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Bioeconomic modelling of marine fisheries: Seeking keys to sustainable income for marine fishers of Mumbai, India

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To address the issue of overfishing, sustainability and its effect on marine fishers' income, this study was taken up in Mumbai, India. Greater Mumbai was studied at micro level. Primary data on capital costs, operating costs and returns to mechanized fishing were collected. Secondary data on marine fish landings, landings from the trawlers and total effort of trawlers was collected from 2000 – 2018. The Gompertz-Fox Model was used, and results showed that Maximum Sustainable Yield (MSY) was at 1,04,099 tonnes of fish and effort level corresponding to MSY (E_{MSY}) at 43,363 fishing trips against the current 1,31,118 tonnes and 33,466 trips. Maximum Economic Yield (MEY) was calculated to be 1,03,030 tonnes, while the estimated value of effort (E_{MEY}) was 37,429 trips. Therefore, the current fishing yield was found to be both biologically and economically unsustainable. The study concluded that the catch and income of fishers may be sustainably enhanced by following the MSY and MEY approach. Fishing at MEY will yield increased income in real terms as well as saved catch will ensure minimisation of environmental damage. Reducing the input costs will enable savings on wasteful operational costs, resulting in increased savings, which in other words, is income, since averted loss is income earned.

[**Keywords**: Gompertz-Fox model, Income, Marine Fisheries, Maximum Economic Yield, Maximum Sustainable Yield, Sustainability]

Introduction

India's 8129 km coastline and a 2.02 million km^2 Exclusive Economic Zone (EEZ) offer a significant opportunity for enhanced food production. India, the seventh-largest marine capture producer, has seen rapid growth in marine fisheries. Over the past seventy years, production has escalated from 0.5 million tonnes (mt) in 1950 to 3.49 mt in 2018(ref. 1), maintaining a steady 1 % growth to the nation's GDP over the last five years[2]. This upswing in production is an outcome of diverse factors, such as the expansion of trawl fleets, introduction of purse seining, motorization of traditional fishing crafts, adoption of ring seines, and shift from resource-centric export trade to a food-engineering-based industry[3]. In 2017, Indian marine capture landings reached 3.83 mt, the second-highest on record, slightly below the 2012 peak of 3.92 mt. The 2017 landings marked a marginal 5.6 % increase from 2016 landings[4].

Despite its significance, marine fishery resources confront a consistently fluctuating trend due to its spectrum of challenges. While fishery resources are considered inexhaustible, there is a risk of extinction, as observed in various cases globally, particularly if continuous and indiscriminate harvesting practices persist[5]. The current state of marine fishery indicates a decline and stagnation in stock levels. The population of marine fish, subject to exploitation, is influenced by various elements within the complex ecological system, including overexploitation, pollution, and habitat loss. The persistence of overfished stocks is indeed a matter of great concern. Worm *et al.*[6] reported that 63 % of assessed fish stocks globally need rebuilding. Among these factors, only one-predation by humans is within the domain of control and/or modification to a significant extent through human actions. The alarming reality and a point of concern lie in the increase of the population engaged in the blue economic sector, despite the precarious gamble of fluctuating stocks[7]. This ultimately translates into a disturbing rise in unemployment.

The income generated from fisheries plays a pivotal role in economic development. However, disguised unemployment prevails across all sectors, as earnings from marine fisheries do not align proportionately with the increasing number of fishers[7]. The income situation for marine fishers is not promising, with sectoral incomes experiencing a decline. Furthermore, income distribution is skewed in favour of mechanized and motorized fishers[7]. The income of a fisher, primarily engaged in fishing, is significantly influenced by their catch and the prices they can command in the market. However, the potential for increased income linked to higher landings has hit a plateau, with no further expected rises. Even at the peak of fishers' productivity, realizing the maximum potential income from their catch becomes challenging. The demand for marine fish primarily demonstrates inelastic demand and is currently driven by its availability[8]. In relation to marine fisheries, the scope for income enhancement through increased landings is practically non-existent due to unbridled overfishing and unsustainable fishing practices[7]. An alternative worth exploring should focus on establishing a balanced, secure, and cost-effective income structure and reducing costs in this sector.

Hollowed *et al.*[9] conducted a review on the application of multi-species models as tools for evaluating the impacts of fishing on marine communities, comparing them with single-species models. Additionally, Bhatt & Bhatta[10] conducted a bio-economic analysis of marine fisheries in the State of Karnataka. They utilized single-species and multi-species simulation models, with the single-species model estimating sustainable yield and maximum economic yield, overlooking interactions between species, stocks, gears, labour and marketing factors. In 2005, Dong-Ryul & Pascoe[11] developed a straightforward surplus production bio-economic model for the flounder fishery in Korea. Their model integrated various effort standardization approaches to estimate the optimal effort level in the fishery. Thanh[12] investigated the sustainability of shrimp trawl fishery in the Tonkin Gulf, Vietnam, using surplus production models, including Verhulst Schaefer and Gompertz-Fox. Moreover, Ahmed *et al.*[13] focused on the Gulf of Thailand demersal fisheries, utilizing Schaefer and Fox surplus production bio-economic models. Their objective was to estimate both the Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY). The study aimed to reveal evidence of biological and economic overfishing and examine the resulting consequences.

