

**BIO-ECONOMIC ANALYSIS OF AMBLYGASTER SIRM FISHERY IN
SRI LANKA**

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ABSTRACT

The coastal fishery of Sri Lanka faces the critical issue of declining productivity, threatening livelihoods and food security. This study aims to assess the sustainability of the *Amblygaster sirm* fishery, a significant contributor to coastal fish production, by analysing bioeconomic reference points. Data collected from 2000 to 2021 using stratified random sampling and secondary sources from the Ministry of Fisheries and other sources formed the basis of the analysis. Schaefer static approaches were employed to estimate key reference points, including the Fishing Mortality at Maximum Sustainable Yield (FMSY-90631.25 hours), Maximum Sustainable Yield (MSY 65712 Mt), and Maximum Economic Yield (MEY - 31190). The study also estimated the impact of fuel price increases under two scenarios: 50% and 100% increases. The results revealed significant fluctuations in the Maximum Economic Yield of the fishery under both scenarios, indicating a drastic effect on the economic viability of fishing operations. The findings indicate fluctuating *Amblygaster sirm* production around the MSY threshold. The absence of effective management strategies exacerbates this situation, leading to erratic fish production trends. Recommendations include estimating the Maximum Sustainable Yield (MSY) and Maximum Economic Yield (MEY) for the *Amblygaster sirm* fishery. It helps in comprehending the resource and economic status of the fishery, allowing the establishment of appropriate input or output limitations. Furthermore, it is recommended to enhance the data collection mechanism, apply an output management system, collaborate with stakeholders, and strengthen monitoring and enforcement procedures in coastal fishing operations to facilitate more effective policy recommendations for the fishery.

Keywords: Bioeconomic reference points, MSY, MEY, fisheries sustainability, coastal fisheries, *Amblygaster sirm*, Sri Lanka.

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ABBREVIATIONS

MEY	Maximum Economic Yield
MSY	Maximum Sustainable Yield
IUU	Illegal, Unreported, and Unregulated
CPUE	Catch Per Unit Effort
GS	Gordon Schaefer Modal
FAD	Fish Aggregate Devise
TAC	Total Allowable Catch
OA	Open Access
MEI	Morpho-edaphic Index
OSY	Optimum Sustainable Yield
OAE	Open Access Equilibrium
NARA	National Aquatic Resources Research and Development Agency
MBRD	Marine Biological Research Division
FAO	Food and Agriculture Organisation
EEZ	Exclusive Economic Zone
TR	Total Revenue
TC	Total Cost
MR	Marginal Revenue
MC	Marginal Cost

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1 INTRODUCTION

Sri Lanka is an island nation in the Indian Ocean. It is situated between latitudes 5°55' and 9°51' N and longitudes 79°41' and 81°53' E, with a maximum length of 268 miles (432 km) and a maximum width of 139 miles (224 km). The island has diverse and rich marine and coastal habitats that span its 1,620 km shoreline. Sri Lanka's fishing sector is crucial for food security and the economy of the country. Fish comprise approximately 50% of Sri Lankans' animal protein intake, a ratio three times the global average (World Bank, 2022b). It has three key subsectors: coastal, offshore, and deep-sea, as well as inland and aquaculture. These sectors engage 224,190 active fishermen, create approximately 586,000 jobs (Ministry of Fisheries, Sri Lanka, 2023), and support 2 million livelihoods (Department of Fisheries, Sri Lanka, 2023). The nation's extensive maritime resources, including historical waters and a 517,000 sq.km Exclusive Economic Zone, offer substantial potential for economic growth (USAID, 2009).

The total capture fish production in the country has gradually declined since 2017 and recorded its lowest production in 2022 after ten years. A decline in coastal capture fish production was noted from 2016, whereas a decline in deep-sea production began in 2018. However, aquaculture fish production has steadily increased over the last five years, and its contribution to total fish production is approximately 30% (Ministry of Fisheries, Sri Lanka, 2023). The coastal fishing sector is crucial to the socio-economic system of the country because it supports a considerable section of the population's livelihoods and makes a substantial contribution to national food security.

The production of coastal fish peaked in 2016 at 274,160 metric tons, and thereafter, it started to progressively fall. The production of coastal fish was measured at 149,440 metric tons in 2022, a 16% decline from that in 2021. Therefore, it is remarkable that during this time, there was no appreciable drop in the activity of coastal fishing fleets. In addition, the cost of fuel (kerosene, diesel, and lubricant) has increased by more than three times since 2016, affecting the operation cost of fisheries. Consequently, the profit margins of the coastal fishing industry are currently lower. Therefore, it is important to determine the level of fishing effort that maximises the economic benefit derived from coastal fishing operations in the country.

The *Amblygaster sirm* fishery is a significant aspect of Sri Lanka's coastal fishing industry. Fishers across coastal districts heavily rely on *Amblygaster sirm* because of its abundant presence and the income it generates. Numerous studies have highlighted its importance from social, economic, and ecological perspectives, particularly in terms of livelihoods, food security, and coastal resource utilization (Karunasinghe & Wijeyaratne, 1991; Wijeyaratne & Maldeniya, 2003). However, management decisions aimed at sustaining this fishery have been inadequate, primarily because of a lack of understanding of its biological and economic reference points of the fishery. Therefore, this study focused on estimating these reference points to enhance the management strategies for *Amblygaster sirm* fishery, thereby ensuring its sustainability.

1.2 Problem statement and background.

The Sri Lankan fishery industry can be categorised into different sectors based on the requirements of the studies. Categorisation based on fishing zones, fishing places, fishing boats, and species is major among others. Although there are common issues in fisheries, specific issues related to different sectors of fisheries can also be observed.

The fishery policy of the country directly focuses on achieving the social, economic, biological, and environmental objectives of the fishery industry. However, the achievement of the policy depends on key assumptions such as fixed input prices, suitable weather conditions, a stable political situation, proper functioning of the supply chain, and a competitive market structure. Unexpected changes in assumptions can negatively influence the policy objectives of fisheries. Although nine fisheries policies have been applied to Sri Lankan fisheries, the objectives and targets of policies have been repeated. This indicates that the application of policies is weak.

The decline in coastal capture fish production, inefficiency, low productivity, resource degradation, increases in fishing input prices, and indebtedness are still major issues in Sri Lankan coastal fisheries. These issues are interconnected. As a result of fishing inputs, prices have gradually increased in the recent past, and the profit shares of the fishers have declined. The productivity of coastal fisheries is comparatively low in the country. Fishing inputs are closely related to major coastal issues in the country.

Coastal fisheries constitute over 50% of marine capture fisheries, involving more than 80% of the country's marine fishermen and fishing craft operations, predominantly within coastal zones as opposed to deep-sea areas. However, since 2016, there has been a substantial and concerning decline in coastal fish production. Concurrently, the operational costs of fishing, particularly the steep rise in fuel prices, have increased significantly. This adverse economic shift has inflicted severe hardships on coastal fishermen. To address these challenges and restore economic sustainability to this vital sector, a decisive initiative is underway to conduct a comprehensive Maximum Economic Yield (MEY) estimation for coastal fishing operations in the country.

Despite the significant importance of the *Amblygaster sirm* fishery in coastal fishing operations, the efforts invested in its protection and management are notably lower than those directed towards export-oriented fish species in the country. Consequently, the contribution of the *Amblygaster sirm* fishery to total coastal production has dwindled, influenced by various factors. These include a lack of understanding of the resources associated with *Amblygaster sirm*, operational costs, and the prevalence of illegal, unreported, and unregulated (IUU) fishing practices in some areas. Therefore, it is urgent to consider the approach to the *Amblygaster sirm* fishery from different perspectives. This study focuses on the abundance of resources and economic prospects of fisheries to address these challenges effectively.

1.3 Project objectives

1.3.1 Primary objective

- a. To estimate the Maximum Economic Yield (MEY) and maximum sustainable yield (MSY) of the *Amblygaster sirm* fishery in Sri Lanka.
- b. To conduct a comprehensive analysis to determine the optimal level of fishing effort in *Amblygaster sirm* fishing operations that maximises economic benefits while ensuring the sustainable utilisation of marine resources.

1.3.2 Secondary Objectives

- a. Assess the status of coastal fishery
To identify the current status of coastal fisheries in Sri Lanka and analyse various aspects, such as catch trends, fishing effort, trade, and socio-economic impacts on local communities.

- b. Evaluate the impact of rising operational costs on coastal fishermen
Examine the economic implications of the notable increase in operational costs, especially fuel prices, on the *Amblygaster sirm* fishery.
- c. Propose policy recommendations for the *Amblygaster sirm* fishery.
Formulate recommendations for sustainable fishing practices and policy interventions aimed at restoring and maintaining the economic viability of coastal fishing operations while ensuring the long-term health of marine ecosystems.

1.4 Significance of the study

The coastal fishing industry holds immense importance globally (GEF, 2024), including in Sri Lanka (FAO, 2023), from a socio-economic perspective. It has generated significant employment opportunities and ensured food security for the coastal communities. However, due to poor management practices, the fisheries sector has faced negative impacts worldwide (Asha & Bhuvanewari, 2024) and in Sri Lanka. The importance of sustainable utilisation and conservation of fisheries has been clearly identified by international agendas and Sri Lankan National Policies (Ministry of Fisheries and Aquatic Resources Development, 2018). For instance, targeting the Sustainable Development Goals (SDGs) (United Nations, 2015), particularly Goal 14 and sub-targets 14.2 and 14.4, is crucial. Target 14.2 aims to sustainably manage and protect marine and coastal ecosystems to prevent significant adverse impacts and promote resilience while advocating for restoration efforts to achieve healthy and productive oceans. Similarly, target 14.4 emphasises the need to regulate harvesting effectively, prevent overfishing and illegal practices, and implement science-based management plans to restore fish stocks to sustainable levels. Achieving these targets necessitates an increase in scientific knowledge, research capacity development, and the transfer of marine technology, as highlighted in the sub-targets of SDG 14.

The Fishery Sector Strategy (2023) and the Ministry of Fisheries' Mid-Term Plan of Actions for 2023-2027 clearly emphasizes the importance of conservation, sustainable utilisation, and the application of scientific and technical knowledge in fisheries management. Sri Lanka's Fisheries Department is taking steps to improve fisheries management by suggesting changes to the draft Fisheries Act. The draft act introduced input and output control systems to protect fisheries.

This study aims to conduct a bio-economic analysis of the *Amblygaster sirm* fishery, which is a major sector in the country's coastal fishing operations. The production of *Amblygaster sirm* in the country has fluctuated significantly over time, with recent years witnessing a gradual decline. This was confirmed by recent studies (Bandaranayake et al., 2023). This study applies scientific approaches to Sri Lankan coastal fisheries, providing valuable insights for policymakers to make decisions aimed at protecting and conserving them. This indirectly helps ensure livelihoods and food security in the country. Therefore, this study contributes to supporting both national and global policy targets.

1.5 Structure of the research project

This study is structured into five chapters. The initial chapter provides an overview of the study background, outlining its significance and context. In the second chapter, relevant literature pertaining to the research topic is reviewed and synthesised. Chapter three elucidates the methodology employed in this study, detailing the research design, data collection methods, and analytical approaches. The fourth chapter explores the Sri Lankan fishery industry, offering

insights into its historical development, present status, and sectoral importance, including its contribution to the national economy. Chapter five presents the findings derived from the data analysis conducted in this study, providing a comprehensive explanation of the results obtained. Additionally, it expounds on the methodology utilised, detailing the selection of data sources, sampling techniques, and statistical models applied. Chapter six discusses the findings, analysing their implications and offering interpretations within the broader context of the research area. Finally, Chapter Seven presents the conclusion and recommendations, encapsulating the key insights derived from the study and suggesting avenues for further research and practical applications.

2 LITERATURE REVIEW

Countries aim to regulate fisheries by considering biological, economic, social, and political factors. Various policies, such as those in the U.S. Sustainable Fisheries Act, the European Common Fisheries Policy, and the United Nations Convention on the Law of the Sea, highlight the significance of setting target yields that balance economic, environmental, and social aspects (Dichmont et al., 2010). Bioeconomic modelling is a superior tool for fisheries management because it enables a better understanding of the relationships between those exploiting resources, economic structures, and ecosystem dynamics (Gumulira et al., 2019). Fisheries bioeconomic analysis serves two primary purposes. First, it predicts the operation of a fishery under changes in effort and stock size. Second, it suggests and evaluates measures to regulate fishermen to achieve the desired fishing effort level. While achieving the second objective is an ongoing process, fisheries bio-economic analysis is a crucial tool for developing effective fisheries management policies (Jueseah et al., 2020).

The combination of biological and economic data collection and analyses helps in the efficient management of fisheries. Several bioeconomic models can be applied to fisheries. These model analyses allow for a discussion of the interactions between effort, harvest, and stock size (Fortes & Haraldsson, 2022). The Schaefer, Fox, and Pella-Tomlinson models are widely recognised for bioeconomic analysis in fisheries (Barua & Panhwar, 2017); (Jurado-Molina et al., 2021). Researchers commonly apply the Schaefer model for MEY and MSY analyses in fisheries (Tsikliras & Froese, 2018). MSY and MEY are integral components of fish resource utilisation (Chande et al., 2019); (Pascoe et al., 2023). Effective fisheries management should consider both biological and economic factors. MEY is recognised as a primary management objective in some countries (Dichmont et al., 2010).

To examine the degree of over-utilisation of fishery resources over time in Bangladesh, both Schaefer's surplus production model and Fox's variant of the model were applied by Khan and Haque (Chande et al., 2019). Data on catch and effort in trawl fishing were obtained for a period of 16 years from 1981 to 1997 for the study and obtained catch per fishing day (CPUE). The MSY according to Fox's model was greater than that of Schaefer's model. Similarly, the MSY effort level of Fox's model is much higher than that of Schaefer's model.

The bioeconomic models of Gordon Schaefer (GS) and Gompertz were used by Anna et al. (2020) for hammerhead sharks. As a result, the three types of gears used for the fishery were standardised to measure them in equal units. Many fishing gear types have been considered and developed in maximum sustainable yield studies from a single species perspective. Fulton et al. (2022) applied multispecies fisheries aggregate production models for the Gulf of Thailand, and time-series data were used for the analysis.

The Schaefer surplus production model is the most commonly used in fisheries management and can be applied to data-poor stocks (Tsikliras & Froese, 2018). However, it has been difficult to apply to fishery management (Pan, 2021). Schaefer's model was improved by incorporating a nonlinear catch per unit effort (CPUE) by Pan.

To investigate the performance of bioeconomic models in Fish Aggregate Devices (FAD) associated with tuna fisheries, Kendarii in Indonesia, Mohamad Natsir (Proctor et al., 2019) applied bioeconomic models to analyse fishery policy related to the FAD. The surplus production model developed by Schaefer was applied in this study, and cost, revenue, and profit were analysed from the primary data collected. In addition to bio-economic analysis, stochastic frontier analysis was used to measure technical efficiency for estimating efficiency for the FAD associated tuna fisheries. It was found that the FAD-associated tuna fishery is still in good shape around the MEY level and is profitable, and an increasing number of FAD tends to have an impact on technical efficiency.

Another study conducted by Gumulira et al. (2019) in the southeastern region of Lake Malawi sought to evaluate the *Usipa Engraulicypris* sardella fishery. A bioeconomic model utilising the Gordon-Schaefer model was constructed to ascertain the MSY and MEY. Catch and effort data from 2000 to 2015 were analysed using ASPIC software version 7 and Microsoft Excel 2016. A sample of 139 gear owners was collected using snowball sampling. To maintain consistency, all costs from previous years were standardised to the 2015 value using the reported annual inflation rates. These results suggest that the current fishing activity surpasses sustainable thresholds.

Chae and Pascoe (2005) focused on the mixed gear, multi-species inshore fleet, addressing overexploitation in the Korean fishing industry. This study determined the appropriate effort levels despite limited data. A surplus production bioeconomic model for the flounder fishery was developed using various effort standardisation approaches. This study contributes valuable insights into sustainable management strategies, despite data limitations.

Bintoro et al. (2022) employed the Schaefer and Fox models to assess the sustainability of longtail tuna (*Thunnus tonggol*) in the South Java Sea through bioeconomic analysis. This study estimated crucial parameters, such as MSY, Total Allowable Catch (TAC), and MEY, to guide fisheries management. Using a sample of 987 fish from 2010 to 2019, bioeconomic aspects were employed using tuna resource data. Production, fishing effort, and CPUE were processed using Microsoft Word and Excel. The results indicate an overexploited condition, suggesting the need for restrictions on fishing efforts to ensure long-term sustainability.

Dewi (2016) analysed rasbora (*Rasborasp*) bioeconomic status with MSY, MEY, and Open Access (OA) indicators. The Gordon-Schaefer Model was used in this study, with the main data collected by a census of 31 gillnet fishers. In addition, secondary data on Rasbora (*Rasborasp*) production for 10 years from 2003 to 2012 were used for analysis. MSY and Morpho-edaphic Index (MEI) were calculated for nine reservoirs by Wijeyaratne and Amarasinghe (1984). The Schaefer Model was used to estimate MSY, while the methodology applied by Henderson and Welcome (1974) was used to measure MEI.

