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Techno-economic efficiency of marine fisheries in Gulf of Mannar Biosphere Reserve, India

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Capture marine fisheries play a significant role in social, cultural, and economic dimensions of Indian capture fisheries that contributes to the blue growth strategies. Here the small-scale fisheries (SSF) constitute about 60 % and remaining 40 % large-scale fishing fleets (LSF). In this study, we have highlighted the techno-economic key indicators and technical efficiency of SSF and LSF of Gulf of Mannar Biosphere Reserve, India using Cobb-Douglas function, and Data Envelopment Analysis. The technical efficiency was slightly higher in SSF (TE = 0.961) with better quantity of fish produced per litre of fuel (5.05 kg) compared to the LSF (TE = 0.951). The labour efficiency such as value ($87.56) and quantity of fish produced per day (83.39 kg) was greater in LSF than the SSF ($7.07 and 14.26 kg, respectively). Though production cost was higher for LSF, the better gross revenue of $658.27 was generated than SSF ($42.41) and it mainly related to higher engine power (150 – 200 hp) and longer fishing ground distance from the shore (117.50 km) for LSF than SSF (9.9 to 25 hp and 48.80 km, respectively). Results of the present study suggest that there is limited scope to improve the technical efficiency of the fishing fleet since both were operated at better efficiency conditions. However, the lower gross revenue per trip in SSF can be improved and higher production cost in LSF can be minimized by improving the performance of the fishing fleets in Biosphere Reserve.

[**Keywords**: Capacity reduction, Large-scale fisheries, Management, Overfishing, Sustainability]

Introduction

Wild-caught fish provide food and supports livelihoods globally[1]. Capture marine fisheries have a conspicuous role in economic and social development[2]. Availability of fossil fuels and improvement in technologies[3] leads to industrialization that promptly turned most marine fisheries into the global corporate enterprises from domestic entities[4] which was mainly driven by rising disposable income[5]. This growth has gone haywire, encouraged rampant indiscriminate fishing activities, based on greed, rather than on rational management[6] led to augmentation in fishing effort and pressure resulting in diminished catch per unit effort (CPUE)[7], and higher operating cost[8]. Despite, subsidies accrued by the fishing sector to compensate the economic loss further exacerbates the decline of fishery resources, and it creates an illusion that fishing is a flourishing and viable business[3]. Further, the focus of fishing activities in coastal areas – entry of new fishing fleet, overcapacity, and poor management – put marine fishery resources under extreme pressure and many stocks were overfished[9]. Overexploitation and decline in fishery resources were evident, prompting reforms in fishery management[10]. Hence, stringent fishing regulation and robust governance framework are essential to truncate fishing overcapacity in order to sustain fish catch over the long-term and support viability of the resources for the benefit to fishers and consumers[11]. Yet, enhanced augmentation of fishing capacity, engine power, and fleet size have been noticed and on the other side, the fraction of fish stock that is within a biologically sustainable level is exhibiting a diminishing trend and stocks fished at biologically unsustainable levels have increased[1]. Therefore, the question to be answered is whether all the fishing fleet earned similar economic returns? However, considerable variation exists in fisher's income[8] and operational efficiency[12] among the fishing fleet as well as within similar kind of fishing fleet due to productivity and distribution of fish stocks[13], engine power and fleet size[13], skipper skills[14], fishing experiences, fishing days[12,15] and mesh size of the fishing gear. The inefficient fishing fleet can be removed from the fishing through buyback methods and offers alternative livelihood options[16]. It is very much essential to estimate the efficiency of the fishing fleets operating in the sea, which helps the policymaker and fishery manager to exploit the resources sustainably.

