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Evaluation of the status of marine fishery resources of Tamil Nadu, India using surplus production models

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The present study used surplus production models for the assessment of fisheries stock and to evaluate the marine fishery status of Tamil Nadu. Present study computed and analysed annual catch and effort between 1998 and 2018 using Catch Effort Data Analysis (CEDA) software. The mean annual catch of Tamil Nadu marine fisheries was 4.14 lakh tonnes, ranging from 2.87 lakh tonnes (2005) to 5.20 lakh tonnes (2018). The Biological Reference Points (BRP), such as Maximum Sustainable Yield (MSY), Biomass at MSY (B_{MSY}), and Fishing mortality at MSY (F_{MSY}), were estimated using three error assumptions (Normal, Log Normal and Gamma) of Fox, Schaefer, and Pella-Tomlinson production models for Initial Proportion (IP) ranging from 0.1 to 1. From the results, MSY, B_{MSY} and F_{MSY} estimated by the best fit Schaefer-Log Normal (IP value of 0.8) were 5.32 lakh tonnes, 35.3 million tonnes and 0.151, respectively. The BRP determined from the Schaefer and Pella-Tomlinson models was similar. The predicted MSY values were higher than the most recent catch (5.20 lakh tonnes) of 2018. According to the reference point results, the stocks are secure; however, it is advised to keep fishing at present level in order to preserve the stock at a nearly optimal fishing pressure.

[**Keywords**: Biological reference points, CEDA, Marine fishery status, Surplus models]

Introduction

India having a coastline of approximately 8,118 kilometres (km) and a 0.53 million square kilometres (km^2) continental shelf spread over 2.02 million km^2 Exclusive Economic Zone (EEZ)[1]. India stands in third place in world marine fish landings and second in aquaculture production after China[1]. The total fish production of the country is 14.73 million tonnes, accounting for around 7.96 % of global fish production[1]. Among Indian maritime states, Tamil Nadu was ranked in the first position in the marine capture fisheries of India during 2018-19 period[2]. Overall marine fish landings in Tamil Nadu have increased through time, from a meagre 0.38 lakh tonnes during 1950 to 5.2 lakh tonnes during 2018. The marine fishery of Tamil Nadu is a fast-growing industry with great growth potential and a number of creative, developmental and welfare programmes. It can be separated into three ecosystems based on its characteristics, namely the Gulf of Mannar (GM), Palk Bay (PB), and the Coromandel Coast (CC), with each region having its own unique fishing grounds, fishing patterns, fishing crafts, gears and fishery practices[3].

Marine fish landings data for India are published by various organisations, but the data vary from one another. Limited information is available on the catch and effort in Indian fisheries using scientific methods[4]. Information on the catch and effort data of Tamil Nadu marine fisheries was unavailable, with the exception of annual fish landing data[5]. Data on the stock status of Tamil Nadu marine fishery resources employing Catch Effort Data Analysis (CEDA) software is also limited. Hence, the current study computed catch and effort data from 1998 to 2018 and analysed the exploitation status of the Tamil Nadu fishery using CEDA software.

The present study estimated Biological Reference Points (BRP) such as Maximum Sustainable Yield (MSY), Biomass at MSY (B_{MSY}) and Fishing mortality at MSY (F_{MSY}) and predicted the future status of stock biomass to evaluate the efficiency of management measures. This study will provide crucial information to many agencies regarding the current status of the marine fisheries, which are passing through a drastic change from traditional to mechanised fisheries.

Materials and Methods

Reconstruction of catch and effort data

The present study computed catch and effort data from various sources using the methodology outlined in Bhathal[4]. The catches for the maritime state of Tamil Nadu were compiled for this study following Bhathal[4] and reports of the Ministry of Agriculture, Government of India[6-7]. The fishing effort was estimated by gathering information on the total number of vessels, fishing days, gear type from reports of central and state government committees formulated for specific purposes and reports of published sources such as government documents, research articles, as well as fisheries survey data, grey literature and databases from 1998 to 2018[refs. 4,8-19].

The Central Marine Fisheries Research Institute (CMFRI) used to collect data on fishing effort on a regular basis, but the availability of authorised data sets in the public domain was limited and grey literature was frequently unavailable. To deal with the situation, all relevant information was gathered and organised, including the number of boats equipped with or without engines, their overall power (measured in HP units), the number of fishing days, and the size of the crew. Vessels with engines were further divided into outboard engines (mechanised) and inboard engines (motorised). The overall fishing effort was calculated by adding the number of boats, total power output (crew size for non-motorised vessels), and the total number of fishing period at sea for every sector. The details of fishing crafts and gear were gathered from the Government of Tamil Nadu Policy notes[20-31]. Consequently, the 'horsepower-days' for fishing vessels were defined as a compilation of the total number of vessels, the mean HP, and the number of fishing days per year for each category of vessel. The final data consists of fishing effort represented by horsepower-days (million HP days) including all vessel types in Tamil Nadu from 1998 to 2018, whereas total catch for the species is expressed in terms of catch weight in lakh tonnes.

