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EVALUATING THE SUSTAINABILITY AND POTENTIAL OF COASTAL FISHERIES IN LIBERIA: A BIO-ECONOMIC ANALYSIS

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ABSTRACT

Liberian coastal waters support both pelagic and demersal fisheries, providing essential resources for local communities. However, increasing pressure on fish stocks, particularly due to the rise in artisanal fishing vessels, raises concerns about potential declines in harvests. This study assesses the sustainability of Liberia's coastal fisheries using a surplus-production bio-economic model under the CMSY (Catch-Maximum Sustainable Yield) approach to estimate management reference points. A mixed approach used disaggregated data to describe SSF and employed CMSY to aggregate the data, both of which were secondary data. An analysis of the disaggregated data revealed that more Fanti vessels were sampled. In addition, the results showed that SAE (Flat bonny) was the species most caught by Fanti, while ILI (Gbapleh) was the species most caught by Kru. Furthermore, seasonal patterns were observed along the catch composition varieties for different periods within the sampled year. Using catch and effort data from 2001 to 2021, the CMSY model estimated abundance based on catch per unit effort (CPUE). The results suggest a low depletion rate (0.35–0.65) based on prior initial relative biomass (B/k) estimates. Furthermore, the stock displayed medium resilience (0.3–0.68) as classified by CMSY. The study found that the maximum economic yield (MEY) closely aligns with the maximum sustainable yield (MSY), indicating low fishing costs and that the pelagic fishery is approaching full exploitation.

Key Words: Coastal fisheries, bio-economic analysis, CMSY model, sustainability assessment, Liberia, fisheries management.

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1 INTRODUCTION

1.1 Background

Liberia is in West Africa within the Mano River basin which includes Guinea, Sierra Leone, and Cote D' Ivoire. As a coastal state, fishing activities are carried out within the coastal perimeters of nine (9) counties which run from Grand Cape Mount in the Southwest to Cape Palmas, Maryland County in the Southeast. Liberia is fronted along the shores of the Atlantic Ocean. Liberian waters are consistently warm, between 26^0 and 28^0 °C, with low salinity and nitrogen levels (32%), thanks to the Guinea surface waters (FAO, 2017). Liberia also has a 200 Nautical Miles (NM) Exclusive Economic Zone (EEZ) and a total land space of approximately 111370 Km^2 (FAO, 2017). The EEZ has also been stratified with a 6 NM Inshore Exclusive Zone (IEZ) reserved exclusively for small-scale fisheries. Recent estimates have placed Liberia´s population at approximately 5.4 million (Worldometer, 2024). Fisheries is a major supply of protein and work for many Liberians living along the coast (Belhabib, Sumaila, & Pauly, 2015). According to the Food and Agriculture Organization (FAO), the average per capita consumption of fish by Liberians is 4.8 kg/year, with the sector employing over 33,000 people both directly and indirectly (Ministry of Agriculture, 2014).

Liberian coastal waters contain important resources for both pelagic and demersal fisheries (Jueseah, 2022). Liberian fisheries consist of coastal fisheries and offshore fisheries which mainly target tuna species. Coastal fisheries comprise industrial vessels and artisanal fishing vessels of Kru and Fanti descent which target shallow, medium, and large pelagic and demersal species (Ministry of Agriculture, 2014). This Liberian sector contributes approximately 10% of the GDP (Belhabib , Sumaila, & Pauly, 2015). There are no restrictions on the number of days that the artisanal fisherfolk can operate. However, they are mostly restricted by the weather during the rainy season. While they use a variety of fishing techniques, Kru canoe operators primarily fish in the shallow and deep waters with hook and lines, longlines, gill nets, cast nets, and traps, and above the "thermocline" targeting demersal fish species like cassava fish, butter-nose, and sole fish and below the thermocline species such as groupers, snappers, and grunters. Large ring nets are mostly used by Fantis to catch small pelagic species, such as Atlantic flying fish, bonny, and porjoe (Jueseah, 2022).

Blue food is an important source of protein in Liberia. Daily Liberian diets contain blue food obtained from the Liberian coastal fishery. However, fish consumption by Liberians is regarded as one of the lowest in the region (4.8 kg) (USAID, 2015). While tiny pelagics make up over 80% of the Fanti landed value and shallow water demersals make up less than 5%, shallow water demersals account for approximately 60% of the Kru landed value. Therefore, Kru operators rely primarily on shallow water demersals, which have traditionally required much work, whereas the economics of the Fanti fleet are primarily dependent on small pelagic stocks (Arnason, 2016).

The industrial coastal fishery consists of bottom- and mid-water trawlers that target demersal fish and shrimp populations, with an average gross registered tonnage of 180 (Juseah, Tomasson, Knutsson, & Kristofersson, 2021). Many trawlers are owned by foreign companies and work in partnerships with fishing organisations registered in Liberia (MRAG, 2013).

Since 2010, there has been an increase in the number of small-scale vessels (SSV), mainly Kru canoes, owing to the profitability of fisheries as a result of the imposition of the 6 nm IEZ (Arnason, 2016), while the Fanti canoe seems to have a relatively stable increase in the number of boats (Juseah, Tomasson, Knutsson, & Kristofersson, 2021). This increase in the number of SSV is reportedly contributing to reduction in the average amount of landings for these vessels in recent years (NaFAA, 2018)

When it comes to fishing and determining the boundaries of fish stock exploitation, management reference points such as the maximum sustainable yield (MSY) are essential tools for fisheries management (Arnason, 2016). The MSY is the maximum allowable yield for a given time for the overall biological stock. Using the available data on fisheries catch and effort, non-equilibrium surplus-production models were used to evaluate the condition of these fish stocks in the Liberian Seas.

1.2 Rationale

It is believed that over half of the population, including many rural populations, women, and young people, depends on fishing for their livelihoods to some extent. Fish make up approximately 65% of the animal protein consumed in the nation, solely because of its availability and substantially lower cost compared to meat or chicken. Nevertheless, the average annual consumption per person is approximately 4 kg, which is far less than the 17 kg average for other coastal states in sub-Saharan Africa and the 22 kg average for the entire world

(Ministry of Agriculture, 2014). Liberia imports cheaper small pelagic species for domestic use, despite having abundant fish resources (Ministry of Agriculture, 2014).

Coastal fisheries in Liberia are conducted along the continental shelf with four (4) out of the six (6) stocks assemblages of finfish contributing the most to landed catch (Arnason, 2016). Numerous marine fish species exist in the continental shelf region of Liberia (Ministry of Agriculture, 2014). Some of the world's best fishing grounds are found in Liberia's nine coastal counties (Figure 1), which greatly benefit the country's economy, nutrition, and means of subsistence. Approximately 10% of Liberia's GDP currently comes from the fishing industry. Approximately three million people are employed in the fishing industry along the coast of West Africa. Approximately 33,000 people work full-time, and thousands work part-time in Liberia's fishing industry (WACPFC, 2023).

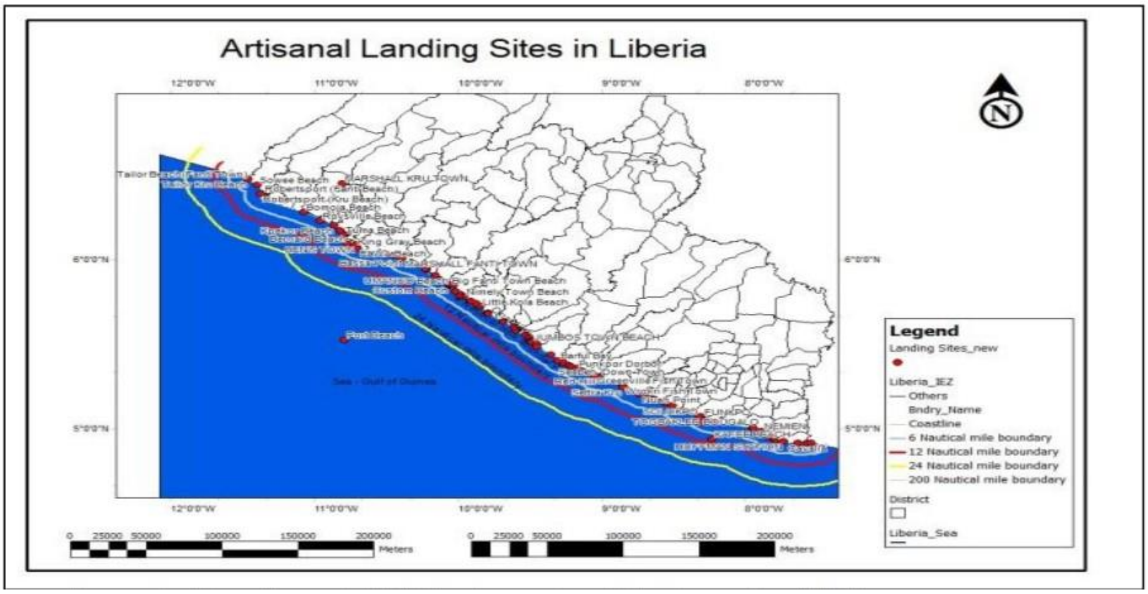

Figure 1. Map of Liberia showing landing sites in nine (9) coastal counties. Source: NaFAA Artisanal Survey 2020.k

Arnason (2016) reported that medium and small pelagic fish were being mildly and moderately exploited, respectively. However, the report revealed that both demersal stocks, whose estimated stock sizes are one-third of their carrying capacities, are severely overexploited. Therefore, the report stated that expert advice in 2014 should be for no increase in the amount of fishing effort to allow stocks to recover. However, it was realised that owing to the profitability of fisheries for small-scale fleets, the number of fleets continued to increase. Jueseah (2021) also emphasised the need to reduce or phase out small-scale fishing.

While there are efforts to manage small-scale fisheries and to ensure that the fisheries become more profitable, and against policy advice for the fisheries authorities to keep the 6 nm restriction as an operating space for small-scale fisheries, the Government of Liberia issued Executive Order #84, reducing the IEZ from 6 nm to 3 nm (WACPFC, 2023). The Liberian fisheries policy adopted in 2014 seeks to

> *…provide increased profitable fisheries employment opportunities while offering an enabling environment for upgrading technical skills for enhanced value-added fisheries vocations; engage participatory fisheries management institutions based on community and stakeholder structures for the creation of opportunities for socio-economic development; contribute to Gross Domestic Product, national food and nutritional security, and improving living conditions by upgrading and adopting appropriate, modern, and efficient fisheries capabilities for increased fish production while reducing losses through illegal fishing; and derive net benefits from a vibrant fish trade supported by value addition systems and fisheries infrastructure for fish landing and export, as well as efficient fishing input supply and distribution systems.* (Ministry of Agriculture, 2014).

Recently, Liberia signed a $40 million United States Dollars (USD) agreement with the World Bank under the Liberia Sustainable Management of Fisheries Project (LSMFP) "*to improve fisheries management and enhance livelihood and income for government and targeted beneficiaries"* (World Bank, 2024).

With reports of increasing pressure on fish stocks especially from the increase in the number of Artisanal boats which could lead to decline in harvests (Jueseah et al, 2020), this and with limited data to support scientific analysis of the status of the various stock assemblages; this project sought to evaluate the sustainability of the coastal fisheries in Liberia using the Schaefer surplus production model under the CMSY approach to estimate reference points for management.

Liberian fisheries have been assessed using surplus models by Arnason (2016), Jueseah (2020 & 2021), and Johns (2023), and none employed the CMSY approach under a surplus production model. As the current project runs in Liberia, the CMSY model deployed a subtle approach by considering the current state of the fish population, based on the foundation of achieving Sustainable Development Goal 14 (SDG 14) Life beneath Water. It ascertained the ideal catch levels that consider the unique circumstances of the fishery, which could result in more flexible and cautious management techniques.

1.3 Objectives

This project evaluated the sustainability of coastal fisheries in Liberia using the surplus dynamic bio-economic model under the (CMSY) approach to estimate reference points for management.

Specific Objectives:

1. Use disaggregated data to describe the status of Liberian coastal fisheries
2. The maximum sustainable yield (CMSY)
3. Determine the maximum economic yield
4. Estimate the maximum efforts required to produce the maximum sustainable yield
5. Suggest appropriate management options for the sustainability of coastal fisheries in Liberia

2 LITERATURE REVIEW

2.1 Structure of the Liberian Fisheries Sector

The 570 km coastline of Liberia includes an exclusive economic zone (EEZ) that stretches 200 nautical miles offshore and is composed of comparatively mild, low-nutrient seas. The continental shelf has an average width of 34 km, and its broadest portion is in the central region of Liberia, stretching from Côte d'Ivoire to Robertsport. The six nautical miles nearest to the shore were designated as an inshore exclusion zone (IEZ), and trawling was not permitted. The IEZ is used only for subsistence, artisanal, and semi-industrial fishing activities (Ministry of Agriculture, 2014).

2.1.1 Coastal Fisheries and its importance in Liberia

Coastal Fisheries in Liberia are conducted along the continental shelf. There are two subdivisions of Liberian coastal fisheries: Industrial and Artisanal. The artisanal fisheries, also described as small-scale fisheries, are also sub-divided between non-motorised vessels which are mostly owned by Kru fisherfolks, and motorised vessels owned by the Fanti fisherfolks from Ghana.

