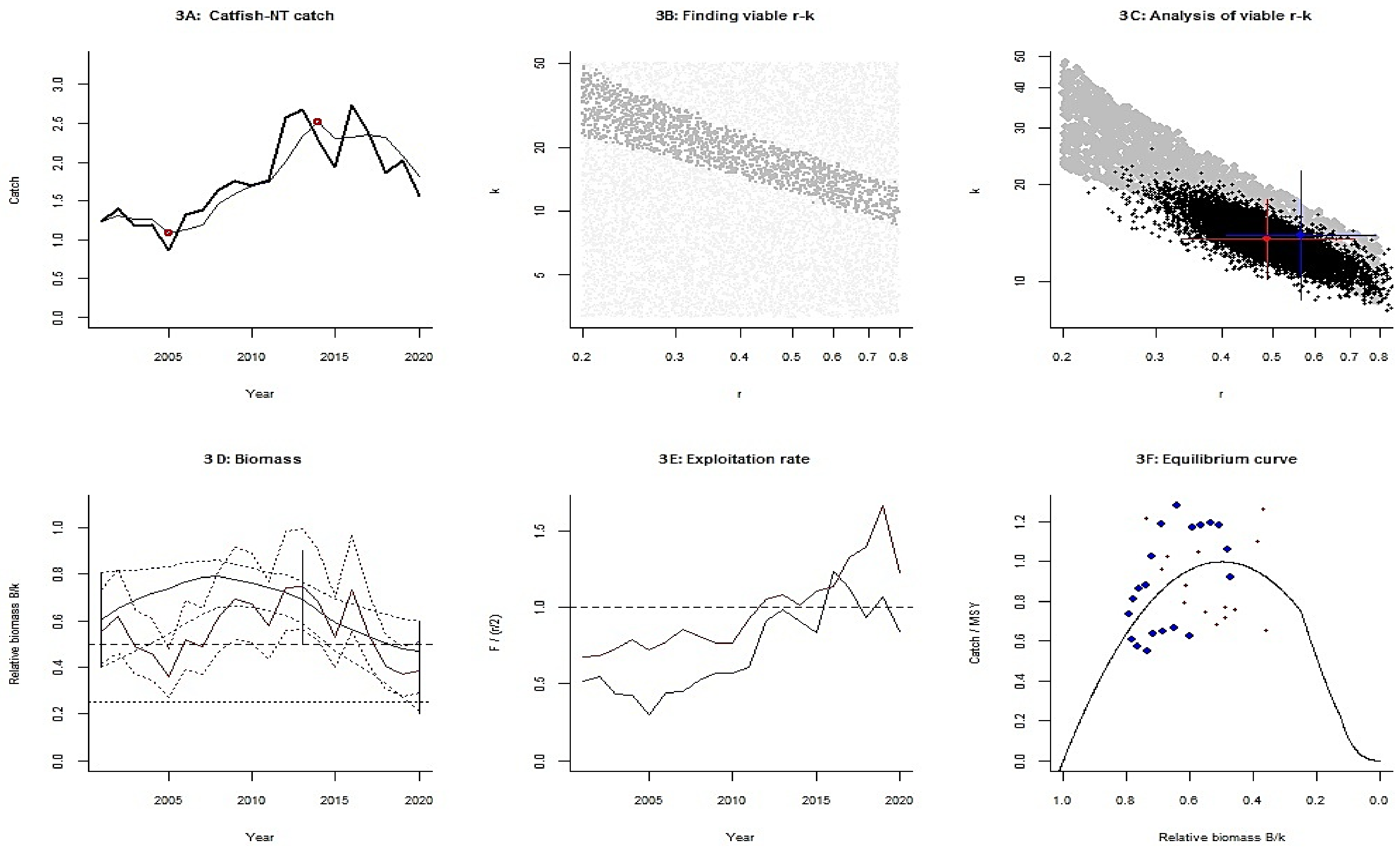

Figure 3. The results of the CMSY (blue) and BSM (red) analysis. **A**. Annual catch trend (black line) with a three-year moving average of catch, with high and low catch (red dots). **B.** Finding viable r-k pairs in medium resilience (0.2-0.8). **C**. Investigation of viable r-k pairs with confidence interval (dotted lines) in medium resilience range. **D**. Estimated biomass trajectories for the 2.5th and 97.5th percentiles (dotted lines). **E**. Exploitation trajectories of both models. **F**. Equilibrium curve of the relative biomass versus catch /MSY forecasted by both models.