Analysis of catch and effort data

The CEDA (version 3.0.1) computer programme was employed to execute stock assessment procedures in developing countries in order to formulate fisheries management plans[32]. CEDA is a software package that uses analytical approaches to assist and aid stock assessments, resulting in a prediction of present population size in terms of numbers or biomass, as well as a more accurate assessment of fishing mortality by relating catches to the population size[33]. CEDA can evaluate the parameters of Schaefer model[34], Pella-Tomlinson model[35] and Fox model[36] under three different error assumptions (Normal, Log Normal, and Gamma). Catch Per Unit Effort (CPUE) is a biomass indicator used as a primary input in surplus production models. The non-equilibrium production model implemented by CEDA software was used to assess trends in the catch, effort, biomass and CPUE of marine fisheries in Tamil Nadu from 1998 to 2018.

The CEDA program enables the fitting of surplus production models using catch, effort and/or abundance information to determine a variety of intermediate variables (K, r, q and R^2), indexes (historical and future stock sizes), and reference points (MSY, B_{MSY} and F_{MSY})[33]. CEDA used to assess fishery resources, requires a major attribute of an Initial Proportion (IP) (initial population size over carrying capacity) and integrates a confidence interval method via bootstrapping. The present study used an IP of 0.8 as the beginning biomass was 80 % of the highest catch and used a fixed starting biomass for detailed assessment, *i.e.* B1 = K. The Schaefer-Log Normal model was considered the best fit from the CEDA software results for additional reference point analysis. CEDA software offers the capability of making future estimates of stock size by altering future Total Allowable Catch (TAC) and effort and recognising outliers from the observed data. This allows monitoring of the effects of various management strategies for ensuring sustainable fisheries.

Results

Catch, effort and CPUE trends

The total catch and effort of marine fisheries in Tamil Nadu from 1998 to 2018 were reconstructed and presented as Table 1. As shown in Table 1, total marine fish landings in Tamil Nadu fluctuated between 2.87 lakh tonnes (2005) and 5.20 lakh tonnes (2018). From 2005 onward, marine fish landings showed an increasing trend. Reconstructed effort for all sectors of Tamil Nadu marine fisheries showed a progressive increasing trend from 1998 (194 million HP days) to 2010 (216 million HP days). Except for the reduction in effort recorded during 2011 – 2013, total fishing effort recorded an increasing trend until 2018 (209 million HP days).

The contribution of vessels without engines to the total fishing effort has decreased during last two decades due to shifting of fishing units to motorised sector. Considering vessels with engines, outboard engines (motorised) had the major contribution, followed by inboard engines (mechanised). Trawlers made the largest contribution among vessels with inboard engines, followed by gillnetters, liners, and others (Fig. 1). The CPUE of Tamil Nadu marine fisheries showed a decreasing trend from 1998 to 2005 with slight fluctuations during some years (Fig. 2). However, after the year 2005, there was a continuous increase in CPUE up to 2014 and without much change during recent years (Fig. 2).

Table 1 — Total catch (in lakh tonnes) and effort (in million Horse power days) of marine fisheries of Tamil Nadu during 1998 – 2018

Year	Total catch (in lakh tonnes)	Effort (in million HP days)
1998	4.32	194.03
1999	3.83	200.68
2000	4.03	200.68
2001	3.60	200.68
2002	4.08	200.68
2003	3.64	238.14
2004	4.02	238.14
2005	2.87	200.54
2006	3.87	201.66
2007	3.93	203.02
2008	3.65	204.36
2009	4.02	205.69
2010	4.05	216.39
2011	4.27	207.20
2012	4.30	170.31
2013	4.32	167.13
2014	4.57	182.49
2015	4.67	187.70
2016	4.72	192.04
2017	4.97	201.13
2018	5.20	209.17

CEDA outputs

CEDA computer software used three models (Fox, Schaefer, and Pella-Tomlinson) with three-error assumptions (Normal, Log Normal, and Gamma) to estimate the MSY of the Tamil Nadu marine fishery with 0.1 to 1 IP (Table 2). Results from the CEDA program were quite sensitive to input IP measures between 0.1 and 0.9 (Table 2). The results of several intermediate parameters and reference points determined with an IP of 0.8 are presented in Table 3. Accordingly the Fox model projected a greater catchability coefficient (q) than the other production models, although the Schaefer and Pella-Tomlinson models predicted higher carrying capacity (K) and intrinsic population growth rate (r) compared to the Fox model (Table 3). MSY estimated by the Fox model-Normal, Fox model – Log Normal and Fox model-Gamma were 2.21, 4.30 and 6.44 lakh tonnes,