Surplus production models (Gordon-Schaefer model) were applied by Wijeyaratne (2001) to develop a Surplus Yield Model for MSY, Optimum Sustainable Yield (OSY) and Open Access Equilibrium (OAE) of coastal fisheries in Sri Lanka. As coastal fisheries comprise both manual

and mechanised fishing operations, both fishing efforts were estimated in horsepower hours. The cost of fish catch and prices were also estimated using data available from the Ministry of Fisheries. It was found that MSY was at 165,235 tons valued at Rs 11,236 million and attained at an effort level of 220 million horsepower hours, and the open access equilibrium was at 320 million horsepower hours. Wijeyaratne (2001) concluded that the coastal fisheries in Sri Lanka were fully exploited, and further exploitation would cause a decrease in fish harvest as well as a decline in profits.

Estimating the economic and reference points for fish species in coastal regions is crucial for informing policy decisions and guiding fishers to adapt their practices for long-term benefits of the fishery. The *Amblygaster sirm* fishery is a major contributor to the coastal fishing industry in terms of the volume of fish caught. Additionally, the livelihoods it sustains are significant compared with other fishing operations in coastal areas. Therefore, it is imperative to determine the biological and economic reference points for this fishery. This study aims to precisely estimate these reference points for the *Amblygaster sirm* fishery in the country. In addition, this study plans to estimate the MSY in coastal fisheries in Sri Lanka 20 years after the Wijeyaratne study.

3 METHODOLOGY

Fisheries data in the country are primarily collected by the Ministry of Fisheries, specifically through its Statistics Department, which utilises regional offices established under the Department of Fisheries. Each office affiliated with the department submits monthly data to the ministry. Additionally, sample data primarily collected by the National Aquatic Resources Research and Development Agency (NARA) are utilised for various purposes. For this study, data were gathered by the Marine Biological Research Division (MBRD) of NARA.

3.1 Sample Data collection

Data sampling was collected from 14 fisheries districts by samplers stationed within each respective district, along with research assistants from the MBRD. The data collection method employed a Stratified Random Sampling technique, with sample sites chosen based on the density of fishing boat operations in coastal areas.

Data collection commenced in 2000, with a primary focus on the predominant types of boats and crafts utilised in coastal fishing operations. As time progressed, data collection techniques evolved in tandem with technological advancements to enhance data quality. Coastal fisheries catch and effort data were gathered from every fisheries district, except for the Killinochchi fishery district.

These data cover various variables, including landing dates, gear and boat types, engine capacity, trip frequency, departure and arrival times, fishing duration, income, fuel expenses, fishing depth, and total catch across different fish species.

3.2 Selection of the data for analysis

While data collection encompasses multiple species caught in the coastal region using various fishing gears, this study focuses solely on the *Amblygaster sirm* fishery harvested specifically by small-meshed gill nets. Sampling data collected from 2000 to 2021 in the Kalmunai fisheries

district were used for the analysis. The Kalmunai fishery district was selected based on the availability of data representing three types of fishing boats: outboard engine fibreglass reinforced plastic (OFRP) boats, motorised traditional (MTRB) boats, and non-motorised traditional (NTRB) boats. Figure 1 presents sample sites based on the density of fishing boat operations in the coastal areas.

Total Boats	Total Fishing Time (H)	Total Catch (Kg)
180	738.70	4233
234	1243.80	3456
189	940.90	4321
188	953.50	5012
182	910.90	4020
133	738.93	3850
124	696.82	3385
190	1044.63	5027
141	579.33	5197
170	613.00	4481
179	663.08	4419
184	771.75	3810
158	655.85	3764
201	944.75	4115
240	1220.67	5518
163	762.25	3303
81	435.75	1699
80	385.75	1920
181	869.42	5286
81	393.75	1094
25	108.00	354

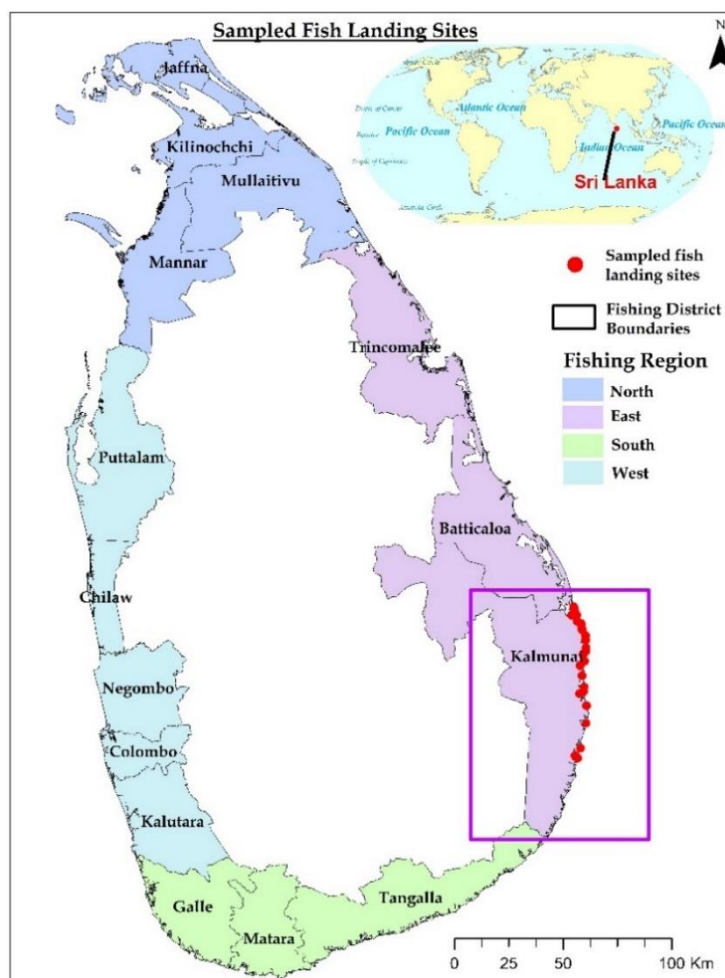


Figure 1. Sample sites and sample sizes of the study.

The three types of boats were represented in the sample; therefore, the relative CPUE was calculated to estimate the MSY for the fishery (Figure 2). The guidelines provided by the Food and Agriculture Organization (FAO) were used to estimate the relative CPUE (Per Sparre, 1989).



Figure 2: Small scale coastal fishing boats/craft used in coastal fishing operations. (1) OFRP-out-board engine fiberglass reinforced plastic boats, (2) MTRB-motorised (3) NTRB-non-motorised traditional boats.

3.3 Secondary data

As the Ministry of Fisheries collects fish production data, it plays a crucial role in analysing the Sri Lankan fishing industry and its trends. In addition to production data, the ministry gathers information on the fishing community, fishery-related infrastructure, fishing fleet, external trade, fish prices, and aquaculture. These data serve as valuable secondary sources for analysis. The Ministry of Fisheries publishes these data annually on its website. Furthermore, the Central Bank publishes data related to all industries, including fisheries. Additionally, data published by the FAO (FishStatJ) were used as secondary data.

The Ministry of Fisheries collects coastal fish harvest data from all fisheries districts. However, species-wise coastal fish production was not specified in these reports. Consequently, sample data collected by the MBRD were used to estimate the annual catch of *Amblygaster sirm*. The estimation of the *Amblygaster sirm* harvest is presented in Table 1 below.

Table 1: Estimated *Amblygaster sirm* harvest (Mt) from 2000 - 2021

Year	<i>Amblygaster sirm</i> contribution for the coastal fish production	Coastal Fish Production (Mt)	<i>Amblygaster sirm</i> Production (Estimated-Mt)
2000	16%	179280	29301
2001	28%	167530	47326.9
2002	27%	176250	46922.6
2003	21%	163850	34080.7
2004	28%	154470	43572.3
2005	31%	63690	19919
2006	34%	121360	40754.7
2007	36%	150110	54161.2
2008	41%	165320	67569.7
2009	38%	180410	69117.8
2010	33%	202420	66239.8
2011	32%	222350	71974.9
2012	34%	257540	86291.7
2013	22%	267980	58852.2
2014	16%	278850	45603.9
2015	22%	269020	59957.9
2016	26%	274160	70027.7
2017	33%	259720	86518.2
2018	20%	249020	51011.6
2019	12%	242580	28544.4
2020	11%	182560	19696
2021	13%	178260	23557.1
*. Based on the sample data collection (MBRD)			

Fish price data were obtained from a dataset published by the Ministry of Fisheries. Weekly and annual fish price data based on important fish species are made available online by the ministry. Fishing costs were derived from sample data collected by the MBRD. In addition to the primary data, research publications (Wijayarathne & Maldeniya, 2003) were also referred to estimate labour costs and other fishing costs associated with coastal fishing operations in Sri Lanka.

3.4 Data Analysis techniques

Fisheries management aims to ensure the long-term sustainable use of fish stocks while considering various outcomes (Holma et al., 2019). Effective management of marine ecosystems requires solutions that carefully balance economic and social drivers with biological and environmental considerations (NOAA Fisheries, 2022). Bioeconomic models play a crucial role in this process by integrating economic and biological factors to inform management decision-making.

These models attempt to capture the complex interactions between economic activities and biological resources in marine ecosystems (Waldo et al., 2014). Reference points, such as MSY and MEY, are important tools for aligning ecological dynamics with management objectives (Holma et al., 2019).

The models developed by Gordon (1954) and Schaefer (1954) are commonly used to estimate reference points for fisheries (Froese et al., 2017). These models consider factors such as fish stock dynamics, fishing effort, and economic parameters to determine optimal harvest levels (Udumyan et al., 2010) that maximise long-term benefits while ensuring fish population conservation. By integrating economic and biological considerations and using robust modelling techniques, fishery managers can develop effective strategies to achieve sustainable fishery management goals.

To estimate the MEY and MSY of Sri Lankan coastal fisheries, a static Gordon-Schaefer model was applied. In particular, the bioeconomic analysis will be conducted using the surplus production model developed by Schaefer, and cost, revenue, and profit functions will also be estimated from the primary data. Finally, the estimates of the static reference points were obtained. The basic Schaefer model serves as a fundamental framework for understanding fish population dynamics and is characterised by a logistic growth equation that reflects the natural growth dynamics of fish populations. This equation captures the relationship between reproduction, mortality, and environmental factors in shaping population size over time. The following equation is commonly used to describe the growth of fish populations over time.

$$F(X) = rX \left(1 - \frac{XK}{KX} \right) \quad \mathbf{1}$$

Where

$F(X)$ is the rate of change in population size (denoted by X) with respect to time, r is the intrinsic growth rate of the population, and K is the carrying capacity of the environment, which is the maximum population size that the ecosystem can sustain indefinitely. At K , the population growth rate reaches zero as the resources become fully utilised.

As the population size (X) approaches the carrying capacity (K), this term becomes smaller, leading to a reduction in the growth rate.

Fishing effort is related to fish population biomass and catchability. The following equation offers insights into the impact of fishing activities on population sustainability and the delicate balance between exploitation and conservation.

$$H(E, X) = qEX \quad \mathbf{2}$$

This function defines the harvest rate, which is the number of fish removed from the population through fishing activities. The harvest rate is influenced by both the fishing effort (E) and the biomass of the fish population (X). If the fish harvest is equal to the growth of the fish population, it can be observed that an equilibrium condition exists for fisheries management. The following equation explains this condition:

$$\frac{dy}{dx} = F(X) - H(E, X) = 0 \quad \mathbf{3}$$

The following equation provides insight into the maximum sustainable biomass. This provides an understanding of the sustainable population size of fish under specific fishing pressures.

$$X = K \left(1 - \frac{qE}{r} \right) \quad 4$$

The equation is derived from Equation (3) by setting the growth rate equal to the harvest rate and solving for the biomass (X) at equilibrium. At equilibrium, the growth rate of the fish population (F(X)) is equal to the harvest rate (H(E,X)), indicating that the population neither grows nor declines over time. MSY and MEY can be estimated using the following equations. (A step-by-step equation explanation can be found in Annex 2.)

The estimation of MSY (Nguyen, 2011) and MEY (Natsir, 2015) can be summarised as follows:

Table 2: Parameters for maximum sustainable yield (MSY) calculation

Equation		Definition
h_{MSY} or Y_{msy}	$\frac{Kr}{4}$	Harvest at Maximum Sustainable Yield (MSY)
X_{MSY}	$\frac{K}{2}$	Biomass at Maximum Sustainable Yield (MSY)
E_{MSY}	$\frac{r}{2q}$	Fishing Effort at Maximum Sustainable Yield (MSY)

Here, 'K' is the carrying capacity of the fishery (maximum biomass it can support) and 'r' is the intrinsic growth rate of the fish population (rate of natural increase). 'q' is the catchability coefficient (a measure of fishing efficiency).

Table 3: Parameters for maximum economic yield (MEY) calculation

Equation		Definition
X_{MEY}	$\frac{K}{2} \left(1 + \frac{c}{pqK} \right)$	The biomass level (X) at which the fishery operates at MEY. It calculates the equilibrium biomass level based on the carrying capacity (K), cost, and price parameters (c, p, and q).
E_{MEY}	$\frac{r}{2q} \left(1 - \frac{c}{pqK} \right)$	The optimal level of fishing effort (E) that maximizes economic rent. It calculates the effort level based on the intrinsic growth rate (r), catchability coefficient (q), cost, and price parameters (c, p, and K).
h_{MEY}	$q \cdot X_{MEY} \cdot E_{MEY}$	The economic rent (h) obtained from the fishery operating at maximum economic yield. It calculates economic rent by multiplying the optimal biomass level (XMEY) and the fishing effort level (EMEY) by the catchability coefficient (q).

3.4.1 Standardising fishing effort

Standardising fishing effort is crucial for accurately assessing fish stocks, especially when dealing with various types of fishing gear and boats. The concept of relative effort, as outlined in the FAO 306/1 technical paper "Introduction to Tropical Fish Stock Assessment" (Per Sparre, 1989), provides a method to achieve this standardisation.

Relative effort involves quantifying fishing effort in a standardised manner, typically by expressing it relative to a common reference point. This reference could be the number of fishing trips, hours spent fishing, or any other consistent measures. This allows for fair comparisons of fishing efforts across different gear types and boats. This enables the calculation of the common catch per unit effort (CPUE) for all.

Step 1. Calculate CPUE for each type of boat

$$CPUE_i(y) = \frac{Y_i(y)}{f_i(y)} \quad 5$$

$$CPUE \text{ (OFRP) Year 1} = \frac{\text{Catch OFRP} - \text{Year 1}}{\text{Effort OFRP} - \text{Year 1}} \quad 6$$

By employing this method, CPUE needs to be calculated annually for each type of boat.

Step 2. Then, the mean CPUE needs to be calculated, and the estimated CPUE of each year for each type of boat needs to be divided by the respective mean CPUE.

$$R_i(y) = \frac{CPUE_i(y)}{\text{Mean } CPUE_i} \quad 7$$

$$R_i(Y) = \frac{CPUE \text{ OFRP Year 1}}{\text{Mean } CPUE \text{ of OFRP}} \quad 8$$

Step 3. The relative CPUE for each year was multiplied by the relevant fish catch associated with the boat type and then divided by the total fish catch of all three types of boats.

$$R(y) = \frac{(R_i(y) * Y_i(y))}{Y_s(Y)} \quad 9$$

$$R(Y) = \frac{\text{Relative } CPUE \text{ OFRP Year 1} * \text{Fish catch of OFRP year 1}}{\text{Total Fish Catch of Three types of boats of year 1}} \quad 10$$

Step 4. Calculate Normalized Relative Effort adding three values of the R(Y) This normalised relative effort was utilised to calculate the effort of the fish catch, aiding in the estimation of MSY and MEY for the analysis.

4 SRI LANKAN MARINE FISHERY

Fish and fisheries products play a crucial role in ensuring global food security. According to a report by the Food and Agriculture Organization, approximately 600 million livelihoods depend, at least partially, on fisheries and aquaculture (*The State of World Fisheries and Aquaculture*) (FAO, 2022). Globally, aquatic foods contribute approximately 17 percent of animal protein. However, in several countries in Asia and Africa, this figure rises to over 50 percent, highlighting the significant reliance on aquatic resources for protein intake in these regions (FAO, 2022). In 2020, the total fisheries and aquaculture production reached an all-time high of 214 million tonnes, consisting of 178 million tonnes of aquatic animals and 36 million tonnes of algae. Specifically, global capture fisheries production (excluding algae) amounted to 90.3 million tonnes, whereas aquaculture production reached a record 122.6 million tonnes (FAO, 2022). Although Sri Lanka's contribution to global fisheries is relatively low (0.05%) (FAO, 2019), it significantly impacts the Sri Lankan economy in various ways.

The Democratic Socialist Republic of Sri Lanka is a lower middle-income country (*Charting the Course, 2024; World Bank, 2022a*) located in the Indian Ocean, south of the Indian peninsula. It spans an area of approximately 656,610 square kilometres (sq. km) and is home to an estimated population of 22.2 million people as of 2022 (Figure 3). The Gross Domestic Product (GDP) per capita, calculated at current prices, is estimated to be US\$ 77.1 billion in 2022 (Central Bank-Sri Lanka, 2023). Sri Lanka possesses a maritime zone with a territorial sea area of 21,500 sq. km and an extended zone (Exclusive Economic Zone) of 517,000 sq. km, granting sovereign rights. The country's narrow continental shelf spans 22 km from the baseline, and Sri Lanka's ocean area is approximately 7.8 times larger than its land area (Arachchige et al., 2017). Sri Lanka has two main types of fisheries: marine and inland (freshwater). Marine fisheries are split into offshore, where fishing occurs beyond the continental shelf using multi-day boats, and coastal, which operates within the narrower waters of the continental shelf (Premawardana, 2010).

