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ASSESSING MANAGEMENT TARGET REFERENCE POINTS AND IMPLICATIONS OF *SARDINELLA MADERENSIS* IN THE COASTAL WATERS OF LIBERIA

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ABSTRACT

Small-scale fisheries, which gather small pelagic fish, are a crucial sector in Liberia for supplying food to the local population and generating revenue for subsistence. *Sardinella maderensis* which is caught by motorised (Fanti) canoes using gill nets and seine nets, dominates the catches of the sector. To identify management target reference points and concerns for the *S. maderensis* fishery, this study applied the Schaefer production models to aggregate and disaggregate catch and effort data of *S. maderensis* in the small-scale fisheries of Liberia. The National Fisheries and Aquaculture Authority of Liberia (NaFAA) research and statistics division collected catch and effort data from samples taken between 2018 and 2022. The results of the aggregated and disaggregated analyses showed that the biological target reference points MSY and effort corresponding to MSY (E_{MSY}) were higher than the present (2022) catch landing and effort, indicating less fishing pressure on *the S. maderensis* stock. However, the results showed that the stock is being fished close to management economic target reference points, MEY, and the effort corresponding to MEY (E_{MEY}). Economic overfishing occurs when the cost of fishing is higher than the price of fish. This study gathered that the unit cost of effort is considerably high compared to the unit price of catch for *S. maderensis* in Liberia due to inefficient and ineffective fishing boats, as well as the social responsibilities of the fishery. Furthermore, the study findings showed that direct input controls are the sole management strategy for the fishery. This study recommends the combination of input and output control management strategies, adaptation of better fishing technologies, and the provision of alternative livelihoods for coastal communities to fully utilise the *S. maderensis* fishery.

Keywords: Small-scale fisheries management, *Sardinella maderensis,* target reference points (maximum sustainable yield (MSY), maximum economic yield (MEY)), bioeconomic stock assessment, Liberia.

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1 INTRODUCTION

1.1 Background

Liberia is a small West African State that lies between latitude 7^0 45’ 0” North and longitude 10^0 39’ 0” West on the eastern central Atlantic region of the Gulf of Guinea. Liberia is bordered by Cote D’ Ivoire, Sierra Leone, Guinea, and the Atlantic Ocean on the east, west, north, and south respectively. Due to the Guinea surface waters, the waters of Liberia are uniformly warm, approximately 26 – 28^{0}C and contain low nutrients and salinity, 32% (FAO, 2017). Liberia has a land area of approximately 111,370 Km^2 and an extended exclusive economic zone (EEZ) of 200 nautical miles (NM) with a coastline of 570 km in length (FAO, 2017). Liberia has a population of approximately 4.57 million, and the per capita fish consumption is about 4.8 kg/year (World Bank, 2019). Over 80% of the country´s population relies on the fisheries sector for animal protein, and it serves as a major source of livelihood and income generation for over 33,000 full-time fishers, processors, and traders (BNF, 2014). The fisheries sector of Liberia contributed 10% of the GDP, more than Ghana’s 3%, Senegal ’s3%, and Nigeria’s 4% in 2015 (Belhabib, Sumaila, & Pauly, 2015).

Two types of marine fisheries are practiced in Liberia: industrial and artisanal. Industrial marine fisheries are conducted beyond six nautical miles from the coast and offshore, whereas marine artisanal fisheries are performed below six nautical miles in the inshore exclusive zone (IEZ). The artisanal fishery is exploited throughout the year by two main groups of people. The first group is the Indigenous Kru ethnic group. These fishers and their canoes pursue all fish species that fall prey to their gear (gill nets, set nets, and hook-and-line) (BNF, 2014). The second group of people are migrants from Ghana, Togo, Benin and Côte d’Ivoire. They consist of the Fanti, Ewe, and Popoh ethnic groups. They use large wooden canoes made of planks to fish. It is believed that these people migrated to Liberia in the 1920s (Belhabib et al., 2013). The catches of these canoes are higher than those of the Kru canoes (Jueseah, Tomasson, Knutsson, & Kristofersson, 2021). In general, artisanal marine fishery production dominates Liberia’s fishery sector (Figure 1).

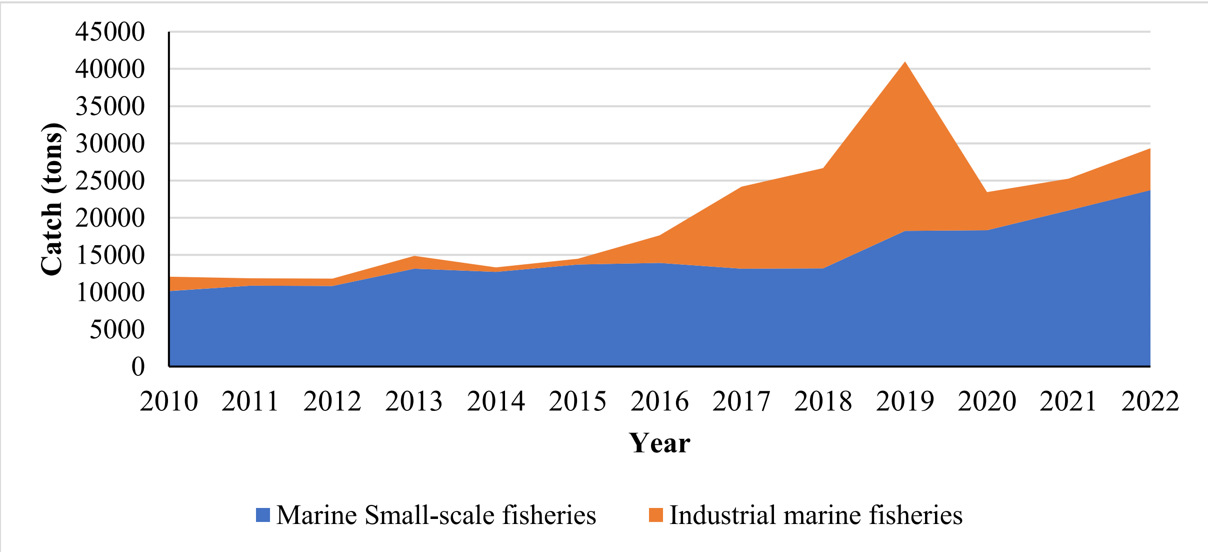


Figure 1: Catch trends of Marine Small-scale and Industrial fisheries of Liberia from 2010 to 2022. Data Source: NaFAA

Sardinella species are mostly caught in large quantities compared to other pelagic species. In 2016, the sardinella species constituted 25% of the artisanal fishery production (NaFAA, 2017). *Sardinella maderensis* is an abundant species of sardinella caught in Liberia. *S. maderensis* is an elongated body shaped keeled belly coastal pelagic fish. The 25 to 30 cm fish is found distributed in the Mediterranean and the eastern Atlantic Ocean. The fish is more adaptable to low salinity and 24^0C water temperatures (Whitehead, 1985). According to Whitehead (1985), the fish feed on small planktonic invertebrates and spawn during warm weather. Some studies (Wehye & Amponsah, 2017) and (Yokie, 2020) have assessed the stock of *Sardinella maderensis* in the coastal waters of Liberia by various means and reported high fishing pressure on the stock. However, these studies did not consider the target reference points and management implications of the species.

Management reference points, such as the maximum sustainable yield (MSY), should be considered a vital instrument for fisheries management in the case of fishing and when considering the limits of fish stock exploitation (Abd El Barr, 2016). The MSY is the highest yearly catch that can be sustained for an indefinite period, while the stock can produce more (Sparre & Venema, 1998). MSY is the theoretical balance between the fish that have been caught and those that are being caught. According to Spare and Venema (1998), MSY can be derived if catch and effort data over time are available. The current project aimed to estimate the management reference points of *S. maderensis*, one of the important and abundantly caught artisanal species in the coastal waters of Liberia and provide management suggestions.

1.2 Problem Statement

Globally, the percentage of overfished fish stocks has increased from 10% in the 1970s to over 35% in 2019 (FAO, 2022). The increase in the unsustainable harvesting of fisheries resources may be caused by overfishing (FAO, 2020). Overfishing harvests the fish stock above the limit that it can no longer produce, creating adverse effects on ecosystem functions, biodiversity, and extreme reduction in fish landings, leading to negative impacts on livelihood and unproductive economic activities (FAO, 2020).

It is difficult to estimate the status of nearly all marine biodiversity in Liberia because of factors such as poor data collection from fisheries, resource scarcity, conflicts, and illegal, unregulated, and unreported (IUU) fishing. Fisheries managers also face several difficulties (Wehye & Amponsah, 2017). Artisanal fisheries are harvested throughout the year using non-motorised and motorised canoes targeting pelagic and demersal species using various fishing methods (Belhabib D., 2016). Artisanal fishery is the major source of protein for over 80% of the country's population, and it also generates income and provides employment (BNF, 2014). Small pelagic species made up the highest catch in the artisanal fisheries (NaFAA, 2019). *S. maderensis* is a very important commercial species in the artisanal fisheries. It is inexpensive, profitable (Yokie, 2020), and relatively easy to process. Artisanal fisheries are not adequately monitored, and the collection of useful fishery information such as location, speed, and catch composition of landings (Yahn, 2020) from artisanal fishery fleets is not available. These constraints cause inaccuracies in the data and create challenges for fisheries management.

There have been reports of increased fishing pressure on some fish stocks in the coastal waters of Liberia. *Pseudotolithus senegalensis* and *Pseudotolithus typus* were reported to be overexploited and close to the optimum fishing level, respectively (Wehye & Amponsah, 2017). *Sardinella aurita* and *Pseudotolithus senegalensis* were also reported to be exploited at optimal levels on the coast of Liberia (Leesolee, 2018). In addition, Jueseah, Kristofersson, Tómasson, & Knutsson, (2020) reported that the current fleet size in the artisanal fishery sector of Liberia will lead to fish stock decline over time. Additionally, artisanal fishery production has recently declined (NaFAA, 2018).

Based on these backdrops and the need to sustainably manage the fishery resources of Liberia in accordance with the United Nations sustainable development goals number 14.4, this project aims to derive management reference points for *Sardinella maderensis*, an important coastal pelagic commercial species in Liberia. The benefits of the project to the fisheries sector of Liberia are sustainable management practices, optimal productivity based on the derived management reference points, and the provision of information on the stock of *S. maderensis*.

1.3 Objectives

The project's goals are to determine the fishery's management target reference points for *S. maderensis* and to assess its economic sustainability. In addition, the project will provide an alternative management strategy that will help sustainably manage *the S. maderensis* fishery in Liberia's coastal waters.

1.3.1 Specific Objectives:

- Assess *S. maderensis* sustainable harvest at catch reference points
- Determine target effort reference points
- Evaluate *S. maderensis* economic productivity in the artisanal fisheries of Liberia
- Propose alternative management practices for the sustainability of *S. madrensis* fishery

2 LITERATURE REVIEW

2.1 Development of Fisheries in Liberia

The exploitation of fishery resources in Liberia began in 1848 when Joseph Jenkins Roberts, the first president of Liberia, turned his yacht into a fishing vessel. The German company Woerman operated the first fishing trawlers from 1938 to 1939 on the coast of Liberia (Subah, 2010). The United Nations Food and Agriculture Organization (FAO) and the government of the United States of America (USA) assessed the fisheries potential of Liberia in 1952 and found it feasible to establish a medium-scale fishing industry. Subsequently, an industrial fishery, largely aimed at shrimp harvesting, was established in Liberia (Subah, 2010).