The current study operated under the premise that elevated fish production alone does not guarantee increased incomes for marine fishers. The increased income hinges on elements such as weather risk, institutional support (say, insurance), market structure, conduct, performance, and the threshold of fishery sustainability[14]. A substantial portion of a fisher's income is bushed up on the procurement of inputs like diesel, winches, ice, gears, etc. Hence, any measures aimed at reducing input costs while maintaining a steady harvest level would yield benefits by augmenting net revenue and income. It is also crucial to contemplate whether the focus should be on doubling income or on regulating the production process at optimal levels. This consideration is essential for ensuring sustained high incomes over the years in specific sectors. The assessment of the bio-economic conditions of commercially exploited marine fish resources in Mumbai becomes pivotal in making informed decisions regarding the sustainability and profitability of the industry. Maximum sustainable and maximum economic levels of yield and effort for major resources give information on their sustainable harvest levels[2]. When fish stocks are exploited beyond the MSY and MEY, their yield falls short both in biological and economic terms compared to what could be achieved with optimal management[15]. The specific objective of the given study was to assess the bio-economic conditions of marine fish production and to assess the sustainability of current level of fishing effort and to suggest policy options for sustainable marine fish production. This paper explores MSY and MEY calculations in multi-species single-fleet fisheries (trawlers) applied to the Mumbai fishery. With the total number of trawlers outweighing the total number of mechanized crafts in Mumbai, the study is focussed on multi-species single-fleet rather than a multi-species multi-fleet approach.

Materials and Methods

Study area

Maharashtra, a significant marine fish producing state in the country, features 720 km long coastline and holds a fifth position among India's maritime states[4]. Among Maharashtra's seven maritime districts, Mumbai city emerged as the highest contributor with 1,40,105 tonnes, constituting 29.5 % of the total state landings. Thane district followed closely with 1,14,399 tonnes, contributing around

24.2 %. Following this trend, Ratnagiri fell next in line with the substantial contribution of 80,340 tonnes, accounting for 17 % of total landings. Mumbai sub-urban added another significant portion of 66,228 tonnes representing 14 % of total landings. Raigad district contributed 53,338 tonnes, constituting 11.2 %, while Sindhudurg district made a noteworthy contribution of 20,582 tonnes, accounting for 4.3 % of the total landings[16]. Mumbai taking the lead in marine capture landings is primarily because of critical single-centre zones like Sassoon Dock (SSD), New Ferry Wharf (NFW), and Versova (VRS), which are strategically located within the city[17].

The study was thus carried out in the Greater Mumbai region of the State of Maharashtra, encompassing two maritime districts - Mumbai city and Mumbai suburban (Fig. 1). There are 15,716 fishing boats in operation, with 13,002 being mechanized[18], 19 landing centers, 36 fishing villages, 8,147 fishermen families, including 7,862 traditional fishermen families and fisherfolk population of 32,516(ref. 19). Out of the total fishermen families, 5,949 families are classified under Below Poverty Line (BPL)[19]. Additionally, Mumbai city features 2,297 mechanized crafts, 1,179 motorized crafts, and 704 non-motorized/artisanal crafts. Among the provided mechanized crafts, trawlers make up approximately 1,726 in total, contributing 75 % to the total mechanized gears[19].

Methodology

Time series data covering annual landings, effort, and boat-side prices for the years 2000 – 2018 (18-year data) were gathered from annual reports of Department of Fisheries (DOF), Maharashtra. The chosen period was specifically selected due to the availability of gear-wise information on catch and effort of resources starting from the year 2000. A well-structured interview schedule and observation method were used for collecting primary information on variables such as fuel, wages, repairs, auction charges, ice, water, docking, and returns from the trip. Boat owners were interviewed personally. A total of 150 boat owners were interviewed purposively from Versova, New Ferry Wharf and Sasson dock, taking 50 from each centre. Data on capital and operating costs, returns of mechanized fishing units and prices of different species of fishes were collected during the period of January to March 2019.