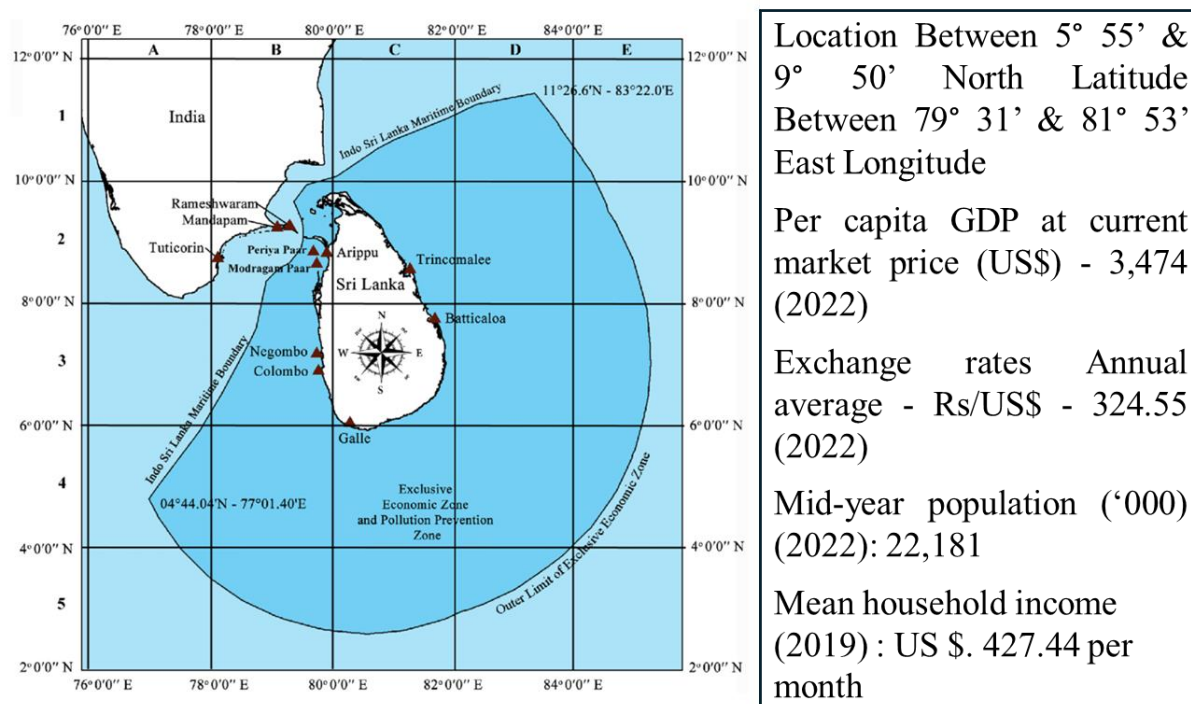


Figure 3. General information about Sri Lanka

The fishery industry, which is an essential element of the Sri Lankan economy, makes an estimated 2 percent contribution to the country's gross domestic product. This industry provides essential means of subsistence, employing more than two million people directly and indirectly as of 2022, with 223,490 direct marine fishers affiliated with 186,500 fishing families. Fish is the predominant protein source for the Sri Lankan population, constituting more than 50% of the protein provision. Per capita fish consumption reached 19.7 kg by 2022 (*Fisheries_statistics_2022_compressed.Pdf*, n.d.).

4.1 Historical development of Sri Lankan Marine Fishery

The historical narrative of Sri Lankan coastal fisheries is complex and influenced by multiple factors and interventions. Renowned as the "The pearl of the Indian Ocean", Sri Lanka is celebrated for its exceptional natural beauty, diverse biodiversity, and precious gemstones, including pearls (Lanka, 2013). The island's rich history of pearl exploitation dates back more than 3500 years (Katupotha, 2019). During the Anuradhapura kingdom period (437 BC to 1017), pearl fishing was a primary source of foreign exchange (Sri Lanka Inland Revenue, 2015). This practice persisted through Dutch (1658–1796) and British colonial (1796–1948) rule, with the British deriving significant revenue from Ceylon pearls (Katupotha, 2019). Although the pearl fishing industry flourished primarily in the northwest coastal areas, it faced extinction by 1950 (Katupotha, 2019).

Fishing methods have evolved over time, with beach seining dominating the mid-to-late 1800s and continuing as a predominant technique into the twentieth century (Joseph, 1984). The introduction of bottom trawling during British colonial rule marked a significant shift in fishing practices (Harper and Zeller, 2011). In 1940, the establishment of the Department of Fisheries formalised fisheries management in Sri Lanka, laying the groundwork for further sectoral developments (Wijayaratne & Gudmundsson, 2001).

The evolutionary trajectory of fishing craft development in Sri Lanka saw three significant milestones: the motorisation of traditional fishing crafts in the 1960s (Piyasena, 1992; Wijayaratne & Gudmundsson, 2001), the introduction of multiday offshore fishing vessels in the 1970s (Premawardana, 2010), and the adoption of outboard motorised FRP boats and the introduction of large boats (8 – 12 m) in the 1980s (Bay of Bengal Programme, 1986; Dissanayake, 2005). These advancements aimed to enhance resource exploitation efficiency. Foreign-funded fisheries projects in the late 1970s expanded and diversified the fishing fleets. For example, the Southwest Coast Fisheries Development, backed by the Asian Development Bank, introduced new boats despite facing design challenges. Similarly, the Northwest Coast Fisheries project, funded by the Abu Dhabi Development Fund, supplied multi-day boats and trawlers, facilitating offshore fishing growth (Piyasena, 1992). In terms of data collection and management, efforts to record fisheries data began during British rule, but rigorous island-wide attempts to estimate total landings commenced after the country's independence. The establishment of the Department of Fisheries in 1940 marked a significant step in this direction (Harper and Zeller, 2011).

Despite these advancements, Sri Lanka faces challenges, such as the devastation caused by the 2004 Indian Ocean tsunami, which significantly impacted the fishing industry. Additionally, civil unrest, notably the 26-year civil war (Reuters, 2009) (Associated Press, 2009), disrupted economic development, particularly in coastal regions. The fishing industry suffered greatly

from the tsunami waves that struck two-thirds of the island's coastline. Approximately 80% of fishermen were affected, with over 75% of fishing boats either destroyed or damaged. Many small-scale fishing vessels and equipment were also lost. Among the 12 fishing harbours, 10 were severely damaged, including the breakwaters, buildings, machinery, and equipment. Furthermore, public and private facilities, such as ice plants, landing ports, markets, and homes of the fishing community, were destroyed (Central Bank of Sri Lanka, 2004). The tsunami resulted in approximately 35,400 fatalities and caused damage and losses totalling US\$1.3 billion (The World Bank, 2017).

In terms of data collection and management, efforts to record fisheries data began during British rule, but precise island-wide attempts to estimate total landings commenced after the country's independence. The establishment of the Department of Fisheries in 1940 marked a significant step in this direction. Initially, landings were quantified with the appointment of 12 fisheries inspectors (FIs) within 20 fisheries districts. By 1950, the number of FIs had increased to 24 (Harper and Zeller, 2011). Currently, 148 fisheries inspector divisions are spread across 15 fisheries districts (Ministry of Fisheries, 2023b).

From 1971 to 2022, Sri Lanka's marine capture fish production exhibited fluctuating trends in both the coastal and deep-sea/offshore sectors. Coastal fish catch exhibited a general upward trend from the early 1970s, peaking in early 2016. However, a noticeable decline was observed after 2016. This fluctuation in fish production can be attributed to various factors, such as changing environmental conditions, overfishing, regulatory measures, and economic influences, especially the increase in cost inputs. Notably, after 2005, there was a clear increasing trend up to 2016, which can be attributed to the development of infrastructure (Diffey, 2012) (UNOPS, 2013), donations of small boats from various donors following the damage caused by the tsunami (IFAD, 2017), and tariff concessions from EU regions (Daily Mirror, 2017; Export Development Board, 2018). These factors significantly contributed to the increase in marine fish catch in the country during this period (Figure 4).

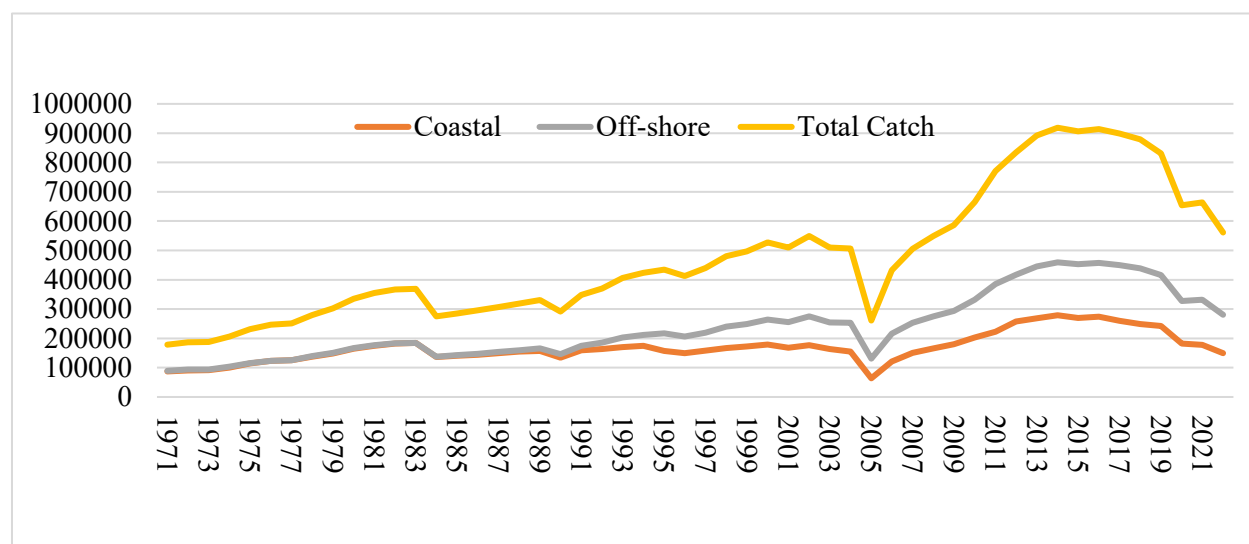


Figure 4. Sri Lankan capture fish production (Mt). Marine Sector 1971 - 2022

4.2 Biological resources of Sri Lankan coastal fisheries

A total of 610 coastal fish species have been reported in Sri Lanka. The more common species caught are *Sardinella sp.*, *Amyblygaster sp.*, *Rastrelliger sp.*, *Auxis thazard*, *Anchova*

commersoni, and *Hirundichthys coromandelensis*. Most of these species live near the water surface. These small pelagic fish account for approximately 40 percent of the coastal fish production. Species such as *Lethrinus sp.*, *Trichurus sp.*, *Caranx sp.*, species of skates and rays, *Cynoglossus sp.*, and *Jojnius and Tolithus sp.* live at the bottom of the coastal region (demersal) (Gunawardane et al., 2010).

Many species of fish live between the surface and the bottom, while some 90 species of oceanic pelagic varieties of fish have been reported to live in Sri Lankan offshore and deep-sea waters. Moreover, approximately 60 species of sharks and about 215 demersal fin and shellfish species have been reported in oceanic waters around Sri Lanka (Piyasena, 2006).

Table 4. Fish catch of major commercial group by Mt (1992-2022)

Major Commercial fish group	1990	1995	2000	2005	2010	2015	2020	2022
Seer	3,210	2,990	3,130	2,970	10,200	8,940	7,360	3,675
Trevally	8,040	8,910	10,450	5,950	16,740	34,050	13,610	9,810
Skipjack tuna	12,230	33,550	49,110	28,040	66,910	54,040	46,520	46,120
Yellowfin tuna	8,410	26,050	29,320	17,030	45,450	46,430	37,930	29,890
Other blood fish	9,190	17,640	27,890	16,560	48,930	46,930	39,680	29,510
All Bill fishes	***	***	***	***	***	26,040	14,950	8,120
Sharks/Sketes	14,830	22,120	28,790	6,430	13,290	5,860	10,290	6,105
Rock fish	6,780	10,450	14,910	10,570	20,150	34,960	18,060	12,470
Small fishes	67,920	60,610	76,250	24,870	77,210	136,790	96,470	103,585
Shrimps	4,470	8,000	7,540	4,680	17,640	20,090	12,770	7,280
Lobsters	630	950	1,150	240	890	630	155	160
Crabs	**	**	**	**	6,260	9,670	8,100	6,890
Other marine varieties	10,080	26,230	15,140	13,060	8,590	28,460	21,035	16,995
Total	145,790	217,500	263,680	130,400	332,260	452,890	326,930	280,610
*** Included in other blood fish group ** Included in others group								

The provided data offer insights into the trends and fluctuations within Sri Lanka's major commercial fish groups over three decades. Between 1990 and 2010, there was a noticeable surge in total fish production, rising from 145,790 tons to 332,260 tons. This period witnessed significant fluctuations in individual species' yields, exemplified by species such as Skipjack Tuna and small fishes, which experienced considerable increases in production, indicating a period of growth and perhaps favourable conditions for these species. However, from 2010 onwards, there has been a shift in this trend. While the total production remains relatively high, peaking at 452,890 tons in 2015, it has subsequently declined to 280,610 tons in 2022.

A Norwegian research vessel ("Dr. Fridtjoff Nansen") (Fernando, 1980) (Wijayarathne & Gudmundsson, 2001) which carried out acoustic surveys for fish resources around the coastal waters of Sri Lanka in 1978, 1979 and 1980 estimated the potential yield from the coastal fish

resources to be 250,000 tons per year. Of this potential yield, 80,000 tons were estimated to be available from demersal resources.

According to the 2018 Acoustic Ecosystem survey of Sri Lanka (National Aquatic Resources Research and Development Agency (NARA), 2018), the biomass of two pelagic groups, PEL1 (Clupeidae, Dussumieriidae, and Engraulidae) and PEL2 (Carangidae, Scombridae, Barracuda, and Hairtails) was calculated. Sri Lanka's PEL1 biomass totalled 21,000 tonnes, with over 18,000 tonnes concentrated on the Southwest coast, notably off Negombo, led by clupeoids. The PEL2 estimated biomass reached 101,000 tonnes, primarily abundant along the south and west coasts, dominated by various Carangid species. These figures represent relative indices that reflect the stock within the surveyed areas. However, indications suggest that pelagic fish are distributed beyond the surveyed coastal and offshore regions.

The survey estimated a total demersal biomass of 53,000 tonnes, excluding non-fish items such as jellyfish and debris. Across different regions, biomass varied: the north-west coast had the lowest estimate of 967 tonnes, while the south-east region, particularly off Batticaloa, recorded the highest at 8,173 tonnes. The southwest coast followed with 7,894 tonnes, and the south coast's Hambantota banks had 6,901 tonnes. The biomass on the central east coast was 4,003 tonnes, and the far northeast Pedro Bank was estimated to be 4,485 tonnes. Additionally, the total jellyfish biomass was 15,600 tonnes, with the majority, 14,200 tonnes, found off Batticaloa. Comparing surveys from 1978-1980 and 2018, there was a significant decline in demersal fish stocks in Sri Lanka.

Sri Lankan fisheries are characterised by their multi-gear and multi-species nature (Premawardana, 2010). A wide variety of fishing gear is employed to catch many species, particularly in coastal and brackish water fisheries, but not as much in offshore fisheries. Gillnets, longlines, and purse seines are the major types of fishing gear used in offshore fisheries (Sujeewa Ariyawansa et al., 2023). Fishermen in coastal waters target pelagic species such as tuna and tuna like species, mackerel, sardines, and anchovies, often using small-meshed gill nets with meshes less than 3 1/2 inches. Longlines are used to catch tuna and sharks, whereas bottom longlines are used for demersal species. Troll lines are deployed to catch tuna species. Additionally, coastal fishermen utilise various other fishing gear, such as ring nets, trammel nets, bottom set gillnets, beach seines, cast nets, and hand lines, suitable for both pelagic and demersal fish stocks. In brackish water fisheries within lagoons, gillnets, bottom-set nets, trammel nets, lagoon seines, drag nets, cast nets, scoop nets, and fish traps are commonly employed for fishing activities (Premawardana, 2010).

4.3 Socio -economic aspects of Sri Lankan marine fisheries

Sri Lankan marine fisheries are vital for both the economy and livelihoods. Contributing 1.1% to GDP (Ministry of Fisheries, 2023b), they sustain over 2.5 million people and support nearly a million fishers and their families (FAO, 2023). Beyond economics, fisheries are crucial for food security and the well-being of communities. As an island nation, Sri Lanka's social and economic fabric relies heavily on its marine resources.

The data on fishers in marine fisheries reveal a steady increase in fisher numbers until 2020, followed by stabilisation. However, marine production exhibited an increasing trend until 2016, after which it began to slightly decline (Ministry of Fisheries, 2023b). This discrepancy suggests potential overfishing or depletion of fish stocks in the country's marine capture

fisheries, emphasising the urgent need for sustainable fisheries management to safeguard marine resources and livelihoods.

The trend in the average marine capture fish production per year per fisher fluctuated over the provided period. Initially, there was an increase from 1.56 to 2.09, peaking around the midpoint. However, following this peak, there was a gradual decline in the average production, with some variability. The values fluctuated between 1.45 and 2.09, indicating a less stable trend in recent years (Figure 5).

