Economic Analysis of the Coastal Fisheries of Liberia

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Abstract

During the civil conflict which started in 1989, there was a complete lack of governance in the Liberian fisheries resulting in widespread illegal, unregulated and unreported (IUU) fishing. Following the end of the civil conflict in 2003, successive governments have focused on governance reform, and in 2010 a major policy reform was introduced with the assistance of the World Bank supported West Africa Reginal Fisheries Program (WARFP). Governance and transparency measures were implemented, including the introduction of a 6 nm Inshore Exclusion Zone (IEZ) for the artisanal fisheries and the establishment of a functional Monitoring Control and Surveillance (MCS) system in the industrial fisheries which were mostly owned and operated by foreigners.

In three published articles and one white paper in this thesis, the development of the Liberian fishing industry is examined empirically in light of the 2010 policy changes. The focus is largely on the state of the coastal fishery resources, profitability and the fleet development, technical efficiency, and productivity of the coastal fleet as well as the fishery value chain.

The policy changes in 2010 have been successful in attaining certain parts of the Sustainable Development Goal (SDG) 14 (i.e. conserve and sustainably use the oceans, seas and marine resources for sustainable development). In particular targets 14.4 and 14B have been addressed, in terms of stock recovery and increasing small-scale fisheries (SSF) access to coastal resources. This has resulted in a redistribution of the benefits from the industrial operators to the small-scale fishers and influenced how the coastal fleet in Liberia has developed. However, the 2010 policy reforms may have been at the expense of economic efficiency in the Liberian fishing industry. There has been a 9-fold increase in the number number of small-scale Kru and Fanti boats, while the coastal industrial fishery sector experienced considerable disinvestment. The development of the small-scale coastal fleets has mostly been driven by differences in profits. Apart from shallow-water demersal species, key stocks appear to be underutilized.

During the civil conflict there was limited investment in new fishing technology. This resulted in a major inefficiency problem among the small-scale fleets, although the boats are on average profitable. The fishery value chain is characterized by little or no value-addition services and lack of transparency stemming from power asymmetries and lack of information flow in the value chain. The case studies presented in this thesis call for the Liberian government attention to adopt policy measures and recommendations aimed at

improving the performance of the fishing industry including both harvesting and post-harvest sectors.

The case studies presented in this thesis call the Liberian government's attention to adopt policy measures and recommendations aimed at improving the performance of the fishing industry, including both harvesting and post-harvest sectors. As a way forward for the small-scale Kru and Fanti fleets, there is a need for the government to address the open access situation. A new domestic semi-industrial sector with new harveting technology such as fiberglass reinforced plastic vessels could be introduced. This would make them better equipped to fish for the deep water demeral species and make better handling of the fish possible, promoting value-addition. In general, it is important to improve fisheries management in Liberia to support the livelihoods of those who depend on the fishing industry as well as to lift the yellow card imposed on Liberia by the EU thereby enabling them to find new markets for their products.

Ágrip

Á tíma borgarastyrjaldarinnar, sem hófst árið 1989, ríkti algjört stjórnleysi í sjávarútvegi í Líberíu og veiðarnar voru að mestu stjórnlausar og skráningu afla var mjög ábótavant. Eftir lok átakanna árið 2003 hafa stjórnvöld lagt áherslu á umbætur á stjórnarháttum og árið 2010 var ráðist í miklar stefnubreytingar, með aðstoð frá Alþjóðabankanum. Þær fólu í sér að einungis smábátaveiðar voru leyfðar innan sex mílna og komið var á vaktkerfi fyrir iðnvæddar veiðar, sem aðallega eru stundaðar af erlendum aðilum.

Í þremur ritrýndum greinum og einni hvítbók í þessari ritgerð er þróun sjávarútvegs í Líberíu skoðuð í ljósi stefnubreytinganna 2010. Áhersla er lögð á ástand veiðistofna, þróun, tæknilega skilvirkni, framleiðni og arðsemi strandveiðiflotans, sem og virðiskeðju fiskveiða.

Stefnubreytingarnar á árinu 2010 hafa skilað árangri í að ná ákveðnum markmiðum sem tengjast heimsmarkmiðum Sameinuðu þjóðanna númer 14 (þ.e. stuðla að verndun og sjálfbærri nýtingu auðlinda sjávar) og markmið 14.4 og 14B hvað varðar endurheimt og uppbyggingu nytjastofna og að tryggja aðgengi smábátaveiða að þeim. Ávinningur smábátaútgerðar hefur aukist á kostnað stærri útgerða sem endurspeglast í þróun strandveiðiflota í Líberíu. Stefnubreytingin 2010 hefur hins vegar verið á kostnað hagkvæmni í sjávarútvegi í Líberíu. Kru og Fanti smábátum hefur að meðaltali fjölgað um það bil 9-falt en dregið hefur úr útgerð stærri skipa til veiða á landgrunninu. Þróun strandveiðiflotans hefur að mestu verið hagnaðardrifin. Að undanskildum botnfisktegundum á grunnsævi, ofan hitaskila, virðast helstu nytjastofnar vera vannýttir. Þessa þróun má að miklu leyti rekja til stefnubreytinganna í sjávarútvegi sem voru innleiddar árið 2010.

Á tíma borgarastyrjaldarinnar var takmörkuð fjárfesting í nýrri veiðitækni. Þetta leiddi til óhagræðis í smábátaútgerð þó bátarnir séu að meðaltali arðbærir. Virðiskeðja afla einkennist af lítilli eða engri virðisaukandi þjónustu og skorti á gagnsæi sem stafar af valdaójafnvægi og skorti á upplýsingaflæði í virðiskeðjunni. Niðurstöður tilviksrannsókna sem kynntar eru í þessari ritgerð mæla með því að stjórnvöld í Líberíu ráðist í stefnumótun sem miði að því að bæta afkomu í sjávarútvegi, jafnt í veiðum sem í vinnslu.

Niðurstöður rannsóknanna sem fram koma í þessari ritgerð benda á tækifæri stjórnvalda í Líberíu til umbóta bæði í fiskveiðistjórnun sem og í geymslu og vinnslu afla. Stjórnvöld þurfa að finna leið til þess að innleiða fiskveiðistjórnun sem takmarkar sókn smábáta. Stuðla þarf að þróun veiðanna þannig að

skilvirkni þeirra aukist með aukinni tæknivæðingu svo nýta megi betur vannýttar auðlindir bornfiska sem finna má á meira dýpi. Stuðla þarf að umbótum í meðferð afla til að bæta nýtingu hráefnis og auka verðmætasköpun í virðiskeðju sjávarafurða. Slíkar umbætur eru afar mikilvægur hlekkur í að fá gula spjaldi veiðanna, sem sett hefur verið af Evrópusambandinu, lift með það að markmiði að afla nýrra og arðsamari markaða fyrir sjávarafurðir frá Líberíu.

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I would like to express my sincere gratitude to a number of institutions as well as individuals who supported me spiritually, financially and technically in the completion of this research project and thesis. The spiritual inspiration, wisdom, and strength to carry out this research project were given to me by the Almighty God through our Lord and savior Jesus Christ. National Fisheries and Aquaculture Authority (NaFAA) through the EU Sectorial Support Funds and the UNESCO affiliated GRÓ-Fisheries Training Program in Iceland provided grants in support of my research activities, without which I would not have been able to carry out this entire research.

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I would like to thank the NaFAA Administration, not least for the timely support and the colleagues in the research and statistics division of NaFAA for their support in providing data and information on the Liberian fisheries, while writing the articles and white paper of this thesis.

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Paper I: A. S. Jueseah, O. Knutsson, D. M. Kristofersson and T. Tómasson (2020a). Seasonal flows of economic benefits in small-scale fisheries in Liberia: A value chain analysis. Marine Policy, 2020, 119, 104042

Paper II: A. S. Jueseah, D. M. Kristofersson, T. Tómasson and O. Knutsson (2020b). A Bio-Economic Analysis of the Liberia Coastal Fisheries. Sustainability, 2020, 12, 9848

Paper III: A. S. Jueseah, T. Tómasson, O. Knutsson and D. M. Kristofersson (2021). Technical efficiency analysis of coastal small-scale fisheries in Liberia. Sustainability, 2021, *13*(14), 7767.

Paper IV: A. S. Jueseah (2021). A critical review of the Liberian fisheries sector: A technical report, NaFAA September 15, 2021.

PART I OF THESIS

1 Introduction

Liberia, situated on the west coast of Africa, is the 9th poorest country in the world with an estimated per capita GDP of around US$ 1,400 (2020 est)[1]. It has a coastline of 579 km and an exclusive economic zone (EEZ) of 246,000 km^2 which is home to valuable demersal and pelagic fishery resources. For several decades, the fisheries have been exploited by small-scale and industrial fleets to various extents in coastal and offshore waters using multiple fishing craft and methods (Ministry of Agriculture 2014; MRAG 2014; Chu et al, 2017).

The coastal fisheries are conducted on the continental shelf (Ssentongo 1987). Six exploitable fish stock assemblages in the Liberian waters are small, medium, and large pelagics, shallow- and deep-water demersals and crustaceans (MRAG 2014). These stock assemblages are targeted by small-scale Kru and Fanti boats along the coast, a coastal industrial fleet, and an offshore industrial fleet.

The small-scale and industrial fleets usually operate in different fishing zones in the Liberian EEZ (MRAG 2013:2014; Ministry of Foreign Affairs 2019). Small-scale fishing changes with the seasons and is influenced by currents, weather, and fish distribution (MRAG 2013). The depths and extent of operation of the Kru and Fanti boats may vary between landing sites along the coast (MRAG 2013). For instance Kru canoes from Robertsport, during the rainy season usually fish inside the 6 nm IEZ in waters of less than 60 m depth (Figure 1a) (MRAG 2013). During the dry season, Kru canoes venture further out, up to 20 km from the shore, where water depths can be over 100 m (Figure 1b) (MRAG 2013). Fanti fishing typically occurs both inside and outside the 6 nm IEZ but where they specifically fish depend on where their target species are normally between 30-60 m (Figure 1c). The coastal industrial vessels are required to operate outside the 6 nm IEZ, although trawles may be granted rights to do experimental fishing outside 4 nm using approved gear (Ministry of Foreign Affairs 2019).

[1] Liberia - The World Factbook (cia.gov). Accessed 02.25.2022.

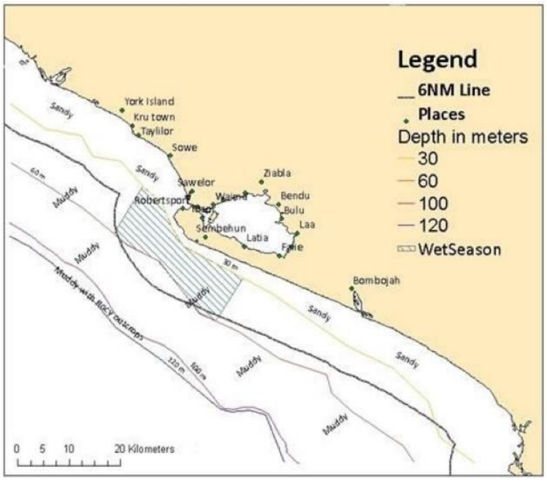

Figure 1a: The main fishing grounds of Kru operating from Roberstport during the rainy season.
Source: (MRAG 2013)

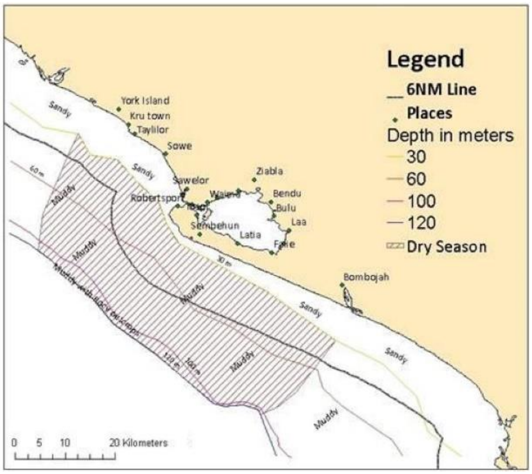

Figure 1b: The main fishing grounds of Kru operating from Roberstport during the dry season.
Source: (MRAG 2013)

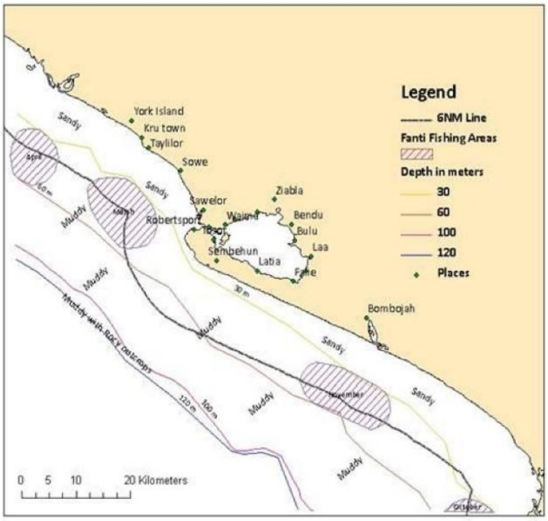

Figure 1c: The main fishing grounds of Fanti operating from Roberstport.
Source: (MRAG 2013)

Local Kru operators primarily fish from non-motorized dugout canoes, mostly using handlines and gillnets targeting shallow- and deep water demersal stocks above and below the thermocline (Ssentongo 1987). Kru canoes also to a lesser extent target some crustaceans, primarily lobsters and crabs, using traps and gillnets (Jueseah et al, 2020). The Fantis are mainly migrant fishermen from Ghana who use larger motorized open wooden boats, mostly deploying ring nets and surface set drift nets targeting small pelagics (Chu et al, 2017; Jueseah et al, 2021). Kru and Fanti operators, to a much lesser extent, also catch some large and medium pelagic species. Since 2010 the SSF have had exclusive access up to six nautical miles offshore, but they may also fish further out.

The coastal industrial fleet is composed of foreign owned trawlers employing bottom and mid-water trawls and mainly target shallow- and deep-waters demersal stock assemblages, and coastal shrimp (MRAG 2013). The offshore fleet consists of EU and private large industrial tuna vessels that employ multiple fishing methods but primarily purse seines and target large tuna and tuna-lke species (MRAG 2014). The small-scale Kru fleet is the only domestic sector that is owned by Liberian fishermen, while both the small-scale Fanti boat (mainly Ghanaian fishermen who live in Liberia but tend to take their fisheries income back to Ghana) and the industrial trawlers are foreign owned (Chu et al, 2017).

The number of small-scale Kru canoes grew from less than 50 in 1960 to approximately 3,815 in 2019 (Figure 2a). The growth of the Kru fleet has mostly been propelled by profitability although their harvesting technology is largely inefficient (Jueseah et al, 2020; Jueseah et al, 2021; Jueseah 2021). The number of Fanti boats, on the other hand, increased from 200 boats in 2000 to aroud 750 in 2010 (Figure 2a). However, their numbers since then have been relatively stable (Figure 2a). Although the Fanti fleet is found to be quite profitable, the lack of access to big forest trees used to build the boats has constrained its growth since 2011. Available data indicate large fluctuations in the total catch of the SSF (Figure 2b). This can largely be attributed to fluctuations in the Fanti fleet catches of small pelagics. The SSF primarily supplies the domestic market. Between 2013-2020 the Fanti fleet accounted for around 63% of the total SSF catch (Jueseah et al 2020).

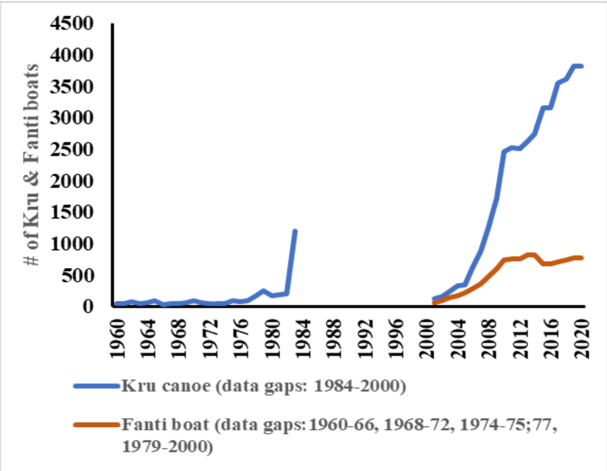

Figure 2a: Number of Kru & Fanti boats over time
Sources: Shotton (1983), Ssentongo (1983), NaFAA statistics (2001-2020)

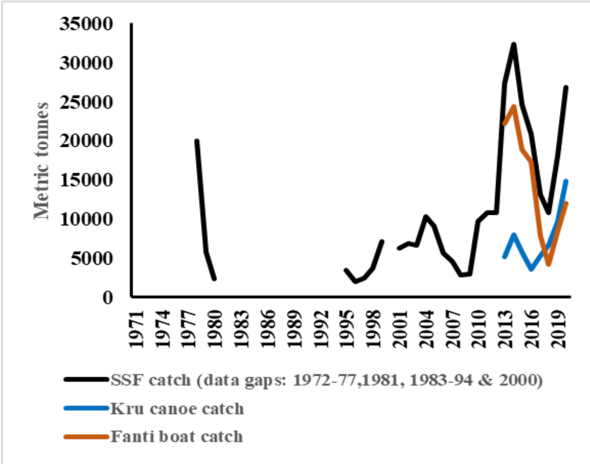

Figure 2b: Total catch of Kru & Fanti boatsover time
Sources: Shotton (1983) (1971-1980, 1982), FAO (1995-1999) NaFAA statistics (2001-2020)

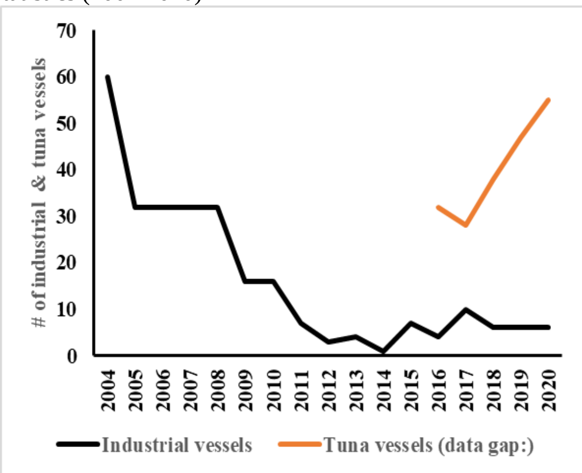

Figure 2c: Number of coastal industrial & tuna vessels operating in Liberian waters
Source: NaFAA Statistics

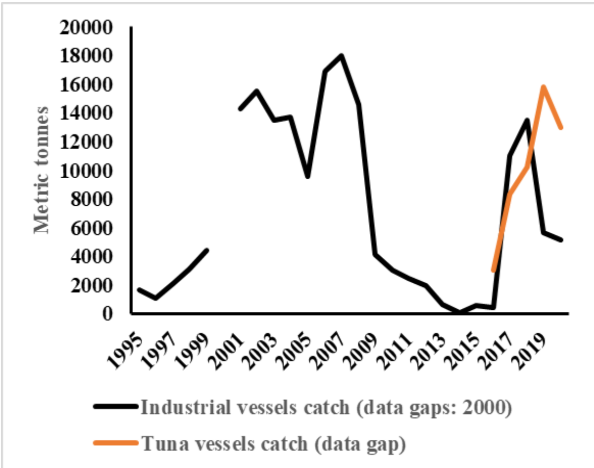

Figure 2d: Total catch of coastal industrial & tuna vessels
Source: FAO (1995-1999) & NaFAA statistics (2001-020)

The number of industrial vessels operating in the coastal waters of Liberia, have decreased from 60 in 2004 to 6 vessels in 2020. Governance in the fisheries sector, during the civil war, was absent resulting in widespread IUU fishing. However, successive governments since 2004 have focused on governance of the fisheries sector which has resulted in significant exits of the industrial fleet from the fishery (Figure 2c) (Chu et al, 2017; Jueseah et al, 2020). The decrease in the number of industrial vessels seems to be partly due to the policy change introduced by the government in 2010 and the establishment of a 6 nm IEZ to protect the SSF and in part due to the trawlers failure to pass the pre-licensing inspection test, as many of them were old and in disrepair (Jueseah et al, 2020).