A legislative act created the Bureau of National Fisheries (BNF) under the Ministry of Agriculture (MOA) in 1956 to monitor, manage, and conserve Liberia's fisheries resources. In 1973, the Liberian government, through the BNF with assistance from the FAO, amended the legal framework and set guidelines for several fishing activities. In addition, for more conservation and sustainability of fishery resources, the United Nations Convention on the Law of the Sea (UNCLOS), which also regulates the use of the ocean, was ratified in 1982. The BNF faced many challenges after the prolonged civil crisis in Liberia, despite adopting some components of the FAO Code of Conduct for Responsible Fisheries (CCRF) in 2008. The challenges included inadequate human resources and institutional development of the BNF, an increase in illegal, unreported, and unregulated (IUU) fishing, as well as ecosystem damage and destruction of fish spawning grounds (Yahn, 2020). The World Bank sponsored West Africa Regional Fisheries Project (WARFP) signed a Memorandum of Understanding (MOU) with the BNF in 2010, aimed at addressing the challenges through the strengthening of monitoring, control, and surveillance (MCS) of the industrial fishery and co-management association to manage the artisanal fishery through territorial use rights of fisheries (TURF).

At present, the only governmental agency charged with the authority to regulate all fishing and fishing-related activities in the Republic of Liberia is the National Fisheries and Aquaculture Authority of Liberia (NaFAA). The institution was created by a legislative act in 2017, replacing the natural resource law of 1956 that created the BNF. The entity is charged with the responsibility of managing its own affairs by building its own capacity and managing its resources. The main objective of NaFAA is the long-term management, conservation, development, and sustainable use of fisheries, aquaculture, and related ecosystems for the benefit of the people of the Republic of Liberia.

2.1.1 Coastal Fisheries and its importance in Liberia

Liberia's coastal marine fisheries have two subcomponents:

- The Industrial Fisheries (containing the shrimp and finfish trawl fishery), and
- The Small-scale (Artisanal) Fisheries

i. Coastal Industrial Fisheries

According to the New Fisheries Regulations of 2010 of Liberia, the use of vessels with engine above 100bhp and length greater than 28 meters for large-scale fish collection is described as an industrial fishery. The coastal industrial fisheries consist of vessels that do mid-water and bottom trawling targeting shrimp and shallow and deep-water demersal species. These vessels vary in size, ranging from 50 to over 200 gross tonnage (GRT), and contain processing and cold storage facilities onboard. Fish caught by these vessels are all landed in Liberia, frozen, and ready for the domestic market (BNF, 2014). These vessels are mostly foreign-owned but operate under joint-venture agreements in Liberia by acquiring fishing permits through their Liberian counterparts. There were ten (10) coastal industrial fishing vessels licenced to fish in Liberia in 2017, but the number declined to six (6) in 2018 and has since been stable for the past few years.

The fishing days of the coastal industrial fishing vessels do not exceed 25 days. Coastal industrial fishing activities are conducted outside the six (6) nautical miles offshore to avoid violating the new fisheries regulations of 2010 which bans industrial vessels from trawling within the six (6) nautical miles or the Inshore Exclusive Zone (IEZ). Fisheries Observers are usually deployed on coastal industrial vessels on each fishing trip to collect scientific information for fisheries management. There are 3-4 hauls made by each vessel a day. Each haul is sampled, and information such as retained catch, discards, species type, location, and ocean depth is recorded by the fisheries observer. The coastal industrial fisheries hit a peak of production above 22,000 metric tons in 2019, but there was a huge decline in 2020 and 2021 (Figure 2). The increase in production in 2019 may have been caused by the reduction in the number of vessels in 2018, while the decline in 2020 and 2021 may have been the result of the coronavirus outbreak in those years.

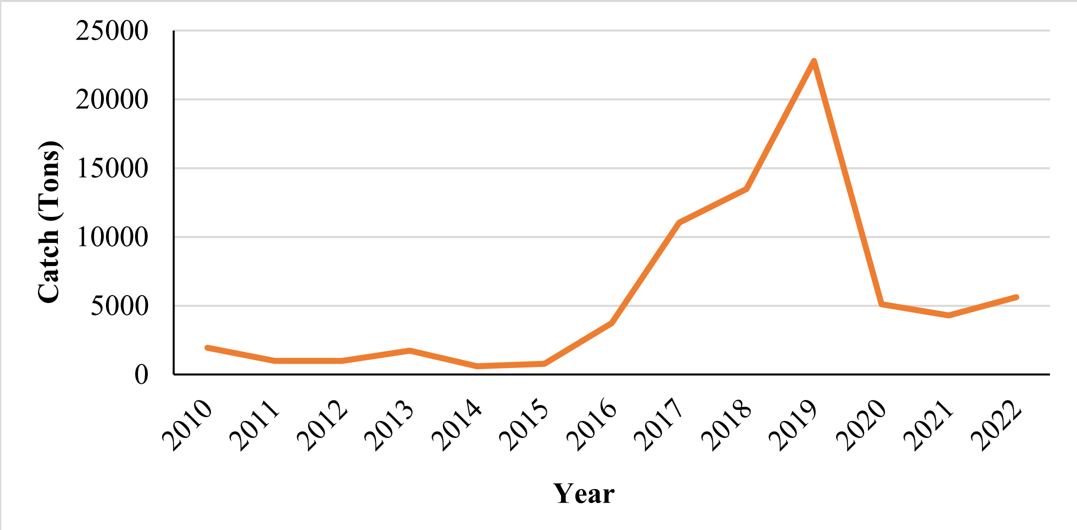


Figure 2: Liberia coastal industrial fisheries catch from 2010 to 2022. Data source: NaFAA

ii. Coastal Marine Small-scale (Artisanal) Fisheries

In Liberia, artisanal fisheries are mostly conducted within 6 nautical miles (NM) inshore of the EEZ. More than 50% of marine fishery production comes from the artisanal sector (NaFAA, 2018). Artisanal fisheries are exploited throughout the year by two main groups of people. The first group is the indigenous Kru tribe of Liberia. These Kru groups have engaged in fishing activities since the foundation of the country. They use small wooden dugout canoes, usually less than 7 meter (m) in length and approximately 60 centimeters (cm) depth (Figure 3). Paddles and sails are used to move the canoe. The canoe can hold one to three individuals at a time. Notably, 92% of the canoes used by this group are not motorised. These fishermen and their canoes pursue all fish species that fall prey to their gear (gill nets, set nets, and hook-and-line) (BNF, 2014). Their catches are usually for home consumption and/or exchange for other food items (Belhabib et al. 2013). These types of canoes account for approximately over 70% of the artisanal fisheries of Liberia (Wilson, 2019).

The second group of people are migrants from Ghana, Togo, Benin, and Ivory Coast. They consist of the Fanti, Ewe, and Popoh ethnic groups. They use large wooden canoes made of planks to fish. The length ranges from 12 to 16 metres, with the capability of housing 15 crew members (Figure 4). It is believed that these people migrated to Liberia in the 1920s (Belhabib et al. 2013). Based on the fishing season, passive and active gears are used by these canoes to pursue all species using different fishing methods. Outboard engines ranging from 8 to 40 horsepower are attached to these canoes to enhance their effectiveness and catchability.

Figure 3: Small-scale fishery Kru Canoe, (Jueseah, Tomasson, Knutsson, & Kristofersson, 2021)

Figure 4: Small-scale fishery Fanti Canoe, (Jueseah, Tomasson, Knutsson, & Kristofersson, 2021)

The artisanal fisheries sector is a key component of the Liberian Fisheries through which 80% of Liberians, the majority of whom are women engaged in post-harvest activities, earn their living (NaFAA, 2018). Since the introduction of the new fisheries regulation restricting the Inshore Exclusive Zone to small-scale fisheries, the production of artisanal fisheries has increased. Production increased from 13,000 metric tons in 2018 to approximately 21,000 metric tons by 2021 (Figure 5). All annual production in the sector is locally processed. The processing conditions include smoking, drying, and icing. Nearly all production in this sector is intended for local consumption (Subah, 2010).

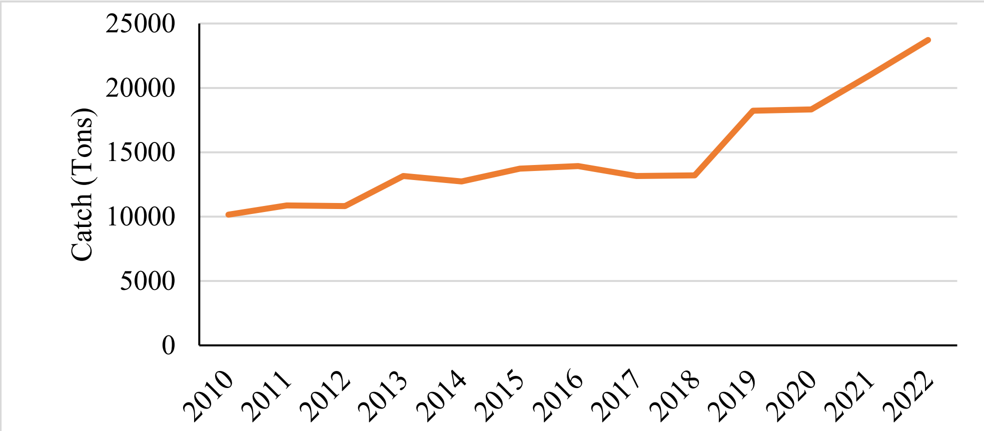


Figure 5: Catch trends of marine small-scale fisheries of Liberia from 2010 to 2022

2.1.2 Management of Liberia Fisheries

The FAO defined Fisheries Management as the entire procedure for acquiring data, analysing it, planning, consulting, making decisions, allocating resources, and creating and enforcing regulations or rules that control fisheries activities to maintain the efficiency of the resources and achieve other fisheries goals (Cochrane, 2002). To apply this concept to the fisheries sector of Liberia, the national legislature in 1956 enacted the Natural Resource Law, thus creating the Bureau of National Fisheries (BNF) under the Department of Technical Services within the Ministry of Agriculture to monitor, manage, and conserve the fisheries resources of Liberia (Wiles, 2005).

The BNF used the amended Natural Resource Law of Liberia and other internationally binding conventions and treaties, such as UNCLOS, as legal frameworks to manage the fisheries resource of Liberia up to 2010. Between 1956 and 2010, there were no specific legal fisheries regulations unique to the management of fisheries. The World Bank-sponsored West Africa Regional Fisheries Project (WARFP) began operations in the fisheries sector of Liberia in 2010. The WARFP introduced key management reforms within the sector. Through the assistance of the project, a new fisheries regulation that considered international conventions and protocols relating to fisheries management was developed in 2010. The new regulation created a Monitoring, Control, and Surveillance (MCS) division within the BNF, consisting of the Fisheries Monitoring Center (FMC), Fisheries Observer, and Inspectorate units for effective management. Four years later, in 2014, the National Fisheries and Aquaculture Policy and Strategy of 2014 was launched with the main goal of sustainably managing the fisheries resources of Liberia.