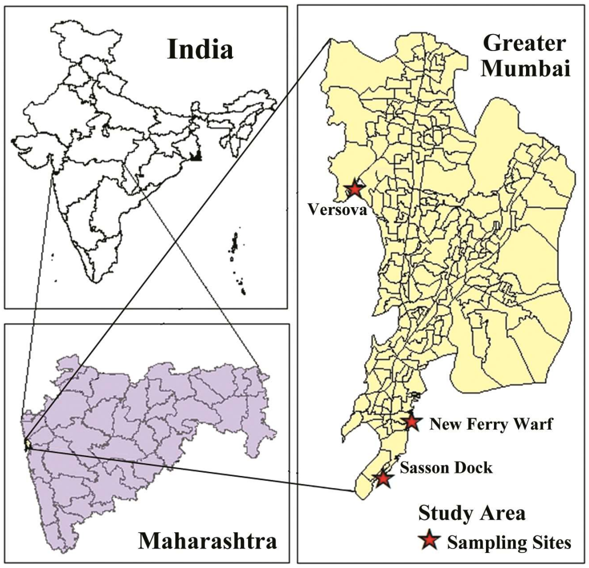

Fig. 1 — Map showing study area

Estimating Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY)

Production surplus analysis through Catch Per Unit Effort (CPUE) of total marine fish stock for the Greater Mumbai trawl fishery was analysed according to Gompertz-Fox model. Production surplus analysis used two tools including MSY and MEY.

Maximum Sustainable Yield is the yield obtained by applying the optimal level of effort that can be sustained without negatively impacting the long-term productivity of the stock. It is the maximum yield that can be taken indefinitely from a stock; that is, the maximum harvest that is sustainable in the long term[20]. It is thus the optimal yield of the fishery.

World-known biologist, Schaefer[21] took the whole stock of fishery as one unit and explained the MSY in a stationary equilibrium population. The Gordon-Fox[22,23] model follows the assumptions developed by Schaefer[21] for the biological model:

1. The population is in equilibrium, exhibiting a relatively consistent pattern. Changes in the trajectory of catch and effort can be utilized to make predictions about the future behaviour of the system.
2. In equilibrium, fishing mortality (F) remains a constant proportion of effort (E), represented by the catchability coefficient (q).

$$F = qE$$

3. Catch Per Unit Effort (CPUE) serves as a relative index of population abundance.

$$CPUE = \frac{Y}{E}$$

4. The stock is constrained by a constant carrying capacity of the environment.

5. The stock will respond immediately to variations in the magnitude of the effort applied.
6. Constant fishing technology.
7. Prices and marginal/average costs remain constant and are independent of the level of effort exerted.
8. Total Cost (TC) is proportional to effort, and a change in the slope of the TC curve determines variations in Bioeconomic Equilibrium (BE) and MEY levels.

Two essential parameters required for MSY estimation are catch and effort. The logistic form of the population growth is as follows:

$$Ln\ CPUE = f(effort)$$

$$Ln\ \frac{Y}{E} = \alpha + \beta E \quad \ldots (1)$$

Where, Y = total annual catch; α, β = constant parameters; and E = effort

Exponentiating both sides and solving for Y, gives

$$Y = Ee^{(\alpha+\beta E)} \quad \ldots (2)$$

Differentiating Y with respect to E in the above equation, setting the result equal to zero, and solving for effort (E_{MSY}) that maximizes Y, we obtain

$$E_{MSY} = -\frac{1}{\beta} \quad \ldots (3)$$

The corresponding MSY can be obtained by substituting equation (3) into equation (2)

$$MSY = -\frac{1}{\beta} e^{(\alpha-1)} \quad \ldots (4)$$

Maximum Economic Yield (MEY) is the yield that would generate the maximum resource rent from the fishery, signifying the profit earned. MEY is achieved when the marginal cost of fishing effort equals the marginal revenue from the fishery. Assuming a fixed price (P) for the fish caught, Total Revenue (TR) can be expressed as:

$$TR = PY$$

In fisheries economics, the input is the fishing effort, which can be considered as an intermediate product requiring inputs such as labour, capital, and investment. If C is the unit cost for each unit of effort (E), the total cost in the fishery may be defined as:

$$TC = CE$$

From equation $Y = Ee^{(\alpha+\beta E)}$,

$$TR = PY = PEe^{(\alpha+\beta E)} \quad \ldots (5)$$

The economic objective is to maximize resource rent from the fishery. At MEY, MR = MC

$$\frac{\partial TR}{\partial E} = \frac{\partial TC}{\partial E}$$

In order to reach the economic objective, the fishing effort must be cut down to the point where marginal cost is equal to marginal revenue. There will be a gain and better off situation in the sense that at that point, there is an efficient use of both the fish resources and all factors of production (*i.e.* input use, labour, capital asset, etc.).

$$MR = P(\beta E + 1)e^{(\alpha+\beta E)} \quad \ldots (6)$$

Using MR = MC,

$$P(\beta E + 1)e^{(\alpha+\beta E)} = C \quad \ldots (7)$$

C denotes the cost of a unit effort.

