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Optimising Efficiency of Ring Seine Fishing Vessels Using DEA: A Resource and Catch Analysis

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ABSTRACT

The study examines the efficiency of ring seine fishing vessels operating in Goa, which are crucial in capturing pelagic fish like sardines, mackerels, and anchovies. The research uses Data Envelopment Analysis (DEA) to evaluate the operational efficiency of these vessels. Data from 120 fishing trips during 2021-2022 were analyzed using an input-oriented DEA model, focusing on minimizing inputs like diesel, ice, and freshwater while maintaining catch levels. The study reveals significant efficiency variations among freshwater, with the 10th Decision-Making Unit (DMU) achieving 100 per cent efficiency, setting a benchmark for the fleet. The average cost efficiency across all vessels was 33.6 per cent, indicating substantial room for improvement. The study highlights that improving resource usage, particularly diesel, can improve cost efficiency and sustainability. The findings offer practical recommendations for policymakers and vessel operators, including optimizing input usage, improving energy efficiency, and implementing training programs based on the most efficient vessels. These insights promote operational efficiency and sustainability in Goa's ring seine fishing industry, benefiting the local economy and coastal communities reliant on this method for livelihood.

Keywords: Data Envelopment Analysis, optimization technique, Ring Seine Fishing Vessel, CCPU, technical, allocative and economic efficiency.

JEL codes: C61, D24, Q22, Q57

I

INTRODUCTION

The fishing industry plays a crucial role in the economic and nutritional landscape of coastal regions worldwide. In Goa, ring seine fishing vessels are a cornerstone of local fisheries, contributing significantly to the economy and food security. The ring seine fishing system is a prevalent method used by Indian coastal fishermen to catch pelagic fish species, including sardines, mackerels, and anchovies Pravin, P., & Meenakumari, B. (2016). This system involves deploying large circular nylon nets from fishing vessels to encircle and capture fish, operating extensively along the Indian coastline from Gujarat to West Bengal (Sainsbury, 1996). This method supports coastal communities by providing employment opportunities and contributing to local consumption and export markets. The government regulates ring seine fishing to ensure sustainability, mitigate environmental impacts, and promote responsible fishing practices.

The ring seine method evolved from traditional ring seine fishing, introduced to India by the Indo-Norwegian Project in 1954. Advances in vessel technology, gear handling equipment, and fish detection techniques have enhanced the efficiency and effectiveness of ring seine fishing (Mukundan & Hakkim 1980; Hameed &

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Boopendranath 2000). The ICAR-Central Institute of Fisheries Technology developed and introduced the mini ring seine for operation from motorized boats in the traditional sector during the early 1980s, significantly reviving the conventional fishing sector in Kerala and reducing the dominance of larger ring seines. Ring seine fishing remains a dominant method for harvesting coastal shoaling pelagic resources in India (Menon 1970), with approximately 1,213 ring seiners operating along the west coast, including around 300 in Goa. Despite challenges, ring seine fishing continues to be sustainable and efficient, benefiting local communities and the broader economy.

In this study, a comprehensive analysis of resources such as fuel, crew, and ice to catch fish by evaluating Ring Seine Fishing Vessels operated along the Goa coast will be carried out (Oommen 1989). The study further attempts to optimize fishing vessel efficiency using Data Envelopment Analysis (DEA) (Subhash 2004). DEA is a non-parametric linear programming method to analyze the efficiency of multiple-unit systems, constituting an adequate method to evaluate fishing capacity. However, the present study argues that the minimization of operational inputs in DEA studies may deserve further analysis regarding the output used for the optimization. Consequently, the main aim of this research is to understand how to generate operational benchmarks for fishing fleets using the DEA method (Jara Laso, *et al.* 2018). Through this comprehensive analysis, the study aims to support the sustainable development of the local fishing industry, ensuring that it remains economically viable while minimizing its environmental footprint. The results will benefit vessel operators and inform policymakers and stakeholders involved in fisheries management in Goa and similar coastal regions.

II

DATABASE AND METHODOLOGY

The study was conducted on ten ring seine fishing vessels operating out of the Goa fishing harbour. Data were collected from each vessel over 12 continuous fishing trips, totaling 120 fishing trips during the 2021-2022 period. On average, each fishing trip lasted nine days, with some trips extending up to 18 days.

