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RESEARCH

Assessment of *Amblygaster sirm* fishery in Sri Lanka: A Bio-Economic Analysis

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ABSTRACT

Amblygaster sirm is a major fishery species in the coastal fisheries of Sri Lanka, particularly in the eastern coastal fisheries districts, especially the Kalmunai Fisheries District. Majority of fishers in the district are small-scale and depend on one-day fishing operations. However, inadequate biological and economic assessments hinder proper management of the fishery. Therefore, major objective of the study was to estimate the bio-economic reference points of the *Amblygaster sirm* fishery in the district. This study used 20-year time series (2000–2020) of catch and effort data for three types of boats categories. The Gordon-Schaefer bioeconomic model was used in this study to estimate reference points, namely Maximum Sustainable Yield (MSY), Maximum Economic Yield (MEY), and Open Access Equilibrium (OAE). The results found that MSY was 4,041.14 metric tons at an effort level of 6357 thousand hours, while MEY was 3,603.85 metric tons at 4265 thousand hours. In comparison, the OAE was estimated at 7,207.70 metric tons at 8531 thousand hours. The findings suggest that the current fishing effort remains below MSY, pointing to an underexploited fishery. However, evidence suggests that unmanaged fishery, rising input costs, and illegal unreported and unregulated fishing threaten to the sustainable fishing operation in the district. The analysis highlights the need for goal-based policy measures namely effort management, co-management at the community level, and improved monitoring systems to avert biological and economic inefficiencies.

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INTRODUCTION

With a coastline of more than 1,620 km, the fisheries of Sri Lanka are important in providing food security, and economic stability to millions of people (World Bank, 2022). Fish accounts for nearly 50% -60% of the animal protein intake of Sri Lankans, a figure significantly higher than the global average (Jayasekara *et al*., 2022). The fisheries sector, in particular considering the livelihoods, of over 224,000 active fishers directly depend on fishery, while indirectly supports nearly two million people (NARA, 2022). However, the trend of the fish production in recent past is declining and characterized by higher input costs, unregulated harvesting methods, and gaps in management practices.

Amblygaster sirm (Spotted Sardinella) is a main coastal fishing operation of Sri Lanka (Bandaranayake *et al*., 2024). Further, the *Amblygaster sirm* has become major in Kalmunai Fisheries district due to its abundance, accessibility, and demand in the local fish market. Despite its socio-economic significance of the fishery, scientific assessments and clear management policies for this fishery remain insufficient (Angel, 2022). Compared to export-oriented species such as tuna, sea cucumber, crab and shrimp, *Amblygaster sirm* has been received comparatively low attention national fisheries strategies. As a result, in insufficient monitoring and a lack of well-defined management reference points have not setup relating to important coastal fish species. At present, there are no specific reference points or gear restrictions for the species in this fishery (Bandaranayake *et al*., 2024). This emphasizes the steps need to be taken for species-specific management, especially size limits, seasonal closures, or effort caps. These steps are aligned with the principles of ecosystem-based management as well (García and FAO, 2003).

National coastal fish production in Sri Lanka peaked at 274,160 Mt in 2016 and declined sharply to 149,440 Mt by 2022 (Ministry of Fisheries, 2023) At the district level, Kalmunai's coastal fish catch fell from a peak of 23,410 Mt in 2012 to 7,345 Mt in 2022, a decline of 69% while the number of active fishers fell only modestly from 25,960 to 15,750, and fuel and input costs more than trebled over the same period. Consequently, annual production per fisher in Kalmunai dropped from 1.27 Mt in 2017 to 0.47 Mt in 2022. This deviation between collapsing output and a relatively stable fleet size constitutes the practical issues that the study investigates.

Existing published national coastal surplus-yield estimate for Sri Lankan coastal fisheries (Wijayaratne 2003) is more than a decade old and is not species specific. Recent bioeconomic studies in Sri Lanka has concentrated on south coast species, and no biological or economic reference point has been established specifically for *Amblygaster sirm* (Bandaranayake *et al*. 2024). Fisheries managers therefore lack quantitative benchmarks needed to distinguish biological overfishing from economic contraction, or from effort displacement caused by Illegal Unreported and Unregulated (IUU) that goes uncounted in official effort statistics.

The Fisheries Act no. 2 of 1996 does not directly explain application of the reference points of the fisheries. However, Mid-Term Sector Plan 2023–2027 mandate evidence-based input and output controls. Such controls are unfeasible without species-specific reference points. This study provides the first estimates of MSY, MEY, and OAE for *Amblygaster sirm* in the Kalmunai district and shows how increases in input costs reduce the range of economically profitable fishing operations. This information can support fisheries management in the eastern coastal districts.