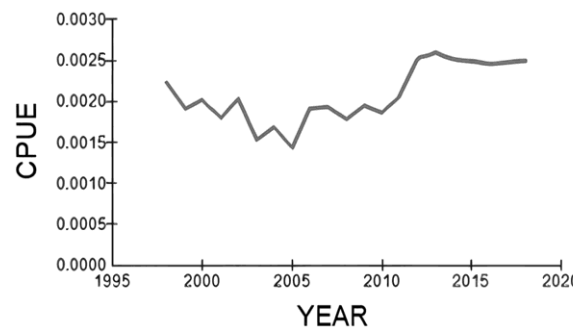

Fig. 2 — Catch per unit effort (CPUE) trend of marine fisheries of Tamil Nadu using CEDA software from 1998 – 2018

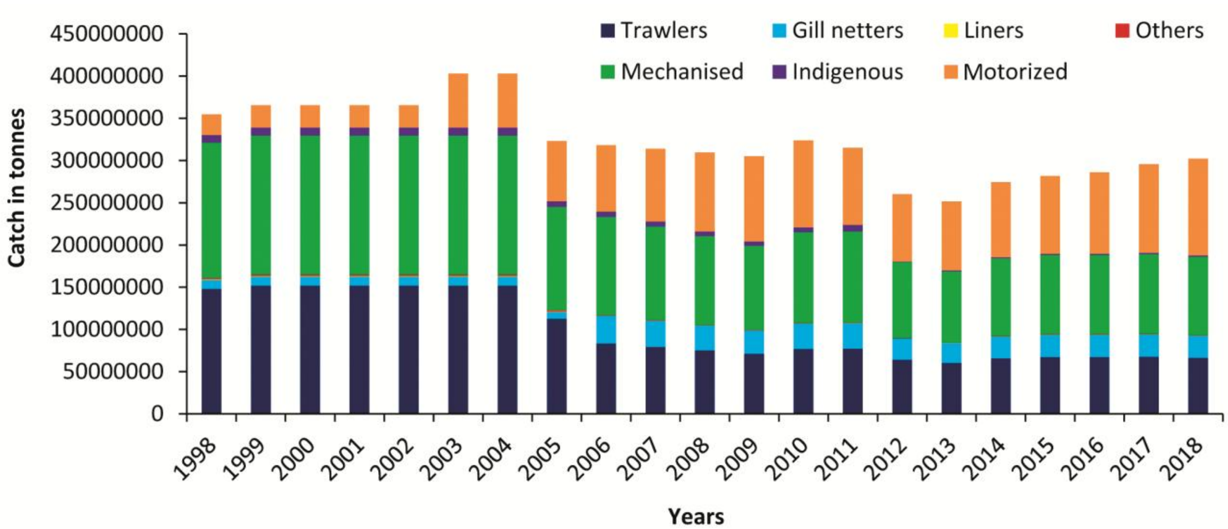

Fig. 1 — Reconstructed total fishing effort scenario of marine fisheries of Tamil Nadu from 1998 to 2018

Table 2 — Maximum Sustainable Yield (MSY) estimated by CEDA software using three production models (Fox, Schaefer and Pella-Tomlinson) with three error assumptions (Normal, Log Normal and Gamma) of the marine fishery resources of Tamil Nadu during 1998 – 2018 applying various initial proportions (0.1 to 0.9)

IP	Fox model			Schaefer model			Pella-Tomlinson model		
	Normal	Log Normal	Gamma	Normal	Log Normal	Gamma	Normal	Log Normal	Gamma
0.1	609456	1218911	1828367	923391	1846782	2770174	923391	1846782	2770174
0.2	409634	819268	1228902	492249	984498	1476747	492249	984498	1476747
0.3	334701	669402	1004103	349667	899333	1049000	349667	899333	1049000
0.4	292239	584478	876717	278375	756751	835126	278375	756751	835126
0.5	267261	534523	801784	237637	675275	712912	237637	675275	712912
0.6	247279	494558	741837	210479	620958	631437	210479	620958	631437
0.7	232293	464585	696878	191807	583615	575422	191807	583615	575422
0.8	221053	430712	644127	180499	522295	424247	180499	522295	424247
0.9	212310	424621	636931	166346	432692	399039	166346	432692	399039

Table 3 — Biological reference points for marine fisheries of Tamil Nadu during 1998 – 2018 with an IP value of 0.8 computed using CEDA software

Model	*K*	*q*	*r*	R yield	R^2	B	MSY	B_{MSY}	F_{MSY}
Fox (Normal)	6008832	6.09E-10	0.1	12536	-2.12	2242385	221053	2210526	0.10
Fox (Log Normal)	7213124	4.04E-10	0.20	430608	-1.80	4442837	430712	2653560	0.20
Fox (Gamma)	6742487	3.92E-10	0.3	465372	-1.90	4918764	644127	2480422	0.30
Schaefer (Normal)	8012173	4.34E-10	0.09	86557	-1.68	1098570	182898	4006087	0.05
Schaefer (Log Normal)	7061226	3.81E-10	0.30	444625	-1.27	4959577	531728	3530613	0.15
Schaefer (Gamma)	8323294	3.09E-10	0.30	454774	-1.78	6330040	424247	4161647	0.10
Pella-Tomlinson (Normal)	8012173	4.34E-10	0.09	86557	-1.68	1098570	182898	4006087	0.05
Pella-Tomlinson (Log Normal)	7061226	3.81E-10	0.30	444625	-1.27	4959577	531728	3530613	0.15
Pella-Tomlinson (Gamma)	8323294	3.09E-10	0.30	454774	-1.78	6330040	424247	4161647	0.10

