UNIVERSITY OF CAPE COAST

ASSESSMENT OF THE SUSTAINABILITY OF EXPLOITATION OF FISH STOCK AND MANAGEMENT MODALITIES IN LIBERIA'S SMALL-SCALE FISHERIES

KORTO DOECIOUS NEUFVILLE

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BY

KORTO DOECIOUS NEUFVILLE

A thesis submitted to the Department of Fisheries and Aquatic Sciences of the College of Agriculture and Natural Sciences, University of Cape Coast, in partial fulfillment of the requirements for the award of a Master of Philosophy degree in Fisheries Science

DECEMBER 2022

DECLARATION

Candidate's Declaration

I hereby declare that this thesis is the result of my original research and that no part of it has been presented for another degree in this university or elsewhere.

Candidate's Signature ………………………… Date …………………

Name: ……………………………………………………………………

Supervisor's Declaration

We hereby declare that the preparation and presentation of the thesis were supervised by the guidelines on supervision of the thesis laid down by the University of Cape Coast.

Principal Supervisor's Signature…………………… Date ………………

Name: …………………………………………………………………....

Co-Supervisor's signature …………………………… Date ………………

Name: …………………………………………………………………..

ABSTRACT

This study examined the exploitation rate, catch trends, and sustainability of the fishery, evaluated the effectiveness with which the national institution is managing the fisheries resources in Liberia, and offered some insight into the underlying factors influencing its efficiency. Secondary data covering the period of 11 years (2010-2021), was obtained from the National Fisheries and Aquaculture Authority (NaFAA). Qualitative and quantitative methods were used for the primary data collection on managerial effectiveness in four major fishing landing sites. The sector utilized different types of fishing gear to exploit the multiple-species fishery. The total mortality rate of Butter nose, *Galeoides decadactylus* estimated using the length-converted catch curve method was 0.22 year-^{1}, and the fishing mortality rate (F) was 0.06 year-^{1}. The estimated catch per unit effort (CPUE) and maximum sustainable yield (MSY) (12,729.2 MT) from data on the size composition and landings from the fishery, provided evidence that the small scale fishery (SSF) in Liberian coastal waters are not only fully exploited but are being overfished. The maximum annual production was estimated as 63,663.7 MT (in 2021), and the least was 13,160.99 MT (in 2017). The estimated f_{MSY} was 4,000, which is higher than the MSY, which indicates the need to implement input controls in the fishery. However, results from the survey indicate that compliance with national and local regulations is high, due to participatory decision-making and community monitoring.

KEY WORDS

Exploitation

Growth and mortality

Sustainability

Regulations

Small-scale

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DEDICATION

To my late father, Mr. Daniel Yaba Neufville.

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LIST OF ACRONYMS

AAU	Association of African University
AU	African Union
BRPs	Biological Reference Points
CDA	Cooperative Development Agency
CIs	Confidence Intervals
CMA	Collaborative Management Association
CPUE	Catch per unit effort
FGDS	Focus Group Discussion
FPIs	Fishery Performance Indicators
IDA	International Development Association
IDIs	In-depth Interview
IEZ	Inshore Exclusion Zone
IUCN	International Union for Conservation of Nature and Natural resources
IUU	Illegal Unprotected Unregulated
LAFA	Liberia Artisanal Fishermen Association
LRPs	Limited Reference Points
MOU	Memorandum of Understanding
MSY	Maximum Sustainable Yield
NaFAA	National Fisheries and Aquaculture Authority
PRPs	Precautionary Reference Points
SDGs	Sustainable Development Goals
SSF	Small-scale fishery

TRPs	Target Reference Points
UCC	University of Cape Coast
WARF-P	West Africa Regional Fisheries Program

CHAPTER ONE

INTRODUCTION

Background to the Study

Fisheries globally are crucial to human well-being because they provide millions of people with basic food supplies, jobs, livelihoods, leisure activities, and foreign exchange (Kevern, 2009). In West Africa, the fishing industry directly and indirectly employs around 3 million people (World Bank, 2020). The demand for fish is rising along with global population expansion, placing further pressure on marine fisheries resources (FAO, 2018a). Illegal Unreported Unregulated fishing (IUU) further adds to these challenges, which reduces fish populations and further impoverishes marginalized coastal communities (Kevern, 2009).

The fishery sector in Liberia provides around 12% of the agricultural GDP and less than 3.2% of the national GDP (NaFAA, 2020). The sector employs 35,000 people directly or indirectly (NaFAA, 2020). Fish provides a rich source of nutrients including proteins, vitamins, fats, lipids, minerals, low calories, and omega-3 fatty acids (Leech, 2019). In Liberia, the average per capita of fish consumption was 5.67 kg in 2021, and it is expected to drop to 5.36 kg in 2022, which is lower than the global average of 19.3 kg for developing countries and 14 kg for the ECOWAS zone (ECOWAS, 2020). Fish makes up about 20% of the country's animal protein intake, and 80% of the population relies on fish as their primary source of protein.

The marine sector has struggled with a significant number of IUU fishing activities and widespread destruction, resulting from poor management systems, which have led to a reduction in food security (MOA, 2014).

However, in 2010, implementation of activities on the West Africa Regional Fisheries Program (WARF-P) significantly decreased illegal fishing in all coastal areas, enabling Liberia to achieve the UN Sustainable Development Goal (SDG) 14.4, which calls for the elimination of destructive harvesting methods, overfishing, and IUU fishing (World Bank, 2020). The program executed a 6-mile inshore conservation zone announced by the Liberian government in 2010. As a result, fishing communities in Liberia have started to see the resource base rebuilt and some fish stock recovery at the level (World Bank, 2019).

Marine fisheries fall under two main sectors: the small-scale or artisanal and the industrial sector. Small-scale fisheries are essential for food security and employ more than 33,000 people, 60% of whom are women (FAO, 2012). The sector is largely dependent on resources from marine fisheries with little support from inland or aquaculture (NaFAA, 2020). Marine fisheries must be managed sustainably in Liberia in order for the sector to offer opportunities for food security and to support regional and national economies. However, the national institution's role in managing the fisheries resources has been inadequate, and are unable to resolve fisheries-related problems (MOA, 2014). This is crucial because the sector provides a considerable amount of fisheries resources, which present opportunities for growth in the coastal environment (NaFAA, 2020). In response to these difficulties, community-based organizations have emerged as a solution to these challenges (FAO, 2018b). The idea is codified in the UN FAO's Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries (SSF Guidelines), which align with and offer a chance to put into practice the fundamental ideals of participation, representation, collaboration, and coordination (FAO, 2018b). Millions of people who significantly rely on fish resources may see a decline in biodiversity as well as in their socioeconomic conditions and livelihoods if fish populations are not managed effectively (Cochrane, 2002). Liberia's 2030 agenda for transformation specifically emphasizes that to meet the sector's long-term goals there should be community-based management (GOL, 2018).

Statement of the Problem

The contribution of the small-scale sector from 2010 to 2018, rose from 9, 800 to 13, 201 tons, reaching a peak of 13.914 tons in 2016 (NaFAA, 2018). Small-scale fishers mostly exploit fish stocks in Liberia all year long by using a variety of fleets and gears to target multi-species of fish. However, fish stocks have decreased making the industry unprofitable (Belhabib et al. 2013a). The catches in Liberia are barely documented because of the poor quality data and a lack of skills in evaluating data within the sector (Belhabib et al., 2013a, 2013b; Belhabib, 2016). As a result, there are data gaps in artisanal and industrial fishing boat landings despite advancements in the collection of fisheries statistics (Wilson R., 2018). Yokie (2019) also stated that due to limited information on stock assessment, more research on the growth parameters of species within the sector is compulsory. In order to determine the state of the fisheries, it is crucial to continuously undertake studies to assess the sustainability of the industry. Moreover, some potential scenarios of outcomes if these problem are addressed would lead to an improve data collection and analysis, improve food security, and more sustainable and profitable fishing practices in the small scale sector of Liberia

, as well as economic opportunities for fishing communities. Hence, the study assessed the viability of the small-scale sector using biological information of important commercial species as well as document management regimes being implemented at the various coastal communities.

Purpose of the Study

Due to the scarcity of data on stock trends in Liberia's small-scale sector, the purpose of the study was to evaluate the extent to which some commercial species are being exploited, and determine the sector's sustainability as well as the management implications by evaluating resource users, which will serve as a benchmark for long-term sustainability.

Research Objectives

Overall objective

The study's overall goal is to assess the sustainability of artisanal fisheries in Liberia and the effectiveness of current management modalities of the fisheries.

Specific Objectives

The specific objectives are to;

i. Investigate the exploitation rate of the most commercially landed species in the artisanal sector
ii. Assess the sustainability of the small-scale fishery using biological reference points.
iii. Assess the fishing gears used in exploiting fish stocks in the small-scale fishery
iv. Appraise the effectiveness of existing management modalities.

Significance of the Study

The small-scale industry is crucial to Liberia's maritime economy, supplying thousands of people with livelihood (NaFAA, 2020). However, the current condition of the sector is both vulnerable (MOA, 2010), and unstable, resulting in a decline in stocks (Belhabib et al., 2013a), which can prevent the sector from experiencing maximum economic gains. To avoid overexploitation and the collapse of the fisheries, it is crucial to evaluate the sustainability of the current fishing method used to exploited the fisheries resources. However, the maximum sustainable yield (MSY) estimate would be useful not only to know the state of the fishery but also to assess the state of the fishery, and provide baseline information for policymakers in understanding the status of the sector and the right methods to employ in sustainable management. This will support fisher's livelihoods, the nation's food security, and economic growth through sustainable production of fish yields. The African Union's (AU) policy on small-scale fisheries development aims to increase and strengthen the sector's contribution to the reduction of poverty, the security of food and nutrition, and the socioeconomic advantages of fishing communities (Africa Union, 2014). The Sustainable Development Goals of the United Nations (SDGs), which include 1- Zero hunger; 2- Sustainable cities and communities; 14-Life below water; and 15- Life on land, are also relevant to this research.

The finding of this research will contribute to the scientific knowledge, of the species being studied, which will benefit fisheries managers, as well as policymakers in terms of sustainable management of species.

Delimitations of the Study

The study focused on Liberia's small-scale sector viability and management implications at four landing sites in the Western and West-eastern regions. This may have resulted in the loss of some information that may pertain to other coastal fishing communities. The models generated in this study were based on estimates of the sector's Maximum Sustainable Yield (MSY), and exploitation status of main commercial species. The key tools for evaluating managerial implications were in-depth interviews and focus group discussions. Findings were dependent on the responds provided by respondents within the selected communities, which may not necessarily reflect the views of all fishers within the SSF. Results of this study is not applicable to the industrial sector of the marine fishery in Liberia due to the fact that this present study focused on small-scale fishery. In addition, the study did not include the activities of fishmongers and factors influencing self-governance in the fishery.

Limitations of the Study

The length and catch-per-unit effort (CPUE) data were secondary data sets gathered from the department of research and statistics (NaFAA). The catch and effort data obtained from NaFAA (2010- 2021) for the small-scale sectors was not standardized because the sector deploys various types of gears to target multi-species. There was no information on the number of gears deployed monthly or on an annual basis, which could not be determined for further biological information on the fishery. There was no data available on the species for a few months from the one-year (2021) length of data obtained.

However, the bootstrapping approach used to analyze the data gave some qualification to the results.

For the primary data collection, leaders from some landing sites were unwilling to participate in the Focus Group Discussions (FGDs) due to self-oriented issues. Based on past assessments that have not been favorable to fishers, it was also challenging to get their consent for the in-depth interview.

Organization of the Study

The study has been structured in the following manner: The first chapter, Chapter 1, provides an introduction of the study, background, statement of the problem, the purpose of the study, research objectives, the significance of the study, delimitations, limitations, and, organization of the study. Chapter 2 is a review of the literature, which provides an overview of Liberia's small-scale fisheries sector. It describes the three main ethnic groups involved in artisanal fishing in Liberia, the types of gear, and the species they target. It also gives an account of the local governance structure of the small-scale sector and the implementation of the West Africa Regional Fisheries Project (WARF-P) in Liberia. Literature on growth modeling, surplus production model, stock assessment and, co-management as a sustainable approach to small-scale fisheries management and the theoretical framework adopted by the research are also included in Chapter 2.

A primary data collection of managerial effectiveness, the profile of gear regulations, focus group discussions (FGDs) procedures, equipment, and materials utilized in the research as well as analysis of data are presented in Chapter 3. Secondary catch and production data from NaFAA and estimated percentage composition by species are also captured in this section.

Additionally, using the Schaeffer surplus-production model (Fox, 1970), the estimated catch-per-unit-effort (CPUE) and maximum sustainable yield (MSY) of Liberia's small-scale sector and the exploitation rate of one commercial species are included in chapter 3. In Chapter 4, the outcomes of the analysis are presented in tabular and graphical forms under the theme, Results. These results are explained, discussed, reasons are assigned to outcomes under Chapter 5, and summary recommendations and conclusions are provided in Chapter 6.

CHAPTER TWO

LITERATURE REVIEW

General Information on Liberia's Fisheries Sector

Liberia has a fishing ground about 20,000 km^2 in size and extends to a depth of 200 nautical miles with a 570 km coastline and a continental shelf about 34 km wide (NaFAA, 2020). Numerous fish species are found on Liberia's continental shelf, serving as a source of livelihood, foreign currency, etc. (NaFAA, 2020). For subsistence fishing practices, the six nautical miles closest to shore are designated as an inshore exclusion zone (IEZ). Hence, trawling with any gear used by industrial fishing operators is prohibited within this zone **(**NaFAA, 2020**)**. According to the Marine Resource Assessments Group (MRAG, 2014), there are six fish species that are exploitable: small, medium, and large pelagic, shallow and deep-water demersal, and crustaceans.

The aquaculture sector in Liberia also contributes to livelihood and improved utilization of farmland for food production (Kpadeh, Z.A., 2012). In Liberia, there are approximately 1,050 part-time subsistence fish farmers. Fish farming employs about 2,500 people, including those who build and manage ponds, provide extension services, and harvest fish (Kpadeh, Z.A., 2012).

Exploited species and gears used in the small-scale sector

"Artisanal fishing" refers to small-scale commercial fishing using traditional fishing vessels outfitted with primitive equipment and labor-intensive fishing techniques (Smith & Basurto, 2019). Fishing in the coastal waters of Liberia is dominated by the artisanal fleet, which employs a range of canoe sizes propelled by oars, sails, and increasingly use of outboard motors (MOA, 2014). Along the coast of Liberia, there are nine counties (i.e., Grand Cape Mount, Montserrado, Grand Bassa, Sinoe, Grand Kru, Rivercess, Margibi, Bomi, and Maryland). The majority of artisanal fishermen use non-motorized wooden dug-out canoes to target demersal species, using various fishing techniques and gear (MOA, 2014) Barracuda, soles, croakers sharks, and rays are the major fish species categories and constitute 19.5% of the catch of artisanal fishermen (Wilson R., 2018).

The Kru people of Liberian ancestry, the Fanti and Ewe Ghanaian origin, and the Popoh of Togolese origin are the three main ethnic groups involved in artisanal fishing in Liberia (NaFAA, 2020). However, the Kru and Fanti ethnic groups dominate the sector. The Kru primarily use small dugout canoes (approximately 7 meters long) with paddles or sails and crews of one to three people, who use a variety of gears (hooks, longlines, and gill nets) to target fish species. The canoes used by this group, make up about 75% of the canoes in the small-scale sector and catch demersal species such as cassava fish (*Pseudotolithus senegalensis*) butter nose (*Galeodes decadactylus*), and sole fish (*Cynoglossus lingue*). Other captured fish species include groupers (*Epinephelus coioides*), snappers (*Lutjanus Lutjanus*), pike fish (*Sphyraena guachancho*), and grunters (*Pomadasy maculayus*) (World Bank, 2015). Further, Kru operators also target some crustaceans, primarily crabs and lobsters, deploying gill nets and traps.

The Fanti operators used boats that are 10–15 m long, powered by outboard motors with horsepower ranging from 8 – 40hp. They usually carry a crew of six to twenty-six people. According to Chu et al. (2017), the majority of Fanti's boat operators are from Ghana. To catch small pelagics like bonny (*Sardinella madarensis*), porjoe (*Chloroscombrus chrysurus*), and Atlantic flying fish (*Cheilopogon melanurus*), they typically use ring nets (MRAG, 2014). Both Kru and Fanti operators also catch big and medium pelagic fish, albeit to a much lesser extent. The majority of their catches are brought in during the dry season, which lasts from October to April when the weather is cooperative. They have exclusive access to waters up to six nautical miles. The sea is calm and ideal for fishing during this time. Although Fanti canoes can travel farther than six nautical miles (Jueseah et al., 2020), during the rainy season, all artisanal fleets' fishing activities are hampered by strong ocean currents, violent storms, and heavy rain (MRAG, 2013).