Currently, Sri Lanka is recognised as a top exporter of high-quality fish and seafood. Sri Lanka primarily supplies yellowfin and bigeye tuna, crabs, prawns, and various mollusc species to

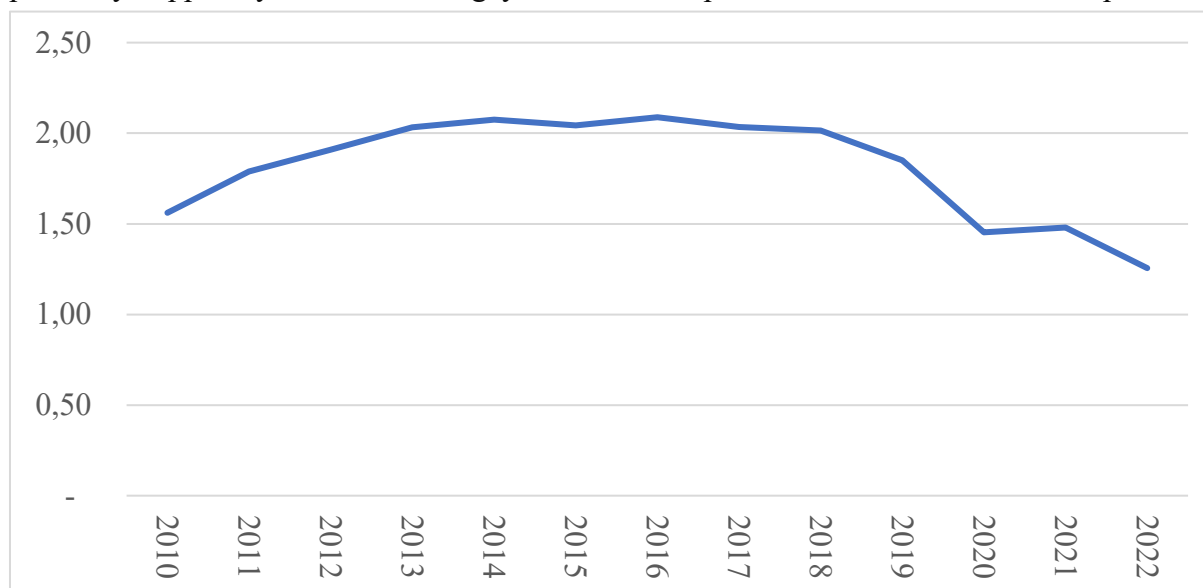


Figure 5. Marine fish production per fisher (Mt /Year)

global markets (EDB Sri Lanka, 2024). Over the past 12 years, Sri Lanka's fish export and import patterns have fluctuated. Between 2000 and 2022, fish exports generally increased, showcasing greater engagement in the global seafood market and boosting the economy. Despite fluctuations, the export value peaked at Rs. 97,243 million in 2022. Although there were deficits in the balance of fish trade, such as in 2015 and 2016, the trade balance notably improved post-2020 (Figure 6). This improvement is attributed to increased exports and regulated imports (Jayasinghe, 2022), reflecting government policies.

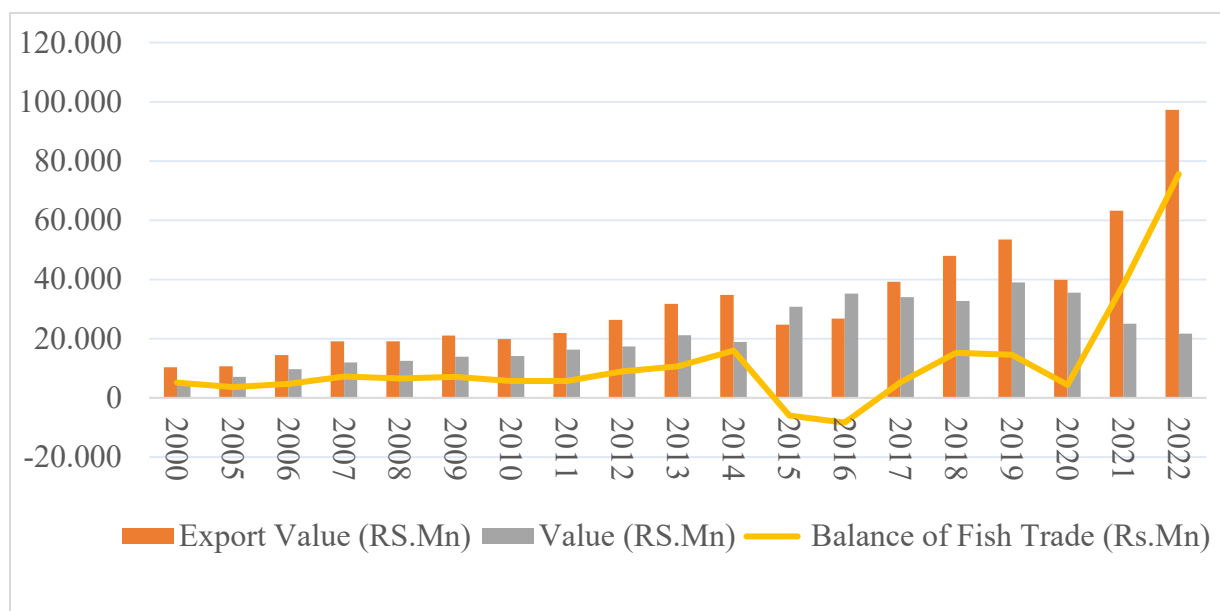


Figure 6. Trade balance of Sri Lankan fish export (2000-2022)

Sri Lanka is focusing on enhancing its local high-seas fishing fleet by introducing 24 to 45-meter class tuna long-line fishing vessels. Additionally, it aims to target unutilised or underutilised high-value species, such as squid and deep-sea lobster, within its Exclusive Economic Zone (EEZ). Furthermore, the country emphasises value addition to locally produced fish products intended for export (Ministry of Fisheries, Sri Lanka, 2024). Currently, most fish, shrimp, and other fishery products are exported only after basic processing (i.e. dressing). Expanding value-added processing could boost income from fishing operations and create more job opportunities in the industry.

4.4 Application of fisheries policy in Sri Lankan fisheries

The Ministry of Fisheries has outlined several policy objectives across various development plans spanning 1959 to 2025. The overarching goal has been to foster sustainable fishing practices and conserve coastal and aquatic environments, as reflected consistently throughout the plans. Additionally, there has been a concerted effort to increase fish production, enhance per-capita fish consumption to improve the population's nutritional status, and elevate the income and living standards of fishermen. These objectives align with the broader aim of generating employment opportunities in the fisheries sector. Furthermore, there is a focus on minimising post-harvest losses and ensuring the quality and safety of fish products to meet acceptable standards. Notably, there is a consistent emphasis on increasing foreign exchange earnings from fish products, highlighting the sector's economic significance. The latest policy (Ministry of Fisheries and Aquatic Resources Development, 2018) also underscores compliance with regional and international obligations and aims to provide improved opportunities for leisure, employment, and enterprise development. Overall, these objectives reflect a comprehensive approach aimed at achieving sustainable development and economic growth in the fisheries sector while safeguarding environmental and social interests of the fishers. The Policy objectives of recent fisheries policies are summarised in Table 5.

Table 5. Sri Lankan fisheries policies objectives (1990-2018)

Policy objectives	National Fisheries Development Plan 1990-1994	National Fisheries Development Plan 1995-2000	Six years fisheries Development Plan 1999 - 2004	Ten years development Policy Framework 2007-2018	The national fisheries and aquaculture policy 2018 – 2025
To conserve the coastal and aquatic environment. (fishing sustainably)	✓	✓	✓	✓	✓
To Increase fish production	✓	✓		✓	✓
Increase the per capita consumption of fish (increase nutritional status of the population)	✓	✓	✓	✓	✓
Increase the income and living standards of fishermen	✓	✓	✓	✓	✓
Generate employment opportunities.	✓	✓	✓	✓	
To minimise post-harvest losses and improve the quality and safety of fish products to acceptable standards	✓		✓	✓	✓
To increase foreign exchange earnings from fish products	✓	✓	✓	✓	✓
Compliance with regional and international obligations					✓
Improved opportunities for leisure, employment, and enterprises development					✓

The fisheries sector in Sri Lanka has been shaped by successive presidential administrations, each introducing policies to address the industry's various challenges and opportunities. From Chandrika Kumarathunga's tenure in the late 1990s to Gotabaya Rajapaksa's leadership in the late 2010s.

Chandrika Kumaratunga's presidency, spanning from 1994 to 1999 and 2000 to 2005 (two terms). Initially, the government prioritised sustainable resource exploitation, modernising fishing equipment, and promoting aquaculture. Efforts aimed to prevent unauthorised exploitation and diversifying exports. Subsequently, the focus remained on sustainable management, increasing fish production, and conserving coastal environments. However, marine fish production has fluctuated, suggesting implementation challenges. Consistent and effective policy implementation, along with adaptive management, is crucial for addressing the complex dynamics of the fisheries sector.

During Mahinda Rajapaksa's tenure from 2005 to 2015 (two terms), Sri Lanka saw a comprehensive fisheries policy aimed at addressing challenges and harnessing the sector's potential. The Mahinda Chintana manifesto (Ministry of Finance and Planning, 2005) (Ministry

of Finance and Planning, 2010) outlined solutions for weak management, post-harvest losses, and underutilised resources. The objectives included increasing production, promoting sustainability, and improving socioeconomic conditions. Policies focused on data, technology, and infrastructure. However, marine fish production fluctuated, sometimes declining, and did not align with the targets. Factors such as environmental variability, conflict, and post-tsunami recovery affected the outcomes. Implementation challenges highlight the need for robust governance, adaptive management, and sustained investment in infrastructure to ensure long-term sustainability and growth.

From 2015 to 2019, the New Democratic Front, led by Maithripala Sirisena, prioritised sustainable development and environmental conservation in Sri Lanka's fisheries policy (Sirisena, 2015). The Sustainable Sri Lanka 2030 Vision (Munasinghe, 2018) aims to promote eco-friendly fishing practices, expand marine protected areas, enhance fishery harbour infrastructure, and crack down on illegal fishing activities. Additionally, the policy aims to support small-scale fisherfolk by offering insurance coverage and boosting marine research. These measures reflect the dedication to balancing economic growth and environmental protection in the fisheries sector.

During the period of 2019-2020 under the Sri Lanka Podujana Peramuna led by Gotabaya Rajapaksa, the fisheries policy (Gotabaya Rajapaksha, 2019) aimed to modernise infrastructure, expand international fishing operations, and promote innovation in the industry. The policy emphasised scientific methods to increase fish populations, modernise fishery harbours, and introduce interest-free loan schemes for quality improvements in fish catch. Despite these initiatives, marine fish catch has declined, possibly indicating challenges in implementation or the need for further policy adjustments to align with production goals and sustainability targets.

4.5 Infrastructure facilities for fishing operations

The infrastructure supporting Sri Lanka's fisheries has significantly expanded and developed over the years. Major fishery harbours have steadily increased in number from 16 in 2000 to 23 in 2022, indicating a consistent effort to enhance port facilities and infrastructure. The data also reflect a fluctuating but overall increasing trend in the number of proposed fishery harbours for upgrading, suggesting ongoing modernisation initiatives (Ceylon Fishery Harbour Corporation, 2020). Proposed new fishery harbours have been identified mainly on the northeast coast of Sri Lanka, indicating potential expansion plans for multi-day fishing operations within the Exclusive Economic Zone (EEZ) and high seas. Both anchorages and minor fish landing centres have demonstrated steady growth, reflecting increased infrastructure along the coast to support coastal fishing activities (Figure 7). Additionally, there has been a consistent increase in the number of active ice plants and ice production capacity, highlighting efforts to improve fish preservation and quality. Currently, 104 ice plants operate island-wide, primarily along the western and southwestern coasts, with a capacity to produce 3,581 metric tons of ice per day (Ministry of Fisheries, 2023b). Overall, these developments underscore Sri Lanka's commitment to modernising its fisheries infrastructure to support industry growth and enhance productivity and efficiency in fishery operations.

The data on landing sites in Sri Lanka's 15 fisheries districts provide insights into the distribution and intensity of fishing activities across coastal and lagoon areas. The landing sites can be categorised as major (H), medium (M), and minor (L) based on the varying levels of boat landings (figure 7). Districts such as Batticaloa, Jaffna, and Trincomalee show numerous landing sites, indicating high levels of small-scale coastal fishing operations. In contrast, districts such as Colombo and Kilinochchi display lower activity levels and less intensive coastal fishing operations. These variations are crucial for fisheries management and resource allocation, ensuring that policies and interventions are based on the specific needs and challenges of each district.

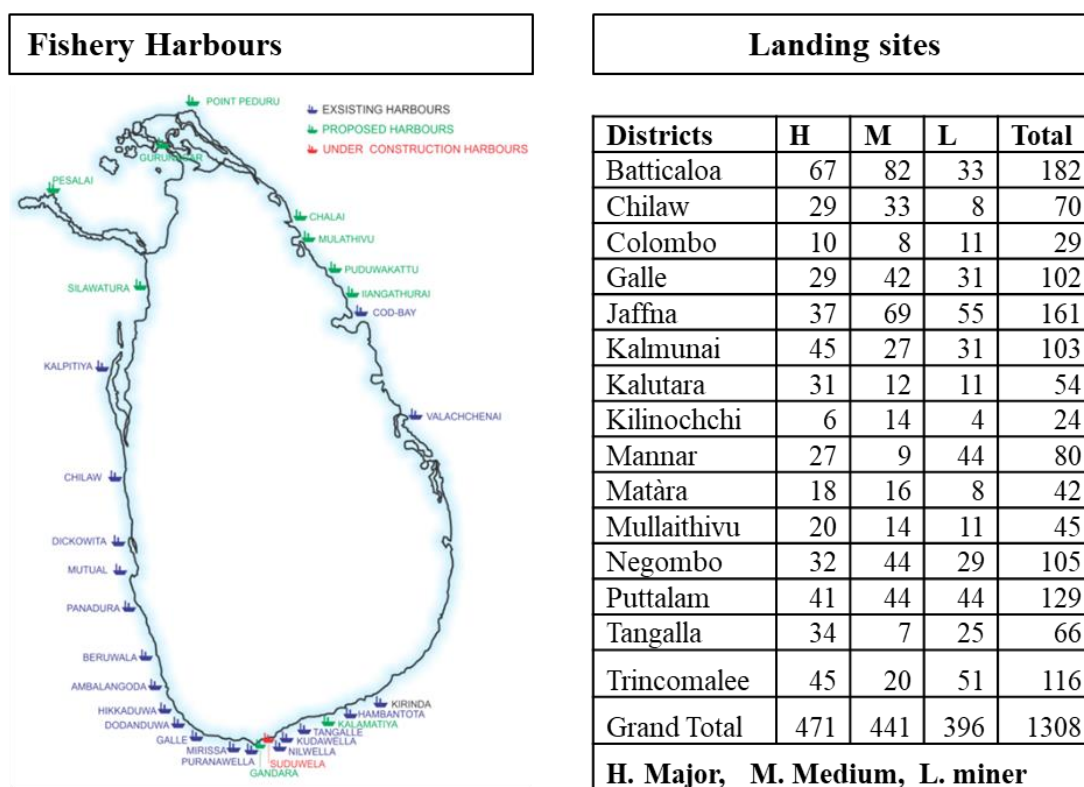


Figure 6: Sri Lankan fishery harbours and landing sites

4.6 Issues of Sri Lanka marine capture fisheries

Sri Lanka's fisheries sector plays a vital role in the country's economy, providing livelihoods to thousands of coastal communities and contributing significantly to food security and exports. However, the sector is confronted with challenges that threaten its sustainability and productivity (Ministry of Fisheries, 2023). From economic hardships and resource mismanagement to compliance issues and declining fish stocks, the fisheries sector faces complex and interconnected issues that require urgent attention from policymakers. In this analysis, the following are the key challenges facing Sri Lanka's fisheries.

1. **Economic Hardships:** Escalating fuel prices, labour costs, and input expenses diminish fishers' interest in the industry, affecting productivity and livelihoods (NewsWire, 2024) (Weerasooriya, 2023) (Ministry of Fisheries, 2023).

2. **Poor Resource Management:** Inadequate scientific management of coastal resources results in overexploitation and habitat destruction, necessitating improved conservation measures and law enforcement (Bandaranayake et al., 2024), (Ministry of Fisheries, 2023).
3. **Technical and Financial Constraints:** Limited resources hinder the adoption of modern research methods and awareness programs, exacerbating ecosystem degradation (Munasinghe, 2018) (Central Bank of Sri Lanka, 2004).
4. **Illegal Fishing:** Threatening illegal and harmful fishing practices undermine conservation efforts and threaten marine biodiversity (Ministry of Fisheries - Sri Lanka, 2023), (Ministry of Fisheries - Sri Lanka, 2023) (Ministry of Fisheries - Sri Lanka, 2023) ,
5. **Resource Depletion:** Overexploitation and resource destruction further jeopardise long-term sustainability and ecosystem health (Ministry of Fisheries, 2023).
6. **Post-Harvest Losses:** High post-harvest losses persist, necessitating strategies to enhance handling, storage, and processing infrastructure (Ministry of Fisheries, Sri Lanka, 2018).
7. **Poaching Incidents:** Incidents of Indian fishers poaching in Sri Lankan waters exacerbate resource management challenges and strain bilateral relations (Ministry of Fisheries, Sri Lanka, 2023), (Madanayaka & Madanayaka, 2015), (Jayasinghe et al., 2024).