1.0 and B/B_{MSY} was more than 1.0 in 2001, which shows there was no overfishing/ overfished during the initial stage of the study. But, during 2013, both values exceeded one, indicating heavy fishing pressure on the stock. In 2020, a drop of B/B_{MSY} from one was recorded, demonstrating overfishing of the resources leading to an overfished status (Figure 4D).

Discussion

Reconstructed catch and effort data of sin croaker fishery in Tamil Nadu registered an overall increasing trend since 2005 except 2020 (Table 1). A decrease in catch and effort reported during 2020 may be due to the Covid-19 pandemic, which resulted in the loss of fishing days (CMFRI, 2020). However, CPUE of sin croaker fishery registered an overall increasing trend upto 2013, followed by a decreasing trend with large-scale fluctuation (Figure 1). CPUE provides preliminary information on fishery status but may not be proportional to abundance over the whole exploitation history. However, standardization of CPUE data is considered as an attempt to make them proportional to abundance (Maunder et al., 2006). The present study used standardized catch and effort data to estimate CPUE. Hence this index of relative abundance can be used to infer the status of the fishery.

CEDA

The MSY calculated using the best fit model (Schaefer log-normal) was greater than the average catch (1,794 t). However, since 2011 annual landings were higher than MSY. Moreover, BRPs like B_{MSY} and F_{MSY} (Table 4) concluded that the sin croaker fishery stock attained a stage of overfishing but was not overfished in Tamil Nadu. Overcapitalization of the fishery (Table 1) can be attributed as a major reason for this phenomenon. Rahul (2017) opined that intensified fishing by artisanal and mechanized fishing sectors resulted in a declining trend of near-shore fishing in Tamil Nadu. It implies that the fishery needs to be controlled by reducing the fishing effort.