2.1.2 Coastal Industrial Fisheries

The Ministry of Agriculture (MoA) and the Bureau of National Fisheries (BNF, 2010) have described industrial vessels weighing varying lengths between 50 and 200 gross reference tons (GRT).

> "*Industrial fishing" means any large-scale fishing or related activities using an industrial fishing vessel. Industrial fishing vessel means a decked fishing vessel with an internal engine with a capacity greater than 100bhp that is greater than ninety feet in length*" (BNF, 2010).

Marine industrial fisheries can be separated into two categories: offshore large pelagic fisheries and trawl fisheries for shrimp and demersal finfish, which supply refrigerated whole fish and shrimp for the market at home. The diverse demersal fishery is not doing its best right now. It uses antiquated and occasionally broken ships, machinery, ports, and processing facilities in an atmosphere that frequently puts workers' safety at risk and pollutes the environment (Ministry of Agriculture, 2014). Many demersal finfish, including croakers, grunts, threadfins, seabreams, sea perches, and others, as well as coastal penaeid shrimps, are the target of industrial trawl fisheries (FAO, 2024) and important contributors to the value of the industry (Ministry of Agriculture, 2014).

Since 2018, six (6) registered industrial vessels have mostly been foreign owned. Coastal trawlers are prohibited from fishing within the 6 nm IEZ (BNF, 2010). Coastal trawlers employ shallow- and mid-water trawls targeting demersal species outside the IEZ (MRAG, 2013). Liberian fisheries regulations (2010) require fisheries observers to be deployed on industrial vessels. "*Each vessel makes three to four hauls per day. The fisheries observer samples every haul and records data on species type, location, depth of the ocean, discards, and retained catch"* (Johns, 2023).

Recent data on industrial catch showed fluctuations, with an increase in catch for 2019 of an estimated 22,000 metric tons (MT), partly due to the large exit from the industry as a result of enforcement by fisheries authorities of the 6 nm IEZ policy (Figure 2). However, preceding years have shown deep declines, mainly attributed to COVID-19. Since the emergence of IEZ restrictions, industrial fleets have declined.

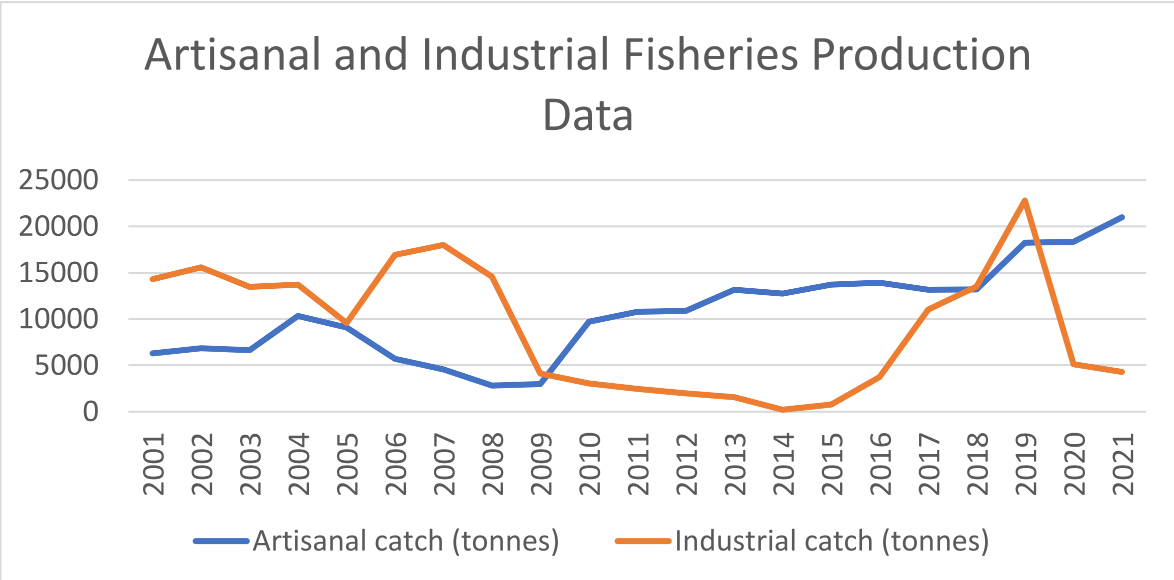

Figure 2. Artisanal and Industrial fisheries production. Source-NaFAA

2.1.3 The Coastal Marine Small-scale Fisheries

This fishery, which is made up of semi-industrial, artisanal, and subsistence subsectors, supports over 33,000 full-time fishermen and processors in nine coastal counties: Grand Cape Mount, Montserrado, Grand Bassa, Sinoe, Grand Kru, Rivercess, Margibi, Bomi and Maryland (Ministry of Agriculture, 2014). The 2010 fisheries regulations reserve six (6) NM IEZ exclusively for this fishery. "*Artisanal fishing vessel" means any fishing vessel, canoe or un-decked vessel of not more than sixty feet which is motorised or un-motorised, powered by an outboard or inboard engine with a capacity not exceeding 40bhp, sails or paddles, used for artisanal fishing in the Fisheries Waters*" (BNF, 2010). The 579 kilometers of coastline in Liberia is home to coastal settlements where the SSF is carried out (Figure 3). Kru canoes are locally made, usually non-motorised, and range in length from 5 to 7 m, while Fanti boats are larger, usually propelled by outboard or inboard engines (Jueseah , Ogmundur, Kristofersson , & Tomasson , 2021). Using a variety of fishing gear in coastal waters, Kru can primarily target demersal fish species such as grunters (*Pomadasys spp.),* cuta (*Barracuda spp.),* solefish (*Cynoglossus spp.),* groupers (*Epinephalus spp.),* snappers (*Lutjanus spp.),* and some crustaceans (mostly crabs and lobsters) (MRAG, 2013).

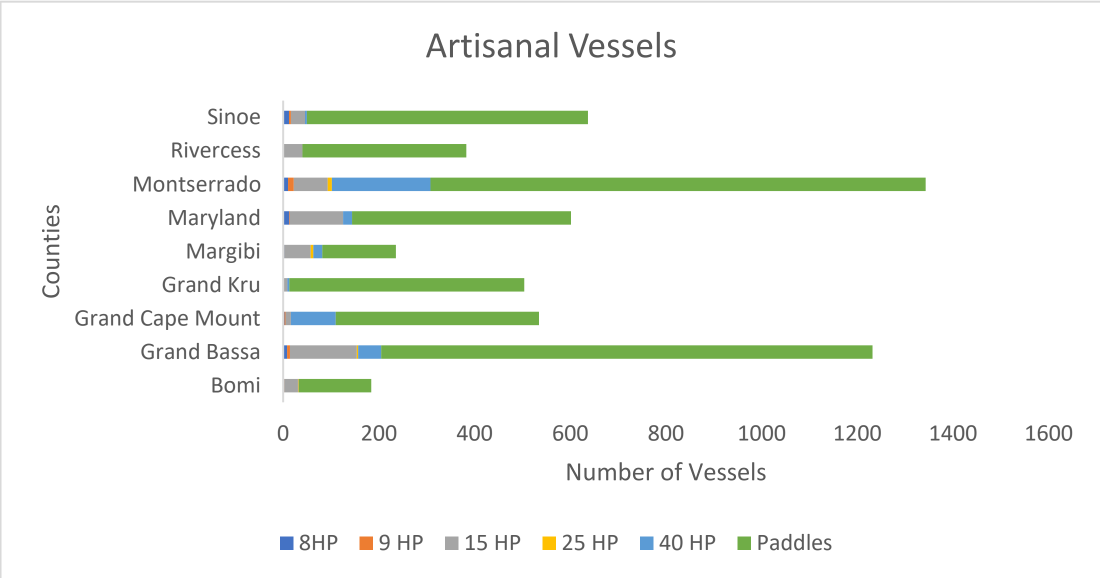

Figure 3. Artisanal vessels by county. Source: NaFAA Artisanal Frame Survey, 2020

Although these little dugout canoes can hold a crew of up to three men, the Kru fisherman often fishes alone. With sails or paddles, Kru canoes fish all day long, taking off in the morning on an offshore wind, and returning in the afternoon on an onshore wind. Along the continental shelf, fishing grounds available to the Kru people are restricted (NaFAA, 2020). Compared to the Kru, the Fanti fishermen, who are primarily from Ghana, use more sophisticated fishing techniques. They live under one enclosure and work in groups of up to 20 men. Fanti fishermen have made their homes in several fishing spots around the coast of Liberia, including Sinoe, Grand Bassa, Montserrado, and Maryland (NaFAA, 2020). In the coastal seas, the Fanti boats typically use ring nets to catch small pelagics such Atlantic flying fish (*Cheilopogon melanurus*), porjoe (*Chloroscombrus chrysurus*), and bonny (*Sardinella spp.)* The domestic economy receives all the SSF's catch (Juseah et al., 2021). Based on the fishing data (Figure 2), the SSF catch has been increasing rapidly, especially in Kru fleets. The SSF has continued to increase since 2010 with the emergence of IEZ regulations. Thus, since fisheries seemed profitable, SSF boats have increased over time. The SSF catch increased from over 9000 MT in 2010 to over 20, 000 MT in 2021.

The type of fishing craft utilised, depth of the water, and season all affect artisanal fishing. In choppy seas, fishermen using a dug-out Kru canoe cannot function. In addition, seasonal variations in the quantity of overfished stocks and capture and catch rates affect the fishing patterns. Thus, fishermen can be seen as working full-time or part-time. Artisanal fisheries in Liberia are still in their infancy. Bonga, sardinella, croakers, and carangids are the target species that canoe fisherman capture (NaFAA, 2020).

2.2 Management of Liberian Coastal Fisheries

To guarantee the sustainability of fish production from Liberia's fisheries management units and to enable fisheries resources to significantly contribute to local economies, fisheries authorities aim to take steps to restore the biomass capacities of the major indicative fish species to levels that can yield maximum sustainable yields (BNF, 2010). In order to maintain the efficiency of the resources and accomplish other fisheries goals, the FAO defined Fisheries Management as the "*entire process of gathering data, analyzing it, planning, consulting, making decisions, allocating resources, and creating and enforcing regulations or rules that control fisheries activities*" (Cochrane, 2002). Even though Liberia's industrial fisheries industry has been around for decades, efforts to regulate fisheries only got underway in 2009. Significant progress has been made since the introduction of the West Africa Regional Fisheries Project (WARFP): the creation of a legislative foundation for the industry and the release of Liberia's initial fisheries legislation currently functions as a manual for appropriate fisheries management (Davis, 2018).

Liberia uses input control to manage its fisheries. An input control fisheries management system limits the amount of fishing that can be performed in a given area, season, capacity, and time (Johns, 2023). Input control for the industrial sector is carried out through licencing, relying on the 2010 fisheries regulations which may be either allotting quotas or fishing gear, mesh size, or other regulations as determined by the fisheries authorities as a management regime. Furthermore, the fisheries regulations (2010) for the management of SSF in compliance with any restrictions that may be specified, fishing rights must be granted before artisanal fisheries licenses can be issued. These rights may also specify the usage of specific types of vessels, gear, or fishing areas that are subject to the right. A fishing right may only be held for a maximum of 15 years, after which it will automatically expire and return to the state to be redistributed in compliance with applicable laws and regulations.

2.2.1 Pelagic Fisheries

According to NaFAA statistics, since 2013, the capture of coastal pelagics has fluctuated between 11,000 and 27,000 tons. This difference is approximately four times higher than that reported by FAO, which is likely due to the lack of high-quality data on Liberian fisheries. According to research, pelagic populations in Liberia's coastal waters are moderately to lightly exploited (Jueseah, 2021).

According to Arnason (2016) the pelagic fisheries are sub-divided into small pelagic which is a focus of the SSF using "multi-gears" including gill-nets, ring-nets, set-nets, etc. and the primary species are Atlantic flying fish (*Cheilopogon melanurus*), which is a significant seasonal fishery for both Fanti and Kru fishermen, porjoe (*Chloroscombrus chrysurus*), which is targeted by Fanti fishermen, and porjoe (*Sardinella spp*.), which is taken by Kru fishermen; medium pelagic which consists of "*Barracuda species (Sphyraena spp.) of importance to Liberia's fisheries includes Sphyraena barracuda (Great Barracuda), S.guachancho and S.Sphyraena (Pike Fish)*"; and large pelagic which consist of Tuna and Tuna-like species within the Liberian Exclusive Economic Zone (EEZ).

2.2.2 Demersal fisheries

The demersal fisheries include shallow demersals with which the primary species that the small-scale fishing industry targets are butternose (*Galeoides decadactylus*) and cassava fish (*Pseudotolithus* spp.), though there have also been reports of significant captures of sea bats and *mobulid* rays (*Mobulidae*). In addition, *pseudolithus* is maintained in industrial trawl fishing. For the industrial demersal trawlers, a variety of shrimp species, including *Penaeus notialis*, *Parapenaeus longirostris*, and P. *Atlantica*, constitute a valuable commercial catch (Arnason, 2016). Deep water demersals consisting of "small *quantity of groupers (Epinephalus spp.) and snappers (including Lutjanus monostigma and L.johnii) are taken by Kru fishers using hook and line. While these species are potentially valuable, they are potentially vulnerable to over-exploitation*" (Arnason, 2016).