5 DATA COLLECTION AND DATA ANALYSIS

This study focuses on the Kalmunai fishing district, located on the eastern coast of Sri Lanka. This district has a significant presence in fishing work, with 12 divisions allocated to fishing and a total of 14,280 households engaged in fishing. With 15,750 active fishers and a household population of 76,530, this area depends heavily on small boat fishing operations for their economy (The Gazette, 2014). The choice of Kalmunai's fishery district for small-scale fisheries research is highly significant because of various aspects. The fishing population of the district is broad, with many fishing households and active fishermen. This provides a valuable and diverse dataset for extensive analyses. Furthermore, Kalmunai's significant economic dependence on fishing operations highlights the importance of comprehending small-scale fishing operations for well-informed policymaking and the implementation of sustainable development projects or programs. In addition, the district is prominently involved in a range of fishing activities, mostly focused on coastal fishing operations that utilise various types of fishing vessels. Furthermore, a substantial quantity of data has been gathered, and the diversity of the data is crucial for comprehending coastal fishing in the country.

According to the data collected (Annex 2, Table 1), over 85% of the fishing equipment utilised in coastal fishing activities included small-meshed gill nets. The main objective of these nets is to capture small pelagic fish in the coastal waters. Among these species, *Amblygaster Sirm* is of considerable importance in coastal fisheries in terms of the quantity harvested (Annex 2, Table 1). On the other hand, *Amblygaster sirm* is a valuable species commonly found in small-scale coastal gillnet fishing in Sri Lanka (Haputhantri et al., 2007). The fishery is also socially

vital because it provides numerous livelihood opportunities in the coastal regions (Figure 8). Hence, this study specifically examines the *Amblygaster sirm* fishery, which involves the use of small-meshed gill nets for harvesting. Gill nets with approximately seven stretched mesh



Figure 7. Sri Lankan *Amblygaster sirm* fish landing; 1. Western coast, 2. Eastern Coast.

sizes ranging from 2.3 to 3.8 cm are used for the *Amblygaster Sirm* fishery in Sri Lanka (Karunasinghe & Wijeyaratne, 1991).

5.1 Fish Production of the Kalmunai fishery district

The fish production trends in the Kalmunai fisheries district have fluctuated over the years. Between 1990 and 2005, fish production was consistent; however, starting in 2010, there was a substantial increase in production. This increase reached its maximum in 2016, followed by a modest decline in the subsequent years. Both Kalmunai and the overall coastal fish production of the country witnessed a decline in output after 2016 (Figure 9).

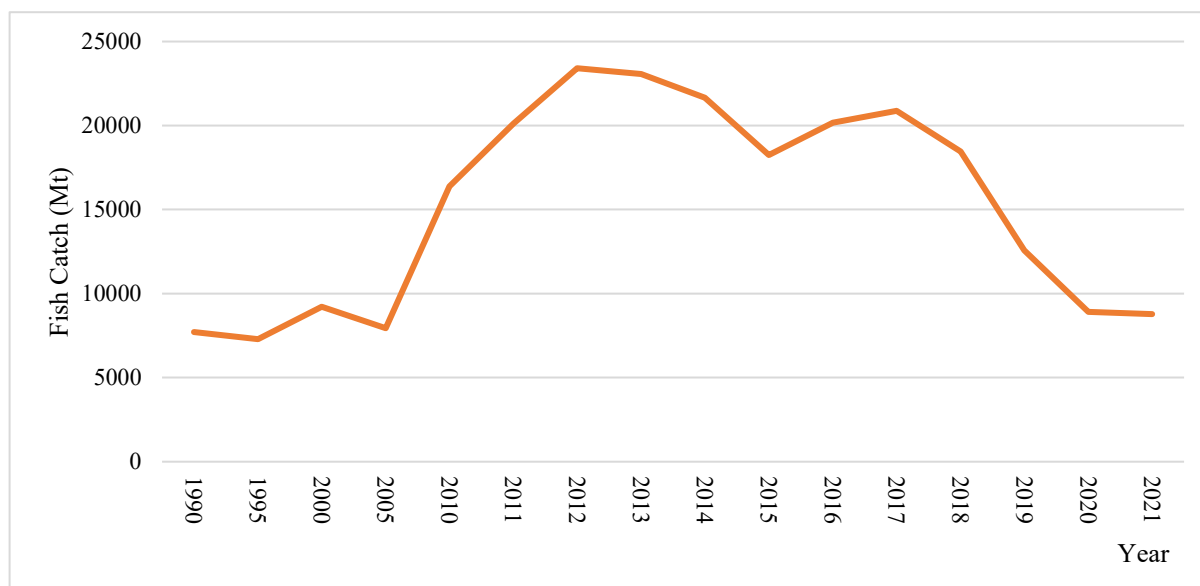


Figure 8: Kalmunai fishery districts' fish production trend 1990 – 2021.

The fish production data for the Kalmunai fisheries district in 2022 revealed a wide variety of catches, including significant quantities of different species. The main contributors to the catch are skipjack tuna (11%), yellowfin tuna (7%), and Shore Seine captures (49%). Commercial

fishing operations in the area focus on catching profitable pelagic species, including skipjack tuna and yellowfin tuna. This highlights the significance of the district in pelagic fisheries. Furthermore, the significant capture of Shore Seine species shows the district's importance in small-scale coastal fishing operations. Some important catches in the area also include trevally, various blood fishes, and rock fish, which demonstrate the wide range of fishing activities and the abundant marine resources in the region.

Figure 10 illustrates the variations in Kalmunai's fish productivity and the number of active fishers from 2011 to 2022. When examining the fish production of the districts over the past 10 years, a significant trend is the progressive decrease that has occurred since 2017. The fish

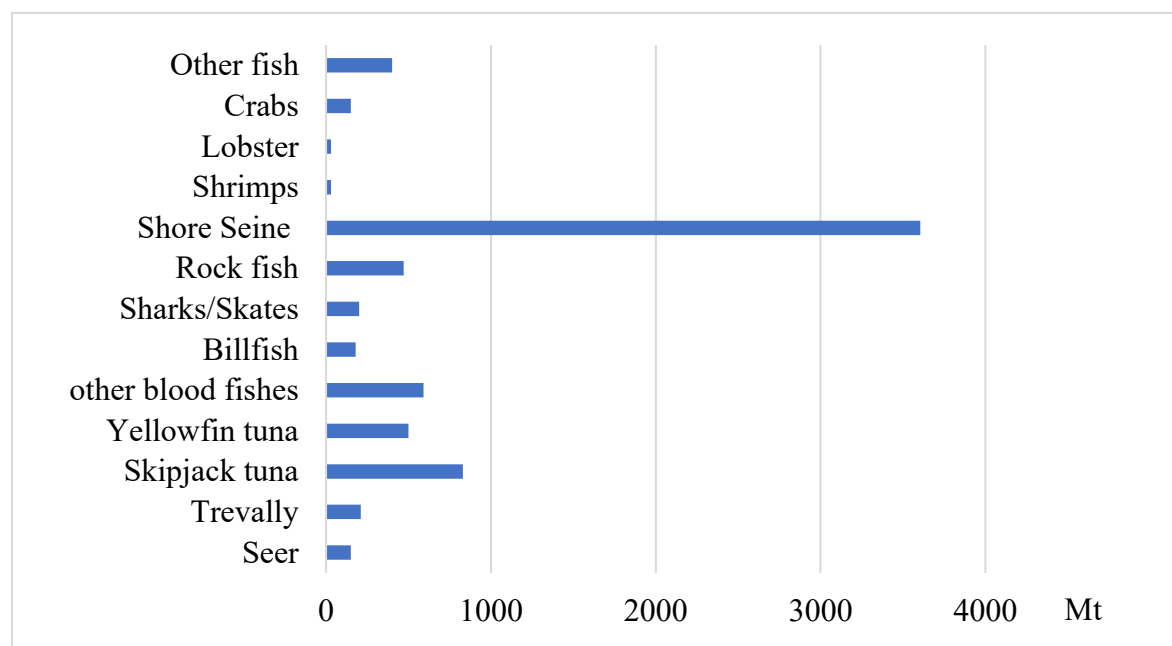


Figure 9. Fish catch composition (species) of Kalmunai fishery district - 2022

output in the district reached its highest point in 2012, with a total of 23,410 metric tons (MT). However, it recorded its lowest production in 2022, with only 7,345 MT in the past 12 years. Simultaneously, the number of engaged fishermen was roughly constant until 2016 and then experienced a minor decrease. Nevertheless, the production per fisherman exhibited a downward trajectory starting in 2017 (Table 6). The decline in fish populations may be attributed to a range of issues, including overfishing, insufficient management strategies, environmental shifts, and economic difficulties (United Nations Sri Lanka, 2023); (UNDP, 2023); (De Silva et al., 2023). Therefore, further research is necessary to ensure the implementation of sustainable fisheries management.

Table 6. Fish production (Mt) and active fishers in Kalmunai Fishery District 2011-2022.

Year	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022
Kalmunai fish production (Mt)	20,120	23,410	23,070	21,660	18,240	20,180	20,880	18,450	12,580	8,910	8,780	7,345
Active Fishers Kalmunai	26,040	26,460	25,960	26,190	20,400	22,290	16,380	16,670	15,970	16,090	15,820	15,750
Annual production per fisher (Mt)	0.77	0.88	0.89	0.83	0.89	0.91	1.27	1.11	0.79	0.55	0.55	0.47

5.2 Results of Schaefer modal data analysis

The regression analysis performed on the relationship between catch per unit effort and fishing effort for *Amblygaster sirm* fishing operations in the Kalmunai fisheries district produced valuable findings. The model exhibited a robust positive correlation between the catch per unit effort and fishing effort, as evidenced by the substantial R-squared value. The coefficient of determination (R Square) of 0.5169 indicates that approximately 51.7% of the variance in capture per unit effort can be accounted for by the change in fishing effort (Table 7).

Table 7. Regression result output

Multiple R	0.718933287
R Square	0.51686507
Adjusted R Square	0.492708324
Standard Error	0.228332633
Observations	22

The table below indicates that the intercept coefficient of 1.450108841 represents the projected catch per unit effort when the fishing effort (Total Effort) is zero. The data suggest that even in the absence of fishing activity, there is still an expected capture rate of approximately 1.450108841 per unit of effort. This signifies that there are more elements that impact capture, apart from fishing effort. The coefficient for Total Effort is $-8.56044E-06$ (0.0000075), which is the rate of change in catch per unit effort for each unit (hour) increase in fishing effort. The presence of a negative sign indicates that there is an inverse relationship between fishing effort and catch per unit effort, meaning that as the fishing effort increases, the catch per unit effort decreases. This indicates that as fishing effort increases, the resulting returns or benefits would gradually decrease. The t-statistic of -4.6256 and the p-value of 0.00016 suggest that the coefficient for Tot Effort is statistically significant.

Table 8. Regression results output.

variable	Coefficients	Standard Error	t Stat	P-value
Intercept	1.450108841	0.10407	13.9345	9.3E-12
Tot Effort	-8E-06x	1.6E-06	-4.6256	0.00016

The ANOVA table shows that the regression model was highly statistically significant ($p < 0.00016$) (Table 9). There is a clear correlation between the amount of fishing activity and the

quantity of fish caught per unit of effort in the coastal fisheries of the Kalmunai fishery district. Consequently, fluctuations in fishing activity are responsible for a substantial proportion of the fluctuations observed in the catch per unit effort. The F-statistic (21.39) provides additional evidence of the model's relevance, suggesting that the explained variability is significantly higher than the variability expected by chance.

Table 9: ANOVA regression results.

ANOVA	<i>df</i>	<i>SS</i>	<i>MS</i>	<i>F</i>	<i>Significance F</i>
Regression	1	1.11551	1.11551	21.3963	0.000163326
Residual	20	1.04272	0.05214		
Total	21	2.15823			

The figure below is a scatterplot that shows the relationship between the standardised Catch Per Unit Effort (CPUE) and fishing effort (hours) of the country. This visualisation provides significant insights into the correlations between these variables. Most of the data falls between the range of 40000 and 80000 fishing hours and relative CPUE values between 0.80 and 1.20, implying that when fishing effort grows within this range, there is a tendency for CPUE values to move towards a central value. Significantly, there are five data points that show a high CPUE with lower effort below approximately 50000 fishing hours. This indicates that effective fishing operations or a higher quantity of fish can be achieved with less effort. However, only two data points exhibited significantly divergent average values. In conclusion, the scatterplot revealed a consistent pattern of decreasing CPUE as fishing effort increased (Figure 11).

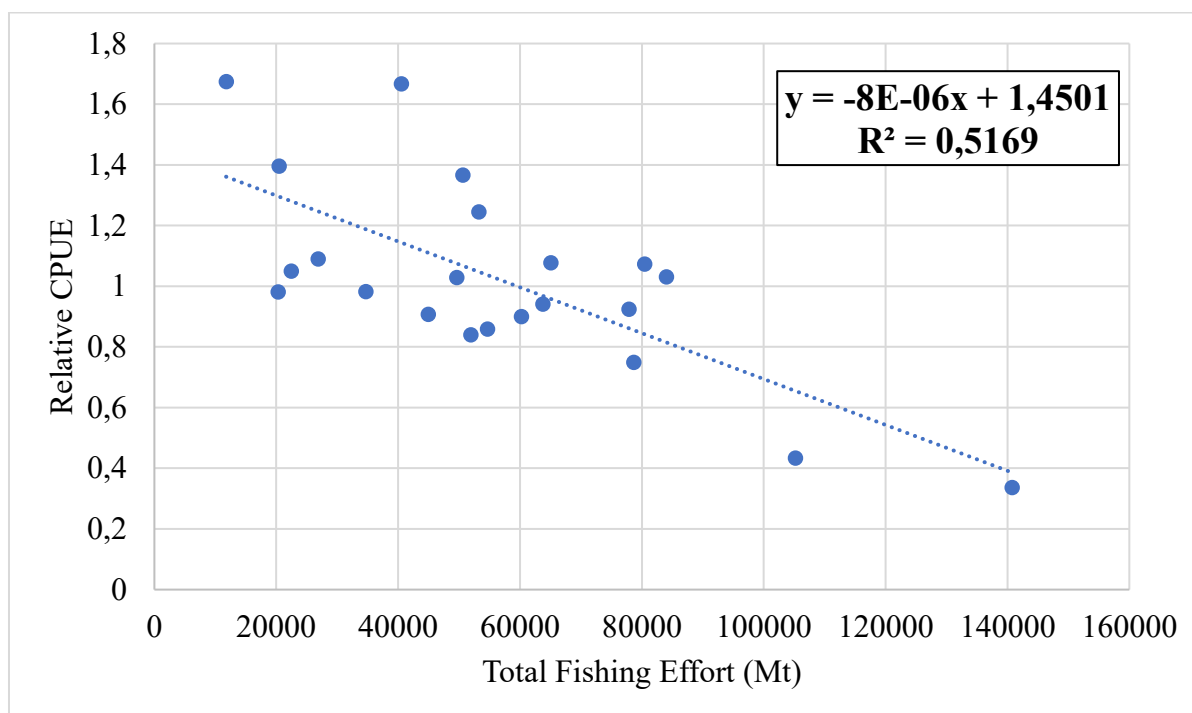


Figure 10. Scatterplot analysis of CPUE vs. fishing effort.

The Schaefer sustainable fishing curve is a graphical representation of the correlation between fishing effort (level of fishing activity) and actual catch in a fishery. The illustration displays the principle of MSY, which refers to the highest quantity of fish that can be harvested without causing the long-term depletion of the fish population. The graph demonstrates that when the fishing effort escalates, the catch also rises until a specific threshold (MSY) is reached. Beyond

this point, further intensification of fishing effort leads to the depletion of resources. The curve reaches its highest point at a certain location known as the MSY, where the number of fish caught is maximised without causing harm to the fish population. Hence, the Schaefer curve aids in determining the most advantageous degree of fishing effort to achieve a harmonious balance between fishing activity, ecological sustainability, and ongoing fisheries yield.

According to the results of the analysis, the MSY was recorded as 65712 Mt and FMSY (Effort) was recorded as 90631 h (a detailed analysis is provided in Annex 1). In Figure 12, the actual yield values represent the observed catch levels from the fishery over time. According to the results of the analysis, the MSY was recorded as 65712 Mt and FMSY (Effort) was recorded as 90631 h (a detailed analysis can be found in Annex 1). In Figure 12 the actual yield values represent the observed catch levels from the fishery over time. It has been plotted against the sustainable yield curve; actual yields below the curve indicate sustainable harvesting practices, while values beyond the MSY point indicate overfishing, potentially leading to stock depletion (Ritchie & Roser, 2023). According to the results, the sum of actual yield values falling below the MSY and FMSY (Rate of Fishing mortality consistent with achieving MSY) points on the curve imply that the fishery is operating at or below sustainable levels.