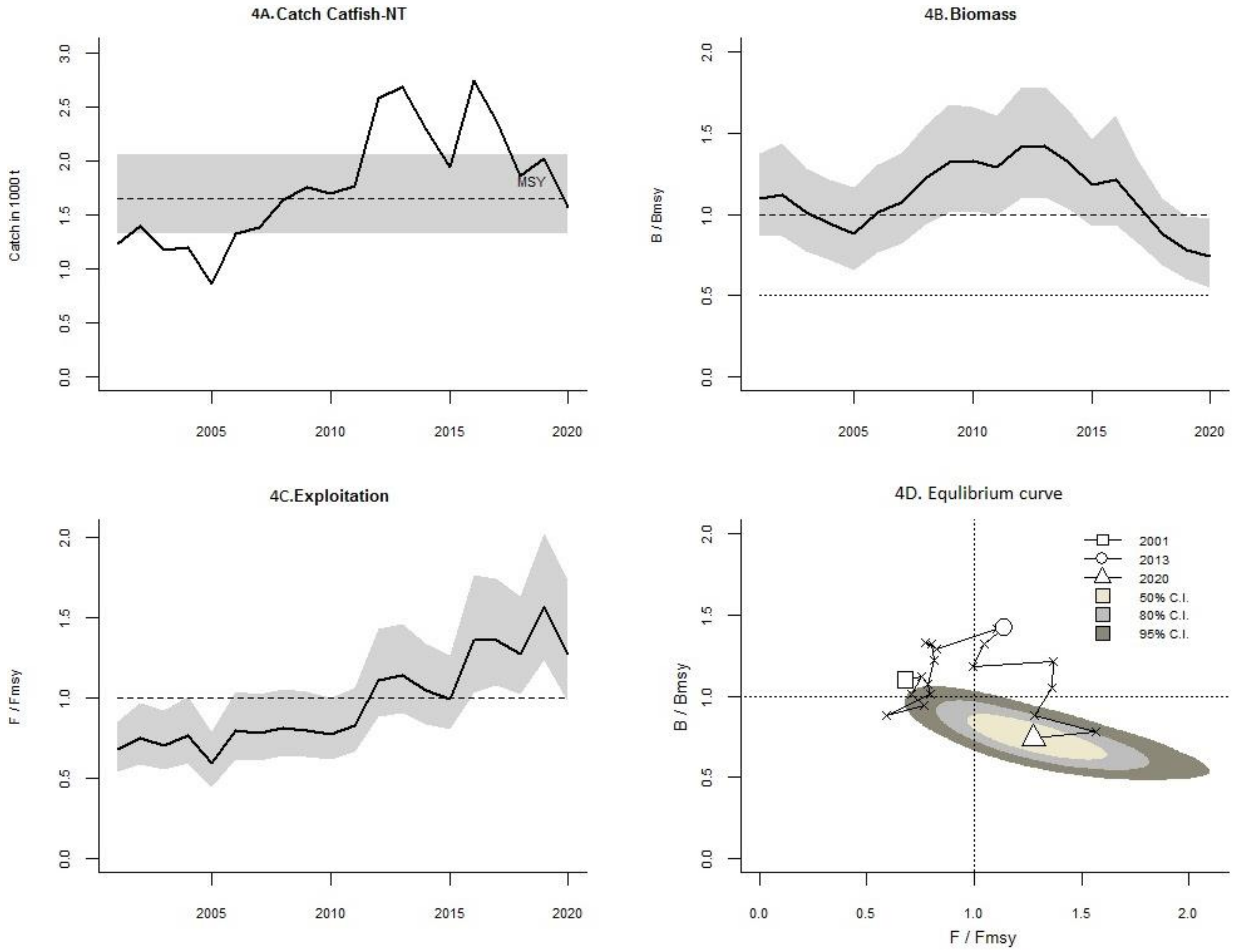

Figure 4. A. The relation between catch and MSY with 95% confidence limit by CMSY and BSM models of sin croaker fishery in Tamil Nadu from 2001 to 2020. **B**. The trend of biomass projection (B/B_{MSY}) of the sin croaker fishery in Tamil Nadu from 2001 to 2020. **C**. The trend of Exploitation rate (F/F_{MSY}) with a confidence interval for the sin croaker fishery in Tamil Nadu from 2006 to 2020. **D**. he relationship between B/B_{MSY} and F/F_{MSY} for the sin croaker fishery from 2001 to 2020, with different confidence intervals (50%, 80%, and 95%).

Table 4. The comparison between the output of the CEDA (Schaefer log-normal model with an initial proportion of 0.5) and BSM models

Outputs	B	F	MSY	B_{MSY}	F_{MSY}	B/B_{MSY}	F/F_{MSY}
CEDA	15434	0.12	1746	16619	0.11	0.93	1.11
BSM	50400	0.31	1650	68000	0.24	0.74	1.28

*B, current biomass; F, Fishing mortality; MSY, maximum sustainable yield; $B_{MSY,}$ biomass giving MSY; $F_{MSY,}$ Fishing mortality giving MSY; B/B_{MSY}, a ratio of biomass to biomass giving MSY; $F/F_{MSY,}$ a ratio of fishing mortality to fishing mortality giving MSY.

CMSY and BSM Models

A comparative study of annual landings with estimated MSY showed that recent year landings were above the level of MSY, which indicates overexploited status of the fishery (Figure 4A). Memon et al. (2015) and Mohsin et al. (2020) also opined that the calculated MSY lower than catch statistics indicates overexploitation of the stock. The reduction of biomass against B_{MSY} recorded during recent year's shows overexploitation (Figure 4B). Biomass at the same or below the level of B_{MSY} indicates unsustainable fishery (Najmudeen et al., 2019; Varghese et al., 2020). The plots of exploitation illustrated an increase of F/F_{MSY} from the beginning of the fishery and it crossed one in 2012 (Figure 4C). From this, it can be inferred that the fishery entered into overfishing in 2012. Wang et al. (2020) and Barman et al. (2022) observed similar phenomena of increased F value leading to overfishing. However, the B/B_{MSY} and F/F_{MSY} plots (Figure 4D) depict overfishing leading to overfished status during recent years. Zhang et al. (2020) and Wang et al. (2020) reported that a plunge of B/B_{MSY} below one indicates overfished status. Hence, it can be concluded that the sin croaker fishery of Tamil Nadu has reached overfishing leading to overfished status.