In tropical countries such as India, fisheries are mostly multi-species in nature and different fishing fleet and gears are used. Mechanization eased the dramatic increase in the number of fishing fleet, resulted in stagnancy in marine fish landing in India. The 30 % of fish species (Whitefish, Ribbonfish, Flatfish, Elasmobranchs, and Mullets) stocks declined out of the 26 fishery resource groups in India. The flying fish and unicorn cod were depleted and had collapsed. They are in need of management interventions to recover their resources[17]. Tamil Nadu is one of the coastal states, which is located in south-eastern part of India contributing 20 % of the total of India’s marine fish production in 2018(ref. 18). The coastal area of Tamil Nadu is classified into Coromandel Coast, Palk Bay and Gulf of Mannar on geographical distribution basis among which the Gulf of Mannar is the first Marine biosphere reserve in South East Asia, which lies between 8°35′ N – 9°25′ N and 78°08′ E – 79°30′ E; consists of a chain of 21 islands, and Tuticorin is the core zone. A total of 4223 species of flora and fauna including coral reefs, algal resources, seagrass beds, mangroves, sea turtles, and sea cows were reported from the coast. The mechanized fishing fleets increased from 3.65 % in 1980 to 16.96 % in 2010 but the small-scale fishing fleet (non-mechanized) decreased from 96.35 % to 62.59 % during above mentioned years out of the total 15148 fishing fleets in Gulf of Mannar[19,20]. The gill net was used widely followed by hooks & lines, driftnet, trawl net, troll line, ring seine, boat seine, and other gears. Earlier, the small-scale fishing fleet had alone contributed about 98 % of the total landing in Gulf of Mannar but it has been changing over period due to improvement in fishing fleet and gears. Against this importance, studies were conducted worldwide *i.e*. English channel[13], Australia[21], Sweden[22] and in different countries[6] in which the efficiency results of the fishing fleet was used to improve the performance of efficiency and enhance the income of the fishers. It is believed that large-scale fisheries (higher engine capacity fishing fleets) had higher economic returns and greater technical efficiency over the small-scale fisheries and hence, it is pivotal to know whether the fishing fleets are performing efficiently or not. Since such kind of studies are very limited in India, the present study aimed to investigate the techno-economic efficiency, cost-income ratios and technical efficiency through data envelopment analysis and its determinants with Cobb-Douglas production function for the small-scale fisheries (SSF) and large-scale fisheries (LSF) in Gulf of Mannar Biosphere Reserve (GOMBR), India.

Materials and Methods

Data source

The data used in this study were sourced from fishing fleet operating in the Gulf of Mannar Biosphere Reserve, India (Fig. 1). The stratified random sampling procedure was adopted to collect the data from September 2012 to April 2013. Finally, 40 respondents each in small-scale and large-scale fishing fleet, respectively, were selected in this study. The surveyed respondents were primarily engaged in fishing activities for their livelihoods. The interview schedule was piloted from 10 respondents to improve further. Face-to-face interviews were conducted with the respondents at their workplace. The schedule majorly covered the technical, operational, and commercial information of the fishing fleet.

Technical efficiency analysis

Technical efficiency (TE) is the ability of a firm to obtain the maximum output from the given set of

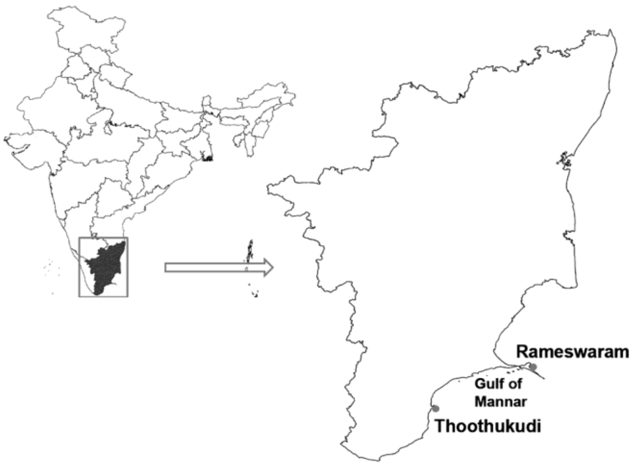

Fig. 1 — Map showing the study locality of the Gulf of Mannar, India

inputs and the factors that determines the crucial importance in production and allows the stakeholders to take measures for improvement[23]. Fisheries are complex systems, which interact with several variables and whose relationship and feedback loops are often difficult to model[24]. TE in fisheries is characterized by the relationship between the observed fish catch and potential fish catch of the fleet[25] when potential production is not reached, then fleet is considered as technically inefficient. Technical efficiency may be reduced through the use of a constrained input or be improved through the alternative use of inputs or taking a measure that properly defines the property rights[23]. The impact of fishing activities on those resources requires regulations, which help to establish underlying factors, assess the effect of management measures, and ensure the sustainable harvest. The following methods were used in the present study to estimate the technical efficiency.