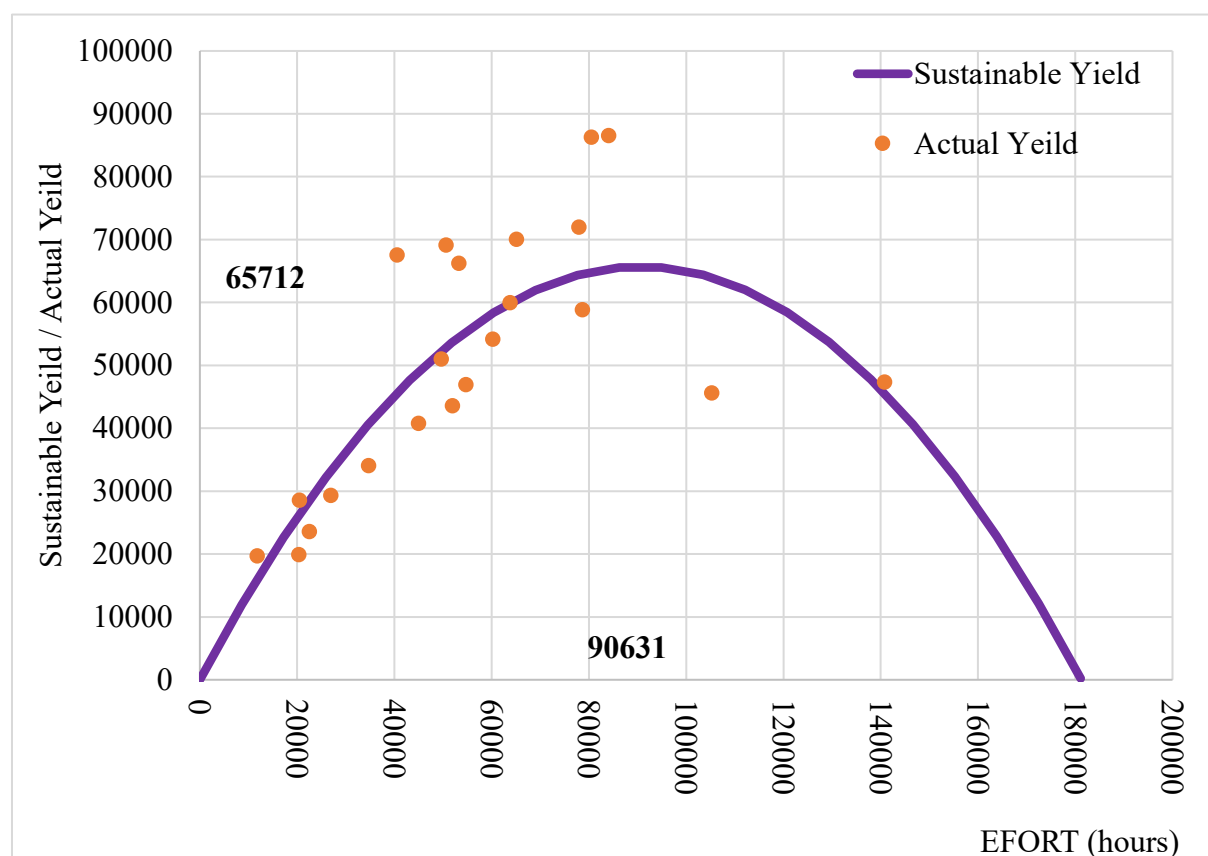


Figure 11. Sustainable yield and actual fish production.

In an open-access fishing system, where entry is unrestricted, new fishing vessels continually join the fishery until all potential profits are depleted. As more fishing attempts are made, the total cost of fishing increases. Further efforts lead to diminishing returns as overfishing depletes fish stocks, causing revenue to decline. In the Schaefer production function, revenue increases with fishing effort until it peaks at the maximum sustainable yield. Further effort leads to

diminishing returns as overfishing depletes fish stocks, causing revenue to decline. As more fishing attempts are made, the total cost of fishing increases steadily.

According to the results, as shown in Figure 13, the intersection of the Total Revenue (TR) and Total Cost (TC) curves, where TR equals TC, signifies the open-access equilibrium at 62381 hours of fishing effort per year, representing the zero-profit level. However, the point of highest profit, where Marginal Revenue (MR) equals Marginal Cost (MC), is indicated by the greatest gap between TR and TC, occurring at 31190 hours of fishing effort per year (as summarised in Table 10). This point delineates the optimal balance between revenue and cost, maximising fishery profitability.

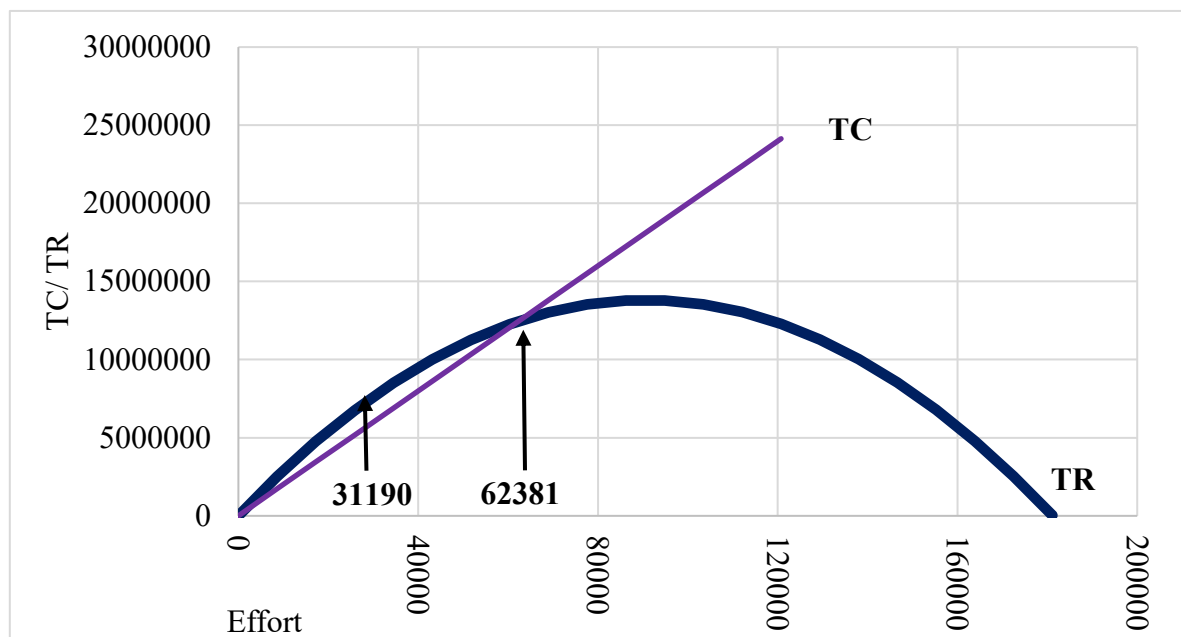


Figure 12: MEY and OAE estimation.

Table 10: Bio-economic reference points.

Indicator	Value
A	1.4501
B	0.000008
FMSY	90631.25
MSY	65712.19
EMEY	31,190.35
OAE	62380.70

5.3 Impact of Input Price Increase

The Sri Lankan coastal fishery has been significantly impacted by the COVID-19 pandemic since 2020 (Amaralal et al., 2023a), resulting in shortages of fuel and substantial increases in fuel prices and other inputs such as fishing gear. These new conditions have had both positive and negative effects on coastal fisheries, particularly impacting resources, livelihoods, and the economy. Figure 14 explains the increase in the fuel prices (kerosene) of the country.

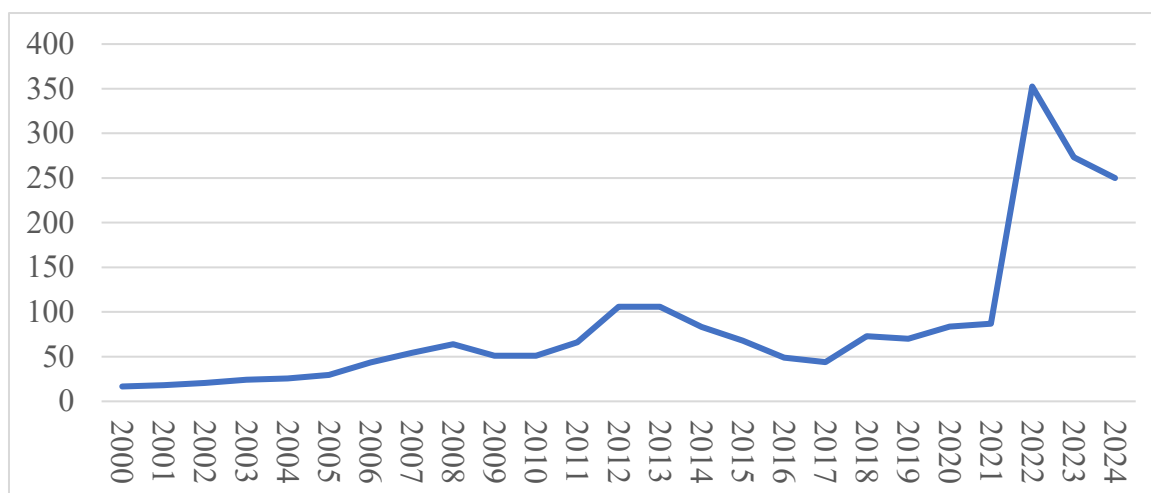


Figure 13. Trend of fuel (kerosene) price increase in Sri Lanka 2000 – 2024.

This chart illustrates the trend in kerosene fuel prices in Sri Lanka. Between 2000 and 2008, prices rose gradually, with a slight drop in 2009 and 2010. Subsequently, there was an upward trend from 2010 to 2013. However, prices decreased notably from 2013 to 2017. In 2021, there was a dramatic surge to 352.5 SL Rs, followed by a considerable drop in 2023 and a further reduction in 2024 to SL Rs 250.

Table 11. Economic reference point changes after fuel price increases.

Indicator	Present Condition	Indicator	50% Up	Indicator	100% UP
EMEY	31,190.35	EMEY	16,330.13	EMEY	1,469.90
OAE	62380.7017	OAE	32660.25214	OAE	2939.8026

The above table and subsequent graph reveal the intense influence of fishing costs, particularly fuel expenses, on fishery resources. The price of fuel, a significant operational cost in fishing, has increased by over 100% in recent years. This considerable increase implies a diminishing open-access equilibrium (OAE), resulting in catches that fall below the MSY reference points. This can be observed under the 100% price increase scenario. Consequently, MEY has also declined. This condition is important for the conservation and sustainable management of fisheries.

The diagram in Figure 15 illustrates the impact of price increases on the TC curves. TC illustrates the current state of fisheries, whereas TC (50% fuel up) and TC (100% fuel up) progressively illustrate the effects of input price increases of 50% and 100%, respectively. This shift allows the relocation of the open-access equilibrium towards the left side.

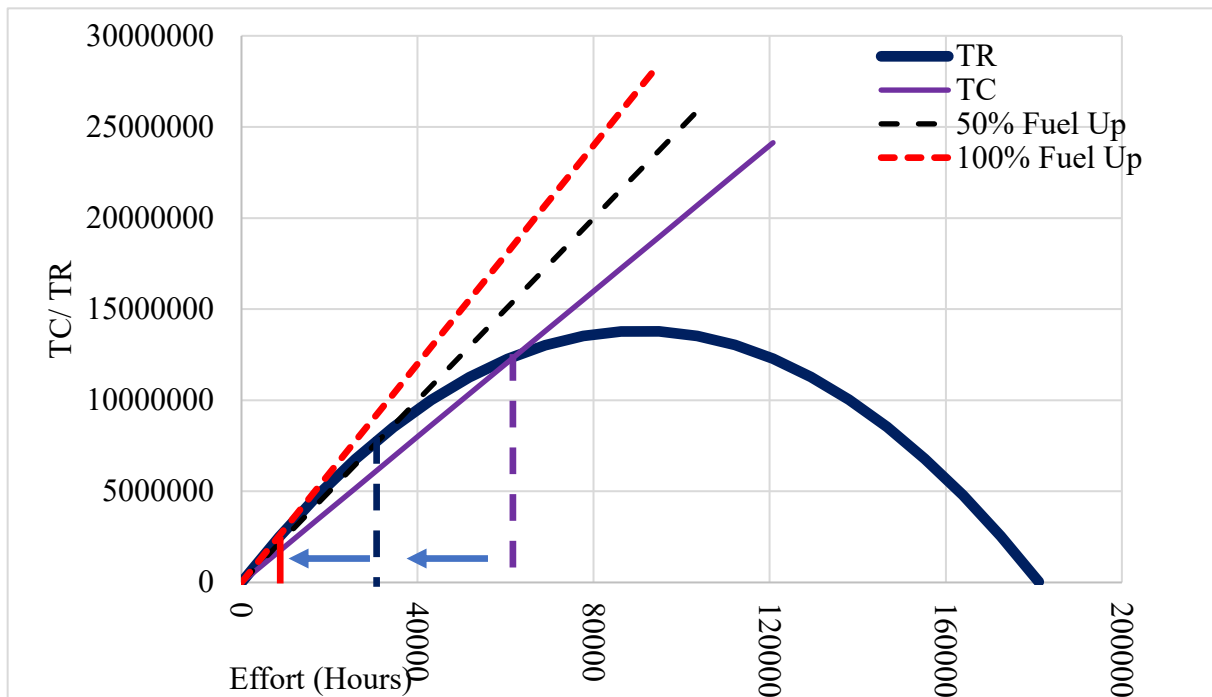


Figure 14. Changes of the cost curve as a result of increase of the fuel prices.

However, as a result of diminishing revenues, some fishermen are turning to illegal fishing techniques to increase their catches. These illegal methods, predominantly carried out through the use of light attraction, have caused enormous damage to both natural resources and fishermen who adhere to legal ways.

6 DISCUSSION

6.1 Catch Per Unit Effort

The WEPT technique and surplus production model are methodologies employed to comprehensively understand and regulate fish populations. The WEPT examines multiple variables, such as fish age, habitat, and interactions with other species. The surplus production model is used to estimate the maximum amount of fish that can be harvested without harming the population. These strategies assist fisheries managers in making well-informed decisions to maintain fish population health and ensure sustainable fishing practices. This study is based on a surplus production model. The surplus production model supports the utilisation of both Schaefer and Fox models. This study was based on the Schaefer model. Estimating CPUE is essential in both models, and both models anticipate that CPUE will decrease as the effort increases. The results of the analysis clearly show a negative correlation between CPUE and effort (Per Sparre & Venema, 1998).

Although, there is no exact ideal R-squared value for the association between CPUE and fishing effort in fisheries. However, a higher R-squared value is generally considered acceptable (Mohsin et al., 2017), (Ozili, 2022). The R-squared result of the regression analysis exceeded 0.6, indicating that the model was acceptable. The P value of the model confirmed this. Catch per unit effort (CPUE) is a helpful indicator in fishery management that provides information on the relative abundance of fish populations (Haggarty & King, 2006). CPUE patterns can serve as indicators of fluctuations in fish population abundance, offering valuable insights into fishery evaluations. Furthermore, CPUE can be used to evaluate the productivity of fishing activities and the overall effectiveness of fisheries (Tikadar et al., 2021). Nevertheless, it is crucial to acknowledge the constraints of CPUE data. The raw CPUE may not consistently provide an accurate measure of fish abundance because of multiple factors that can affect the rate at which fish are caught. To tackle this issue, CPUE data are frequently standardised to eliminate any biases (Maunder et al., 2006), (Maunder & Punt, 2004).

This study analysed the CPUE of three different categories of fishing vessels involved in coastal fishing activities in the Kalmunai fisheries district, with a specific focus on the *Amblygaster sirm* fishery. To enhance the precision of the CPUE, the relative CPUE was computed in accordance with the technical requirements outlined by the Food and Agriculture Organization (FAO), (Per Sparre & Venema, 1998). The objective of this approach was to minimise biases in the CPUE estimate, thereby improving the reliability of the results (Maunder & Punt, 2004).

The examination of CPUE values for the *Amblygaster sirm* fishery carried out by three fishing vessels between 2000 and 2020 provides significant understanding of the fishery's relative abundance, fishing effectiveness, and overall success. By analysing the specific CPUE values for each type of boat, it becomes evident that there are fluctuations over time, suggesting that the catch rates of *Amblygaster sirm* vary over time. Although certain years, such as 2005 and 2010, have greater CPUE values than others. This indicates possible periods of increased abundance or fishing success. However, no consistent pattern was identified over the entire dataset. This unpredictability may be attributed to inherent fluctuations in fish populations, alterations in fishing activity, or other influencing environmental factors.

Based on the relative CPUE figures calculated for each type of boat, a consistent pattern of variability was observed. The relative CPUE values provide a consistent metric for measuring catch rates between boat types, regardless of the fishing effort or capacity of the boats. Notably,

there were deviations from this average. For instance, specific years, such as 2001 and 2018, demonstrated higher relative CPUE values, indicating catch rates that surpassed the average, whereas others, such as 2007 and 2015, exhibited lower values. This variety highlights the ever-changing nature of the fishery and indicates that fishing success may vary over time.

These findings suggest that although fishing effectiveness and the presence of *Amblygaster sirm* may vary, these changes are not consistent or predictable over time. The observed trends are influenced by factors such as environmental variability, alterations in fish behaviour, and the efficacy of fishing strategies (Maunder et al., 2006), (Baptista et al., 2022), (Monaghan et al., 2024). Furthermore, the inconsistent performance of fisheries, as indicated by fluctuations in CPUE values, emphasises the necessity for adaptive management strategies that can effectively address evolving conditions and uncertainties within the fishing ecosystem. Additional examinations, such as trend analysis and correlation studies, could offer a more profound understanding of the factors that cause fluctuations in CPUE (Dennard et al., 2010) and help develop management techniques to support the sustainable harvesting of *Amblygaster sirm* populations.