The overall results of the three models (CEDA, CMSY, and BSM) revealed that the sin croaker fishery in Tamil Nadu is overcapitalized. Hence a reduction of fishing effort is required to ensure sustainable sin croaker fishery. Studies on the status of the sciaenid fishery of Tamil Nadu (Mohanraj et al., 2003) suggested that the fishing effort of all sciaenid species is to be maintained at the present level as a further increase is detrimental to the stocks of sciaenids. However, Santhoshkumar et al. (2011) recorded a low exploitation rate of *Nibea maculata* from the Thoothukudi coast of Tamil Nadu. Studies on the fishery of *Otolithes biauritus* from Diu water bodies (Ghosh et al., 2010), *Otolithes cuvieri* from Veraval coast (Manojkumar, 2011), *Johnieops sina* from the Malabar Coast (Manojkumar, 2011), *Otolithoides panna* from Hooghly-Matlah estuary of West Bengal (Bhakta et al., 2020), *Panna heterolepis* from the Bay of Bengal waters (Sabbir et al., 2021) and croaker fishery from Bangladesh waters (Barman et al., 2022) revealed fully exploited/ overexploited status of the stock and recommended control/reduction of fishing effort. Moreover, based on the available information FAO (2020) warned that stock of croaker and drums are likely to be overfished in major fishing areas around the world.

In addition to decreasing fishing effort, more cautious tactics will be deemed essential for better planning and management of fishery. Ban on trawling during the monsoon period to sustain the spawning and juvenile populations, Control on juvenile fishing through implementation of cod end mesh size of 25-30 mm, declaring closed areas of the shallow protected coastal region which serve as nursery grounds for croakers are some of the regulatory measures for protecting the stock from future pressure (Mohanraj et al., 2003). Hence, the present study recommends a reduction of fishing effort and conservation measures like ban on trawling, mesh size regulation, protection of nursery ground, and declaration of closed areas for ensuring sustainable fishery of sin croaker in Tamil Nadu India waters.

Conclusion

The present study reconstructed catch and effort data of sin croaker fishery of Tamil Nadu from 2001 to 2020. Fitting of catch and effort data to SPMs revealed that the sin croaker fishery was healthy during the initial period and reached to an overfishing status in 2013. Overcapitalization of fishing efforts was considered as a major reason for overfishing. Hence, present study recommended a reduction in fishing efforts to ensure a sustainable fishery.

Ethical Statement

Not applicable

Funding Information

Not applicable.

Author Contribution

Rajendran Abinaya: Conceptualization, Writing - review and editing, Data Curation, Formal Analysis, Visualization and Writing -original draft; Moosambikandy Sajeevan: Investigation, Methodology, Supervision, Writing - review and editing.

Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in the paper.

Acknowledgements

We are grateful to Prof. (Dr.) Riji John, Hon; ble Vice-Chancellor and Prof. (Dr.) Rosalind George, Dean, Kerala University of Fisheries and Ocean Studies, Panangad, provides the necessary facilities for undertaking this research at the University.

References

Abinaya, R., & Sajeevan, M. (2022). Stock status of giant catfish *Netuma thalassina* (Rüppell, 1837) from Tamil Nadu, India waters. *Fisheries Management and Ecology*. https://doi.org/10.1111/fme.12583

Barman, P.P., Shamsuzzaman, M.M., Schneider, P., Mozumder, M.M.H., & Liu, Q. (2022). Fisheries Reference Point and Stock Status of Croaker Fishery (Sciaenidae) Exploited from the Bay of Bengal, Bangladesh. *Journal of marine science and engineering*, 10(1), 63. https://doi.org/10.3390/jmse10010063

Bhakta, D., Das, S.K., Das, B.K., Nagesh, T.S., & Samanta, R. (2020). Growth, mortality and exploitation status of *Otolithoides pama* (Hamilton, 1822) from Hooghly-Matlah estuary of West Bengal, India. *Regional Studies in Marine Science*, 39, 101451. https://doi.org/10.1016/j.rsma.2020.101451

Bhathal, B. (2014). Government-led development of India's marine fisheries since 1950: catch and effort trends, and bioeconomic models for exploring alternative policies. Doctoral dissertation, University of British, Columbia, 355p. http://hdl.handle.net/2429/46277

CMFRI, K. (2006). Marine Fisheries Census 2005 Part III (4), Tamil Nadu. Department of Animal Husbandry, Dairying and Fisheries and Central Marine Fisheries Research Institute, Cochin, 408p. http://eprints.cmfri.org.in/id/eprint/5525.