These canoes use passive and active gear depending on the fishing season. Set gillnets, surface gillnets, and trap lines are the primary passive gears used by the Kru and Fanti canoes in the dry and wet seasons, while ring nets and other active equipment are deployed to target *Sardinella* spp. (BNF, 2013).

The catch from this subsector is estimated to be over 3,000 tons annually. Most of these catches are processed locally or primarily through salting, drying, and smoking and consumed locally (BNF, 2014). However, some of the fish are exported for foreign exchange to nearby nations like Sierra Leone, Guinea, and the Ivory Coast (BNF, 2014). High-value fish species are often sold fresh to restaurants, the market, or private houses right after being captured (BNF, 2014).

The Surplus Model, Schaefer and Fox Production model

Surplus production models are called holistic models because they both are less data-demanding methods of assessing the fish stock. These approaches also disregard many of the details of the analytical models (Cortés et al., 2012). The models do not use age or length structures in the description of the stock but consider the stock as homogeneous biomass (Cortés et al., 2012). These models could be computed with fewer input data points, compared to analytic models. The model also deals with total stock biomass, effort, and yield. Applying a surplus production model to a time series and effort data is one of the simplest methods for modeling a fishery. Schaefer (1957) and Fox (1970), who used the concept of equilibrium to model a fishery over the long term, developed this approach. They started by calculating various fishery biological parameters using a dynamic model. Then, the parameters for fishery management, including the maximum sustainable yield, were estimated using an equilibrium model. Therefore, the dynamic models served two purposes: first, to account for the non-equilibrium components of a fishery; and secondly, to precisely estimate the biological parameters. Many authors (Walter 1973; Schnute 1977; Uhler 1980; Lleonan & Salat 1989) have since developed their dynamic versions of the Schaefer and Fox models to better assess unstabilized fisheries.

The two dynamic approaches examined in this paper are the original (finite difference) versions and the integrated versions (Schnute 1977; Yoshimoto, S. S., & R. P. Clarke. 1993). The advantage of the surplus production model is that, by treating each stock as a unit stock, it can be used to estimate a first approximation of the sustainable yield from fisheries that operate on multiple stocks in a clearly defined area. According to Schaefer (1957), a careful analysis of time series data on effort and catch could aid in pinpointing the various stages of a fishery's growth, from its inception to its peak and then down to its decline. These phases could be identified in the relative and absolute yield curves by phase-appropriate identification marks, which would increase the model's usefulness and usability as a tool for management and development decisions (Walter, 1973). Relative to the Schaefer model of surplus production, the Fox model seems to be more realistic when a fishery undergoes a transition from a traditional to a mechanized state or when a mechanized fleet is added on to the existing traditional fleet, which causes changes in yield and effort in qualitative terms (Fox, 1970). These models' main flaw is that they only take into account the entire stock, ignoring factors like mesh size or the biology of the fish (Pauly, 1995).

Biological Reference Points for Fisheries Resources Management Strategies

To achieve the goals for fisheries management, the fishing levels that adversely affect the perpetuation of the stocks or allow greater yield or biomass and allow a considerable amount of the biomass to be left behind to replenish the stocks must be taken into consideration (Cadima, 2003). The Biological Reference Points (BRPs) are the names given to these fishing-level values. Target Reference Points (TRPs), Limit Reference Points (LRPs), and Precautionary Reference Points (PRPs) are the BRPs that fishery managers typically use. According to the ICES Advisory Committee (ACFM) report (1987) on fisheries management, there is no biological reference point, which can be used as universal target. Instead, biological reference points should serve as management guidelines (Caddy & Mahon, 1995). The highest catch that can typically be made from a fish stock each year in a sustainable way without lowering the productivity of the fish stock is known as the maximum sustainable yield (MSY) (Beverton & Holt, 2012). When a stock is too large, the yield is constrained by cannibalism, food competition, or the environment's carrying capacity restrictions. Between overfishing and overly large stocks, there is a stock size known as MSY, where the sustainable catch is at its highest level.

According to Cadima (2003), TRPs, also known as the reference points for management, "are biological reference points defined as the level of fishing mortality or of the biomass, which permits a long-term sustainable exploitation of the stocks with the best possible catch." It is categorized by fishing levels, such as $F_{0.1}$ (fishing mortality at 10% less than the maximum yield), F_{max} (maximum value of fishing mortality), and F_{MSY} (fishing mortality for maximum sustainable yield). LRPs, also known as the reference points for conservation, represent "maximum values of fishing mortality (F_{lim}) or minimum values of biomass (B_{lim}) which must not be exceeded." PRPs are used with assumptions in cases where there is a lack of knowledge about the stock parameters to prevent overexploitation. With levels like F_{pa} (maximum values of fishing mortality with precautionary approach) and B_{pa} (minimum values of biomass with precautionary approach), they are more restrictive than LRPs and control fishing mortality more strictly (Cadima, 2003). Since BRPs need to account for periodic changes in the stocks' biological parameters or exploitation patterns, the TRPs are most commonly used.

Not all scientists fully agree on the value of MSY as a tool for fisheries management. For instance, ecologists and others have harshly criticized MSY for both theoretical and practical reasons (Milner-Gulland & Mace, 1998). According to Larkin (1977), the MSY put populations at undue risk because it ignored spatial productivity variability, ignored species other than the fishery's target species, focused only on the positive aspects of fishing rather than its negative ones, and was vulnerable to political pressure. However, Safina (2012) noted that despite its drawbacks, MSY has been very beneficial in the places where it has been used, citing the flourishing US fisheries (where MSY is applied) and the collapsed UK fisheries (where MSY was not accepted until recently). The MSY approach has received much support as a fisheries management goal.

Yield per recruit /Analytical Model

The use of TRPs and the estimation of fishing mortality that yields the maximum sustainable yield are essential for effective fisheries management. To predict the effects of management measures on the fisheries due to changes in fishing mortality and/or the size of the first capture, models like the Beverton and Holt model (Beverton & Holt, 1957) and the Thompson and Bell 1934 model (NOAA, 2013) can be used (Cadima, 2003). The model act as a direct link between the evaluation of fish stocks and the management of fisheries resources (Mahmoud, Osman, Ezzat, & Saleh, 2010). These production models, also known as yield-per-recruit (Y'/R) models, are employed to determine how well a stock is performing relative to reference levels (Mildenberger et al., 2017). The exploitation pattern, growth parameters, and natural mortality affect the yield-per-recruit (Cadima, 2003;

Mahmoud et al., 2010). If the associated exploitation pattern, growth parameters, and natural mortality are given for a given level of fishing mortality, an equilibrium value of the yield-per-recruit could be determined. This Y'/R-value increases with fishing mortality until a level where the maximum sustainable yield is achieved. Beyond this level of maximum sustainable yield, overfishing occurs and the population collapses (Mahmoud et al., 2010).

The fishing mortality (F_{max}) that produces the maximum yield (Y_{max}) also gives a corresponding maximum biomass (B_{max}) that can be taken out to allow stock replenishment. However, when the fishing mortality (F) is less than the F_{max}, a greater biomass than B_{max} is produced, while fishing mortality greater than F_{max} will result in biomass that is less than B_{max} and lead to overfishing (Cadima, 2003). Through the use of Y '/R analysis and models like the Thompson and Bell model, the "TropFishR" package enables the estimation of these reference points (Abobi et al., 2019; Mildenberger, 2019; Mildenberger et al., 2017).

Growth modeling

To understand the evolution of the biomass of that cohort or fish stock, it is crucial to simulate the individual growth of fish. The two primary techniques employed in the modeling of growth are the age-based and length-based processes. Because they are less expensive and labor-intensive than age and tagging investigations, length-based approaches are widely utilized in research. They may also be employed on species that cannot be aged individually and for which fisheries laboratories only have historical length-frequency data (Pauly & Greenberg, 2013). Length-based stock assessment has been used to interpret a fish's growth, mostly by modal progression (Schwamborn, Mildenberger, & Taylor, 2019). Using this method, monthly length frequency (LF) distributions of the fish are presented using a modal progression, which connects the modes to show how each cohort grows with time (Pauly & Morgan, 1987; Schwamborn et al., 2019). The von Bertalanffy Growth Function (VBGF) (von Bertalanffy, 1938), adapted by Beverton & Holt (1957), is the recognized growth model used in fisheries biology to study the growth of a fish and fitted to the monthly length-frequency data (Schwamborn et al., 2019). This VBGF model's fundamental principle is that there exists an asymptotic length (L), which is the maximum that each length tends to, a growth coefficient (K), which represents the curvature of the growth curve, and a theoretical age at length zero (to) of the fish (Cadima, 2003).

The modal progression approach, together with the "Petersen method," was combined into an "integrated method" (Pauly, 1983), which was later incorporated into a computer package known as "ELEFAN (Electronic Length Frequency analysis (Pauly & David, 1981; Pauly & Morgan, 1987). These techniques have recently been integrated with certain additional functions into packages like "TropFishR" (Mildenberger, Taylor, & Wolff, 2017; Mildenberger, 2019) and "ELEFAN in R" (Pauly & Greenberg, 2013). However, the 'TropFishR' appears to be the most improved package, because it comes with improved versions of all the FiSAT II and ELEFAN functions, in addition to some modern optimization techniques (Mildenberger et al., 2017; Mildenberger, 2019; Schwamborn et al., 2019; Taylor & Mildenberger, 2017).

Stock Assessment Methods

Assessments of fish stocks have grown in importance as a tool for managing fisheries resources sustainably. Getting the greatest possible usage of the resource for the benefit of the community is the aim of fisheries management (FAO, 2018). Fish stock assessments have developed into a crucial tool because they offer decision-makers scientific guidance on the state of the fish stocks and their fisheries today and in the future (NOAA, 2012). Therefore, models used to evaluate various aspects of fishing activity are included in fisheries stock assessments (Cadima, 2003). There are two categories of models used in fisheries stock assessment: structural models and production models. Examples of models classified in these categories are the Lotka-Voterra (structure) model, general production models, growth (age-structured) models, yield-per-recruit (production) models, and stock-recruitment (structured) models. These models offer metrics such as biomass, exploitation rate, growth, and mortality and represent the dynamics of the fishery.

West Africa Regional Fisheries Project (WARF-P) in Liberia

In Liberia, the fisheries sector is crucial for thousands of people's livelihoods and sources of income (FAO, 2019). In spite of the natural resource's worth, the sector is not sufficiently boosting economic growth because of resource overexploitation and subsequent depletion by unlawful operatives as a result of the inadequate capacity to manage marine resources sustainably (World Bank, 2019). The West Africa Regional Fisheries Program, funded by the International Development Association (IDA) of the World Bank, aims to assist nations in overcoming these obstacles by providing assistance to collaborate and strengthen the governance of the use of marine resources so that they recover to levels that are significantly more environmentally sustainable and economically profitable. Additionally, make investments where they are required to raise the proportion of these resources' value that is retained locally in the region. Numerous milestones have been attained in Liberia since the start of the West Africa Regional Fisheries Project (WARF-P) in 2009 to ensure the preservation, protection, and sustainable management of the fisheries.

Liberia developed an inshore exclusive zone (IEZ) for artisanal fishermen as part of the West Africa Regional Fisheries Program (WARF-P), drafted the necessary legislation, completed the registration of small-scale fishing fleets, improved national fishing fleet licensing policies in several fisheries, increased licensing transparency generally, and improved monitoring capabilities by establishing a satellite-based vessel (World Bank, 2019). To date, there have been several community-managed associations established in the sector. According to a review of the use of Fishery Performance Indicators (FPIs) in a sample of communities in Liberia, the country has benefited from the WARF program, which has enhanced performance in the social, economic, and ecological facets of sustainable fisheries. Liberia's levels of illegal fishing were significantly impacted by the WARF-Program overall, with more than 50% less violations occurring on average. Because of this, Liberian fishing towns and communities have started to see a localized rebuilding of their resources and an increase in production. Considering this, Liberia has begun the protracted process that is often required to switch to sustainable management practices for the fisheries sector. To promote excellent practices at the community level, it is essential to secure the full and active involvement of fishing communities in the creation of policies and specific fisheries management actions (such as access control and surveillance) (World Bank, 2019).

Governance structures of the small-scale fisheries of Liberia

The National Fisheries and Aquaculture Authority (NaFAA), the Liberian Artisanal Fishermen Association (LAFA), Co-management and fishing cooperatives jointly oversee Liberia's small-scale sector (Fig. 1). Although the development and regulation of fisheries are shared among the four levels of authority, the actual implementation of management strategies is primarily done at the cooperative level (NaFAA, 2020).

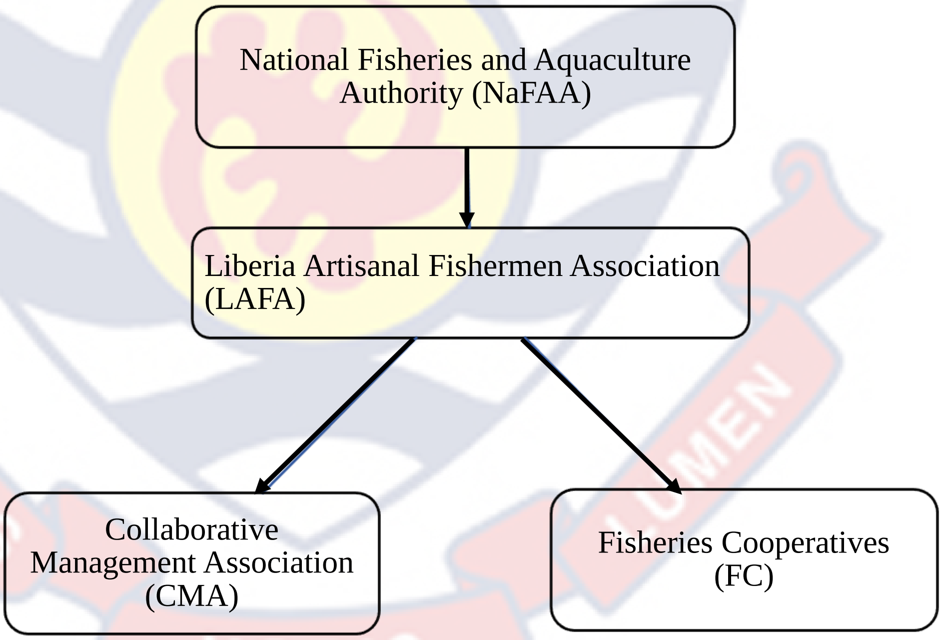

Figure 1: Governance structures of the small-scale fisheries of Liberia

The National Fisheries and Aquaculture Authority (NaFAA), which serves as the first point of contact for global, regional, sub-regional, and bilateral cooperation for fisheries management, is involved in overarching logistical and administrative responsibilities. The NaFAA encourages adaptive research and stakeholder involvement in the management and development of capture and culture-based fisheries and improves monitoring, control, and surveillance capabilities. For better fishing and financial gains, the institution also works to improve fish superiority and value-adding technologies. The Liberia Artisanal Fishermen Association (LAFA) represents the small-scale sector both nationally and internationally. The organization acts as the primary intermediary between local associations and national authorities by interceding and disseminating information. The NaFAA and the Liberia Artisanal Fishermen Association (LAFA) collaborate with non-governmental organizations to provide opportunities that benefit the sector by identifying gaps in fisheries management and creating potential roadmaps for addressing the gaps. For instance, Section 3.2 -Institutional Arrangements – of the Fisheries and Aquaculture Management and Development Law 2019 by NaFAA, (mandated the creation of Collaborative Management Associations (CMA) in six coastal counties namely: Montserrado, Grand Bassa, Sinoe, Rivercess, Margibi and Maryland (NaFAA, 2020). The main goal of these institutions is to jointly play crucial roles in supporting the monitoring and management of the coastal ecosystems that provide food and livelihoods to fishing communities to ensure sustainable fisheries throughout Liberia.

The Collaborative Management Association (CMA) oversees and upholds regional, state, and local fisheries management laws and regulations. These regulations are adaptive and based on effective fisheries laws. For instance, capturing protected species is prohibited; fishing is not permitted outside of the SSF IEZ; any form of violence within fishing communities is prohibited, and canoes must be licensed before being allowed access to Liberia's small-scale fishery. These measures are taken to reduce IUU and environmental degradation. Users actively monitor and enforce the laws, and there are consequences for individuals who violate them. The CMA leaders, however, have little power beyond their communities because they represent more than one fishing community and thus work closely with the Liberia Artisanal Fishermen Association (LAFA).