During the past decade, coastal fish production of the country has witnessed an alarming decline (Ministry of Fisheries, 2023). The capture fish production has gradually increased with minor fluctuations, particularly following the attainment of its highest point in 2016. This reduction of the fish catch has been driven by many reasons such as overfishing, IUU fishing, climate variability, and rising operating costs. This reduction of capture fish production is common for all fisheries district of the country. In Kalmunai, for instance, catches from coastal fish have fallen from 23,410 metric tons in 2012 to 7,345 metric tons in 2022 (Ministry of Fisheries, 2023). While open-access fishery and absence of effort control measures pose the risk of overexploitation in the future. Moreover, the lack of species-specific economic analyses limits the development of rational policy interventions that improve sustainability without undermining resources as well as livelihoods. Incorporating scientific methods such as bioeconomic modelling is principal to solving these issues and informing policy agendas. Based on the global priority areas such as the Sustainable Development Goal (SDG) 14 of conserving and using oceans and their resources sustainably (Huck, 2022), Sri Lanka's National Fisheries Policy (2018), it is required to apply and promotes embracing scientific practice and ecosystem-based management.

The objective of this study was to conduct a comprehensive bioeconomic assessment of the *Amblygaster sirm* fishery in the Kalmunai Fisheries District. Therefore, the study uses MSY, MEY, and OAE as key reference points to look at biological sustainability, economic efficiency, and the risks of overexploitation. By integrating biological and economic parameters, the study aims to give useful guidance on how to improve policy interventions, make fisheries more profitable, and make sure that Sri Lanka's coastal fisheries are sustainable in the long term.

METHODOLOGY

Theoretical and empirical background

Fisheries management aims to ensure the long-term sustainable use of fish stocks as well as fulfill the social and economic requirements. To maintain the effective management of marine ecosystems therefore, requires carefully balance economic and social drivers with biological and environmental considerations (NOAA, 2022). Bioeconomic models play a major role in this process by integrating economic and biological factors to inform management decisions. These models discuss the important reference points, such as MSY and MEY, supporting the fisheries management objectives (Holma *et al*. 2019).

Surplus production approach comprises several functional forms rather than a single specification. The biomass dynamic tradition originated with Graham (Hashim 2008) and was formalised by Schaefer (Seijo *et al*. 1998a), (Palomares *et al*., (2020) links logistic growth of a stock to fishing effort. These approaches provided the foundation for estimating biological reference points from catch and effort data alone. Fox (Musick and Bonfil 2005a) modified the Schaefer model by replacing the logistic growth assumption with a Gompertz growth function. This produces an asymmetric yield curve, where the MSY occurs at a lower stock level, around 37% of carrying capacity (0.37K), while the Schefer modal estimate the 50% of carrying capacity (0.50K) (Tsikliras and Froese 2019). Pella and Tomlinson (1969) developed a generalized surplus production model that includes a shape parameter to estimate the form of the production curve from the data (Winker, Kerwath, and Bruyn 2018). Traditional bioeconomic model, like the Gordon–Schaefer model is widely used in data-limited fisheries because they require only basic catch and effort data. Unlike advanced frameworks such as

Bio-Economic Impact Assessment using FLR (FLBEIA)(Garcia *et al*. 2017) , bio-economic stock assessment (BESA) method (Froese *et al*. 2017), Lancker *et al*., 2023) , JABBA (Just Another Bayesian Biomass Assessment), introduced by Winker(Winker, Carvalho, and Kapur 2018), or Bio-Economic Analytical Model (BEAM) (FAO 2001) (FAO 2025), which depend on detailed biological, economic, and management time series and specialized software, traditional models are simpler and more practical for small-scale and developing fisheries.

Against this background, the static Gordon-Schaefer model was selected for the present study on structural and data related grounds rather than as an a priori preference. The Schaefer surplus production model is the most widely applied biomass dynamic model (Sumaila *et al*. 2012), and is recommended for data limited tropical stocks (Musick & Bonfil, 2005), (Kokkalis *et al*. 2024) because it requires only catch and effort data and yields a linear catch per unit effort and effort relationship. Its two parameter structure is identifiable from the twenty year (2000–2020) series compiled for the *Amblygaster sirm* fishery, whereas the additional shape parameter of the Pella-Tomlinson model (m or n) is often difficult to estimate accurately and can cause problems during model fitting (Rankin and Lemos 2015).The Schaefer model was selected because it integrates directly with the Gordon (1954) economic framework, allowing the estimation of key bioeconomic reference points, including MSY , MEY, and OAE. In addition, the model is well suited to the available catch and standardized effort data derived from the three boat categories operating in the district, making it an appropriate and practical choice for the present study.

The Gordon–Schaefer bioeconomic model, originally developed by Gordon (1954) and formalised by Schaefer (1957) provides a unified framework for assessing fishery performance by integrating biological dynamics with economic parameters (Kevern L. C, 2002) Biologically, it is assumed that fish stocks follow a logistic growth pattern governed by the intrinsic growth rate and carrying capacity of the population. The catch is proportional to both fishing effort and stock abundance. At equilibrium, population growth equals harvest, generating a dome-shaped sustainable yield curve. The peak of the curve defines the MSY, the largest catch that can be taken indefinitely without impairing stock recovery (Khan 2012). Economically, the model extends this biological foundation by comparing the total revenue generated from fish sales against the total cost of fishing effort. This estimation allows identification of two further reference points, MEY, which is the effort level at which net profit is greatest, and OAE. The OAE point at which unrestricted entry drives profits to zero as revenues are fully offset by costs. The model uses the observed relationship between CPUE and fishing effort and can be applied when only basic catch and effort data are available.