CMFRI. (2010). *Annual Report 2009-2010*. Central Marine Fisheries Research Institute, Kochi, Kerala, 173p.

CMFRI. (2011). *Annual Report 2010-2011*. Central Marine Fisheries Research Institute, Kochi, Kerala, 166p.

CMFRI. (2012a). *Annual Report 2011-2012*. Central Marine Fisheries Research Institute, Kochi, Kerala, 190p.

CMFRI. (2012b). *Marine fisheries census 2010 Part II (4)*, Tamil Nadu. Central Marine Fisheries Research Institute, Kochi, Kerala, 110p.

CMFRI. (2013). *Annual Report 2012-2013*. Central Marine Fisheries Research Institute, Kochi, Kerala, 204p.

CMFRI. (2014). *Annual Report 2013-2014*. Central Marine Fisheries Research Institute, Kochi, Kerala, 353p.

CMFRI. (2015). *Annual Report 2014-2015*. Central Marine Fisheries Research Institute, Kochi, Kerala, 291p.

CMFRI. (2016). *Annual Report 2015-2016*. Central Marine Fisheries Research Institute, Kochi, Kerala, 296p.

CMFRI. (2017). *Annual Report 2016-2017*. Central Marine Fisheries Research Institute, Kochi, Kerala, 291p.

CMFRI. (2018). *Annual Report 2017-2018*. Central Marine Fisheries Research Institute, Kochi, Kerala, 304p.

CMFRI. (2019). *Annual Report 2019*. Central Marine Fisheries Research Institute, Kochi, Kerala, 368p.

CMFRI. (2020). *Annual Report 2020*. Central Marine Fisheries Research Institute, Kochi, Kerala, 284p.

Coppola, G., & Pascoe, S. (1998). A surplus production model with a nonlinear catch-effort relationship. *Marine Resource Economics*, 13, 37-50. https://doi.org/10.1086/mre.13.1.42629217

DADF. (2009). *Handbook on fisheries statistics 2008*. Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, New Delhi, 91p.

DADF. (2012). *Handbook on fisheries statistics 2011*. Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, New Delhi, 38p.

Dalzell, P., Corpuz, P., Ganaden, R., & Pauly, D. (1987). Estimation of maximum sustainable yield and maximum economic rent from the Philippine small pelagic fisheries. *BFAR Technical Paper Series*, 10(3), 23. ICLARM, Manila, Philippines and Bureau of Fisheries and Aquatic Resources, Quezon City, Philippines.

FAO. (2011). Yearbook of fishery and aquaculture statistics 2009. Capture production. Food and Agriculture Organization of the United Nations. Rome.

FAO. (2020). *The State of World Fisheries and Aquaculture 2020*. Sustainability in action. Food and Agriculture Organization of the United Nations. Rome. https://doi.org/10.4060/ca9229en

Fox Jr, W. W. (1970). An exponential surplus yield model for optimizing exploited fish populations. *Transactions of the American Fisheries Society*, 99(1), 80-88. https://doi.org/10.1577/1548-8659 (1970) 99<80: AESMFO>2.0.CO;2

Froese, R., Demirel, N., Coro, G., Kleisner, K.M., & Winker, H. (2017). Estimating fisheries reference points from catch and resilience. *Fish and Fisheries, 18(3)*, 506-526. https://doi.org/10.1111/faf.12190

Ghosh, S., Mohanraj, G., Asokan, P.K., Dhokia, H.K., Zala, M.S., Bhint, H.M., & Anjani, S. (2010). Fishery and population dynamics of *Protonibea diacanthus* (Lacepede) and *Otolithoides biauritus* (Cantor) landed by trawlers at Vanakbara, Diu along the west coast of India. *Indian Journal of Fisheries*, 57(2), 15-20. http://eprints.cmfri.org.in/id/eprint/2349

GOT. (2004). *Tamil Nadu Policy note 2003-04*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 29 p.