In 2021, the NaFAA signed a memorandum of understanding (MOU) with the Cooperative Development Agency (CDA) of Liberia to establish a grassroots organization (fisheries cooperatives) that would involve everyone's participation at every landing site within the nine coastal counties.

Fisheries co-management and common property

The process by which government and the local fishing community share power and responsibility to manage a fishery is known as "fisheries co-management" (Pomeroy, 1994). Many authors agree that co-management falls under the umbrella of common property theory (Hardin, 1968; Pinkerton, 1989; Pomeroy, 1994). Hardin (1968) stated that resource utilization must be equal to the productivity of the common resource base. Moreover, it is best for users of common resources to keep their use patterns below the carrying capacity because unrestricted access to common resources depletes the resource. To address the degradation and overexploitation of common property resources, Hardin suggested privatization or governmental control.

In order to maintain a common resource area's carrying capacity, the top-down strategy advocated by Hardin's model ignores the significance of effective user consultation or participation (Pomeroy, 1994). As a result, the centralized management system leads to a decision-making process that is detached from the resource users and their needs. According to Ostrom (1999), while Hardin correctly observes that a resource that belongs to everyone would be overharvested, his prediction of an unavoidable tragedy is unjustified. She believes that a common tragedy is easily avoidable. Also, fishing communities that have developed effective collective control to reduce overharvesting have increased returns from fishing while helping to ensure resource sustainability

Concisely, resource depletion and overexploitation have not been addressed by the promotion of centralization as a management strategy for common resources (Pomeroy, 1994). To avoid further degradation and overexploitation, it is crucial to improve fishery resource management.

As a result, there have been a shift in governance towards an alternative strategy that requires the involvement of fishers, local stewardship, and institutions in the management of fisheries through a co-management system (Pomeroy, 1994).

According to Saavedra-Dáz et al (2016), Colombia's small-scale fishers experience a variety of issues and conflicts as a result of their lack of full recognition as significant stakeholders in the fisheries management process. The three groups of stakeholders—fishers, local leaders, and fisheries experts—presented a specific recommendation to reform and restructure governance through co-management and to build consensus among the key government and user stakeholders in order to address the major issues. More than 50% of each stakeholder group thought that using a bottom-up fisheries management strategy, like co-management, would be effective in addressing environmental issues and resource crises.

The International Union for Conservation of Nature and Natural Resources (IUCN) has been working in Guinea-Bissau since 1991 on a project for the co-management of fisheries resources. Baran & Tous (2000) presented a report on the project's accomplishments (Rio Grande de Buba region). Institutions and fishers collaborated, each party accepting the legitimacy of the other. Currently, fishers have access to effectively managing their local fisheries considering participatory management strategies and a precautionary approach to resource management.

On the other hand, Okusu (2020) emphasized that the Ghanaian fishery sector did not have success with the institutionalized approach to managing natural resources known as co-management. This was brought on by the challenges that contributed to the underperformance of co-management, which included a weak institutional framework, a lack of active participation, a lack of empowerment, and a lack of trust. To find out what obstacles stand in the way of effective co-management, a case study with Fante fishermen was conducted in Elmina. However, it was advised that policymakers pay close attention to the co-management principles, as this will support the sector's sustainability (Okusu, 2020).

Despite the advancement of gear registration of the sector, there exist limited studies that unravel the effectiveness of the management system and the factors that are influencing the sustainable utilization of the resources.

Conceptual framework of co-management of fishers for the four landing sites

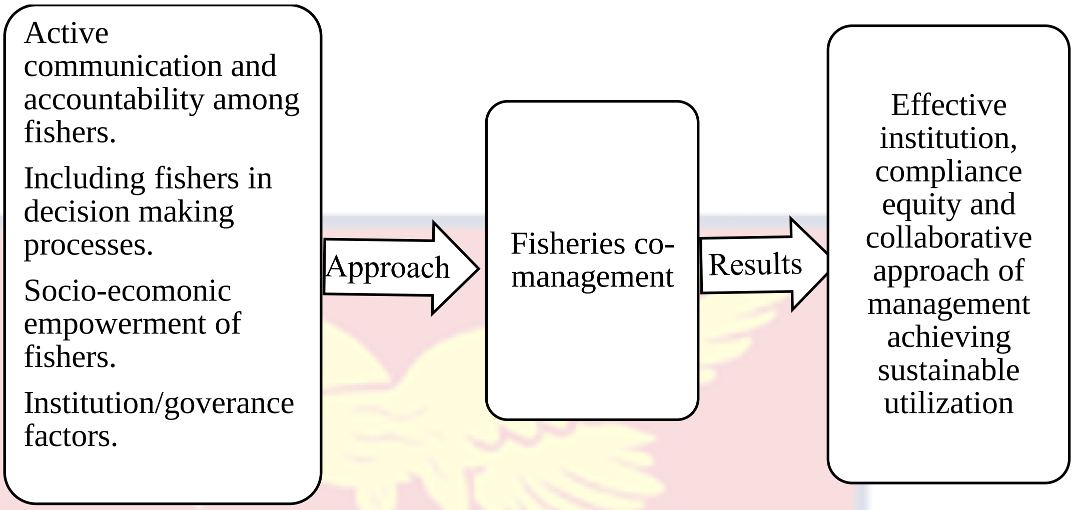

Figure 2: Conceptual framework

Based on the primary data gathered, the co-management structure model is depicted in the above diagram, which is shown in Figure 2. The three pillars of regulatory, normative, and cultural rationality should be included in the construction of a strong institution, according to Scott (1992). The fishers in the study areas would follow these pillars as a guide for their actions. Fishermen's capacity will grow and their social and economic empowerment will make them more aware of the need to conserve fisheries resources. Their perspectives on their peers and the government would change over time as well. It would be possible to build trust between the various stakeholders through open communication, accountability, and transparency. These strategies will produce outcomes like an effective institution, compliance equity, and a collaborative approach to management achieving sustainable utilization when they are fully implemented.

CHAPTER THREE

MATERIALS AND METHODS

The procedures, techniques, and tools utilized for data collection and analysis for the study are described in this section. The study areas, research design, demographic and sampling methods, research tools, data collection, data processing, and statistical analysis methods used are described in detail.

Study Area

Information was gathered from all nine coastal counties (Cape mount, Bomi, Montserrado, Margibi, Grand Bassa, Rivercess, Sinoe, Grand Kru, Maryland) of Liberia using secondary data sets to evaluate the viability of the small-scale sector and the exploitation rate of four main commercial species (Figure 3). Four landing sites within two coastal counties (Montserrado and Grand Bassa) were used to gather primary data for the study's socioeconomic and ecological components. Out of the seven (7) landing locations in Montserrado County, West Point and Point Four were selected within the Monrovia electoral district #16. This forms part of the country western region which is home to about 3,166 fishermen. Out of the twenty-one (21), landing sites in Grand Bassa County, Korkorwin, and Big-Fanti Town were selected. An estimated 949 fishermen are living at the two landing locations, which are in District #3 in the west-eastern area (NaFAA, 2020). These landing sites (Figure 3) were selected based on the population, geographic distribution, and intensity of fishing operations.

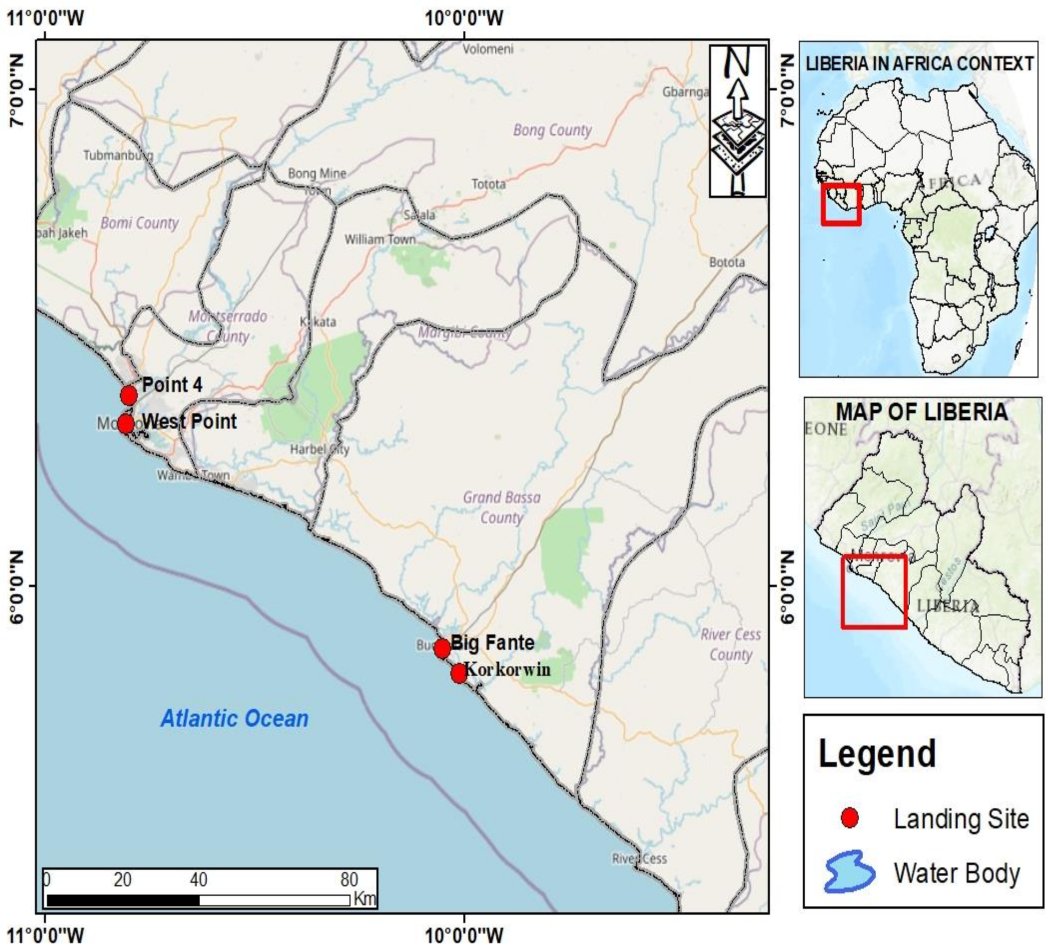

Figure 3: Map of Liberia's nine coastal counties and four major landing sites.

Research Design

A mixed-method study design combines quantitative and qualitative methods in research., The qualitative phase sort to explore the views of participants on the research subject before the quantitative phase, which involved a range of numeric data for statistical analysis. The exploratory sequential mixed approach, which is a component of the mixed method, was used for the study. Berman (2017) emphasized that when it comes to research associated with well-being, public health, and other relevant facts, the exploratory sequential mixed technique is the most appropriate study design under the mixed methods to be applied for the aforementioned. The lack of scientific data on the effectiveness of management implications in the study area, as well as the local approaches governing its management, makes the use of a purely quantitative approach insufficient. This approach also guided the structure of instruments used for the quantitative phase of this study. As a result, focus group discussions (FGDs) and in-depth interviews (IDIs) were incorporated into the research design. A combination of quantitative and qualitative methodologies was thus the most efficient way to conduct this research, taking the scope and objective of the study into consideration.

Secondary Data Source

For the secondary data sets, catch and effort data from the nine (9) coastal counties (2010–2021) were gathered from the Department of Research and Statistics Division under the National Fisheries and Aquaculture Authority (NaFAA), Liberia. A one-year (2021) length data on species within the sector was also obtained. The obtained data sets were used to assess the sustainability of the sector using the Schaeffer production model (Schaefer, 1957) and the exploitation rate of the commercially species within the small-scale sector of Liberia.

Species composition for Liberia's small-scale fishery

A secondary catch and effort dataset for recent years (2018–2021) was used to estimate the catch and percentage composition of sixteen (16) commercially landed species from the nine (9) coastal counties of Liberia. Data was obtained from the NaFAA.

Estimation of Growth Parameters

The growth patterns of *Galeoides decadactylus* with respect to relative age and length based was determined. *Galeoides decadactylus* was selected because it forms a part of commercially species, which from economic perspective, provide revenue for fishing communities and industry as a whole. The estimated growth parameters (L∞, K, tanchor, C, ts, ϕ') with their corresponding confidence intervals (CIs) will be obtained by using the 95% quantiles of the posterior distributions. The von Bertalanffy growth equation:

$TL_t = TL_\infty \times [1- e^{(-K\times(t-t_0)}]$ (von Bertalanffy, 1938)

The growth of the one commercially landed species was described by fitting the growth curves to the length-frequency data as follows: TL_t is the total length at age t, TL∞ is the asymptotic length, K is the growth rate coefficient, and t_0 is the theoretical age at length zero (Gayanilo et al., 2005). The growth parameters (TL, K, and t_{anchor}) were calculated via modal progression analysis using the ELEFAN function in the "TropFishR" package, where t_{anchor} is the proportion of years when yearly recurring growth curves intersect at a length equal to zero (Mildenberger, 2019).

Determination of growth performance index

The growth performance index (ϕ') was calculated by the equation:

$\phi' = log10\ K + 2log10TL\infty$ (Pauly & Munro, 1983)

Estimation of mortality coefficients

Using the growth parameters and the empirical equation of Pauly (1983) with M, TL_∞, K, and T°C, (the main sea temperature of 27. 8 °C in Liberian waters (World Sea Temperature, 2021) the natural instantaneous mortality coefficient (M) was estimated as follows:

$Log_{10}M$ = -0.0066 - $0.279 log_{10}TL_{\infty}$+ $0.6543 log_{10}K$ + $0.4634 log_{10}T^{o}$C

(Pauly, 1980)

The fishing mortality rate (F) was calculated from the equation:

$F = Z - M$ (Ricker, 1975)

Determination of exploitation ratio

The exploitation ratio (E) was established by the equation:

$E = \frac{F}{Z}$ (Ricker, 1975)

The parameter t_0 which refers to the age at which the length of the fish is zero (Gulland, 1983) was estimated from Pauly's (1983) equation:

log10 t0 = –0.3922- 0.2752 log10 L∞–1.038 log10 K

Estimation of longevity

The longevity or natural lifespan (t_{max}) of the stocks was assessed using the equation:

t_{max} $\frac{3}{K}$ (Pauly, 1983)

Catch trends and catch-per-unit-effort (CPUE) for the small-scale sector

The small-scale sector of Liberia is a multi-species fishery where all gear types target various species, resulting in an effort not being standardized. Therefore, to compute production against effort and the CPUE for the sector, the annual landing data from 2010 to 2021 was used.

Estimating the MSY Using the Schaefer's Surplus Production Model

Both Schaefer's and Fox's models, which are the two most common surplus production models, are known to produce almost the same estimates, with neither of the two being superior to the other (FAO, 2014). For this study, Schaefer's model, as proposed by Graham (1935), was used to estimate the MSY and the fishing effort, and F_{MSY} needed to produce the MSY for the Liberian small-scale fishery using the equilibrium assumptions. Under disequilibrium conditions, it is assumed that the biomass does not change between two consecutive periods, thereby making the removal in the form of annual yield equivalent to the production (Masters, 2007). The Schaefer model assumes that yield is related to the fishing effort by a symmetrical parabola.

The effort (f) in years and catch per unit effort (CPUE) in metric tons per year were plotted with the effort on the horizontal axis and CPUE on the vertical axis. This was done for the small-scale sector of Liberia. The intercept (a) and the slope (b) of the scatter, from Microsoft Excel, are determined. The study calculated the maximum sustainable yield (MSY) and its effort, which follows the Schaefer harvest function:

(1) CPUE = $a + bf$ ……… (1)

(2) Y = $af + bf\,2$ ………. (2)

Where: a = intercept of plot; b = slope; f = effort and Y = yield.

(3) MSY= $-a^2/4b$ ……….. (3)

(4) (4) FMSY= $-a$ / $2b$ ………. (4)

(Graham, 1935; Schaefer, 1957)

Fishing gears used in exploiting fish stocks in the small-scale fishery

In Liberia's small-scale sector, the main fishing gears used are bottom gillnets, floating nets, longlines, set nets, surface gillnets, and trap lines. The measurement of the mesh sizes of various gears was done. A tape measure was also used to measure the bar mesh and stretch mesh. To provide a profile of the gears used in small-scale fishing to exploit fish stocks, the measurement of these gears was compared with what has been crafted within the 2019 fishing regulations

Target Population

Two groups of people made up the study's targeted population. Local government agencies and organizations made up the first group of respondents. These respondents were selected because of their involvement and representation of fishing communities nationally. However, the success or failure of the management of local fisheries governance somehow depends on these groups of people. Organizations, local authorities, and fisher representations were engaged during the first phase of the socioeconomic and ecological study through FGDs.