Bioeconomic models have been shown to work for both inland reservoirs and coastal fisheries in Sri Lanka in the past, such as Wijeyaratne and Amarasinghe (1984) and Wijayaratne (2010) These studies show that bioeconomic models could be useful for making decisions about how to manage different types of water bodies in a way that is benefits for the environment. Even though *Amblygaster sirm* is one of the most common small pelagic fish species targeted in Sri Lanka, especially along the Eastern coast, there are no species-specific bio-economic assessments of it. This species is very important for the income and food security of small-scale fishers (Bandaranayake *et al*., 2024).

Study Site

Kalmunai is an important study area because it is one of the largest fisheries-dependent districts on Sri Lanka’s east coast. It has a large fishing community, with over 14,000 fishing households and more than 15,000 active fishers (NARA, 2022). Small-scale one-day operations using small-meshed gillnets targeting *A. sirm* constitute the dominant livelihood activity in the district. Fish production pattern of the district is also highly relevant for the study as it increased until the early 2010s and then declined sharply.

Table1: Trends in Fish Production, Active Fishers, and Productivity in Kalmunai Fisheries District (2013–2022)

Year	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Fish production (000, Mt)	23.07	21.66	18.24	20.18	20.88	18.45	12.58	8.91	8.78	7.35
Active Fishers	25.96	26.19	20.40	22.39	16.38	16.67	15.97	16.09	15.82	15.75
Annual production per fisher (Mt)	0.89	0.83	0.89	0.91	1.27	1.11	0.79	0.55	0.55	0.47

Source. Ministry of fisheries – Annul Statistics 2023

The data shows that total fish catch has considerably been declined over the period of the decade, from 23,070 metric tonnes in 2013 to only 7,350 metric tonnes in 2022. The number of active fishers also went down, from 25,960 to 15,750. Initially, production per fisher stayed the same, but then it went down. These trends show that the Kalmunai district needs specific actions to improve sustainability and the loverhoods of fishermen Field study was carried out in the Kalmunai Fisheries District (Latitude 7.4330° N, Longitude 81.8320° E), located in the eastern coast of Sri Lanka. The one-day fishing operations in the area conduct from three types of fishing boats. Therefore, three main categories of fishing crafts considered for analysis were Outboard Fiberglass Reinforced Plastic Boats (OFRP), Motorized Traditional Boats (MTRB), and Non-Motorized Traditional Boats (NTRB). *Amblygaster sirm* harvest is made by using small-meshed gill nets, and the gear selectivity was kept uniform always with all types of fishing boats.

Target species

Amblygaster sirm is among the most important and socio-economically significant small-pelagic species in Sri Lanka's coastal fisheries. Small pelagic collectively account for approximately 30% to 40% of national coastal production, (Bandaranayake *et al*. 2024) and *Amblygaster sirm* is the principal species targeted by small-meshed gillnet operations along the eastern coast, underpinning livelihoods for thousands of small-scale fishing households in Kalmunai districts. Despite this importance *Amblygaster sirm for* local food security, the scientific management attention in Sri Lanka has historically been directed toward high-value export species such as tuna, sea cucumber, and shrimp.

Data Collection

Though the analysis requires species-and-gear-disaggregated catch and effort data, Ministry of Fisheries annual statistical bulletins record coastal landings by district. It provides aggregate estimates but does not disaggregate the results by individual species or gear type. Therefore, it is not possible to reconstruct species-specific CPUE time series for other districts using only published secondary data. The NARA Marine Biological Resources Division (MBRD) sample data used in this study covering catch, effort, craft type, trip cost, and market price by boat category are among the very few district-level datasets in Sri Lanka. All three craft categories (OFRP, MTRB, and NTRB) operating on the same target species with the same gear (small-meshed gillnet) are collected by MBRD. This data structure complies with FAO's recommended method of standardizing fishing effort, (Sparre and Venema 1998) enabling the application of the Gordon–Schaefer modal.

The Marine Biological Resources Division (MBRD) of NARA provided the data for the years 2000 to 2020 of the district. A trained enumerator in the district gathered data by randomly selecting fishing boats from different landing sites. Each record had information about the type of gear used, the type of boat used, the number of hours spent for fishing, the size of the crew, and the amount of money spent and earned from the fishing operation. To ensure reliability, the data was cross-checked monthly and audited by supervisors, as per FAO fisheries monitoring standards (Sparre , 2000). In addition to the above sources, Secondary data others were collected from annual statistical bulletins published by the Ministry of Fisheries (2023), technical publications of FAO relating to stock assessments and bio-economic modelling, and research findings on fishing cost structures (Wijayaratne and Maldeniya, 2003). These were used to derive constant parameters like mean fish market price per kilogram and fishing effort unit cost by various boat categories. Costs that were inflation adjusted, where possible, were used in an attempt to ensure time series consistency.