By the end of the WARFP mandate in 2015, the BNF was more capable of managing Liberia's fisheries resources. Two years after the withdrawal of the Project, the BNF was transformed into the National Fisheries and Aquaculture Authority by an act of the National Legislature in 2017. The new authority which is independent of the Ministry of Agriculture, began operations in 2018 with a goal similar to that of the BNF.

Fisheries management in Liberia is conducted through input control. An input control fisheries management is where fishing effort in a fishery is regulated by input restrictions, which include fishing capacity, areas, seasons, and times (Bellido, Sumaila, Sanchez-Lizaso, Maria , & Pauly, 2019). Input control management focuses on regulating the fleet and technical characteristics of the gears, fishing ground access, and retained catch and discards. Input controls are important management tools for fishing because they can be quantified (fishing capacity, gear size, mesh, hooks, fishing times, access to fishing grounds, etc.) and are simple to measure. The application of technical measures is not always effective. Every time a new technical measure is introduced, especially one that the fishing community does not readily accept, there is an effort to go around the rule or, at the very least, to lessen its impact (Bellido, Sumaila, Sanchez-Lizaso, Maria, & Pauly, 2019).

In Liberia, the Input control management is performed through licencing and vessel registration. Management measures are more directed towards industrial vessels than artisanal fleets. Industrial vessels are required to be granted fishing licences before fishing. To grant an industrial vessel a licence, it is subjected to a pre-licencing inspection for fishing capacity, gear size, mesh, hooks, and fishing times. If the industrial vessel is granted a fishing licence, a fisheries observer is deployed on the vessel to sample each haul made by the vessel, and information such as retained catch, discards, species type, location, and ocean depth is recorded for management. While fishing, the industrial vessel is monitored through the Vessel Monitoring System (VMS) in the FMC and is also subject to inspection upon arrival at the port by fisheries inspectors. Unlike industrial vessels, artisanal fleets are only subject to registration. Artisanal fisheries are essentially open access, while coastal industrial fisheries are subject to stringent entry controls and other management procedures (Jueseah & Kristofersson, 2020).

2.2 *Sardinella Maderensis* Biology

Sardinella maderensis, referred to locally as "Flat Bonny" provides nutrition to many households in Liberia because of its continuous availability all year round, easy processing method (mainly hot smoking), and relatively low price (US$2/kg) compared to other fish products (Yokie, 2020). Generally, Sardinella species are small, zooplankton-feeding pelagic fish with a brief lifespan and a maximum fork length of 30 cm (Ba, Thiaw, Lazar, & Maila, 2016). *S. maderensis* form part of the genius sardinella and the family of Clupeidae. It is a marine pelagic rayfinfish that is distributed throughout the Mediterranean and Eastern Atlantic Ocean (Baali, Falah, Bourassi, & Abderrazik, 2017). *S. maderensis* prefered coastal waters with low salinities and temperatures of about 24^0C. The species move in schools, feed on planktonic invertebrates, larvae of fish, phtoplanlton, and spawn during warm weather. *S. maderensis* has an elongated body with a sharp keeled belly, and like other sardinella species, it is silvery in appearance with a grey caudal fin (Whitehead, 1985).

In Liberia, pelagic species account for over 60% of marine fishery production. *S. maderensis* is a coastal pelagic species that forms part of the total catch. The species is mostly caught in large quantities by larger artisanal fleets (Fanti canoes) using ring nets, set nets, and drift nets (Jueseah, Ogmundur, Kristofersson, & Tomasson, 2020). Although there are fluctuations in the production of *S. maderensis* due to seasonality (Jueseah, Ogmundur, Kristofersson, & Tomasson, 2020), it remains the major fish available for local consumption. Production was stable from 2010 to 2013, with fluctuations from 2014 to 2019 and a major increase in 2021 (Figure 6). The large disparity between the monitored total catches in 2021 and other years was attributed to the huge increase in sampling effort in 2021. For example, 10,844 MT of catch records were listed for 2021, whereas 3,125 MT of catch records were recorded in 2010.

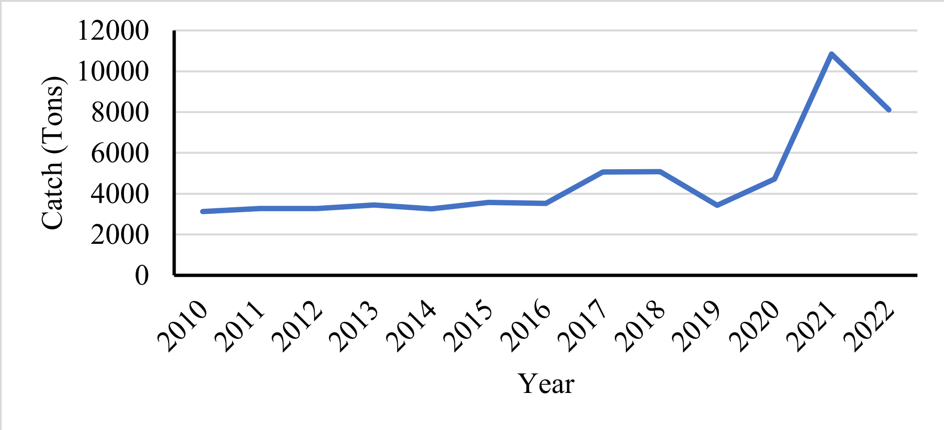


Figure 6: *S. maderensis* catch from 2010-2022. Data source: NaFAA

2.3 Surplus Production Model

Surplus production models, also referred to as Surplus Yield or biomass dynamic models, describe the relationship between surplus production and stock biomass or index of stock biomass based on the assumption that a fish stock produces surplus biomass that can be harvested. The assumption is that recruitment and growth are regarded as production, and if this production is greater than mortality (M), biomass will increase. Biomass produced in excess of that required to replace losses is regarded as surplus production, and the surplus can be harvested without adversely affecting the stock (Zhang, 2020). When there is a lack of good data on age, length structure, and natural mortality, surplus production models are employed to evaluate stock status and exploitation (Beverton & Holt, 1957). The Schaefer model is the most popular surplus production model used to determine fisheries management reference points, such as the maximum sustainable yield (Cousido-Rocha et al., 2022).

The highest potential equilibrium yield that may be consistently extracted from a stock while operating under current (average) environmental conditions is known as the maximum sustainable yield (MSY) (FAO, 2001). Milner Schaefer introduced the MSY and created a model that bears his name based on the logistic curve of population growth (Schaefer, 1954). The foundation of MSY is a classical ecological theory of logistic population expansion that was created in the 1830s (Verhulst, 1838), extending Robert Malthus's early demographic research (Malthus, 1798). Johan Hjort and his associates used the logistic model for the first time on marine species in the 1930s when they analysed blue whale fisheries using mortality and reproduction data (Hjort, Jahn, & Ottestad, 1933). Using their observations of fin whales in Iceland, cod, and herring in Norway, they established that the best catches occurred at intermediate levels of exploitation (Holt, 2014). It was proven that the greatest rate of population growth increase occurs when the population size is approximately half its ultimate size (Hjort, Jahn, & Ottestad, 1933) and that there is a maximum catch that can be sustained (Hart & Reynolds, 2002). In addition, Graham applied the logistics population growth equation to fisheries data between 1935 and 1943, identifying slow and fast population growth phases, with fast growth, low density, and young fish at low population sizes, and slow growth, high density, and many older fish at large populations close to carrying capacity. According to his observations, a fishery's overall yield stops increasing after a certain point (Graham, 1935).

Schaefer then used the logistical growth curve for California Sardine to create the Schaefer model. He used biomass instead of population counts and yield as the definition of surplus output. As a result, he officially proposed the idea of MSY, also known as the maximum equilibrium catch (Schaefer, 1954). At the Rome Conference on Fisheries Problems in 1955, Schaefer's excess production model was used to quantify the MSY (Smith, 1994). Following the late 1950s, several international organisations and nations chose MSY as their main management objective (Mace, 2001). The MSY concept is a requirement under the United Nations Convention on the Law of the Sea (UNCLOS) for fishing in the economic exclusive zones of signatory states.

However, it has been questioned and disputed whether MSY as a catch can be implemented continually, regardless of recruitment, stock size, stock structure, and environmental factors (Beverton & Holt, 1957; Larkin, 1977). There have been several reminders of its presumptions, uncertainties, restrictions, and incorrect applications (Hilborn & Walters, 1992; Holt, 2009). It is claimed that surplus production models are insufficiently complex to accurately capture the dynamics of populations that are influenced by fluctuations in recruitment, interactions with other species, catchability, selectivity, environmental factors, and climate (Pella & Tomlinson, 1969), and they necessitate a clear contrast between fishing effort and stock abundance (Hilborn & Walters, 1992). The MSY concept has evolved over time and has been enhanced to become a restriction that should be avoided (Kesteven, 1997; Mace, 2001). It is an exaggeration to say that MSY excludes environmental factors and species interactions (Froese, Demirel, Coro, Kleisner, & Winker, 2017). After reform and ongoing updating, MSY remains a practical idea and method for managing and governing fisheries (Kesteven, 1997). According to John Gulland, "MSY is the most important concept in Fisheries Management (Mangel, Marinovic, Pomeroy, & Croll, 2002). Additionally, MSY conveys a straightforward message that appeals to legislators and inspires public support; as a result, it is still commonly utilised in determining stock status and exploitation (Mesnil, 2012). The evaluation of fish stock using MSY can be easily adopted when fishing effort and catch data are available (Sparre and Venema, 1998).

The Maximum Economic Yield (MEY) is another indication or reference point for fisheries management. MEY is the yield level that produces the highest possible economic return from fishing (Narayanakumar, 2017). One of the bases for suggesting the ideal fleet size is provided by the estimation of excess fishing capacity by MEY. Excessive fishing capacity, diminished yields, and reduced profitability will occur if resources are utilised beyond the MEY target. Economists have long advocated using the biomass that increases a fishery's economic profit as a management goal because when the present biomass is smaller than the MEY, it has the potential to provide both economic profits and increase the size of the fishery. This has led to the MEY being increasingly employed as a management target (Grafton, Kompas, Chu, & Che, 2010). In the creation of any national fishery management policy, the biological reference point (MSY) and the economic reference point (MEY) should be used, as they are always complementary to one another (Narayanakumar, 2017).

3 MATERIALS AND METHODS

3.1 Project Location

The project considered all artisanal fishery landings of S. maderensis in Liberia. Small-scale fisheries are conducted on the continental shelf close to the shore within 6-10 NM inshore. There are nine coastal counties or regions that contain 114 landing sites for small-scale fishers to land their catches. The nine coastal counties are Montserrado, Grand Capemount, Bomi, Margibi, Grand Bassa, Rivercess, Grand Kru, Sinoe, and Maryland. These counties are shown in colour on the map of Liberia (Figure 7). Within these counties, fisheries enumerators are assigned to various landing sites to gather information on small-scale fish catches. This information is sent to the National Fisheries and Aquaculture Authority for research and decision-making on the best management practices.