The second group of respondents included fishers who had practiced fishing as a livelihood in the sector for at least 10 to 20 years. These respondents were chosen for the study based on their participation in the local policy implementation that serves to protect and maintain the resources. Their inclusion aided in achieving objective three of the analysis because their knowledge and involvement in the issues under investigation were considered paramount.

Sampling and Sampling Procedure

Sample size estimation

The determination of the sample size followed the protocol of Yamane (1967)

$$n = \frac{N}{1 + N(e)^2} \dots\dots\dots\dots\dots . eq(5)$$

Where e is the level of precision, N is the size of the population, and n is the sample size. The study calculates its sample size as follows when this formula is applied to the sample shown below:

The population of the study area is 4115 inhabitants.

$$n = \frac{N}{1 + N(e)^2} = \frac{4115}{1 + 4115(0.05)^2} = 365$$

$$n = 365$$

To determine the sample size for the four landing sites,

$$\frac{365}{4} = 91.25$$

Table 1 shows the sample size for the socio-economic and ecological components of the study.

Table 1: Sampled Communities

County	Fishing community	Total number of fishermen	Sample size
Montserrado	Point- 4	768	91
Montserrado	West- point	2,398	91
Grand Bassa	Big Fanti Town	455	91
Grand Bassa	Korkorwin	494	91
Total		**4115**	**365**

Sampling Procedures

Twenty-one (21) respondents participated in the qualitative component of the study, which included two (2) FGDs per coastal county. The groups were represented by organizations, local authorities, and fishermen. Each focus group consisted of 3-8 participants, and the discussion lasted for 60 to 90 minutes. For the quantitative component, coastal counties were chosen using a purposive sampling technique. Here landing sites and fishermen within fishing communities were chosen using based on the intensity of fishing in the area. In the study area, a total of 1,399 fishermen were interviewed. Respondents, aged 25 years and older were selected for the interview because of their broader knowledge and perspectives about fishing on a community level, as the study aimed to document information on specific issues that would be known by fishermen with extensive knowledge and experience in the sector.

Data Collection Instruments

In-depth interviews and focus group discussions were used as the main methods of data collection. These methods offered a general framework and the flexibility for the study to explore new ideas as the interview went on. For the focus group discussions, data was gathered using semi-structured interviews. The discussions gave a natural flow between the interviewer and participants' (Wengraf, 2001). The goal of the focus group discussions was to look into the management implications of maintaining the fishery. The in-depth interview was conducted using the Kobo Toolbox and included both open-ended and closed-ended questions. The interview questions were structured so that respondents or participants would have no difficulties responding to them. The questionnaire had four sections: instruction seeking fishers' consent; general biodata, and managerial effectiveness within the sector.

Primary Data Collection

After being informed about the goal of the study and the anonymity and confidentiality of their statements, fishermen were approached through a social network based on their willingness to participate. The fishermen interaction took place at the fishing sites or their residences and involved project briefing and consent to participate in the interview according to the methodological recommendations of Bunce et al. (2006). An effort was made not to interfere with their operations. For example, no fishermen were requested when they were operating fishing gear or landing their catch for marketing because it was noted that fish quickly started to spoil in the hot sun. The best timing was before or after their daily routine activities. When visits were made to the fishing landing sites, the leaders were first approached, and once they gave their approval for the work to commence, the fishers were then interviewed. Each interview took an average of 20 to 30 minutes. The interview questions were based on managerial effectiveness and the implementation of fisheries regulations, following the 2019 fisheries regulation goal, which is to ensure the long-term management, conservation, development, and sustainable use of the fisheries and related ecosystems for the benefit of the people of Liberia (Appendix B). The number of respondents who took part in the face-to-face interview was approximately (1,039) one thousand and thirty-nine. However, respondents raised concerns about past interviews that were conducted without proactive implementation in the sector.

Data Analysis

The Microsoft Excel was used to analyze the catch composition, catch trends, maximum sustainable yield estimated, and length frequency distribution of a single species in the sector. The length measurements were compiled into 5cm for the length frequency distribution for each species. The packages "TropFishR" (Taylor & Mildenberger, 2017), "fishboot" (Schwamborn, Mildenberger, & Taylor, 2018), "ks" (Duong, 2019), "devtools" (Wickham, Hester, & Chang, 2018), and "fishmethods" (Nelson, 2018) in the statistical computing software "R" were used for all analyses relating to growth modeling, natural and fishing mortalities, and exploitation ratios (version 4.2.2).

A profile on gear utilization was determined using Microsoft Excel. Also, a thematic analysis was used for the focus group discussion. The qualitative data were transcribed and comprehensive outcomes were obtained which helped explained the quantitative data. Data collected from the survey were thoroughly edited to ensure that it was simple for subsequent coding and analysis. Data were analyzed using STATA (15), a Statistical software. All datasets used for the study were cross-check, and processed in Microsoft Excel version 2016 to make sure there were no mistakes that would have affected the analysis's results.

CHAPTER FOUR

RESULTS

This chapter presents results on the exploitation rate of four important commercial species including growth, and mortality parameters and the types of gears used by fishers. The catch trends of species and production levels, and the socio-economic and ecological aspects and responses from the respondents who live and work in the study areas are also presented. Results are presented in tables and graphs, showing the differences in the analysis from the four landing sites.

Figure 4 shows the catch composition of commercially landed species within the sector using a four years (2018-2021) secondary catch and effort data from NaFAA (Appendix A). *Sphyraena guanchacho* and *Sardinella madarensis* constituted 16% and 12% of the total catch respectively. One of the top seven (7) species, *Galeoides decadactylus*, accounts for 4% of the small-scale sector landings whereas 31% was made of other species

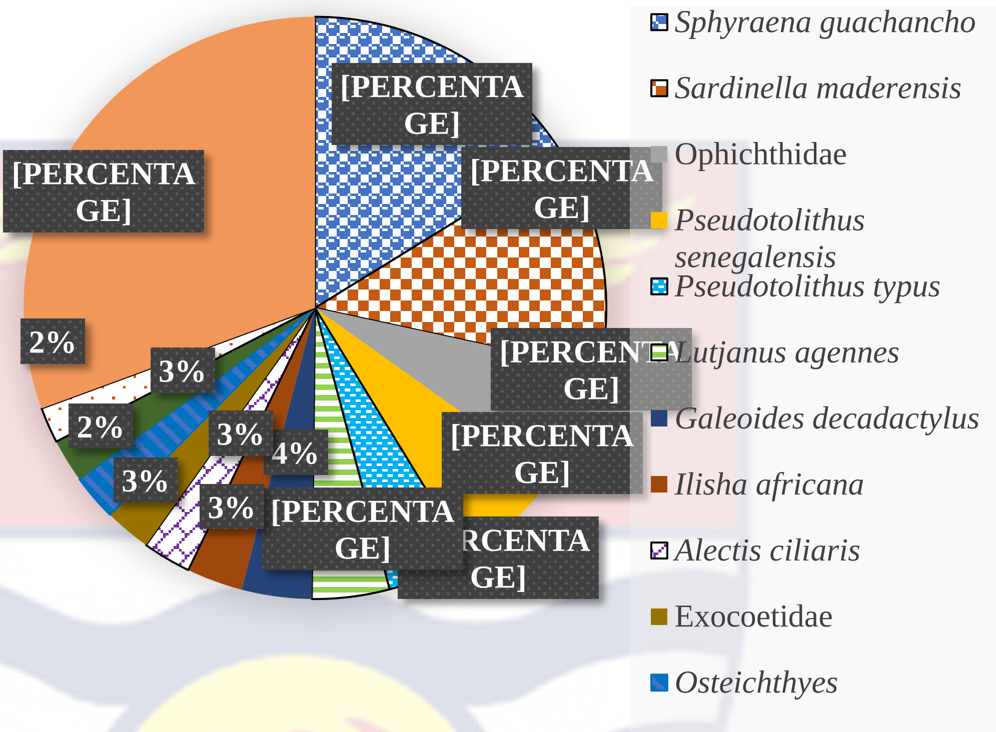

Figure 4: Overall catch composition of commonly landed species in Liberia's small-scale sector (2018 – 2021).

A percentage composition of major species (MT) landed from 2018 to 2021 is shown in Figure 5. The percentage composition of *Sphyraena guanchacho* and *Galeoides decadactylus* decreased in landings from 42.4% to 17.6%, and 6.9% to 3.7% from 2018 to 2021 respectively. However, *Sardinella maderensis* and *Pseudotolithus senegalensis*, increased from 0.42% to 13.6 %, and 1.9% to 8.7%, respectively within the same period.

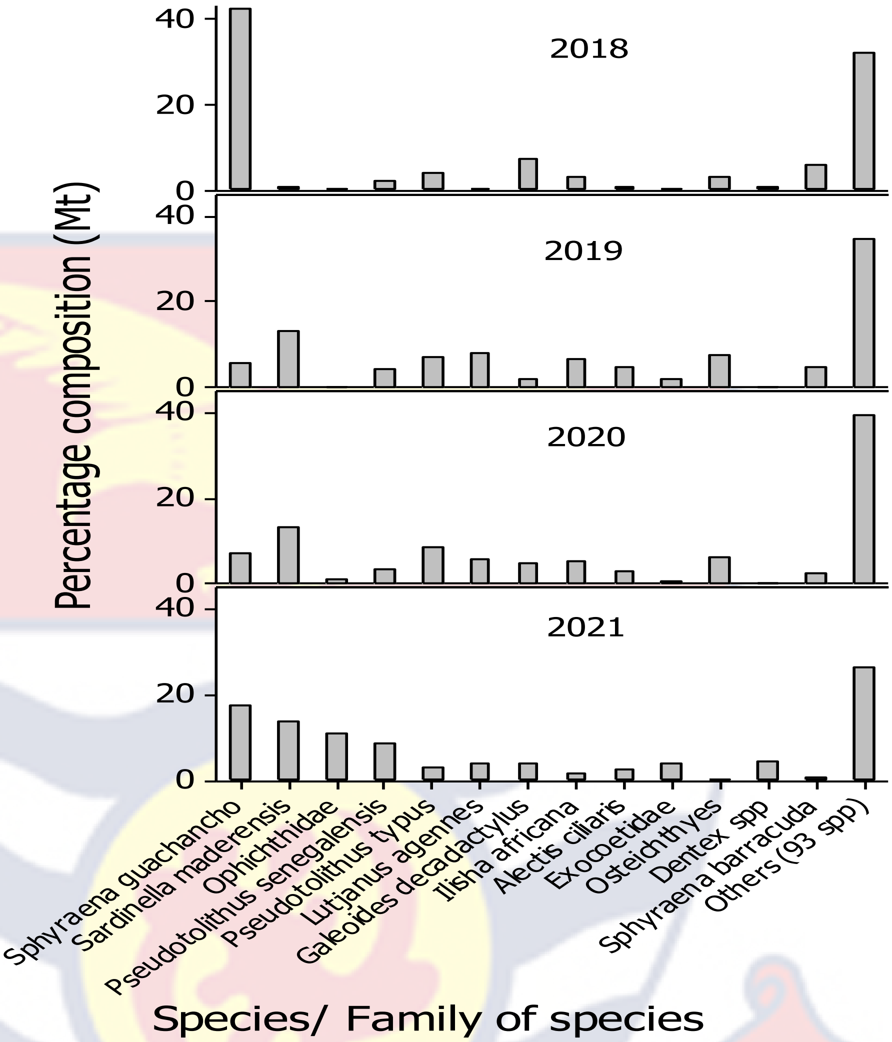

Figure 5: Percentage composition of major species landings from 2018-2021

Catch trends and catch-per-unit-effort (CPUE) for the small-scale sector

The sector deployed different types of fishing efforts to exploit multiple species from 2010 to 2021 (Appendix A). Figure 6 shows the catches against effort for the small-scale sector from 2010 to 2021 from the NaFAA's data. The total production between 2010 to 2018 was stable. There was a gradual increase in catch from 2018 to 2020, with a peak occurring in 2021 (figure 6).

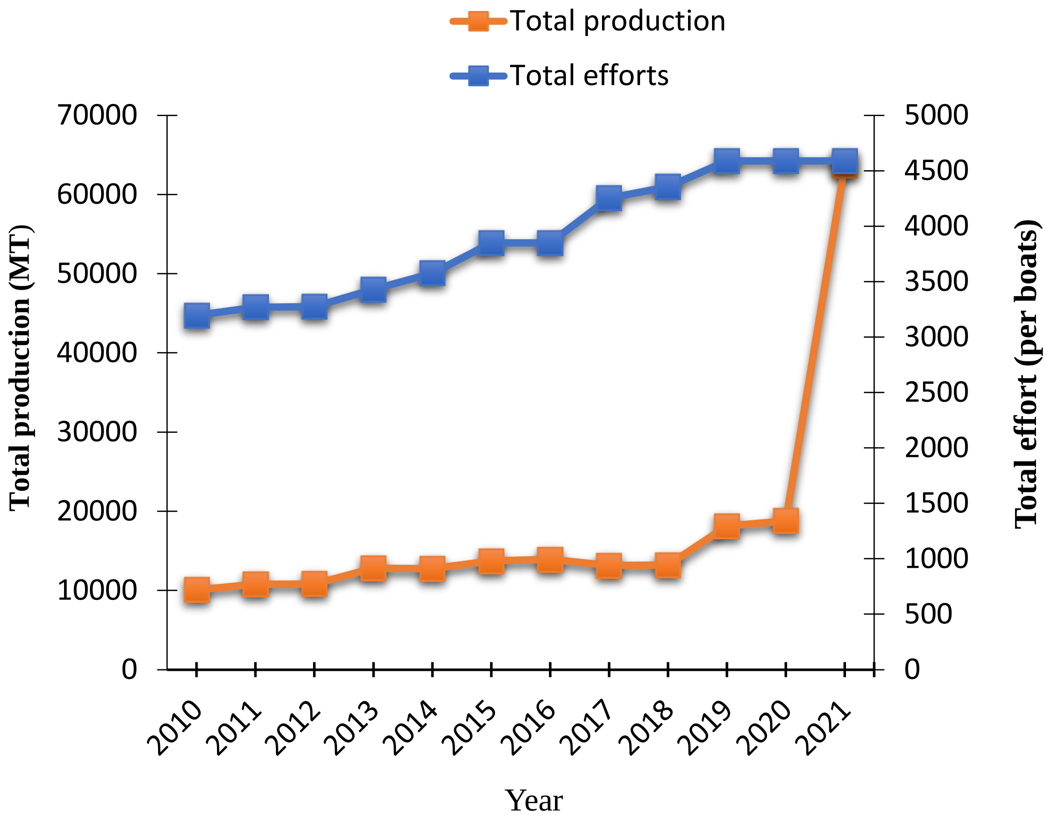

Figure 6: Annual Production and effort of multi-species in Liberia's small-scale sector from 2010 to 2021. Data source: NaFAA 2010-2021

This pattern agreed with the CPUE for the small-scale sector within the said period (figure7).