$$(\beta E + 1)e^{\beta e} = \frac{C}{Pe^{\alpha}} \quad \ldots (8)$$

An expression for the effort E (MEY) that returns MEY is given as follows:

$$E_{MEY} = \frac{1}{\beta}(-1 + \sqrt{\frac{C}{Pe^{\alpha}}}) \quad \ldots (9)$$

$$MEY = E_{MEY} e^{(\alpha+\beta E_{MEY})} \quad \ldots (10)$$

Results and Discussion

Estimation of Maximum Sustainable Yield (MSY)

Trawlers primarily focus on high-value demersal resources, including demersal finfishes, shrimps, and cephalopods, with a predominant emphasis on export-oriented species such as prawns, ribbon fishes, croakers, lobsters, sharks, and eels, among others. Historically, trawlers have been a significant contributor to landings, accounting for more than half (75 %) and establishing themselves as the primary employed gear off the Mumbai coast.

In this study, the term "catch" is used to refer to the yield. The total effort of trawlers was measured in terms of trips. Table 1 shows the annual catch, effort and calculated CPUE of trawlers from 2000 to 2018. The observed decrease in effort over time can be attributed to changes in the efficiency of gears. Figure 2 clearly illustrates a decrease in effort after the year 2009 – 2010. The decline in trawler effort may be attributed to the diversification of gear towards purse seiners and changes in gear efficiency, leading to an increase in horsepower, increase in the number of days at sea and, consequently, a reduction in the number of trips.

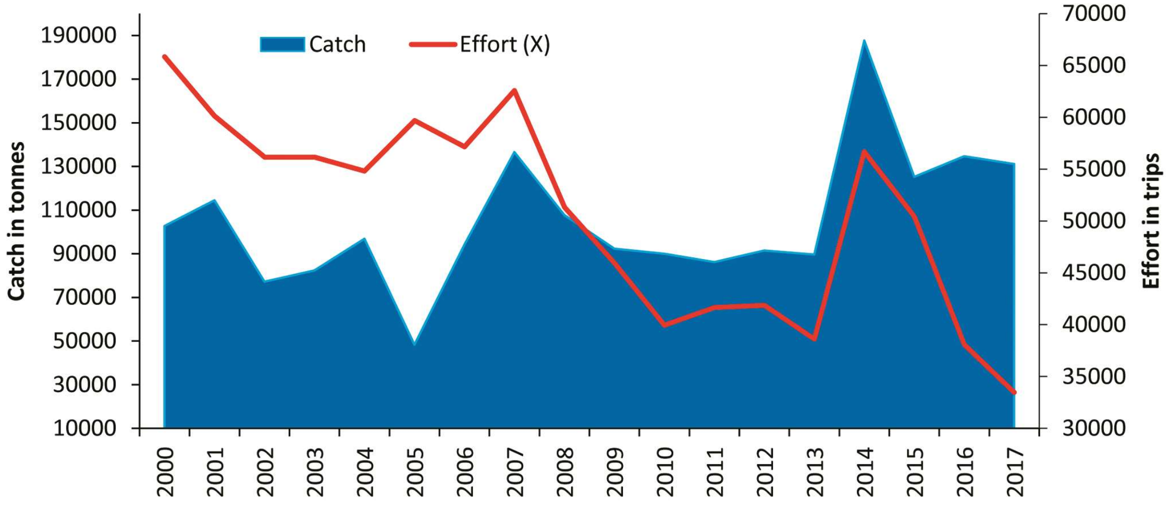

Fig. 2 — Annual catch and effort of trawlers (2000 – 2018)

Table 1 — Annual catch and effort data of trawlers (2000 – 2018)

Year	Catch (in tonnes)	Effort (in trips)	CPUE
2000-01	102720	65846	0.44
2001-02	114480	60126	0.64
2002-03	77210	56153	0.32
2003-04	82362	56153	0.38
2004-05	96862	54817	0.57
2005-06	48331	59668	-0.21
2006-07	94121	57147	0.50
2007-08	136551	62573	0.78
2008-09	107726	51298	0.74
2009-10	92333	45937	0.70
2010-11	90011	39934	0.81
2011-12	86182	41655	0.73
2012-13	91492	41865	0.78
2013-14	89647	38609	0.84
2014-15	105645	56667	1.20
2015-16	125219	50427	0.91
2016-17	134667	38073	1.26
2017-18	131118	33466	1.37

The regression analysis between CPUE and the fishing effort of trawlers reveals a relationship described by the equation $Y = 1.875 - 0.00002E$, where Y is the yield and E is the effort. The correlation coefficient (r) is 0.60, and the determination coefficient (R^2) is 0.3686. Graphically represented in Figure 3, the equation indicates that when there is no effort ($E = 0$), the yield will be 1.875 ton/trawler. The regression coefficient ($\beta = -0.00002$) suggests that a decrease in 0.00002 standard effort will result in an increase in CPUE. The R^2 value of 36.86 % implies that 36.86 % of the variation in CPUE is explained by effort, leaving 63.14 % influenced by other factors which are not analyzed in this study. The strong correlation ($r = 0.60$) indicates a robust relationship between CPUE and standard effort.