In the comprehensive efficiency analysis of ring seine fishing vessels, various methodologies were employed as follows

1. *Catch Efficiency Analysis*

Catch efficiency analysis evaluates how effectively fishing vessels utilize their resources to catch fish. Several key metrics are used, including catch per unit effort (CPUE), average catch per day, and catch per unit of fuel consumption. For ring seine fishing vessels, these formulas can be applied as follows

1a. *Catch Per Unit Effort (CPUE)*

CPUE is a widely used metric to assess the efficiency of fishing efforts. It is calculated as follows:

$$CPUE_j = \frac{Y_j}{E_j}$$

Where,

Y_j - Total Catch is the quantity of fish caught by j[th] vessel (in kilograms).
E_j - Effort is the total fishing time by j[th] vessel (days).

1b. *Catch Per Unit of Fuel Consumption (CPUFC)*

$$CPUFC_j = \frac{Y_j}{FU_j}$$

Where,

Y_j - Total Catch is the quantity of fish caught by j[th] vessel (in kilograms).
FU_j - Fuel Consumption is the total fuel used by j[th] vessel (in liters).

1c. Average Catch Per Day (ACPD)

This metric assesses the average daily catch over a given period. It is calculated as follows:

$$ACPD_j = \frac{Y_j}{FD_j}$$

Where

Y_j - Total Catch is the quantity of fish caught by j[th] vessel (in kilograms).
FD_j - Total Fishing Days is the number of days spent fishing by j[th] vessel.

2. Resource Consumption Analysis

Resource Consumption Analysis evaluates how efficiently a fishing vessel utilizes fuel, engine oil, ice, and freshwater. The key metrics for this analysis include the average resource usage per trip and per kilogram of fish caught ring seine fishing vessels. These formulas can be applied as follows.

2a. Average Resource Usage per Trip

This formula is used to calculate the average amount of each resource used per fishing trip by recording the total amount of each resource used (e.g., diesel, engine oil, ice, freshwater) over a given period, counting the number of trips made by the vessel during the same period, and measuring the total fish caught (kg) overall trips. Using these data points, the resource consumption metrics were computed.

$$\text{Average Resource}_i \text{ Usage per Trip} = \frac{\text{Total Resource Used}_i}{\text{Number of Trips}_i}$$

$$\text{Average Resource}_i \text{ Usage per kg of Fish} = \frac{\text{Total Resource Used}_i}{\textit{Total Fish Caught}_i}$$

3. *Economic Analysis:*

Economic Analysis evaluates fishing vessels' financial performance and profitability by examining total expenditures, costs per kilogram of fish, and profitability metrics for ring seine fishing vessels Panicker, P. A. (1985). Record the Total Expenditure for each resource (e.g., diesel, engine oil, ice, fresh water, ration, etc.) over a given period. Using these, the economic analysis metrics can be computed as follows

$$\text{Total Expenditure per Trip} = \sum_{i=1}^{n} \text{Cost of Resource}_i$$

$$\text{Cost per kg of Fish} = \frac{\text{Total Expenditure}}{\text{Total Fish Caught (kg)}}$$

$$\text{Total Revenue} = \text{Price per kg of Fish} \times \text{Total Fish Caught (kg)}$$

$$\text{Profitability} = \text{Total Revenue} \times \text{Total Expenditure}$$

$$\text{Profitability per Trip} = \text{Total Revenue per Trip} - \text{Total Expenditure per Trip}$$

$$\text{Profitability per Kg of Fish} = \frac{\text{Total Revenue}}{\text{Total Fish Caught (kg)}} - \frac{\text{Total Expenditure}}{\text{Total Fish Caught (kg)}}$$

4. *Data Envelopment Analysis (DEA):*

DEA analysis considered one output variable, fish catch quantity (tonnes), and six input variables: fishing duration (days/trip), crew size, diesel consumption (liters), engine oil (liters), ice bars (numbers), and freshwater (liters). Employing the Charnes, Cooper, and Rhodes (1978) model in an input-oriented approach, it measured the technical efficiency scores of Decision-Making Units (DMUs). This approach was chosen as vessel owners control input usage more than catch. The slacks-based measure of inefficiency sets targets for minimizing inputs to achieve optimal usage levels (Ramanathan 2006; Andreu *et al.* 2006). Costs of inputs were factored into cost efficiency scores using the cost DEA model. The SBM DEA model's flexibility accommodated different input and output units. Assumptions included convexity, scalability, and free disposability. A constant return to scale (CRS) approach was used universally, with the BCC approach applied when scalability varied. Given similar technical characteristics and regulations, an input-oriented approach minimized inputs while maintaining output. The analysis used the Charnes, Cooper, and Rhodes model for cost DEA to gauge technical efficiency, focusing on optimizing input usage and cost efficiency (Coelli 1996; Coelli 2008).