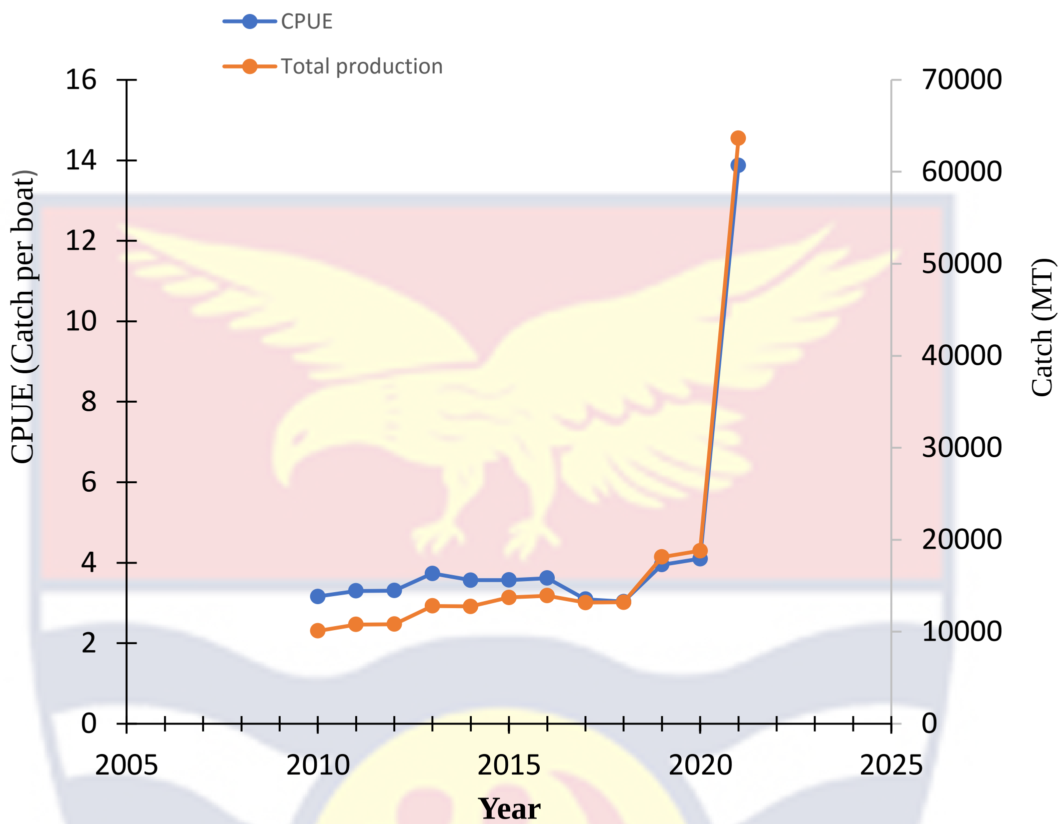

Figure 7: Catches of multi-species in Liberia's small-scale sector from 2010 to 2021. Data source: NaFAA 2010-2021.

Length Distribution

Using one-year secondary data from NaFAA, 136 specimens of *Galeoides decadactylus* were sampled. An interval of 5 cm was used to categorized the length measurements. The total length of all the individuals obtained ranged in size from 6 cm to 100 cm, and the mode obtained was 40 cm Figure 9 shows the length frequency distributions of *Galeoides decadactylus*, comprising the total number of individuals sampled. The study's goal was to assess how frequently four species—*Galeoides decadactylus, Pseudotolithus senegalensis, Sardinella maderensis, and Sphyraena guachancho*—are exploited in the sector. The parameters of other species could not be obtained through bootstrapping ELEFAN due to time constraints and the structure and collection of the data obtained. Therefore, additional research will be done on these species, taking into account their significance to the fishery.

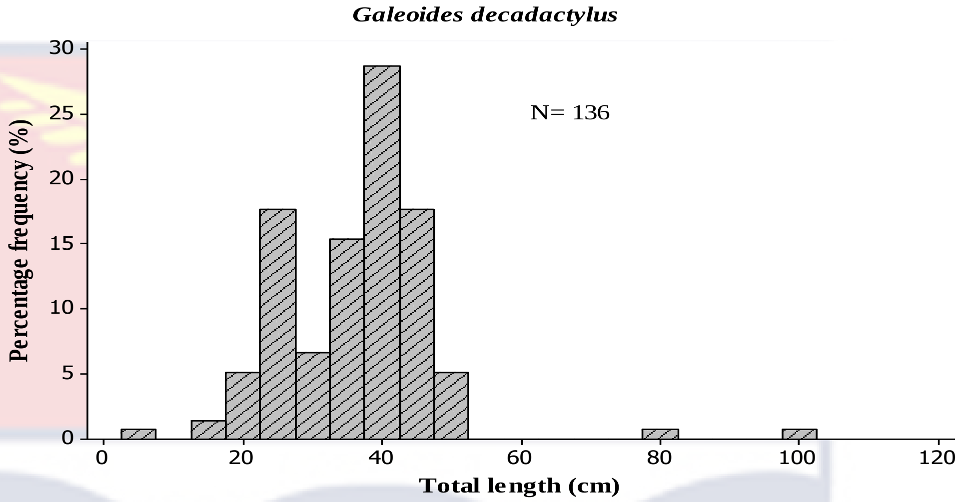

Figure 8: Length frequency distribution of *Galeoides decadactylus* of Liberia's small-scale sector.

Growth Parameters

Length-frequency histograms with the growth curves (dashed lines) obtained through the bootstrapped ELEFAN superimposed for *G. decadactylus*. The monthly length-frequency distribution histograms superimposed with the von Bertalanffy growth curves (dashed lines) obtained through the bootstrapped ELEFAN is presented for both catch frequencies and restructured frequencies for *Galeoides decadactylus* in (Figure 9). A bin size of 1 cm and a moving average of 5 were used for the species. The estimated growth curve fitted through the peaks of these months indicating a modal progression. In addition, the appearance of more the one cohort was observed among the species in the fishery.

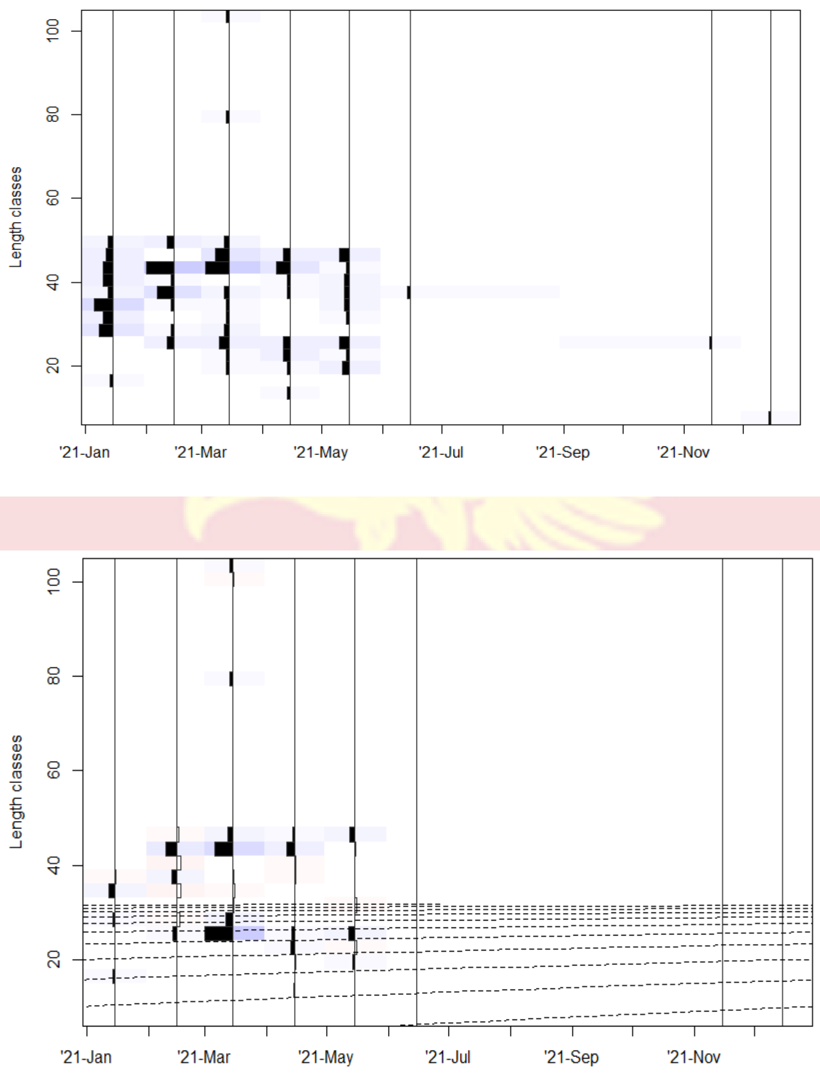

Figure 9: Catch length-frequency and restructured length-frequency distributions of *Galeoides decadactylus* fitted with VBGF growth curves obtained through bootstrapping.

The results of the growth parameters (L∞, K, tanchor, C, ts, ϕ') with their corresponding confidence intervals for *Galeoides decadactylus*, are shown in Figure 10. The estimates of asymptotic length (L∞; cm) for *Galeoides decadactylus* was 69.22, the growth rate coefficient (*k*; year^{-1}) was 0.28, the tanchor obtained was 0.59, ts 0.67, and, the growth performance index (φ') with 0.95 confidence intervals was 3.13.

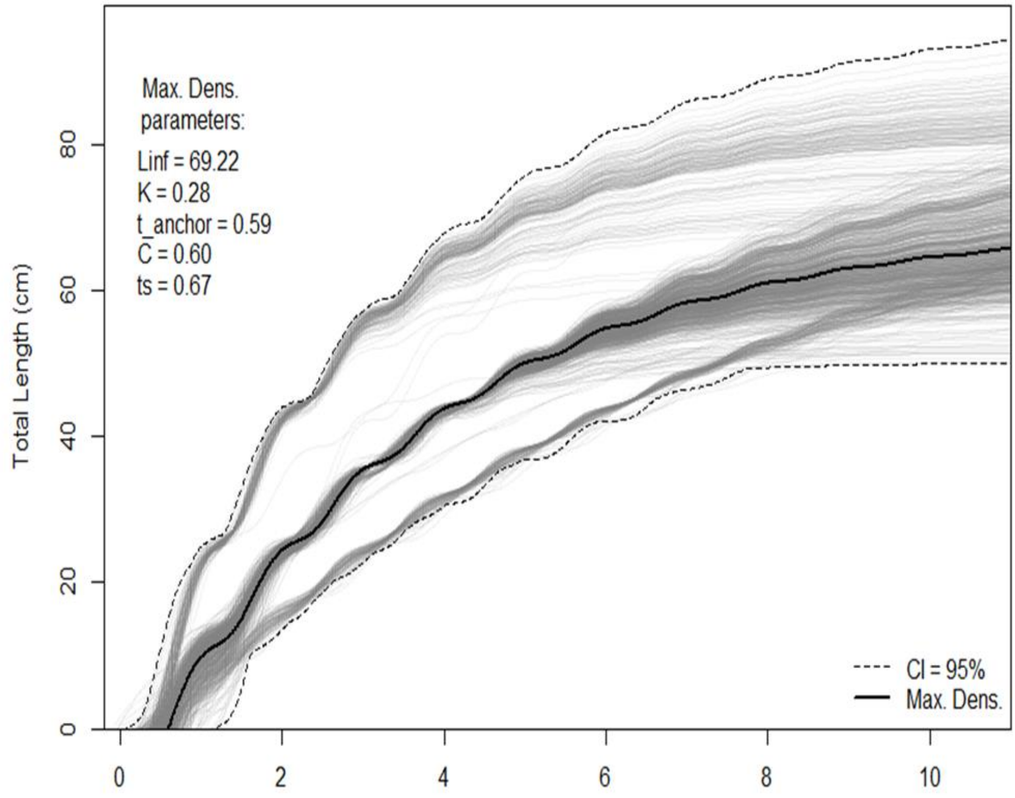

Figure 10: Growth curves representing the growth parameters (shown as the maximum density with a thick black line), their 95% confidence intervals (black dashed lines), and curve swarms (grey lines) for *Galeoides decadactylus.*

Estimates of mortality parameters and mean length at first capture

The total mortality rate (*Z*; mean value ± 0.95 confidence interval) estimated from the linearized length–converted catch curve method was 2.86 ± 0.22 year $^{-1}$ for *Galeoides decadactylus* (Figure 11). The mean length at first capture estimated from the length-converted catch curves is 0.5. The total mortality, Z, and the mean length at first capture estimated from the length-converted catch curves for the one species (*Galeoides decadactylus*) is shown in Figure 11.

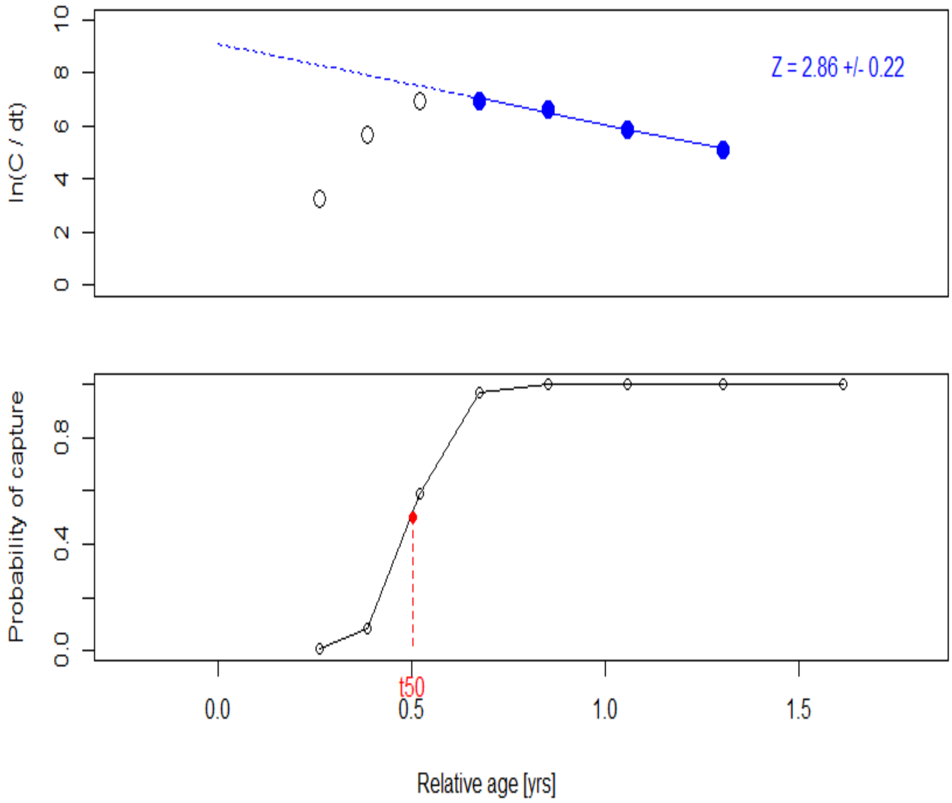

Figure 11: Length-converted catch curve of *Galeoides decadactylus* indicating the value of Z with its corresponding standard error, and (b) the relative age (t50) at first capture, based on inputs from *ELEFAN_GA_boot.* The blue circles indicate data used for the estimation, while the white circles are data not used.

In Table 2, the estimated growth rate (K) was 0.28 year ^{1}. The mean value of natural mortality (M) was 0.62 year ^{1}; fishing mortality (F) rate was computed as 2.25 year^{1} while the exploitation ratio (E) was 0.79. The longevity (tmax) 10.71, as well as the length at first capture (L_c) of 4.37 with its corresponding relative age at first capture (t_{50}) 0.5 was estimated from the selectivity function of the catch curve. The M/K ratio estimated was 2.23 and the values for *Galeoides decadactylus* above the optimal value. The highest and lowest value estimated from these parameters were the longevity (tmax)

10.71 and relative age at first capture (t_{50}) 0.5. The values of the ratio for *Galeoides decadactylus*, is presented in Table 2.

Table 2: Growth and mortality parameter estimates of *Galeoides decadactylus* from Liberia's Coastal Waters

Parameters	*Galeoides decadactylus*	*Remarks*
Z	**2.86**	**Total mortality rate** (the occurrence of death in a defined population during a specified interval)
M (yr^{-1})	**0.62**	**Natural Mortality rate** (species that were killed naturally. Eg age, lack of food, prediction)
F (yr^{-1})	**2.25**	**Fishing mortality rate** (species that was capture through fishing gear)
K (yr^{-1})	**0.28**	**Growth rate** (Growth rate signifies that *Galeoides decadactylu* exhibited a slow growth rate)
E	**0.79**	**Exploitation rate** (the result show that *Galeoides decadactylus* is overexploited because it exceeded the optimum level of 0.5)
Lc (cm)	**4.37**	**Length at first capture** (indicate that fishers are harvesting mature species because the estimated L_C is above 0.5)
t_{50} (yrs.)	**0.5**	**Age at first capture (**which refers to the age at which the length of the fish is zero)

Table 2: ***continued***

Parameters	*Galeoides decadactylus*	*Remarks*
t_{max}	**10.71**	**Longevity (This indicate that** *Galeoides decadactylus* have a high life span due to the low slow growth rate)
M/K ratio	**2.21**	The consistency of the estimated natural mortality rates (M) was ascertained using the M/K ratio, which has been reported to be within the range of 1.12 and 2.5 for most fishers. The M/K ratio in this study fell within the acceptable range.