MF: Minimisation Failure, *K*: carrying capacity, *q*: catchability coefficient, *r*: intrinsic population growth rate, R yield: replacement yield, R^2: coefficient of determination, B: current biomass, MSY: Maximum Sustainable Yield, B_{MSY}: Biomass giving MSY, and F_{MSY}: Fishing mortality giving MSY

Table 4 — Biological reference points for marine fishery resources of Tamil Nadu during 1998 – 2018 estimated by Schaefer-Log Normal model with CEDA software (IP = 0.8)

B	F	MSY	B_{MSY}	F_{MSY}	B/B_{MSY}	F/F_{MSY}
4959577	0.08	531728	3530613	0.151	1.405	0.554

B: current biomass, F: fishing mortality, MSY: Maximum Sustainable Yield, B_{MSY}: Biomass giving MSY, F_{MSY}: Fishing mortality giving MSY, B/B_{MSY}: ratio of biomass to biomass giving MSY, F/F_{MSY}: ratio of fishing mortality to fishing mortality giving MSY

respectively. Consequently, the MSY values estimated by the Schaefer and Pella-Tomlinson models were identical across all error assumptions (Normal, Log Normal, and Gamma), resulting in 1.82, 5.31, and 4.24 lakh tonnes, respectively. By evaluating R^2 values and graphically assessing expected and observed catch, Schaefer and Pella-Tomlinson (Log Normal) demonstrated a higher correlation to the data. From Table 3, the best-fitting Schaefer-Log Normal model was selected for further investigation on BRP (Table 4). Furthermore, the ratio (B/B_{MSY}) was greater in the Fox-Log Normal model than other models (Table 3). The calculated B/B_{MSY} values for the Schaefer and Pella-Tomlinson models were the same. The equilibrium yield curve of total marine fish production in Tamil Nadu from 1998 to 2018 is depicted in Figure 3. The MSY varied with the biomass. However, the estimated biomass that provides the maximum yield, *i.e.* $B_{MSY,}$ was

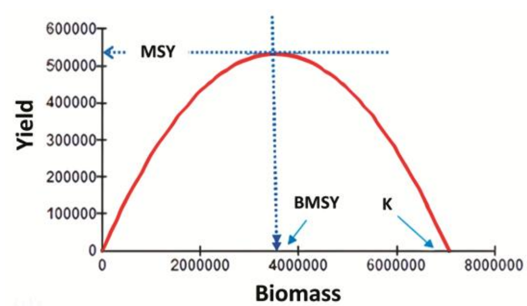

Fig. 3 — Equilibrium yield curve indicating biological reference points fitted with Schaefer-Log Normal assumption model with an IP of 0.8 using CEDA software for marine fisheries of Tamil Nadu from 1998 – 2018