4a. Technical Efficiency (CCR Model)

The technical efficiency score θ of a decision-making unit (DMU) is found by solving the following linear programming problem:

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq \theta x_{io,} \qquad for\ all\ i = 1, 2, \ldots., m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro,} \qquad for\ all\ r = 1, 2, \ldots., s$$

$$\lambda_j \ \geq 0, \qquad for\ all\ j = 1,2, \ldots, n$$

Where:

θ is the technical efficiency (TE) score.
x_{ij} is the input i for DMU_j.
y_{rj} is the output r for DMU_j.
λ_j are the weights assigned to each DMU.

4b. Allocative Efficiency

Allocative efficiency is the ability of a DMU to use inputs in optimal proportions, given their respective prices. It is calculated by comparing the cost of inputs used by the DMU to the cost of inputs if the DMU were fully technically efficient (Farrell, 1957).

For the cost-minimizing input quantities z_i

Objective:

$$\sum_{i=1}^{m} \mathrm{w}_i \ z_i$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} \leq z_{i,} \qquad for\ all\ i = 1, 2, \ldots., m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} \geq y_{ro,} \qquad for\ all\ r = 1, 2, \dots, s$$

$$\lambda_j \geq 0, \qquad for\ all\ j = 1,2, \dots, n$$

Where:

w_i is the price of input i.

z_i is the cost-minimizing input quantity for input i.
Then, calculate allocative efficiency (AE):

$$AE = \frac{\sum_{i=1}^{m} w_i \theta x_{io}}{\sum_{i=1}^{m} w_i z_i}$$

4c. Overall Economic Efficiency

Overall, economic efficiency is the product of technical efficiency and allocative efficiency. It measures the ability of a DMU to use the least-cost combination of inputs to produce a given output level.

$$\text{Economic Efficiency } (EE) = \text{Technical Efficiency } (TE)\ X \text{ Allocative Efficiency } (AE)$$

Since Technical Efficiency θ is already found, and Allocative Efficiency (AE) is calculated as above (Chandrasekar & Gopal (2015), Overall Economic Efficiency can be expressed as:

$$EE = \theta \times \frac{\sum_{i=1}^{m} w_i \theta x_{io}}{\sum_{i=1}^{m} w_i z_i}$$

Solving these equations determines technical, allocative, and economic efficiencies, providing insights into resource utilization and improvement areas. DEA results identify input targets to achieve efficient average catch.

4d. Determine Slack Variables

After solving the above linear programming problem, determine the slack variables s_i^- by solving the following:

Objective:

$$Maximise \quad \sum_{i=1}^{m} s_i^-$$

Subject to:

$$\sum_{j=1}^{n} \lambda_j x_{ij} + s_i^- \leq \theta x_{io,} \qquad for\ all\ i = 1, 2, \dots, m$$

$$\sum_{j=1}^{n} \lambda_j y_{rj} + s_r^- \geq y_{ro,} \qquad for\ all\ r = 1, 2, \dots, s$$

$$\lambda_j \geq 0,\ s_r^- \geq 0,\ s_r^+ \geq 0 \qquad for\ all\ j, i, r$$

Using the CCR input-oriented model, the technical efficiency score θ for each DMU was estimated.

4e. Calculate Input Targets

The input targets x_i* for each input i can be calculated using the following equation:

$$x_i^* = \theta x_{io} - s_i^-$$

Where:

x_i* is the target input level for input i.

θ is the technical efficiency score of the DMU.

x_{io} is the observed input level for input i.

s_i^- is the slack for input i.

This will determine target input levels to maintain average catch while minimizing inputs, achieving technical efficiency, and identifying areas for improvement in resource utilization.