Catches of the industrial vessels have fluctuated widely over time (Figure 2d). After the introduction of the 6 nm IEZ, the industrial trawlers have not had access to many of their key target species like the shallow water demersals and the coastal shrimp (Chu et al, 2017; Jueseah et al, 2020b). Instead, the coastal industrial vessels have increasingly targeted pelagic species resulting in a large increase in their catch towards the end of the data period (Figure 2d).

The number of offshore vessels increased from 32 in 2016 to about 55 vessels in 2020 (Figure 2c). Offshore vessels operating in the Liberian EEZ prior to 2016 were regarded as conducting IUU fishing, primarily because of the lack of governance in the sector (Braimah 2012). With the establishment of governance in the Liberian fishing industry, the EU signed a five year sustainable fisheries partnership agreement (SFPA) with Liberia for access to its tuna resources. The tuna vessels total catch increased from 3,025 t in 2016 to 15,798 t in 2019 then decreased again in 2020 to around 12,993 t (Figure 2d). In the past two decades, the annual total catch has averaged around 20,800 t. Potential yield has been estimated to range between 18,520 to 30,735 t year^{-1} (Jueseah 2021).

In the decades preceding the civil war, the coastal industrial fishery was relatively well equipped and increased considerably from around 7 vessels in 1960 to around 14 vessels in 1981 catching about 3,000 t of demersal finfish and 2,000 t of shrimp year^{-1} (Ssentongo 1983; Shotton 1983; Ministry of Agriculture 2014). The fishing industry was greatly affected by the prolonged civil conflict which started in 1989, as was the case for most sectors of the economy, and the damage ranged from fishing vessels, landing piers and cold chain infrastructure to human capital (Republic of Liberia 2014). Nonetheless, today fisheries play a major role in food and nutritional security, where fish provides 65% of the animal protein consumed, employment for around 33,000 Liberians, revenues and foreign exchange earnings for the government and accounts for around 10% of GDP (Belhabib et al, 2015).

Major policy documents such as the Fisheries and Aquaculture Policy and Strategies (FAPS) and the Pro-poor Agenda for Prosperity and Development (PAPD) (Ministry of Agriculture 2014; Republic of Liberia 2018) have been prepared and adopted by the Liberian Government to guide development in the fisheries sector. However, the lack of appropriate fisheries management has reduced the contribution of the fishery resources to the economy. The introduction of effective fisheries management is impeded by factors such as: lack of ability to identify efficient harvesting and fisheries development paths for the main fishing fleets (harvesting sector), poor fishery value chains (post-harvest sector), limited understanding of the fleets' harvesting technologies; inadequate administrative capability and the lack of political will. This PhD research project aims at remedying the first three deficiencies by developing a bio-economic model for the main fishing fleets that allows identification of economic efficient harvesting paths for the fleets, conducting a value chain analysis for the key fisheries to obtain an assessment of value and benefits generated in the various nodes and by actors in the SSF value chain; and conducting technical efficiency analysis of the small-scale fleets, to determine the state of the harvesting technology in the fishing industry. Finally, the development of the Liberian fisheries is critically reviewed to evaluate the performance of the sector in light of current policies. This is to obtain a holistic outlook of the Liberian fishing industry.

This research has four main objectives addressed in three published case studies and a white paper (Figure 3). Paper I examines the post-harvest sector of the SSF. Seasonal flows and distribution of net benefits and relationships between actors in the small-scale Kru and Fanti value chains were investigated. The value-adding role of the main actors was assessed and the impact of seasonal changes in fish supply and organizational structures and marketing channels of the value chains. The objective of paper II was to develop a bio-economic model to identify and evaluate economically feasible fishing effort and harvesting paths for the main coastal fleets operating in Liberia. More specifically, the case study investigated the current state of the coastal fisheries and how management of the resource could be better aligned with the SDG 14 targets 14.4 and 14B, and the economic outcomes of the coastal fleets. In paper III the objective was to better understand the state of the harvesting technology used by the different SSF fleets. Particularly, the case study analyzed the technical efficiency of the small-scale fleets. Paper IV provides a critical review of the development in the Liberian fisheries and evaluates the performance of the sector based on current policies drawing on empirical evidence and results in the three case studies in papers I-III (Figure 3).

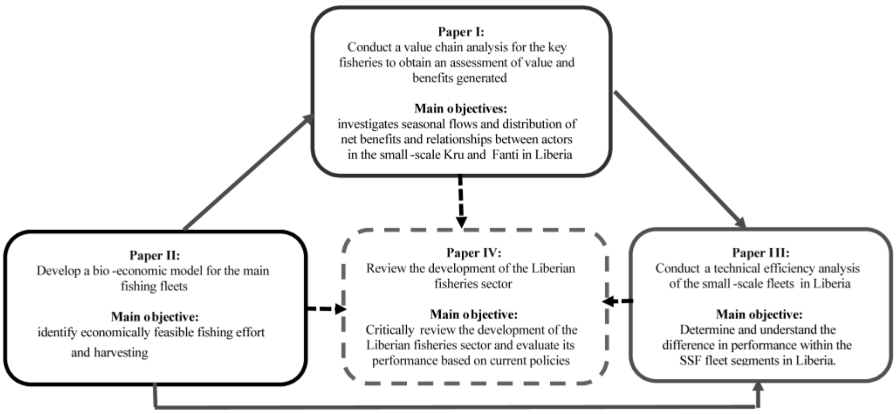

Figure 3: Structure of the case studies in this research project

This thesis is divided into two parts. The first part contains three sections. The background and rationale of this dissertation is introduced in section one. Section two gives the brief background on the theoretical framework employed and past research pertinent to this dissertation. Section three outlines in more detail the research questions specific to each of the three articles and one white paper and their key findings. The white paper serves as both introduction, summary, and the overall conclusion of this thesis. Part II of this thesis consists of the three published articles i.e. papers I-III and the white paper. Papers I-III have been published in peer-review journals and the white paper, a technical report of the Liberian fisheries, has been published by NaFAA.

2 Theory and Literature Review

This section presents a brief description of the theories used in each of the three published articles presented in this thesis.

2.1 Value chain analysis

A value chain describes how products pass through all activities of the chain in a sequence and the added value of each step (Hempel 2010). Value chain analysis is thus used to evaluate the structure of a particular market by describing the comprehensive range of value-addition activities implemented by different actors such as primary producers, processors, traders and service providers, necessary to convey a product or service from conception, via its processing or physical transformation, to delivery of the product to its end consumer (M4p 2008; Webber and Labaste 2010; UNIDO 2011).

Value chain analysis may be applied to either describe a particular industry or as a tool that provides a basis for an analytical investigation (Kaplinsky 2000; Kaplinsky and Morris 2001; Hempel 2010). When value chain analysis is used as a descriptive tool, the analyst attempts to describe what happens sequentially through the production process and probably assign values to the various links in the chain, as was done in value chain studies of seafood commissioned by FAO (Asche et al., 2006; Bjørndal et al, 2014). When employed as an analytical tool, the researcher uses the description of the value chain as a starting point in searching for causal relationships between the links, usually to explain what is happening between the actors in the chain, what connects the actors, what information is exchanged between them, and how the relationship between them is evolving (M4p 2008; Hempel 2010).

Value chain analysis was adopted and applied as an analytical tool to investigate seasonal flows and distribution of net benefits and relationships between actors in the Kru and Fanti small-scale fisheries in Liberia (Paper I). The concept of value chain also encompasses the issue of organization and coordination-governance, the strategies and power relationships of the various actors in the value chains (M4P 2008; UNIDO 2011). Governance analysis relates to the cooperation and coordination between the actors facilitating the delivery of a product from primary production to final use (McCormick and Schmitz 2001; Kaplinsky and Morris 2001; Bair 2009; UNIDO 2011). It involves the ability of some key actors to exert control over others through their bargaining power, to allocate the value produced in the value chain (McCormick and Schmitz 2001; Kaplinsky and Morris 2001; Bair 2009; UNIDO 2011). Governance supports that the relationships between actors within the value chain display some form of organization instead of just being casual and is key to better understand how and why a value chain functions (Kaplinsky and Morris 2001).

Based on the complexity of transaction in the value chain, Gereffi *et al.* (2005) identified five types of governance in value chains, market, modular, relational, captive and hierarchy. Every value chain, as a system of production, has a system of coordination which consists of formal and informal arrangements between the actors (M4P 2008). To ensure compliance with official or unofficial rules and standards and to make maximum use of investment capital, coordination structures evolve to allow enterprises to fulfil the competitive requirements of intermediate and final markets (M4P 2008). The coordination constructs may vary from a quite loosely coordinated i.e. market-based trading relationship, to strongly coordinated i.e. vertically integrated production (Figure 4) (M4P 2008). The five types of global value chain governance are ranked based on the degree of power asymmetries and explicit coordination.

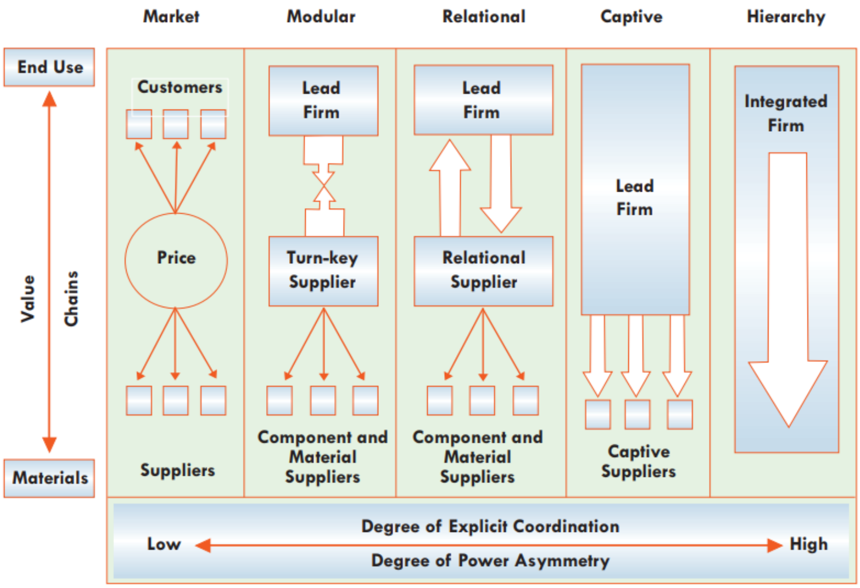

Figure 4: Five global value chain governance types according to Gereffi et al (2005)

As the governance type moves from market to hierarchy form, the degree of explicit coordination and power asymmetry between buyers and suppliers increases (Figure 4). The governance structure of Gereffi et al, (2005) mirrors the governance arrangement in the Kru and Fanti SSF value chains in Liberia. Therefore, the governance framework of Gereffi and associates (2005), has been applied by analysts to assess fisheries value chains (Nguyen et al 2020; Somasekharan et al, 2015), and was adopted and employed to identified types of relationships between actors in the Kru and Fanti fish value chains in Liberia.

2.2 Bio-economic analysis

The theory of fisheries bio-economic analysis was first introduced by Gordon's (1954) and Schaefer's (1954) static model of a single species commercial fishery and is widely used to describe and compare equilibrium solutions of a fishery (Arnason 2009; Larkin et al, 2011; Bjørndal and Munro 2012). The Gordon-Schaefer static fishery surplus production model illustrates the economic inefficiency of an open access fishery equilibrium, compared with the economically efficient outcome that maximizes long-term profits i.e. maximum economic yield (MEY). Gordon's (1954) model can also be used to find possible solutions to the overfishing problem and has formed the basis for several "regulated entry" fishery programs introduced in a number of countries around the world in an attempt to overcome the "common property problem" (Saville 1997).

There are two main purposes of fisheries bio-economic analysis (Anderson and Seijo 2010). First, it is used to show how a particular fishery will possibly operate given changes in effort that is applied in the fishery and the stock size (Seijo et al, 1998; Anderson and Seijo 2010). Secondly, it can be used to recommend and analyze procedures for regulating fishermen so that the desired level of fishing effort is obtained, although accomplishing the second objective remains an ongoing process (Anderson and Seijo 2010). Fisheries bio-economic analysis, however, can be a very important analytical tool in the development of practical fisheries management policy (World Bank and FAO 2009; World Bank 2017; Anderson and Seijo 2010; Larkin et al, 2011) as it can be used to address how rapidly the stocks can recover and a fishery rebuilt (Larkin et al, 2011, World Bank and FAO 2009; World Bank 2017).

Fisheries dynamic analysis was pioneered in the mid-1950s and extended in the mid-1980s with introduction of optimal control theory (Scott 1955; Clarke and Munro 1975; Clarke 1985; Larkin et al, 2011). The direct effect that fishing has on subsequent recruitment could now be captured using delay-difference models. Cohort or year-class models expanded on the delay-difference models by differentiating the individuals in a fish stock by size or age, thus allowing researchers to study the effects of gear restrictions (e.g. mesh size, net design or hook size) in a given fishery (Larkin et al 2011). Cohort models require detailed biological data which is usually not available for fisheries in developing countries, while surplus production models have less demands for data (Saville 1997). These types of models are easily adapted to represent a variety of bio-economic characteristics of a fishery and are much more flexible to bio-economic analysis than cohort models (Saville 1997). Bio-economic analysis can, therefore, be static-to determine the sustainable equilibrium, or dynamic-to model/simulate transitions and harvesting paths, the objective can be to reflect the current situation or a proposed alternative such as to maximize catch or benefits (Larkin et al, 2011).

On this basis, in paper II a fisheries bio-economic model is developed and used to evaluate the fisheries and identify economically feasible fishing effort and harvesting paths for the fleets operating in Liberia. The bio-economic model adopted and used in paper II is basically a dynamic version of the Gordon-Schaefer (1954) static model.

2.3 Technical efficiency analysis

The concept of technical efficiency in production theory of an enterprise, its measure and the factors that determine technical efficiency are crucial in microeconomics (Fried et al, 1993). The theory was pioneered by Koopmans (1951) who defined technical efficiency as a feasible input or output vector where it is technically infeasible to increase any output and/or reduce any input without simultaneously reducing another output and/or increasing another input

(Koopmans 1951; Fried et al, 1993; Ruggiero 2000). In other words, technical efficiency is the ability of an enterprise to obtain the highest output from a given set of inputs or to produce an output using the lowest possible amount of inputs (Kumbhakar and Lovell 2000).

A producer is technically efficient, if an increase in an output necessitates a reduction in at least one other output, and if a reduction in any input entails an increase in at least one other input or a reduction in at least one output (Koopmans 1951). A technically inefficient producer should be able to produce similar output with less of at least one input or could use similar inputs to produce more of at least one output.

Debreu (1951) and subsequently Farrell (1957) introduced an input-based measure of technical efficiency defined as one minus the maximum equi-proportionate reduction in all inputs that still permits continued production of given outputs (Fried et al, 1993; Ruggiero 2000). While an index of unity indicates technical efficiency because no equi-proportionate is possible, a score of less than unity indicates the severity of technical inefficiency (Fried et al, 1993). Figure 5 illustrates technical efficiency in the form of a simple production process with a single input and output, which is further explained in the text below.

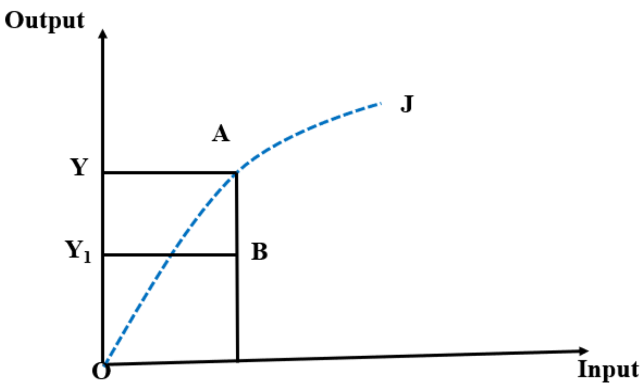

Figure 5: Technical efficiency and inefficiency of a single input-output production
Source: Fried et al., (1993)

The production frontier is the broken blue curve between “O” and “J” (Figure 5). A firm that produces at point “A” along the frontier “OJ” is technically efficient with technical efficiency score of unity, whereas a firm that produces at point “B” is technically inefficient with a technical efficiency score of < unity calculated as OY_1/OY (Fried et al., 1993). An enterprise technical efficiency and the level of the use of variable inputs determines the output and capacity utilization of an enterprise. The level of output an enterprise can produce will increase as a result of technological changes that affects the ability of an enterprise to combine inputs (Coelli et al., 2005). These technological changes cause the Production Possibility Frontier to shift outward when more output is obtained from the same level of inputs. Determining the factors affecting technical efficiency, therefore, allows policy makers to take appropriate measures to limit or even improve it.

The basic production theory used for estimating technical efficiency is determined employing four key determinants including capital, labor, energy and materials. In fisheries production literature, however, analyses have used composite effort variables to represent the production function based on the objective of the researcher (Mpomwenda 2018). For instance, in fisheries the capital input is heterogeneous encompassing vessel-specific measures like outboard or inboard engines, size or power of engine, type and size of gear, and fishing strategies like fishing duration or length of hauls among others (Mpomwenda 2018). Heterogeneity of the capital input, in this case, is accounted for, and the different variables can be categorized, and the constrained input variables can be substituted. Further, classifying the inputs that are controlled such as vessel features can allow for the substitutability between the controlled and uncontrolled outputs (Mpomwenda 2018). This helps to determine the level to which input controls such as vessel and engine size in fisheries are expected to be effective as well as their impact on the efficiency of harvesters in the fishery (Kompas et al., 2004). The primary purpose of measuring technical efficiency of a fleet is to improve the productivity in the fishery either through reducing inputs because of overcapitalization or as a way to improve input variables through technological change of the fleet like vessel and engine size, fuel efficiency, etc.