Techno-economic efficiency

To estimate the techno-economic efficiency, the key efficiency indicators can be worked-out from the costs and returns data of the fishing operation and for calculation Sathiadhas *et al.*[26] were followed. The ratios are measured by following standard procedures[27].

Cobb Douglas (CD) production function

The C-D function model is used to assess the input utilization of mechanized trawlers[28], and production economics of the artisanal fisheries in Jamaica[29] has been applied for this study. The C-D production function model is expressed as follows:

$$Log\,Y = log\,a + \sum_i b\, log(X_i) + log\,U_i$$

Explanatory variables used in this study explain the economic efficiency of the small-scale and large-scale fishing fleet and the following empirical C-D model is used in this study.

$$\begin{aligned} Log\,Y_i = log\,a &+ b_1\,log\,X_{1i} + b_2\,log\,X_{2i} \\ &+ b_3\,log\,X_{3i} + b_4\,log\,X_{4i} \\ &+ b_5\,log\,X_{5i} + b_6\,log\,X_{6i} \\ &+ b_7\,log\,X_{7i} + b_8\,log\,X_{8i} \\ &+ b_9\,log\,X_{9i} + b_{10}\,log\,X_{10i} + log\,U_i \end{aligned}$$

Where, Y is the marine fish landing in quantity terms (kg per annum), X_1 is the fleet size (meter), X_2 is the fleet speed (knots), X_3 is the crew size (numbers of persons), X_4 is the annual fishing days (number of days), X_5 is the fishing distance from the shore (Nm), X_6 is the fuel cost (\$ yr^{-1}), X_7 is the cost of ice (\$ yr^{-1}), X_8 is the labour wages (\$ yr^{-1}), X_9 is the food expenses (\$ yr^{-1}), X_{10} is the other operating cost (\$ yr^{-1}), and U_i is error term. The calculated regression coefficient as a percent by itself is the elasticity of production.

Data Envelopment Analysis (DEA)

Data Envelopment Analysis (DEA) is a linear program and a non-parametric method, which assumes the production function is unknown[30–33]. DEA technique never accounts for the random variation in output but it clearly attributes any shortfall in output and technical inefficiency. The random error is in its production and leads to misinterpreting error in the inefficiency of the individual fishing fleets. DEA is formulated as a linear programming model, whereas the value of θ for the individual fishing fleet is estimated by using the amount of input used and the amount of output produced. The DEA is not only applied to estimate the TE, but also for to capacity utilization[34], revenue maximization and profit maximization behaviour[30,35–37]. The catch from the fishing fleet is not only the function of inputs given by the fishers; it also depends on the existing fish stocks, because most of the species exhibit seasonal abundances, which vary with places. Lack of a stock biomass indicator is a common issue in fisheries, therefore to elude this, the stock was considered as constant round the year and dummy variables were also used[15]. The TE wherein fish catch as dependent variable and the technical details of the fleet as independent variables[38,39] but in another study TE is measured based on the fish catch (volume) or revenue (value) as dependent variable and cost details were considered as independent variable and clinched that catch based estimation appropriate rather than revenue[40]. We have considered the fish catch data as dependent variable and technical and cost details as independent variables to estimate the technical efficient output. The DEA model of TE measure is as given below:

An output-oriented model primarily used for calculating Constant Return to Scale and Variable Return to Scale measures.

$$\text{Max}_{\theta,\lambda}\theta_i$$

$$\text{Subject to} \sum_{j=1}^{n} \lambda_j y_j - \theta_i y_i - s = 0$$

$$\sum_{j=1}^{n} \lambda_{jx} k_j + ek = xki$$
$$\lambda_j \geq 0; s \geq 0\ ek \geq 0$$