III

RESULTS AND DISCUSSION:

*1. Catch Efficiency Analysis***:**

The catch efficiency analysis of ring seine fishing vessels in Table 1 reveals that DMU-7 is the top performer, with an annual catch of 223 tons and 18,587 kg per trip, indicating high efficiency or increased operational days. DMU-7 also shows high diesel consumption at 9,374 liters, suggesting potential inefficiencies. DMU-4 leads in catch per unit effort (CPUE) at 2.6, while DMU-8 excels in daily catch rates at 1,730 kg/day, demonstrating superior fuel efficiency. Overall, DMU-8 stands out for efficiency and profitability, contrasting with higher diesel use in vessels like DMU-7, highlighting areas for improvement in operational practices.

TABLE: 1 ANNUAL CATCH AND EFFICIENCY INDICATORS FOR RING SEINE FISHING VESSELS

Fishing vessel	Annual total catch (tonne)	Catch (Kg/Trip)	Diesel	Catch per Unit Effort (CPUE)	
				Catch per litre	Catch per day
(1)	(2)	(3)	(4)	(5)	(6)
DMU-1	106	8870	4300	2.1	1109
DMU-2	105	8709	3965	2.2	1089
DMU-3	134	11173	4592	2.4	1596
DMU-4	109	9100	3555	2.6	1138
DMU-5	173	14415	5940	2.4	1602
DMU-6	142	11848	7354	1.6	1481
DMU-7	223	18587	9374	2.0	1690
DMU-8	145	12110	5338	2.3	1730
DMU-9	212	17666	8979	2.0	1472
DMU-10	133	11095	4524	2.5	1233
Average	148	12357	5792	2.1	1373

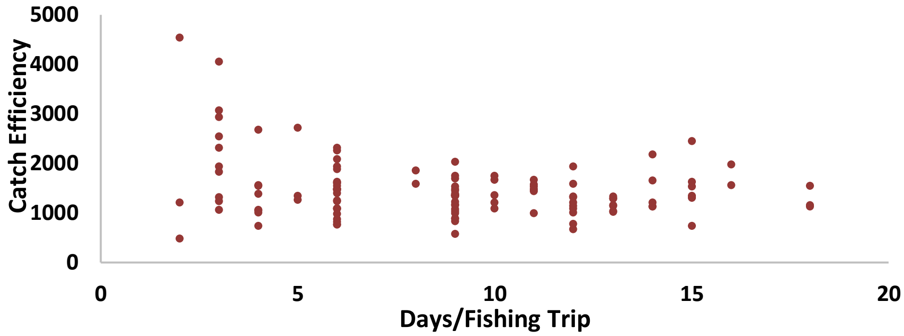

Figure 1: Relationship between Catch Efficiency and Number of Days per Ring Seine Fishing Trip

2. Resource Consumption Analysis:

In the ring seine fishing operation, resource usage is considered a major part, including diesel, engine oil, ice, and freshwater for each trip. Calculations of the average resource usage per kilogram of fish caught are shown in Table 2.

TABLE 2: EFFICIENCY OF FISHING VESSEL RESOURCE USAGE COMPARED TO CATCH QUANTITY

Fishing Vessel (1)	Diesel (Litre) (2)	Engine Oil (ml) (3)	Ice block (Kg) (4)	Fresh Water (Litre) (5)
DMU-1	485	0.93	1.1	14
DMU-2	455	0.84	1.4	9
DMU-3	411	0.60	1.3	9
DMU-4	391	0.64	1.6	14
DMU-5	412	0.32	0.8	5
DMU-6	621	0.77	1.3	13
DMU-7	504	0.52	0.8	8
DMU-8	441	0.43	0.9	7
DMU-9	508	0.42	0.8	8
DMU-10	408	0.44	0.9	9
Average	469	0.56	1.0	8

Analysis of per unit resource usage per kilogram of fish caught reveals insights into fishing vessel efficiency. Diesel consumption ranges from 391 to 621 milliliters per kg of fish, averaging 469 ml/kg, indicating varying engine efficiency and practices. Engine oil use averages 0.56 ml/kg, with DMU-5 using the least, reflecting maintenance differences. Ice block consumption averages 1 kg/kg, essential for fish preservation and varies among vessels. Fresh water use averages 8 liters/kg, which is crucial for hygiene and suggests room for efficiency improvements across the fleet, notably in DMU-6 for diesel and DMU-5 for oil and ice.