Estimates of MSY and FMSY by the small-scale Sector

Figure 12 shows a graph indicating the MSY and f_{MSY} of the small-scale sector of Liberia. The MEY was determined by considering the 2012 European Union Common Fisheries Policy, which states that, the MEY is typically achieved at catches that are 10-20% smaller than MSY using Schaefer's Surplus Production method. The MSY and f_{MSY} were computed using the formula, MSY= $-a^2/4b$ and = f_{MSY} $-a/2b$ where b is the slope, and 'a' is the intercept, a. The corresponding MSY, $f_{MSY,}$ MEY, and f_{MEY} were 12,729.2, 4000, 12, 538 and 3,500.05 respectively.

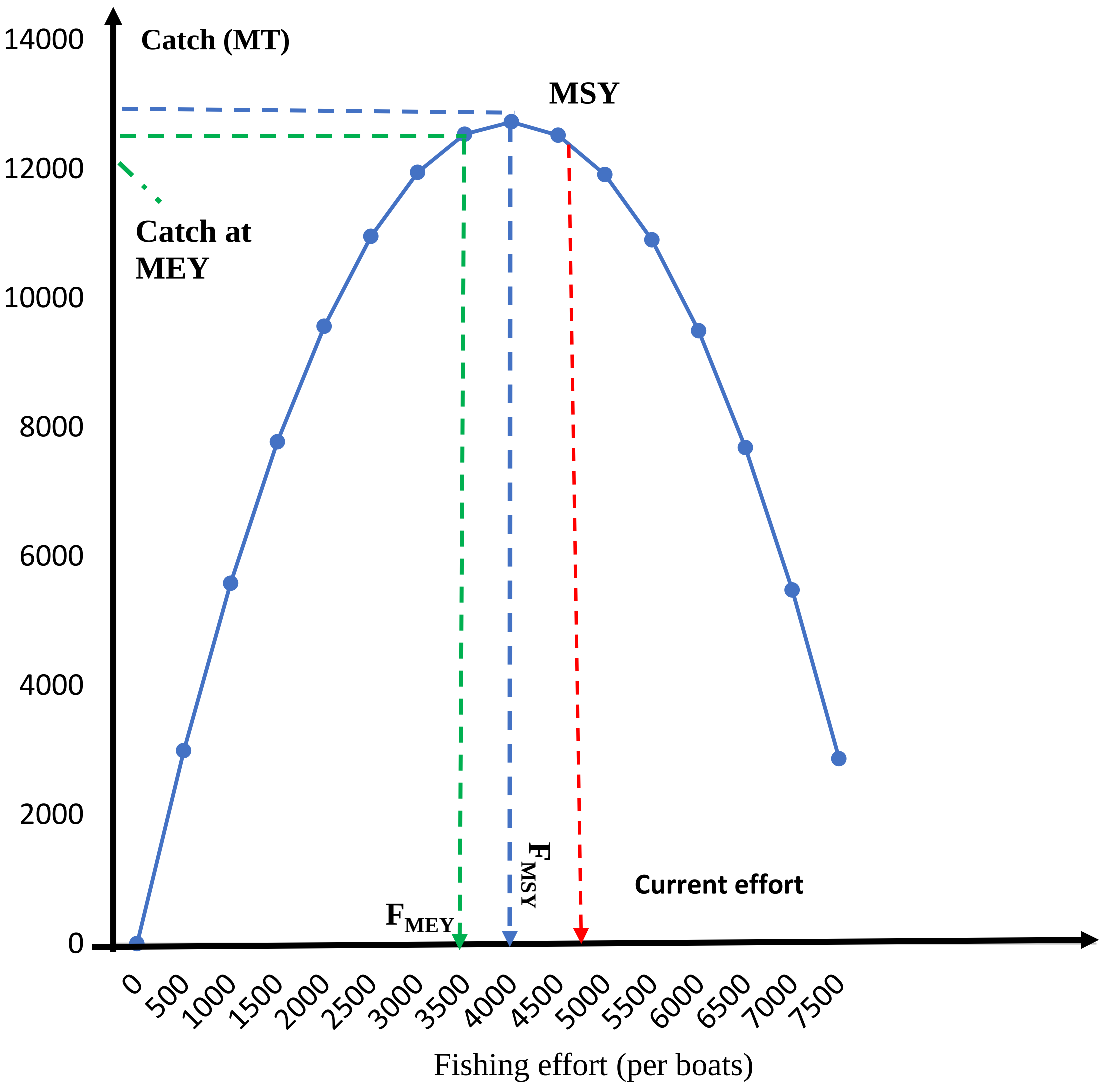

Figure 12: The MSY, fMSY, MEY and fMEY of Liberia's small-scale sector

A profile of gears used in small-scale fishing to exploit fish stock

The small scale utilizes eight different types of gears to exploit different species namely: floating nets, gillnets, surface gillnets, set nets, bottom gillnets, ring nets, trap lines, and, longlines. This study documented the use of five (5) major types of fishing methods in the study areas. These include floating nets, surface gillnets, set nets, bottom gillnets, and ring nets. These gears have mesh sizes ranging from 0.5 inches to 6 inches (12.7mm to 152.4mm) as shown in Table 3.

Table 3: Mesh Measurement for four landing sites within the study area

Types of fishing gear	Length/square or bar measurement	Stretched measurement	The texture of netting material	Types of gillnet
Bottom gillnet	Head, Middle, Bottom: 3 inches	Head, Middle, Bottom: 6 inches	Cotton	Multifilament
Set net	Head, Middle, Bottom: 2 inches	Head, Middle, Bottom: 4 inches	Nylon	Monofilament
Set net	Head, Middle, Bottom: 3 inches	Head, Middle, Bottom: 6 inches	Cotton	Multifilament
Set net	Head, Middle, Bottom: 1.25 inches	Head, Middle, Bottom: 2.50 inches	Cotton	Multifilament

Table 3: ***Continued***

Types of fishing gear	Length/square or bar measurement	Stretched measurement	The texture of netting material	Types of gillnet
Surface gillnet	Head, Middle, Bottom: 1.25 inches	Head, Middle, Bottom: 2.50 inches	Nylon	Monofilament
Floating net	Head, Middle, Bottom: 1 inches	Head, Middle, Bottom: 2 inches	Cotton	Multifilament
Floating net	Head, Middle, Bottom: 2 inches	Head, Middle, Bottom: 4 inches	Cotton	Multifilament
Ring net	Head, Middle, Bottom: 0.5 inches	Head, Middle, Bottom: 1 inches	Nylon	Monofilament

Socio-demographic Survey of management modalities within the small-sale sector

Leadership structure of local organization

Over the years, a chief and elders in terms of fishing operations headed the small-scale governance structure. Under customary traditions, the chief is selected from the royal family and holds executive, judiciary, and power legislative powers in his communities under the traditional law, and is thereby regarded as someone of high prestige (Kraan, 2009). During this period, the chief fishermen served as liaison between the government and his community by negotiating with government and organization about benefits, credit and inputs for the fishermen.

However, in 2010, the West African Regional Fisheries program (WARF-P) established the Liberia Artisanal Fishermen Association (LAFA) as an umbrella organization to assist management monitor, supervise and working with fishing communications due to the ineffectiveness of traditional leadership. Currently local governance is functioning under the jurisdictions of the Liberia Artisanal Fishermen Association (LAFA), Collaborative Management Association (CMA), and Fisheries Cooperatives (FC) for sustainable utilization of the sector. Below are the leadership structures of local organizations shown in Figure 13.

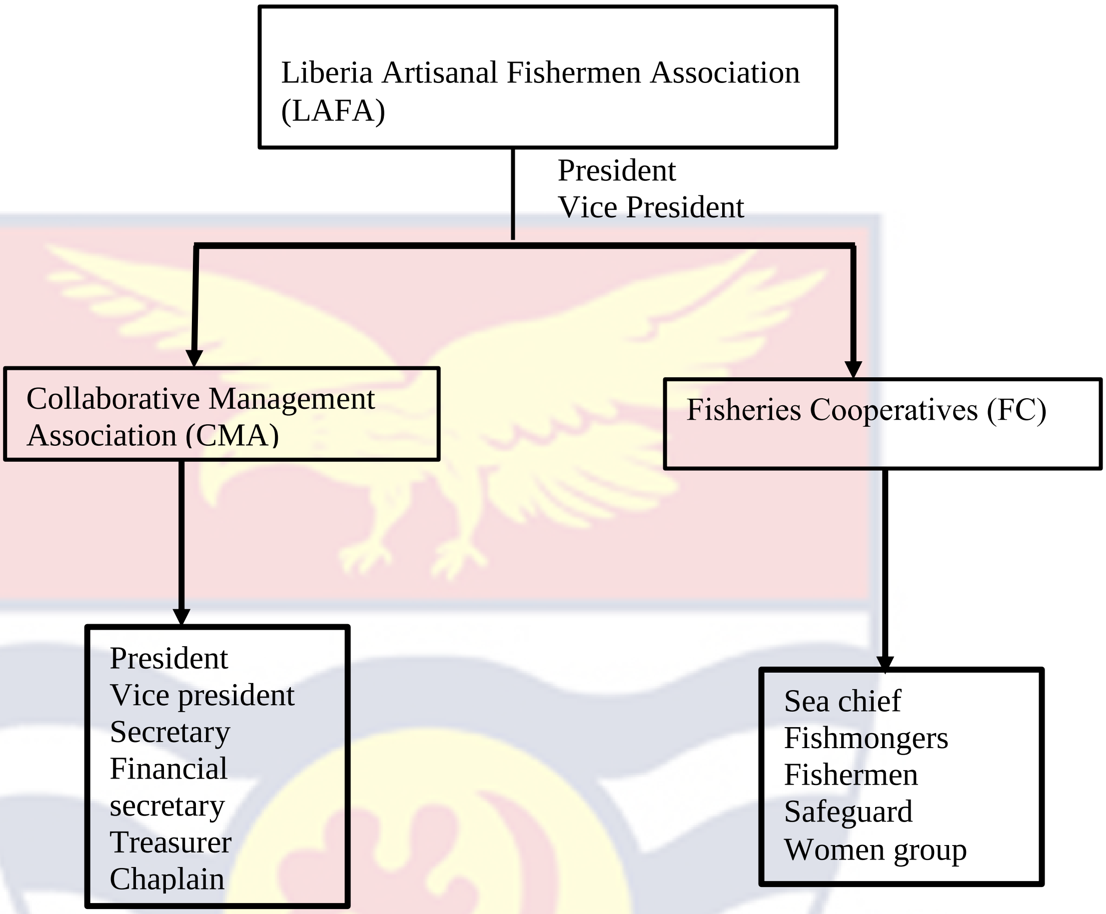

Figure 13: Leadership structure of local organizations

Table 4 illustrate the result of the Focus Group Discussion (FGDs**).** As the structure, organization, and function of co-management and cooperatives vary among the study sites, all landing sites have the same governance structure. Management implications were measured based on the effectiveness of the 2019 fisheries regulations at a local level.

Table 4: Results from focus group discussions

Fisheries regulations	Implementations	Status	Weakness
Community-based organizations	➢ The establishment of Co-management within six coastal counties to involve everyone's participation in resource management ➢ The establishment of Fisheries cooperatives within seven counties ➢ The establishment of local policy to involve resource users in decision-making for sustainable utilization of the SSF	Effective	Low community participation in some landing sites Lack of optimal inclusion of all stakeholders in decision-making.
Compliance with management policies	➢ Capturing protected species is prohibited ➢ Fishing is not permitted outside of the SSF IEZ ➢ Any form of violence within fishing communities is prohibited ➢ Canoes must be licensed before being allowed access to fishing ➢ Daily reporting of catch ➢ Gear inspection	Effective	Management sometimes overstepped their bounds without consulting the local leaders which leads to an ineffective system
National institutions collaborating with agencies to reduce IUU activities and other related fisheries programs	➢ Environmental justice foundation (EJF) ➢ Catholic Agency for Overseas Development ➢ The World Bank	Effective	Fisheries programs by these organizations are not effective in all fishing communities

Background characteristics of FGD respondents

Table 5 shows the study's overall landing sites and the total number of participants (21) for the FGDs. FGD participants were all males, which included local leaders and fishers. The groups were represented by organizations, local authorities, and fishermen. Each focus group consisted of 3-8 participants, and the discussion lasted for 60 to 90 minutes.

Table 5: Number of respondents for the FGDs

Respondents	Big Fanti Town	Korkorwin	Point four	West point
LAFA President	1	1	1	1
CMA president	1	1	1	1
F-Cooperative president	0	0	1	0
Fishermen	3	5	3	1
Total	5	7	6	3

Background characteristics of the survey

Table 6 captures the characteristics and distributions of the survey sample across the four landing sites under study. More respondents were included from ‘West Point’ (33%; n = 343), followed by ‘Point four’ (25%; n = 263) and the least was Big Fanti Town. More Liberians (65%) than Ghanaians (35%) were included in the study. The educational status of the respondents was somewhat evenly distributed although high school dropouts dominated the study, representing 33%. The least were those with vocational education (1.5%). However, more respondents with vocational education from

West Point were included (64%). More respondents from the four landing sites have a net income “between” 18-30 $USD. The amounts were recorded in Liberian Dollars ($LD) and converted to United States (USD) dollars at the exchange rate that was used on average from April to June 2022, which was $LD 170 for every 1 dollar. The NaFAA and EJF had the highest (79.31%) participation in community-based fisheries programs at four landing sites. Hence, respondents also expressed their views about past and current management policies from the four landing sites. However, all landing sites show the highest percentage (68.24%) of management efforts for sustainable fisheries. Questionnaire is shown in (Appendix B).

Table 6: Descriptive statistics for fishers across the study areas

Variables	Respondents (%)				
	Big Fanti town	Korkorwin	Point four	West-point	Overall
Nationality					
Ghanaian	20.22	29.78	7.38	42.62	35.23
Liberian	20.51	16.64	35.07	27.79	64.77
Educational status					
High school dropout	19.76	26.25	32.74	21.24	32.66
High school graduate	13.90	19.32	24.07	42.71	28.42
Junior High	35.57	19.59	19.07	25.77	18.69
No formal education	19.62	23.42	20.89	36.08	15.22
Tertiary	6.25	0.00	6.25	87.50	1.54
Vocational	8.33	0.00	27.78	63.89	3.47
Net income					
LD $ 0- 3,000 (0-18 USD)	0.00	6.38	93.62	0.00	9.05
LD $ 3,001- 5,000 (18-30 USD)	16.58	23.12	28.31	31.99	57.46
LD $ 5,001 -10,000 (30-59 USD)	38.06	0.00	3.87	58.06	14.92
Greater than LD $ 10,000 (59 USD)	27.98	39.00	0.00	32.12	18.58
Agencies					
Catholic Agency for Overseas Development	0.00	0.00	0.00	100.00	15.21
EPA/NaFaA	100.00	0.00	0.00	0.00	0.67
NaFAA/EJF	20.51	26.82	30.22	0.00	79.31
NaFAA/WORLD BANK	72.00	0.000	28.00	0.00	4.81
Ranking management					
Good	12.16	19.22	26.67	41.96	24.54
Making effort	20.45	22.14	27.50	29.90	68.24
Not good	48.00	20.00	0.00	32.00	7.22

CHAPTER FIVE

DISCUSSION

This section describes all the results obtained from the study and consideration in relation to similar works conducted on the sustainability and profile of gears used in small-scale sectors, species, and management implements in other parts of the world.

Catch trends and CPUE by Boats

Given the current fishing methods employed in the sector, the annual trends of catch are important indicators of the state of the fish stock. However, there was a marginal increase in landings from 18,126 MT to 18,799.6 MT from 2019 to 2020. This was followed by a sharp increase to 63,663.7 MT in 2021. It could be an indication of improved data collection which was a major challenge confronting the fishing sector. However, there is the need to be cautious with the phenomenal rise in catch as this may not necessarily reflect the true occurrence. Dunbar (2017) reported that the canoes of the Fanti are larger and have higher horsepower, such that they employ more sophisticated gears and equipment and travel longer distances than the Kru non-motorized canoe, impacting an effective fishing effort. The introduction of these powered canoes was an important factor in driving fishing effort trends. It is also revealed that the Fanti-motorized canoe dominated the sector, and almost 43% of the Fanti operate more than 6 NM from the shore, while the corresponding rate of the Kru is 10% (Dunbar, 2017). Mayotte in Mozambique, for example, had the lowest effective fishing effort in 1950, with no motorized fishing fleets. With the introduction of motorization after 1970, effective fishing efforts steeply increased over the subsequent decade as fleets were rapidly motorized (Zeller et al., 2021). In contrast, the small-scale fishing fleets in Madagascar were the largest in terms of the number of boats. Although its effective fishing effort is still increasing due to continuing growth in the number of non-motorized vessels, the very low proportion of vessels that are motorized (0.03% in 2016) limits the fishing power and fishing capacity of its large, small-scale fleets (Zeller et al., 2021).