Where, θ_i is proportional increase in output possible for the i^{th} fleet, λ_j is an Nx1 vector of weight relative to efficient observation, s is the output slack and ek is the k^{th} input slack. A craft is efficient when the values of θ and λ_i are equal to 1; and $\lambda_j = 0$. On the contrary, an observation of inefficient TE when $\theta > 1$, $\lambda_i = 0$ and $\lambda_j = 0$.

$$\mathrm{TE}_i = \frac{Y_i}{Y_i^*} = \frac{1}{\theta_i}\ 0 \leq \mathrm{TE}_i \leq 1$$

Where, Y_i and Y_i^* are observed and maximum possible output respectively. It calculated exerting Data Envelopment Analysis (Computer) Program (DEAP version 2.1), that is written and developed by Coelli[41].

Results

In the present study, the trawler was representative of LSF, and Catamaran and FRP craft represented SSF fishing fleet in GOMBR. They were classified based on the engine with deck equipment and engine power (hp). LSF and SSF fleet with a length of 9 to 20 m and 7 to 12 m Overall Length (OAL) and with 150 – 200 hp and 9.9 to 25 hp engine power, respectively were operated in the study area. The mean value of the variables included in the model of CD function and DEA is presented in Table 1. The LSF fleet had the highest fleet length of 15.7 meters and could cover longer distances to fishing grounds from the shore driven by a powerful engine, which largely explains its higher annual catch of 122 tons with the largest crew size of eight fishers (195 days). Table 1 also shows that the SSF fleet could only obtain the lowest annual catch of 18 tons and put in the maximum number of fishing days *i.e.* 210 days. Of the cost ratios, the operating cost ratio of 0.75 was calculated for SSF (Fig. 2), which indicated that 75 % of the gross revenue was used to cover the operating expenses whereas 82 % for LSF. The gross ratio was found to be lower (0.86) in SSF and higher in LSF (0.90) and similar kind of results also observed operating in ratio (0.82 in LSF and 0.75 in SSF) and capital turnover ratio (4.34 in LSF and 2.51 in SSF).

Table 1 — Summary statistics of the surveyed fishing fleet (1$ = ₹ 68.68; n = 40)

	Small-scale fishing fleet	Large scale fishing fleet
Annual catch (kg)	18099.7 ± 320.3	122041.2 ± 2040
Fleet length (m)	12.1 ± 0.3	15.7 ± 0.3
Fleet speed (knots)	7.5 ± 0.2	8.6 ± 0.2
Crew size (nos.)	6.0 ± 0.1	8.0 ± 0.1
Fishing days yr^{-1}	210 ± 3	195 ± 1.2
Fishing ground distance (km)	48.80 ± 2.2	117.50 ± 2.7
Fuel cost ($ yr^{-1})	39.35 ± 1.9	1023.65 ± 21.4
Ice cost ($$yr^{-1}$)	10.49 ± 0.54	49.83 ± 0.84
Wages ($ yr^{-1})	150.74 ± 3.95	722.14 ± 9.64
Food cost ($ yr^{-1})	-	22.1 ± 0.38
Other operating cost ($ yr^{-1})	19.11 ± 4.77	-

Values presented as mean ± SE of the surveyed samples

Table 2 shows the mean value of the techno-economic efficiency of SSF and LSF. The quantity of fish produced per person per day (83.39 kg) and value of fish produced per person per day ($87.56) was significantly greater in LSF when compared to the SSF (14.26 kg and $7.07, respectively). Nevertheless, the quantum of fish production per litre of fuel was more than four-fold in SSF (5.05 kg per litre of fuel) than the LSF (1.15 kg per litre of fuel) that leads to four-fold reduced fuel cost per kg of fish in SSF ($0.14 per litre of fuel) than the LSF ($0.58 per litre of fuel). However, the highest gross revenue per trip of $658.27 was observed in LSF and lowest of $42.41 in SSF.