3. Economic Analysis:

Economic analysis of ring seine fishing vessels evaluates financial performance through cost breakdowns, revenues, and profitability to optimize resource use and maximize returns. It assesses expenditures on diesel, engine oil, ice, freshwater, and rations against catch values to calculate profitability. Detailed comparisons across vessels (DMU-1 to DMU-10) reveal average costs, revenues, and profits per kilogram, fishing day, and trip. Vessels like DMU-1 and DMU-6 maintain profitability despite higher costs. The analysis shows an average profit of Rs. 42 per kg of fish, Rs. 58,300 per fishing day, and Rs. 5.25 lakhs per trip, with high-profit vessels like DMU-7 and DMU-9 earning up to Rs. 8.11 lakhs per trip, indicating potential areas for efficiency enhancement.

TABLE 3: OVERALL ECONOMIC PERFORMANCE OF RING SEINE FISHING VESSELS

Fishing Vessel	Rs/ Kg of Fish Catch			Rs/ Fishing day			Rs Lakhs/ Fishing trip		
	Value	Cost	Profit	Value	Cost	Profit	Value	Cost	Profit
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
DMU-1	113	70	42	124762	77771	46991	9.98	6.22	3.76
DMU-2	95	66	29	103379	71414	31965	8.27	5.71	2.56
DMU-3	99	60	39	158663	95784	62880	11.11	6.70	4.40
DMU-4	106	66	39	120397	75542	44855	9.63	6.04	3.59
DMU-5	100	48	51	159388	77124	82263	14.34	6.94	7.40
DMU-6	111	73	37	164071	108621	55450	13.13	8.69	4.44
DMU-7	95	54	41	160655	91263	69392	17.67	10.04	7.63
DMU-8	99	52	47	171553	90695	80859	12.01	6.35	5.66
DMU-9	101	56	46	149338	81749	67589	17.92	9.81	8.11
DMU-10	97	53	44	120081	65419	54661	10.81	5.89	4.92
Average	101	59	42	138743	80443	58300	12.49	7.24	5.25

Breakdown of Expenditure

The expenditure breakdown for each category (diesel, engine oil, ice, freshwater, ration, and others) in the pie chart indicates that diesel is the primary cost driver in ring seine fishing operations. Improving fuel efficiency, optimizing engine performance, streamlining routes, or investing in fuel-efficient technologies could significantly reduce costs. Additionally, targeting the 'Other' category, such as repair and maintenance costs, can enhance operational efficiency.

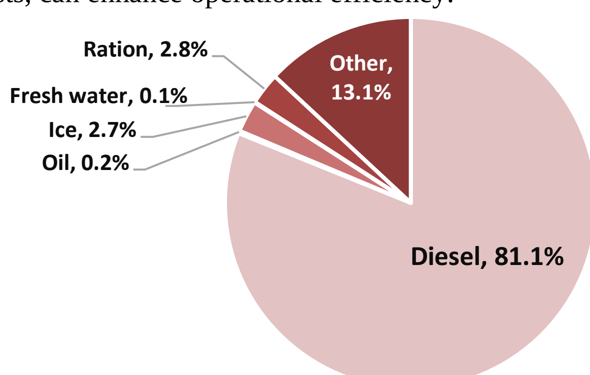

Figure 2 Percentage Share Contribute to the Total Expenditure of the Ring Seine Fishing Vessel

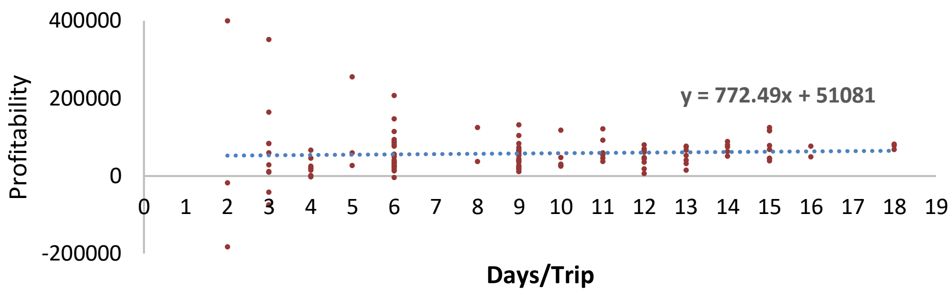

Figure 3: Profitability Based On Number Of Days Per Fishing Trip

Figure 3 illustrates the relationship between the number of days per trip and profitability. According to the trend line, there has been a significant increase in the profitability of ring seine fishing vessel operations, with an increase in the number of days per trip. A wider range of profits is observed up to a maximum of 13 days, with profitability continuing to grow until 18 days.