Effort Estimation

Since there were three types of boats, standardization of fishing effort was necessary in order to compare them. Relative effort estimation was conducted based on the FAO's recommended method (Sparre and Venema, 1998) in the following steps. The catch per unit effort (CPUE) was calculated as the average kilograms of fish caught per boat per hour (kg/boat/hour), based on annualized data for each vessel type. The estimation of CPUE for each boat type on an annual basis as follows, Effort = Yield / CPUE as CPUE = Yield / Effort. Accordingly, the fishing effort can be estimated when catch or yield and CPUE values are known. As the study is considers different types of boats that are operate in the coastal fishing, it is important to normalize the effort. Normalize CPUE by dividing each boat type's annual CPUE by its mean CPUE over the time series can be estimate as follows, $Y_i(y)$ = yield of boat *i* in year *y.* This defines $Y_i(y)$ as the total yield or harvest gained by boat type *i* during year *y*. This variable characterizes the annual production from each category of fishing boats, namely OFRP, MTRB, and NTRB in the study area. $f_i(y)$ = effort of boat *i* in year *y.* This defines $f_i(y)$ as the fishing effort exerted by boat type *i* in year *y*. This variable shows the intensity of fishing operations for each craft type during the observed period. The calculation of the CPUE for boat type *i* in year *y*, serving as a measure of fishing efficiency for each gear category over time as $CPUE_i(y) = Y_i(y) / f_i(y)$. To standardize the effort, two-step standardization process was applied. First, the CPUE values for each boat type were weighted by the proportion of the total catch that the respective boat type contributed in each year. Then, the Relative Effort of each year is estimated by adding the weighted CPUE values of all boat types. This aggregation provides a normalized effort index, and it expresses the combined fishing effort from all craft types (OFRP, MTRB, NTRB) in terms of standardized effort hours. This standardized relative effort index used for estimating the bioeconomic reference points (MSY, MEY, and OAE). It provides the consistency and comparability across the 20-year dataset.

Bioeconomic Model and Parameter Estimation

Overview of Gordon–Schaefer model

The Gordon–Schaefer model combines biology and economics parameters to assess fishery performance and estimate key management reference points(Kevern L. C, 2002). Biologically, it assumes that fish stocks grow according to a logistic growth pattern, determined by the stock's growth rate (r) and carrying capacity (K).(Chamera *et al*. 2025a) Catch is related to fishing effort (E), stock biomass (X), and catchability (q) through the harvest equation H equal to qEX. At equilibrium, fish population growth equals harvest, producing a sustainable yield curve (Khan 2012). The highest point of this curve represents the MSY. The model compares TR from fish sales with TC of fishing. The MEY occurs where profit (TR – TC) is highest, while the OAE occurs where revenue equals cost and profit equals zero.

The model parameters are estimated using a linear relationship between Catch Per Unit

Effort (CPUE) and fishing effort(Chamera *et al*. 2025b).

To estimate the key bioeconomic reference points, MSY, MEY, and OAE, this study applied the Gordon–Schaefer model, a classical static bioeconomic framework that couples the Schaefer (1954) surplus production function with the Gordon (1954) economic theory of a common-property fishery (Larkin *et al*., 2010; Arnarson and Jensson, 2021). The model integrates the biological dynamics of the stock with the economics of the fishing operation, allowing optimal effort levels to be identified under both biological and economic objectives. It is widely adopted in data-limited fisheries because it requires only catch and effort data and yields reference points directly from a linear catch-per-unit-effort (CPUE) relationship.

The harvest (yield–effort) function

The Schaefer surplus production model expresses sustainable harvest (H) as a quadratic function of fishing effort (E):

$$H = \alpha E - \beta E^2 \quad (1)$$

where α is the productivity (or intrinsic catch-rate) coefficient and β is the depletion coefficient. The linear term (αE) captures the increase in catch as effort rises, while the quadratic term ($-\beta E^2$) captures the reduction in catch caused by stock depletion at higher effort. Equation (1) therefore describes a parabolic yield–effort relationship: harvest increases with effort up to a maximum, then declines as additional effort erodes the stock faster than it can regenerate. This diminishing-returns structure is the basis for deriving the biological and economic reference points below.

Estimation of model parameters (α and β)

The coefficients α and β were obtained from the linear relationship between CPUE and effort. Dividing Equation (1) by E gives the catch-per-unit-effort form:

$$CPUE = \frac{H}{E} = \alpha - \beta E \quad (2)$$

Equation (2) is linear in effort, so α (the intercept) and β (the negative of the slope) were estimated by ordinary least squares regression of the standardized annual CPUE on standardized annual effort over the 2000–2020 series. The estimated α and β were then substituted into the reference-point expressions that follow (Garcia *et al*., 1989; Chae and Pascoe, 2005; Habib *et al*., 2014; Evora, 2017; Mardhatillah *et al*., 2019; Kasri and Tahang, 2019; Hengbin *et al*., 2020; Madhuri *et al*., 2024).

Biological reference points (MSY)

The effort that produces the MSY is found by differentiating the harvest function (Equation 1) with respect to effort and setting the derivative equal to zero:

$$\frac{dH}{dE} = \alpha - 2\beta E = 0 \;\Rightarrow\; E_{MSY} = \frac{\alpha}{2\beta} \quad (3)$$

E_{MSY} is the effort level at which the marginal gain in productivity is exactly offset by the marginal loss from stock depletion. It corresponds to half the effort at which catch would fall to zero, and represents the long-term effort consistent with the highest sustainable catch under prevailing environmental conditions.