2.3 Surplus Production Model

In fisheries science and management, the surplus production model is used to evaluate the sustainable yield of a fishery based on the availability of surplus biomass. The model assists in determining the highest point at which long-term fishing can be performed without contributing to overfishing or fish population depletion. The surplus production model is frequently used when determining the condition of fish stocks and directing fisheries management decisions (Arnason, 2016).

The Maximum Sustainable Yield (MSY) concept, which denotes the greatest quantity of fish that may be collected without endangering the population's long-term survival, is commonly linked to the surplus production model. The foundation of this concept is the hypothesis that fish populations produce more than is required to sustain the current stock size (Zhang, 2020). The Schaefer model is the most popular surplus production model that can be used to determine fisheries management reference points, such as maximum sustainable yield (Arnason, 2016).

The basic surplus production model equation is often expressed as:

$$R = r * B * \left(1 - {}^{B}/_{K}\right) - M * B$$

Where:

- R is the surplus production (potential catch),
- r is the intrinsic growth rate,
- B is the biomass of the fish population,
- K is the carrying capacity, and
- M is the natural mortality rate.

However, fisheries management aims to harvest a portion of surplus production to maximise sustainable yield while ensuring that the population remains healthy and viable. The surplus production model is often used iteratively in fisheries assessment and management, adjusting fishing efforts or quotas based on the observed changes in stock size and fishing mortality (Beverton & Holt, 1957; Larkin , 1977). There are assumptions about the model which should be considered (Hilborn & Walters, 1992; Holt, 2009) It is important to note that the surplus production model is a simplified representation of the dynamics of fish populations, and real-world fisheries are influenced by various ecological, environmental, and human factors. Advanced stock assessment models may incorporate more complexity, considering age structure, spatial distribution, and environmental variability, to provide more accurate and realistic estimates for sustainable fisheries management (Pella & Tomlinson,, 1969).

To enhance and account for some of the uncertainties of the MSY model and become more flexible in incorporating other factors, researchers have deployed the Monte Carlo Catch at Maximum Sustainable Yield (CMSY) approach. The CMSY model offers a more sophisticated method that considers the current situation of the fish population. It seeks to ascertain the ideal catch levels that consider the unique circumstances of the fishery, which could result in more flexible and cautious management techniques (Nguyen & Tran, 2023).

Few studies have focused on analysing the coastal marine fisheries in Liberia. In a study conducted by (Arnason, 2016), the status of the artisanal fisheries in Liberia was examined using bioeconomic concepts. They concluded that small- and medium-sized pelagic fish were both moderately and weakly fished, and pelagic stock complexes were in excellent health overall. In comparison, it was discovered that the two demersal stocks, with sizes estimated at one-third of their carrying capacity, were severely overexploited. Similarly, Jueseah et al. (2020) analysed the coastal fisheries of Liberia. The findings indicated that all fish stocks in Liberia's coastal waters, apart from shallow water demersals, seem to be underutilised and inadequately invested.

2.4 CMSY Description

(Froese, Demirel, Coro, Kleisner, & Winker, 2017) described the CMSY model used by (Nguyen & Tran, Management of MultiSpecies resources and multi-gear resources, 2023). Accordingly, Froese *et al.* (2017) explained that using data on capture and species resilience, CMSY calculates biomass, exploitation rate, MSY, and associated fisheries reference points. They further used a Monte Carlo technique to screen probable ranges for the highest intrinsic rate of population growth (r), and untapped population size or carrying capacity (k) were screened to identify "viable" r-k pairings.

Moreover, in contrast to the Catch-MSY or MSY approaches, CMSY looks for the most likely r in the triangle's tip area rather than the centre. This is predicated on the fundamental idea that defines r as the population under study's maximal rate of growth, which falls between the highest feasible r-values (Froese, Demirel, Coro, Kleisner, & Winker, 2017).
The predictions of the CMSY method are validated by comparing them with simulated data, which include known biomass data and parameter values. The predictions of the CMSY method are compared against matching parameters and abundance estimations produced from completely or partially assessed stocks, where biomass or catch-per-unit effort (CPUE) data

are provided in addition to catch data for comparison with real-world fisheries (Nguyen & Tran, Management of MultiSpecies resources and multi-gear resources, 2023).

- The CMSY model considers uncertainties which include Process uncertainties **(**the term "process uncertainty" in the CMSY (Catch-at-Maximum Sustainable Yield) model refers to the unpredictability surrounding the biological and ecological processes that control fish populations. This kind of uncertainty recognises that a variety of factors affect the dynamics of fish populations, and that our knowledge of these processes may be incomplete or variable. The process uncertainty of the CMSY model is frequently considered when determining sustainable capture limits and evaluating the health of fish stocks).
- Observational uncertainty: Data collected to assess fish populations, such as biological parameters, abundance estimates, and capture statistics, may contain biases, errors, or limitations.
- Model Uncertainty: Sustainable capture levels are determined in fisheries science using the CMSY model, a stock evaluation method. Model uncertainty acknowledges that different models can provide different outputs and conclusions, depending on how decisions and hypotheses are changed.
- Implementation Uncertainty: This level of uncertainty recognises that the effective implementation of fisheries management strategies may face a number of obstacles and that factors outside the scope of the model itself may affect the effectiveness of interventions.

Jueseah et. al. (2020) used the bio-economic model based on the surplus production model to assess the coastal fisheries and found that shallow water demersal were overharvested and many other species underharvested. This was based on the 2010 regulations imposed by the government. The study also found that Fanti fleets were technically inefficient. Furthermore, the research found that there was high profitability in 2016 which was mostly concentrated in the SSF (Jueseah, Kristoferson, Tomasson, & Knutsson, 2020). Johns used a bio-economic surplus production model to assess the management of coastal fisheries in Liberia and found that the Sardinella maderensis stock (a pelagic species) was biologically sustainable (Johns, 2023). Another study conducted by Jueseah et al. (2021) assessing the seasonal flows and economic benefits in Liberia found that the wet season saw less effort from fishermen, which is why the amount of fish traded during the dry season was approximately six times greater than that during the rainy season (Jueseah, Ogmundur, Kristofersson, & Tomasson, 2021). A recent scientific survey of demersal fisheries showed that the catch and number per unit effort of the species found in this zone were 292 kg/h and 4003 individuals/h, respectively. The data indicate that yields are higher in shallower coastal zones (0–30 m) than in deeper waters (101-200 m), and research also notes that abundance decreases with depth. The report also showed that the estimated biomass for the current year (22,708 tons) was lower than that in 2007 (27,068 tons) (Thiam & Sarre, 2023).

Froese et. al. (2017) estimating fisheries reference points from catch and resilience in data limited stock when compared to BSM projections for actual stocks or verified using "true" values of simulated stocks, CMSY's predictions are surprisingly accurate (Froese, Demirel, Coro, Kleisner, & Winker, 2017). In an analysis of management of multi species and multi-gear fisheries in Vietnam, results indicate that the prior ranges for the r parameters are medium (0.2-0.6) and preceding relative biomasses (B/k) for start, intermediate, and end biomass are medium (0.2-0.6) and low depletion (0.4–0.8) (Nguyen & Tran, 2023). Nguyen (2011) found that surplus production is adaptable to complicated periodic analyses, accounting for uncertainties in fisheries.

3 METHODOLOGY

3.1 Research Location

This study focused on all landing sites in nine (9) coastal counties of Liberia (Figure 4). There are 114 landing sites for SSF spread across the Atlantic coast of Liberia. SSF activities are conducted along the continental shelf of Liberia which spread across the nine (9) counties with codes uniquely identifying the location and region of the landing site ranged from 100 – 900 (Grand Cape Mount (100), Bomi (200), Montserrado (300), Margibi (400), Grand Bassa (500), Rivercess (600), Sinoe (700), Grand Kru (800) and Maryland (900)).

Figure 4. Map of Liberia Showing the nine (9) coastal counties. Source: Author´s contribution based on knowledge of landing sites.

3.2 Collection, Description, Structuring, and Filtering of disaggregated data

3.2.1 Collection of Data

A mixed-method approach was adopted to achieve this objective. Secondary data (aggregated (2001-2021) and disaggregated (2015-2024)) showing artisanal landings submitted by enumerators from the nine (9) coastal counties were obtained from the NaFAA Division of Statistics. The data represent samples from landing sites and vessels across the Atlantic coast of Liberia. Data were obtained from enumerators spread across the coast based on the selection of sampling sites. The SSF vessel sampling data and their respective catch compositions were obtained from 63 (55.3%) of 114 landing sites (Bomi-2, Grand Cape Mount-5, Montserrado-7, Margibi-5, Grand Bassa-13, Rivercess-3, Sinoe-14, Grand Kru-8, and Maryland-6).

3.2.2 Description and Structuring of Data

The data is a direct submission of various vessels and their catch composition submitted by enumerators through electronic means by an application (APP) known as “NASIAPP”. The APP can reportedly function in both online and offline modes. Catch records obtained from the sampled landing vessels were submitted through this APP. The submitted data are therefore received, indicating the dates and time of submission (beginning and ending dates and time), device ID, SIM ID, site date, site major and minor strata, site enumerator, site fishing unit, site-trip duration, site fish yesterday, site fish before, site number of days fished, site longitude and latitude Geographical Positioning System (GPS) altitude and accuracy coordinates, Meta-instance ID, Key, submitter name and ID, species, catch weight, price, total value, Parent Key and Key 2. Once received, the data were restructured to display the unique start and end dates, as well as the start and end times of the submission.

3.2.3 Data filtering

The data are uniquely organised according to the start and end dates, as well as the start and end times. However, the data did not include vessel ID which made it practically impossible to identify the individual SSF vessels that were sampled. Although the submissions did not include individual vessel ID, looking deeply into the raw data, we discovered a unique pattern of difference that separated one vessel catch from the other. We observed a unique flow of pattern between the **start time** and **end times**, **longitude** and **latitude GPS coordinates**, and the **KEY2 column** (indicating the catch composition by number for each vessel uniquely tied into the longitude and latitude GPS and start and end time). Using this flow, we observed that for the data years **2015, 2020, 2021, 2022, 2023, and 2024** (up to February), 17,638 vessels were sampled. However, during filtering, we also observed some vessels with the same species but with different catchweights and prices. Therefore, we considered those categories of observations as different species based on the differences in their values and catchweights and assigned similar unique numbers to the individual vessels. The differences in the prices of these species indicate their quality.

3.1 CMSY Model

3.1.1 Data analysis

To determine various reference points, we used the Monte Carlo method (CMSY) and a Bayesian State-space implementation of the Schaefer production model (BSM). By utilising catch data, resilience, and qualitative stock status information, these models proved to be especially beneficial in determining reference points for stocks with little data. By applying these methods, we can alleviate skewed estimates of stock size and productivity and loosen the equilibrium assumption in the Schaefer model (Nguyen & Tran, Management of MultiSpecies resources and multi-gear resources, 2023). A Bayesian state-space version of the Schaefer model (BSM) will be created by utilising catch and abundance data to forecast r, k, and MSY:

$$B_{t+1} = B_t + r\left(1 - {}^{B_t}/_{K}\right) B_t - C_t \quad (1)$$

Where:

B_{t+1} is the exploited biomass in the subsequent year t+1,

B_t: is the current biomass,

C_t: is the catch in year t, and

K: is the environmental carrying capacity.

$$B_{t+1} = B_t + 4\frac{B_t}{k} r\left(1 - \frac{Bt}{k}\right) B_t - C_t | \frac{B_t}{k} < 0.25 \quad (2)$$

3.1.2 Determining the boundaries of the r-k pairs

To ascertain previous r-ranges for the species undergoing evaluation, the "*proxies for the species' resilience*", as offered in (Froese, Demirel, Coro, Kleisner, & Winker, 2017), were converted to r-ranges (Table 1).

Table 1. Prior ranges for parameter r, based on classification of resilience.

Resilience	prior *r* range
High	0.6 – 1.5
Medium	0.2 – 0.8
Low	0.05 – 0.5
Very low	0.015 – 0.1

Following this exercise, a previous range for k was determined using three assumptions. Initially, the size of the unexploited stock (k) was greater than the maximum catch in the time series because of the low likelihood that a fishery will locate and capture every member of a previously unexploited stock in a single year.

The time series maximum catch was used to determine the lowest boundary of k. Additionally, the productivity of the stock determines the maximum sustainable catch, which is represented as a percentage of the biomass that can be harvested (FMSY). This link was explained by dividing the greatest catch by the upper and lower bounds of r and utilising these values as guidelines for the upper and lower limits of k. Finally, in severely reduced stocks, as opposed to mildly depleted stocks, the maximum catch represents a higher fraction of k.

$$k_{low} = \frac{\max(c)}{r_{high}}, k_{high} = \frac{4\,max(c)}{r_{low}} \quad (3)$$

Where:

max(C): is the maximum value in the catch series, and

k_{low} and k_{high}: are the lower and upper bounds of the previous range of k.

r_{low} and r_{high}: are the lower and higher bounds the range of r-values that the CMSY technique will investigate respectively.

$$k_{low} = \frac{2max(C)}{r_{high}}, k_{high} = \frac{12max(C)}{r_{low}} \quad (4)$$

where Equation 3 defines the variables and parameters.

Accordingly, "*Stocks with low prior biomass at the end of the time series were subjected to Equation 3, and stocks with high biomass were subjected to Equation 4. A 3-year moving average was used to smooth the catch data to lessen the impact of extreme captures*" (Froese, Demirel, Coro, Kleisner, & Winker, 2017).