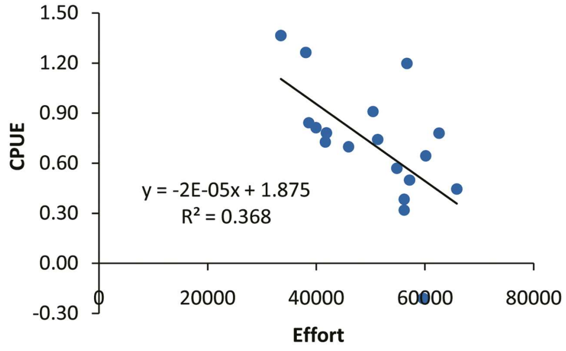

Fig. 3 — CPUE of Greater Mumbai Trawlers (Schaefer[21])

Using the Fox model for estimating MSY and E_{MSY} of trawlers in Greater Mumbai, the optimal effort (E_{MSY}) was found to be 43,363 fishing trips, 29.58 % lower than the actual 33,466 trips. The MSY was calculated to be approximately 1,04,099 tonnes, compared to the current 1,31,118 tonnes. The actual catch exceeds MSY by 25.96 %, with the catch in the previous four years surpassing the MSY level. While the effort for the last two years is below sustainable levels and the effort for the year 2014 – 2016 has exceeded the sustainable effort level. The optimal fishing effort that maximizes landings is lower than the actual effort. There exists a need to reduce the landings by 26 % in order to overcome overexploitation. With increasing exploitation, there are more chances that the stock can suffer a collapse since stock fluctuations become wider, and the time span needed to re-attain equilibrium increases[24].

Estimation of Maximum Economic Yield (MEY)

MEY is the level of fishing activity at which the difference between the total revenue earned from fishing and the total cost of fishing is maximized. It represents an optimal balance between harvesting the resource for economic gain and ensuring the sustainability of the fishery over the long term. While MSY ensures maximum harvest that is sustainable in the long term[20], MEY aims at maximising the profits (positive rents) by keeping a check on inputs and thus increasing the revenue[10]. Following Gordon's approach[22], fishery input and output values are expressed in terms of total cost and total revenue as functions of fishing effort. For the estimation of MEY, important parameter to be estimated is cost. To estimate costs, both operational and fixed costs were considered. The effort generating MEY results in maximum annual net profit. From a sample of 150 trawlers, the values of investment, returns and costs were calculated.

Fixed costs

Fixed costs encompassed both capital costs and opportunity cost. Capital costs involved expenses for the vessel (hull), winch, wire rope, otter board, engine, gears, icebox, GPS, echosounder, and batteries. The opportunity cost, calculated at the prevailing bank interest rate of 10 %, was also considered. The total fixed costs amounted to ₹ 29,76,667, and this value was regarded as the initial investment in a multi-day trawler.

Operational costs

The average operational cost per fishing trip for trawlers was determined based on the 150 sampled units. Operational fishing costs covered expenses such as fuel, food for the crew, wages, ice, auction charges, repair and maintenance, and landing charges (Table 2). The calculated average operational cost for a multi-day trawler was ₹ 2,16,603 per trip. Considering an average of 18 trips per year, the total operational cost amounted to approximately ₹ 38,98,854.

Average fixed cost of multi-day trawlers was worked out based on the total costs, opportunity cost (interest rate) and expected life of trawler. With 10 % of interest, average lifespan of the trawler being 25 and the total cost being ₹ 68,75,521, the average fixed cost for a year was amounted to be about ₹ 7,57,462.

Maximum Economic Yield and effort were amounted from the formulas given below:

Table 2 — Average operational cost and returns of multi-day trawlers

Items	Operational costs and returns of multi day trawlers/trip (INR)
Fuel	102000
Wages	73725
Repairs	1500
Auction charges	10000
Ice	25539
Water	2880
Docking	959
Total operating cost	*216603*
Total Returns from trip/ catch	351655
Net operating income	135052

Table 3 — Fox model-based sustainability of marine trawl fish landings

Particulars	Parameters
Intercept (α)	1.87572
Slope (β)	-0.000023
Optimal catch /MSY (tonnes)	104099
Optimal effort/ E_{MSY}	43363
Economic catch/MEY (tonnes)	103030
Economic Effort/ E_{MEY} (trips)	37429

$$E_{MEY} = \frac{1}{\beta}\left(-1 + \sqrt{\frac{c}{Pe^{\alpha}}}\right)$$

$$MEY = E_{MEY}e^{(\alpha+\beta E_{MEY})}$$

The calculated MEY stands at 1,03,033 tonnes of catch, and the E_{MEY} (economic effort) was calculated to be about 37,429 trips. The actual catch exceeds MEY by 27.21 %. Detailed results of the Fox model regression are presented in Table 3.