Substituting E_{MSY} back into Equation (1) gives the MSY

$$H_{MSY} = \frac{\alpha^2}{4\beta} \quad (4)$$

H_{MSY} is the largest catch that can be taken indefinitely without compromising the stock's regenerative capacity, under the assumptions of a stable environment and constant fishing efficiency (catchability).

Economic reference points (MEY)

The economic optimum incorporates the price of fish and the cost of effort. Total revenue (TR) and total cost (TC) are defined as:

$$TR = p \cdot H = p(\alpha E - \beta E^2) \quad (5)$$

$$TC = cE \quad (6)$$

where p is the ex-vessel price per kilogram of harvest and c is the unit cost of fishing effort. Economic profit (π) is the difference between revenue and cost:

$$\pi = TR - TC = p(\alpha E - \beta E^2) - cE \quad (7)$$

E_{MEY}, the maximum economic yield occurs where profit is greatest, obtained by differentiating the profit function (Equation 7) with respect to effort and setting it to zero:

$$\frac{d\pi}{dE} = p\alpha - 2p\beta E - c = 0 \;\Rightarrow\; E_{MEY} = \frac{p\alpha - c}{2p\beta} \quad (8)$$

E_{MEY} is the effort at which marginal revenue equals marginal cost. Because it accounts for the cost of effort, E_MEY is always lower than E_{MSY}; the difference widens as costs rise relative to price.

H_{MEY}. Substituting E_{MEY} into the harvest function gives the corresponding sustainable catch at the economic optimum:

$$H_{MEY} = \frac{p^2\alpha^2 - c^2}{4\beta p^2} \quad (9)$$

H_{MEY} depends not only on stock productivity (α, β) but also on the market price of fish (p) and the cost of effort (c). This makes MEY the more policy-relevant target where the objective is to maximise net economic benefit rather than biological yield alone.

Open Access Equilibrium (OAE)

Under open access, with no restriction on entry or effort, fishers continue to enter the fishery until profit is fully dissipated, that is, π = 0. Setting Equation (7) to zero:

$$p(\alpha E - \beta E^2) - cE = 0 \qquad (10)$$

Dividing through by E and solving for effort gives the open-access effort level:

$$E_{OAE} = \frac{p\alpha - c}{p\beta} \qquad (11)$$

Comparison of Equation (11) with Equation (8) shows that $E_{OAE} = 2 \cdot E_{MEY}$; the open-access effort is exactly twice the economically optimal effort. The corresponding harvest is obtained by substituting E_OAE into Equation (1):

$$H_{OAE} = \alpha E_{OAE} - \beta E_{OAE}^2 \quad (12)$$

At the OAE, the fishery still yields a positive catch, but economic profit is zero (rent is fully dissipated) and biological sustainability is typically compromised, because economic incentives drive effort beyond both the biological optimum (E_MSY) and the economic optimum (E_MEY). This is the classic outcome of the "tragedy of the commons" in an unregulated fishery.

RESULTS AND DISCUSSION

Estimated bio-economic model

This section explains the usage of the Schaefer model to look at the *Amblygaster sirm* fishery in the Kalmunai fisheries district from a bioeconomic point of view. It guides us how fishing effort affects CPUE and figures out important reference points like MSY, MEY, and OAE. This helps maintain the fishery in a healthy state for the environment and makes sure that the right amount of fishing takes place in the area.