3.1.3 Finding viable r-k pairs

Within the previous ranges for r and k, a random r-k pair is chosen in order to identify suitable r-k pairs (Table 2).

Table 2. Default of prior biomass (B/K) ranges for CMSY.

Very strong depletion	**Strong depletion**	**Medium depletion**	**Low depletion**
0.01 – 0.2	0.01 – 0.4	0.2 – 0.6	0.4 – 0.8

The expected biomass for the following years was then determined using Equations 1 or 2, with the starting biomass for the first year being chosen from the previous biomass range. Any of the following circumstances results in the discarding of an r-k pair, they include:

1. Fish stocks crash if the biomass is less than 0.01k;
2. The estimated biomass is found beyond the range of the previous biomass of the intermediate year;
3. The estimated biomass is found to be beyond the range of the final year.

The r-k pair and the estimated biomass trajectory are deemed viable and are stored for investigation if none of these conditions hold true (Froese, Demirel, Coro, Kleisner, & Winker, 2017; Nguyen & Tran, 2023).

The BSM and CMSY parameters were computed in relation to common fishery reference points in the following manner:

$$MSY = \frac{rk}{4} \tag{4}$$

Where:

MSY: is the Maximum Sustainable Yield, and

r = is the intrinsic growth rate.

The MSY-corresponding fishing mortality is:

$$Fmsy = 0.5r \tag{5}$$

the biomass that matches MSY is:

$$Bmsy = 0.5k \tag{6}$$

There are several methods to quantify fishing efforts in coastal fisheries, including total horsepower, number of fishing vessels, and fishing days. Usually, the biomass of the collected coastal species is expressed in tons (Nguyen & Tran, Management of MultiSpecies resources and multi-gear resources, 2023). This project considered catch and effort (CPUE) aggregated data which constitute the four major stock assemblages that are of high concentrations for coastal fisheries in Liberia. The relative catch per unit effort must be converted and standardised to compare fishing efforts across various types of boats. The following formulas adapted from (Nguyen & Tran, 2023) can be used to accomplish this.

$$CPUEit = \frac{yit}{fit}, \overline{CPUEi} = \frac{\sum_{t=1}^{T} CPUEit}{T}, Rit = \frac{CPUEit}{\overline{CPUEi}},$$

$$Rt = \frac{\sum_{i=1}^{n} Rit * yit}{\sum_{i=1}^{n} yit} \quad (7)$$

Where:

Y_{it}: yield of vessels i in year t

F_{it}: effort of vessels i in year t

$CPUE_{it}$: catch per unit of vessels i effort in year t

$CPUE_{i}$: average catch per unit of vessels i effort for the period from the first year to year T

R_{it}: relative catch per unit of vessels i effort in year t

R_{t}: sum of relative catch per unit of effort weighted by the yields of n vessels in year t

In this investigation, we employed a theoretical model to ascertain the ideal harvest time route that maximises subsequent functions (Nguyen & Tran, Management of MultiSpecies resources and multi-gear resources, 2023).

Using the Schaefer model analysis applied by (Nguyen, 2011) to determine the Total Revenue (TR) and Total Cost (TC) functions:

$$TR(t) = p * H\big(E(t), X(t)\big) \quad (8)$$

$$TC(t) = c * E(t) \quad (9)$$

Where p is the price per unit of harvest and c is the cost per unit of effort. The profit function for the Schafer can be derived as follows:

$$\pi_t = TR_t - TC_T = P * H\big(E(t), X(t)\big) - c * E(t) \quad (10)$$

It is normal for fisherfolks in the industry to enter fishing until the marginal cost (MC) equals the average revenue (AR) (Nguyen, 2011). The open access biomass (XOA), which is determined by using the unit cost of effort, price per unit of harvest, and catchability coefficient (q), is as follows:

$$MC = AR \Leftrightarrow c = \frac{p*H}{E} = pqX_{OA} \Leftrightarrow X_{OA} = \frac{c}{pq} \quad (11)$$

Open Access efforts (E_{OA}) and Yield (Y_{OA}) are determined as follows:

$$E_{OA} = \frac{c-py}{py_1} = \frac{r}{q}\left(1 - \frac{c}{pqk}\right) \text{ and } Y_{OA} = \frac{c^2-pcy}{p^2y_1} = \frac{rc}{pq}\left(1 - \frac{c}{pqk}\right) \quad (12)$$

The open access fishing effort that produces the maximum sustainable yield is derived:

$$E_{MSY} = \frac{r}{2q} \quad (13)$$

Thus, the fishing effort that produces the Maximum Economic Yield (MEY) is as follows:

$$E_{MEY} = \frac{r(pqk-c)}{2pq^2k};\ MEY = \frac{r(p^2q^2k^2-c^2)}{4p^2q^2k} \quad (14)$$

Adopting from (Nguyen, 2011), the present value (PV) is maximised as follows:

$$\max_{0 \le H_t \le H_{max}} \max_{0 \le H_t \le H_{max}} \sum_{t=\infty}^{t=1} \rho^t \pi^t \quad (15)$$

Where p denotes the discount factor. Thus, deriving further the PV;

$$L = \sum_{t=\infty}^{t=1} p^t\{\pi(t) + \rho_{t+1}[X_t + F(X_t) - H_t - X_{t+1}]\}$$

$$subject: X_{t+1} - X_t = F(X_t) - H_t$$

The necessary conditions include:

$$\frac{\partial L}{\partial H} = \rho\{\pi - \rho\lambda\} = 0$$

$$\frac{\partial L}{\partial x} = \rho\{\pi \mp \rho[1 + F(X)]\} - \rho\lambda$$

The equilibrium condition suggests that:

$$\pi'_H = \rho\lambda$$

$$\rho\lambda[1 + F'(X) - (1 + \delta)] = \pi'_X$$

Where δ is the rate of discount. With constant prices $\pi, (X, H) = p * H - c * E$ and $H = q * E * X$, thus,

$$\pi = (X, H) = pH - \frac{cH}{qX}$$

By substituting into the necessary conditions, we get:

$$F'(X) + \frac{cF(X)}{X(pqx - c)} = \delta \qquad (16)$$

We can now obtain the optimum biomass from Equation (10) thus:

$$X^* = \frac{K}{4}\left(\left(\frac{c}{pqk} + 1 - \frac{\delta}{r}\right) + \sqrt{\left(\frac{c}{pqk} - 1 + \frac{\delta}{r}\right)^2 + \frac{8c\delta}{pqkr}}\right) \qquad (17)$$

Thus, the optimum effort level can be derived as:

$$E^* = \frac{F[X^*]}{qX^*}$$

4 RESULTS

The raw data were restructured to reflect the submissions of each vessel sampled during the data period. From the structured data, a summary analysis of different gears and the number of vessels was conducted to reflect the contribution of each gear type to the harvest for the data period, as shown in Table 3.

4.1 Disaggregated Data

Table 3. Distribution of gear type from vessel.

SUMMARY TABLE

GEAR	2015	2020	2021	2022	2023	2024	%
KRU-HL	3	0	125	234	812	132	0.75
KRU-SN	0	1	289	2464	1395	438	2.48
KRU-GN	0	0	178	1328	1159	259	1.47
KRU-LL	0	0	34	215	366	49	0.28
FANTI-GN	0	0	227	2503	2271	444	2.52
FANTI-SN	0	0	130	1417	1070	95	0.54

Fanti canoes using gill nets (FANTI-GN or FGN) were the most sampled vessels during the sampling period. The low value and single gear recorded for 2015, with no information for the other gears during this period and 2020, is largely due to missing data in the samples. This is also indicative of some gears in 2021. Data for the year 2024 were obtained until the end of February. The years with full data submissions for each category were 2022 and 2023.

a) Gear contribution to harvest.

The most efficient gear contribution to the harvest for the period was the FGN, with over 69.44% of the reported catch, followed by the Fanti Seine-nets (FSN) vessels. These vessels are motorised vessels operated by Fanti fisherfolks (Figure 5)**Error! Reference source not found.**

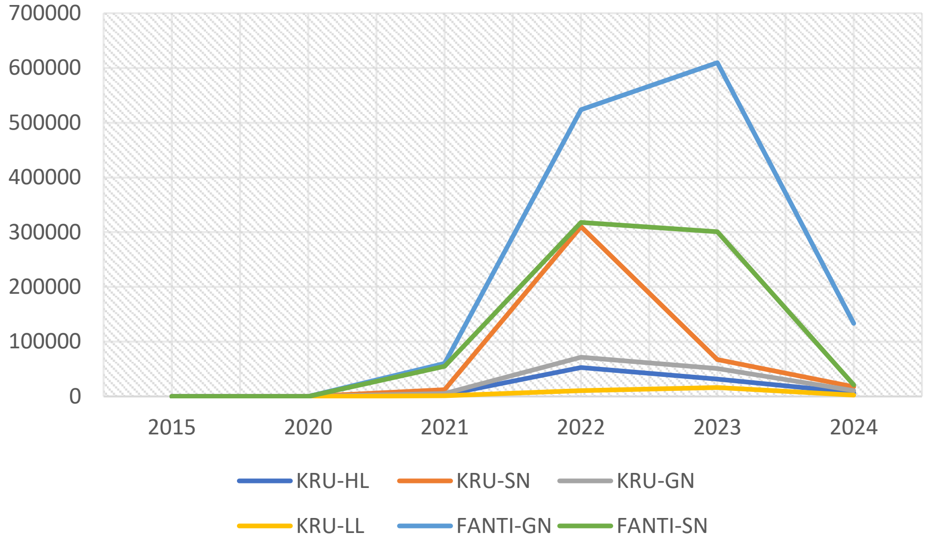

Figure 5. Gear/vessel contribution to harvest. Source: NaFAA Data

Kru vessels are usually unmotorized vessels operated mostly by Liberian fishermen. The most efficient gear contribution for this category was the Kru Seine nets (KSN) with 9.13% of the reported catch Figure 5**Error! Reference source not found.**.

b) Major harvested species

During the data sampling period, 95 different species were recorded in the reported catch. The species were then sorted to reflect the major harvested species using the reported catch (Figure 6)**Figure 6Error! Reference source not found.**.

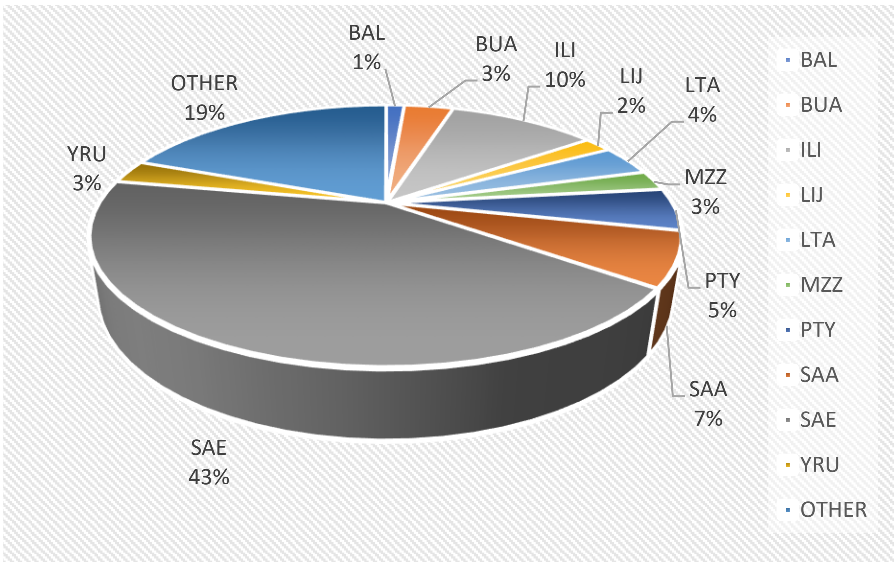

Figure 6. Major harvest species. Source: NaFAA Data

The species included *Chloroscombrus chrysurus* - BUA (Porjoe), *Hemiramphus brasiliensis*-BAL (Penten fish), *Ilisha Africana*-ILI (Gbapleh), *Alectis ciliaris*-LIJ (Pampano), *Euthynnus alletteratus*-LTA (Little tunny), *Osteichthyes*-MZZ (Mixed fish), *Pseudotolithus typus*-PTY (Cassava fish), *Sardinella aurita*-SAA (Round bonny), *Sardinella maderensis*-SAE (Flat bonny), and *Sphyraena guachancho*-YRU (Pike fish) **Figure 6**.

c) Distribution of Harvest by Landing sites and Region

As discussed earlier, there are nine (9) coastal counties in Liberia from which the data were sampled. The reported catch was sorted and aggregated according to landing site and summarised by county, with Grand Cape Mount recording the highest reported catch (Figure 7)**Figure 7Error! Reference source not found.**.