Commission Agent, Crew, and Ownership Profit-Sharing Analysis

The analysis of profit allocation among crew, skipper, second officer, engine operator, and owner in Goa fishing harbor reveals a 50:50 profit-sharing ratio after deducting expenses like diesel, engine oil, ice, and rations. Economic data shows an average catch value of Rs. 1,248,688 per trip, with DMU-9 highest at Rs. 1,792,061 and 10 per cent commission costs, as shown in Table 4.

TABLE 4: CATCH VALUE, COMMISSIONS, AND PROFIT SHARE FOR RING SEINE FISHING VESSELS

Fishing Vessel	Catch Value (Rs/trip)	Commission (Rs)	Crew share (Rs)	Owner share (Rs)	Others (Rs)
DMU-1	998098	99810	138059	138059	41000
DMU-2	827029	82703	86508	86508	58000
DMU-3	1110643	111064	164546	164546	66000
DMU-4	963179	96318	131263	131263	66000
DMU-5	1434488	143449	298460	298460	50000
DMU-6	1312571	131257	156173	156173	83000
DMU-7	1767209	176721	293295	293295	83000
DMU-8	1200874	120087	222962	222962	41000
DMU-9	1792061	179206	315932	315932	83000
DMU-10	1080727	108073	191940	191940	41000
Average	1248688	124869	199914	199914	61200

Technical and Allocative Efficiency Using DEA:

Efficiency analysis of each decision-making unit (DMU) showed that DMU-10 was operating at full efficiency and serving as a benchmark for others (Table 5). Cost efficiency was determined using each DMU's technical and allocative efficiency, providing an overall efficiency measure. The results indicate that the 10th DMU is 100 per cent efficient in technical and allocative terms. The average cost efficiency for all ten ring seine fishing vessels operating in the Goa fishing harbor is 33.6 per cent, suggesting potential for further improvement in overall efficiency by minimizing and optimizing input usage without affecting the output (fish catch).

TABLE 5: RING SEINER EFFICIENCY SCORE AND RANKING OF 10 DMU'S OBTAINED FROM THE DEA MODEL

Ring seiner (DMU's)	Technical Efficiency (TE)		Allocative Efficiency (AE)		Cost Efficiency (EE)	
	Score	Rank	Score	Rank	Score	Rank
(1)	(2)	(3)	(4)	(5)	(6)	(7)
DMU-1	1.000	3	0.341	7	0.341	4
DMU-2	0.881	7	0.406	2	0.358	3
DMU-3	0.629	10	0.390	3	0.245	8
DMU-4	0.745	8	0.372	5	0.277	6
DMU-5	1.000	4	0.286	8	0.286	5
DMU-6	0.716	9	0.355	6	0.254	7
DMU-7	1.000	5	0.228	9	0.228	9
DMU-8	1.000	2	0.377	4	0.377	2
DMU-9	0.896	6	0.227	10	0.203	10
DMU-10	1.000	1	1.000	1	1.000	1
Mean	0.883		0.376		0.336	

The second major purpose of this analysis is to provide an optimal quantity of input targets recommended for each inefficient DMU to achieve their targeted average output while reducing input usage, as detailed in Table 6. Figure 4 presents a graphical representation of the technical efficiency and inefficiency of the ten ring seine fishing vessels operating in the Goa fishing harbour. Figure 5 shows the cost efficiency and inefficiency for individual DMUs, with efficiency percentages displayed in a bar chart for easy reference. The analysis reveals that the 10th DMU is 100 per cent efficient in both technical and cost efficiency, operating at the efficient frontier level. This DMU is a reference for the others who have overused their inputs. Additionally, DMUs 1, 5, 7, and 8 are technically 100 per cent efficient but exhibit allocative inefficiency.