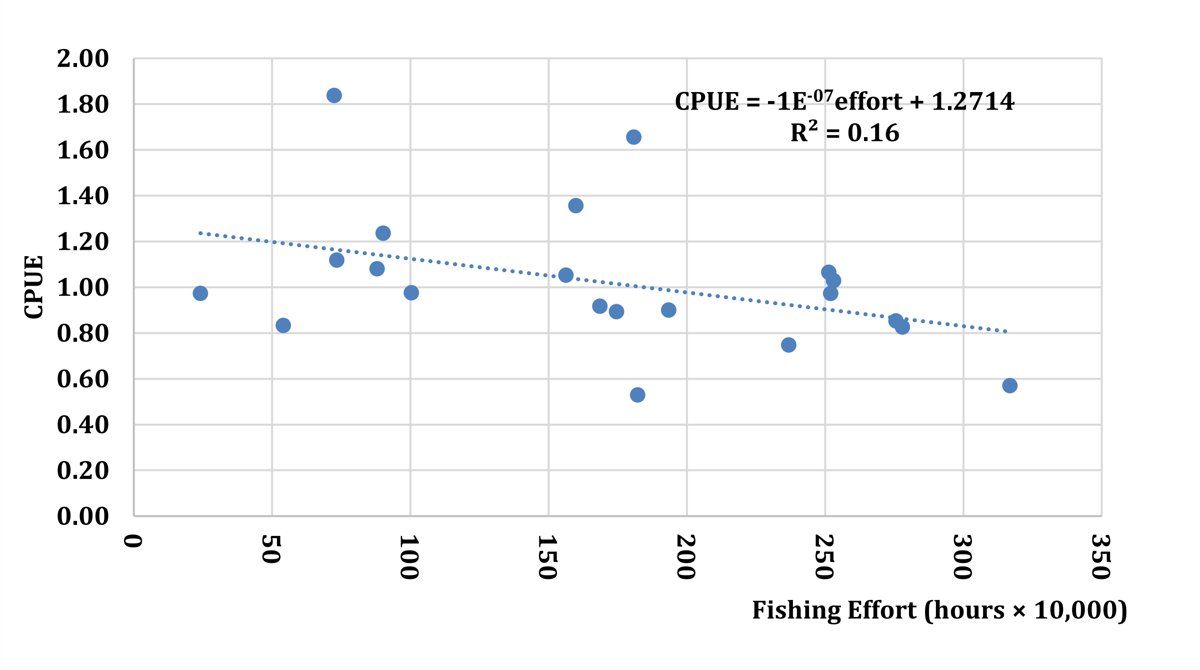

Figure 1: Relationship Between Catch Per Unit Effort (CPUE) and Fishing Effort in the *Amblygaster sirm* Fisher in Kalmunai fisheries district.

The relationship between fishing effort and CPUE for the *Amblygaster sirm* fishery in the Kalmunai fisheries district has been shown in the figure 1 According to the theory, there is negative relationship with effort and the CPUE. It is clear that the theoretical pattern can also be observed by the data selected for the study. The negative linear trend shows that the CPUE systematically decreases as fishing effort rises (Jannah *et al.*, 2023). The regression equation is $CPUE=1.2714−1.0×10^{-7}effort$, with a coefficient of determination $R^2 = 0.1602$ and it indicates that the effort alone accounts for about 16% of the variation in CPUE. The trend is still biologically significant and consistent with Schaefer surplus production models, despite the moderate fit (Schaefer, 1991). The slope ($−1.0×10^{-7}$) indicate the resources depletion when the exploitation is increased. The fishery is becoming overfished as CPUE gets closer to zero with increased effort Furthermore, the declining trend of CPUE highlights that regulatory action is required for the fishery. Both economically and biologically sustainable harvest level can be achieved through sustaining fishing efforts that is close to the MSY and reducing the MEY effort further could maximize economic returns while conserving resources (Grafton *et al.*, 2008; Rosen, 2022). Regular stock assessments, effort regulation, and stakeholder engagement are crucial for maintaining the fishery at MSY level for long-term sustainability and avoiding overexploitation.

Table 2. Key Bioeconomic Parameters and Reference Points for Sustainable Fisheries Management

Parameter	Description	Value	Unit
E_{MSY}	Effort at MSY	6.36	Mn Hours /year
H_{MSY}	Harvest at MSY	4.04	Mn kg/year
E_{MEY}	Effort at MEY	4.27	Mn Hours/year
H_{MEY}	Harvest at MEY	3.60	Mn kg/year
E_{OAE}	Effort at OAE	8.53	Mn Hours/year
H_{OAE}	Harvest at OAE	7.21	Mn kg/year

The E_{MSY} and H_{MSY} have been estimated as 6.36 million hours and 4.04 million kg annually. These numbers represent the biological optimum, after which overfishing causes the stock to start declining. MEY takes into account both revenue and costs. Accordingly, H_{MEY} is 3.60 million kg/year and E_{MEY} is 4.27 million hours/year in the fishery Profitability is increased and resource stress is decreased when the fishery is operated at MEY. In an unregulated fishery, where open entry and exist occurred fishers, generally overcapitalize for their fishing operation. The H_{OAE} is 7.21 million kg/year, and the estimated EOAE is 8.53 million hours/year in the fishery. Even though OAE has the largest harvest, it is not economically and biologically sustainable, which causes long-term stock degradation and fishery collapse.

Figure 2 shows a comparison of modelled sustainable yield and real harvest data plotted against annual fishing effort (measured in hours × 10,000) for the *Amblygaster sirm* fishery in the Kalmunai Fisheries District. The blue parabolic curve shows the theoretical sustainable yield based on the Gordon-Schaefer bioeconomic model. The classic concave production curve shows that both effort and the harvest increase up to MSY level and then harvest yield gradually decline as the stock is being overexploited.

The orange dots on top of this curve show the actual annual harvests that were recorded over a 20-year period. Most of these data points are clustered to the left of the MSY curve, which means that the fishery has not yet reached its full biological exploitation capacity.

This observation suggests that the fishery is still underused or moderately used, which means that there is a chance to sustainably increase harvests. The non-linear spread of data points, on the other hand, also shows that catch efficiency can change. This could be because of changes in the environment, fisher behaviour, IUU fishing operations or changes in stock abundance that are not just due to effort.

The results showing current fishing effort below E_{MSY} alongside declining production are not inconsistent once economic dynamics and reporting tools are separated from biological stock status. The increase in fuel prices and other inputs forced many small-scale fishers in the districts to shorten trip durations, reduce trip frequency, or temporarily exit the fishery. These income shocks may compress observed effort well below the biological optimum (Hossain, 2013).