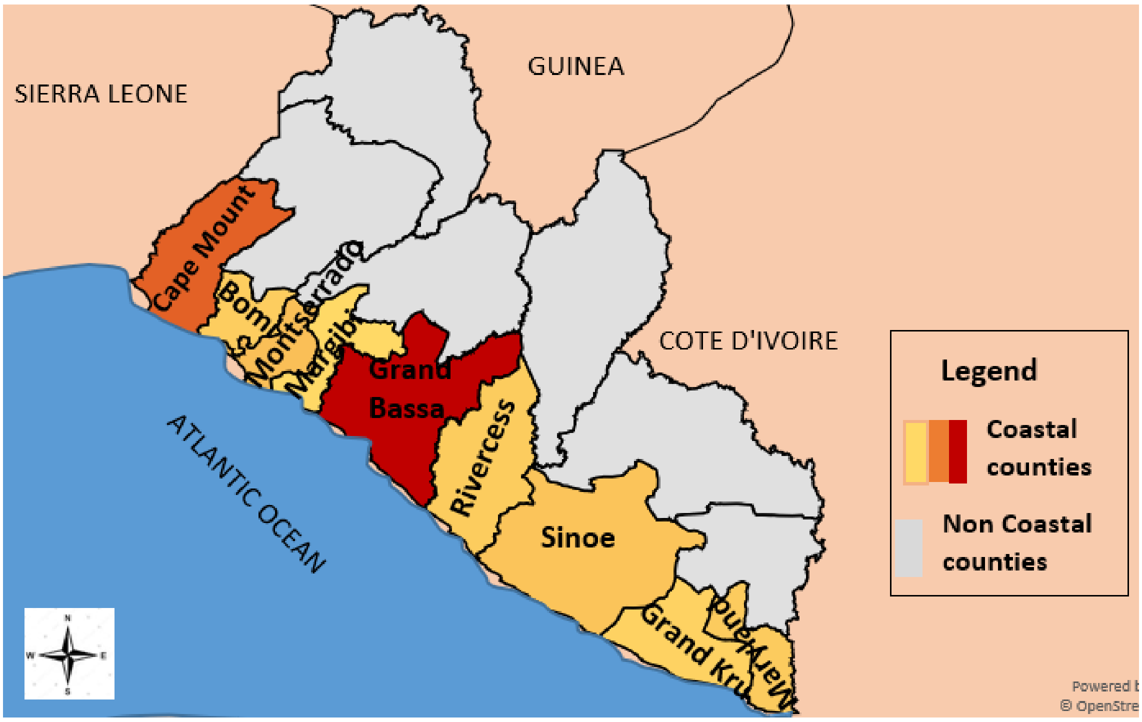


Figure 7: Map of Liberia showing the nine coastal counties where small-scale fisheries catch data are collected. Source: Author's contribution based on *S. maderensis* catch data.

3.2 Method

3.2.1 Harvest function

An appropriate bioeconomic model was applied in the analysis. The model includes the natural growth, harvest, and cost functions which are the three cardinal functions of the fisheries bioeconomic model (Clark, 1990). Using the harvest function for an exploited stock, a general growth model can be expressed as follows:

$$\frac{dx}{dt} = F(x) - H(E, X) \quad (1)$$

where *F(x)* is the function of the stock's biological expansion and *H(E,X)* is the harvest function, which is influenced by stock biomass *(X)* and fishing effort *(E)* (Clark, 1990). Belgian mathematician Pierre-Francois Verhulst initially suggested the use of biological growth of stock as a model of population (Verhulst, 1838; Schaefer, 1954).

$$\boldsymbol{F(X) = rX\left(1 - \frac{X}{K}\right)} \tag{2}$$

In this equation, *K* represents the carrying capacity of the environment, and *r* represents the rate at which growth occurs.

At equilibrium, $\boldsymbol{\frac{dx}{dt} = 0}$, the stock doesn't change. In other terms, the sustainable yield that may be obtained while maintaining a fixed stock level (*X*) is equal to the natural growth *F(X)*. Consequently, under equilibrium or steady-state conditions, the sustainable yield is calculated using the following equation:

$$\boldsymbol{F(x) = H(E, X)} \text{ (Clark, 1990).} \tag{3}$$

Many times, it is considered that a fishery's harvest function is expressed as

$$\boldsymbol{H = (E, X) = qE^{\alpha}X^{\beta}} \tag{4}$$

where *E* is the effort, *X* is the stock biomass, *q* is the catchability coefficient, and α and β are parameters (Clark, 1990). If $\alpha = \beta = 1$, then,

$$\mathbf{H(E, X) = qEX.} \tag{5}$$

3.2.2 Schaefer Model

This model presupposes that biological growth adheres to the logistic growth function (Schaefer, 1954). Fishing effort (*E*) is assumed to be the aggregation of motorised canoes, and biomass (*X*) consists of a single species harvested by different gears and measured in tons. Formulas (2), (3) and (4) can be used to obtain

$$\boldsymbol{qEX = rX\left(1 - \frac{X}{K}\right),\ qE = r - \frac{rX}{K},\ X = K - \frac{KqE}{R}} \tag{6}$$

The yield that can be sustained at a particular level of effort is determined by

$$\boldsymbol{H(E) = qKE - \frac{q^{2K}}{r}E^2} \tag{7}$$

Where $\boldsymbol{\alpha = qk,\ \beta = q^2K}$ and the relationship between Catch Per Unit Effort (*CPUE*) and Effort (*E*) are linear, the equation written as

$$\boldsymbol{H = CPUE = \frac{H(E)}{E} = qk - \frac{q^2K}{r}E = a + bE.}$$

$$\boldsymbol{H = aE + bE^2\ .} \tag{8}$$

3.2.3 The Economic Function

Schaefer (1954) and Clark (1990) specified the fishery total cost (*TC*) and total revenue (*TR*) as follows:

$$\boldsymbol{TRt = \mathcal{P} * H(t);\ TC = c * Et,} \tag{9}$$

where, $\mathcal{P}$ is the constant price per unit of biomass harvested and c is the constant cost of effort per unit. The sustainable economic rent offered by the fishing resource at any given level of effort is the difference between the total sustainable revenue (*TR*) and total cost (*TC*). It can be expressed as

$$\boldsymbol{\pi t = TR(t) - TC(t).} \tag{10}$$

When equation (9) is substituted in equation (10), it can be written as

$$\boldsymbol{\pi t = \mathcal{P} * H(t) - c * Et} \tag{11}$$

The sustainable economic rent offered by the fishing resource at any given level of effort can be obtained by substituting Equation (8) into Equation (11):

$$\boldsymbol{\pi t = \mathcal{P}H - CE = (\mathcal{P}\alpha - c)E + \mathcal{P}\beta E^2.} \tag{12}$$

3.2.4 Refernce Points

I. Open Access Yield (Y_{OA})

Under an open-access scenario, fishermen will participate in the fishery until the marginal cost (MC) equals the average revenue (AR). The cost per unit effort, price, and catchability coefficient are used in this instance to define the open access stock biomass (X_{OA}):

$$\boldsymbol{MC = AR \leftrightarrow c = \frac{\mathcal{P}H}{E} = \mathcal{P}qXoA \leftrightarrow XoA = \frac{c}{\mathcal{P}q}} \tag{13}$$

The function used to estimate the effort and yield under open access conditions is given in Table 1.

Table 1: Function of Effort and Yield in open access

Model	Effort at Open access (E_{OA})	Yield at open access (Y_{OA})
Schaefer	$\boldsymbol{EoA = c - \frac{\mathcal{P}\alpha}{\mathcal{P}\beta}}$	$\boldsymbol{y_{OA} = \frac{C^2 - \mathcal{P}C\alpha}{P^2\beta}}$

II. Maximum Sustainable Yield (MSY)

By differentiating Equation (8), the efforts that generate the highest yield (E_{MSY}) and the Maximum Sustainable Yield (MSY) can be determined using these expressions (Table 2).

Table 2: E_{MSY} and MSY for Schaefer Models

Model	Effort at MSY (E_{MSY})	MSY
Schaefer	$\boldsymbol{EMSY = -\frac{\alpha}{2\beta} = \frac{r}{2q}}$	$\boldsymbol{MSY = -\frac{\alpha^2}{4\beta} = \frac{rK}{4}}$

III. Maximum Economic Yield (MEY)

At the equilibrium point, where the fishing effort generates the largest economic rent (E_{MEY}), the maximum economic rent (*MEY*) is obtained by differentiating Equation (12) with respect to Effort (*E*). The results are presented in Table 3.

Table 3: Function of Effort and maximum economic yield

Model	Effort at MSY (EMEY)	MEY
Schaefer	$\boldsymbol{E_{MEY} = \frac{c - \mathcal{P}\alpha}{2\mathcal{P}\beta} = \frac{r(\mathcal{P}\alpha k - c)}{2\mathcal{P}^2\beta}}$	$\boldsymbol{MEy = \frac{C^2 - \mathcal{P}^2\alpha^2}{4\mathcal{P}^2\beta} = \frac{r(\mathcal{P}^2q^2k^2 - c^2)}{4\mathcal{P}^2q^2k}}$

3.2.5 Catch per Unit Effort (CPUE)

To quantify fishing effort, the total number of active motorised canoes engaged in the harvest of *S. maderensis* each year was considered. Metric tonnes were used as the unit of measurement for harvested *S. maderensis* (biomass). *S. maderensis* (Flat bony) is mainly caught by using gill nets, and seine nets. For the fishing effort of different gears, there is a need to standardise the harvest and convert it to a relative catch per unit effort. The method of Spare and Venema (1998) was used to standardise the *CPUE*.

$$\boldsymbol{CPUE_{it} = \frac{y_i t}{fit}\ ,\ \overline{CPUE} = \frac{\sum_{t=1}^{T} CPUE_{it}}{T},\ R_{it} = \frac{CPUE_{it}}{\overline{CPUE}},\ R_t = \frac{\sum_{i=1}^{n} R_i t * y_{it}}{\sum_{i=1}^{n} y_{it}}} \qquad (14)$$

When:

y_{it} represents yield of gear *i* in year *t*,

f_{it} is the effort of gear *i* in year *t,*

$CPUE_{it}$ is the catch per unit effort of gear *i* effort in year *t*,

$\overline{CPUE}$ is the average catch per unit of gear *i* effort from the period of the first year to year *T*,

R_{it} is the relative catch per unit of gear *i* effort in year *t*, and

R_t represents the sum of relative catch per unit of effort weighed by the yields of *n* gears in year *t*

3.3 Data and Parameters for estimating the model.

The production of fish for local consumption and income generation for livelihoods are two factors that make small-scale fisheries a vital sector in Liberia. Approximately 11,000 full-time fishers and 22,000 fish processors and traders rely on small-scale fisheries for their livelihood (Chu, Garlock, Sayon, & Anderson, 2017; Drammeh, 2007). *S. maderensis* made up 34% of the total landings of the small-scale fisheries in 2022 (Figure 8). *S. maderensis* is harvested mainly by motorised (Fanti) canoes using gill nets and seine nets as gears. The Fanti canoes target small pelagic species such as Sardinella spp., *Cheilopogon melanurus*, and *Chloroscombrus chrysurus* (Jueseah, Dadi, Tómasson, & Knutsson, 2020).