TABLE6: INPUT TARGETS FOR ACHIEVING THE EXISTING AVERAGE CATCH OF EACH RING SEINER FISHING UNIT

DMUs (1)	Quantity catch (Tonne) (2)	Trips duration (days) (3)	Crew (Nos) (4)	Diesel qty (Litres) (5)	Engine oil qty (Litres) (6)	Ice qty (Bar) (7)	FW qty (Litres) (8)
DMU-1	8.9	9	20	3410	10	280	1000
DMU-2	8.9	5	14	2785	8	178	1310
DMU-3	8.0	5	13	2833	6	151	1075
DMU-4	8.0	6	15	2735	6	149	1180
DMU-5	16.0	12	20	7336	8	264	1500
DMU-6	5.3	4	9	1922	4	96	716
DMU-7	10.5	9	20	6464	5	260	1000
DMU-8	15.7	9	20	5400	15	310	2000
DMU-9	9.4	8	18	5792	4	233	896
DMU-10	5.5	4	20	640	5	120	1500

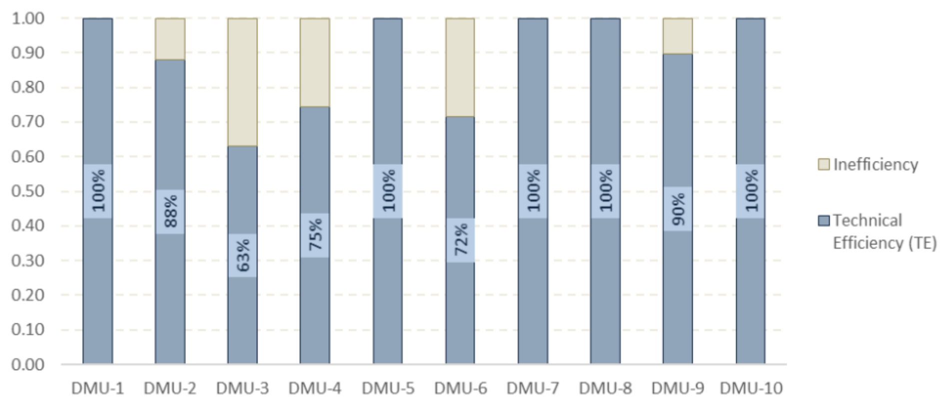

Figure 4: Technical Efficiency of the Ring Seiner Fishing Vessel Operated in the Goa Fishing Harbour

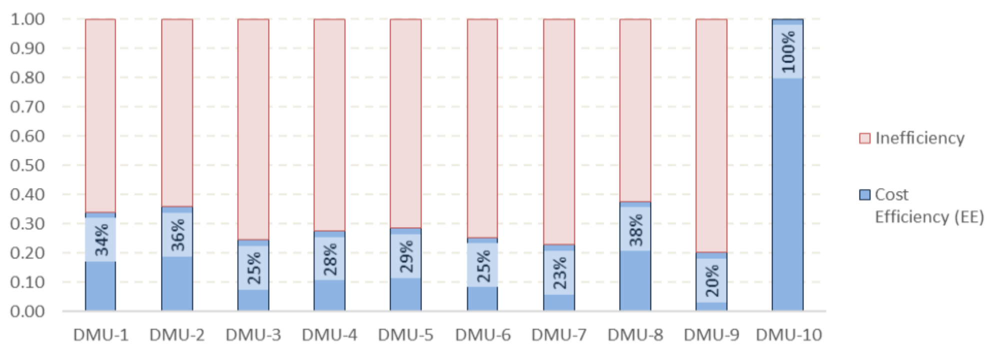

Figure 5: Cost Efficiency of Ring Seiner Fishing Vessel Operated in the Goa Fishing Harbour

IV

CONCLUSION:

The analysis of ring seine fishing vessels in the Goa fishing harbor reveals substantial opportunities for efficiency improvement. We evaluated ten vessels over 120 trips and found an average trip length of 9 days, with an average catch of 12.4 tonnes valued at Rs.12.49 lakhs. Each trip costs around Rs.7.24 lakhs, with diesel comprising 52 per cent of this expense. After expenses, the average profit was Rs.5.25 lakhs per trip, split equally between the crew and owner. The cost efficiency analysis showed the 10th DMU at 100 per cent efficiency, while the average cost efficiency was 33.6 per cent, indicating room for optimization. The 10th DMU, despite higher diesel consumption, achieved better catches, setting a benchmark for others. This highlights potential efficiency gains in Goa's ring seine fishing through improved input management and cost control. Therefore, it is suggested that the 10th DMU be used as a benchmark to develop guidelines and training for other vessel operators, focusing on energy-efficient engines and optimal input utilization. Establish comprehensive data collection and monitoring systems to track efficiency and promote sustainable practices through incentives and certification programs. Encourage collaborative efforts among fishermen, improve infrastructure at the fishing harbour, and provide financial assistance and capacity-building programs. Regularly review and adjust policies based on feedback from the fishing community to ensure the continued promotion of efficiency and sustainability in Goa's ring seine fishing operations.