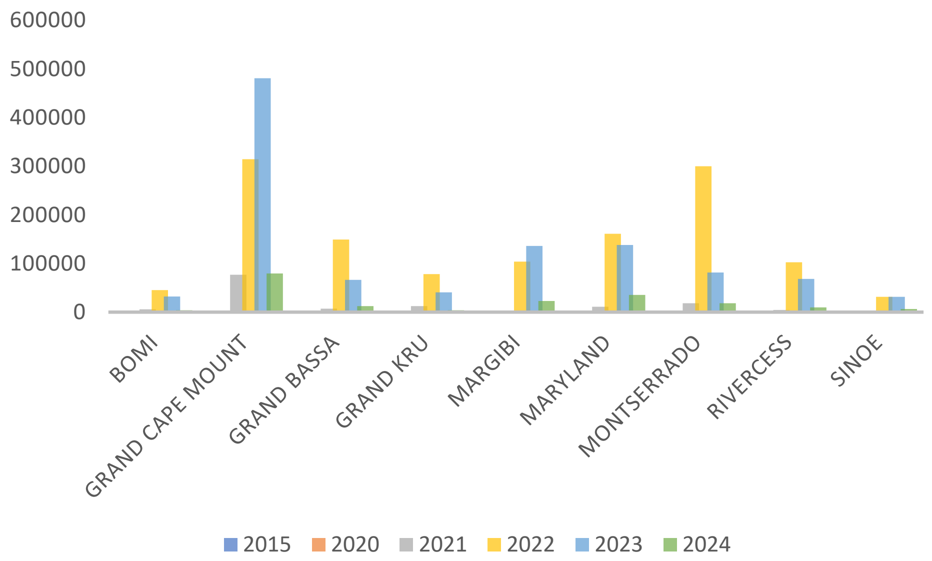

Figure 7. Distribution of harvest by county.

Consequently, the Western region has the highest reported catch. The nine (9) coastal counties are divided into three regions: the Western Region (Bomi, Grand Cape Mount, and Montserrado counties), the West-Eastern Region (Margibi, Grand Bassa, and Rivercess counties), and the South-Eastern Region (Sinoe, Grand Kru and Maryland Counties). The Western region reported the highest catch during the study period (Figure 8)**Figure 8**.

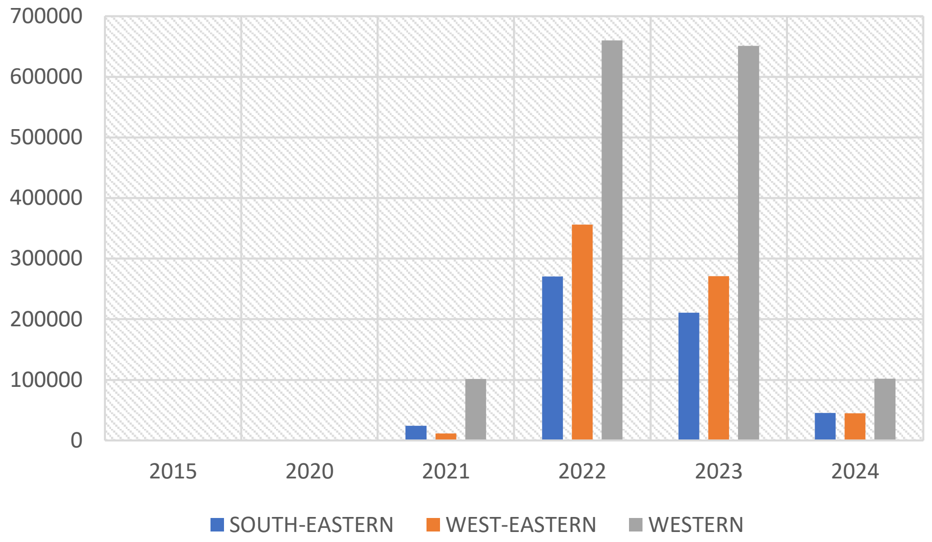

Figure 8. Distribution of harvest by region. Source: NaFAA Data

d) *Distribution of harvest by Month and Seasonal variations*

The samples were sorted and aggregated according to the monthly distribution of the harvest for the data period, as shown in Figure 9.

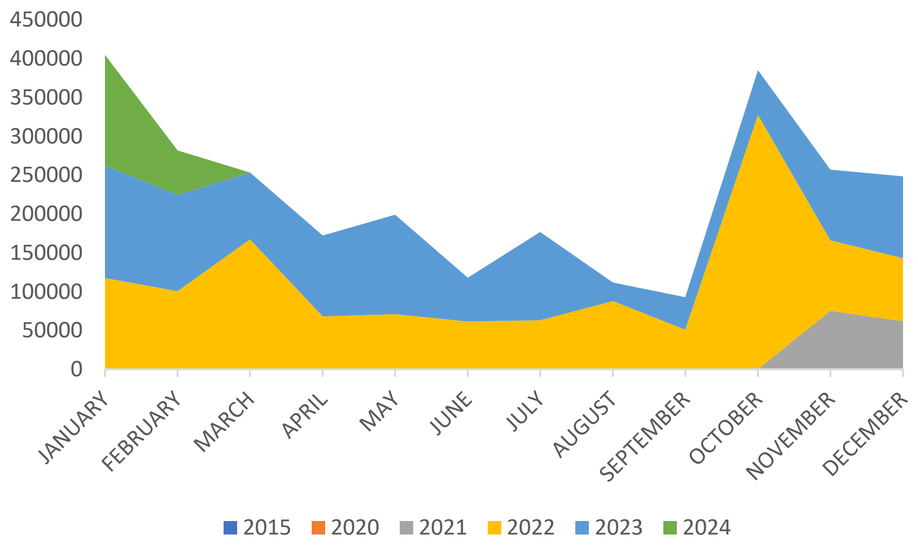

Figure 9. Distribution of Harvest by month. Source: NaFAA Data

The data were sorted and aggregated according to seasonal variations. The highs of the catch for the period are from October – March (Figure 10), which is the Dry Season in Liberia, as compared to the period April – September which is the Rainy season. Seasonal variations are shown in Figures 11 and 12.

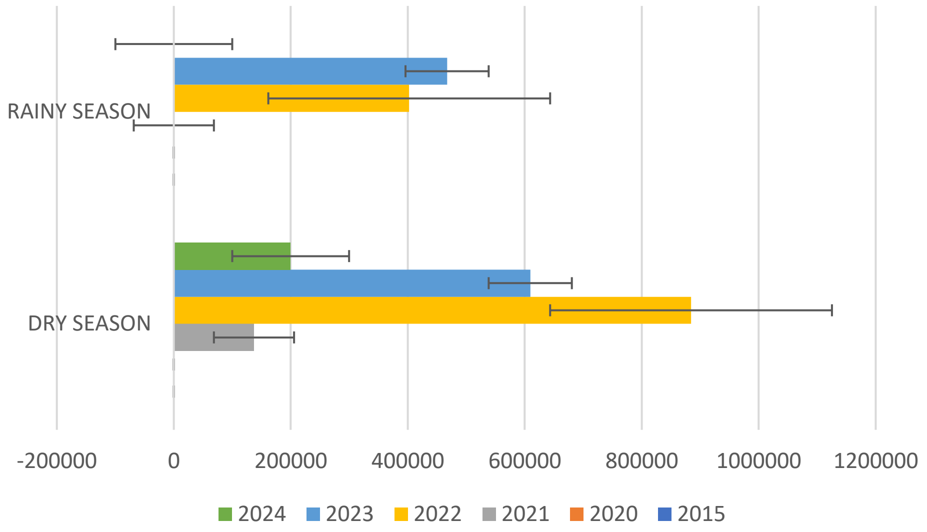

Figure 10. Seasonal observations in reported catch.

e) Seasonality on total catch

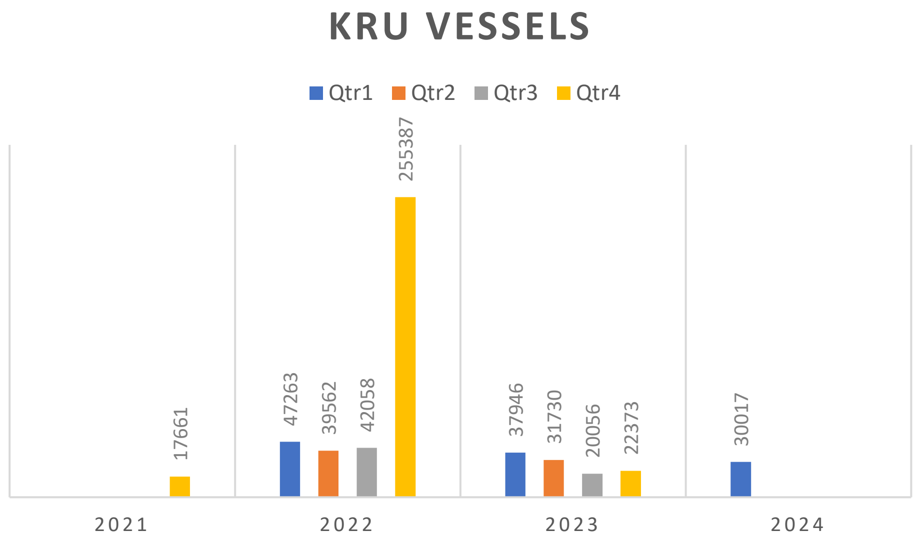

Figure 11. Seasonality on Kru Harvests.

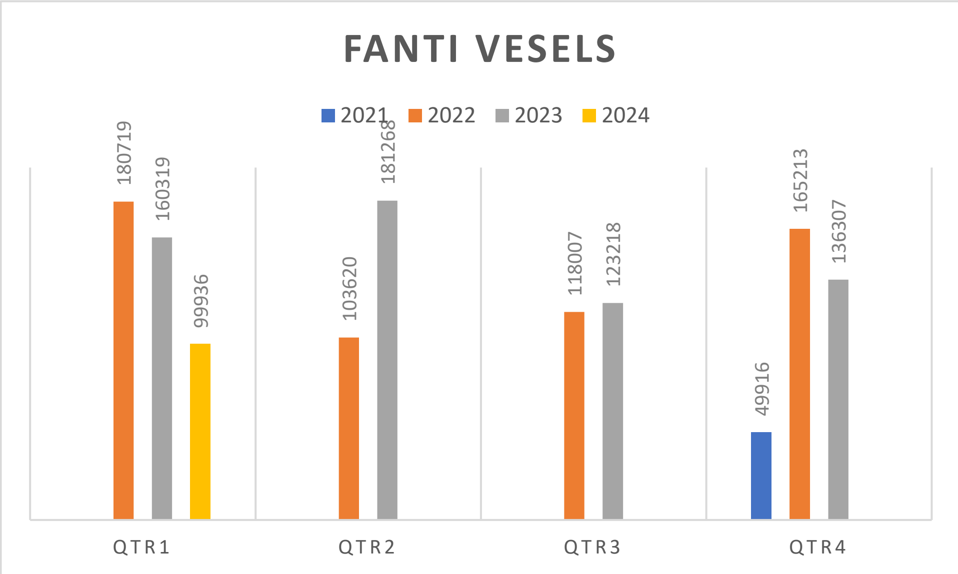

Figure 12. Seasonality on Fanti vessels catch.

f) Seasonality on catch composition and quantity

Figure 13 shows the catch composition of Fanti vessels in different time periods for all vessels during the data period. At the same time, Figure 14 below shows the catch composition of Kru vessels during the data period.

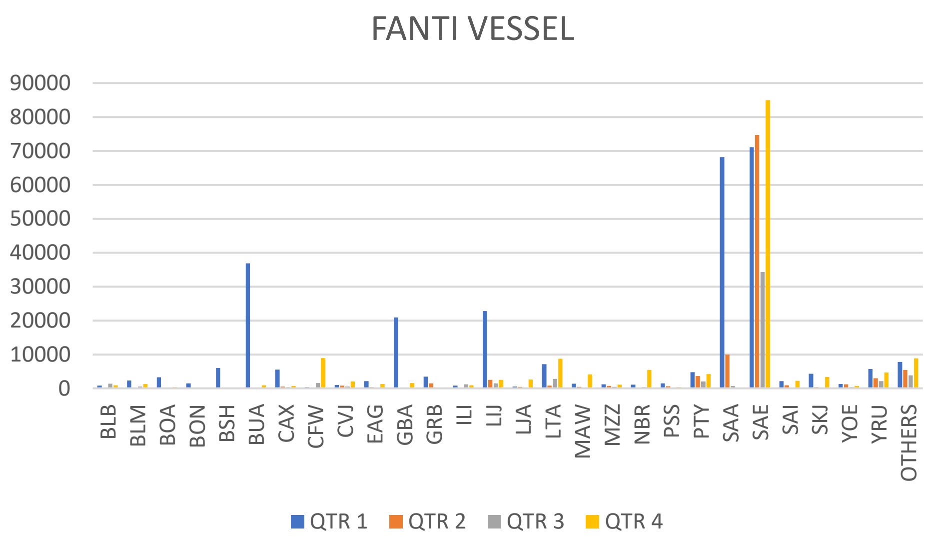

Figure 13. Catch composition of Fanti vessels in different periods. Source: NaFAA Data

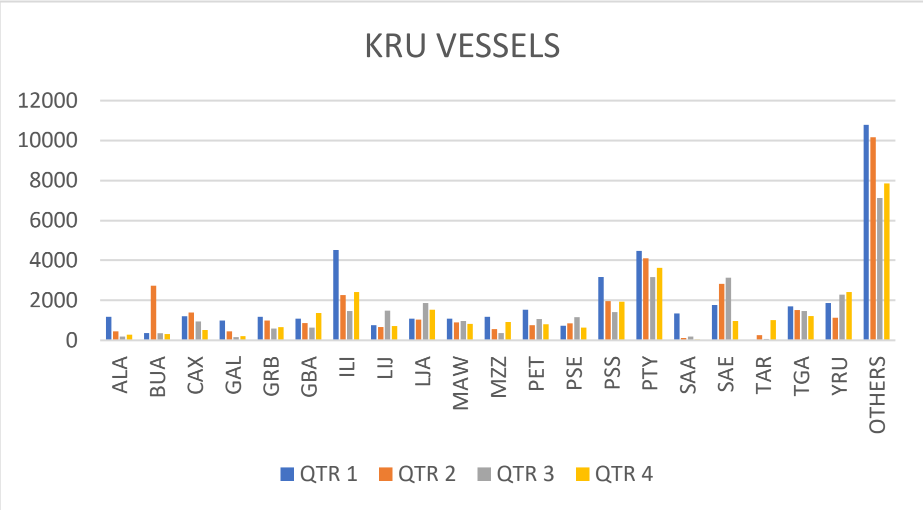

Figure 14. Catch composition of Kru vessels during different periods.