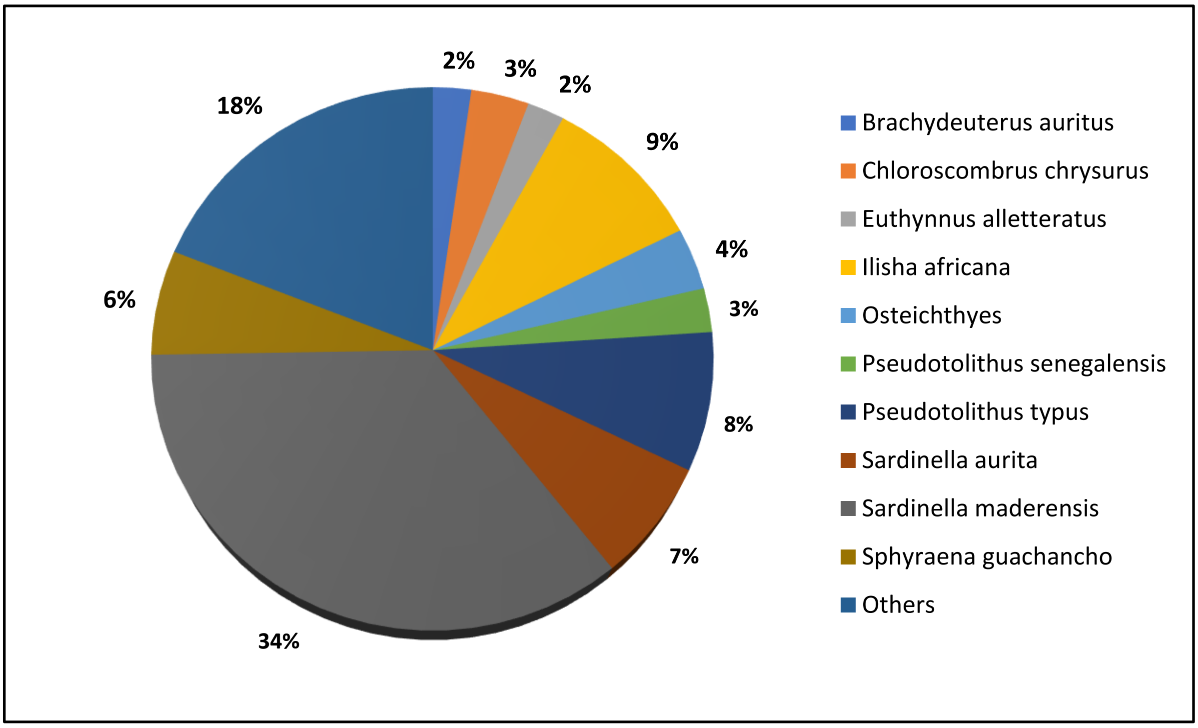


Figure 8: Liberia small-scale fisheries species landings in 2022. Data Source: NaFAA

For this project, annual catch and fishing effort time series data of *S. maderensis* from the Research and Statistics Division of the National Fisheries and Aquaculture Authority (NaFAA) for the period of 2018 to 2022 were used. There have been reports of inconsistencies in small-scale fisheries data collection, limited training for data collectors, and existing challenges in entering sampling data into databases in Liberia (Wilson, 2019). Because there were some gaps in the data due to inaccurate data sampling, the project used two approaches to analyse the data with the Schaefer Model: Aggregated and Disaggregated. The Aggregated approach considered the accumulated landed data of *S. marderensis* for each year and counted the missing values as zeros. The aggregated five-year data provide five observations of catch per unit effort (CPUE) that fluctuate with the increase and decrease of effort (Figure 9).

For the disaggregated approach, the five years data were arranged in a panel data set structure based on three geographical locations, the southeastern, westeastern, and the western regions, and considered the missing values to meet the conditional expectations. Over the analysis period, the CPUE displayed inconsistent behaviour without a clear trend. In contrast to the aggregated approach, the disaggregated approach makes the fluctuations of CPUE and Effort more obvious. The diverse qualities of the boats can partially explain these variations in CPUE.

The number of boats in operation that exhibited fluctuations can also help explain the CPUE behaviour.

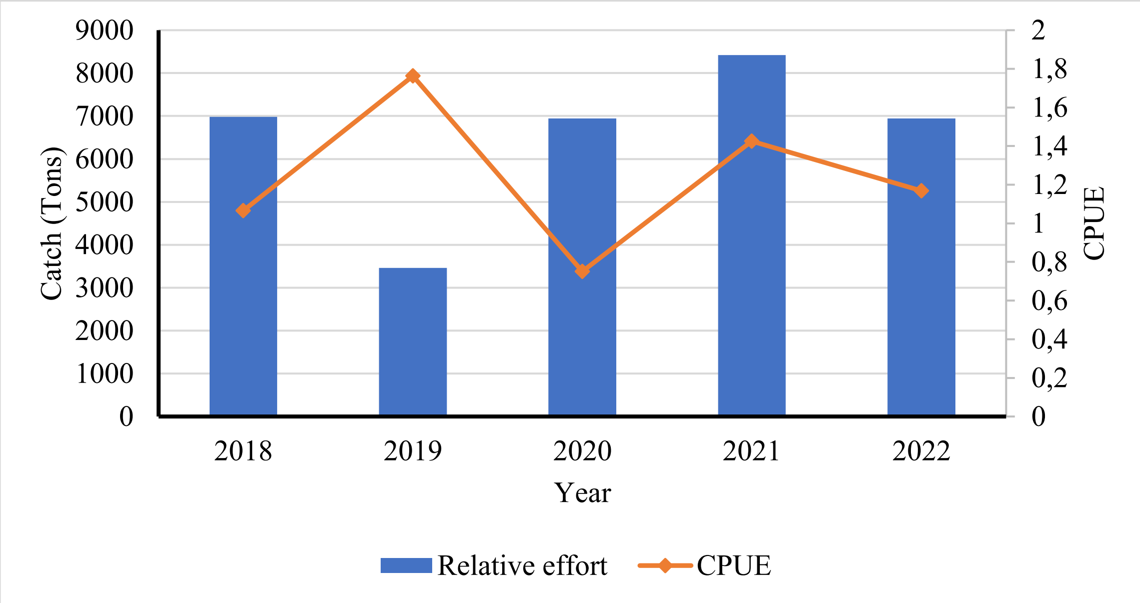


Figure 9: Aggregated CPUE against relative effort

S. maderensis is a schooling pelagic species that is landed in the nine coastal counties of Liberia. Each region is made up of three counties. Grand Kru, Maryland and Sinoe counties made up the Southeastern region, Grand Bassa, Margibi and Rivercess counties made up the Westeastern region, while the Western region contain Bomi, Grand Capemount and Montserrado counties. The dataset was divided into three regions for each year into a Panel pooled regression model to provide more observations. The observations show that an increase in effort resulted in a decrease in CPUE and vice versa (Figure 10). Panel analysis examines the dynamics of change using brief time series when sufficient cross-sections are observed repeatedly (Yaffee, 2003).

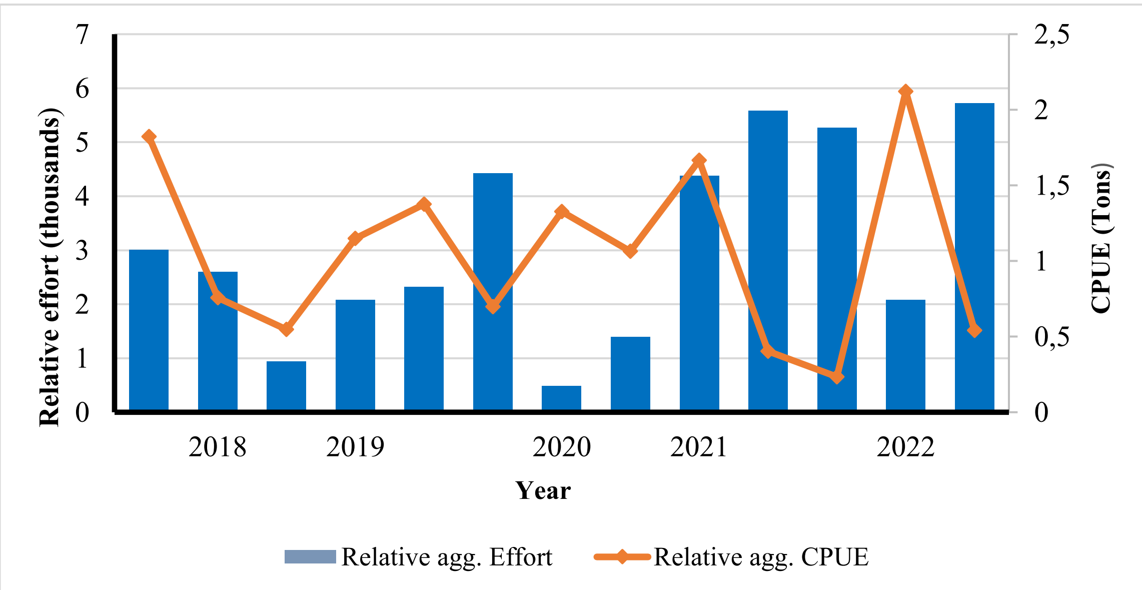


Figure 10: Disaggregated CPUE against relative effort. Source: Author's calculation

The data of the two major gear types, gill nets and seine nets, used to harvest the species were aggregated into relative effort to represent fishing effort. Between 2018 and 2022, 69% of *S. maderensis* landings were harvested by gill nets, 28% by seine nets, and 3% by other gears (Figure 11).