In Figure 3, the CD production function results for the main model specified in equation 2 holding the variables are presented. The model explains the efficiency, which has all the influencing variables. The ten explanatory variables in the models explain 99 % of the variation in SSF and LSF. The fleet size, fleet speed, annual fishing days, fishing distance from the shore and labour wages passively influenced the fish production in LSF but annual fishing days and fleet length were statistically significant ($p < 0.05$) and remaining other explanatory variables negatively

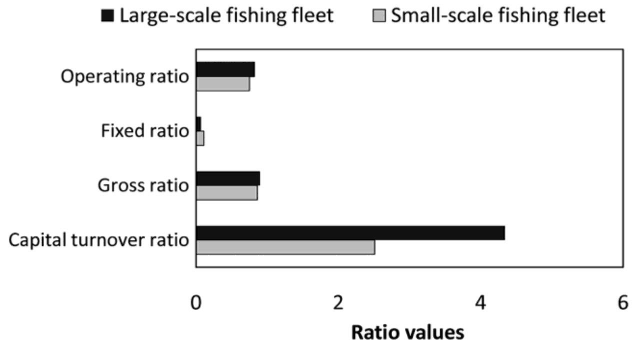

Fig. 2 — Cost and income investment ratio for the small-scale and large-scale fishing fleets

Table 2 — Techno-economic efficiency of the small-scale and large-scale fishing fleet (1$ = ₹ 68.68; n = 40)

Sl. No	Particulars	Small-scale fishing fleet	Large scale fishing fleet
1	**Labour efficiency**		
	Number of crew per trip	6.00	8.00
	Quantity of fish produced per person per day (kg)	14.26	83.39
	Value of fish produced per man day ($)	7.07	87.56
2	**Fuel efficiency**		
	Fuel (litre)	18.83	553.95
	Quantity of fish produced per litre of fuel	5.05	1.15
	Fuel cost per trip ($)	12.33	362.95
	Fuel cost per kg of fish ($)	0.14	0.58
3	**Economic efficiency**		
	Average catch per trip (kg)	86.38	625.87
	Gross revenue per trip ($)	42.41	658.27
	Average value realized per kg of fish ($)	0.49	1.05
	Average operating cost per trip ($)	31.78	540.77
	Operating cost per kg of fish ($)	0.37	0.87
	Total cost per day ($)	36.56	590.13
	Average total cost per kg of fish ($)	0.43	0.94

Values presented as mean ± SE of the surveyed samples

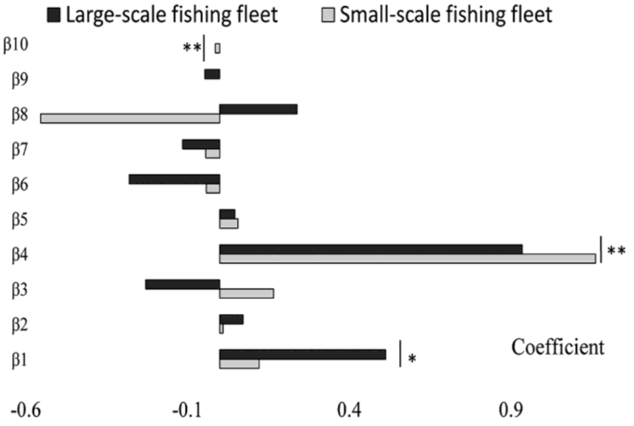

Fig. 3 — Cobb-Douglas production function estimation for small-scale and large-scale fishing fleets (*and ** Significant at 1 % and 5 %, respectively)

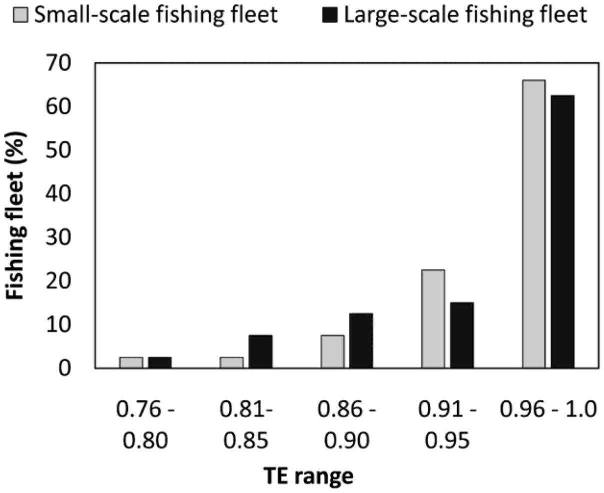

Fig. 4 — Technical efficiency of the small-scale and large-scale fishing fleet output oriented

influenced the hauls. The annual fishing days and bait purchasing cost were passively and negatively significantly ($p < 0.05$) influenced the fish production for SSF. Other things being equal, one unit increase in the fleet size is associated with a 0.122 % and 0.513 % increase in the landing of fish for SSF and LSF, respectively. Moreover, one percentage point increase in annual fishing days results in 1.162 and 0.935 percentage point increase in marine fish landing, respectively.