6.2 Biological reference points

TRPs and LRPs are divided into fishing mortality-based (F-based) and biomass-based (B-based) categories (Nickson, 2016). Biological reference points are vital for sustainable marine fish management. They set safe harvesting levels, often based on minimum biomass or maximum fishing mortality (Collie and Gislason, 2011). The reference points use historical data and fish species' traits, either directly or as proxies, depending on data quality (Gabriel & Mace, 1999), (Nickson, 2016). In fisheries management, there are three main types of reference points namely limit (LRPs), target (TRPs), and trigger reference points. TRPs and LRPs are divided into fishing mortality-based (F-based) and biomass-based (B-based) categories (Nickson, 2016). Two related reference points, FMSY and MSY, are widely used as biological reference points (Gopalakrishnan, 2017).

This study aimed to estimate the fishing mortality rate at maximum sustainable yield (FMSY) and MSY for the *Amblygaster sirm* fishery in the Kalmunai fisheries district of Sri Lanka. However, there were a few years in which harvests exceeded the MSY threshold. These findings suggest that the fishery in the Kalmunai fisheries district of Sri Lanka generally remained within the sustainable fish harvest level in the majority of years. However, there were few years during which harvests exceeded the MSY threshold. The chart in Figure 16 clearly displays the actual fish catch level in each year compared to the sustainable fish catch.

Specifically, the catch rates of coastal pelagic species are greatly influenced by seasonal factors, such as the southwest monsoon and inter-annual fluctuations, which are closely linked to chlorophyll concentration (Bandaranayake et al., 2024). Studies on coastal fisheries have

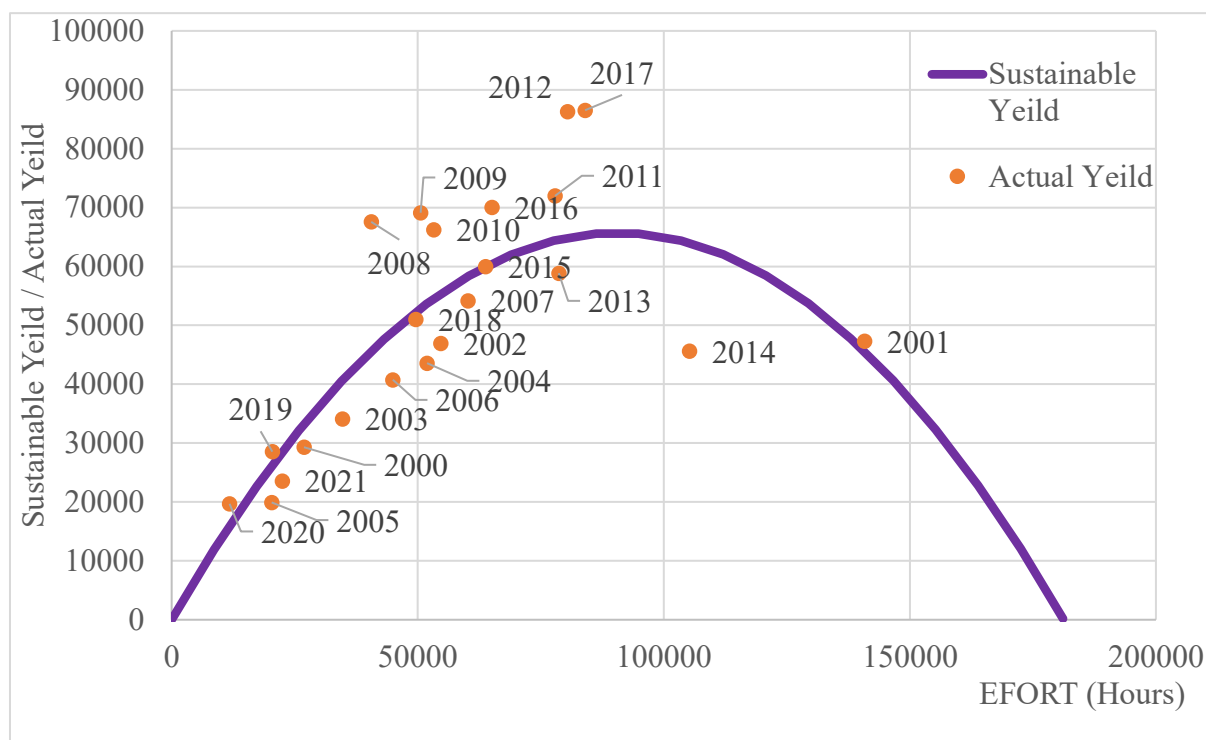


Figure 15: Sustainable yield and Actual fish catch.

revealed high variability in catch rates without a discernible trend (Samarayanke, 2003). Based on the fish harvest data, there has been a substantial decrease in fishing activity and CPUE in recent years. In the years 2020, 2021, and 2019, there has been a substantial decrease in fishing attempts and the amount of fish caught. This situation is crucial for the fishery. Studies on coastal fisheries reveal a high variability in catch rates without a discernible trend (Samarayanke, 2003). Specifically, catch rates of coastal pelagic species are greatly influenced by seasonal factors such as the southwest monsoon and inter-annual fluctuations, which are closely linked to Chlorophyll concentration (Bandaranayake et al., 2024).

These factors have led to shorter fishing trips and an increase in illegal fishing operations, particularly along the eastern coast of Sri Lanka (Ministry of Fisheries, 2023a). These factors have led to shorter fishing trips and an increase in illegal fishing operations, particularly along the eastern coast of Sri Lanka (Ministry of Fisheries, Sri Lanka, 2023a). Additionally, the rising prices of fishing inputs further reduced fishing activity. In 2020, fishing effort noticeably decreased due to fuel shortages, attributed to various factors, including the COVID-19 pandemic (Amaralal et al., 2023b). Additionally, rising prices of fishing inputs further reduced fishing activity. These factors led to shorter fishing trips and an increase in illegal fishing operations, particularly along the eastern coast of Sri Lanka (Ministry of Fisheries, 2023a).

To estimate the reference points, this study applied the Schaefer surplus production model which is a commonly used approach to describe the dynamics of fisheries and estimate quantities such as MSY and MEY. However, this model has several limitations when applied to real-world fisheries scenarios.

Assuming stable environmental conditions, overlooks age structure within a population and presumes that CPUE directly reflects stock abundance are some limitations of the model

(Haddon, 2023), (Kuriakose & Kizhakudan, 2017). Therefore, these limitations in the model can sometimes result in deviations from real conditions, affecting the accuracy of the results.

6.3 Economic reference point

Hence, this study also considered economic reference points. Reference points serve as benchmarks for comparing the current status of the fishery management system (Harvest Strategies, 2024). Most fisheries management systems worldwide regularly consider economic outcomes (Pascoe et al., 2022). Recently, there has been a discussion over the comparison between MEY and MSY. The primary objective of MEY is to optimise financial gains rather than the overall quantity of fish caught, and it typically falls below the level of MSY (Pascoe et al., 2022). Hence, the study has also taken into account economic reference points.

Owing to insufficient data on labour costs in coastal fisheries, this study focused primarily on other operational expenses, particularly fuel costs for fishing operations. Hence, the MEY values need to be adjusted downward to account for labour costs.

Several factors may contribute to this, including economic (Macusi et al., 2017), social, management, regulatory, and data collection-related issues (Rahim & Hastuti, 2023), (Chakravorty & Fisher, 2003); (Pascoe et al., 2024). According to the results, it was found that the fishery did not reach the open-access equilibrium level in many years, despite the fishery is being open access.

During economic recessions or changes in market conditions, such as shifts in fish prices or increasing operational costs, the fishing sector may encounter reduced profitability. As a result, fishermen may choose to reduce the scale of their fishing activities to minimize prospective financial losses. Moreover, rising operational expenditures, such as fuel or equipment charges, may additionally motivate fishermen to reduce their fishing activities to sustain their profit margins.

It is evident that there is a noticeable disparity between the wholesale and retail prices within the fish market (NARA, 2022), primarily due to the significant influence of intermediaries. Consequently, fishermen often receive lower prices for their catch, particularly on days with higher fish yields. Many fishermen have established permanent relationships with fish buyers, often because of obtaining loans from them for fishing equipment and personal needs. Consequently, the buyers tend to undervalue the fish, impacting fishing operations negatively, particularly by reducing fishing effort due to increased uncertainty about profits. Additionally, the absence of stable prices for fishing gear in local markets, coupled with a lack of regulation and guidelines, results in inflated prices at fishing gear retail points, thereby increasing the overall cost of fishing operations. These factors collectively contribute to the underperformance of fisheries in the area, highlighting the necessity for a comprehensive study to identify appropriate policy solutions for increasing or decreasing fishing effort.

After the study period (post-2020), the operational costs of fisheries have markedly increased, significantly impacting fishing operations. This situation is illustrated graphically under two scenarios: a 50% increase and a 100% increase in fuel costs. Both coastal and deep-sea fishing costs have more than doubled in the present considered to the fuel prices, resulting in a notable reduction in fishing operations, particularly in deep-sea fishing across the country.

The high operation costs have led to an increase in illegal fishing operations in the area, primarily aimed at boosting fish catch and reducing operation costs. However, this has had adverse effects on legal fishers, resulting in reduced fish harvests (Sosai, 2015). Moreover, illegal fishing operations are not accounted for as fishing effort, leading to an underestimation of fish harvests in the area (Ministry of Fisheries, 2023a). These issues can be categorized as management challenges in coastal fishing operations in the country.

Poor sample data collection also influences the recording of reduced fishing effort in the area. While deep-sea fishers maintain fish logbooks for record-keeping, coastal fishers do not practice this. Additionally, there is no proper fish catch measurement system in coastal fisheries, and sometimes fish are sold in bulk without being weighed. As a result, it is challenging to measure the exact quantity of fish harvested. Data collectors must rely on information provided by fishers, leading to potential issues with the data collection system (Gunawardane et al., 2010). These issues may indirectly contribute to the underreporting of fishing effort in the fishery.

7 CONCLUSION

The coastal fishery sector plays a key role in the socio-economy of Sri Lanka, contributing significantly to livelihoods and food security across the country. Among the various fisheries, the *Amblygaster sirm* fishery stands out as one of the most important, spanning all fisheries districts in the country. Coastal fish productivity began dropping in 2016 because of many reasons including increasing operation cost. This creates challenges to livelihoods and food security in the country.

The collapse of the coastal fisheries would have serious repercussions, especially given the enormous contribution of *Amblygaster sirm* to coastal fish production. This trend is visible in available data and previous studies on the *Amblygaster sirm* fishery in Sri Lanka.

The primary problem is the absence of regulations, guidelines, or management strategies to govern the inputs or outputs of the fishery, resulting in unpredictable variations in fish production over time. The lack of efficient management techniques worsens the difficulties encountered by the sector.

The analysis, using bioeconomic reference points, indicates that the fish production of *Amblygaster sirm* fluctuates both below and above the MSY over the time. The latest fishing effort data are below the MSY, showing the use of sustainable fishing practices. Multiple factors contribute to this situation, including the impact of fishing expenditures. The substantial rise in operational expenses of the fisheries after 2021, caused by the consequences of the COVID-19 epidemic and fuel shortages, has had an adverse influence on fishing operations. This increase in fishing costs has not only reduced profitability but has also resulted in an increase in IUU fishing operations as fishers look for ways to cover losses.

The prevalence of IUU fishing in some places, particularly along the eastern coast, causes the problem by underreporting fish catches, which impedes accurate data collecting and fisheries management activities. This highlights the urgent need for strong effective management methods to address the issues faced by the *Amblygaster sirm* fishery and ensure its long-term survival.

Finally, authorities, stakeholders, and the fishing community must work together to address the complex issues that Sri Lanka's coastal fishery sector faces. Implementing sustainable management techniques, improving monitoring and enforcement procedures, and fostering community engagement are critical steps toward preserving the survival of the *Amblygaster sirm* fishery and safeguarding the socioeconomic well-being of coastal communities.

7.1 Recommendations

- The implementation of an output-controlling system (TAC system) in the *Amblygaster sirm* fishery is crucial to manage the highly fluctuating fish harvest and ensure sustainable fishing practices in the country.
- The implementation of a TAC system presents certain challenges within the framework of Sri Lankan fisheries. Factors such as the multitude of fish landing sites, a substantial coastal fishing population, and the absence of adequate facilities for weighing fish harvests must be carefully accounted for. Therefore, a methodical, step-by-step approach, involving extensive discussions with fisher cooperatives, is necessary to address these complexities effectively.
- Enhance the data collection mechanism and strengthen monitoring and enforcement procedures in coastal fishing operations to facilitate more effective policy recommendations for the fishery.
- Engage fishers, local communities, scientists, policymakers, and other stakeholders in collaborative research initiatives to promote ecosystem-based management.

ACKNOWLEDGEMENTS

I extend my sincere gratitude to the administration of GRÓ Fisheries Training for their efforts in arranging and conducting the training. Special gratitude is extended to the individuals and organisations who gave financial assistance, mostly for developing nations to improve their fisheries sectors, thereby greatly contributing to the expansion of scientific knowledge in this area.

I am deeply indebted to Professor M.J.S. Wijeyaratne, Chairman of the NARA, for appointing me to participate in the training programme, which has been instrumental in shaping my understanding and skills in fisheries management.

I would like to express my appreciation to all the staff members of Akureyri University who provided invaluable support throughout the programme, with special mention to Hreiðar Þór Valtýsson and Magnús Víðisson for their guidance and assistance.

Furthermore, I am grateful to my supervisors, Dadi Mar Kristofersson and Thanh Viet Nguyen, for their guidance and mentorship throughout the training period.

Finally, I extend my heartfelt thanks to the staff members of the Marine Biological Resources Division of NARA for generously providing the necessary data for my study. I am deeply appreciative of the assistance provided by all individuals who helped me in various capacities, without which this research would not have been possible.

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APPENDICES

Appendix 1. Data Analysis

1. Sample size.

No	Year	Fishing Time OFRO boat	Fish Catch of OFRP	Sample size of OFRP	Fishing Time TM boat	Fish Catch of TM boats	Sample size of TM	Fishing Time NMT boat	Fish Catch of NMT boats	Sample size of NMT	Total Fishing Time	Total Catch
1	2000				701	4078	171	38	156	9	739	4233
2	2001				1450	3000	233	6	6	1	1244	3456
3	2002				941	4321	189				941	4321
4	2003				954	5012	188				954	5012
5	2004				869	3927	172	42	93	10	911	4020
6	2005				727	3823	131	12	27	2	739	3850
7	2006	7	30	1	690	3355	123				697	3385
8	2007				1045	5027	190				1045	5027
9	2008	20	255	6	559	4942	135				579	5197
10	2009				613	4481	170				613	4481
11	2010	3	25	1	660	4394	178				663	4419
12	2011	10	29	3	762	3781	181				772	3810
13	2012				656	3764	158				656	3764
14	2013	432	1885	89	513	2230	112				945	4115
15	2014	650	2200	115	600	2000	125				1221	5518
16	2015	437	2400	95	325	1369	68				762	3303
17	2016	97	465	18	227	775	41	60	459	22	436	1699
18	2017	147	828	34	220	1039	42	19	150	4	386	1920
19	2018	528	3106	112	337	2176	68	4	4	1	869	5286
20	2019	80	800	33	60	700	48				394	1094
21	2020	24	250	6	55	193	12	29	86	7	108	354
22	2021	72	516	18				26	61	7	98	577

2. Data standardisations

CPUE OFRP	CPUE TM	CPUE NMT	Avg CPUE OFRP	Avg CPUE TM	Avg CPUE NMT	Rel CPUE for OFRP	Rel CPUE for M	Rel CPUE for TNM	Rel CPUE	Fishing Effort (Kalmunai)	Sri Lanka Ambligaster Sirm Fish Catch estimation
	5.8	4.1		1.1	1.2		1.0	0.0	1.09	3883.45	29301.02
	2.1	1.1		0.4	0.3		0.3	0.0	0.33	10279.28	47326.88
	4.6			0.9			0.9		0.85	5034.14	46922.56
	5.3			1.0			1.0		0.98	5101.55	34080.68
	4.5	2.2		0.8	0.6		0.8	0.0	0.84	4788.06	43572.32
	5.3	2.3		1.0	0.6		1.0	0.0	0.98	3926.53	19918.97
4.3	4.9		0.7	0.9		0.0	0.9		0.91	3732.83	40754.65
	4.8			0.9			0.9		0.90	5589.15	54161.22
12.8	8.8		2.0	1.7		0.1	1.6		1.67	3118.20	67569.69
	7.3			1.4			1.4		1.37	3279.76	69117.76
7.7	6.7		1.2	1.2		0.0	1.2		1.24	3551.40	66239.82
2.9	5.0		0.4	0.9		0.0	0.9		0.92	4123.16	71974.90
	5.7			1.1			1.1		1.07	3509.02	86291.70
4.4	4.4		0.7	0.8		0.3	0.4		0.75	5499.68	58852.24
3.4	3.3		0.5	0.6		0.2	0.2		0.43	12727.97	45603.94
5.5	4.2		0.8	0.8		0.6	0.3		0.94	3512.56	59957.92
4.8	3.4	7.7	0.7	0.6	2.2	0.2	0.3	0.6	1.08	1578.13	70027.72
5.6	4.7	8.1	0.9	0.9	2.3	0.4	0.5	0.2	1.03	1864.14	86518.21
5.9	6.5	1.0	0.9	1.2	0.3	0.5	0.5	0.0	1.03	5138.48	51011.58
10.0	11.7			2.2			1.4		1.39	784.10	28544.42
10.2	3.5	3.0	1.6	0.7	0.8	1.1	0.4	0.2	1.67	211.17	19696.05
7.1		2.4	1.1	0.0	0.7	1.0	0.0	0.1	1.05	550.05	23557.09