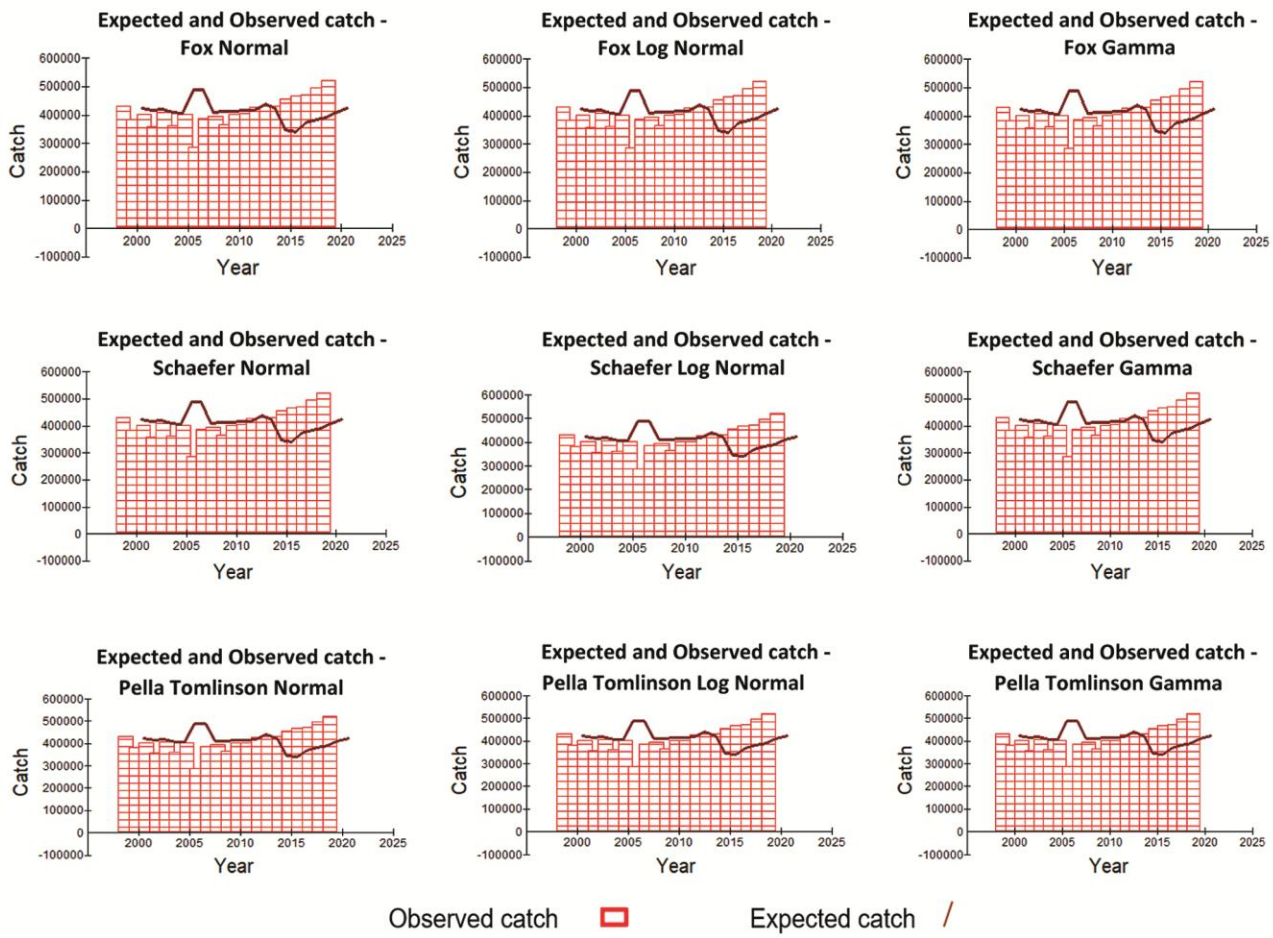

Fig. 4 — Annual expected and observed catches (in lakh tonnes) of marine fisheries of Tamil Nadu (1998 – 2018) with an IP = 0.8 from the three production (Fox, Schaefer and Pella-Tomlinson) models with error assumptions (Normal, Log Normal and Gamma) using CEDA software

35.3 million tonnes, and the maximum yield that can be exploited was 5.32 lakh tonnes (Fig. 3). Figure 4 depicts the relationship between observed and estimated catches across all models. The observed and estimated catches by the Fox and Schaefer models were much closer. The stock biomass projection based on TAC and future efforts fitted with a Schaefer-Log Normal model are shown in Figure 5, which depicts reduced stock size from its initial biomass of 1998 to the biomass of 2018. Total biomass exceeded the targeted B_{MSY}. According to projections, a TAC of 2.86 lakh tonnes and a future effort of 167 million HP days will lead to a maximum expansion of stock biomass. The future effort of 209 million HP days will increase stock biomass, which is less than the maximum. The total effort of 238 million HP days will indeed keep the population in almost the same condition as in 2018. The MSY catch of 5.31 lakh tonnes and the recent catch of 5.2 lakh tonnes will result in a higher reduction of stock biomass in the following decade (2018 – 2028) (Fig. 5).

Discussion

CEDA employs three surplus production models that require catch, effort, and CPUE as input data to calculate MSY. It does not take into consideration that the population at equilibrium or not[37]. The coefficient of determination (R^2) demonstrated the model appropriation and explained the best-fit model representation of observed and expected cumulative catch values. Future stock biomass was predicted based on the TAC and future efforts.

Interpretation of catch, effort and CPUE trend

Increased fishing efforts since 1998, fishing area expansion[38], improved fishing technology[39], and increased demand for fish[40] can be attributed to the increase in marine fish landings in Tamil Nadu

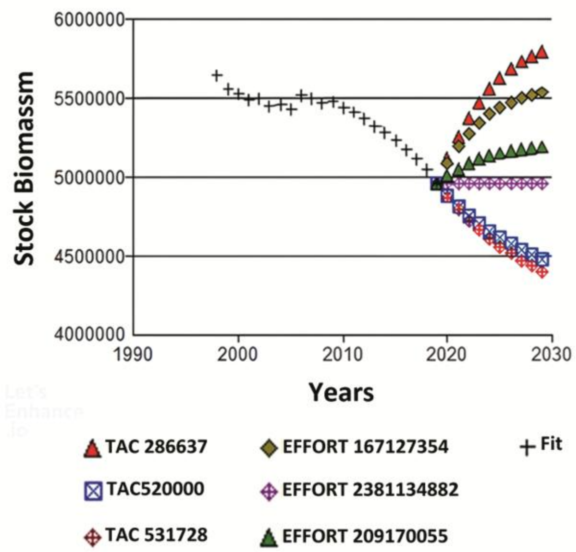

Fig. 5 — Future stock biomass predictions using a variety of different TAC and total effort scenarios from 2018 to 2028 fitting with Schaefer-Log Normal assumption model with an IP of 0.8 using CEDA software for marine waters of Tamil Nadu from 1998 – 2018

(Table 1). The present study recorded the replacement of vessels without engines with mechanised vessels. Abdussamad[41] stated that the marine fisheries had evolved considerably as a result of the motorisation of traditional boats and the introduction of mechanised fishing units, as well as the widespread implementation of innovative gears and techniques in collaboration with mass harvesting technology and the present study is also in agreement with these findings.