The fish catch consistently surpassed the MEY level for nearly all the years. The effort dedicated to marine fish production also significantly exceeded MEY levels. This leads to the conclusion that the current fishing effort has surpassed economically optimal levels, resulting in unnecessary wastage of resources such as money, manpower, and fuel in the fishing industry. Optimal fleet management and the rehabilitation of surplus vessels through a systematic lot system may be the most effective approach to limit the current catch levels[27]. Regulations can also be put up by placing an upper limit on engine horse power[30].

Figure 4 illustrates the levels of MSY and MEY. When the fish population is abundant and expanding, it is more cost-effective to catch. However, when the fish population is reduced beyond MSY, the population's recruitment rate will correspondingly decrease. To maintain the biological growth of the fish

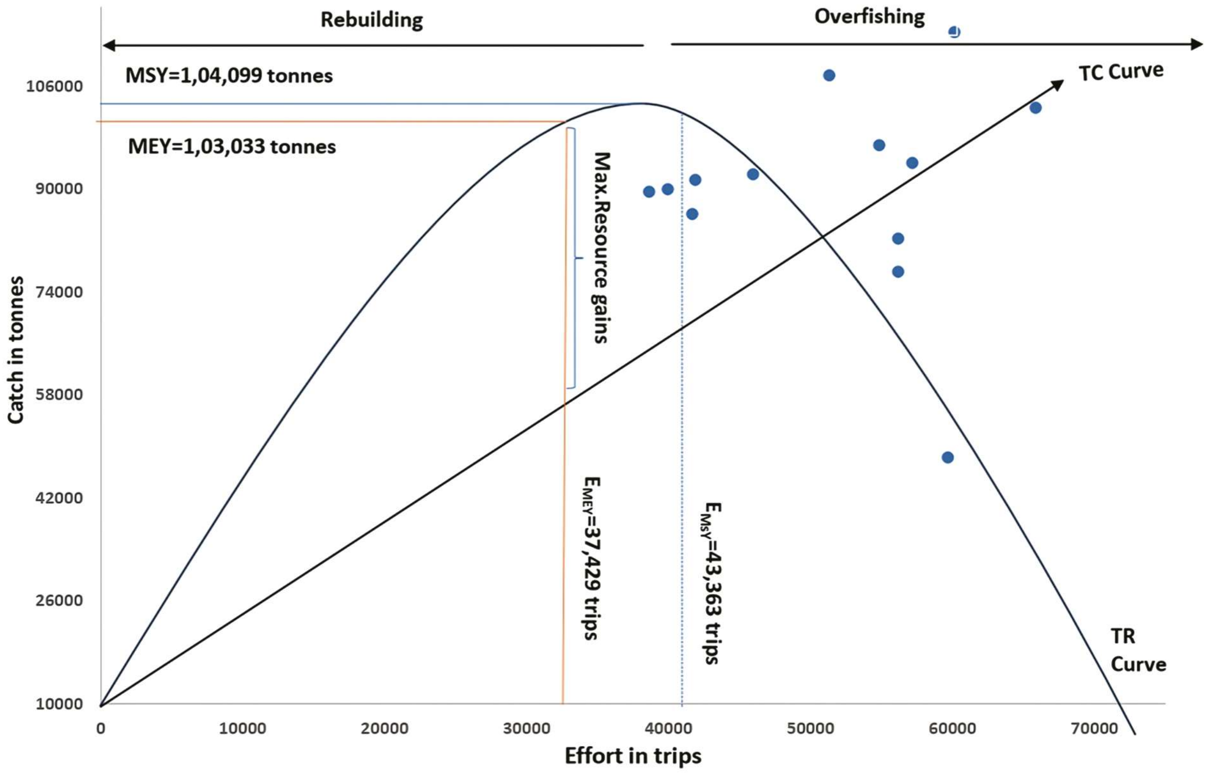

Fig. 4 — Maximum sustainable and maximum economic yield curve

population, it is advisable to harvest up to MSY levels. However, economically, it is not optimal due to the increased efforts required to reach MSY levels. Additionally, the marginal returns for every unit of effort added to the total effort would result in diminishing revenue. Thus, economists recommend exploiting fish at the level of MEY, where marginal revenue equals marginal cost (MR = MC) to optimize given inputs. Bhatt & Bhatta[10] used the Fox model to estimate MSY, MEY and their respective yield levels for the marine fisheries sector of Karnataka. The effort generating MEY results in maximum annual net profit. Maximum Economic Yield maximizes economic potential while also addressing conservation objectives. It goes beyond profit maximization by considering cost management. It also ensures optimal utilization of fishing inputs to maximize profit by maximizing the difference between total revenue earned and total costs. The reasons why fisheries should maximize economic net benefits via MEY are therefore broadly recognized[25]. In a race of catching more and more fish, fishers forget that they are investing more on inputs; thus, either total revenue equals total cost, or total cost is more than total revenue earned. The profits earned are, therefore, negative rents. Profits can be maximised by keeping a check on fishing inputs and investing less than earnings.