3. Sustainable Yield estimation

After estimation of Total effort (Total Fish Catch /Relative CPUE). It is required to estimate the regression model using CPUE against the effort.

$$y = -8E-06x + 1.4501$$

$$R^2 = 0.5169$$

The MSY and FMSY then estimated as follows.

$$\text{FMSY or EMSY} = -a/2b \quad (1.4501/ 2*-0.000008) = \mathbf{90931.25}$$

$$\text{MSY} = -a^2/4b \quad \text{or} \quad a*\text{EMSY} - b*\text{EMSY}^2 = 1.45*90931.25 - (-0.000008^2) = \mathbf{65712.19}$$

4. Fishing cost and fish price information

Year	Fish Prices (Rs)	Average fuel cost per Trip	Kerosin Price Sri Lanka	Average fishing time	Total no of fishing trips/ sampel	Cost for fishing operations	Unit Cost (varibal cost)
2000	64.00	623.00	16.65	5.01	180	112140	28.87637
2001	79.73	645.53	18.07	4.62	234	151053.8	14.69497
2002	75.00	989.37	20.72	4.65	189	186991.1	37.14459
2003	81.00	846.62	24.1	4.80	188	159165.4	31.19938
2004	83.00	1028.35	25.5	4.78	182	187159.3	39.08872
2005	98.00	949.95	29.5	5.02	133	126343.8	32.17689
2006	122.00	771.88	43.67	4.71	124	95712.54	25.64072
2007	170.00	897.31	54.29	4.60	190	170488.6	30.50349
2008	187.00	2027.23	64	4.69	141	285840.1	91.66817
2009	191.00	1625.65	51	4.37	170	276361	84.2625
2010	197.00	1780.88	51	4.56	179	318777.5	89.76106
2011	180.00	1738.26	66	4.70	184	319838.9	77.57115
2012	200.00	2126.45	106	4.86	158	335978.5	95.74697
2013	241.00	2429.47	106	5.06	201	488323.9	88.79132
2014	225.00	1968.75	83.5	5.18	240	472500	37.12296
2015	260.00	3077.34	68	5.11	163	501605.7	142.8034
2016	312.00	3926.18	49	4.85	81	318020.3	201.5162
2017	319.00	4113.93	44	5.47	80	329114	176.5499
2018	298.00	2789.74	73.1	6.02	181	504943.6	98.26696
2019	374.00	2427.86	70	5.93	81	196656.4	250.8051
2020	420.00	3068.56	83.67	4.32	25	76714	363.2782
2021	447	3547.66	87	3.93	25	88691.5	161.2403

5. Estimation of MEY and AMEY (Open access)

Effort	sustainable yeild	TR	TC	Profit	50% Fuel Up	100% Fuel Up
0	0	0	0	0	0	0
8625	11911.98	2503537.00	1723988.01	779548.986	2154985	2585982
17250	22633.72	4756919.70	3447976.02	1308943.67	4309970	5171964
25875	32165.21	6760148.09	5171964.03	1588184.05	6464955	7757946.1
34500	40506.45	8513222.18	6895952.04	1617270.14	8619940.1	10343928
43125	47657.43	10016141.98	8619940.06	1396201.92	10774925	12929910
51750	53618.17	11268907.47	10343928.07	924979.395	12929910	15515892
60375	58388.66	12271518.66	12067916.09	203602.572	15084895	18101874
69000	61968.90	13023975.55	13791904.1	-767928.55	17239880	20687856
77625	64358.88	13526278.13	15515892.11	-1989614	19394865	23273838
86250	65558.62	13778426.42	17239880.12	-3461453.7	21549850	25859820
94875	65568.11	13780420.40	18963868.13	-5183447.7	23704835	28445802
103500	64387.35	13532260.08	20687856.15	-7155596.1	25859820	31031784
112125	62016.33	13033945.46	22411844.16	-9377898.7	28014805	33617766
120750	58455.07	12285476.54	24135832.17	-11850356	30169790	36203748
129375	53703.56	11286853.32	25859820.18	-14572967	32324775	38789730
138000	47761.80	10038075.80	27583808.19	-17545732	34479760	41375712
146625	40629.79	8539143.97	29307796.21	-20768652	36634745	43961694
155250	32307.52	6790057.84	31031784.22	-24241726	38789730	46547676
163875	22795.01	4790817.42	32755772.23	-27964955	40944715	49133658
172500	12092.25	2541422.69	34479760.24	-31938338	43099700	51719640
181125	199.23	41873.65	36203748.26	-36161875	45254685	54305622

6. Reference point estimations

$$\text{EMEY} = (a * \text{average price of fish} - \text{average cost of fishing}) / (2 * \text{average price of fish} * b)$$

$$= 1.4501 * 210.17 - 199.88) / (2 * 210.17 * 0.000008)$$

$$\text{EOA} = (a * \text{average price of fish} - \text{average cost of fishing}) / (\text{average price of fish} * b)$$

$$= 1.4501 * 210.17 - 199.88) / (210.17 * 0.000008)$$

Variabl e	Value	Indicator	Present Condition	Indicato r	50% Up	Indicato r	100% UP
a	1.4501	EMEY	31190.35	EMEY	16330.13	EMEY	1469.901
b	0.000008	EOA	62380.7	EOA	32660.25	EOA	2939.803

Appendix 2. Derivation of equations.

To estimate MEY and MSY of the Sri Lankan coastal fisheries, it is applied, static Gordon-Schaefer model for the study. Especially, the bioeconomic analysis will be done using surplus production model developed by Schaefer and cost, revenue and profit functions will also be estimated from the primary data. Finally, estimates of static reference points. The basic Schaefer model serves as a fundamental framework for understanding fish population dynamics, characterized by a logistic growth equation that reflects the natural growth dynamics of fish populations. This equation captures the relationship between reproduction, mortality, and environmental factors in shaping the population size over time. The following equation commonly used to describe the growth of fish populations over time.

$$F(X) = rX \left(1 - \frac{XK}{KX} \right) \quad 1$$

Where

$F(X)$: is rate of change of the population size (denoted by X) with respect to time.

r : is the intrinsic growth rate of the population.

K : is the carrying capacity of the environment, which is the maximum population size that the ecosystem can sustain indefinitely. At K , the population growth rate reaches zero as resources become fully utilized.

As the population size (X) approaches the carrying capacity (K), this term becomes smaller, leading to a reduction in the growth rate.

Fishing effort relates between the biomass of the fish population, and catchability. The following equation offers insights into the impacts of fishing activities on population sustainability and the delicate balance between exploitation and conservation.

$$H(E, X) = qEX \quad 2$$

This function defines the harvest rate, which is the amount of fish removed from the population through fishing activities. The harvest rate is influenced by both fishing effort (E) and the biomass of the fish population (X). If the fish harvest is equal to the growth of the fish population, it can be observed that an equilibrium condition exists for fisheries management. The following equation explains this condition.

$$\frac{dy}{dx} = F(X) - H(E, X) = 0 \quad 3$$

The following equation gives the insight into the maximum sustainable biomass. It gives the understanding of the sustainable population size of fish under specific fishing pressures.

$$X = K \left(1 - \frac{qE}{r} \right) \quad 4$$

The equation is derived from equation (3) by setting the growth rate equal to the harvest rate and solving for the biomass (X) at equilibrium. At equilibrium, the growth rate of the fish population ($F(X)$) equals the harvest rate ($H(E, X)$), meaning that the population neither grows nor declines over time. The estimation of the MSY and MEY can be obtained from the following equations

In summary, the equilibrium biomass (X) in terms of the carrying capacity (K), catchability coefficient (q), fishing effort (E), and intrinsic growth rate (r). The long-term capture equation therefore, describe from the following equations.(Rago & Van Dyne, 1978).

$$H(E) = qKE \left(1 - \frac{qE}{r}\right) = qKE - \frac{q^2K}{r} E^2 \quad 5$$

The above equation provides the biomass level ($X =$ sustainable yield function) at which the fish population stabilizes under the given fishing effort (E). It's the point where the population reaches equilibrium, neither growing nor declining over time. This equation provides the insight into the maximum sustainable biomass that the ecosystem can support under the prevailing fishing effort, catchability, and intrinsic growth rate. The equilibrium condition can be written as following equation as well.

$$\frac{dC}{dE} = qK - \frac{2q^2K}{r} E = 0 \quad 6$$

This indicates that the point at which the rate of change of the total catch with respect to fishing effort is zero. In other words, it's the point where the total catch is maximized or optimized given the available fishing effort.

If the equation (5) ($= qKE - \frac{q^2K}{r} E^2$) divide from the fishing effort (E) and its connection to catch per unit effort (CPUE). CPUE represents the amount of catch obtained per unit of fishing effort, often measured in terms of time, gear deployment, or other relevant metrics (Liyana, N. I., & Sin, M. S., 2022). The following equation explains the catch per unit of fishing effort derived from 5.

$$CPUE = \frac{H(E)}{E} = qK - \frac{q^2K}{r} E \quad 7$$

According to this equation, the left side of the equation represents the CPUE ($H(E)/E$), as it quantifies the catch obtained per unit of fishing effort. The right side of the consists of two components. qK represents the catchability coefficient (q) multiplied by the carrying capacity (K) of the fish population. While $-(Q^2 K/r)E$ represent the the reduction in CPUE as fishing effort (E) increases. This can be shown as a linear function as below.

$$y = \alpha + \beta x \quad 8$$

In this equation (8) dependent variable y represents the total harvest ($H(E)$ or CPUE), while the independent variable x corresponds to the fishing effort E . The slope β of the linear regression model is given by $-q^2K/r$, and the intercept is represented by α (qK).

When considering the profitability of fishing activities, it is crucial to estimate both the Total Revenue (TR) and Total Cost (TC) of fishing operations. TR in fishing operations can be obtained from the following equation.

$$TR(E) = p \cdot H(E) \quad 9$$

The $TR(E)$ represents the total revenue generated from fishing activities at a given level of fishing effort (E). The p represents the price per unit of harvested fish and $H(E)$ represents the total harvest resulting from the fishing effort (E). The total cost represents the total expenses incurred in fishing operations at a *given level of fishing effort (E)*.

$$TC(E) = c \cdot E \quad 10$$

The cost of fishing include all the cost such as labor, fuel, maintenance, and others. Total cost can be calculated by multiplying the fishing effort (E) by the unit cost of fishing (c). The profit ($\pi(E)$) represents the financial gain or loss resulting from fishing activities at a given level of fishing effort (E). It is calculated as the difference between total revenue and total cost.

$$\pi(E) = TR(E) - TC(E) = p \cdot H(E) - c \cdot E \quad 11$$

7.1.1 The Logistic Growth Model and its Application to Maximum Economic Yield (MEY)

The logistic growth model, pioneered by Schaefer and implicitly utilized by Gordon (1954), serves as a foundational framework for understanding the dynamics of fish populations and their exploitation in fisheries management. Gordon was among the first to use this model to create a bioeconomic framework for fisheries, which helped define the concept of Maximum Economic Yield (MEY).

Gordon's application of the logistic growth model to fisheries management marks a significant milestone in the development of bioeconomic models. By incorporating the dynamics of fish populations into economic analysis, Gordon demonstrated the importance of considering ecological factors in determining optimal harvesting strategies.

The concept of Maximum Economic Yield (MEY) emerges from this integration of ecological and economic principles. MEY, or Maximum Economic Yield, signifies the specific level of harvesting activity that optimizes economic advantages, aiming to achieve the most favourable balance between revenue generation and resource sustainability in fisheries management. The model can be summarized as follows:

Maximizing Total Profit (π):

We want to find the level of effort (E) that maximizes total profit (π). This occurs when total revenue (TR) equals total cost (TC).

$$\pi = TR - TC \quad 12$$

Total profit (π) is calculated as the difference between total revenue (TR) and total cost (TC) $\pi = P \cdot Q - c \cdot E$ 13

The total profit (π) is calculated as the difference between total revenue (P x Q) and total cost (c x E). P = Represents the price of each unit of output (e.g., price per unit of fish). Q = Represents the quantity of output (e.g., quantity of fish caught). c = Represents the cost per unit of input (e.g., cost per unit of fishing effort). E = Represents the level of input (e.g., level of fishing effort).

$$\pi = P(\alpha E - \beta E^2) - c \cdot E \text{ or } P \cdot \alpha E - P\beta E^2 - c \cdot E \quad 14$$

α = Represents the coefficient of the linear term (related to revenue).

B = Represents the coefficient of the quadratic term (related to cost).

From this, the effort level in the maximum economic yield, EMEY, can be discovered using the first order condition. Calculate the derivative of ' π ' with respect to 'E'.

$$\frac{d\pi}{dE} = P(\alpha - 2\beta E) - c = 0 \quad 15$$

This equation represents the derivative of the total profit (π) with respect to the level of effort (E) set equal to zero, as we're looking for the maximum point of the profit function.

$$P\alpha - 2P\beta E - c = 0 \text{ or } -2P\beta E = P\alpha + c \quad 16$$

$$E = P\alpha - \frac{c}{2P\beta} \quad 17$$

This is the level of effort (E) that maximizes total profit (π). This value of E represents the optimal level of fishing effort that balances the revenue generated from fishing activities with the associated costs, resulting in the highest possible profit.

Estimation of MSY (Nguyen, 2011) and MEY (Mohamad Natsir, 2015) can be summarized as follows.

Table 12. Parameters for Maximum Sustainable Yield (MSY) Calculation

Equation		Definition
h_{MSY} or Y_{msy}	$\frac{Kr}{4}$	Harvest at Maximum Sustainable Yield (MSY)
X_{MSY}	$\frac{K}{2}$	Biomass at Maximum Sustainable Yield (MSY)
E_{MSY}	$\frac{r}{2q}$	Fishing Effort at Maximum Sustainable Yield (MSY)

Here, '**K**' is the carrying capacity of the fishery (maximum biomass it can support) and '**r**' is the intrinsic growth rate of the fish population (rate of natural increase). '**q**' is the catchability coefficient (measure of fishing efficiency).

Table 3. Parameters for Maximum Economic Yield (MEY) Calculation

Equation		Definition
X_{MEY}	$\frac{K}{2} \left(1 + \frac{c}{pqK}\right)$	The biomass level (X) at which the fishery operates at maximum economic yield (MEY). It calculates the equilibrium biomass level based on the carrying capacity (K) and cost and price parameters (c, p, and q).
E_{MEY}	$\frac{r}{2q} \left(1 - \frac{c}{pqK}\right)$	The optimal level of fishing effort (E) that maximizes economic rent. It calculates the effort level based on the intrinsic growth rate (r), catchability coefficient (q), and cost and price parameters (c, p, and K).
h_{MEY}	$q \cdot X_{MEY} \cdot E_{MEY}$	The economic rent (h) obtained from the fishery operating at maximum economic yield. It calculates economic rent by multiplying the optimal biomass level (XMEY) and fishing effort level (EMEY) by the catchability coefficient (q).

The Open Access Equilibrium (OAE)

The Open Access Equilibrium (OAE) is a state in resource management where the exploitation of a resource occurs under unrestricted access, leading to the dissipation of all economic rents, resulting in no economic profits. In the Open Access Equilibrium (OAE), the resource price (P) falls to zero because there are no restrictions on resource extraction, allowing individuals to freely access and extract the resource without any constraints.

To estimate the effort level at the Open Access Equilibrium, we can employ a mathematical model that captures the relationship between effort, revenue, and cost. This model typically involves equations that describe the revenue generated from resource extraction, the costs associated with extraction, and the level of effort exerted by individuals. The OAE model can be summarized as follows:

$$TR - TC = 0 \quad 18$$

Total revenue (TR) minus total cost (TC) equals zero. This equation represents the condition where economic profits are zero.

$$P \cdot \alpha E - P\beta E^2 - c \cdot E = 0 \quad 19$$

Total revenue ($P \cdot \alpha E$) minus total cost ($P\beta E^2 - c \cdot E$) equals zero. This equation represents the revenue generated from fishing efforts ($P \cdot \alpha E$) minus the costs associated with fishing ($P\beta E^2 - c \cdot E$) equals zero.

$$P \cdot \alpha E - P\beta E^2 - c = 0 \quad 20$$

It is important to Simplifying the equation by removing the squared term to make it easier to solve.

$$P\beta E_{OAE} = P \cdot \alpha - c \quad 21$$

Setting the equation derived to find the effort level (E_{OAE}) at the Open Access Equilibrium.

$E_{OAE} = \frac{P \cdot \alpha - c}{P\beta}$ Solving for E_{OAE} by dividing both sides by $P\beta$.

$$E_{OAE} = \beta(\alpha - Pc) \quad 22$$

Expressing E_{OAE} in terms of α , c , P , and β to understand the relationship between these variables.