Analysis of CEDA outputs

The results of CEDA varied with input IP values (Table 2). This is in agreement with Wang & Liu[42] as they opined that IP should be determined with consideration when fitting these models. Using an IP of 0.8, CEDA software estimated different outcomes that contradicted each other (Table 3). However, thorough examination proved that all of the error assumptions employed in the three production models were certainly close to each other; however, they deviated in details. Similar findings were reported earlier by Karim *et al.*[43] and Mohsin *et al.*[44]. Hence, the results are in concurrence. Considering the coefficient of determination (R^2) (the goodness of fit) and the expected and observed catch (Fig. 3), the Schaefer (Log Normal) model was determined to be the best-fit model. The results of the study by Mohsin *et al.*[44] are in harmony with the present study. However, Panhwar *et al.*[45] opined that the Fox model seems to be more reliable than Schaefer.

Reference points

MSY has an important role in fishery research, and it is frequently referred to as a target BRP, which was initially proposed in 1992[refs. 46-47] and served as a biological standard for measuring stock status[46].

The estimated MSY value (5.31 lakh tonnes) was nearly identical to the recent catch (5.20 lakh tonnes). According to Memon *et al.*[48], when the catch value exceeds the calculated MSY value, the stock population drops. The stock is in a state of sustainability when it reaches the MSY value, and the catch must be maintained at the calculated MSY level rather than increased or decreased. When the catch volume is less than the calculated MSY value, the stock species thrives and is heavily exploited. When the amount of catch is less than the calculated MSY value, the population of the stock thrives and is vastly overexploited. Hence, it can be inferred that there has been no overexploitation of marine fishery resources in Tamil Nadu over the last two decades. The reference point data suggested that the present fishing intensity may have pushed the stock close to near-optimal fishing pressure, and it is advised that the stock be maintained at the same level in order to prevent overexploitation in future.

Future of Tamil Nadu fisheries

In recent decades, marine fisheries have seen significant fluctuations due to changes in fishing patterns, the launch of innovative fishing vessels, the extension of fishing grounds, the expansion of fishing fleets, the introduction of new fishing methods, and the modification of existing infrastructure facilities. These changes increased marine fish production in Tamil Nadu state[3]. Total marine fish landings in Tamil Nadu recorded during 2018 (5.2 lakh tonnes) were 98 % of the MSY estimated by the present study. In the meantime, twenty years of fishing activity led to a reduction of initial biomass recorded in 1998. From the results, it can be inferred that the present level of fishing may result in a higher reduction of stock biomass in the following decade (2018 – 2028) (Fig. 5). Stock biomass predictions indicate that a TAC of 2.86 lakh tonnes and a reduction of effort equivalent to 1998 (167 million HP days) will bring the biomass back to the initial level at 1998. However, a drastic reduction of effort and fixing of TAC near to half of the present catch is impossible. Maintaining the present effort (209.17 million HP days) results in a marginal increase in biomass. Hence, maintaining the present fishing effort will be a viable management measure. The strict regulation of fishing efforts has always been an option, according to Shepherd[49], who claims that using TACs and quotas in fisheries management hasn't been adequate.

Researchers who studied the marine fisheries of Tamil Nadu have concluded that the Tamil Nadu fishery has undergone a perceptible change due to a sustained increase in fishing activities. According to the XI five-year plan, 19 % of trawlers and 44 % of gill netters operated in Tamil Nadu are in excess of the recommended vessel strength. According to the Sivadas *et al.*[3], there is overcapacity in the Tamil Nadu fishery. The engine capacity of the vessel is found to be larger than required, juveniles are harvested indiscriminately, and non-edible resources are exploited unsustainably. Meanwhile, the Tamil Nadu government provided Rs 2285.2 million in subsidies for the acquisition of new craft, gear, life jackets, navigational equipments and for the construction of coastal infrastructure during 2017 – 18[(ref. 3)]. Subsidies for the purchase of new gears and vessels will lead to overcapitalisation of the fishery; therefore, the government must redirect the subsidy schemes for welfare measures and alternative job creation.