Furthermore, harvesters' variables like skipper experience can also be employed to determine the fishing fleet efficiency and can be attained through applying proxies like education and experience in fishing, and skipper's age and nationality. In the process of production, these are often regarded as unobservable inputs which are not specified in the original production function (Kirkley and Squires, 1998; Eggert, 2001; Squires et al. 2003; Lokina, 2009). For output, fisheries consist of a single or multiple species, though most fisheries are multispecies. The production functional specification, therefore, can be applied in estimating efficiency to include multiple outputs (species) which allows researchers to assess the degree of jointness or separability among the species and affects how the various species could be managed (Madau, et al, 2009). Furthermore, the production environment can also influence fishing through random shocks like movement of the fish stocks, seasonal variations in species availability or unavoidable weather factors that affect technical efficiency. When specifying efficiency models, analysts must take into account this randomness.

Several approaches have been developed and used to estimate technical efficiency in fisheries and other economic sectors. They include the non-parametric data envelopment analysis (DEA), the parametric stochastic production frontier (SPF) analysis and the econometric transformation approaches to measure technical efficiency (Charnes et al, 1978; Aigner et al, 1977; Meeusen and Van Den Broeck 1977; Banker et al, 1984; Färe et al, 1985; 1994; Ruggiero 2000). However, in fisheries, majority of the analyses have used DEA and the SPF analysis. The use of the SPF or DEA approach is in general based on the objective of the researcher. The DEA approach, pioneered by Charnes et al, (1978) and later Banker et al, (1984) and Färe et al, (1985;1994), is based on mathematical programming that envelops the observed data to determine a best-practice frontier (Fried et al, 1993). The main advantage of the DEA is that it can be used for multi-species fisheries because it incorporates multiple inputs and outputs in the analysis as opposed to the SFP analysis which is only used in single species fisheries, i.e. multiple inputs-single output. DEA is sensitive to measurement error and the selection of variables. It does not adjust for random error and may therefore be biased for production process such as fishing that generally consists of stochastic components (Fried et al.1993; Truong et al. 2011). The SPF analysis, introduced simultaneously by Aigner et al, (1977) and Meeusen and Broeck (1977), entails a functional specification, which considers and specify vessels technical inefficiency caused by randomness, vessel features or both, and distribution assumption on the empirics. This approach, therefore, accounts for random noise such as could be caused by climatic and fishing conditions (Herrero 2004; 2005; Lokina 2009; Truong et al. 2011). The specification allows for a non-negative random part in the error term to produce a relative estimate of technical inefficiency i.e. a ratio of actual versus expected maximal output, considering the inputs and prevailing technology (Kompas et al. 2004). SPF analysis is usually applied to estimate relative technical efficiency of an enterprise that exploits renewable resources such as fisheries that are typically prone to natural shocks such as adverse weather and seasonal stock fluctuations as has been done by Kirkley et al, (1995), Sharma and Leung (1998), Lokina (2009), Sesabo and Tol (2006), and Truong et al, (2011).

In paper III, SPF analysis is adopted and used to determine and understand the difference in performance within the SSF fleet segments in Liberia, because fishing is a stochastic activity prone to random shocks such as weather and seasonal stock variations.

3 Summary of findings

The research questions and key results which emerged from each of the three published articles and one white paper are summarized in this section. The article is first introduced, followed by the aim, research questions and discussion. This is followed by the main findings in the paper.

3.1 PAPER I: *Marine Policy* 2020, 119, 104042

Title: Seasonal flows of economic benefits in small-scale fisheries in Liberia: A value chain analysis.

Authors: A. S. Jueseah, O. Knutsson, D. M. Kristofersson, T. Tomasson.[2]

Received 16 July 2019; Received in revised form 19 May 2020; Accepted 20 May 2020, Available online 2 July 2020

The effects of seasonality on fishing activities, fish supply and net benefits of actors in the Kru and Fanti SSF are investigated. The following research questions were put forward:

I. What is the value-adding role of the main actors in the value chains and how are their benefits impacted by the relationships among them and the seasonal changes in fish supply?
II. What are the organizational structures and marketing channels of the value chains and the differences in average net benefits of actors at each node of the value chains during the dry and rainy seasons?

Value chain analysis was used in paper I, to evaluate the organizational structure and value-addition activities in the Kru cassava fish and Fanti bonny fish value chains in Liberia. To shed light on the distribution of net benefits flowing between actors, price analysis was conducted using price and cost data from actors in the different links of the Kru and Fanti fish value chains.

The mean monthly catch of the Kru fish value chain (FVC) was around six times higher during the dry season than the rainy season. During the dry season, Kru fishermen sold their catch directly to their wives, Korean wholesalers, artisanal fish traders, mini cold store operators or individual consumers, whereas during the rainy season mini cold store owners and artisanal fish traders do not buy because of limited supply (Figure 6). Fish caught and traded by Kru fishermen is generally of low quality since there is no value-addition

[2] The doctoral student (Alvin Slewion Jueseah) role in this paper was to conduct all research activities relating to seasonal flows of economic benefits, the data collection and analysis, the methods used, and the writing of the paper. The remaining authors supervised the doctoral student during the research activities, writing and editing of the paper.

service in either season. This has implications for the fish products produced and traded at the wholesale, processing, and retail as well as the consumption nodes of the Kru FVC (Figure 6).

Kru fishers' wives buy around 60% of the catch during the dry season and 88% during the rainy season (Figure 6) mostly based on bargained price in exchange for providing, through issuing informal credits, future access to gear and other operational expenses. The nature of the relationship existing between Kru fishers, and their wives can be viewed as captive due to operational dependency or even hierarchy due to the family relationships.

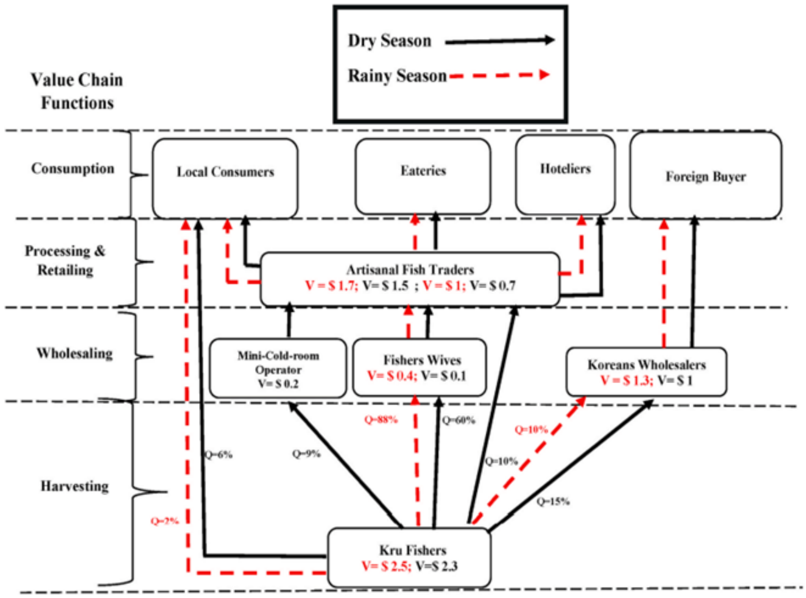

Figure 6: Kru fishers value chain for shares (%) of cassava fish traded and value-added by each actor, based on responses from fishers and fish trader groups interviewed in the dry- and rainy seasons. Seasonal average value-added kg^{-1}.

Korean wholesalers are the second biggest buyer in the Kru FVC and purchased around 15% of the total catch in the dry season and 10% during the rainy season (Figure 6). Korean wholesalers usually finance the purchase of fishing canoes and gear, and sometimes even provide operational expenses, according to key informants. Kru fishers in return repay the Koreans with cassava fish, usually up to 50% of a predetermined price (Jueseah et al, 2020). Because of the financial dependency between Korean wholesalers and Kru fishermen, the relationship between the parties can be regarded as captive.

Artisanal fish traders are the third biggest buyer and they buy around 10% during the dry season (Figure 6) paying market price based on demand and supply. Local consumers who buy fish for their own consumption from Kru fishers are the smallest buyers, buying around 6% during the dry season and 2%

during the rainy season. The exchange is purely market-based as there is no financial dependency on either side (Figure 6).

In the wholesale node, Kru fishers´ wives typically without any value-adding service apart from sometimes washing the fish with seawater, wholesale their fish fresh to artisanal traders through market-based sales.

Mini cold-room operators in the wholesale node, wash using sea- or fresh-water and preserve their fresh fish in coolers before selling to artisanal fish traders through market trade. The main value-addition services, therefore, performed by local middlemen during the dry and rainy seasons are washing and chilling to maintain freshness, and transport.

On the other hand, Korean wholesalers add value to the fresh fish through services such as washing, sorting and packaging the fresh fish, storing in chill boxes and transporting to Monrovia before export, using inputs like water, plastic crates, chill boxes and vehicles (Jueseah et al, 2020). This suggests the Korean middlemen performed the most value-addition services during both seasons in the Kru FVC.

Retailers, add value through services such as washing, icing, traditional smoking and transporting (Jueseah et al, 2020). Hoteliers pay higher average price for fresh fish in both seasons while processors retailing to eateries received the best price for smoked fish (Figure 6). The price paid by hoteliers, which is by far the highest, is most probably related to the quality of the fish (Jueseah et al, 2020).

Value-addition by fresh fish retailers averaged around US\$ 1.5 kg^{-1} in the dry season and US\$ 1.7 kg^{-1} in the rainy seasons, while those dealing in smoked fish added around US\$ 0.7 kg and US\$ 0.6 kg^{-1}. It seems the relatively low value generated by processors can most probably be attributed to the quality of fish they smoke and sell. Because cassava typically attracts better price when sold fresh. Retailers normally smoke what fish they cannot sell fresh.

Fanti fishers' wives purchase about 85% and 90% of the total quantities traded during the dry and rainy seasons (Figure 7). The trading relationship between the Fantis and their wives is similar to that observed in the Kru value chain and they are the only middlemen wholesaling bonny in both seasons. This indicates a complete lack of competition. Artisanal fish traders buy around 10% of the total quantity traded during the dry season but nothing directly from Fanti fishermen during the rainy season (Figure 7). The exchange is based on demand and supply because there is no operational dependency between the parties. Local consumers who purchase about 2% and 10% of the total quantities of bonny from the Fanti fishermen in the dry and rainy seasons, are the smallest customers and the business relationship is market-based.

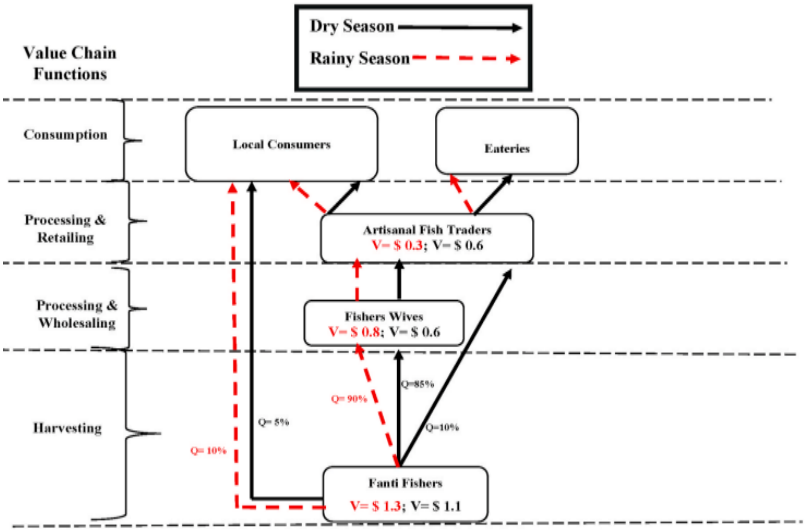

Figure 7: Fanti fishers value chain for shares (%) of bonny quantity traded and value-added by each actor, based on responses from fishers and fish trader groups interviewed in the dry and rainy seasons. Seasonal average value-added kg^{-1}.

In the wholesaling and processing node, Fanti fishers' wives typically wash and smoke the bonny before wholesaling to artisanal fish traders (Drammeh 2007; Jueseah et al, 2020). The business relationship is market-based because there is no transactional dependency between the actors (Figure 7) (Jueseah et al, 2020). Bonny wholesalers added value on average around US$ 0.6 kg^{-1} in the dry season and US$ 0.8 kg^{-1} in the rainy season (Figure 7).

Artisanal fish retailers, usually carry out services such as transportation and smoking before they take the bonny to local consumers and eateries in Monrovia and other parts in Liberia (Figure 7). Because there is no transactional dependence between the parties, the exchange is purely market-based. Retailers created averaged value-added of around US$ 0.6 kg^{-1} in the dry season and around US$ 0.3 kg^{-1} in the rainy season.

The average price fishermen received, in both Kru and Fanti fishery value chains, were based on the type of relationships and did not vary much between seasons. Generally, market-based relationships encouraged more competition among buyers than captive or hierarchy relationships. Differences in the prices fishermen received in both the Kru cassava fish and Fanti bonny value chains can be attributed to the lack of transparency. The SSF value chains in Liberia are characterized by low value-addition services and lack of transparency which stems from power asymmetries and lack of information flow. SSF landing sites lack basic infrastructure for fish handling and processing, ice and chill storage facilities, and potable water supply, Sanitary facilities are not available and environmental hygiene is a major issue in the SSF (Drammeh 2007).

3.2 PAPER II: *Sustainability*, 2020, 12.9848

Title: A Bio-economic Analysis of the Liberian Coastal Fisheries

Authors: A. S. Jueseah, D. M. Kristofersson, T. Tomasson, O. Knutsson.[3]

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A background of the Liberian fisheries, in terms of the main fisheries resources, the fishing fleets exploiting them, the fleets' development as well as the key fisheries management reforms initiated by the Government in 2010, is presented in paper II. The focus of the paper was to develop a bio-economic model to assess the coastal fisheries and identify economically feasible fishing effort and harvesting paths for the main coastal fleets operating in Liberia. The specific research questions addressed are as follows:

I. What is the current state of the coastal fisheries and how could management of the resource be better aligned with the SDG 14 targets 14.4 and 14B?
II. What are the economic outcomes of the coastal fleets?

An aggregative discrete-time dynamic bio-economic model, for the species assemblages, was adopted and used in this analysis. The data was collected by the Liberian authorities and comprehensively cover the landings of the Liberian domestic fleet as well as foreign vessels. Although transshipments could possibly have taken place, they are illegal. The fishery is monitored both through a vessel monitoring system and onboard observers are unlikely to be substantial.

Most of the stock assemblages appear to be underexploited, except the shallow water demersals which are overfished. The prolonged civil crisis and the establishment of the 6 nm IEZ in Liberia are the most likely reasons for the observed under-harvesting of the deep water demersals and crustaceans in the Liberian coastal fisheries. The change in the fleet structure have had different effects of the different stocks.

Prior to 2010, there was no political will or ability to manage the foreign industrial sector resulting in rampant IUU fishing and overexploitation of the coastal stocks (Braimah 2012; World Bank 2017; Jueseah et al, 2021). With financial support from the World Bank and collaboration with the Liberian Coast Guard, governance in the fishing sector was finally established in 2010 (World Bank 2017). Fishing pressure on the coastal fish stocks was reduced mostly due to a new fisheries regulation that established a 6 nm IEZ and increased enforcement. The number of foreign trawlers in Liberia‘s coastal waters was reduced from 60 vessels in 2004 to 6 vessels in 2020 (Arnason and

[3] The role of the doctoral student (Alvin Slewion Jueseah) in this paper was to carry out all research activities relating to bio-economic analysis of the Liberian fisheries and writing the paper. The remaining authors guided the doctoral student during the research activities, writing and editing of the manuscript.

MRAG 2016; World Bank 2017). This allowed fish stocks to recover to the benefit of the local small-scale fleets (World Bank 2017; Jueseah et al, 2020).

At the end of 2016, the coastal fisheries were profitable. While SDG 14, targets 14.4 and 14B were met in terms of stock rebuilding and increased access of the SSF, the research results indicate that this was at the cost of some economic efficiency. The SSF are lacking the appropriate harvesting technology to exploit the valuable shrimp and deep-water demersal resources (Jueseah et al, 2021). The 2010 policy has led to a redistribution of benefits from the foreign industrial operators to local small-scale fishers and changes in the coastal fleets development. Increase of the Kru fleet has contributed to overfishing of the shallow-water demersal, whereas other stocks were underexploited perhaps because the small-scale fleets do not have the proper technology to harvest them.

There was a considerable incentive for new investments in the Liberian coastal fisheries because both the Kru and the Fantis were realizing good profits. Regulatory actions are now needed for the small-scale fleets, if the fishery is to be sustainable. Limiting access in the SSF will be required step for improvements in fisheries management. The fundamental question for long term successful management is how to work with communities to help monitor and manage the SSF sector without incurring too much cost for the central government. Still, crafting an effective policy for SSF will be a complex task.

3.3 PAPER III: *Sustainability***, 2021,** ***13*****(14), 7767**

Title: Technical efficiency analysis of coastal small-scale fisheries in Liberia.

Authors: A. S. Jueseah, T. Tomasson, O. Knutsson, D. M. Kristofersson.[4]

Received: 6 June 2021; Accepted: 9 July 2021; Published: 12 July 2021.

This paper gives a background on the Liberian coastal fisheries catches and fleets' development before and after the civil crisis and policy changes introduced by the Liberian government in 2010. The main management measures that are applied for the Liberian fisheries are also described. The aim of paper III was to determine and understand the difference in performance within the Kru and Fani fleets, analyzing technical efficiency. The following research questions were addressed:

[4] The doctoral student (Alvin Slewion Jueseah) role in paper III was to carry out all research activities relating to determining differences in performance within the small-scale coastal fleets segments in Liberia and writing the paper. The rest of the authors supervised the doctoral student during the research activities, writing and editing of the manuscript.

I. What is the current state of the harvesting technology?
II. Are the small-scale fleets in the coastal fisheries technically efficient?

The main findings are that there were substantial heterogeneities in terms of operational and technical characteristics such as quantity of inputs used, and output produced by the small-scale Kru and Fanti fleets in Liberia. The input quantities of capital stock and crew used, and the output produced by the Kru canoes were by far lesser than the Fantis.

The technical efficiency score for the Kru canoes averaged 0.53 and decreased significantly with increase in canoe length and skipper age, while for the Fanti boats it averaged 0.70 and increased significantly with boat length and skipper age. Younger skippers (≤40 years), using newer and smaller dugout Kru canoes (≤ 6.1 m), were more efficient than older operators (> 40 years) deploying older and larger canoes. While it is possible to fish using hook and line from small canoes, it is more difficult to deploy small vessels when ring nets are employed. This is interesting and indicates it might be easier to operate Kru canoes, because operating a typical Kru canoe just requires muscle power to propel, which is why younger skippers do better than older skippers. It is more difficult to run a Fanti boat which have a large crew needed to operate the gear, therefore, experience and the size of the vessel do matter.

The technical efficiency scores of about 28% of the observed Kru canoes ranged between 0.61 to 0.80, whereas approximately 44% of the Fanti boats' technical efficiency indices falls into the same bracket. This indicates that a considerable proportion of the small-scale fleets have potential for improvement in their productivity considering the current low-level technologies and the state of the marine resources.

Among the Kru and Fanti, there were efficient and inefficient boats but on average they were profitable. This may explain the increase in the Kru fleet since the end of the civil conflict and following the zoning regulatory action instituted by the government in 2010.