Conclusion

Fishing is the primary income source for Mumbai fishers, yet diminishing catches endanger both fish populations and the livelihoods of fishers. The increasing demand for fisheries resources can drive overexploitation, risking stock depletion and the potential extinction of certain species[26]. Sustainable management through monitoring and control is vital to prevent depletion and safeguard incomes.

Urgent measures are required to limit the current levels of catch. One recommended policy option is the implementation of fishing catch quotas, vessel catch quotas, and restrictions on vessel size in terms of tonnage. However, it is crucial for the national and regional fisheries policies and planning makers and fishermen to be informed with an accurate understanding of the economic performance of fisheries, their social contributions, and their sustainability.

To mitigate catch losses sustainably, enforcing measures like banning destructive fishing gear, monitoring mesh sizes, and reducing vessel numbers is crucial. These strategies aim to achieve MSY and MEY which can ensure not only the maximum long-term yield from the fishery but also maximize the sustainable income of the fishers. MSY and MEY as fisheries management tool is complex due to intricate interactions within social, economic, and ecological systems, making it a challenging "wicked problem"[28,29]. Active fishers' participation in the decision-making process for fisheries management is crucial. This involvement will empower them as active contributors to fisheries management, ensuring a balance between rights and responsibilities. Hence, governing interactions that are participatory, communicative, and adaptive are required[29]. Further, extension services for strengthening knowledge dissemination are also an indispensable measure of boosting income.

Doubling income doesn't necessarily mean making the income two-fold. It also connotes enhancing the income. Fundamentally, the income of fishers may be enhanced by increasing the gross income and reducing the costs. Enhancing the real prices received by fishers can positively impact income. Additionally, income can be boosted by increasing the production. Sustainable methods are crucial for achieving increased production that meets the present needs of fishers without jeopardizing the prospects of future generations. A substantial increase in income necessitates significant growth in output coupled with a reduction in input costs, a goal which can be attainable by adhering to the MSY and MEY levels.

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Conflict of Interest

Authors hereby declare that they have no affiliation with any organization with a direct or indirect financial or personal interest in the subject reported in the manuscript.

Ethical Statement

The paper reflects the authors' own research and analysis in a truthful and complete manner. Data collection and analysis have been conducted with transparency, honesty, and commitment.

Author Contributions

SNR: Original draft, data collection, formal analysis & writing – review and editing; NWQ: Conceptualisation and writing – review and editing; MK: Conceptualisation and supervision; PSA: Formal analysis and investigation; and NP: Data collection - both secondary and primary data and formal analysis.

References

1 CMFRI, *Annual Report*, (Central Marine Fisheries Research Institute, Kochi), 2019, pp. 364.

2 Narayanakumar R, Sathiadhas R & Aswathy N, Economic performance of marine fishing methods in India, *Mar Fish Infor Serv*, *T&E Ser*, 200 (2009) 3-16.

3 Devaraj M & Vivekanandan E, Marine capture fisheries of India: Challenges and opportunities, *Curr Sci*, 76 (3) (1999) 314-332.

4 CMFRI, *CMFRI Annual Report 2017-2018 - Technical Report*, (CMFRI, Kochi), 2018, pp. 304.

5 Narayanakumar R, Maximum economic yield and its importance in fisheries management, In: *Course Manual Summer School on Advanced Methods for Fish Stock Assessment and Fisheries Management*, *Lecture Note Series No. 2/2017*, (CMFRI Kochi), 2017, pp. 252-257.

6 Worm B, Hilborn R, Baum J K, Branch T A, Collie J S, *et al.*, Rebuilding Global Fisheries, *Science*, 325 (5940) (2009) 578-585. https://doi.org/10.1126/science.1173146

7 Sathiadhas R & Prathap K S, Employment Scenario and Labour Migration in Marine Fisheries, *Asian Fish Sci*, 22 (2) (2009) 713-727. https://doi.org/10.33997/j.afs.2009.22.2.032

8 Robinson M A, Determinants of Demand for Fish and their Effects upon Resources, *J Fish Res Board Canada*, 30 (12) (1973) 2051-2058. https://doi.org/10.1139/f73-330

9 Hollowed A B, Bax N, Beamish R, Collie J, Fogarty M, *et al.*, Are Multispecies Models an Improvement on Single-Species Models for Measuring Fishing Impacts on Marine Ecosystems? *ICES J Mar Sci*, 57 (3) (2000) 707-719. https://doi.org/10.1006/jmsc.2000.0734

10 Bhat M G & Bhatta R, *An economic analysis of sustainability of marine fish production in Karnataka*, Working Paper Series: MES-1, (Indira Gandhi Institute of Development Research, Mumbai, India), 2001.