Exploitation Level of Commercially landed Species

Thirteen species representing 69% of the total commercially landed species of the country were recorded in this study. However, *Sphyraena guanchacho*, *Sardinella madarensis*, *Pseudotolithus typus* and *P. senegalensis* comprised 39% of the total landing. The decline in species landings indicates that they are not exploited at a sustainable level and that overfishing is occurring. This could be due to the types of fishing gear and methods utilized by fishermen within the sector. Whereas, the fisheries of many countries tend to be dominated by 6-10 commercially landed Species (Gutiérrez et al., 2016), the fisheries of Liberian coastal had relatively higher number of commercially landed species.

The monthly length-frequency data obtained from the NaFAA for the analysis of dominant species were inadequate to represent the population. However, the full bootstrapping approach with the fit algorithm addressed this limitation to estimate the VBGF curve (Schwamborn et al., 2018). The growth rate estimated for this study (0.28 year^{-1}), was higher than that recorded for *Galeoides decadactylus* in Liberian waters (0.19 year^{-1}) (Wehye, 2017). However, this is lower than the growth estimate (0.34 year^{-1}) for *Galeoides decadactylus* in Sierra Leone (Konoyima, et al., 2022). This indicates that

Galeoides decadactylus in Liberia's coastal waters observed a relatively slow growth rate, evidenced by the high longevity of 10.71 years (Table 2). The estimated slow growth rate of *Galeoides decadactylus* in this study may be a result of differences in ecological characteristics such as habitat, fish adaptive life pattern, and location. Environmental conditions as a result of regional differences, food abundance, or size composition of the stock directly affect growth the rate as well (Pajuelo & Lorenzo, 1995). Some implication to the fishery could be Vulnerability of overfishing, conservation measures, ecosystem impacts, and extended recovery time.

The asymptotic length of (69.22 cm TL) for *Galeoides decadactylus* varied compared to the same species in different years and regions. Such as 54.08 cm in (Wehye, 2017), and 43.3 cm in (Konoyima et al., 2022). Espino et al (2008) emphasized that growth parameters are very sensitive to samples, as such, larger individuals tend to increase in asymptotic length as the growth rate decreases. Hence, individual size ranges play key role in estimating the asymptotic length. The variations in estimates of asymptotic lengths may therefore be a result of the maximum observed length, sampling methods, computation methods used, and the obtained length frequency (Amponsah, et al., 2016). However, according to Qamar et al (2016), the change in growth parameters may be related to latitudinal differences, the type of climate, and ecological traits like habitat, fish life patterns, and location that have a direct impact on growth rate. The length at capture (Lc) from the study (4.37) indicated that fishermen in Liberia are harvesting mature fish because the calculated Lc was above 0.5 (Tirtadanu, 2019).

The growth performance index recorded by Wehye (2017) was 2.75 for *Galeoides decadactylus*. This point estimate compared positively with the range observed in this study (3.13), which indicates the normal rate of fish. The difference between the estimates, however, could be due to oceanographic conditions, which would apparently affect the growth rates of different stocks (Pajuelo & Lorenzo, 1995). The ϕ' values for *Galeoides decadactylus* was approximately 3.13, which is common for species similar within related taxa (Pauly & Munro, 1983).

The rate of mortality depends on which aspect of natural mortality occurs in a given species (Pauly, 1980). Fish with shorter life spans (t_{max} = 1 year) have higher natural mortality (M) values than fish with longer life spans (Hordyk et al., 2015). The natural mortality (M) and t_{max} values from this study indicates that *Galeoides decadactylus* has a relatively long lifespan. The t_{max} estimate was greater than 5, indicating that the species could survive for a considerable amount of time before getting depleted in the fisheries.

According to De Queiroz et al (2018), the consistency of the estimated natural mortality rates (M) was ascertained using the M/K ratio, which has been reported to be within the range of 1.12 and 2.5 for most fishes. The M/K ratio in this study 2.21 falls within the acceptable demarcated range. Variations in the fishing mortality rate as compared to other studies could be as a result of adaptations to local conditions and levels of exploitation. (De Queiroz, et al., 2018). From the present study, the natural mortality rate of 0.62 $year^{-1}$ was lower than the fishing mortality rate of 2.86 $year^{-1}$. This result is in variance with that of Wehye et al (2017) who reported natural mortality of 0.49 $year^{-1}$ and fishing mortality of 0.42 $year^{-1}$ for the same species. This suggests that *Galeoides decadactylus* are more disposed to fishing gears than naturally induced mortality situations caused by age, predation, and lack of food, spawning stress, diseases, and pollution (Amponsah, et al., 2016). The relatively higher fishing mortality rate than the natural mortality rate indicates an imbalanced stock position (Azim et al., 2017).

The exploitation rate of 0.78 for *Galeoides decadactylus* was higher than 0.46 recorded in 2017 by Wehye (2017). The exploitation rate for this species surpasses the optimum level of 0.5 (Gulland, 1971).

MSY Estimates for the Liberian Small-scale Fishery

The total MSY estimate for the Liberian small-scale fishery, based on catch and effort data from 2010 to 2021 from the NaFAA, was 12,729.2 MT. Over the last five years, the maximum annual production was 63,663.7 MT, and the least was 13,160.99 MT, resulting in an average of 38,412.3 MT. Thus, current production by the Liberian fishery is extremely above the estimated MSY. Consistent with the precautionary approach of the MSY, it is preferable that landings are lower than the MSY, which shows evidence that the stocks in the small-scale sector of Liberia are being fished beyond their sustainable level.

The F_{MSY} estimate for the sector was 4,000, which is lower than the highest landings of effort (4,589) for the past five years. This could mean that the population of species in the small-scale sector is being exploited unsustainably. Hence, it is not favorable for fish populations to reach abundance levels that readily support maximum sustainable yields (Pauly, et al., 2020).

Findings from this study indicated that, per the most recent data available (2017 to 2021), the trends of production observed showed that the Liberian small-scale fishery is fully exploited and being overfished. This is in reference to precautionary principle of management and in which the current status contradicts postulations that the fishery can withstand more fishing pressure (García, S. M., Zerbi, A., Aliaume, C., Do Chi, T., Lasserre, G., & Newton, C., 2003). This was evidently supported by the average production values for the last five years compared to the MSY for the fishery. Thus suggesting urgent national management actions and regulations in order to prevent severe depletion of the stocks and keep the fishery at a sustainable level. This will require minimizing or enforcing gear restrictions until the biomass and abundance of stocks can fully recover so that the fishery can make maximum economic gains to ensure sustainability. Management could also develop a policy to provide an alternative livelihood for fishermen in the sector to reduce pressure on the resource and avoid depletion or collapse of the fishery. Given the importance of small-scale fisheries in Liberia, the adoption and enforcement of such policies could result in considerable improvements in food and nutrient security as well as the socio-economic condition of coastal communities in the region.

A profile of gears used in small-scale fishing to exploit fish stock

According to the literature, the characteristics of fishing in the small-scale sector are based on particular skills related to fishers' ethnicity (MRAG, 2014). The Liberian ancestry Kru operators, utilize hand lines and gillnets to catch demersal species such as cassava fish (*Pseudotolithus senegalensis*), butter nose (*Galeodes decadactylus*), and sole fish (*Cynoglossus lingue*). They also captured groupers (*Epinephelus coioides*), snappers (*Lutjanus Lutjanus*), pike fish (*Sphyraena guachancho*), and grunters (*Pomadasys maculayus*). They use non-motorized wooden dug-out canoes (around 7 meters long) with crews of one to three people, making up about 75% of the canoes used in the small-scale sector (World Bank 2015), utilizing various fishing techniques and gear (BNF, 2014). However, because of the equipment and fishing methods employed by the fishermen, the majority of their catches are done using hand lines. over half of the Fanti (53%) operate at fishing grounds 4-6 nm from shore. They do not travel long distsnces on sea like other nationalities.

The Fanti from Ghana generally deploys ring nets, and gillnet, to catch small pelagic and demersal species like bonny (*Sardinella spp.)*, porjoe *(Chloroscombrus chrysurus)*, and Atlantic flying fish *(Cheilopogon melanurus*), cassava fish (*Pseudotolithus senegalensis*.), butter nose (*Galeodes decadactylus*), and pike fish (*Sphyraena guachancho*) (MRAG, 2014). The Fanti utilize large plank canoes (approximately 12–15 meters) and more powerful, with crews of 15 and 8–40 horsepower (hp). They can employ more sophisticated gears and equipment and travel longer distances than the Kru. (Dunbar, 2017). The catch-per-unit effort (CPUE) and the size of their harvest vary between these groups due to different fishing methods, which could be one of the contributing factors to Overexploitation.

Bjordal (2002) stated that different types of fishing gear affect all Bycatch, habitat, and the rate of overfishing differently; therefore, the fishing equipment should be specifically designed for target species to avoid overfishing. However, regulation 19, Section 10.14.e of the Law of Liberia's 2020 fisheries and aquaculture regulations stated, "The dimensions of fishing nets used for fishing from artisanal and semi-industrial vessels shall not exceed, the maximum length of 1000 meters and minimum mesh size of 45 mm for Ringnets (Bonga, herring), and bottom set nets (mixed, demersal)".

Considering the aforementioned, the result from the study indicates that fishermen are using mesh sizes that are below the minimum mesh size prescribed by the 2020 Fisheries and Aquaculture regulations. It is therefore important to take action to ensure compliance with regulations and protecting the fishery in Liberia. This will require a comprehensive approach that includes education and awareness raising, enforcement, incentives, alternative gear technologies, and stakeholder engagement. By working together, it is possible to reduce the use of small mesh sizes and promote sustainable fishing practices that support the long-term health and productivity of the fishery.

Effectiveness of management modalities at a Local Level

A personal communication was done among local leaders and fishermen to examine management effectiveness within four coastal counties. The NaFAA set up CMAs and fisheries cooperatives in all four landing sites under study. This implementation by NaFAA conforms to the 2019 fisheries act of Liberia, which enjoins NaFAA to set up these decentralized management units at each landing site, representing a 100% achievement of the target. The CMAs and cooperatives at the landing sites take responsibility for governing and managing local-level activities in fisheries, which leaders have recognized as playing a significant role. A personal communication was done among local leaders and fishermen to examine management effectiveness the president of the Liberia Artisanal Fishermen Association (LAFA) remarked that:

"Involving resource users in decision-making has been very helpful to the sector because local associations are making sure that resource users compile with fishery policy for everyone's benefit, resulting in effective management processes".

Leaders of the collaborative management associations (CMA) responded with similar opinions, saying that they ensure that local fishery laws are effective in all fishing communities to share the responsibility for the resource's sustainable utilization. According to Melissa et al (2012), a participatory approach to decision-making and community monitoring encourages compliance with local laws. Fishing communities can, however, set up collective governance of resources from a common pool, and the empowerment of shared responsibilities among resource users can result in successful management methods. They concluded that the village fishing associations were effective through the implementation of local governance to ensure the long-term viability of their fishery.

To ensure the capturing of protected species is prohibited, management has educated fishers on the importance and necessity of avoiding catching prohibited fish. Management has also employed enumerators at various landing sites to conduct regular checks of gear and audits of catches, and fining culprits. For instance, between three and four protected species (sharks, rays, and sea turtles) were saved. In compliance with fisheries regulations participants, expressed that:

"Management has made it clear in the regulation that fishermen must not catch unwanted species. If you go against this law, your

canoe will be seized for some time". This regulation is effective and fishermen are going in line with it."

"NaFAA has employed enumerators at all landing sites for catch and daily gear inspection. If you are caught, landing unwanted species and inappropriate mesh size, your catch will be seized and you will be suspended.

Another important implementation was the guidance against (five) fishers who attempted to fish outside of the SSF IEZ. This involved issuing punishment and penalties in the form of fines to deter culprits. A fisherman from one of the landing sites made it clear that "*one of our local policy state that, you will pay a fine of 10,000 LD if you are caught fishing beyond the inshore exclusive zone (IEZ)."* Guarded by local fisheries regulations, any form of violence is not allowed within the fishing community studied. Participants stated, *"any form of violence is not allowed at all landing sites. There is a penalty for anyone that goes against the law"*.

Canoes must be licensed before being allowed access to fishing. This implies that fishermen whose canoes are not licensed are prohibited from fishing. Those that forcibly fish have their canoes ceased, and the culprit is suspended indefinitely. It was also stated by fishers *"management is very straight in making sure that your canoe is licensed before being allowed access to fishing."*

National institutions are collaborating with agencies to reduce IUU activities and other related fisheries programs. As the first point of contact for international, regional, sub-regional, and bilateral cooperation on fisheries management, the NaFAA has made significant strides in Liberia's combat against IUU fishing through the WARF Program. Management has also succeeded in establishing a vessel monitoring system that tracks every vessel for illegal activities in and out of the SSF IEZ. Community-based fisheries organizations collaborate with donor agencies, non-profit organizations (NGOs), and other civil society organizations to inform and build the capacities of fisher folk on how to avoid destructive fishing practices and engage in sustainable harvesting of fish. The study's findings is in line with a study conducted by Romero (2014) from Mexican and Gulf of California regions' small-scale fisheries sector, which analyzed that multi-scale governance generates and optimizes resources for maximum impact on fisheries resources. However, NGOs in the Gulf of California region have significantly influenced the following key attributes of multi-scale governance: institutional scale representation, cooperative management, collective action, and match with ecological scales; information sharing; social learning; and institutional interplay (Romero, 2014). Some fishers maintained that:

> *"Agencies' involvement in local fishing activities has greatly helped most fishing communities by educating us on the effect of all forms of destructive fishing practices. NaFAA is collaborating with these NGOs to make us conscious of the fact that if we continue to use harmful substances and inappropriate fishing gear, we will kill smaller fishes that are supposed to grow to replenish the fishery, resulting in inadequate supply in the future".*

” EJF has installed a ‘DASE’ mobile app on smartphones and given to us to report illegal activities at sea and gather evidence for compensation claims (damage to canoes, fishing gear) by Trawlers. A few months ago, a Chinese trawler enter our IEZ and damage a fisherman’s gear. A picture was taken and sent to EJF using the mobile app, and when they received the claims immediate action was taken”.

Weaknesses/ Challenges in Fisheries Governance

Nevertheless, the FGD leaders noted some implementation challenges and weaknesses, which are in turn discussed. These weaknesses were low community participation, a lack of optimal inclusion of all stakeholders in decision-making, and sometimes stepping out of bounds by management. These compromise the implementation of some of the regulations, which the discussants subsequently rated as 75% effective in terms of implementation. Below are participant’s views.

a. As regards participation, it is difficult to have everyone participate meaningfully in all landing sites. This is because of perceived inequalities in the access to and distribution of production resources. At one of the landing sites, the CMA president affirmed that:

"*As president of the CMA, I represent more than one fishing community, and getting the full participation of cooperatives is challenging because other nationalities feel that they are not recognized and their voices are not heard by management. Because of this, some organizations are not functioning as expected. This has had an impact on some communities,* *leading to low community participation. While it is true that management is making efforts to ensure fisheries regulations are implemented on a local level, these are some of the challenges that need to be addressed."*

b. Management sometimes overstepped their bounds without consulting the local leaders, such as cooperatives and co-management, which leads to mismatches between the provision of fishing equipment and fishers' needs, which lead to conflicts and sometimes boycotts of collaborations. A fisherman bemoaned that:

"In most cases, the CMA does not include us in discussions with management about our well-being. For example, management selected a gear that is not suitable for fishing, and they demanded that we use it. Because we do not want to, it is creating issues between fishers and management. We are the people that are going on the sea, and we know the texture of gears that are suitable for fishing, so if management wants to change the gear we are using, they should at least consult us and get our views."

Considering management efforts to ensure sustainable fisheries, broader socio-economic, ecological, and environmental perspectives must be included in management policy for the long-term viability of fisheries and marine ecosystems. Looking at the current state of the small-scale sector, more attention should be drawn to research, which will enable the sector to regulate changes in the abundance of stocks to avoid collapse or depletion of the fishery. About thousands people are employed in the small-scale sector, of whom 60% are women (FAO, 2012). The implementation of fisheries regulation may not be sufficient to achieve sustainable use and conservation of marine resources given the size of the population dependent on the sector and the estimated low average fish consumption (5.3kg), according to the ECOWAS-2020. A 2013 report from *the* Liberia Comprehensive Food Security and Nutrition Survey (CFSNS) estimated that 49% of Liberians experienced some level of food insecurity, and 34% had inadequate food consumption patterns characterized by high intake of cereals and low intake of protein-rich foods.