The small-scale fishery is characterized by both considerable inefficiency and use of low-level harvesting technology and unsustainable utilization of the fish stocks. There has been about a 9-fold increase between 2004 and 2016 in the total number of Kru canoes and Fanti boats (Jueseah et al, 2021), but their total catch has only doubled over the same period of time. This in part indicates how inefficient and primitive the fishing technology deployed by the Kru and Fanti boats is and in part reflects overfishing of the shallow water demeral stocks as most of the increased fishing effort has been by the Kru (Jueseah et al, 2020; Jueseah et al, 2021). It should however be noted that catch data from the Liberian fisheries and those from FAO reported by Liberia are at best unreliable although data collection has improved (Belhabib et al, 2016; Jueseah 2021).

While Kru operators' investment over recent years has been in low-level harvesting technology that has not been working well, the Fantis find themselves in a situation where they do not have access to the needed raw materials used for construction of new traditional boats. There is a technical regress in the Liberian SSF which impacts the livelihoods of all those involved in the subsector. However, the limited scope the traditional boats offer to improve harvesting technology suggests a need for a technological leap in the SSF that will both improve the profitability and livelihoods of the small-scale operators.

In order to land high quality fish, the small-scale vessels need space onboard for ice and coolers, but the evolution of Kru and Fanti fleet is moving towards smaller vessels. Larger and more efficient vessels, such as fiberglass reinforced plastic (FRP) vessels, would make it possible to improve the quality of the landed fish and increase profitability. Limiting new entries while introducing new harvesting technology for the current small-scale fleet seems worthwhile. This type of policy may have implications for the existing value chains. In particular the role and livelihoods of women in the post-harvest sector need to be considered. Women should be included in all training and business development plans. Care must also be taken to regulate fishing effort to match the productive capacity of the fishery resources.

With new harvesting technology, operators should be able to take chillers and ice on board their boats for improved quality preservation post-harvest which would have a major effect on value addition in the post-harvest part of the SSF value chains. Transformation of the SSF will also require improved monitoring and assessment of the resources to assess the state of the stocks and economics of the fleets post-change in harvesting efficiency. This is necessary to gauge the policy impact on the fisheries based on evidence.

This transition will, however, require removing a number of socio-economic and emotional obstacles such as sourcing investment funds and operational costs. Fishermen would need to be able to accumulate wealth to be able to invest in and operate improved harvesting technology. The government also needs to consider establishing a system for technology transfer and capacity building, for fishers to acquire the necessary knowledge and skills needed to operate new technology. In this case, building on and respecting traditional culture, creating a good buy-in from existing actors will facilitate the sector’s transition especially through incentives mechanisms such as low interest microloan and capacity building. It would be particularly important to train the small-scale boat owners on technical and business management aspects of their fishing enterprises, as fishing becomes more market driven (Severin 2012).

3.4 PAPER IV: NaFAA 09.15.2021

Title: A Critical Review of the Liberian Fisheries Sector: Technical Report

Author: A. S. Jueseah[5]

Editors/Reviewers: O. Knutsson, T. Tómasson and D.M. Kristofersson

Published: September 15, 2021

The aim of paper IV was to critically review the development of the Liberian fisheries and evaluate the performance of the sector based on the existing fisheries policies. Key national development policy documents such as the Pro-poor Agenda for Prosperity and Development (PAPD), (Republic of Liberia 2018) and the current Fisheries and Aquaculture Policy and Strategies (FAPS) (Ministry of Agriculture 2014) are reviewed. This paper gives a background of the Liberian fishing industry, presenting the key fish stock complexes and catches, the fleets' development, the status of stocks, the fishery value chain, and the governance of the fisheries sector. This is followed by an illustration of a conceptual model of the costs and benefits of fisheries management. The conceptual model is then used to evaluate management options of the different fleets (fisheries). The performance of the PAPD and FAPS are reviewed. The PAPD goals are reviewed first ensued by the vision for the fishing industry. The goal and prime objectives of the FAPS for sustainable use of the Liberian fisheries resources are reviewed. This is followed by the review of progress made since the implementation of these policies in 2014.

Fisheries catch and effort data prior to and during the civil war (1989- 2003) are largely unreliable, although in recent years fisheries statistics have improved. Summary of survey results and analyses, particularly the Soviet sponsored demersal survey in 1983, indicates substantial stocks of deep-water demersals which supports the notion that the fleet may not be equipped to harvest these resources efficiently. This, however, needs further research.

The coastal shrimp also represent a valuable resource that is possibly underutilized in Liberia. Maximum economic yield for the coastal shrimp resources was in the 1970s estimated at 800 t for 14 vessels, valued at US$ 5.7 million (Shotton 1983). The landed value today for 800 t of shrimp at US$ 10,200 ton^{-1} would be about US$ 8.2 million. The actual abundance and value of the coastal shrimp resources today is practically unknown. There has been an interest in exploiting the shrimp fishery and NaFAA has licensed three

[5] The doctoral student (Alvin Slewion Jueseah) role in paper IV was to carry out all research activities relating to critically reviewing the evolution of the Liberian fishing industry and evaluate the performance of the sector based on current policies and writing the technical report. The reviewers supervised the doctoral student, during the review, writing and editing of the technical report.

industrial shrimpers to explore the shrimp stocks inside the 6 IEZ but beyond 4 nm.

The small-scale Kru and Fanti fleets suffered dramatically from the foreign trawlers' presence near shore. The 6 nm IEZ was introduced in 2010 during the World Bank financed WARFP, and this was crucial because the IUU from foreign industrial trawlers had been rampant and destructive. The 6 nm IEZ covers a large part of the continental shelf, and the number of foreign trawlers has been significantly reduced and today there are only 6 trawlers licensed to fish in the coastal fisheries (Arnason and MRAG 2016; World Bank 2017). This has favoured the local SSF sector in terms of food security and livelihoods.

With the restriction, the government received much more revenue from around US$400,000 in 2011 to around US$6.22 million in 2011 from license fee and fines compared to pre-restriction when the trawlers fished in the Liberian water illegally inside 3 nm (Minsitry of Agriculture 2014; Braimah 2012; World Bank 2017). The fine increased at the beginning when MCS was trengthened with the introuction of VMS, but later there was a transition of revenues from high proportion of fines to high proportion of license fees (World Bank 2017) as improved management paved the way for the EU to sign a SFPA with Liberia, which brought both revenue and sectoral financial support[6].

In 2017, the EU issued a yellow card because of Liberia's lack of effort to combat IUU fishing, leading to a suspension of the SFPA, resulting in loss of revenues and support from the EU (Jueseah 2021). There is a need for Liberia to identify the issues leading to the suspension of the SFPA and resolve them if she intends to maximize resource rents of the tuna stocks in its EEZ. The government of Liberia has not shown enough progress nor political will to correct the IUU situation in the last 4-5 years. Therefore, fisheries governance is still an important issue to improve the sector's performance especially in the offshore industrial fishery subsector.

It may be difficult to implement an economically efficient management for the SSF, where in the foreseeable future the cost of management may be greater than the benefits. This may be the reason why SSF in general seem to be unmanageable, and this phenomenon seems to manifest itself in the Liberian SSF. Total artisanal fishing effort in West Africa between 1950-2010 increased by 10-fold compared to a declined in industrial fishing effort since the 1990s (Figure 8) (Belhabib et al, 2018) and supports Jueseah et al (2021) observation in Liberia's SSF. This partly points to lack of management due to the nature of SSF in west Africa and partly because SSF might not be manageable economically.

[6] *Sustainable Fisheries Partnership Agreement - between the european union and the republic of liberia (europa.eu). Accessed 02.23.2022.

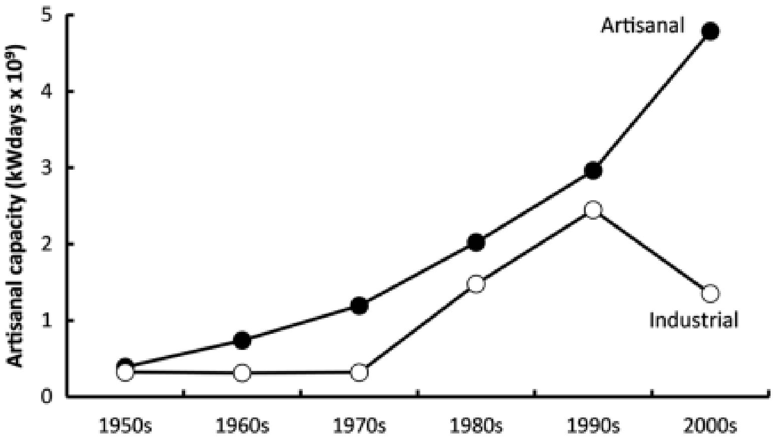

Figure 8: Total fishing effort in kWdays/year for the West African marine small-scale and industrial sectors in averages per decade.
Source: Belhabib et al (2018).

Incremental developments in SSF are, therefore, not likely to produce long-term net benefits for the society, because of the open access nature of SSF, which makes it quite diffcicult if not impossible to implement economically efficient fisheries management. This suggests all costs and benefits of management of each fleet should be evaluated before a decision to manage is taken.

The report, therefore, concludes that the best way to manage the coastal fishery resources in Liberia is to consider the option of phasing out the Kru canoes. The first step could be to stop issuing new fishing. If the Kru canoes can be phased out, the government should explore the feasibility of introducing new harvesting technology like FRP vessels to both increase productivity and profitability in the Liberian fishing industry.

The crucial role of SSF sector in terms of food security and poverty alleviation in Liberia and elsewhere have been well documented (FAO 2005; Béné et al, 2010; World Bank 2017). If an economic evaluation establishes that the costs to society for phasing out the primitive harvesting technology from the SSF subsector is greater than the expected benefits, an alternative management policy such as right-based fishery management should be explored. With technological development, the monitoring cost are becoming less expensive (Yahn 2020). Liberia has, for instance, piloted Automatic Identification System (AIS) on SSF boats which is far less expensive than the industrial Vessel Monitoring System (Yahn 2020; Tassetti et al, 2022). This is another option that Liberia could explore to effectively manage the SSF.

Progress is noted in most of the PAPD and FAPS policy areas (Ministry of Agriculture 2014, Republic of Liberia 2018). Despite this, analyses have shown that there is a lot more to be done to improve the performance of the fishing industry (Jueseah et al, 2020; Jueseah et al, 2020; Jueseah et al, 2021). Five main recommendations emerged from the review:

1. **Manage the SSF by restricting new entries and meanwhile piloting improving the current fleet:**

   While it has been shown that substantial benefits could be derived from reducing the number of Kru canoes in Liberia, managing small-size primitive vessels has proven very challenging in Africa. Community based fisheries management has been established in a number of small-scale fisheries in Africa but there has been limited evidence of success (Chuenpagdee and Jentoft 2007; Etiegni et al, 2017). Classic approaches to fisheries management would require extensive changes to the livelihoods of a large number of people and may not be worth the cost to society. Still, steps need to be taken to reduce the negatve impacts of unmanaged fisheries. Small steps might make a difference. For instance, stopping the issuing of new fishing licenses to Kru canoes. Also, limiting further the already unprofitable industrial fishery and gradually replacing it with manageable semi-industrial domestic fleet should be explored. This will however take time as neither such a fleet nor the competence to run it currently exist in Liberia. In the long run this might support a developmet that would increase productivity and profitability in the Liberian fishing industry. The introduction of such a class of vessels might help to address the current technical regress in the fishing industry and utilize the coastal fishery resources, better in Liberia. Such transition, however, would require removing several socio-economic and emotional barriers and will therefore take time. The government can support such development by improving vocational training for fishermen, look for partnerships with industry to develop solutions and encorage domestic investment in the fishing industry. It is important that any steps to start such a development take into account the socio-economic importance of the SSF. There should, therefore, be an economic evaluation of any option to change the current system.

2. **Establish basic fisheries infrastructure to improve value-addition and reduce waste:**

   The absence of basic fisheries infrastructure such as fish handling and processing areas, storage facilities for processed products, ice and chill storage facilities, potable water supply among others, contributes to the poor handling of the landed catch in the SSF value chain. Interventions such as provision of basic fisheries infrastructure might help address issue related to poor handling of the catch both onboard and ashore and improve value-addition services, market chains and distribution in the SSF value chain. This seems to be a possible way to go in terms of improving the sector performance. The government should look into establishing critical fisheries infrastructure such as ice and chill facilities, suitable sanitary facilities, and provide hands-on training, to enhance value-addition services in the SSF value chain. Such measures have proven successful in similar fisheries elsewere in Africa. The initial funding for this type of intervention could be sourced from the government's development partners such as the World Bank and the EU. Currently the World Bank has a programme of investing US$ 40 million in the Liberian fisheries sector. In the long run, however, private operators would have to take over management of the facilities.

3. **Establish access to financial services**
   Lack of transparency in the SSF value chain has resulted in captive or hierarchy relationships, and lower price and benefits for fishermen than if they were in a market relationship with the middlemen. In order to tackle the lack of transparency in the value chain, government could create access to financial services for the SSF subsector such as less demanding and restrictive microloans as an alternative source of finance and increase access to information in the value chain from end-markets to the fishermen. The establishment of a single fish selling desk that represents the interests of the fishermen might address the current lack of information. Access to financial services might also give the fishermen access to the necessary investment finance to purchase improved harvesting technologies which are needed in the fisheries to increase efficiency and profitability.

4. **Manage the coastal and offshore industrial fleet by improving fisheries governance:**
   Monitoring as well as ensuring transparency is a priority, considering past IUU history of the coastal industrial trawlers and the current state of the fisheries, increased fisheries regulations in terms of areas, species, fishing gear deployment, and mesh size. Trawlers are in general destructive, although the impact depends on local conditions. EU in 2017 issued Liberia a yellow card because of the lack of effort on the part of Liberia to combat IUU fishing. The yellow card has made Liberia lose the SFPA with the EU (Jueseah et al, 2021). This is a major warning sign and indicates the lack of governance overall and the need to identify the main issues and resolve them. The government of Liberia has not shown enough progress or political will to correct the IUU situation in the last 4-5 years. Fisheries governance, therefore, is still an important issue to improve the sector's performance especially in the offshore industrial fishery subsector. Lifting of the yellow

card would allow the EU to renew the SFPA which would increase Liberia's benefits from its tuna resources.

5. **Explore the availability of coastal shrimp and deep-water demersal stocks:**

   Indications exist that the coastal shrimp resources and the deep water demersals may be larger than previous analyses have indicated. The government has already issued licences for exploratory fishing of shrimp and should consider doing the same for the deep water demersals.

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PART II OF THESIS (PAPERS)

Paper I

Paper I

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Seasonal flows of economic benefits in small-scale fisheries in Liberia: A value chain analysis

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ABSTRACT

Artisanal fisheries employ small simple craft making fishers, processors and traders vulnerable to seasonal fluctuations. This study examines effects of seasonality on supply, trading relationships and benefits distribution in two small-scale fisheries in Liberia. Quantities of seafood traded in the dry season were 6 times higher than during the rainy season. Analysis of organizational structures and marketing channels of value chains; and the differences in net benefits of actors, show that market relationships promoted competition among buyers compared to captive relationships. The difference in net benefits between fishers and traders was significant but fishers net incomes were significantly reduced during the rainy season relative to fish traders. We identify key areas of possible policy interventions, such as improving quality and infrastructure, tackling power asymmetries and promoting increased competition among middlemen.

1. Introduction

Seafood is a highly traded product and seafood trade has shaped the livelihoods of millions of people [15,19,30,56]. Seasonal fluctuations in landings lead to an intermittent reduction in fish supply, benefits and related trade [26]. Understanding the impact of seasonality is essential, as the number of people involved in processing and marketing continues to grow [15,26,61].

In most cases prices of raw materials are decided by producers at the harvesting end of value chains [15,54,57]. This is expected to influence how net return among actors and between fishing seasons are distributed along the value chains [57]. Fishers typically derive a relatively low share of the overall benefits flowing from seafood trade compared to actors downstream the value chain [17,48,57].

Different types of customers [58], forms of transactions or governance (patron-client relationships) [2,4,13,20,29,35,36] and gender [21] have been found to affect benefit flow in small-scale fisheries (SSF) [17]. The effects of seasonality in seafood supply on trading relationships and distribution of benefits of SSF producers, is neither well understood nor documented. Earlier analyses investigating differences in prices of seafood products and benefits along the value chains have often neglected seasonal fluctuations in fish supply. This could partly be because SSF value chains can be complex and difficult to examine methodically [9,6,39,52].

This paper investigates seasonal flows and distribution of net benefits and relationships between actors in two SSF in Liberia; the Kru and the Fanti fisheries. To understand the characteristics of the small-scale seafood market, the following research questions are put forward. What is the value-adding role of the main actors in the value chains and how are their benefits impacted by the relationships among them and the seasonal changes in fish supply? What are the organizational structures and marketing channels of the value chains and the differences in average net benefits of actors at each node of the value chains during the dry and rainy seasons? The paper is divided into four parts. A description of the fisheries in Liberia is followed by a description of methods, results, discussion and conclusions.

1.1. Fisheries in Liberia

Libera has a coastline of 579 km and an exclusive economic zone of 246,152 km^2 harboring valuable demersal and pelagic fisheries resources, which in turn are a source of food and livelihoods for many Liberians and an important source of government revenue [44]. The fisheries resources are exploited by Industrial fisheries and SSF

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deploying multiple types of fishing craft and gear [40,42]. The estimated total coastal catch in 2014 was about 30,000 metric tons, about 86% produced by the SSF [40]. The catch is mainly consumed locally, while shortages in fish supply are complemented through imports. The fisheries contribute about 10% to the GDP of Liberia [5].

Industrial fishery is any large-scale harvesting or associated activities using vessels with an engine capacity >100bhp and >90 ft [37]. The industrial fishery comprises coastal trawl- and offshore large pelagic fisheries [38,40]. In the coastal fishery trawlers deploy mid-water and bottom trawls mainly targeting the shallow-water demersal finfish and shrimp species [40]. This fishery accounts for about 14% of the total marine catch landed in Liberia and its catch is supplied to the domestic market, although a part is also exported [38,40].

The offshore large pelagic fishery consists of large vessels that employ purse seines, longlines and pole and line gears primarily targeting tuna and tuna-like species [38]. In 2011 government revenues from the industrial fishery subsector totalled US$ 400,000. This figure increased sharply to about US$ 6.0 million in 2013 [38]. This is most probably because of the fisheries management reforms and increased enforcement introduced by the Government of Liberia in 2010 [12].

The SSF employ canoes powered by sails and paddles and open boats <60 ft motorized with engine capacity not exceeding 40 hp, where the proprietor is directly involved in the daily operations of the business [37]. The SSF are estimated to provide livelihoods for nearly 33,000 full-time participants, around 33% of whom are fishermen [12,18,40]. While Liberian participation in the SSF is about 80%, the rest are foreigners mainly from Ghana, Togo, Senegal and the Ivory Coast. Among the Liberians, 60% are females [40].