4.1.1 The CMSY Model

A Monte Carlo technique called CMSY uses catch data and broad priors for resilience or productivity (r), stock status (B/k), and fisheries reference points (MSY, FMSY, and BMSY) at the start and end of the time series to predict the relative stock size (B/Bmsy), exploitation (F/Fmsy), and other parameters (Table 4). An enhanced version of the Schaefer surplus production model (BSM) implemented in the Bayesian state space was included in the CMSY package. BSM's emphasis on informative priors and acceptance of brief and partial (i.e., fragmented) abundance data stand it apart from other surplus production model implementations (Froese, Demirel, Coro, Kleisner, & Winker, 2017).

Table 4. Reference points

Reference points	Value	Unit	Notes
Fmsy	0.183 - 0.395	-	Results from CMSY and BSM
MSY	4.51 - 7.95	1000 tons	Results from CMSY and BSM
Bmsy (2021)	14.3 - 34.7	1000 tons	Results from CMSY and BSM
Biomass in (2021)	24.2 - 39.6	1000 tons	Results from CMSY and BSM
B/Bmsy	1.09 - 1.78	-	Results from CMSY and BSM
Fishing mortality in 2021	0.116 - 0.19	-	Results from CMSY and BSM
Exploitation F/Fmsy	0.328 - 0.855	-	Results from CMSY and BSM
Stock	22.25	1000 tons	Results from CMSY and BSM

Figure 15 displays evaluation of artisanal fishing harvest in the South-Western Atlantic Ocean of Liberia.

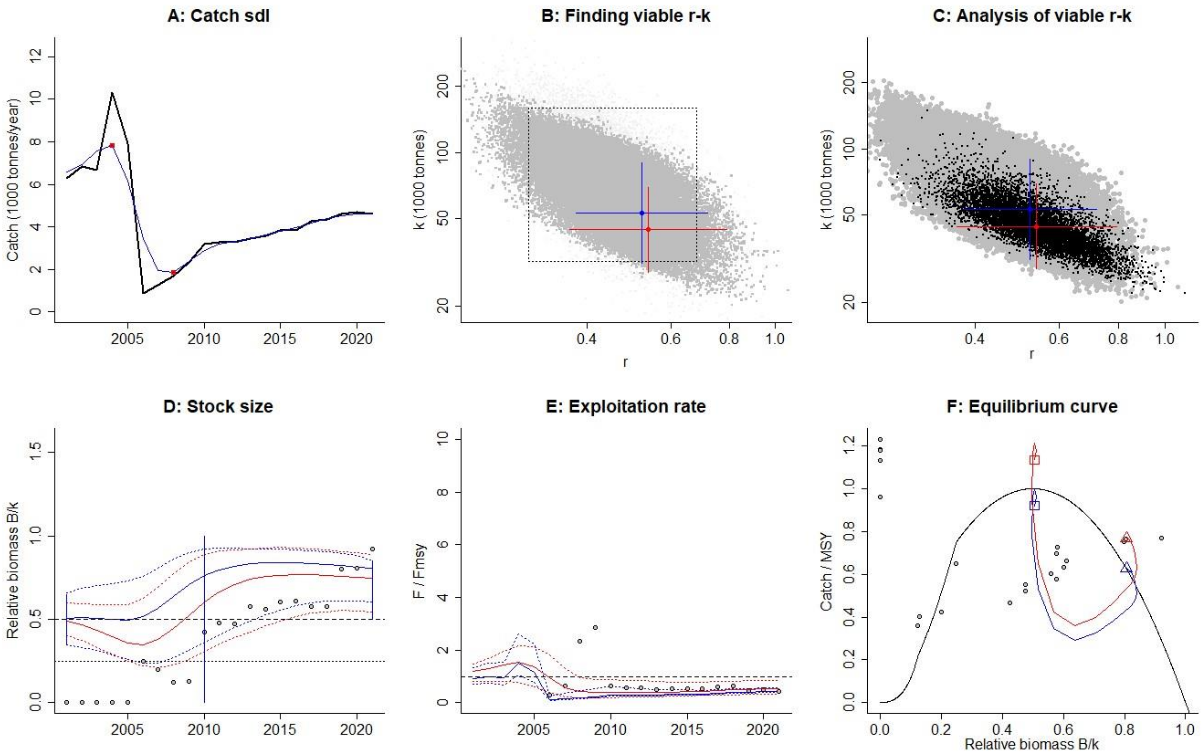

Figure 15. Results of CMSY and BSM analyses for Artisanal Fisheries

As utilised in the estimation of past biomass by the default criteria, **Panel A** displays the time series of catches in black and the three-year moving average in blue, along with an indicator of the highest and lowest catch. The r-k pairs for which the CMSY model is compatible with the captures and the previous data are shown in dark grey in **Panel B** along with the searched r-k log space. The most likely r-k combination in **Panel C** is displayed in blue, along with its approximate 95% confidence bounds. A red cross indicates the most likely r-k pair and its 95% confidence bounds, whereas the black dots represent potential r-k pairs discovered by the BSM model. **Panel D** displays the biomass trajectory calculated by CMSY in blue and the available abundance data in red scaled to the BSM estimate of Bmsy = 0.5 k. The 2.5th and 97.5th percentiles are the dotted lines. The previous biomass ranges are shown as vertical blue lines. In **Panel E**, the harvest rate (catch/abundance) scaled to the BSM r/2 estimate is displayed in red, whereas the matching harvest rate from the CMSY is displayed in blue. **Panel F** displays the catch/MSY Schaefer equilibrium curve in relation to B/k, with an indentation at B/k < 0.25 to reflect lower recruitment at lower stock sizes. BSM estimates were used to scale the red dots, whereas CMSY estimates were used to scale the blue dots.

Figure 16 presents graphs to inform the management.

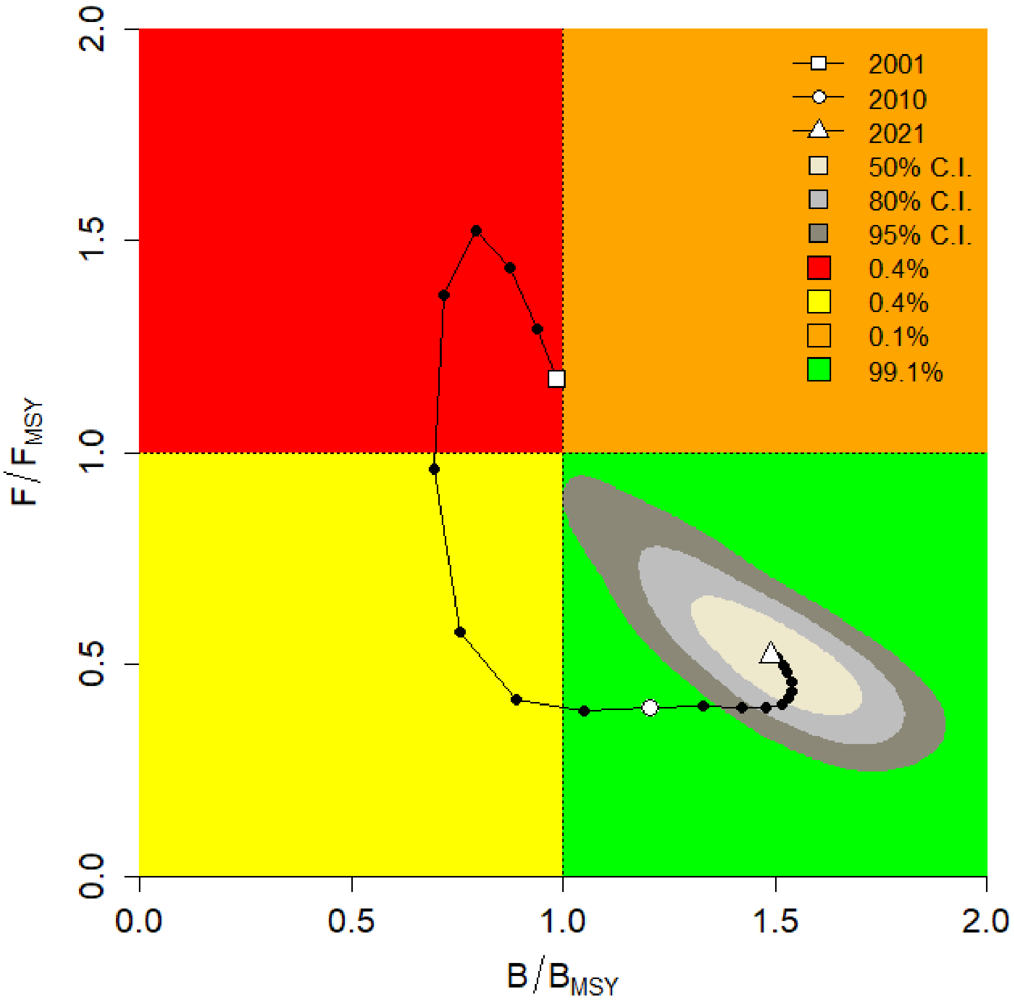

Figure 16: Graphical output of the CMSY code based on BSM analyses.

In Figure 16, the panel above 1.0 F/F_{MSY} (red area) indicates a high level of exploitation beyond sustainable harvest. Towards 2010, sustainable harvests were below the exploitable stock levels (0.5 F/F_{MSY}) for some areas. The black line indicates species distribution which indicates more exploitable stocks of some species in specific areas along the coastal shelf. The results showed that sustainable harvest levels were below MSY.

4.1.2 Economic Parameters

The main data required for the economic model were price (landed price per kilogram of catch) and the unit cost of landing 1 kg of harvest. The price was obtained from the disaggregated secondary data received from the NaFAA and the average price was estimated based on the representation of the weights of the major catch using the weighted mean. The cost per unit effort for a Fanti vessel was adapted from Johns (2023) (Johns, 2023).

The estimated parameters from ordinary least squares (OLS) for the Schaefer model are shown in the table below. The coefficients Alpha (4369,794) and (2,402) are shown in Table 5. The P-value denotes that the parameters of the slope are varied from zero at a significance of 95%. The R^2 value was 0,623 or 62.3% of the variations in catch per unit effort were explained by fishing effort (Table 6).

Table 5. Estimates of Coefficients

Variable	**Coefficient**	**Standard Error**	**t-value**	**P-value**
Catch	4369,794	1318,634	3,314	0,003649
Effort	2,402	0,429	5,503	0,000021

Table 6: Economic Parameters

Small-Scale fleet	**Cost per unit effort ($US\$1000Ton^{-1}$)**	**Price Wet-hold fish ($US\$1000Ton^{-1}$)**
Fanti Boats (Motorized)	1,23	2,21

The open Access Yield (Y_{OA}) was obtained by substituting into Equation (12), the MSY was obtained by substituting into Equation (4) and the MEY was obtained by substituting into Equation (14). The MEY is less than the MSY which indicates that efforts could be maximise d to increase economic benefits while ensuring that fisheries are sustainable. The results show that MEY is closer to MSY due to the lower cost levels that exist in the fisheries (Table 7).

Table 7. Catch reference points.

Model	**Yield at Open Access Tons**	**EMSY Boats (1000)**	**MSY (Tons)**	**EMEY Boats (1000)**	**MEY (Tons)**
Verhulst-Schaefer	0,57	0,525	5,99	0,513	5,98

The TR, TC, and profit functions are substituted into Equations (8), (9), and (10).

Here (Table 8) the positive resource rent signifies that the costs of extracting the resource are low.

Table 8. Summary of economic status of fisheries

Total Cost Year^{-1} (US$ Thousands)	**Total Revenue Year^{-1} (US$ Thousands)**	**Resource Rent Year^{-1} (US$ Thousands)**
0,63	13,22	12,59

By applying the discount rate, the discounted values for optimum stock Y*, X*, E*, CPUE an d π are as follows:

Table 9. Optimum reference points

Model	**δ(%)**	**Y*(1000 Tons)**	**E*Boat(10^{-3})**	**X*(1000 Tons)**	**π'(1000 $USD)**	**CPUE**
Schaefer	0	5,985	0,525	22,25	12,58	11,39200
	5	5,983	0,537	21,78	12,56	11,15002
	10	5,960	0,560	20,80	12,48	10,65041
	20	5,819	0,613	18,54	12,11	9,49368

The rates of discount are important factors in evaluating the sustainability of the fisheries. The values of the discount rate (5%), (10%), and 20(%) represent the "*biological factors, social accounting, and risk-adjusted private interest rates* " (Nguyen, 2011). The 0% result is due to the absence of discounting. Effort varied mostly with the discount rate from 2,12% to 9,53% while profits varied the least.