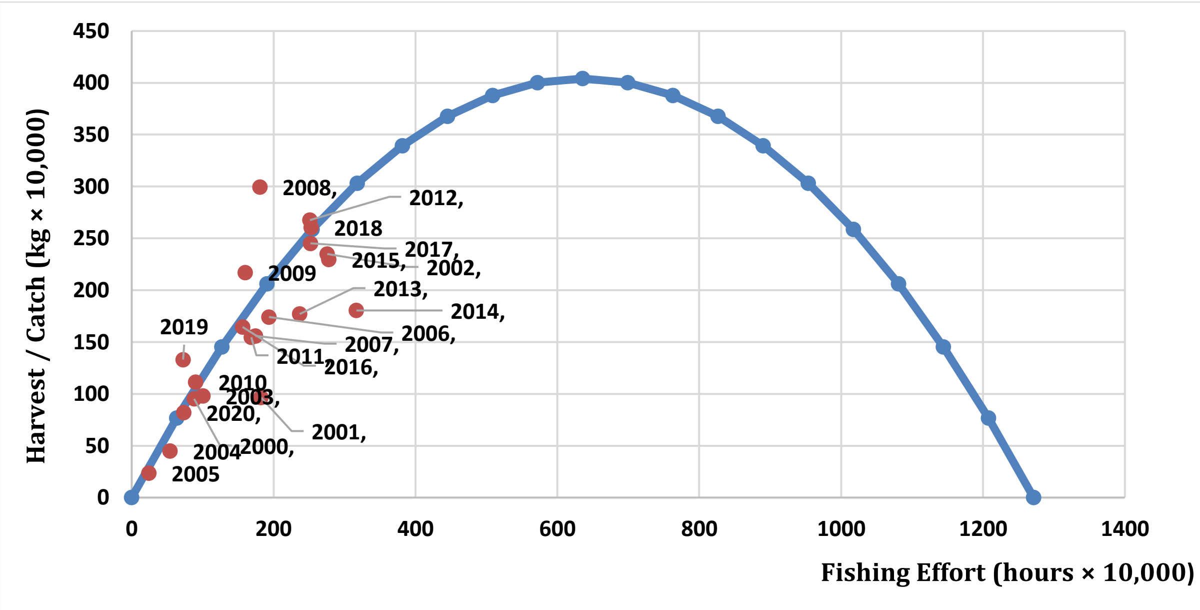

Figure 2. Variation of Sustainable Yield forecast (blue line) and Actual Harvest (scatter dots) in Relation to Fishing Effort

Further, When IUU fishing (like light attraction, illegal gear, and unreported trips) is not included in effort data, the recorded effort is underestimated. So, the model may wrongly interprets this as underfishing, even though the stock is actually heavily exploited (Pauly and Zeller 2016).

Further, Stock productivity can decline as a result of warmer sea temperatures, changing monsoons, or habitat damage. If the fish stock now grows more slowly than in the past, the MSY estimated from historical data may be high than the normal. As a result, current fishing effort may appear sustainable but could actually be unsustainable (Musick and Bonfil 2005c).

Profit in Relation to Fishing Effort

The Figure 3 shows how profit as a function of fishing effort (hours) relates TR, TC. The blue curve shows the TR. It first increases with effort and peaks about MSY effort. (E_{MSY} = 6.35 Mn hours) then start to drop. Assuming each further unit of effort results in a constant progressive cost, the orange line shows the TC curve (Chae & Pascoe, 2005).

Profit shown by the yellow dots is highest about MEY effort (E_{MEY} = 4.26 Mn hours), in which income most effectively exceeds expenses. Beyond E_{OAE} effort, negative profits and economic inefficiency result from costs exceeding income. This trend confirms that too much fishing effort lowers biological sustainability as well as economic inefficient. The black doted curve (TC) shows the total cost, which goes up all the time because operational costs (fuel, labour, gear maintenance, etc.) keep going up. These costs are based on a linear structure with fishing (Chae & Pascoe, 2005). The yellow dashed line (Profit), which is TR minus TC, follows a clear parabolic path. The MEY level is where profit is highest. This is where the marginal revenue from fishing effort is equal to its marginal cost. It is estimated to be 4.27 million hours per year. At this point, the fishery is at its most economically efficient, giving fishing businesses the most money back. After MEY, the profit curve starts to go down because the returns start to go down. The OAE) level, which is 8.53 million hours per year, is the point at which total cost equals total revenue and net profit goes down to zero.