REFERENCES:

Andreu, M. L., & Grunewald, O. (2006). Sources of inefficiency in Kansas farms. Paper presented at the Southern Agricultural Economics Association Annual Meetings, February 5-8, Orlando, Florida.

Chandrasekar, V., & Gopal, N. (2015). Economic efficiency of ring seiners operated off Munambam coast of Kerala using data envelopment analysis. *Agricultural Economics Research Review, 28*(1), 171-177. https://doi.org/10.5958/0974-0279.2015.00015.4

Charnes, A., Cooper, W. W., & Rhodes, E. (1978). Measuring the efficiency of decision-making units. *European Journal of Operational Research, 2*, 429-444.

Charnes, A., Cooper, W., Lewin, A. Y., & Seiford, L. M. (Eds.). (1994). *Data envelopment analysis: Theory methodology and applications*. Kluwer Academic Publishers.

CMFRI. (2012). *Marine fisheries census 2010: Part-I India*. Department of Animal Husbandry, Dairying and Fisheries and ICAR-Central Marine Fisheries Research Institute.

Coelli, T. J. (1996). *A guide to DEAP Version 2.1: A data envelopment analysis (computer) program*. CEPA Working Paper No. 8/96, Department of Econometrics, University of New England.

Coelli, T. J. (2008). *A guide to DEAP Version 2.1: A data envelopment analysis*. Retrieved from http://www.owlnet.rice.edu/~econ380/DEAP.PDF Edwin, L. and Hridayanathan, C. (1996). *"Ring seines of south Kerala coast".* Fishery. Technology., 33(1): 1-5.

Farrell, M. J. (1957). The measurement of productivity efficiency. *Journal of the Royal Statistical Society, 120*(3), 253-290.

Hameed, M. S., & Boopendranath, M. R. (2000). *Modern fishing gear technology*. Daya Publishing House.

Jara Laso, I., Vázquez-Rowe, I., Margallo, M., Irabien, Á., & Aldaco, R. (2018). Revisiting the LCA+DEA method in fishing fleets: How should we be measuring efficiency? *Marine Policy, 91*, 34–40. https://doi.org/10.1016/j.marpol.2018.01.030

Joice, V. T., Premlal, P., & Kurup, B. M. (2003). The ring seine fishery of Kerala - time to act. *Infofish International*, 6, 64-68.

Menon, M. D. (1970). Ring seining oil sardines from medium vessels. *Souvenir*, Central Institute of Fisheries Operatives, 28-31.

Mukundan, M., & Hakkim, L. A. (1980). Ring seining - development in Indian waters. *Bulletin No. 3*, Integrated Fisheries Project.

Oommen, V. P. (1989). A critical study on the exploitation of fishery resources by the Integrated Fisheries Project. *Bulletin No. 12*, Integrated Fisheries Project.

Panicker, P. A. (1985). *"An economic analysis of ring seining from 13.25 m ring seiners and from artisanal fishing craft Thanguvallom along the Kerala coast".* In: Ravindran, K., Unnikrishnan Nair. N., Perigreen, P. A., Madhavan, P., Gopalakrishna Pillai, A.G., Panicker, P. A. and Mary Thomas (Eds.), *"Harvest and post-harvest technology of fish".* Society of Fishery Technologists (India), Kochi, p.173-720.

Panicker, P. A., Sivan, T. M., & George, N. A. (1985). A new fishing gear for traditional craft. In K. Ravindran, N. Unnikrishnan Nair, P. A. Perigreen, P. Madhavan, Gopalakrishna Pillai, P. A. Panicker, & M. Thomas (Eds.), *Harvest and post-harvest technology of fish* (pp. 223-226). Society of Fishery Technologists (India).

Pravin, P., & Meenakumari, B. (2016). Purse seining in India - a review. *Indian Journal of Fisheries, 63*(3), 162-174. https://doi.org/10.21077/ijf.2016.63.3.50404-25

Ramanathan, R. (2006). *An introduction to data envelopment analysis: A tool for performance measurement*. Sage Publications India Pvt Ltd.

Sainsbury, J. C. (1996). *Commercial fishing methods: An introduction to vessels and gear*. Fishing News Books Ltd.

Subhash, C. R. (2004). *Data envelopment analysis: Theory and techniques for economics and operational research*. Cambridge University Press.