From the in-depth interview, all landing sites had lower numbers of respondents who have completed graduate-level education (tertiary education). This section was included to avoid being biased. With a high percentage (32.66%) of high school dropouts from the four landing sites, it could be assumed that the lack of highly educated people in fishing communities may be a result of cultural norms, habits, or a preference for beginning their careers as fishermen at a young age. Most fishers in the study area expressed that having a high level of education is crucial, despite Pollnac (1998) assertion that being a fisher typically does not require formal education but rather a strong body to perform laborious tasks. Nevertheless, based on the analysis of the study, the majority of fishers across the study areas expressed education as being very important for either themselves, their children, or future generations in terms of leadership status and advantages in thinking and behavior. According to Dahuri (2012), the competence of human resources will be improved by providing ongoing education, training, and extension in work ethics, financial and environmental management, and fishing techniques.

Generally, although most fishers' had lower educational status, indicating the children of fishers may insure the sustainability of the sector.

CHAPTER SIX

SUMMARY, CONCLUSION, AND RECOMMENDATIONS

The study was conducted to assess the viability of the sector, establish the current exploitation status of four major commercial species, and manage and gear used to land species from the coastal waters of Liberia. This was done by assessing the catch and effort trends in the landings by the artisanal fleets. Primary data were obtained for two months from four major landing sites in two coastal counties and secondary data from the National Fisheries and Aquaculture Authority (NaFAA) statistics department.

In order to determine the viability of the small-scale fisheries in the coastal waters of Liberia and the management practices, the study used secondary data from the NaFAA. This was done by assessing the catch trends of species in their landings by the artisanal boats through catch and effort data and Schaefer's production model. However, the current exploitation status of one main commercial species was assessed through monthly length data. Primary data collected from four landing sites within two coastal counties was used to evaluate the effectiveness of management through the implementation of fisheries regulation and evaluate the gears used by fishermen when fishing. The results indicate that the sector has exceeded its maximum sustainable yield, resulting in the overexploitation of the fishery. The growth patterns of *Galeoides decadactylus* show isometric growth and are experiencing overexploitation.

Fisheries governance structures at the four landing sites offer a reliable foundation on which to build efficient management strategies. These landing sites demonstrate how collective governance of common pool resources can be achieved within fishing communities and how feelings of empowerment and shared responsibility among resource users can lead to effective management practices.

Conclusion

Despite the importance of the small-scale sector, there is limited information on stock assessment in terms of its management. From the available data and information, the following are the conclusions from this study with respect to the study objectives:

- The landing composition of the top five (5) commercially important species in the small-scale fishery include; *Sphyraena guachancho* (16%), *Sardinella maderensis* (12%), *Pseudotolithus senegalensis* (6%), and *Galeoides decadactylus* (6%). The gears that were mostly utilize by fishers in the sector are surface gill nets, hook and line, trap lines, floating gill net and set net.
- Production has increased considerably from 18,126 MT to 18,799.6 MT from 2019 to 2020, which was followed by a sharp increase to

63,663.7 MT in 2021 with a corresponding increase in CPUE (13.87311).

- The total MSY estimated for the small-scale fishery of Liberia is 12,729.2 MT which was below the average of the annual maximum of 63,663.7 MT (in 2021) and the least 13,160.99 MT (in 2017), production of the sector.
- *Galeoides decadactylus* in Liberia's coastal waters is slow-growing and under high fishing pressure. The species is experiencing overexploitation in Liberia's marine waters.
- The assessment conducted within the two coastal counties in Liberia demonstrates a commendable level of managerial effectiveness in the small-scale sector. The implementation of gear restriction, the establishment of a community-based organization to manage local fishing activities, and the introduction of a vessel monitoring system for tracking illegal activities within the small-scale IEZ have all contributed to the success of management efforts in these coastal region. The progress reflect a strong commitment to sustainable fishing practices and the preservation of marine resources for the benefit of both current and future generation.

Recommendations

The following recommendations focus on practical solutions that would be easily implemented to maintain stock for sustainability.

- To obtain the overall goal of a high sustainable yield in the fisheries management system, management should have technical regulations on fishing gear. Therefore, the management of the National Fisheries and

Aquaculture Authority (NaFAA) should revise the section on mesh size and gear regulations to meet the standards of specific mesh sizes to be used by fishermen in the sector and the types of species that need to be captured by a gear. This will improve the selective properties of fishing gear so that bycatches of juvenile fish are reduced to safeguard recruitment to the larger size groups of fish stock, including the spawning stock.

- By conducting studies on the growth parameters of different fish species in Liberia, researchers could gain a better understanding of how fish populations are changing overtime and what factors may be contributing to the decline in fish stock. This could involve collecting data on factors such as age, size, weight, and reproductive patterns of different fish species, as well as examining factors such as water temperature, habitat quality, and fishing practices that may be influencing fish populations. By collecting empirical data on these factors, researchers could identify potential solutions to help improve the sustainability of the fishing industry in Liberia, leading to more profitable and sustainable practices.
- In accordance with the Precautionary Principle of Management (PPM), all stakeholders involved in the fisheries industry should work quickly to develop and implement national management actions by implementing input controls (to regulate fishing efforts and protect the stocks) until there is sufficient evidence that the fishery can be sustainable. The sector's Fisheries Management Plan will improve the fishery's sustainability as a result of its inclusion.

- Educating fishermen on the negative effects of their actions that contribute to overfishing and the depletion of fish stocks, as well as potential remedies they could use to mitigate them through community-based fisheries management.
- The capacity of each organization to manage fisheries should be improved by increased cooperation and information sharing among the four levels of governance. This will enhance future scenarios workshops, where groups of fisheries stakeholders come to a consensus on desired fisheries outcomes and the best ways to achieve them. This can help stakeholders and managers to jointly investigate opportunities and mitigate risks by addressing potential threats and developing a shared vision of prospective future.
- The establishment of infrastructure and technologies for production and post-harvest operations for the commercial fish industry should receive support as part of NaFAA's (2022) mission to improve fish quality and value-addition technologies to manufacture various types of food to enhance economic returns in fisheries and increase fish consumption that will minimize malnutrition among children across Liberia

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APPENDIX A: A secondary catch and effort (2010 to 2021) data from Research and Statistics Division, NaFAA.

ANNUAL PRODUCTION FROM 2010- 2018									
Year	2010	2011	2012	2013	2014	2015	2016	2017	2018
Efforts (# of Boats)	3196	3269	3275	3429	3575	3848	3848	4254	4355
Species (MT)									
Sardinella spp. (bonny)	3125	3267	3268	3446	3260	3576	3527	5064.39	5079.79
Chloroscombrus chrysurus (Porjoe)	1580	1631	1610	2146	1950	3329	3320	71.1	71.3162
Cheilopogon melanurus (Atlantic flying fish)	874	905	812	1287	1897	907	928	73.1991	73.4217
Ethmalosa fimbriata (bonga)	260	212	211	34	229	390	245	183.67	184.228
Engraulis encrasicolus (anchovy/gbato)	659	708	702	806	735	807	806	110.87	111.207
Sphyraena spp. (Barracuda spp)	68	308	310	308	490	490	270	45.4178	245
Sphyraena guachancho & Sphyraena Sphyraena (Pike fish)	180	1036	944	950	783	784	785	53.88	321
Pseudotolithus spp. (Cassava fish)	507	324	450	563	423	620	674.9	1291.64	1141.89
Galeoides decadactylus (butternose)	480	501	502	1088	1005	1078	1078	611.283	540.414
Cynoglossus Spp (Sole fish)	312	389	390	530	462	256	463	1100.98	973.338
Arius latiscutatus & A.	540	549	560	570	480	480	490	916.255	810.029

Heudeloti (Catfish)									
Epinephalus spp. (grouper/rock fish)	121	161	170	274	260	270	271	17.9588	18.0134
Lutjanus spp. (groupers)	98	110	100	177	187	217	217	282.04	282.897
Sparidae spp. (Seabream/Dentex Spp)	415	169	320	187	150	179	180	770.52	772.863
Pomadasys spp (grunters)	112	123	130	187	169	115	170	61.2153	61.4014
Lobster								49.3672	49.5173
Crabs							100	88.8609	89.1311
Marlins	49	71	89	100	88	57	68	1424.5	1428.83
Sharks	40	61	80	49	98	21	110	390	391.186
Tunas-tuna liked species	673	256	176	101	78	151	212	553.851	555.535
TOTAL	**10093**	**10781**	**10824**	**12803**	**12744**	**13727**	**13914.9**	**13161**	**13201**

ANNUAL PRODUCTION FROM 2019- 2021			
Efforts (# of Boats)			
Year	2019	2020	2021
Efforts (# of Boats)	4355	4355	4355
Species			
Sphyraena guachancho	983.5	1308.65	11188.7
Sardinella maderensis	2354.1	2514.26	8650.8
Ophichthidae	11.3	158.2	7046.8
Pseudotolithus senegalensis	751.9	631.4	5535.8
Pseudotolithus typus	1245.2	1603.21	1875.5

Lutjanus agennes	1456.3	1025.01	2302.5
Galeoides decadactylus	369.5	861.77	2349.4
Ilisha Africana	1206.5	943.32	984
Alectis ciliaris	859.6	507.36	1578.1
Exocoetidae	359.3	90.02	2412.9
Osteichthyes	1365.4	1180.34	
Dentex spp	19.5	37.73	2611.7
Sphyraena barracuda	833.6	429.87	334.1
Istiophorus albicans	134.3	88.76	1678.6
Sardinella aurita	705.6	959.35	68.3
Scomberomorus tritor	86.7	305.41	1330.2
Echiophis creutzbergi	0.1		1652.4
Ariidae	327.2	234.64	1048.1
Ethmalosa fimbriata	610	73.57	778.7
Pseudotolithus elongates	149.5	84.91	302.1
Brachydeuterus auritus	65.4	52.5	1240.7
Chloroscombrus chrysurus	86.3	847.07	353.9
Euthynnus alletteratus	208.7	159.67	810.6
Rhinobatos spp	97.9	239.68	877.6
Hemiramphus brasiliensis	397	323.12	407.5
Thinnus alalunga	41.2	39.2	674.6
Dasyatis margarita	4.4	32.06	1040.2
Caranx hippos	544.8	28.14	165
Lutjanus goreensis		319.27	
Polydactylus quadrifilis	211.1	169.05	429.8
Pentanemus quinquarius	236.5	291.27	180.5

Cynoglossus senegalensis	127	133.7	426.2
Alectis alexandrines	217.6	287.28	155.3
Dentex maroccanus	33.2	170.24	450.1
Sarda sarda	0.3	27.79	2.1
Lutjanus fulgens		450.1	
Prionace glauca	11.8	179.48	226.2
Pteroscion peli	97.9	57.26	264.6
Makaira indica	41.3	306.6	21.6
Carcharhinus leucas	355.7	0.21	
Pomadasys jubelini	41.5	62.16	231.6
Myliobatidae	125.9	78.19	109.7
Katsuwonus pelamis	110.8	83.09	30.2
Priacanthus arenatus			271.8
Auxis thazard	15.7	223.09	12.8
Cheilopogon melanurus	153	95.13	4
Portunus validus	13.2	29.4	202
Rachycentron canadum	60.8	46.48	139.9
Caranx bartholomaei	56.1	38.99	143
Trichiurus lepturus	150.3	50.54	21.7
Dentex macrophthalmus		48.79	172.1
Carcharhinus altimus	46.8	62.51	80.9
Drepane Africana	21.9	41.93	107
Pseudupeneus prayensis	153.9	6.37	
Trachurus trachurus	94.4	62.02	0.5
Auxis rochei	10.6	77.84	43.4
Brotula barbata	9.6	30.73	89.1

Spondyliosoma cantharus	18.7	89.11	18.3
Pagrus caeruleostictus	66.3	35.84	22.6
Carcharhinus falciformis	28	9.45	
Xiphias gladius		8.47	3
Carcharhinus limbatus	19.5	63.91	28.3
Megalops atlanticus	24.2	37.52	28.4
Psettodes belcheri	16.1	47.25	15.9
Stromateus fiatola	52.1	0.84	26
Panulirus spp	5	46.41	26.4
Acanthocybium solandri	3.6	26.18	43.3
Engraulis encrasicolus	69.7	0.21	4
Branchiostegidae	6.6	53.27	11.8
Carcharhinus plumbeus	2.9	0.28	63.1
Galeocerdo cuvier		39.41	
Isurus spp	20.3		40.3
Lethrinus atlanticus	26.6	4.41	29.1
Mugil cephalus	1.3	12.18	45.6
Antigonia capros		1.12	50.2
Alopias superciliosus	37.6	0.84	0
Cephalopholis taeniops		2.31	44.5
Sphyrna mokarran	0.4	31.5	7.8
Boops boops	16.4	0.77	20.3
Isurus paucus		31.64	3.3
Scombridae	0.4		
Tylosurus crocodilus	7.5	8.05	9.6
Cynoglossus spp			

Sphyrna lewini		19.6	
Alopias vulpinus	6	7.35	
Thunnus albacares		12.25	0.8
Scorpaena angolensis	4.6	8.05	
Squalidae	12.2	0	
Elops senegalensis	5.2	0.56	4.8
Parapenaeopsis atlantica		4.9	1.3
Isurus oxyrinchus		6.02	
Thunnus obesus	3.2		
Sphyrna zygaena			
Penaeidae		0.14	
Rhinobatidae			
Snapper old lady/ Loton		0.56	
Sepiidae, Sepiolidae		0.28	0.1
Echeneis naucrates		0.21	
Total	**18126.1**	**18799.62**	**63663.7**

APPEDIX B: Survey questionnaire for fishers across the four landing sites.

ASSESSMENT OF THE SUSTAINABILITY OF EXPLOITATION OF FISH STOCK AND MANAGEMENT MODALITIES IN LIBERIA'S SMALL-SCALE FISHERIES

Instruction: *Our target respondents are fishermen. However, if a fisherman is unavailable to take the interview, a close relative (eg. spouse, elder or son) who is familiar with small-scale fishing activities in the household could represent the fisherman. Kindly get consent from the respondent before you begin filling in the questionnaires.*

○ Read

Seeking consent *Good day Sir: My name is XXXXXXX and I am with Ms. Korto Doecious Neufville , a graduate student at the University of Cape Coast, Ghana. She is collection data for her master's Research. She is looking for information on managerial effectiveness on the small-scale sector and on fishermen livelihood. This information will assist her not only in competing her master's research but also make recommendations to the government of Liberia about the challenges and the involvement of management that needs policy intervention. This will eventually increase our production and income. You have been randomly selected to voluntarily participate in the survey. I assure that the information you provide will be treated with utmost confidentially. If you need any clarification about the information we are collecting, please contact Ms. Korto D. Neufville on cell # 0880228152. Can I proceed with the interview?*

○ Yes ○ No

Fisherman's demographic information

Data of Birth ***MM-DD-YY***

[ ]

Gender

○ Male ○ Female

Nationality [ ]

Educational level

○ No formal education ○ Elementary education ○ Junior High ○ High school dropout ○ High school graduate ○ Vocational ○ Tertiary

Area of fishing

Point-four Beach (Western Region), Montserrado County, Liberia West-point Beach (Western Region), Montserrado County, Liberia Big Fanti Town Beach (West-Eastern Region), Grand Bassa County, Liberia
Korkorwen Beach (West-Eastern Region), Grand Bassa County, Liberia

Managerial effectiveness

Average income monthly

LD $ 0- 3,000 LD $ 3,001- 5,000 LD $ 5,001 -10,000 Greater then LD$ 10,000

Is your boat/canoe registered?

What are some of the benefits of being registered?

Do you report your catch?

Yes No

If yes, how often?

Daily Weekly Monthly Yearly

Have you been educated about fishing activities?

Yes No

If yes, by who?

What specifically have you been educated about?

Do NaFAA enumerator inspect your fishing gear?

Yes No

If yes, how frequently? If no, why?

Are there appropriate laws for fishermen on a community level?

If yes, please list

What are the penalties when one violates?

Have there been any amendment of these laws into policy?

Yes No

How do you rank past management to current reign?

Not good Good Making efforts

Do you have close season?

Yes No

If yes, How many Months in a year?

Which type of gear do you use?