GOT. (2005). *Tamil Nadu Policy note 2004-05*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 15 p.

GOT. (2006). *Tamil Nadu Policy note 2005-06*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 25 p.

GOT. (2010). *Tamil Nadu Policy note 2009-10*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 56 p.

GOT. (2011). *Tamil Nadu Policy note 2010-11*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 37 p.

GOT. (2012). *Tamil Nadu Policy note 2011-12*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 34 p.

GOT. (2013). *Tamil Nadu Policy note 2012-13*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 31 p.

GOT. (2014). *Tamil Nadu Policy note 2013-14*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 80p.

GOT. (2015). *Tamil Nadu Policy note 2014-15*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 173p.

GOT. (2016). *Tamil Nadu Policy note 2015-16*. Animal Husbandry and Fisheries Department, Government of

Tamil Nadu, India, 183p.
GOT. (2017). *Tamil Nadu Policy note 2016-17*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 177p.
GOT. (2018). *Tamil Nadu Policy note 2017-18*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 185p.
GOT. (2019). *Tamil Nadu Policy note 2018-19*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 131p.
GOT. (2020). *Tamil Nadu Policy note 2019-20*. Animal Husbandry and Fisheries Department, Government of Tamil Nadu, India, 138p.
Karim, M.N.A. (1985). Energy expenditure of a group of students at Universiti Pertanian Malaysia. *Pertanika*, 8(1): 155-157.
Lal Mohan, R.S. (1991). A review of the sciaenid fishery resources of the Indian Ocean. *Journal of the Marine Biological Association of India,* 33 (1&2), 134-145. http://eprints.cmfri.org.in/id/eprint/821
Manojkumar, P.P. (2011). Fishery of sciaenids with some observations on the biology and stock assessment of *Johnieops sina* (Cuvier, 1830) exploited along the Malabar coast. *Journal of the Marine Biological Association of India*, 53(1), 68-74. http://eprints.cmfri.org.in/id/eprint/8706
Maunder, M.N., Sibert, J.R., Fonteneau, A., Hampton, J., Kleiber, P., & Harley, S.J. (2006). Interpreting catch per unit effort data to assess the status of individual stocks and communities. *Ices Journal of marine science*, 63(8), 1373-1385. https://doi.org/10.1016/j.icesjms.2006.05.008
Memon, K.H., Liu, Q., Kalhoro, M.A., Nabi, A., & Kui, Z. (2015). Maximum sustainable yield estimates of barramundi Lates calcarifer fishery from Pakistani waters. *Indian Journal of Geo-Marine Sciences*, 44(6), 825-832. http://nopr.niscpr.res.in/handle/123456789/34822
MOA. (2001). *Report of the working group for revalidating the potential of fishery resources in the Indian EEZ 2000*. Department of Animal Husbandry, Dairying and Fisheries, Ministry of Agriculture, New Delhi, 68p.
Mohanraj, G., Batcha, H., & Gomathy, S. (2003). *Sciaenids.* In: Status of Exploited Marine Fishery Resources of India. CMFRI, Cochin, pp. 133-140. http://eprints.cmfri.org.in/id/eprint/6017
Mohsin, M., Hengbin, Y., & Mehak, C.Z.A. (2020). An assessment of overexploitation risk faced by cephalopod fisheries in China: A non-equilibrium surplus production model approach. *Indian Journal of Geo Marine Sciences*, 49(02), 318-325. http://nopr.niscpr.res.in/handle/123456789/54067
MPEDA. (2021). Sciaenids. Marine Products Export Development Authority. * https://mpeda.gov.in/?page_id=1279
MRAG. (2016). Catch and effort analysis (CEDA) v3.0 (Version 3. 0). Marine Resources Assessment Group. http://www.mrag.co.uk/resources/fisheries-assessment-software