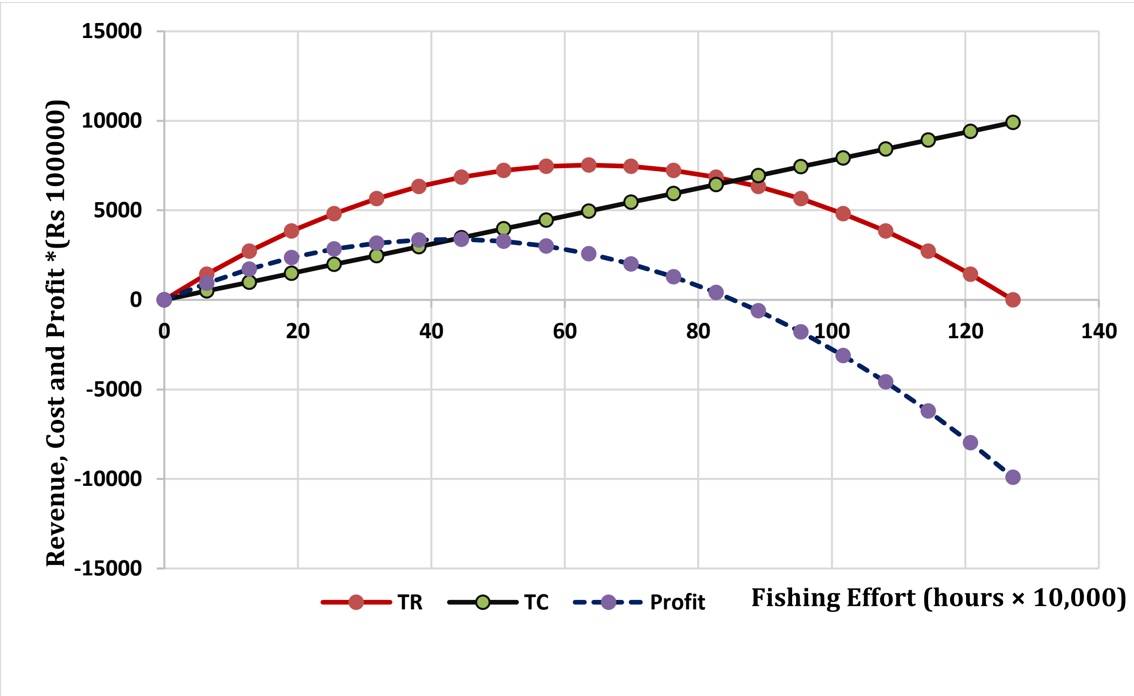

Figure 3. Variation of Total Revenue, Total Cost, and Profit in Relation to Fishing Effort

Summary of key findings

The regression of standardized CPUE on fishing effort was significant (R^2 = 0.52; p < 0.001), confirming the expected inverse CPUE–effort relationship. The estimated biological reference points were MSY = 4.04 Mn Kg at E_{MSY} = 6.36 Mn hours. The economic reference points were E_{MEY} = 4.27 mn hours and an OAE of 8.53 hours. Actual annual yields fluctuated around the MSY, exceeding it in several years and falling well below it few years. This indicating that the fishery has periodically been subject to biological overfishing while remaining economically vulnerable specially as a result of increasing input prices.

Policy implications

The reference point estimates have direct implications for coastal fisheries management. First, because actual effort in recent years lies below the efforts and near or below effort MEY. The immediate policy concern is not biological overfishing but the economic erosion of the fishery under rising input costs, fuel-cost stabilization or targeted fuel subsidy or fuel-efficient fishing operation mechanisms for small-scale fishers would protect economic viability without expanding effort. Second, because current fishing effort is closer to the MEY level than the MSY level, MEY may be a more appropriate management target (Panaĭotou and Panaĭotou 1982), Wang & Wang, 2012). Third, the high variability in annual harvest supports the use of a TAC system and stronger measures to reduce IUU fishing, particularly in eastern Sri Lanka.

Limitations of the study

The study is limited by the assumptions of the static Gordon–Schaefer model, which treats the fishery as being in equilibrium and assumes a linear relationship between effort and CPUE. Further, it assumes stable environmental conditions over time. It also assumes that CPUE is directly proportional to stock abundance. However, these assumptions generalize real-world dynamics. The model does not incorporate age or size structure of the stock, nor does it account for important environmental drivers such as monsoonal variability and changes in chlorophyll concentration, which are known to significantly influence coastal pelagic fish populations (Maddumage, Rajapaksha, and Gunatilake 2023). As a result, the model may not fully capture the biological and environmental complexity of the fishery system(Seijo *et al*. 1998b). Secondly, labour costs could not be fully included due to data limitations. Therefore, the MEY estimates are likely to be slightly overestimated and should be interpreted as upper limits. Thirdly. As a result of the analysis relies on secondary data, IUU catches are not captured. It led to underestimation of true effort and harvest.

CONCLUSIONS

This study is avital attempt to apply the Gordon-Schaefer model to estimate the bioeconomic reference points for the *Amblygaster sirm* fishery in the Kalmunai Fisheries District in Sri Lanka. It estimated important fisheries management reference points like MSY, MEY, and OAE. The results show that the current level of fishing effort is still below the MSY threshold, which means that the fishery is not being fully used. The economic analysis, on the other hand, makes it clear that the most efficient and ongoing harvest is closer to the MEY. Beyond that point, more fishing effort becomes less economically viable because of higher operating costs. The results also show that OAE are a clear threat to the long-term health of fisheries, which could lead to biological overexploitation and economic collapse.

The study highlights the importance to include bioeconomic models in Sri Lanka's small-scale coastal fisheries management framework, especially for species that are economically important. Using the same effort metrics across different types of vessels ((OFRP, MTRB, and NTRB) makes it possible to use the same method in other multi-gear fisheries as well.

This study fills an important gap in species-specific fisheries analysis in Sri Lanka by connecting biological and economic aspects. The results support making decisions based on science and managing resources in a way that protects the environment while also making financial benefits

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