Majority of the small-scale fishers operate 5–7 m long dug-out canoes, using mostly sails and paddles for propulsion [18]. These fishers are traditionally referred to as Kru because of the type of dugout canoe they operate but in practice they may be a mix of people comprising Kru, Vai, Bassa, Grebo and other tribes [40]. The most common gears are cast-nets, beach-seines, gill nets, long lines, hooks and lines, and traps [60]. While Kru fishermen mainly target the inshore demersal stock complexes, the *Pseudotolithus* species locally known as cassava fish is a major commercial target species accounting for about 20% of the overall catch produced in the SSF according to official statistics of the National Fisheries and Aquaculture Authority. In 2013 over 2500 Kru canoes operated from 114 landing sites along the coast (Table 1).

In addition, there are over 750 larger boats (Table 1), 10–15 m long and mostly powered by 15–40 horsepower outboard engines, traditionally called Fanti boats [12]. Most deploy ring nets and principally target small pelagic *Sardinella* species locally called bonny. Some however use set nets, drift nets and hook and line targeting shallow and deep-water demersals and some larger pelagic species [12,60]. About 60% of the total catch in the SSF comes from Fanti fishery [38].

Small-scale fish trading involves multiple actors and purchasing either for processing or for distribution and consumption [19,40]. The actors involved in fish trade are generally artisanal fish traders predominantly women (98%) or large-scale Korean traders. A small-scale fish trader is typically a woman who buys up to 150 kg, on average 70 kg, of fish at a time and goes on foot or uses public transport (such as taxi, tricycle or motorbike) to bring fish to her clients. A Korean trader typically purchases more than 300 kg day^{-1} of cassava fish from Kru fishers and uses privately organized vehicles (usually mini trucks filled with chillers), to transport the fish to Monrovia, before exporting.

Table 1
Locations of small-scale fisheries landing sites and the number of vessels and fishers in 2013.

Coastal county	No of landing sites	No. of Kru canoes	No. of Fanti boats	No. of fishers
Grand Cape Mount	7	222	57	1155
Bomi	2	39	26	161
Montserrado	7	453	213	2151
Margibi	6	72	44	339
Grand Bassa	22	549	187	2454
River Cess	13	247	55	637
Sinoe	24	385	90	985
Grand Kru	24	330	19	798
Maryland	9	234	66	771
Total	**114**	**2531**	**757**	**9451**

Source: MRAG [40].

Seasonality greatly affects small-scale fishing in Liberia [40]. During the dry season, October-April when the weather is good the sea is calm and fishing conditions are favorable; catches can be quite high. During this season, the intermittent advent of big shoals of small pelagic fish in inshore-waters can result in large harvests and considerable increase in downstream activities. Fish traders and processors neither have the capacity nor the means to purchase and process all the landed catch, resulting in increased levels of post-harvest losses [40]. During the rainy season, in May–October, periods of strong ocean currents, heavy storms and rainfall prevent small-scale fishers from going to sea. The small-scale Kru cassava fish and the Fanti bonny fisheries are the focus of this study.

2. Methods

Value chain analysis [55,59] is used to evaluate the organizational structure by describing the value-addition activities in two SSF in Liberia. The concept dates back to Porter 1985 [47] and has since evolved with others making significant contributions on value chain governance and institutions [4,22,23,29,35]. In value chain analysis, governance relates to the corporation and coordination between the participants (actors) facilitating the delivery of a product from primary production to final use and involves the power some key actors manage to exercise control over others through their bargaining power, to be able to allocate the value produced within the respective value chains [3,55]. Gereffi and associates [23] identified five types of governance structure in value chains, based on the complexity and knowledge necessary for transaction, codification and effective transmission of the information between the participants and current competence related to the necessity of transaction, namely market, modular, relational, captive and hierarchy.

Market value chains are characterized by a low level of power asymmetry between producers and consumers in which no single value chain actor has control over others. Buyers typically react to specifications of products in a market exchange established by the producers because information exchange is relatively good [23]. In hierarchy value chains, the highest level of control is concentrated in one lead producer that explicitly coordinates and controls the actors and is typified by vertical integration. Modular value chain mirrors a production arrangement interaction that can effectively adjust products specifications to consumers' needs [43]. Relational value chains incorporate price, specifications, reputation, trust and mutual reliance and direct information and contact between producers and consumers [43]. Captive value chains emerge when the producers' abilities are low, resulting in a greater level of involvement of the buyers on whom the producers become financially dependent. Gereffi and associates [23] governance framework reflects governance context in the small-scale Kru and Fanti fisheries value chains in Liberia. Their governance framework, which has been employed by researchers to analyze fisheries value chains [43,49], is adopted and used to identified types of relationships between actors in the Kru and Fanti fish value chains in Liberia.

To shed light on the distribution of net benefits flowing between fishers and traders, price analysis [6] is conducted using price and cost data from participants in each node of the respective value chains. Based on this, driving forces such as bargaining power and trading relationships, which influence inefficiencies in fishery value chains are identified. This is crucial for determining appropriate policy recommendations, for possible interventions of participants within the value chain itself and those outside it, typically government or non-governmental organizations (NGOs), to upgrade weaker nodes [6, 32].

2.1. Study sites

Primary empirical data and information were collected from boat owners (fishermen) and artisanal fish traders in November-December 2017 and May-June 2018 at three landing sites used by both Kru and Fanti, i.e. Robertsport, Point Four and Marshall beaches in Grand Cape Mount, Montserrado and Margibi counties (Fig. 1).

The selection of study areas was based on convenience [7,51]. In societies like Liberia where the road network is poor, it is difficult if not impossible to implement a more formal sampling method. Therefore, the landing sites were selected based on chance and accessibility. While the sites are samples of convenience, they are still representative of the small-scale Kru and Fanti fisheries in Liberia where fishers deploy their fishing craft and gear where artisanal fish traders and Korean wholesalers participate in seafood trade [40]. They represent a third of the nine coastal counties, with 18% of the 114 landing sites, 30% and 41% of the total number of Kru and Fanti boat operators respectively and 39% of the total number of fishers in the SSF in Liberia (Tab 1). Data were collected to identify the nature of the trading relationships and to assess the net benefits of the different actors in the respective fishery value chains examined.

2.2. Focus group discussions and survey

Data was collected through focus group discussions, personal interviews with actors including fishermen and fish traders and from key informants. Kru fishermen interviewed are local fishers who own and operate Kru type canoes and primarily target cassava fish, while a Fanti fisherman, owns and operates a Fanti type boat targeting bonny. Three focus group interviews were conducted, in November–December 2017 and January–February 2018.

Prior to the actual survey, official letters were written to the fishing communities by NaFAA informing them about the type of study, data to be collected, target respondents and researchers and study period. With support from the fishery authorities and local fishers' leadership, a list of possible interviewees for the focus groups, participating in both fisheries, was prepared before visiting the study sites. The list was prepared based on lists of members of the various fishers' groups, provided by their respective leaderships from which participants were selected for the group discussions. Following this, a systematic random sampling, where each kth participant was chosen from the lists for discussion, was employed [7].

Participants included Kru and Fanti fishermen, fishers' wives, processors, fishmongers, mini cold-room operators, representatives of local fishermen leadership and key informants. For comparison amongst interviewees and landing sites a focus group of 15 SSF actors was selected at each study site and discussions lasted for about 4 h. The open-ended structure of the questions allowed for a follow-up and conversation about initial responses.

Questions were designed to elicit information about the major types of fish products, marketing flows/links and size, actors and the importance and value of the trading relationships, value-adding roles of different actors, credit arrangements and type of repayment as well as seasonal differences in the respective value chains, using semi-structured open-ended questions. The day following the actual interview, notes recorded by hand and direct observations were typed in a Word document for analysis. This was used to check for key concepts pertinent to this analysis and trends in the literature. The information gathered was used to identify and describe the main components of the value chains, actors and their roles in value-adding, trading relationships between actors as well as drawbacks hindering the performance of the value chains.

Random sampling technique was used to choose subjects for the survey (personal interviews) [7]. The questionnaire consisted of structured questions on the details of daily operations and provided additional in-depth information on similar issues captured during the group interviews and quantitative data on prices and costs.

A total of 294 interviews were conducted; 150 in the dry season and 144 in the rainy season, representing 180 in the Kru cassava fish value chain, 60 fishermen and 120 fresh fish traders and processors and 114 in the Fanti bonny value chain including 60 fishermen and 54 processors. The fishermen and fish traders sampled, in the Kru and Fanti fisheries during the dry season, were different from those sampled during the rainy season although the methodology employed was the same. Prices of fish purchased and traded as well as mean quantity of fish sold on a typical day were collected from actors in each node of the value chain.

Korean wholesalers and local cold room operators were not willing to participate in personal interviews. So, in this present investigation, actors are restricted to fishermen (i.e. Kru and Fanti), fresh fish traders and fish processors, that directly purchase seafood from these fishermen and wholesalers[1] (middlemen) and trade at various locations-either to local consumers, hoteliers, eateries or other traders, in Monrovia and its hinterlands. Information was analyzed separately for the dry and rainy seasons.

In addition to the focus group discussion and personal interviews, three key informants were selected based on their specific roles and experience in the value chains examined. This was regarded necessary to overcome the lack of access to the Korean wholesalers and general lack of official data in Liberian fisheries.

Focus group interviews provided additional detail on the types of fish products traded, marketing links, quantities traded, the value-adding roles of the key actors and relationships among them as well as inefficiencies in the respective value chains examined. The qualitative information such as trading links, type of fish products traded, trading relationships and value-adding roles was used to map the marketing structures and trading relationships between actors in the respective fisheries. Data on quantities of fish sold, prices and costs from personal interviews provided information on markup and benefit distribution.

2.3. Net benefits

The net benefits of fishermen and fish traders and processors are defined as the average net difference between total revenues and total costs. The total revenue for the fishermen is a product of the ex-vessel price [50] or retail price (in the case of fish traders) and the quantity of fish sold, whereas the total cost is defined as the aggregate expenditure incurred. For the Kru and Fanti fishers, typical expenses included the costs of vessel, fishing gear, fishing license, labor (crew), outboard engine and fuel/gasoline (mostly Fanti), repair and maintenance, food and bait. For the fish traders, other costs consist of transport, labor, preservation and other inputs.

It proved difficult to obtain full cost estimates from the fishers and artisanal traders interviewed. This was partly because chain actors suspected the study was done on behalf of the national authorities to levy taxes, and partly because fishers do not maintain accurate records of their operations, which is typical in SSF [9,57]. Nevertheless, it is believed that the reported expenses, captured by this work, reflect the typical daily outlays of these value chain actors.

Average net benefits were converted to USD using the average annual exchange rates for 2018, the year the survey was conducted [11]. Non-parametric tests were used for hypothesis testing. The Kruskal-Wallis test was used to test for differences in net benefits

[1] These wholesalers serve are middlemen between the fishermen and end-consumers in external markets. We; therefore, in the paper use the term wholesalers and middlemen interchangeably.

Fig. 1. Map of the study areas. https://commons.wikimedia.org/wiki/Atlas_of_Liberia. Accessed April 12, 2019.fn2

between fishing seasons and actors within each fishery [24]. Mann-Whitney *U* test was performed for further examining differences between net benefits of individual groups [41]. Because of limited official statistics, it was difficult to assess total quantities of cassava fish and bonny traded at each value chain's node in both seasons. However, this analysis estimated these as shares based on the quantities reported by all respondents interviewed.

3. Results and discussion

This section presents analysis and discussion of cassava fish and bonny trade flows, nature of the trading relationships and net benefits of actors in both value chains.

3.1. Kru cassava fish value chain

The reported average daily catch (i.e. traded quantity) was 78 kg in

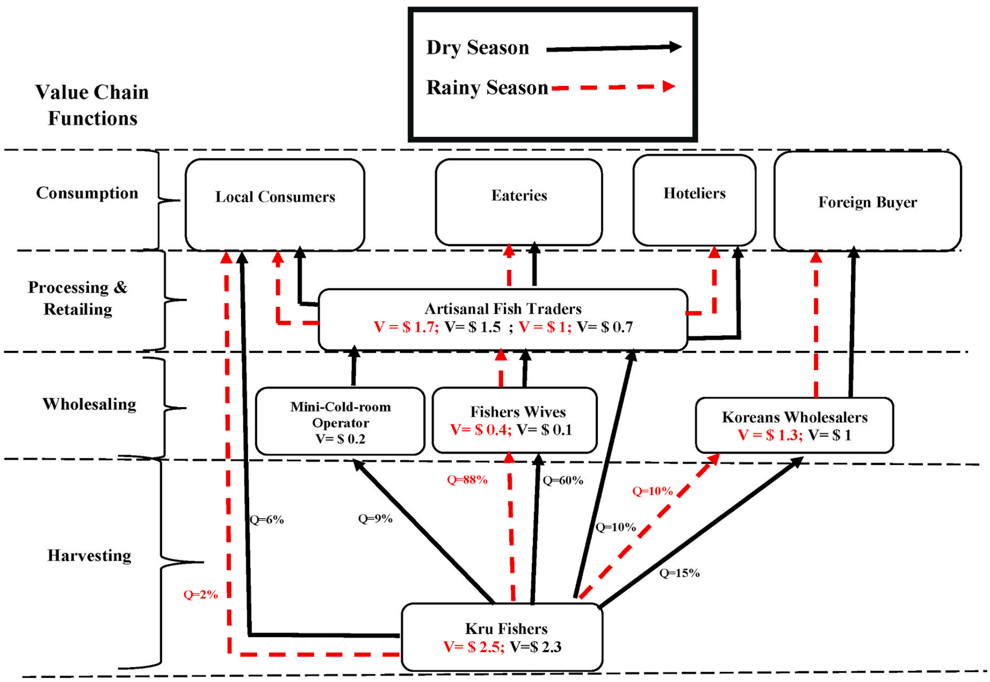

Fig. 2. Kru fishers value chain for shares (%) of cassava fish traded and value-added by each actor, based on responses from fishers and fish trader groups interviewed in the dry- and rainy seasons. Seasonal average value-added kg^{-1} "V" calculated for the different actors is based on the average prices received (Table 2).

the dry season and 32 kg, in the rainy season. Average monthly catch per vessel is estimated to be 1716 kg in the dry season and 288 kg in the rainy season, assuming fishers go out five days a week during the dry season and two days weekly during the rainy season. Average quantities traded in the dry season is nearly six times higher than in the rainy season. This refers to average quantities in a month assuming that this is mainly driven by the fact that the fishing effort in the rainy season is lower.

During the dry season the Kru fishermen sell their fish directly to their wives, Korean wholesalers, artisanal fish traders, mini cold store operators or individual consumers (Fig. 2). Due to limited supply mini cold store owners and artisanal fish traders do not buy during the rainy season (Fig. 2).

Wives buy around 60% of the total catch during the dry season and 88% during the rainy season (Fig. 2). Fishermen normally obtain informal credits from other sources primarily from their wives and other middlemen. Wives provide informal credits to buy fishing equipment such as canoes and nets or occasionally to pre-finance fishing trips. The fishermen in return repay with fish at a price typically up to 20% lower than the highest going price.

This suggests that fishers' wives are getting bargain prices in exchange for providing (through issuing informal credits) future access to gears and other operational expenses. At times, fishers' wives provide fishermen interest-free credits, pay school fees for the kids, food for the home, medication in cases of illness *etc.* Similar financial and non-refundable benefits have been reported for similar fisheries in other parts of the world [2,13,29].

Commercial banks typically require collateral, which is difficult for artisanal fishermen to provide. The lack of access to formal credit services makes participating in informal credit accords with their wives and the Koreans an appealing opportunity, according to fishermen. Crona and colleagues [13] also observed this in similar fisheries elsewhere.

Fishers conceded that "the interest-free credits provided by their wives are very important to them especially during the rainy season when due to adverse weather conditions they cannot go to sea". One fisher wife confirmed this assertion claiming "we are the men during the rainy season providing all the domestic needs for the family". Note that the intermittent operational expenses and interest-free loans provided to fishermen typically increase their debts but do not appear to alter the bargained price.

The nature of the relationship between the fishermen and their wives can be regarded as captive due to operational dependency or even hierarchical due to the family relationships. Wives pay US$ 2.4 kg^{-1} during the dry and US$ 2.6 kg^{-1} during the rainy seasons (Table 2).

If this relationship is regarded as a hierarchy-fishermen and wives can be seen to operate a vertically integrated fishing enterprise, they sell on average US$ 2.5 kg^{-1} which is essentially the same when artisanal fish traders buy directly from the fishermen. This raises questions about the value-adding role of fishermen wives and if it could be improved.

Therefore, it is somewhat difficult to clearly say whether the relationship between the fishermen and their wives is captive (middlemen) or hierarchy (i.e. part of the fishermen's enterprise) or both. This indicates the need for further research to shed more light on their relationships. If it is regarded as captive, this raises the issue of power and information asymmetries which are key obstacles in the value chain, otherwise it is difficult to say.

The second biggest buyers of cassava fish are the Korean wholesalers that buy around 15% of the total catch in the dry season and 10% during the rainy season (Table 2). According to key informants, Korean nationals who own and operate cold stores in Monrovia, commonly finance the purchase fishing canoes and gear, outboard engines and sometimes even provide operational expenses. In return, the fishermen repay the Koreans with cassava fish, usually up to 50% of a predetermined price that remains constant until the loan is paid up. The current bargained price is US$ 3 kg^{-1}. Due to this financial dependency between Korean wholesalers and fishermen the relationship is considered to be a captive one (Table 2).

However, it was difficult to estimate the actual value of the inputs supplied by the Koreans and the interest associated because fishers may not have access to fishing inputs at the same price as the Koreans who are well connected to the Asian market. This indicates a lack of transparency in the value chain. While informal credit agreements between fishers and middlemen are common in SSF, powerful middlemen typically exploit the vulnerability of fishers who are normally positioned in a low-income situation [20,48,52]. In some instances, though, small-scale fishers in rural and remote fishing communities prefer these kinds of informal credit arrangements [2,13,29]. This is partly because they offer security of critical fishing assets which include monetary and non-mandatory benefits that facilitate small-scale fishermen value chain functions [2,13,29] and partly because middlemen also provide connection to outside markets thus lowering the effort and time required by fishers to sell their fish [1,13]. Due to this financial dependency

Table 2
Kru cassava fish value chain quantity traded, average selling prices and relationships in the dry and rainy seasons.

Actors/Buyers	Dry Season			Rainy Season		
	Quantity Traded (%)	Ave. Selling Price (US $/kg)	Type of Relationships	Quantity Traded (%)	Ave. Selling Price (US $/kg)	Type of Relationships
Harvesting node						
Fishers wives	60	2.4	Captive & Hierarchy	88	2.6	Captive & Hierarchy
Korean wholesalers	15	1.5 (3.0)	Captive	10	1.5 (3.0)	Captive
Artisanal fish traders	10	2.5	Market	–	–	–
Mini cold-room operators	9	2.5	Market	–	–	–
Local consumers	6	2.8	Market	2	3.3	Market
Average		**2.3**			**2.5**	
Wholesaling node						
Fishers wives	–	2.5	Market	–	3	Market
Korean wholesalers	–	4	Market	–	4.3	Market
Mini cold-room operators	–	2.7	Market	–	–	–
Average		**3.1**			**3.7**	
Processing & Retailing node						
Local consumers (fresh fish)	–	3.3	Market	–	4.2	Market
Eateries (smoked fish)	–	5.2 (3.4)	Market	–	6 (3.7)	Market
Local consumers (smoked fish)	–	5 (3.1)	Market	–	5.5 (3.4)	Market
Eateries (fresh fish)	–	3.8	Market	–	4.5	Market
Hoteliers (fresh fish)	–	5.2	Market	–	5.4	Market

Authors' Note: 1 kg wet fish = 0.62 kg smoked fish. It was not possible to calculate weighted averages for wholesale and retail nodes due to the lack of official statistics. Average prices in parenthesis correspond to yield equivalent (see text).

between Korean wholesalers and fishermen, the relationship can be regarded as captive.