Najmudeen, T.M., Seetha, P.K., & Zacharia, P.U. (2019). Stock dynamics of the brushtooth lizardfish *Saurida undosquamis* (Richardson, 1848) from a tropical multispecies fishery in the southeastern Arabian Sea. *Aquatic Living Resources*, 32, 9. https://doi.org/10.1051/alr/2019006
Nelson, J.S. (2006). *Fisheries of the World*. John Wiley and Sons, Incorporation. New York. 600p.
Nisar, U., Ali, R., Mu, Y., & Sun, Y. (2021). Assessing Five Major Exploited Tuna Species in India (Eastern and Western Indian Ocean) Using the Monte Carlo Method (CMSY) and the Bayesian Schaefer Model (BSM). *Sustainability*, 13(16), 8868. https://doi.org/10.3390/su13168868
Pella, J.J., & Tomlinson, P.K. (1969). A generalized stock production model. *Inter-American Tropical Tuna Commission Bulletin*, *13(3),* 416-497. http://aquaticcommons.org/id/eprint/3536
Pincin, J.S., & Wilberg, M.J. (2012). Surplus production model accuracy in populations affected by a no-take marine protected area. *Marine and Coastal Fisheries,* 4, 511 - 525. https://doi.org/10.1080/19425120.2012.685145
Plummer, M. (2003). JAGS: a program for analysis of Bayesian graphical models using Gibbs sampling. – In: Hornik, K., Leisch, F., Zeileis, A. (eds.) International Proceedings of the 3rd International Workshop on Distributed Statistical Computing (DSC 2003) March 20-22, Vienna, 2003. Vienna Technical University, Vienna pp. 20-22. https://www.r-project.org/conferences/DSC-2003/Proceedings/Plummer.pdf
Rahul M. (2017). *Open letter: why is Tamil Nadu neglecting its artisanal fishers?* Environment/ The wire newspaper. *h*ttps://thewire.in/environment /artisanal-fishers-tamil-nadu-sri-lanka-trawling
Sabbir, W., Rahman, M.A., Hossain, M.Y., Hasan, M.R., Mawa, Z., Rahman, O., Tanjin, S., & Sarmin, M.S. (2021). Stock assessment of Hooghly Croaker *Panna heterolepis* in the Bay of Bengal (Southern Bangladesh): implications for sustainable management. *Heliyon*, 7(8), e07711. https://doi.org/10.1016/j.heliyon.2021.e07711
Santhoshkumar, S., Jawahar, P., Rajagopalsamy, C.B.T., & Venkatasamy, M. (2011). Growth and mortality characteristics of *Nibea maculata* (Bloch & Schneider, 1801) exploited off Thoothukudi coast, Tamil Nadu. *Indian Journal of Fisheries,* 58, 17-20.
Schaefer, M.B. (1954). Some aspects of the dynamics of populations important to the management of the commercial marine fisheries. *Inter-American Tropical Tuna Commission Bulletin*, 1(2), 23-56. https://doi.org/10.1016/S0092-8240(05)80049-7
Sivadas, M., Zacharia, P.U., Sarada, P.T., Narayanakumar, R., Kizhakudan, S.J., Margaret Muthu Rathinam, A., Surya, S., Remya, L., Rajkumar, M., Chhandaprajnadarsini, E.M., Manojkumar, P.P., Jagadis, I., Kavitha, M., Saleela, K.N., Grinson George, P., Laxmilatha., & Gopalakrishnan A. (2019). *Management Plans for the Marine Fisheries of Tamil Nadu.* Marine Fisheries Policy Series No. 11, Central Marine Fisheries Research Institute, Cochin, pp.1-104.
Varghese, E., Sathianandan, T.V., Jayasankar, J., Kuriakose, S., Mini, K.G., & Muktha, M. (2020). Bayesian State-space Implementation of Schaefer Production Model for Assessment of Stock Status for Multi-gear Fishery. *Journal of the Indian Society of Agricultural Statistics*, 74(1), 33-40.
Wang, Y., Wang, Y., Liang, C., Zhang, H., & Xian, W. (2020). Assessment of 12 fish species in the northwest Pacific using the CMSY and BSM methods. *Frontiers in Marine Science*, 7, 616. https://doi.org/10.3389/fmars.2020.00616
BSM Methods. *Frontiers in Marine Science*, 7, 525363. https://doi.org/10.3389/fmars.2020.525363