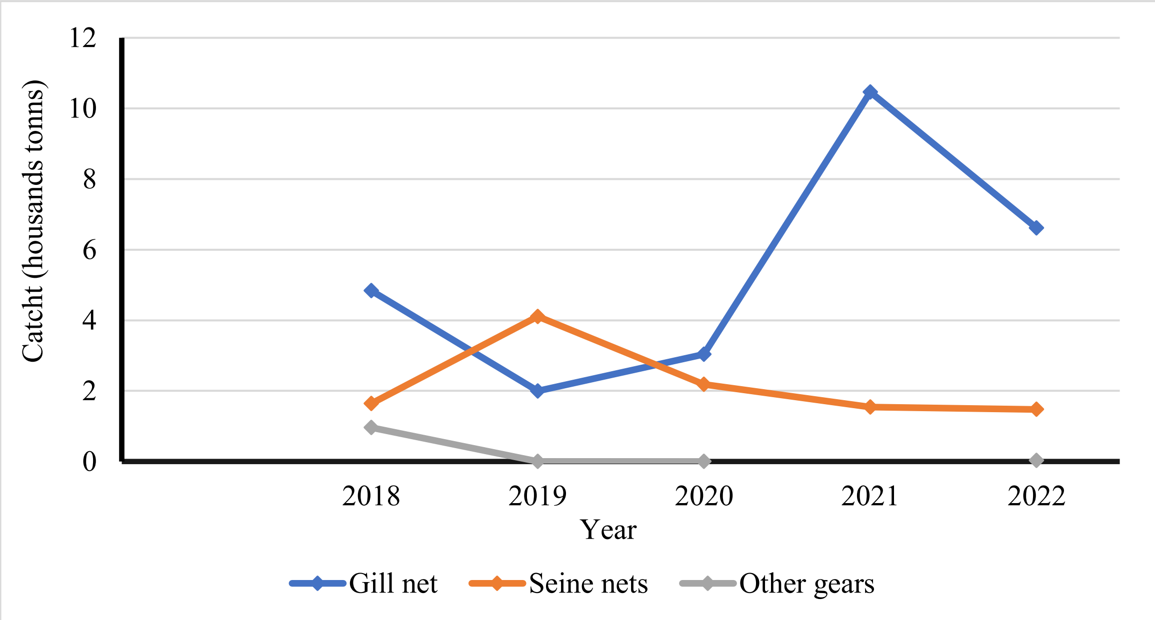


Figure 11: Harvest of *S. maderensis* by gill nets and Seine nets on the coast of Liberia from 2018 to 2022. Data source: NaFAA

The basic economic data needed for the model were the unit price (landed value of 1 kg of *S. maderensis*) and the unit cost (cost for landing one 1Kg of *S. madernsis*). This project determined the unit price of *S. maderensis* based on the landed value provided in the annual report of the Research and Statistic Division of the National Fisheries and Aquaculture Authority (NaFAA, 2021). The price was determined using Equation (9) and converted to United States dollars (USD) at the Central Bank of Liberia's exchange rate of 150 Liberian dollars (LRD) to one USD. The total cost of a motorized Fanti small-scale fisheries canoe for a year which includes cost of boat, outboard engine, gear, license fees, and depreciation was found to be thirteen thousand nine hundred twenty United States dollars (US$13,920) (Jueseah, Dadi, Tómasson, & Knutsson, 2020). The cost per unit of effort was estimated based on the yearly cost for each boat and the yearly landed catch data. See Table 5 for detailed economic data.

Table 4: Economic parameters.

***S. maderensis* Fleet**	**Total Cost Per unit effort (US$1000 Ton^{-1})**	**Price wet-whole fish (US$1000 Ton^{1})**
Fanti boat (Motorized)	1.2255	1.6

4 RESULTS

4.1 Parameters

The catch data of *S. maderensis* from gill and purse seine nets were combined into a single catch to generate management target reference points. The catches and efforts of gill nets and purse seines (number of boats) were normalised and converted to relative aggregated effort and relative aggregated CPUE, as reported by Spare and Venema (1998), since *S. maderensis* is predominantly caught by two major gears. The statistical summary of the catch, effort, and CPUE time series data of both aggregated and disaggregated approaches for the *S. maderensis* fishery in the artisanal fisheries of Liberia from 2018 to 2022 is shown in Tables 5 and 6. The aggregated data have five observations, while the disaggregated data contain 13 observations. The catch and effort statistics from the disaggregated technique had standard deviations that were 17% and 3% (Tables 5 and 6) higher than those from the aggregated approach. However, the standard deviation of the disaggregated CPUE data was 35% (Tables 5 & 6) larger than that of the aggregated data. This study used 2022 as the base year. Table 7 provides the aggregated and disaggregated catch and effort information for the *S. maderensis* fishery for base year 2022.

Table 5: Aggregated data summary statistics of Catch, Relative effort and CPUE of *S. maderensis* fishery on the coast of Liberia

Parameter	Number of observations	Mean	Standard deviation	Minimum value	Maximum value
Catch (MT)	5	7334.26	2493.77	4954.1	11360.17
Effort (Relative effort)	5	6549.82	1837.10	3464.71	8417.07
CPUE	5	1.23	0.38	0.75	1.76

Table 6: Summary statistics of Catch, Effort, and CPUE disaggregated data of the *S. maderensis* fishery on the coast of Liberia from 2018 to 2022.

Parameter	Number of observations	Mean	Standard deviation	Minimum value	Maximum value
Catch (Tons)	13	2820.87	2068.96	508.92	7347.13
Effort (Relative effort)	13	3100	1789.96	486	5724
CPUE	13	1.054	0.586	0.235	2.12

Table 7: Current (2022) aggregated and disaggregated catch and effort data of *S. maderensis* fishery

Approach	Relative Effort	Catch (tons)
Aggregated	6946	7910.92
Disaggregated	13076	7910.92

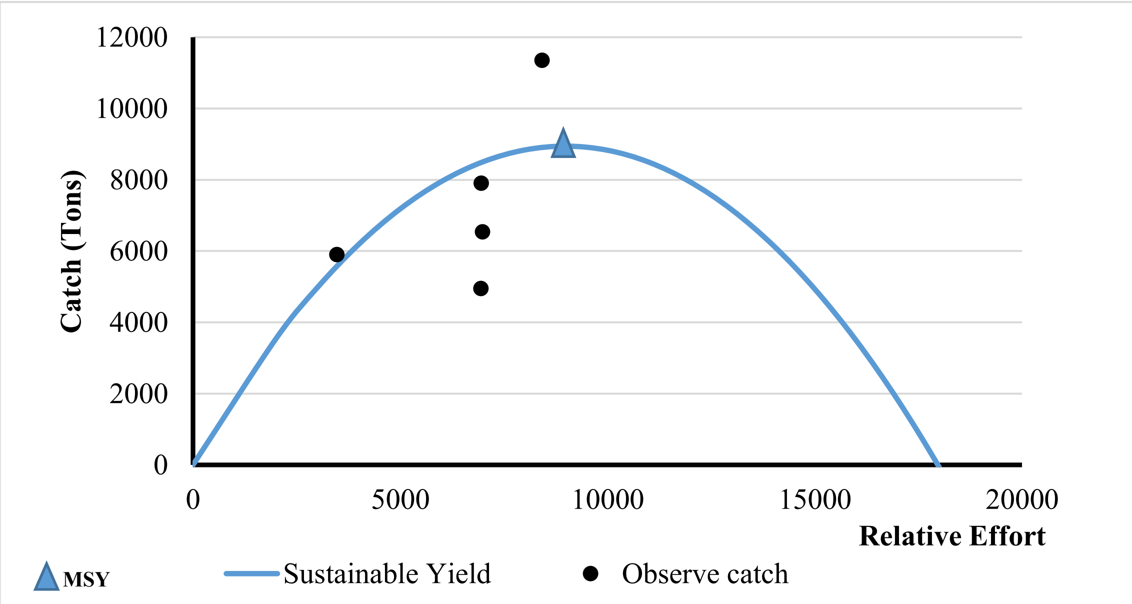
The Schaefer model's α and β parameters for equation (8) were determined via linear regression analysis of the catch and effort data (Table 8). The two approaches aggregated and disaggregated analysis confirm that there is a negative correlation between CPUE and effort. The slope coefficients were -1.11E-04 and -1.39E-04 for aggregated and disaggregated data, respectively. The P-values showed that the coefficients were different from zero at a 95% significance level. The R^2 values of 0.30 and 0.21 indicate that approximately 30% and 21% of the CPUE variations in the aggregated and disaggregated approaches are explained by the Schaefer model, respectively.

Table 8: Regression analysis output and calculated parameters of the Schaefer model

Approach	Variable	Coefficients	Standard Error	t-Stat	P-value	
Aggregated	Alpha (α)	1.99E+00	0.805	2.47	0.13	R^2: 0.30
	Beta (β)	-1.11E-04	0.00012	-0.92	0.45	*F statistic*: 0.84845083
Disaggregated	Alpha (α)	1.42E+00	0.303	4.70	0.00085	*R^2: 0.21*
	Beta (β)	-1.39E-04	8.45E-05	-1.65	0.131	*F statistic: 2.711*

4.2 Model Results

The equilibrium yield graphs derived from the model against effort for the aggregated and disaggregated approaches are shown in Figures 14 and 15. Essential reference points, (MSY), the effort at which the maximum sustainable yield was obtained (E_{MSY}), MEY, and the effort at which the maximum economic yield was achieved (E_{MEY}) for *S. maderensis* were estimated. The blue triangle and black dots in Figures 14 and 15 show the MSY point and the annual catch statistics of *S. maderensis* that were used to determine the sustainable yield for the aggregated



and disaggregated data, respectively.

Figure 12: Aggregated Sustainable yield modelled and catch of *S. maderensis*.

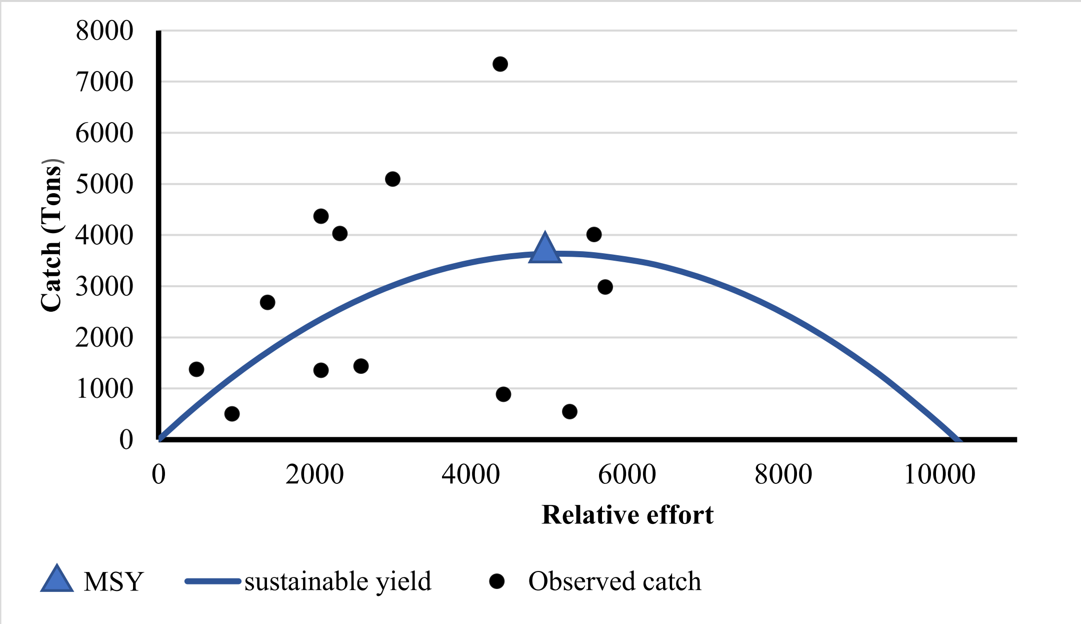


Figure 13: Disaggregated Sustainable yield modelled and catch of *S. maderensis*.

Figures16 and 17 demonstrate the Schaefer model total revenue (TR) and total cost (TC) against effort and the open access equilibrium point (E_{OA}). In contrast to the disaggregated approach, the aggregated approach places the open-access equilibrium point farther from the MSY point.