The third biggest buyers are the artisanal fish traders who buy around 10% directly from the fishermen during the dry season (Table 2). There is no dependency in this relationship, and it is based on demand and supply as evidenced by the fact that they do not buy directly from fishers during the rainy season when there is limited fish supply. The average price they pay is US$ 2.5 kg^{-1} (Table 2). The smallest buyers are the local consumers that approach the fishermen at the landing site to buy fish for their own consumption. The exchange is purely market-based as there is no dependency on either side. Around 6% of the total quantity is exchanged in this way. The weighted average price is US$ 2.3 kg^{-1} during the dry season and US$ 2.5 kg^{-1} during the rainy season (Table 2). While the weighted average prices for market relationships are US$ 2.6 kg^{-1} in the dry season and US$ 3.3 kg^{-1} in the rainy season, they are US$ 2.5 kg^{-1} and US$ 2.6 kg^{-1} for captive relationships assuming the Koreans pay US$ 3 kg^{-1} (Table 2).

In the next node of the value chains fishers' wives, usually without any value-addition service, wholesale their fish to artisanal traders through market sales. Mini cold-room operators, who are usually located at the landing sites, wash and preserve their fish in chillers before wholesaling to artisanal fish traders through market trade. The value-added generated by fishers' wives averaged around US$ 0.1 kg^{-1} in the dry- and US$ 0.4 kg^{-1} in the rainy season, whereas for the mini cold-room operators it was about US$ 0.2 kg^{-1} in the dry season (Fig. 2).

Domestic middlemen thus add value of US$ 0.2 kg^{-1} in the dry season and US$ 0.4 kg^{-1} in the rainy season for services such as washing, chilling to maintain freshness and transport. The value addition services performed by cold-room operators may explain the relatively higher average price kg^{-1} they receive compared to fishers' wives (Table 2). This suggests the role of Kru fishers' wives, in the dry season, is most likely related to assisting in fish sales for the family when supply is relatively high.

The average price received by domestic wholesalers was around US$ 2.6 kg^{-1} in the dry season and US$ 3 kg^{-1} in the rainy season (Table 2). Korean wholesalers, on the other hand, add the greatest value. They clean, sort and package the fish in plastic crates and store in chill boxes, before transporting to Monrovia for export, adding on average about US $ 1.0 kg^{-1} in the dry season and US$ 1.3 kg^{-1} in the rainy season, according to key informants (Fig. 2).

Artisanal fish traders wash the fish and preserve with ice (chillers) or sometimes no ice before transporting and retailing through market relationships to local consumers, eateries and hotels in Monrovia and other parts of Liberia. Fish processors remove scales, gut and cut the head off the fish and in the case of large fish, cut the fish into pieces before smoking and retailing (Fig. 2). This suggests retailers add value by performing services such as washing, icing, traditional smoking and transporting. Given that yield of smoked fish is around 62% [53], this indicates processors sell 38% less quantities. Although the study on yield from the Torry Research Laboratory [53] is rather old the yield is used for this study as there have not been any major changes in smoking technologies and product development since it was conducted.

Traders supplying hoteliers received the highest average price of nearly US$ 5.2 kg^{-1} in the dry season and US$ 5.4 kg^{-1} in the rainy season relative to those targeting other customers. Processors retailing smoked fish to eateries received average prices of around US$ 5.2 kg^{-1} and US$ 6 kg^{-1}, which when yield is considered correspond to US$ 3.4 kg^{-1} and US$ 3.7 kg^{-1} of fresh fish (Table 2). Hoteliers pay by far the highest price which is most probably linked to the quality of the fish they buy. This indicates that improved quality attracts higher prices in the value chains in both seasons. On average fresh fish retailers received around US$ 4.1 kg^{-1} in the dry season and US$ 4.7 kg^{-1} in the rainy season, while processors obtained around US$ 3.3 kg^{-1} and US$ 4 kg^{-1} for smoking. Value-added produced by fresh fish retailers averaged around US$ 1.5 kg^{-1} in the dry season and US$ 1.7 kg^{-1} in the rainy seasons, whereas processors added about US$ 0.7 kg^{-1} and US$ 0.6 kg^{-1} (Fig. 2).

The relatively low value produced by processors can most likely be attributed to the quality of fish they smoke and sell. Since cassava fish normally attracts better price when marketed fresh, retailers usually first attempt fresh sales and smoke what fish they cannot sell fresh. It would be worthwhile for the Government and NGOs to provide support, such as training in early decision-making regarding processing options and quality management, to the SSF subsector.

Kru fishers exchanged roughly 75% and 98% of the total traded quantities of cassava fish based on captive relationships in the dry- and rainy seasons (Table 3). In the rainy season, fishers usually sell directly to their wives who reap increased benefits from higher prices created by the excess fish demand (Fig. 2).

The prices fishers received did not differ noticeably between seasons and were primarily based on the type of customers and relationships, which has also been reported elsewhere [20]. While fishers realized on average roughly US$ 2.6 kg^{-1} in the dry season and US$ 3.3 kg^{-1} in the rainy season from market sales, they obtained about US$ 2.5 kg^{-1} and US$ 2.6 kg^{-1} from captive trades assuming the Koreans pay US$ 3 kg^{-1}.

Value-added services performed by middlemen were limited and indicative of low service value chains [14]. Because of the credits provided to Kru fishers and family connections, fishers' wives and Korean middlemen wielded higher control in the value chain which was reflected in their bargaining power. To address the challenges of financial dependencies and power asymmetries, the national government could implement policy to provide access to microloans to the small-scale fishermen to relieve them from transactional dependencies and increase benefits derived by fishers. Microloans might help to improve healthy competition, when there is an alternative source of finance rather than depending on traders in the value chains for finance, boats and equipment, and the value adding role of fishermen's wives as reported by Bjorndal and associates [6].

Hoteliers pay more than double the average price fishermen received, in both seasons. The difference in market prices paid by end-market buyers, is primarily based on freshness. There is a quality incentive in the market that fishers are not receiving perhaps because of the lack of information flow along the value chain.

Kru fishers earn significantly (p-value < 0.05) less benefits in the dry- and rainy seasons (US$ 584 and US$ 107 $month^{-1}$) than to artisanal fish traders (Fig. 3). Fresh fish traders made the most benefits (US$ 1458 and US$ 919 $month^{-1}$) followed by processors in both seasons. Other studies on SSF have found similar differences between fishermen and fish traders [17,33,45,48,57]. Fresh fish traders derived significantly higher benefits than processors who operated in similar node (p-value < 0.05), which was also observed by Wamukota et al. [57].

3.2. Fanti bonny value chain

The 30 fishers sampled reported daily traded quantities of 706 kg in the dry and 292 kg, in the rainy seasons. Because fishermen fish on average five and two days weekly in the dry and rainy seasons, this suggests average monthly quantities of 15,532 kg in the dry season and 2,628 kg in the rainy season. In the rainy season small pelagics are not typically found in inshore waters in Liberia, and Fanti fishermen are less active [40]. During the dry season Fanti fishermen market their bonny, directly to their wives, artisanal fish traders and local consumers (Fig. 4). Because of reduced supply, fishers sell only to their wives and local consumers during the rainy season.

Wives purchase roughly 85% and 90% of the total quantities traded during the dry and rainy seasons (Table 3). They smoke the bonny and sell on to artisanal fish traders through market interactions. Wives also offer similar informal credits, as observed in the Kru value chain. Fishers in return repay with fish at up to 10% lower than the maximum price at the landing sites. The business relationship between the fishermen and their wives is the same as described for the Kru. The wives pay on average US$ 1.1 kg^{-1} during the dry season and US$ 1.3 kg^{-1} during the

Table 3
Fanti bonny value chain quantity traded, average selling prices and relationships in the dry and rainy seasons.

Buyers	Dry Season			Rainy Season		
	Quantity Traded (%)	Ave. Selling Price (US $/kg)	Type of Relationships	Quantity Traded (%)	Ave. Selling Price (US $/kg)	Type of Relationships
Harvesting node						
Fishers wives	85	1.1	Captive & Hierarchy	90	1.3	Captive & Hierarchy
Artisanal fish traders	10	1	Market	–	–	–
Local consumers	5	1.2	Market	10	1.4	Market
Weighted Average		**1.1**			**1.3**	
Wholesaling node						
Fishers wives	–	2 (1.4)	Market	–	2.5(1.7)	Market
Processing & Retailing node						
Local consumers	–	2.3(1.5)	Market	–	2.8 (1.9)	Market
Eateries	–	2.6 (1.7)	Market	–	2.9 (1.9)	Market
Average		**2.5 (1.7)**			**2.9 (1.9)**	

Authors', note 3 kg fresh bonny produce 2 kg of smoked fish. It was not possible to calculate weighted averages for wholesale and retail nodes due to the lack of official statistics. Average prices in parenthesis correspond to yield equivalent (see text).

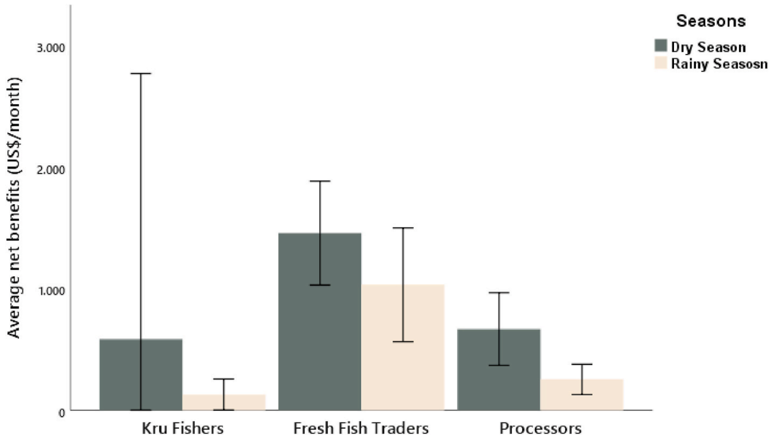

Fig. 3. Net benefits month^{-1} of Kru fishermen and fish traders in the dry and rainy seasons. Bars indicate two standard errors.

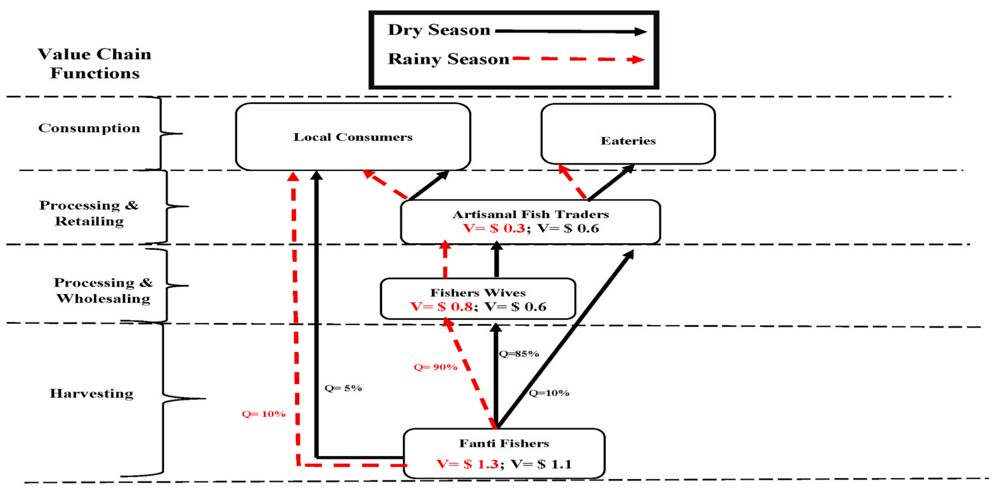

Fig. 4. Fanti fishers value chain for shares (%) of bonny quantity traded and value-added by each actor, based on responses from fishers and fish trader groups interviewed in the dry and rainy seasons. Seasonal average value-added kg^{-1} "V" calculated for the different actors is based on the average prices received (Table 3).

rainy season (Table 3) and they are the sole middlemen wholesaling bonny in both seasons, which indicates a complete lack of competition. The features of the credit arrangements in the Kru and Fanti fisheries are comparable to those described for similar SSF elsewhere [2,13,29,36].

Artisanal fish traders are the second most important buyers who purchase directly from the fishermen about 10% of the total quantity traded during the dry season but nothing directly during the rainy season. There appears to be no operational reliance in this bond, and it is based on supply and demand and thus a market relationship. They pay on average around US$ 1 kg^{-1} of bonny, during the dry season (Table 3). The relatively low price paid by artisanal fish traders in market transactions during the dry season can be attributed to market gluts, when fishers typically sell to anyone at any price to obtain some value from their catch [40]. This is because their wives do not have the capacity to smoke the whole catch. Local consumers, who purchase bonny from the fishermen, are the smallest customers (Fig. 4). The trade is market-based. About 2% and 10% of the total quantities traded are sold in this way, in the dry- and rainy seasons (Table 3). They pay average prices of US$ 1.2 kg^{-1} and US$ 1.4 kg^{-1} during the dry- and rainy seasons.

In the subsequent node of the value chain, fishers' wives wash and smoke the bonny and wholesale to artisanal fish traders (Table 3). There seems to be no transactional dependency in this trade, which is based on market relationships. Because yield of smoked bonny is roughly 67% [53] of its wet weight, it is assumed that bonny wholesalers exchange 33% less quantities. Average prices received by bonny wholesalers were around US$ 2 kg^{-1} in the dry season and US$ 2.5 kg^{-1} in the rainy season (Table 3) corresponding to US$ 1.4 kg^{-1} in the dry season and US $ 1.7 kg^{-1} in the rainy season kg^{-1} for fresh fish . The value-added produced by bonny wholesalers averaged around US$ 0.6 kg^{-1} in the dry season and US$ 0.8 kg^{-1} in the rainy season (Fig. 4). Bonny wholesalers generate higher value in comparison to the cassava fish domestic wholesalers. The lack of competition in the wholesaling node and the value-added by smoking may explain the higher value added by bonny middlemen.

Artisanal fish traders normally transport and retail their products to local consumers and eateries in Monrovia and other places in Liberia (Fig. 4). The exchange between the parties is market-based, because there is no transactional reliance and it depends on demand for and supply of fish. Retailers targeting eateries received better average prices of roughly US$ 2.6 kg^{-1} in the dry season and 2.9 kg^{-1} in the rainy season compared to those aiming for local consumers who receive on average US$ 2.3 kg^{-1} and US$ 2.8 kg^{-1}. The average prices received by retailers were roughly US$ 1.7 kg^{-1} in the dry season and US$ 2 kg^{-1} in the rainy season (Table 3). The value-added created by retailers averaged approximately US$ 0.6 kg^{-1} in the dry season and US$ 0.3 kg^{-1} in the rainy season. While the average mark-ups by bonny retailers were about 20% in the dry season and 12% in the rainy season, they were 55% and 62% for bonny middlemen indicating retailers added less value in both seasons.

Fanti fishers in the dry- and rainy seasons sold around 95% and 90% of the total quantities of bonny to their wives, while roughly 2% and 10% were sold through market interactions (Table 3). As observed in the Kru value chain, during the rainy season, when there is excess fish demand and prices are high, Fanti fishers typically sell to their wives to increase overall family benefits.

Prices received depended on the type of relationships and did not differ much. Fishers realized average prices of roughly US$ 1.2 kg^{-1} in the dry season and US$ 1.4 kg^{-1} in the rainy season from market arrangements, whereas they received around US$ 1.1 kg^{-1} and US$ 1.3 kg^{-1} from captive and hierarchy sales.

There seem to be indications that if Kru fishers were financially independent of middlemen informal credit arrangements and sold all cassava fish at market price (i.e. US$ 2.6 kg^{-1} in the dry and US$ 3.3 kg^{-1} in the rainy seasons), average monthly revenues could increase to $\leq$ US$ 4500 in the dry and US$ 950 in the rainy season for them compared to about US$ 4300 in the dry and US$ 750 in the rainy season from captive or hierarchy sales. This may be unlikely in rural and remote SSF. Captive or hierarchy relationships are apparently commonplace elsewhere [see, 2, 13, 29]. The Fantis (at US$1.1 kg^{-1} in the dry- and US $ 1.4 kg^{-1} in the rainy reasons) indicate average monthly revenues of $\leq$ US$ 17,085 and US$ 3700 compared to US$ 17,085 and US$ 3420 from captive or hierarchy sales in both seasons.

However, this does not take into full account the benefits that may be included in the informal credits agreements with the middlemen which according to fishermen and their financiers are quite substantial and essential for their daily operations. There are no indications that all fish produced by small-scale fishermen in both value chains could be sold at market price. There is a need to further assess the probable benefits small-scale fishermen in Liberia derive from the informal credits schemes with middlemen.

In this case, market sales appear to be economically beneficial for Kru fishers relative to captive or even hierarchy, whereas it represents $\leq$8% increase in monthly revenues for Fanti fishers during the rainy season.

As observed in the Kru value chain, the differences in price paid by end-market buyers are based on the type of smoked bonny. The price paid by eateries nearly doubles in both seasons, suggesting a market incentive for quality improvement.

In both seasons, Fanti fishermen realize on average significantly lower monthly net benefits (US$ 1940 and US$ 114 $month^{-1}$) relative to processors (US$ 2154 and US$ 540 $month^{-1}$) (p-value < 0.05) (Fig. 5). The current analysis of net benefits flows between fishers and traders in the bonny value chain follow similar pattern reported elsewhere [17,33, 45,48,57], as was also observed in the Kru chain.

4. Conclusion and policy recommendations

This study set out to understand the value-adding roles of the main actors in the Kru and the Fanti fish value chains and how their net benefits are impacted by the relationships among them and the seasonal variations in fish supply. Primarily the cassava fish value chain consists of Kru fishers, middlemen and retailers in both seasons. Middlemen were mainly engaged in the buying of cassava fish, cleaning and cooling it before wholesale, whereas retailers were involved in purchasing, processing and retailing in end-markets. There are fewer actors in the value chains associated with the Fanti boats, such as the bonny, compared to the Kru value chains.

Fishers' wives and Korean buyers occupy central roles as fishers' main financiers in the cassava fish value chain and therefore wield higher power and handle the major share of the total quantities traded in both seasons. This represents a captive or hierarchy relationship with Kru fishers and is caused by financial dependency between the parties.

Mini cold-room operators buy cassava fish from Kru fishers in an operation based on demand and supply. Mini cold-room operators and the Koreans increase value by washing, packing and chilling, whereas fishers' wives appear not to add any value to the fish. Retailers buy cassava fish through market relationship with Kru fishers, and add value by washing, chilling and smoking before selling to consumers.