5 DISCUSSION

Small-scale or Artisanal Fisheries management in Liberia is a complicated endeavour. This endeavour draws out unparallel exchanges between actors and regulators. It also leads to huge political and social debates about ownership and rights which increases the complexities of instituting management regimes (Nguyen & Tran, 2023).

Prior to 2010, the Liberian fisheries sector was largely ungovernable (Ministry of Agriculture, 2014). This situation was mostly attributed to the prolonged period of civil conflict which paralysed most of the infrastructure in Liberia, including fisheries. Being largely unregulated, both artisanal and industrial vessels competed for the available resources. Industrial vessels during this period had a comparative advantage over small-scale vessels owing to the structure of the continental shelf. Most coastal fisheries are present along the continental shelf of Liberia (Jueseah, 2022). SSF lacked the sophistication to exploit this area and compete with industrial vessels. This competition out favoured the SSF and would mostly lead to confusion between the actors, with very little to be done by the regulators due to limited capacity.

In 2010, the Government of Liberia adopted a recommendation from the West African Regional Fisheries Program (WARFP) and instituted a six (6) NM restriction for industrial vessels (Johns, 2023). This decision provided relief to the SSF and reduced the commotion between the industrial actors and the SSF actors. It also provided the regulators with some management control over the fisheries (Jueseah, 2022).

5.1 Description of Fisheries

Our analyses of the SSF using the disaggregated data showed that the most sampled vessels during the data period were the Fanti vessels, and that 2022 and 2023 had complete datasets compared to previous years, while 2024 was obtained up to February.

Enumerators are assigned to each county by the research and statistics division of the NaFAA to collect weekly sampling data from designated areas. Each enumerator is required to sample seven (7) boats on a weekly basis from each of the designated landing sites. The landing sites in most areas are stratified among the two (2) main groups of fisherfolks: Kru and Fanti (mostly sub-divided into Kru beach and Fanti Town).

Overall, S*ardinella maderensis* constitute most of the total catch for all fleets. The Fanti fleets recorded more harvest using both gillnets and seine-nets because of their motorised capacity over their Kru fellows, who mostly use the dugout paddled canoe, deploying a range of gear such as set-nets, gillnets, handlines, and longlines (Jueseah , Ogmundur, Kristofersson , & Tomasson , 2021). The Fanti gillnets were the most efficient harvest gear, while the Kru set-net was the most efficient gear according to our analyses of the disaggregated data.

More catch data were reported from sites in the western region, especially Grand Cape Mount County. This could be because of the easy access to landing sites in these areas compared to the southeastern region, as well as the distance of travel time between these sites. At the same time, more catches were reported in the dry season than in the rainy season.

Further analyses of the disaggregated data indicated some pattern of seasonality among the SSF (Jueseah , Ogmundur, Kristofersson , & Tomasson , 2021). The results showed that the total catch of both Fanti (s) and Kru (s) did not significantly affect the seasonality of either fleet. However, the analyses of the composition and catch of the two fleets showed some variations in species composition and catch at different time periods during the year. This is consistent with the findings of (Juseah, Tomasson, Knutsson, & Kristofersson, 2021), who reported more sales in the dry season than in the rainy season. These lower sales could be due to the distribution of different species during different periods and seasons. For instance, the fourth (4^{th}) and first (1^{st}) quarters saw a higher catch of SAE (*Sardinella maderensis*) for the Fantis than any other period during the year. Furthermore, Kru experienced higher levels of ILI (*Ilisha Africana*) and (*Pseudotolithus typus*) in the first (1^{st}) quarter than any other time during the year.

The most caught species for the Fanti were Sardinella maderensis (flat bonny), a small pelagic stock assemblage (SPSA), while the major catch for the Kru were the *Ilisha africana* (Gbapleh), an SPSA, and *Pseudotolithus typus* (Cassava fish) which is a shallow water demersal stock assemblage (SWDSA). Both the Fanti and Kru fleets target other varieties of SPSA, SWDSA, medium-water pelagic assemblage (MWA), large pelagic assemblage (LPA), and deep-water demersal stock assemblage (DWDSA). Over 60% of the landed catch of Kru fleets consists of SWDSA, whereas 80% of the Fanti catch consists of SPSA (Arnason, 2016).

5.2 CMSY Model Estimation

The model estimated abundance by catch per unit effort (CPUE) using catch and effort data from 2001 – 2021 and found prior initial relative biomass to be 0.35-0.65 (expert), prior intermediate relative biomass (0-1) in year 2010 (expert) and prior final relative biomass to be 0.5-0.85. Furthermore, the model found the prior range for the intrinsic growth rate (r) to be 0.3-0.68 (expert) and prior range for the somatic growth rate (k) to be 31.9-159 as well as prior range of catchability (q) to be 0.419-1.26.

The artisanal catch was lower prior to 2010 and began to recover after the imposition of six (6) NM restriction (Jueseah, Kristoferson, Tomasson, & Knutsson, 2020). However, this restriction has led to an increase in SSF fleets (Jueseah, 2022) and catchability. This trend has been steady for extended periods since the restrictions. There have been reports of reduced catch and seasonality among SSF (Jueseah, 2021). The results show that for some species, there is abundance, whereas other species may be overfished, as indicated by the catch compositions of the Fanti and Kru fleets. Jueseah (2022) found shallow-water demersal stocks to be overexploited which is indicative of the catch from the disaggregated data. Most of these species are targets for the increasing efforts of the artisanal fleets and are relatively higher in valuation compared to the SAE and ILI.

A recent scientific investigation conducted by the National Fisheries and Aquaculture Authority (NaFAA) in Liberia focused on the demersal resources within a specific coastal area. The study yielded significant findings related to catch and effort per unit in the Liberian Exclusive Economic Zone (EEZ). Specifically, the study revealed that the catch rate was **292 kg/h**, whereas the effort rate (measured in terms of individuals) was **4,003 individuals/h** for species within this zone. Notably, these figures indicate **higher yields** in shallower coastal regions (ranging from 0 to 30 meters) compared to deeper areas (101 to 200 meters) (Thiam & Sarre, 2023). The predicted biomass for the current year, which was 22,708 tonnes, was lower than the estimated biomass of 27,068 tonnes reported in 2007, according to the report (Jueseah, 2022).

The result of the model showed a low depletion rate (0.35-0.65) based on the prior initial relative biomass B/k ranges for CMSY. The results also indicate that the stock displayed a medium resilience (0.3-0.68) assigned by CMSY based on the classification of resilience

(Nguyen & Tran, 2023). This is consistent with the findings of (Johns, 2023) who also found SAE to be biologically sustainable.

5.3 Economic Parameters

Previous studies have found the pelagic fisheries to be at sustainable harvest levels. Johns (2023) indicated that the high CPUE was related to the low price per kg of landed catch. Jueseah (2022) found the Fanti canoe to be technically inefficient at maximising harvest levels. While these results show sustainability levels for pelagic fisheries, the same does not apply to demersal fisheries. Arnason (2016) and Jueseah (2022) found the demersal stocks to be over-exploited and unsustainable.

The MEY reflects the level of fishing effort that ensures the maximum economic potential of the fisheries. The results show that pelagic fisheries have untapped potential, as denoted by MEY and MSY. Furthermore, technical capacities could be enhanced to optimise economic benefits, but with the caution of operating at a sustainable level. Although pelagic stocks are underexploited (Johns, 2023), demersal stocks appear to be overfished and require efficient management measures (Arnason, 2016).

However, while the MSY exceeds the MEY, increasing fishing efforts in the absence of an effective management regime may lead to unstainable level of efforts which could render stocks depleted especially the dermersal stocks (Arnason, 2016).

Although positive resource rent signifies economic benefits, it could lead to overexploitation, issues of environmental sustainability, resource governance, and equitable distribution. This study suggests that the surplus production model can be applied to more complex fisheries analyses over time (Nguyen, 2011).

5.4 Policy and Management

Managing SSF in multi-species and multi-gear fisheries can be a challenging endeavour that requires careful understanding of the individual variables that affect stock and harvest (Nguyen & Tran, 2023).

In Liberia, the NaFAA is the sole authority required to regulate the fisheries sector in line with the established rules as a sustainable pathway to ensure a more productive fisheries sector. The NaFAA relies on the availability of reported catch data to formulate policies for sector management. These catches are reported by enumerators on a weekly basis based on established sampling techniques and the location of the landing sites.

Artisanal fisheries are largely unregulated because of the nature of fisheries and the distribution of landing sites. Officially, there are 114 landing sites in Liberia that are spread across nine (9) coastal counties (NaFAA, 2020). Most of these landing sites are difficult to reach, particularly in the southeastern region of Liberia. Collecting accurate and real-time data is a challenging exercise for NaFAA.

The fisheries sector has been tipped as one of the reliable sectors of the economy, which is projected to contribute significantly to the GDP. However, to achieve this target, a clear pathway to institute governance in SSF is required. The World Bank has approved a project since 2020, known as the "*Liberia Sustainable Management of Fisheries Project (LSMFP)*", geared towards supporting NaFAA to strengthen regulatory frameworks of the sector and improve the activities of the sector and to contribute to the enhancement of fisheries management and livelihood[1].

Currently, the major regulatory measure used by the NaFAA is input control by restricting the mesh sizes of the nets, banning monofilament nets, and output control, such as catch control (Johns, 2023). Management measures are imposed from time to time, depending on the case. However, resentment for these regulations by SSF actors tend to hamper the enforcement due to political intervention from politicians[2].

Managing SSF in Liberia should also be based on data quality. Quality data collection that disaggregates fish harvests at various landing sites would significantly improve the enhancement of policy measures based on an informed position. Different management measures are required to manage SSF (Arnason, 2016). Recommendations have been made to either maintain the prior efforts of 2014 to ensure the recovery of demersal stocks while other stocks are exploited (Arnason, 2016), as well as to reduce the number of SSF fleets (Jueseah, Kristoferson, Tomasson, & Knutsson, 2020). However, it is important to understand fisheries from a detailed data perspective.

[1] LSFMP: https://liberiaprojects.org/activities/1281
[2] https://www.liberianobserver.com/liberia-house-calms-fishermens-rage

While MEY signifies the potential of the fishery to maximise resource benefits, more efficient management strategies are required to ensure sustainability. Authorities can apply a mix of management regimes to maximise the potential of fisheries (Nguyen, 2011).

6 CONCLUSION & RECOMMENDATIONS

6.1 Conclusion

This research used a mixed approach using disaggregated data (2015-2024) to describe the SSF and employed CMSY to aggregate data (2001-2021) both of which were secondary data. Some data were missing for some years.

An analysis of the disaggregated data revealed that more Fanti vessels were sampled. In addition, the results showed that SAE (flat bonny) was the species most caught by Fanti, while ILI (Gbapleh) was the species most caught by Kru.

Furthermore, seasonal patterns were observed along the catch composition varieties for different periods during the year of the sample. This pattern is consistent with previous findings by (Jueseah , Ogmundur, Kristofersson , & Tomasson , 2021).

The CMSY model was used to estimate abundance by catch per unit effort (CPUE) using catch and effort data from 2001 to 2021 and found a low depletion rate (0.35-0.65) based on the prior initial relative biomass B/k ranges for CMSY. In addition, the results indicate that the stock displayed a medium resilience (0.3-0.68) assigned by CMSY based on the classification of resilience.

These findings are consistent with previous findings which show sustainable harvest levels for pelagic species, but with demersal species being overexploited. The major composition of the Kru catches are shallow water demersals.

The intrinsic growth rate (r) is 0,538, the catchability coefficient (q) is 0,512 while the carrying capacity of the stock (K) is 44,5. EMSY and MSY were found to be 0,525 and 5,99 while the EMEY and MEY were found to be 0,513 and 5,98 respectively. The MEY is very close to the MSY, suggesting that the cost of fishing is very low.

MEY indicates the potential for investment in untapped resources. However, this should be in line with fisheries management policies. While pelagic fisheries appear sustainable, demersal fisheries seem to be overexploited and require a mixed approach to manage small-scale fisheries. Fanti vessels are not technically efficient in competing with industrial vessels for demersal species and may become less profitable in this endeavour. Long-term results show that fisheries may be less profitable without the required management regime. A few recommendations are required to improve fisheries.

6.2 Recommendations

The recommendations below may be necessary to improve the current status of the fishery.

Efficiency and Improvement: In order to reach the MEY, fishing effort costs and catch-related economic gains must be balanced. There might be chances to boost fishing effort or efficiency for pelagic fisheries when the MEY is lower than the MSY, without endangering long-term sustainability or overfishing fish stocks.

Sustainability of the Resource: Despite the greater economic potential associated with MEY, it is crucial to maintain fishing efforts within sustainable limits to prevent the overexploitation of fish stocks and ecosystem degradation. The implementation of fisheries management measures is essential to balance fishing practices with ecological sustainability goals while maximising economic benefits.

Long-term planning: the long-term maximum potential of the fisheries requires long-term planning and well-drawn out management strategies that have set objectives for the sustainable management of the fisheries.

Further study: The aggregated data do not explain in detail the factors that underpin the overall performance of fisheries. The quality of the disaggregated data also made it difficult to run an effective predictive model to analyse the different stock assemblages. Thus, I would suggest the following:

- Further studies are needed to predict the status of different stock assemblages using CMSY and BSM models;
- Economic analysis of the individual stock assemblages and their viability; and
- Economic analysis of the seasonal effect of species distribution on the livelihoods of fisherfolks during different periods.