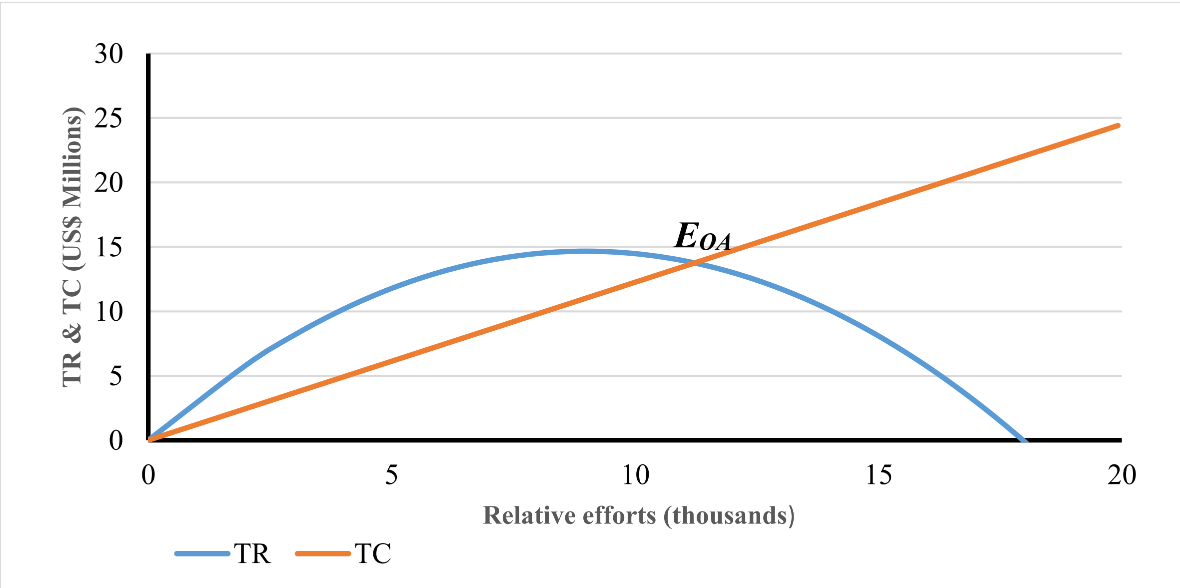


Figure 14: TR and TC against aggregated relative effort.

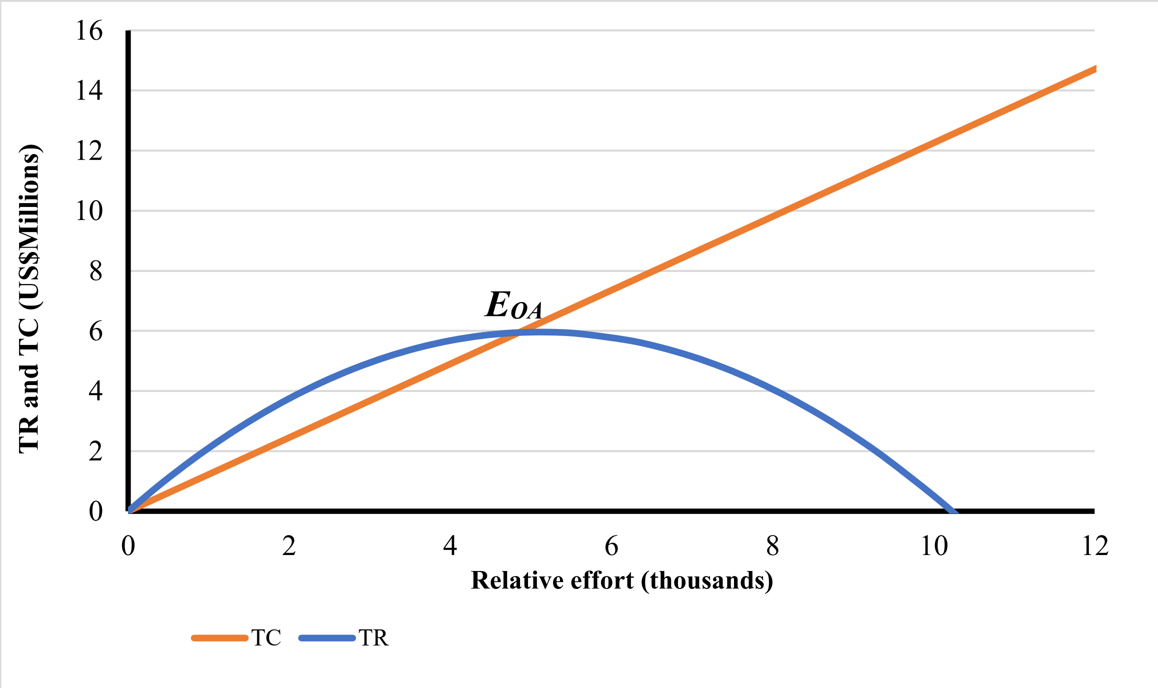


Figure 15: TR and TC against disaggregated relative effort

The estimated open-access yield (Y_{OA}), MSY, and MEY of the aggregated and disaggregated data, as shown in Table 9, differed by 23%, 18%, and 28%, respectively.

Table 9: Aggregated and disaggregated Catch Reference Points

Approach	Y_{OA} (Tons)	MSY (Tons)	MEY (Tons)
Aggregated	8388.58	8943.61	7682.95
Disaggregated	10880.85	10909.39	5515.65

The aggregated and disaggregated data, as shown in Table 10, were different by 23%, 41%, and 23%, respectively, in terms of the estimated relative effort at Open Access (E_{OA}), the relative effort relating to MSY (E_{MSY}), and the relative effort corresponding to the MEY (E_{MEY})

Table 10: Aggregated and disaggregated effort Reference Points

Approach	E_{OA} (Relative effort)	E_{MSY} (Relative effort)	E_{MEY} (Relative effort)
Aggregated	11223	8985	5611
Disaggregated	14557	15342	7279

As indicated in Table 11, the Total Cost (TC) of the aggregated data was 47% lower than that of the disaggregated data, and the Total Revenue (TR) was unchanged. Although the disaggregated data had a negative resource rent, the resource rent (RR) of the aggregated data amounted to 48% of the cost for the current year, 2022.

Table 11: Summary of the estimated economic status of *the S. maderensis* fishery for the current year (2022).

Approach	Total Cost Year^{-1} (US$ Millions)	Total Revenue Year^{-1} (US$ Millions)	Resource Rent Year^{-1} (US$ Millions)
Aggregated	8.51	12.970	4.46
Disaggregated	16.02	12.9705	-3.05

Source: Author's calculation

The computed cost at MSY, revenue at MSY, and profit at MSY for the aggregated data were 41%, 18%, and 59% lower than those of the disaggregated data, respectively, as shown in Table 12. Additionally, the cost and profit at MEY for the aggregated data were 24% and 98% lower than those for the disaggregated data, respectively. However, the revenue at MEY for the aggregated data was 45% greater than the cost at MEY, whereas the revenue at MEY for the disaggregated data was negative.

Table 12: Estimated Economic variables at catch reference points.

Approach	Cost at MSY (US$ Millions)	Revenue at MSY (US$ Millions)	Profit at MSY (US$ Millions)	Cost at MEY (US$ Millions)	Revenue at MEY (US$ Millions)	Profit at MEY (US$ Millions)
Aggregated	11.011	14.66	3.65	6.88	12.60	5.72
Disaggregated	18.8	17.89	8.92	9.043	-0.915	0.123

5 DISCUSSION

5.1 Model Estimation

The Schaefer model predicted appropriate economic outcomes and valid biological parameters for the *S. maderensis* fishery in the coastal waters of Liberia using aggregated and disaggregated data approaches. In addition, the model had statistically significant coefficients that made the results credible. Data limitations for catch and effort were short (Figures 12 and 13) which made it difficult to achieve model accuracy. *S. maderensis* is a small pelagic schooling fish distributed in the Guinea current extending from Mauritania to the coast of Senegal (Ba et al., 2016). The significant results estimated by the model indicate that there is less fishing pressure on the stock of *S. maderensis*; however, exploitation is close to the maximum economic yield in the coastal waters of Liberia. The stock of *S. maderensis* being fished less means that the estimated MSY for both aggregated and disaggregated data was higher than the current year (2022) catch landing (Table 7). Furthermore, the economic optimum condition is because the cost of unit effort is relatively high compared to the price of unit landed fish (Table 4). The results are similar to those of a study which indicated that the pelagic fisheries of Liberia are underutilised (Jueseah, Dadi, Tómasson, & Knutsson, 2020). Other studies, Wehye and Amponsah (2017) reported that *S. maderensis* was being harvested closed to maximum sustainable yield and there was presence of growth overfishing while Yokie (2020) concluded that there was recruitment overfishing on the stock of *S. maderensis* in the coastal waters of Liberia. However, the information utilised for the model was obtained over a short period. These findings may not accurately reflect the global changes in fisheries. The reference points generated by the model solely reflect local conditions. The catch and effort reference points in this study were determined using a model to account for practice-based uncertainty.

5.2 Reference Points

The output from the model revealed that the fishery's open access yield (Y_{OA}) and MSY of both the aggregated and disaggregated data were 6%, 12%, and 27% higher than the current (2022) catch of 7910.92 tons (Table 7). The estimated relative efforts corresponding to the open-access yield and MSY for the aggregated data were 38% and 23% larger than the current (2022) relative effort, 6946. As for the disaggregated data, the estimated efforts corresponding to the open access yield and MSY were 10% and 15% higher than the current (2022) effort, 13076 (Table 13). When the amount of fishing effort exceeds what is necessary to harvest a fish stock at its MSY, the fish stock is biologically unsustainable (Parven, Haque, Hossain, & ASM, 2021). The model results indicate a biologically sustainable stock of *S. maderensis* in the coastal waters of Liberia.

S. maderensis is one of the pelagic fish species that is popular and highly valued on the local market of Liberia. This study examined its possible economic profitability by determining the economic target reference points. The targeted economic reference points, MEY and E_{MEY}, were estimated for the aggregated and disaggregated data as 7682.95 tons and 5611 relative efforts and 5515 tons and 7279 relative efforts, respectively. In addition, the estimated MEY and E_{MEY} for the aggregated data were 3% and 19% lower than the current (2022) catch, 7910.92 tons and 6946 relative efforts. As for the disaggregated data, the MEY and E_{MEY} were 30% and 44% lower than the current catch and relative effort (Table 13).

The results indicate the current Total Revenue (TR) and resource rent for the aggregated data to be 12.970 and 4.46 million United States dollars (Table 10), respectively. The total revenue for the disaggregated data was 12.9705 million United States Dollars, and there was a negative resource rent. However, the cost at MSY was higher than the total revenue at MSY for disaggregated data (Table 12).

From the two approaches, aggregated and disaggregated results, the aggregated analysis presents a profitable *S. maderensis* fishery, while the disaggregated analysis does not. The results suggest an increase in efforts to achieve MSY and MEY; however, the study found that what is needed to achieve the target reference points is technological advancement of efforts.

Table 13: Comparison of estimated target reference points to current (2022) catch and effort data of *S. maderensis* fishery.