Fishers wives and retailers were identified as the main actors in the Fanti value chain. These actors perform different roles in the Fanti value chain as compared to the Kru. The Fanti fishers are the main suppliers of bonny selling to middlemen, retailers and individual consumers in both seasons. Their wives were the sole middlemen and main sponsors exercising greater power in the bonny value chain in both seasons than in the cassava value chain. Wives handled major shares of the total quantities of bonny and bought through captive or even hierarchy relationships with Fanti fishers, as was also observed in the Kru. Bonny middlemen increased value more by smoking compared to Kru fishers' wives, who added little or no value. Bonny retailers purchased bonny based on demand and supply and increased value through smoking. The role of fishers' wives in the Kru value chain is somewhat unclear as they

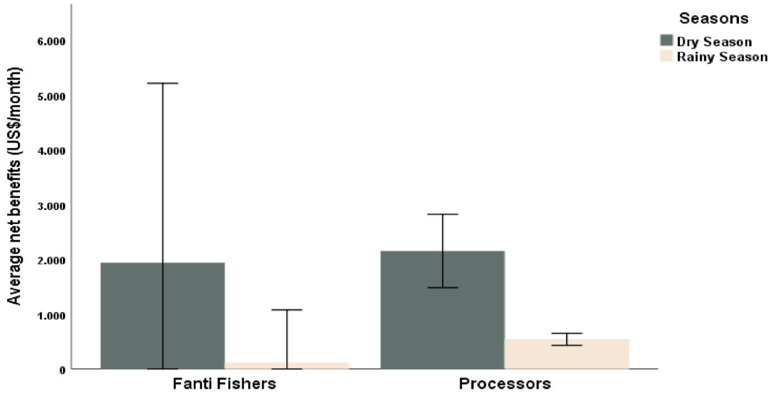

Fig. 5. Net monthly benefits of Fanti fishers and fish processors in the dy and rainy seasons. Bars indicate two standard error.

do not appear to add value. There is a need to better understand the involvement of fishermen's wives and how to improve their role in adding value to the catch.

Average mark-ups of Kru fish processors were 27% in the dry season and 33% in the rainy season in the Kru value chain, whereas they were 58% and 57% for fresh fish traders. This means, in both chains and seasons, bonny retailers generated the lowest value kg^{-1}, while most value was added by fresh fish retailers. The price kg^{-1} received by fishers, in both value chains examined, were based on the type of relationships and did not differ much. The average price kg^{-1} fishermen received between seasons in both value chains may be higher, if the full benefits of the informal agreements were considered.

Generally, market-based relationships encourage competition among buyers, offer better prices and appear to be more profitable for fishermen compared to captive or hierarchy relationships. There are indications that if all catches were to be sold at market price the average Kru fisherman's monthly revenues would increase by up to US$ 115 and US$ 186 during the dry- and rainy seasons and the Fanti fisherman's monthly earnings could increase by up to US$ 1630 and US$ 237 during the dry and rainy seasons compared to current revenues. There is no evidence that this scenario might occur because the informal credits accords with middlemen are invaluable to the small-scale fishermen in both value chains. Establishing a well-functioning market is difficult due to the nature of these fisheries and the existing infrastructure.

The quantities of fish traded in the dry season were roughly six times greater than the rainy season, assuming this is mainly driven by the fact that effort applied by fishermen in the rainy season is lower. The average prices of fish peak during the rainy season. Because of the reduced supply, fishers in both value chains mostly exchange through their wives, during the rainy season. Competition was weak or even lacking because of the bargaining power of fishers' financiers. Both value chains were typified by low value-addition services and poorly developed in comparison to high services seafood value chains in more affluent countries [31,46].

End-market prices indicate opportunities for interventions to increase returns of fishers. Marketing signals linked to quality were reflected in the average prices paid by hoteliers and eateries in both value chains and seasons. While more extensive market trade would be beneficial for fishers, financially dependent relationships and the lack of information generate obstacles for this to happen [20,48]. This means, although it is possible to enhance value for fishers in both seasons, power asymmetries and the information externality in both value chains would need to be tackled through policy interventions.

Kru fishers were not able to estimate the actual costs of the inputs supplied to them by the Koreans who are using their bargaining position to generate more profits by supplying fishermen with inputs on credit. This lack of transparency in the value chain makes it difficult to establish the real price fishermen receive. The same applies to the fishermen's wives that provide funding for the fisherman and pay lower prices than in market relationships. This raises questions about fishermen's access to other funds and puts pressure on the government to provide access to financial services to rescue small-scale fishers from predatory behavior of powerful traders.

Fanti fishers on average realize higher monthly net benefits in both seasons than Kru fishers but the net benefits are relatively higher in the dry rather than the rainy season. Whereas bonny retailers made the most monthly net benefits in the dry season, fresh fish retailers in the Kru value chain realized the greatest benefits in the rainy season. Fresh fish traders earned about US$ 874 more per month in the dry season and US$ 812 more per month during the rainy season than the Kru fishers, whereas processors realized US$ 84 monthly and US$ 148 monthly more. Bonny traders received around US$ 213 per month during the dry season and US$ 426 per month during the rainy more net benefits relative to Fanti fishers. Thus, in both value chains and seasons, fishers earn less benefits in comparison to traders. The net benefits of all actors in both value chains significantly decreased during the rainy season particularly for fishermen.

Given the results of this study, the following policy recommendations emerge. In order to raise fishers' benefits and increase overall efficiency in the value chains, we suggest that:

(i) basic fisheries infrastructures and trainings to improve quality and handling in the value chains should be provided; and
(ii) a microloan facility should be instituted, providing an alternative source of finance and thus increasing competition among middlemen. This might improve fishermen ability to sell their fish at market price in response to market signals.

For this to be possible, the government and or NGOs should provide support through establishing essential fisheries infrastructure such as ice and chill facilities, suitable sanitary facilities and hands-on training to improve quality handling and processing in the value chain. Ideally infrastructure should be established close to the landing sites, equipped and functioning, where fishermen and traders will have direct access to the facilities to add value to the fish. The government needs to provide less demanding and restrictive microloans to the SSF subsector as an alternative source of finance. While this would give fishermen access to the needed investment finance, it would also serve to break their financial dependencies on dominant middlemen and consolidate their ability to sell their fish at market price. If the relationship between the fishermen and their wives is regarded as hierarchy-single fishing enterprise, external microloans might be helpful in improving the handling of the catch i.e. fishers's wives could improve their value adding role which has implications for the price they receive. The value adding role of fishers' wives is unclear and limited.

Increasing competition among middlemen, enabling fishermen to sell 100% of the catch in both seasons at market price, is a policy option that could augment fishers' benefits. This has been observed as a strategy to rescue fishers from powerful traders who want to secure regular supply of fish [58]. However, for increased competition to result in higher market price for fishers, they must be organized as collectives to establish better bargaining position. Further analysis should be undertaken to quantify other economic benefits of the informal credit arrangements provided fishermen in the SSF before implementing this policy measure.

Fishers should be able to respond to quality signals from the high end of the market by taking portable ice containers onboard their canoes to maintain fish quality, which would then lead to a better price for them. Fishers can now sell their fish at market price, to increase their benefits, because they have other source of finance to operate. Cassava fish main middlemen, on the other hand, who before added no value to the fish would then increase value by performing services such as cleaning, icing or smoking before wholesale.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2020.104042.

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Paper II

Paper II

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A Bio-Economic Analysis of the Liberian Coastal Fisheries

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Abstract: Many coastal fisheries are subject to harvesting externalities due to inadequate regulations compounded by limited enforcement. Coastal fisheries in Liberia consist of a fleet of dugout canoes (Kru) primarily targeting demersal finfish, larger open wooden boats propelled with outboard engines targeting small inshore pelagics (Fanti), and a small number of industrial trawlers employing midwater and bottom trawls targeting finfish and shrimp. This paper develops a bio-economic model for the coastal fisheries in Liberia and employs the model to identify economic optimal fishing effort and harvesting trajectories for the different coastal fleets. The results show under harvesting and disinvestments in the coastal fisheries in Liberia. In 2010 the Government of Liberia declared a six nautical mile inshore exclusion zone accessible only to small-scale fisheries (SSF), which was accompanied by increased enforcement. The coastal fleets in 2016 were profitable but the distribution of profits was tilted to the small-scale fleets. The government needs to evaluate what policy options are available to fully utilize the fisheries potential for different species complexes while at the same time reduce the risk of conflict and overharvesting. There appears to be a need for investment in new technologies, which can only take place if fishing in Liberia will remain profitable.

Keywords: bio-economic modelling; coastal fisheries; SDG 14; profits; Liberia

1. Introduction

Liberia is among the poorest countries in the world and fisheries account for about 10% of GDP [1,2]. It has an exclusive economic zone (EEZ) of about 246.000 km^2 and a continental shelf that ranges in width from 16 to 56 km [3]. The fishery resources are currently exploited by offshore and coastal fleets [4]. Potential yield has been estimated at around 40.000 tons year^{-1} [3,4] but total catch between 2013–2016 averaged around 26,700 tons (Table 1).

Table 1. Summary statistics of fisheries data 2013–2016.

Stocks	Statistics	Kru Boats	Fanti Boats	Ind. Vessels	Standardized CPUE (ton boat^{-1} year^{-1})
Small pelagic (tons year^{-1})	Mean	1043.5	16,286.7	86.2	5.9
	Std Dev	451.7	2355.3	73.1	1.4
	Min	656.1	14,048.8	12.5	4.6
	Max	1626.5	19,142.7	166.1	7.3
Medium pelagic (tons year^{-1})	Mean	990.4	3501.7	2.5	1.4
	Std Dev	252.2	705.5	2.1	0.4
	Min	747.9	2568.4	0.4	0.9
	Max	1324.0	4162.7	4.8	1.8
Shallow-water demersal (tons year^{-1})	Mean	1842.1	390.7	129.8	0.6
	Std Dev	245.2	58.5	72.5	0.1
	Min	1518.5	350.9	22.5	0.5
	Max	2088.7	477.4	178.6	0.8
Deep-water demersal (tons year^{-1})	Mean	1055.2	85.4	159.1	0.4
	Std Dev	858.1	62.9	126.8	0.2
	Min	138.0	11.9	34.8	0.1
	Max	2178.0	165.2	313.5	0.6
Crustacean (tons year^{-1})	Mean	342.7	2.9	45.8	0.1
	Std Dev	70.8	2.3	50.8	0.0
	Min	277.6	0.5	5.0	0.1
	Max	425.0	6.0	116.0	0.1
Large pelagic (tons year^{-1})	Mean	353.1	389.4	7.2	- [1]
	Std Dev	198.1	118.7	12.6	-
	Min	184.5	238.8	0.1	-
	Max	640.0	528.3	26	-
Effort (no. of boats year^{-1})	Mean	2922	753	4	-
	Std Dev	283	78	2	-
	Min	2615	685	1	-
	Max	3163	827	7	-
Years observed		4	4	4	-

Source: NaFAA Statistics; [1] not included in the analysis.

While the coastal industrial fishery is subject to strict entry regulations and other management measures, the small-scale fisheries (SSF) are basically open access [5]. Open access fisheries have been reported to be generally characterized by problems of overexploitation and poor economic performance [6,7]. Only a few coastal nations have instituted proper fishery management systems to address this issue [6,7]. Although most commercial fishery resources have the potential to generate substantial profits, a relatively small number of fisheries are therefore profitable [7].

In this paper, a bio-economic model is developed and used to evaluate the fisheries and identify economically feasible fishing effort and harvesting trajectories for the main coastal fleets operating in Liberia. The main research questions are: What is the current state of the coastal fisheries and how could management of the resource be better aligned with the United Nations Sustainable Development Goal (SDG) 14 targets 14.4 and 14B? According to SDG 14.4 fishing should be effectively regulated and overfishing, illegal, unreported, and unregulated fishing, as well as destructive harvesting practices, brought to an end and science-based management plans implemented. SDG target 14.B refers to giving SSF fishers access to marine resource and markets [8]. The final research question is what are the economic outcomes of the coastal fleets?

Background

The offshore fishery in Liberia primarily consists of large industrial tuna vessels mainly from the EU which operate under fisheries partnership access agreement. They employ purse seines, longlines and pole and line. The catch, estimated at around 10,000 tons year^{-1} according to National Fisheries and Aquaculture Authority (NaFAA) statistics, is not landed in Liberia.

The coastal fisheries, which are the focus of this paper, are conducted on the continental shelf. The shelf is on average 36 km wide, narrower in the north between Monrovia and Robertsport with trawling grounds down to 800 m and wider in the south between Monrovia and the Ivory Coast [3]. The waters are stratified and warm (>24 °C) with low salinity levels (<35°/00) [3]. The coastal fisheries are affected by the seasonal oscillation of the thermocline and relatively low nutrients

Six exploitable species assemblages have been identified i.e., small, medium, and large pelagics, shallow- and deep-water demersals and crustaceans [4], which are targeted to a different extent by the small-scale and industrial fleets. SSF include the Kru—non-motorized dugout canoes generally 5–7 m long with 1–3 crewmembers—and the Fanti—larger open wooden boats 10–15 m long propelled by outboard engines with a crew of 6–26—who have exclusive access up to six nautical miles (nm) offshore but may fish further out as well. Kru operators use handlines and gillnets and target demersal species like cassava fish (*Pseudotolithus* spp.), butternose (*Galeodes decadactylus)*, solefish *(Cynoglossus spp*.) above the thermocline and groupers (*Epinephalus* spp.), snappers (*Lutjanus* spp.), and grunters (*Pomadasys* spp.) [9] below the thermocline. Operators of Kru canoes also target some crustaceans mainly crabs and lobsters, using gill nets and traps.

The Fantis boats are mainly operated by foreigners from Ghana [10] and they primarily use ring nets and target small pelagics like bonny (*Sardinella* spp.), porjoe (*Chloroscombrus chrysurus*), and Atlantic flying fish (*Cheilopogon melanurus*) [4]. Both Kru and Fanti also catch large and medium pelagics, as well as crustaceans, but to a much lesser extent.

The SSF provide livelihoods for around 10,800 full-time fishers and 22,100 local and foreign fish processors and traders [10,11]. Most of the catch is landed during the dry season, in October–April, when the weather is good the sea is calm and fishing conditions are favorable. During the rainy season, May–October, periods of strong ocean currents, heavy storms and rainfall limit the ability of the fleets to go out to sea [12].

The coastal industrial fishery comprises of trawlers that deploy mid-water and bottom trawls targeting the shallow- and deep-water demersal species as well as shrimps [12]. The vessels are owned by foreigners mainly from Europe (e.g., Spain, Greece, Russia.) and China, who operate through joint ventures with Liberian registered fishing agencies [12–14].

In the early 80 s, 14 coastal industrial trawlers operated in Liberia mainly targeting shrimps with an annual catch of 746 tons in 1980 [3,15]. During this period, the industrial shrimp fishery was profitable. Maximum economic profits of the 14 trawlers were estimated at around 5.7 million $ [15]. Due to the concentration of shrimps and demersal species in the inshore areas, the trawlers and small-scale fishers came into constant conflict, with the trawlers oftentimes destroying the fishing equipment of the small-scale fishers [15,16].

Shortly after the civil war ended in 2006, almost 40 industrial vessels were in the coastal waters. However, since 2008, there has been a sharp decline and today there are only two such vessels operating in Liberian waters. The coastal industrial fleet size, during the periods of the social unrest, more than doubled in the 1980s [15], a development that seems to be associated with a lack of effective governance. Between 2013 and 2016, there were on average four coastal licensed industrial vessels, averaging about 180 Gross Registered Tonnage (GRT). This decrease in the number of trawlers appears to be due to the establishment of an Inshore Exclusion Zone (IEZ). The catch, whole-fish and shrimp frozen onboard, is supplied to the domestic market, although a part is also exported [12,13].

In 2010, the Liberian Government initiated key fisheries management reforms, with funding from the World Bank West African Regional Fisheries Program [10,17]. A six nm IEZ was introduced to protect the SSF [5]. This was the initial step to control illegal coastal industrial vessels from operating in the inshore zone and allow the commercial fishery resources to rebuild [10,18]. To secure the IEZ, the Government of Liberia established a Fisheries Monitoring Center (FMC) to monitor and control industrial fishing activities. Since then there have been no new investments in this fishery, while there has been an expansion of the Kru fisheries which seems to be consistent with growth trend after the war ended (Figure 1).

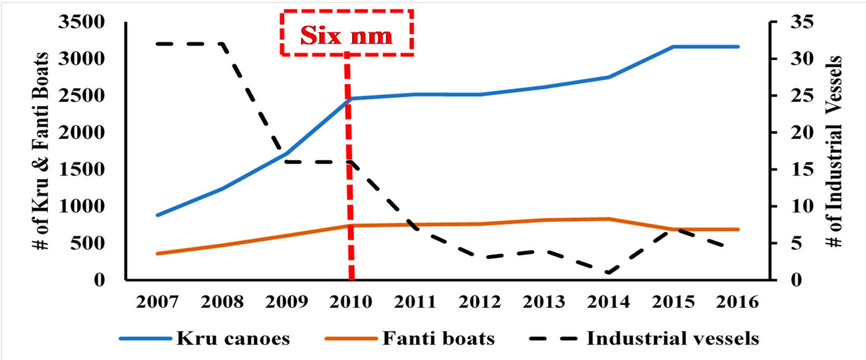

Figure 1. Liberian coastal fleets development trend. Source: National Fisheries and Aquaculture Authority.

2. Analytical Approach

An aggregative bio-economic model for different species assemblages, following the approach of Arnason [6] and World Bank [7], is used in this analysis. It is a discrete-time dynamic model that follows standard fisheries economic theory see [6,19–24]. The model encompasses three primary functions basic to any fisheries bio-economic model: the natural growth function $G(x)$, the harvest function $H(e, x)$, and the cost function $C(e)$ [6,7]. The basic functional relationships of the model are as follow:

$$\dot{x}_t = G(x_t) - h_t \text{ [Net biomass growth function]} \quad (1)$$

$$h_t = H(e_t, x_t) \text{ [Harvesting function]} \quad (2)$$

$$\pi_t = p_t \times H(e_t, x_t) - C(e_t) \text{ [Net benefits function]} \quad (3)$$

Equation (1) describes the instantaneous change in biomass as a function of natural growth $G(x_t)$ denoted by the derivative, $\dot{x} \equiv \partial x/\partial t$, and harvest, h. The instantaneous change in biomass, $\dot{x}$, is approximated in discrete time with $\dot{x} \equiv x(t+1) - x(t)$. Expression (2) describes harvest as a function of fishing effort, e, and stock size, x, while expression (3) defines the net benefits as a function of harvest, prices (p), and fishing costs, $C(e)$. Equilibrium in the model is characterized by stable biomass, $\dot{x} = 0$. Following Arnason [6] and World Bank [7] expressions (1) and (2) can be reduced to $G(x_t) = H(e_t, x_t)$ in equilibrium.