In Figure 4, the results of the TE of the SSF and LSF are presented which were calculated through output-oriented method. The highest mean TE score of 0.961 was recorded for SSF and lowest mean TE of 0.951 in LSF. Further it noticed that most of the fishing fleet in both the SSF and LSF operated above the TE score of 0.90.

Discussion

The principal aim of the present study was to assess the technical efficiency of SSF and LSF fleets in the Gulf of Manner Marine Biosphere Reserve, India. The results of the study showed disparity in efficiency between the SSF and LSF and its determinants. The gross benefits have increased progressively with engine power. Yet, increasing the engine capacity resulted in a higher capital turnover ratio in LSF than the SSF. The LSF fleets utilized the capital investment two-fold efficiently as compared to SSF.

The fish catch was higher in LSF than SSF, due to the size of the fishing vessel, engine capacity and experience of the skipper. Annual fishing days have been remarkably influencing the catch quantity as well as the revenue[1,8]. However, LSF fleet has lesser fishing days per annum compared to SSF[42] owing to weather conditions[6] and fishing ban period as conservation step to aide new recruitment of fish stock in the marine ecosystem, whereas SSF fleet has better advantage in fishing without any discontinuity[43].

Fuel efficiency was more in SSF than that of the LSF and may be attributed to the existence of main fishing grounds not away from the shore like that of LSF. The value realization (kg^{-1}) was higher for LSF because of targeted fishing than the SSF fleet[42]. High catch and gross revenue, which were obtained in LSF was through high engine power and fleet size. Furthermore, it proved that with increasing fishing days, the catch tends to be higher. The returns to scale were calculated to be 1.74 for LSF and 1.82 for SSF. Lower return to scale of 1.42 and 1.26 was found for the Iranian fishery[44] and Trammel netter in Greece[33], respectively. In contrary to the present findings, the large size fleet had a higher efficiency of 0.85 than the smaller fleet TE ratio of 0.6 for the Iranian fishery in the Persian Gulf[44]. Similarly, the Swedish larger size fishing fleet had better efficiency than smaller fishing fleet and may be due to the fact that the vessels have different technology[22].

Crew size has better influence over the efficiency of the fleets, which indicates that increasing the crew size progressively enhanced the efficiency of the LSF in the English Channel[13], and banana prawn fishery in Australia[21]. A positive association between the fishing distance from the shore and TE was observed in Tanzanian coastal fishing village[39], and the present study reflects the same. Only one-third of the variation in TE of the trawler could be explained through fishing fleets characteristics and remaining through non-meristic characteristics including skipper knowledge, skipper experience, weather, and fish stock status[13].

This concludes that the economic return was greater in LSF but with lesser economic performance than SSF. Despite the better technical efficiency found in SSF than that of the LSF in Gulf of Manner Biosphere Reserve, India. This study is constrained by limited sample size. The study suggests that further studies should be taken up in wider scale to compare the technical and economic performance and efficiency within LSF and SSF, because there is a need to judiciously exploit the resources of different fishing distance from the shore to better understand and manage the fishery resources sustainably and for conservation of biodiversity.

Supplementary Data

Supplementary data associated with this article is available in the electronic form at http://nopr.niscair.res.in/jinfo/ijms/IJMS_50(09)729-735_SupplData.pdf

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Conflict of Interest

The authors declare that there is no conflict of interest.

Author Contributions

Conceptualization: RN, KR, MK; formal analysis: KR, RN, IS, JA; resources: MK, RN, JA, IS; software: KR, RN, IS; supervision: RN, MK; original draft: RK, JA, IS; and review & editing: MK, RN.

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