Estimated Variable	Aggregated	Difference	Current (2022) Catch & Effort	Disaggregated	Difference	Current (2022) Catch & Effort
MSY (Tons)	8943.61	12%>	7910.92	10909.39	27%>	7910.92
E_{MSY} (Relative effort)	8985	23%>	6946	15342	15%>	13076
Y_{OA} (Tons)	8388.58	6%>	7910.92	10880.85	27%>	7910.92
E_{OA} (Relative effort)	11223	38%>	6946	14557	10%>	13076
MEY (Tons)	7682.95	3%<	7910.92	5515.65	30%<	7910.92
E_{MEY} (Relative effort)	5611	19%<	6946	7279	44%<	13076

The *S. maderensis* fishery is less profitable because the cost of unit effort is relatively high compared to the price of unit catch (Table 4) which shrinks the profit margin in the disaggregated analysis (Figure 11). The high cost of unit effort in the *S. maderensis* fishery is associated with the ineffectiveness and inefficiency of artisanal Fanti boats used to harvest the species in the coastal waters of Liberia. The results confirmed a previous report that the artisanal Fanti fleets were inefficient and needed to be improved technically (Jueseah, Tómasson, Knutsson, & Kristofersson, 2021). Improved fleet capability management in Europe and North America has helped major fishing fleets perform well, financially and economically (FAO, 2022). Another reason for the high cost can be linked to the social responsibility of the fishery to provide jobs for fishing community residents. The lack of alternative employment activities has caused an overcapacity of artisanal Fanti boats, thus increasing costs. For instance, a technologically advanced fish trawler that measures 25 to 30 meters required about 3-8 people as crew (Voices of the Bay, 2011), but the case is not the same with the artisanal fleets of *S. maderensis* fishery in Liberia. The artisanal Fanti boat measured 10-15 meters but has 12–20 crew members (Chu, Garlock, Sayon, Asche, & Anderson, 2017). The cost of unit effort will tend to be high, and unprofitable fisheries will occur in artisanal pelagic fleets with crews exceeding the ideal level (Mayala, 2018).

The high cost per unit of effort also means a relatively low price per unit of catch. The unit price of a whole landed fish is determined by several factors, including its size and spoilage.

Spoilage conditions occur in whole landed fish based on how the fish are stored or caught (Ali, Jampada, & Gaya, 2008). As mentioned in the literature review, *S. maderensis* is caught using gill and purse seine nets (Figure 8). Based on their inefficiencies, Fanti canoes deploy gill nets and return to recover those nets 12-24 hours. Fish caught by gill nets often die after a long stay and deteriorate (Potter & Pawson, 1991), causing spoilage and reducing price.

Size is usually a crucial factor to consider when determining the price of landed fish (Sjoberg, 2015). The unit price of *S. maderensis* may be relatively low due to its landed size. The length of the first capture of *S. maderensis* is approximately 10 inches (Balde et al., 2019). Wheye and Amponsah (2017) and Yokie (2020) reported growth and recruitment overfishing of *S. maderensis* stock in the coastal waters of Liberia, respectively. Growth overfishing occurs when fish are harvested at a smaller size below the size that could produce a higher yield per recruit, while recruitment overfishing occurs when smaller fish are caught before reaching maturity (Parven, Haque, Hossain, & ASM, 2021). In conclusion, the price of fish will be appreciated based on their size and condition.

5.3 Policy and Management of *S. maderensis*

5.3.1 Current Management regulations

S. maderensis like all other fish species in the marine artisanal fisheries of Liberia is managed in accordance with the regulations relating to fisheries, fishing, and related activities for the marine fisheries sector of Liberia and the Fisheries and the Aquaculture Policy and strategy of Liberia. Amongst the objectives of these instruments are the sustainable management of the vast fishing potential to support social, economic, and environmental benefits and the restoration of important suggestive fish species to MSY levels, ensuring the sustainability of production and enabling fisheries to contribute to local economies. Fisheries regulations provide the use of gears with mesh sizes greater than 50 mm and prohibit the use of monofilament nets. To catch *S. maderensis*, fishers mostly utilise monofilament gill nets and purse seine nets of various sizes (Yokie, 2020). The use of illegal monofilament gill nets has been reported as the main problem impeding the sustainability of artisanal fisheries in Liberia (Dunbar, Mungai, & Muthee, 2021). However, in recent years, the Fisheries Authority has banned monofilament nets.

The measures mentioned in the fisheries regulations are directed toward input-controlled fisheries management. Input control in fisheries management is when fishing efforts in a fishery are controlled by input constraints such as fishing capacity, gear design, areas, seasons, and times (Bellido, Sumaila, Sanchez-Lizaso, Maria, & Pauly, 2019). Input controls are crucial managerial tools for fishing because they are easily quantified. However, it does not always work well. Every time a new input regulation is implemented, especially one that the fishing industry is hesitant to embrace, there are attempts to hedge the regulation or mitigate its effects. For example, Yokie (2020) reported that there is no doubt that fishermen are not adhering to the gear size limitations set forth by the fisheries rules, which results in a *S. maderensis* catch that contains an excessive number of young fish on the coast of Liberia.

5.3.2 Complementary Management measures

Fisheries regulations are imposed to support policies intended to accomplish certain goals. Fisheries Regulations can be divided into two categories: input controls, which are used to regulate fishing efforts, and output controls which are used to regulate catch. The two types of controls are further subdivided into direct and indirect controls. Direct input controls include licencing mesh size restrictions and close seasons, and direct output controls include the quota system, total allowable catch (TAC), and minimum duration of fishing time. Indirect input control is to impose entry tax, and indirect output control is to levy landing tax (Nguyen, 2006). Direct input controls are the main management measures in Liberia's fisheries sector. However, these measures are more rigorous in the marine industrial fisheries than in the marine artisanal fisheries, an open-access fishery (Jueseah, Dadi, Tómasson, & Knutsson, 2020).

The use of multiple management control measures for sustainable fisheries has proven to be effective when input information for policy decisions is not working, and a larger barrier against uncertainty is offered by combining many principal direct fishing control measures rather than by just one type of fishing control measure (Stefansson & Rosenberg, 2005). There have been challenges in the full implementation and enforcement of direct control regulations in Liberia's fisheries sector. The inclusion of close zones in the management plan can also help with effort control, and combining catch quotas with restricted areas can prevent the collapse of fish stocks and maintain both short- and long-term economic gains. In brief, the combination of aspects of input and output controls can be a suitable management strategy to sustain *S. maderensis* stock in the coastal waters of Liberia.

5.4 Limitations and further research

The outcomes were obtained using straightforward models with a short period of time series data, which might not have adequately captured the changing aspects of a complex system. It is important to consider how *S. maderensis* interacts with other species in the ecosystem. To obtain more accurate estimations of the model parameters, it is also necessary to investigate better ways to evaluate effort. To improve proposal regulations, it is also necessary to conduct further research on how to advance efforts and the costs and benefits of doing so to achieve the target reference points of management.

6 CONCLUSION AND RECOMMENDATIONS

Small-scale fisheries are a crucial sector in Liberia because they produce fish for local use and provide revenue for subsistence purposes. Most of the small-scale fishery catches are small pelagic fishes. A small pelagic species known as the flat bony (*S. maderensis*) is primarily caught by small-scale fisheries employing motorised (Fanti) canoes equipped with gill and seine nets. In this study, surplus production models were applied to the aggregated and disaggregated catch and effort data of *S. maderensis* in the artisanal fisheries of Liberia to evaluate management target reference points. The National Fisheries and Aquaculture Authority (NaFAA) research and statistics division provided annual catch and fishing effort time series data for *S. maderensis* from 2018 to 2022. A panel dataset structure based on the three geographic regions was used to provide more observations.

The Schaefer model appears to forecast adequate economic results and reliable biological characteristics for the *S. maderensis* fishery in the coastal waters of Liberia. Furthermore, the results were believable because the model contained statistically significant coefficients, even though the accuracy of the model was hampered by the limited amount of data available for the catch and effort. These outcomes may not accurately depict the global changes in fisheries. The model's reference points solely represent local conditions. In this study, the model estimated catch and effort reference points from aggregated and disaggregated data to account for practice-based uncertainty. Management target reference points, such as MSY and MEY, are necessary for fisheries management policy formulation. The restoration of significant fish species to maximum sustainable yield levels, ensuring the sustainability of production, and enabling fisheries to contribute to local economies are some of the goals of fishery regulations and policies in Liberia. The current fishery management strategy involves direct input control measures.

The model results for both the aggregated and disaggregated data showed that the fishery's open-access yield was greater than the current (2022) catch. The findings indicate a biologically sustainable stock for *S. maderensis* in the coastal waters of Liberia because the aggregated and disaggregated targeted MSY for the species was 12% and 27% higher than the current landing catch, and the relative efforts (E_{MSY}) corresponding to the MSY was 23% and 15% above the current (2022) relative efforts. By identifying the economic target reference points of *S. maderensis*, this study analysed its potential economic profitability. The results of the calculated MEY and E_{MEY} economic reference points of the aggregated and disaggregated data were 3% and 30% and 19% and 44% lower than the current catch and current relative efforts, respectively. The findings show that the present (2022) Total Revenue (TR) and Resource Rent (RR) of the aggregated data are 12.970 and 4.46 million US dollars, respectively. For disaggregated data, the total revenue is the same as the aggregated data with negative resource rents. Furthermore, the cost at MSY was greater than the total revenue for the disaggregated data, indicating a fully exploited economic condition for the *S. maderensis* fishery.

The two approaches of data analysis, aggregated and disaggregated, were used to account for missing values within the dataset and show similarities and differences in the outcomes. The treatment of missing values in the data can determine the size of the estimated Maximum Sustainable Yield (MSY). In this study, the missing values were treated in the aggregated data as zeros and in the disaggregated data to meet conditional expectations or averages.

The study discovered that technological development of efforts and improvement in managem ent methods are required for the achievement of the target reference points, however the result s obtained imply increase of current efforts to achieve MSY and MEY. The *S. maderensis* fishery is exploited close to MEY because the cost of unit effort is relatively high compared to the cost of unit catch, which reduces the profit margin. The high cost per unit of effort in the *S. maderensis* fishery is attributed to the ineffectiveness and inefficiency of the artisanal Fanti boats employed to harvest the species in the coastal waters of Liberia. In conclusion, the results of both the aggregated and disaggregated data showed that the biological management target reference points, MSY and E_{MSY}, were greater than the current (2022) catch landing, indicating less fishing pressure on the S. maderensis stock, and exploitation is closed to management economic target reference points, MEY and E_{MEY}.

Several recommendations can be made to enhance fishing management strategies based on the study's evaluations. First, combining input and output control management techniques, such as close seasons and effort restrictions, is advised to create sustainable fishing practices. Second, by implementing efficient and productive fishing technology, the fishing process can be made more effective while reducing unfavourable effects on the marine ecosystem. Third, reducing the burden on marine resources can be accomplished by providing coastal residents with alternatives to fishing as a source of income. Furthermore, the current gear mesh size standards must be strengthened and enforced to guarantee the sustainable use of fishing gear. Finally, boosting data-gathering programs can help increase the precision and dependability of the information gathered for decision-making processes. In general, following these suggestions can promote sustainable fishing methods, guarantee the long-term survival of marine ecosystems, and sustainably manage the fishery resources of Liberia in accordance with the United Nations sustainable development goals number 14.4.

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