11 Chae D R & Pascoe S, Use of simple bioeconomic models to estimate optimal effort levels in the Korean coastal flounder fisheries, *Aquat Living Resour*, 18 (2) (2005) 93-101. https://doi.org/10.1051/alr:2005012

12 Thanh N V, *Bioeconomic analysis of the shrimp trawl fishery in the Tonkin Gulf, Vietnam*, M. Sc Thesis, University of Tromso, Norway, 2006.

13 Ahmed M, Boonchuwongse P, Dechboon W & Squires D, Overfishing in the Gulf of Thailand: policy challenges and bioeconomic analysis, *Environ Dev Econ*, 12 (1) (2007) 145-172. https://doi.org/10.1017/S1355770X06003433

14 Fishery and Aquaculture Economics and Policy Division, *Review of the state of world marine fishery resources*, FAO

Fisheries Technical Paper 0429-9345, (FAO, Rome), 2005, pp. 242. ISBN: 9251052670

15 Guillen J, Macher C, Merzéréaud M, Bertignac M, Fifas S, *et al.*, Estimating MSY and MEY in multi-species and multi-fleet fisheries, consequences and limits: an application to the Bay of Biscay mixed fishery, *Mar Policy*, 40 (2013) 64-74. https://doi.org/10.1016/j.marpol.2012.12.029

16 Government of Maharashtra, *Fish Production Report*, (Department of Fisheries, Mumbai, Maharashtra), 2018, pp. 162.

17 Annam V P & Sindhu K, Augustine, Marine fish landings in Greater Mumbai during 1998-2004, *Mar Fish Infor Serv, T&E Ser*, 185 (2005) 14-18.

18 Government of Maharashtra, Economic Survey of Maharashtra 2017-18, (Directorate of Economics and Statistics, Planning Department, Government of Maharashtra, Mumbai), 2017, pp. 309.

19 Department of Fisheries, Govt. of India & CMFRI, *Marine Fisheries Census 2016 - Maharashtra*, (ICAR-Central Marine Fisheries Research Institute, Kochi), 2020, pp. 264.

20 Thorpe R B, What is multispecies MSY? A worked example from the North Sea, *J Fish Biol*, 94 (6) (2019) 1011-1018. https://doi.org/10.1111/jfb.13967

21 Schaefer M B, Some aspects of the dynamics of populations important to the management of the commercial marine fisheries, *Bull Math Biol*, 53 (1-2) (1991) 253-279. https://doi.org/10.1016/S0092-8240(05)80049-7

22 Gordon H S, The economic theory of a common-property resource: the fishery, *J Pol Econ*, 62 (2) (1954) 124-142. https://doi.org/10.1086/257497

23 Fox Jr W W, An exponential surplus-yield model for optimizing exploited fish populations, *Trans Am Fish Soc*, 99 (1) (1970) 80-88. https://doi.org/10.1577/1548-8659(1970)99%3C80:AESMFO%3E2.0.CO;2

24 Beddington J R & Robert M M, Harvesting natural populations in a randomly fluctuating environment, *Science*, 197 (4302) (1977) 463-465. https://doi.org/10.1126/science.197.4302.463

25 Squires D & Vestergaard N, Putting economics into maximum economic yield, *Mar Resour Econ*, 31 (1) (2016) 101-116. https://doi.org/10.1086/683670

26 CMFRI, *Annual Report 2016-17*, (ICAR-Central Marine Fisheries Research Institute, Kochi), 2017, pp. 292.

27 Devaraj M & Paralkar S, Economic performance of mechanised trawlers in the State of Kerala, India, *Fish Res*, 6 (3) (1988) 271-286. https://doi.org/10.1016/0165-7836(88)90019-7

28 Jentoft S & Chuenpagdee R, Fisheries and coastal governance as a wicked problem, *Mar Pol*, 33 (4) (2009) 553-560. https://doi.org/10.1016/j.marpol.2008.12.002

29 Rittel H W & Webber M M, Dilemmas in a general theory of planning, *Pol Sci*, 4 (2) (1973) 155-169. https://doi.org/10.1007/BF01405730

30 Krishnan M, *Doubling fishers and fish farmers income*, edited by Dalwai A, (Ministry of Agriculture and Cooperation, Govt of India), 2018, pp. 59.