Conclusion

Considering the biological reference point values, it can be presumed that the marine fishery in Tamil Nadu is approaching a fully exploited state. Total allowable catches and quotas may not be effective for Tamil Nadu; instead, regulation of fishing efforts can be considered an effective management measure. Earlier studies on Tamil Nadu fisheries pointed out the sustained increase in fishing intensity. Modifying the current fleet strength, reducing the existing fleet to an ideal level, and controlling juvenile fisheries are some of the management options available to ensure a sustainable fishery. However, reducing the number of trawlers and gill netters by 19 and 44 % may not be a viable measure in Tamil Nadu. Hence, it is recommended that the issue of new fishing licences and the replacement of old vessels be banned to preserve the stock at a nearly optimal fishing pressure.

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Conflict of Interest

The authors declare no conflict of interest.

Ethical Statement

This article does not contain any experimental studies with animals performed by any of the Authors.

Author Contributions

RA: Writing - original draft, conceptualisation, formal analysis and software. MKS: Investigation, supervision, and writing - review & editing.

References

1 Department of Fisheries, GOI, *Annual Report 2022-23*, (Department of Fisheries, Ministry of Fisheries, Animal Husbandry & Dairying, Government of India), 2023, pp. 150. https://dof.gov.in/sites/default/files/2023-04/Final_Annual_Report_2022-23_English.pdf

2 CMFRI, *Annual Report 2018-2019*, (Central Marine Fisheries Research Institute, Kochi), 2019, pp. 320.

3 Sivadas M, Zacharia P U, Sarada P T, Narayanakumar R, Kizhakudan S J, *et al.*, *Management Plans for the Marine Fisheries of Tamil Nadu*, Marine Fisheries Policy Series No. 11, (Central Marine Fisheries Research Institute, Kochi), 2019, pp. 104.

4 Bhathal B, *Government-led development of India's marine fisheries since 1950: Catch and effort trends and bioeconomic models for exploring alternative policies*, Ph.D. thesis, University of British, Columbia, 2014, pp. 355. https://doi.org/10.14288/1.0103394

5 Abinaya R & Sajeevan M K, Stock status of giant catfish *Netuma thalassina* (Rüppell, 1837) from Tamil Nadu, India waters, *Fisheries Manag Ecol*, 29 (6) (2022) 822-832. https://doi.org/10.1111/fme.12583

6 Ministry of Agriculture, *Handbook on fisheries statistics 2011*, (Department of Animal Husbandry, Dairying & Fisheries, New Delhi), 2012, pp. 38.

7 Ministry of Agriculture, *Handbook on fisheries statistics 2018*, (Department of Animal Husbandry, Dairying & Fisheries, New Delhi), 2018, pp. 190.

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

9 CMFRI, *Annual Report 2011-2012*, (Central Marine Fisheries Research Institute, Kochi), 2012, pp. 190.

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

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

12 Government of Tamil Nadu, *Tamil Nadu Policy Note 2003-04*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2004, pp. 29.

13 Government of Tamil Nadu, *Tamil Nadu Policy Note 2005-06*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2006, pp. 25.

14 Government of Tamil Nadu, *Tamil Nadu Policy Note 2009-10*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2010, pp. 56.

15 Government of Tamil Nadu, *Tamil Nadu Policy Note 2011-12*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2012, pp. 34.

16 Government of Tamil Nadu, *Tamil Nadu Policy Note 2012-13*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2013, pp. 31.

17 Government of Tamil Nadu, *Tamil Nadu Policy Note 2013-14*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2014, pp. 80.

18 Government of Tamil Nadu, *Tamil Nadu Policy Note 2015-16*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2016, pp. 183.

19 Government of Tamil Nadu, *Tamil Nadu Policy Note 2017-18*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2018, pp. 185.

20 Government of Tamil Nadu, *Tamil Nadu Policy Note 2003-04*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2004, pp. 29.

21 Government of Tamil Nadu, *Tamil Nadu Policy Note 2005-06*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2006, pp. 25.

22 Government of Tamil Nadu, *Tamil Nadu Policy Note 2009-10*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2010, pp. 56.

23 Government of Tamil Nadu, *Tamil Nadu Policy Note 2011-12*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2012, pp. 34.

24 Government of Tamil Nadu, *Tamil Nadu Policy Note 2012-13*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2013, pp. 31.

25 Government of Tamil Nadu, *Tamil Nadu Policy Note 2013-14*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2014, pp. 80.

26 Government of Tamil Nadu, *Tamil Nadu Policy Note 2015-16*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2016, pp. 183.

27 Government of Tamil Nadu, *Tamil Nadu Policy Note 2017-18*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2018, pp. 185.

28 Government of Tamil Nadu, *Tamil Nadu Policy Note 2020-21*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2021, pp. 249.

29 Government of Tamil Nadu, *Tamil Nadu Policy Note 2020-21*, (Animal Husbandry and Fisheries Department, Tamil Nadu, India), 2021, pp. 249.

30 Ministry of Agriculture, *Handbook on fisheries statistics 2018*, (Department of Animal Husbandry, Dairying & Fisheries, New Delhi), 2018, pp. 190.