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APPENDICES

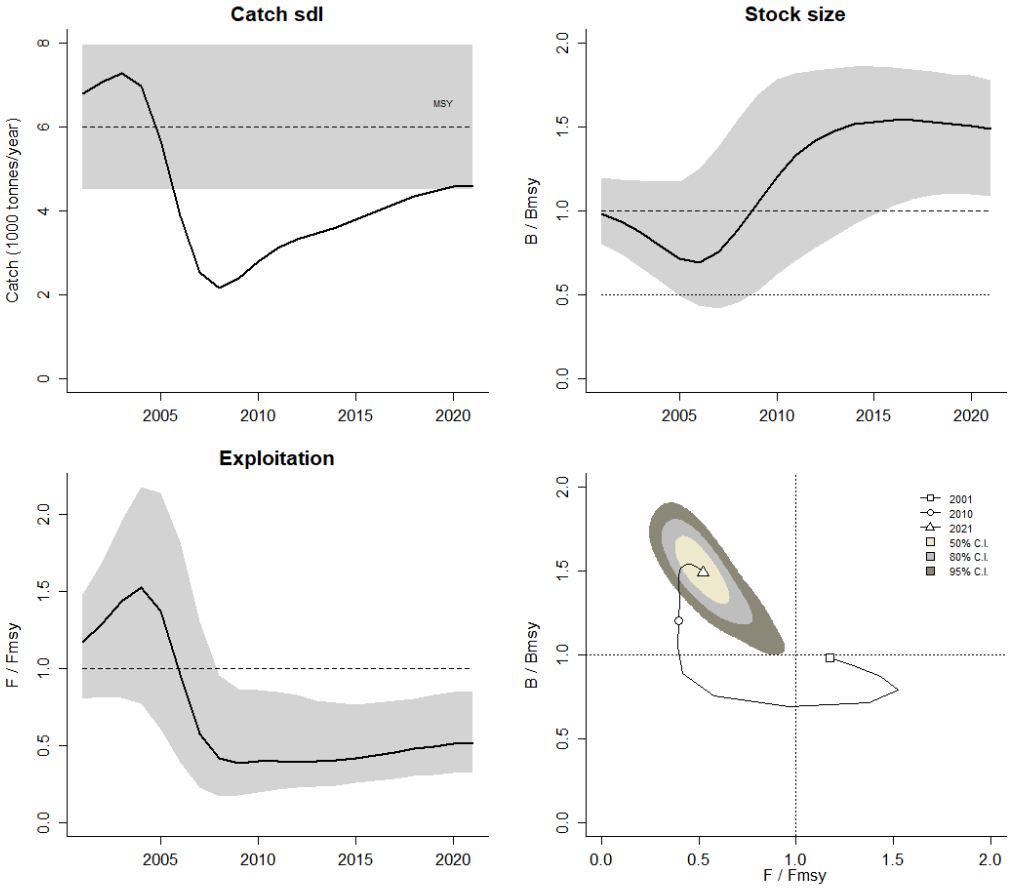
Appendix A

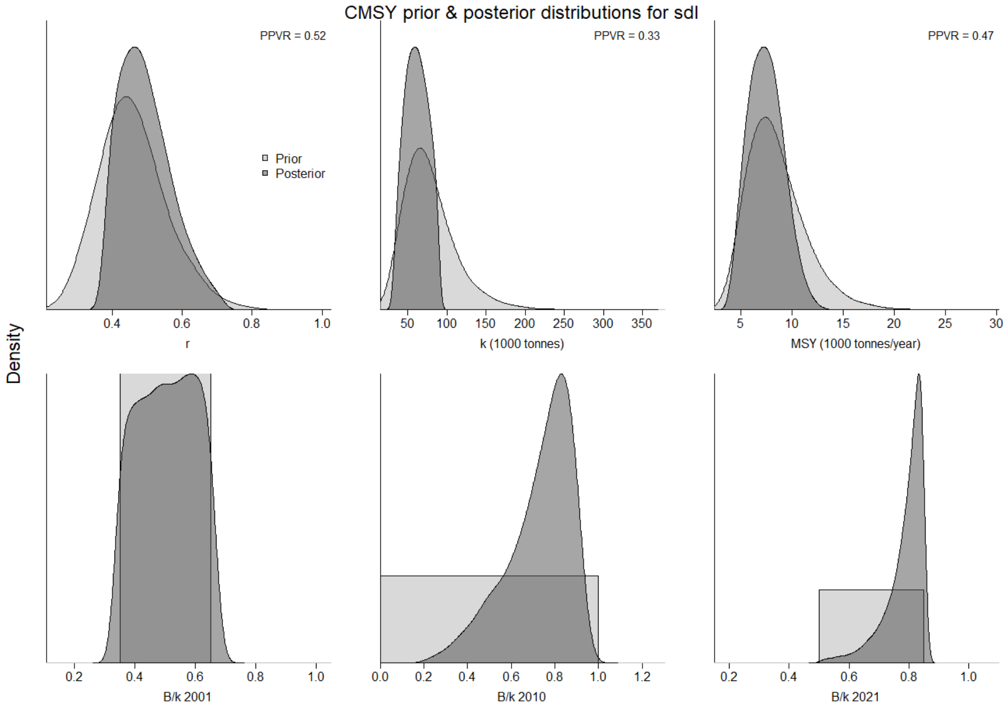
Time series Catch and effort data.

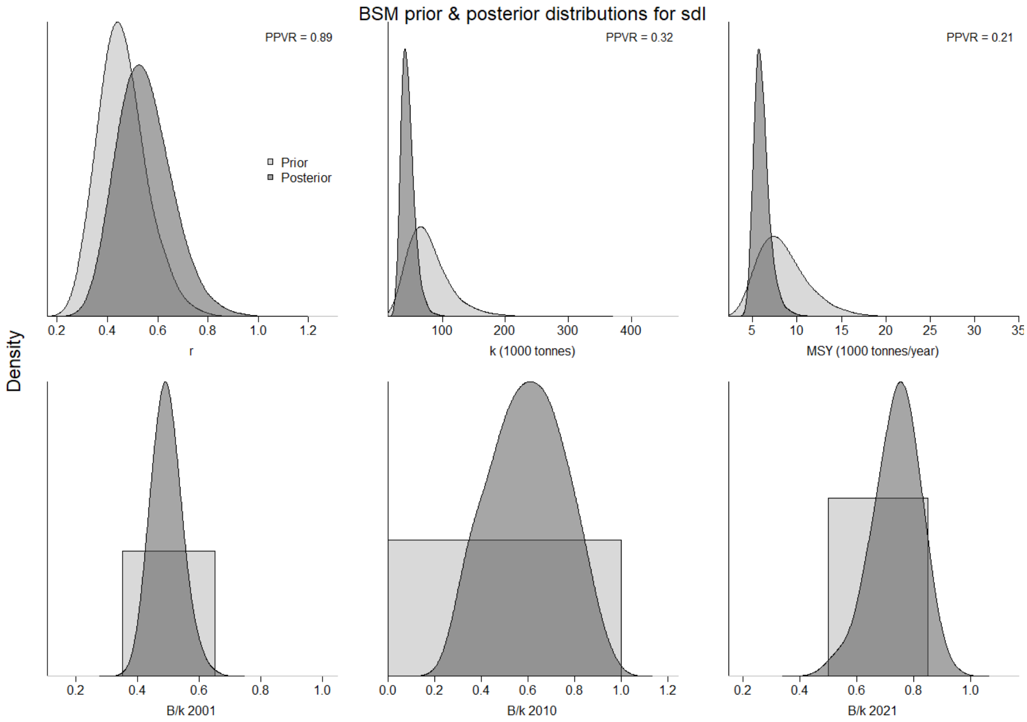
Year	**Artisanal Vessel**	**Artisanal catch (tonnes)**
2001	175	6303
2002	252	6842
2003	377	6650
2004	499	10317
2005	702	9095
2006	890	5701
2007	1239	4560
2008	1709	2813
2009	2316	2968
2010	3196	9700
2011	3269	10869
2012	3275	10824
2013	3429	13149
2014	3575	12744
2015	3848	13727
2016	3848	13915
2017	4254	13160
2018	4355	13204
2019	4589	18229
2020	4712	18332
2021	4589	20982

Appendix B

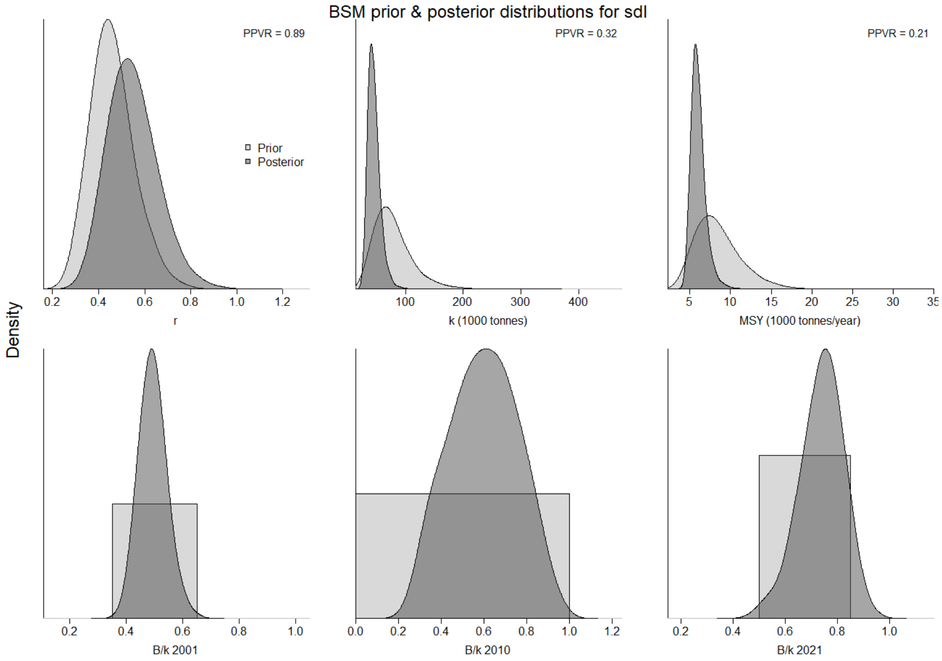
CMSY outputs



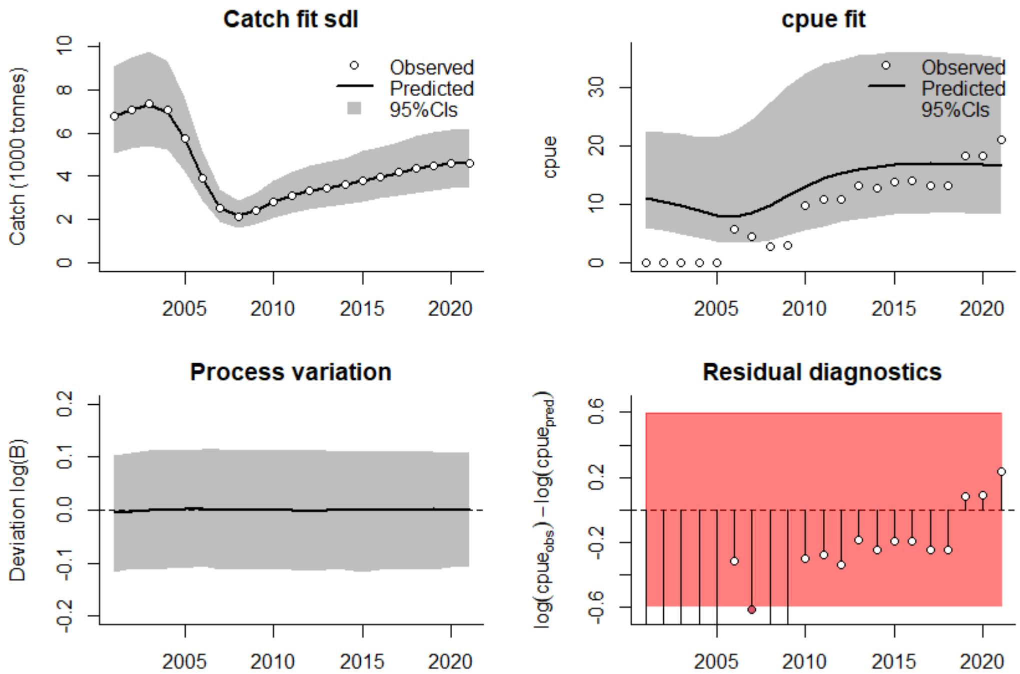




BSM prior & posterior distributions for sdl
PPVR = 0.89
PPVR = 0.32
PPVR = 0.21
Prior
Posterior
Density
r
k (1000 tonnes)
MSY (1000 tonnes/year)
B/k 2001
B/k 2010
B/k 2021



BSM prior & posterior distributions for sdl
PPVR = 0.89
PPVR = 0.32
PPVR = 0.21
Prior
Posterior
Density
r
k (1000 tonnes)
MSY (1000 tonnes/year)
B/k 2001
B/k 2010
B/k 2021



Catch fit sdl
Catch (1000 tonnes)
Observed
Predicted
95%CIs
cpue fit
cpue
Observed
Predicted
95%CIs
Process variation
Deviation log(B)
Residual diagnostics
log(cpue_obs) - log(cpue_pred)