31 Ministry of Agriculture, *Handbook on fisheries statistics 2011*, (Department of Animal Husbandry, Dairying & Fisheries, New Delhi), 2012, pp. 38.

32 Marine Resources Assessment Group, *CEDA Version 3.0., Fisheries assessment software*, (MRAG Ltd, London, UK), 2016. https://mrag.co.uk/resources/ceda-version-30/ (12/2023).

33 Hoggarth D D, Mees C C, O'neill C, Hindson J & Krishna M A, *Guide to Fisheries Stock Assessment using the FMSP Tools*, (Centre for Environmental Education, Ahmedabad, Gujarat, India), 2005, pp. 96.

34 Schaefer M B, Some aspects of the dynamics of populations important to the management of the commercial marine fisheries, *Inter-Am Trop Tuna Comm*, 1 (2) (1954) 23-56. https://doi.org/10.1016/S0092-8240(05)80049-7

35 Pella J J & Tomlinson P K, A generalised stock production model, *Inter-Am Trop Tuna Comm*, 13 (3) (1969) 416-497. http://aquaticcommons.org/id/eprint/3536

36 Fox Jr W W, An exponential surplus yield model for optimising exploited fish populations, *Trans Am Fish Soc*, 99 (1) (1970) 80-88. https://doi.org/10.1577/1548-8659(1970)99<80:AESMFO>2.0.CO;2

37 Soomro S H, Liu Q, Kalhoro M A, Memon A M, Shah S B, *et al*., Maximum Sustainable Yield Estimates of Indian Squid *Uroteuthis* (*Photololigo*) *duvaucelii* (D'Orbigny, 1835) From Pakistani Waters Using ASPIC and CEDA Software, *Lasbela Univ J Sci Technol*, 4 (2015) 1-9.

38 FAO, *The State of World Fisheries and Aquaculture 2022, Towards Blue Transformation*, (Food and Agriculture Organization of the United Nations, UN), 2022, pp. 266.

39 FAO, *The State of World Fisheries and Aquaculture 2020, Sustainability in action*, (Food and Agriculture Organization of the United Nations, UN), 2020, pp. 244. https://doi.org/10.4060/ca9229en

40 Vaughan A, Big increase in fish demand by 2050, *News Technol Environ*, 251 (3353) (2021) 1-19. https://doi.org/10.1016/S0262-4079(21)01690-0

41 Abdussamad E M, Pelagic Fin Fishery Resources of India- Their Potential and Status of Exploitation, In: *Winter School on Climate Change impacts and Resilience Options for Indian Marine Fisheries*, (Central Marine Fisheries Research Institute, Kochi), 2018, 124-129.

42 Wang Y & Liu Q, Application of CEDA and ASPIC computer packages to the hairtail (*Trichiurus japonicus*) fishery in the East China Sea, *Chin J Ocean Limnol*, 31 (1) (2013) 92-96. https://doi.org/10.1007/s00343-013-2073-7

43 Karim E, Liu Q, Sun M, Barman P P, Hasan S J, *et al*., Assessing recent gradual upsurge of marine captured Hilsa stock (*Tenualosa ilisha*) in Bangladesh, *Aquac Fish*, 4 (4) (2019) 156-165. https://doi.org/10.1016/j.aaf.2019.02.005

44 Mohsin M, Mu Y, Memon A M, Kalhoro M T & Shah S B H, Fishery stock assessment of Kiddi shrimp (*Parapenaeopsis stylifera*) in the Northern Arabian Sea Coast of Pakistan by using surplus production model, *Chin J Ocean Limnol*, 35 (2017) 936-946.

45 Panhwar S K, Liu Q, Khan F & Waryani B, Maximum sustainable yield estimates of spiny lobster fishery in Pakistan using non-equilibrium CEDA package, *Russ J Mar Biol*, 38 (2012) 448-453.

46 Baset A, Liu Q, Hanif M T, Liao B, Memon A M, *et al*., Estimation of maximum sustainable yield using production modeling: A stock appraisal of Indian Oil Sardine (*Sardinella longiceps*) from Pakistani Waters, *Pakist J Zool*, 49 (2) (2017) 521-528. http://dx.doi.org/10.17582/journal.pjz/2017.49.2.521.528

47 Smith T & Punt A, The gospel of maximum sustainable yield in fisheries management: birth, crucifixion and reincarnation, In: *Conservation of exploited species*, edited by Reynolds J D, (Cambridge, U K, Cambridge University Press), 2001, pp. 41-66.

48 Memon A M, Liu Q, Memon K H, Baloch W A, *et al.*, Evaluation of the fishery status for King Soldier Bream *Argyrops spinifer* in Pakistan using the software CEDA and ASPIC, *Chin J Ocean Limnol*, 33 (4) (2015) 966-973.

49 Shepherd J G, Fishing effort control: could it work under the common fisheries policy?, *Fish Res*, 63 (2) (2003) 149-153. https://doi.org/10.1016/S0165-7836(03)00125-5