Empirical Model

Following Arnason [6] and World Bank [7], a quadratic functional form [25] is assumed for the biomass growth function, $G(x)$, in expression (1) and is given as:

$$G(x_t) = \alpha \times x_t - \beta \times {x_t}^2 \quad (4)$$

where α and β are parameters. The parameter α measures the intrinsic growth rate of the biomass. It is easy to verify that the biomass carrying capacity (X_{max}) is the ratio of α/β. In discrete-time, the change in biomass is approximated using the expression:

$$x_{t+1} - x_t = \alpha \times x_t - \beta \times {x_t}^2 \quad (5)$$

where the biomass at $t + 1$ less the biomass at time t less harvest is used to identify biomass growth. For the harvesting function, a generalization of a Schaefer harvest function [26] is assumed as:

$$h_t = \delta \times e_t \times {x_t}^{\mu} \tag{6}$$

where δ is the catchability coefficient and μ represents the schooling behaviour of the stock (usually $\mu \in [0,1]$) [6,7,21]. For the net benefit function, the following functional form is specified:

$$\pi_t = (1 - \gamma) \times (p_t \times \delta \times e_t \times {x_t}^{\mu}) - (a_t \times e_t + \mathrm{fc}_t) \tag{7}$$

where γ is the crew's share (or bonus) of the fishing revenues, p the unit ex-vessel price of the landings, a is the unit marginal variable cost of fishing effort and fc the fixed costs. Expressions (4)–(7) should be regarded as the empirical counterparts of the general model, expressions (1)–(3). It is, however, not possible to estimate the empirical model because detailed stock assessments are not available for the species assemblages described earlier.

In empirical fisheries bio-economic models, proxies such as catch per unit of effort (CPUE) can be used for stock size [27–29]. Following Zhang and Smith [29], we designate CPUE such that $y_t = h_t/e_t$. From expression (6) CPUE is proportional to the stock size-$x_t = y_t/\delta$. The conventional method substitutes this proxy, in expression (5), simplifies and adds an error term [29]. The result is an empirical version of expression (5), for estimating α, β and δ, using CPUE as an index of abundance and given as:

$$\Delta y_t = b + c \times y_t + d \times e_t + \varepsilon_t \tag{8}$$

where $b = \alpha$, $c = -(\beta/\delta) \leftrightarrow \beta = -(c \times \delta)$, $d = -\delta \leftrightarrow \delta = -d$ and ε_t is the error term. The error term is assumed to be independent and identically distributed (i.i.d) normal with zero mean and variance ${\sigma_\varepsilon}^2$ ($\varepsilon_t \sim$ i.i.d N (0, ${\sigma_\varepsilon}^2$)). Expression (8) is then estimated by regression analysis. The relative effort factor is obtained by the average catch of fleet i of species assemblage j at time t divided by the average catch of all fleets for species assemblage j at time t. of the relative effort factor of fleet i compared to a standardized vessel at time t was calculated as the mean of the average catch ratio (w = cpue) for the three fleets for each species assemblage j. The aggregate standardized fishing effort ${e_{jt}}^s$ of all fleets for species assemblage j is the sum of the product of the fishing power and fleet i at time t. These are respectively specified as

$$f_{ijt} = w_{ijt}/w_{sjt} \tag{9}$$

The aggregate standardized fishing effort ${e_{jt}}^s$ of all fleets for species assemblage j is the sum of the product of the fishing power and fleet i at time t as specify below

$${e_{jt}}^s = \sum\nolimits_I f_{ijt} \times e_{it} \tag{10}$$

And substituting ${e_{jt}}^s$ in expression (8) yields

$$\Delta y^s{}_{jt} = b_j + c_j \times y_{jt} + d_j \times ({e_{jt}}^s) + \varepsilon_{jt} \tag{11}$$

After estimating (11), using the available data, maximum sustainable yield (MSY), MSY biomass (X_{msy}) and X_{max} were calculated based on the expression (12) which were derived from expression (4).

$$MSY = \alpha^2/(4 \times \beta),\ X_{msy} = \alpha/(2 \times \beta),\ X_{max} = \alpha/\beta \tag{12}$$

3. Model Parameters Estimation

3.1. Data

The bio-economic model, defined by Equations (4)–(7), consists of unspecified biological and economic parameters that must be estimated to make the model operational. The biological parameters include α, β, δ, and μ in the biomass growth and harvesting functions. The economic parameters in the net benefits function are p, γ, a, and fc. The coastal fishery is studied for a certain base year (t^*). The base-year considered here is 2016 (i.e., t^* = 2016). The biological (catch and effort) and economic data used in this analysis were obtained from multiple sources. It was only in 2013 that fisheries data collection was made more systematic. Catch data from the SSF are based on a stratified sampling program [4], while the catch data for the coastal industrial fishery are collected and reported by fisheries observers.

3.1.1. Catch and Effort Data

Data on total landed volume (aggregated by species assemblage), fishing effort, for the period 2013–2016, available biomass estimates, and schooling coefficients were employed to make the model operational. The total catch and fishing effort year^{-1} were obtained from NaFAA used in the calculation of total standardized effort and CPUE (tons boat^{-1} year^{-1}) for the fleets (Table 1). These were used in the estimation of α, β, and δ in expression (11), which defines implicitly MSY, X_{msy} and X_{max}. The assumed base-year biomass estimates for small and medium pelagics, shallow- and deep-water demersals species assemblages were drawn from MRAG [4], while for the crustaceans it was estimated using average standardized CPUE divided by the estimated δ, for the data period. The schooling parameter estimates were obtained from Arnason and MRAG [30].

The number of Kru and Fanti boats in the coastal fishery, following the end of the civil conflict in 2006 and the Government's fisheries management reforms in 2010, has increased (Figure 1) but their harvesting technologies are mostly suboptimal. The efficiency of the coastal industrial vessels is linked to their GRT, although vary substantially with frequent breakdowns and irregular fishing trips.

3.1.2. Economic Data

An independent survey was conducted in 2017 to collect data on investment such as costs of vessels, outboard engines and fishing gear and operational costs including food, fuel, crew revenue sharing ratios, and maintenance and repairs. Data on marginal cost of fishing effort, e, fixed cost, fc, and average unit ex-vessel price, p, of the landed wet- and frozen whole-fish by species assemblages for the coastal fleets were collected in October–December 2017. A total of 15 Kru and 15 Fanti boat operators were randomly selected and interviewed at Robertsport beach in Grand Cape Mount, Point 4 beach in Montserrado and Marshall beach in Margibi counties. Cost adjustments were made, to reflect the replacement cost of fixed assets [31].

Industrial fishing agencies were sceptical of the study and generally unwilling to provide economic information. This study relied mostly on information provided by agents, for an industrial vessel of a local fishing firm, who are responsible for the daily operations of the industrial vessel.

The industrial fishery marginal costs information such as costs of fuel and lubricants, food and water, crew's salary, berthing fees and maintenance, other supplies, and the crew share (bonus) in the catch was provided by three key informants and corroborated with fisheries managers at NaFAA. Investment costs obtained included the cost of vessels, fishing gear, documentation and vessel insurance.

The capital value of the vessel incorporates the vessel and its components i.e., engine and equipment for navigation, communication, freezing and cooling on board the vessel. This work assumes the components of a complete set of trawl gear include wires, ropes, and twines, trawl net and otter boards (or solid beam).

The estimated value of vessels, are based on replacement cost and verified with vessels of similar technical specifications i.e., length overall, GRT and engine capacity [32]. The information was used to calculate annual total cost incurred by the coastal fleets in Liberia.

A random sample of 60 fish sales at the study sites mentioned above was collected to estimate average ex-vessel prices of landings by species assemblages and fleets in the 2016 base-year. The number of sales, weight (kg) and price of the landed fish by species assemblage were recorded. On this basis, the average ex-vessel price (US$ kg^{-1}) by species assemblage was calculated, for the Kru and Fanti boats (Table 2). Fish price information was also obtained from the key informants, for the industrial fishery and used to estimate ex-vessel price (US$ kg^{-1}), using a similar procedure (Table 2). A possible reason for the observed price differences (USkg^{-1}) between the SSF Kru and Fanti boats and the industrial vessels could be due to a different market focus.

Table 2. Summary statistics of ex-vessel prices of the landed wet- and frozen whole-fish for the Kru, Fanti boats and industrial vessels in 2016.

Species Assemblage	Statistics	Kru & Fanti Boats	Industrial Vessels
Small pelagic (US$ kg^{-1})	Mean	1.1	1.3
	Std Dev	0.2	0.4
	Min	0.9	0.8
	Max	1.6	1.9
Sample (n)		10	10
Medium pelagic (US$ kg^{-1})	Mean	2.3	3.5
	Std Dev	0.7	0.9
	Min	1.5	2.3
	Max	3.5	5.0
Sample (n)		15	15
Shallow-water demersal (US$ kg^{-1})	Mean	2.5	2.9
	Std Dev	0.9	0.1
	Min	1.2	2.6
	Max	4.0	3.0
Sample (n)		15	10
Deep-water demersal (US$ kg^{-1})	Mean	3.6	4.0
	Std Dev	1.6	0.3
	Min	2.0	3.3
	Max	7.2	4.0
Sample (n)		15	8
Crustacean (US$ kg^{-1})	Mean	4.0	10.2
	Std Dev	1.1	3.1
	Min	2.2	6.0
	Max	5.0	15.0
Sample (n)		10	8
Large pelagic (US$ kg^{-1})	Mean	1.5	1.7
	Std Dev	0.7	0.1
	Min	0.5	1.5
	Max	3.0	1.8
Sample (n)		10	5

Source: Survey.

3.2. Statistical Approach

3.2.1. Biological Parameters

Biomass growth functions were estimated for five species assemblages i.e., small and medium pelagics, shallow-and deep-water demersals and crustaceans. Biomass growth function was not estimated for the large pelagics because the management of these species is undertaken regionally by the International Commission for the Conservation of Atlantic Tunas [4,33]. Therefore, Liberia has no direct control over the stock.

The parameters α and β in Equation (4) for the five species assemblages were estimated using linear regression analysis of expression (11). The parameter δ, for the species assemblages, was calculated using the expression $\delta = h/e \times x^{\mu}$ derived from expression (6). Standardized CPUEs, biomasses and μ were used to calculate average δ values. The coefficient $d(\delta)$, in the regression analysis, was restricted to the calculated average values for the pelagic and demersal species assemblages following Warui [34], while for the crustaceans it was employed to calculate stock size. For all 5 species assemblages, the values of b and c were estimated. Following this, the explained variable $\Delta y^{s}{}_{jt}$ was regressed against the explanatory variables $y^{s}{}_{jt}$ and $e^{s}{}_{jt}$, using expression (11).

For the small and medium pelagics, about 56% and 87% of the variation in the residuals were explained by the models, while for the shallow- and deep-water demersals about 72% and 92% of the variation in the residuals were accounted for (Table 3). For the crustaceans, about 62% of the variation in the residuals was explained by the model. The p-values of the models for all five species assemblages modelled are at a > 0.05 level of significance (Table 3). This indicates there was not a statistically significant relationship between fishing effort and catch landed. It is important to note that the p-values are low because there are few degrees of freedom. The Shapiro-Wilk test coefficients and p-values, for all 5 species assemblages, indicate that the residuals are not significantly different from normal (Table 3). After estimating expression (11), α and β were calculated (Table 3).

A separate harvesting function per species assemblage and fleet was used. About 97% of the landed catches are generated from the small and medium pelagics, shallow- and deep-water demersals, and the crustacean species. For these species assemblages, fifteen harvesting functions were estimated, using expression (6).

The catchability coefficient, δ, for the fleets and fisheries, were calculated using expression $\hat{\delta}_1 = h/e \cdot x^{u}$ derived from expression (6) (Table 4). Note that fishing vessels do not have the same catchability coefficients, even those in the same category. Therefore, $\hat{\delta}_1$, which measures the change in the harvest with respect to a change in the vessel type i.e., $\partial h/\partial e = \hat{\delta}_1 \cdot x^{\mu}$, should be regarded as the catchability of a standardized Kru, Fanti or industrial vessel.

Table 3. Output of regression analysis on *b*, *c* and *d*, normality diagnostic tests and estimates of α and β.

	Coefficients								Estimates of Alpha & Beta	
Stock	***b***	***c***	***d***	**R^2**	***p*-Value**	**SE**	**Shapiro Wilk Test (w-Value)**	**Shapiro Wilk Test (*p*-Value)**	**Alpha (α)**	**Beta (β)**
Small pelagic	0.41	0.05	-9.2×10^{-5}	0.56	0.66	0.20	0.99	0.94	0.41	4.3×10^{-6}
Medium pelagic	0.46	0.24	-6.2×10^{-5}	0.87	0.36	0.11	0.86	0.26	0.46	1.5×10^{-5}
Shallow-water demersal	0.41	0.20	-5.2×10^{-5}	0.72	0.53	0.05	0.91	0.50	0.41	1.1×10^{-5}
Deep-water demersal	1.18	2.95	-1.2×10^{-4}	0.92	0.28	0.34	0.89	0.38	1.18	3.5×10^{-4}
Crustacean	1.66	13.55	-7.1×10^{-5}	0.62	0.61	0.23	0.82	0.15	1.66	9.6×10^{-4}

Source: Model, Note: *d* values for small and medium pelagics and shallow- and deep-water demersals are restricted to the calculated average estimates of δ, while estimated *d* is used for the crustacean.

Table 4. Estimates of catchability coefficients and schooling parameters for the coastal fleets in base-year.

Species Assemblage	Kru Canoe (1/Boat)	Fanti Boat (1/Boat)	Ind. Vessel (1/Boat)	Schooling Parameter
Small pelagic	5.5×10^{-6}	3.4×10^{-4}	1.54×10^{-4}	0.98
Medium pelagic	1.6×10^{-5}	1.7×10^{-4}	1.2×10^{-5}	0.98
Shallow-water demersal	6.0×10^{-5}	4.6×10^{-5}	3.2×10^{-3}	1.00
Deep-water demersals	2.3×10^{-5}	6.2×10^{-6}	7.04×10^{-3}	1.00
Crustacea	9.6×10^{-6}	5.3×10^{-7}	2.09×10^{-2}	1.00
Large pelagic	5.8×10^{-2} *	3.5×10^{-1} *	6.57 *	0.00

* = measured in unit ton/boat.

3.2.2. Economic Parameters

In the SSF, *fc* comprises capital cost including depreciation and interest payment on boat value and equipment, cost of boat, outboard engine and, gear, and license fees. For the industrial vessels, *fc* includes the capital cost comprised of depreciation and interest payment on the vessel value and gear, vessel, fishing gear, documentation, and vessel insurance. Variable costs are divided into variable costs related to fishing effort and those related to the harvest value i.e., crew share or bonus in the fishing revenues. The Kru boats fish on average 5–6 days week^{-1}, i.e., 20 days month^{-1}, 10 months year^{-1}, while the Fanti boats fish 20 days month^{-1} for 6 months year^{-1}. Kru canoes crew and canoes owners are reported to receive 50% of the value of harvest while 50% is reserved for the enterprise' property for operation and investment costs. For the Fanti, it is based on 40:60, i.e., 40% of the revenue is shared up between the boat's owner and crew and 60% for the enterprise' property.

Note that while globally crew's remuneration arrangements for most fisheries are based on shared remuneration systems (i.e., the fishing crew is paid a proportion of the fishing revenues or value of the landed catch or profits) [35–44], in the Liberian coastal industrial fishery the crew remuneration is time-based, i.e., fixed monthly salary and a bonus, usually paid through the captain and ranges between 5–10% of the value of landings. In this study crew's bonus was estimated to be 8%. Industrial vessels on average attempt two 10 days fishing trips month^{-1} for 11 months of the year, and a month for major repairs. The average ex-vessel prices (US\$ kg^{-1}), for the wet whole-fish landed by the small-scale fleets and the frozen whole-fish landed by the industrial fleet, were used as unit price estimates (Table 2). The total annual cost parameters estimates and crew sharing ratios, for the coastal fleets, are listed in Table 5).

Table 5. Cost parameter estimates in 2016 base-year.

Fleet	Crew Share (γ %)	Variable Cost (vc boat^{-1} yr^{-1}) (US\$ 1000 boat^{-1})	Fixed Cost (fc boat^{-1} yr^{-1}) (US\$ 1000 boat^{-1})	Total Cost (boat^{-1} yr^{-1}) (US\$ 1000 boat^{-1})
Kru canoe	50%	0.60	0.88	1.48
Fanti boat	40%	2.65	10.64	13.29
Industrial vessel	8% *	143.93	329.25	473.18

Source: Survey, * = bonus of industrial vessels crew.

4. Results and Discussion

4.1. State of the Coastal Fishery

Aggregate MSY in the Liberian coastal waters is estimated to be roughly 18,700 tons year^{-1} (Table 6). The shallow-water demersals appear to be overexploited, while biomass estimates for other species assemblages are well above Xmsy levels. MSY estimate for crustacean is now 7100 tons, only'44% of the estimated MSY of 1600 tons in 1983 [15]. It should be noted that the estimate in 1983 was based on industrial shrimp fishery, but today most of the crustacean catch is by the Kru who primarily catch shallow water crabs and lobsters. Only a minor portion of crustacean caught in recent years are shrimp. It can thus be assumed that there is a considerable potential to increase shrimp catches.

Table 6. Stock estimates at the end of 2016.

Species Assemblage	MSY (1000 t)	Xmsy (1000 t)	Xmax (1000 t)	Stock (1000 t)	Stock/Xmax	Stock/Xmsy
Small pelagic	9.52	46.95	93.90	68.83	0.7	1.5
Medium pelagic	3.56	15.41	30.82	25.75	0.8	1.7
Shallow-water demersal	3.91	19.16	38.32	12.87	0.3	0.7
Deep-water demersals	0.99	1.67	3.34	3.05	0.9	1.8
Crustacean	0.71	0.86	1.72	1.26	0.7	1.5
	18.70	84.05	168.09	111.76	0.7	1.3

Source: Model and Authors 'calculations.

Except for the shallow-water demersals, all fish stocks in the coastal waters of Liberia appear to be underutilized (Table 6). A likely explanation is the prolonged civil conflict, underinvestment in the coastal fisheries, and changes in policy. The conflict prevented the expansion of fishing effort in the SSF [45]. Exits from the coastal industrial fisheries seem to have increased after changes in policy in 2010 when the Liberian Government introduced a zoning regulation (Figure 1). It seems this zoning policy may explain the trawlers poor catch of shrimps today since industrial trawling is prohibited within 6 nm inshore zone where the main coastal shrimp resources are concentrated [3,5,15]. The Kru canoes, that operate in that zone, catch some crustaceans, i.e., crabs and lobsters, but are inefficient [46], indicating underutilization of this valuable resources. In this case, it would be worthwhile to introduce some changes making it possible to fully exploit these valuable shrimp resources, while at the same time avoiding conflicts in the coastal fisheries.

During the early 1980s, the trawlers in Liberia were allowed to operate outside 3 nm but in 2010 they had to go outside 6 nm into deeper waters [3,5]. The trawlers operating today are old (≥30 years) and inefficient for trawling in deeper waters [13]. Consequently, the trawlers have been disappearing from the coastal fisheries.

The current state of the small and medium pelagics, deep water demersals and crustacean species assemblages indicate possibilities for new technological investments in the fishery to utilize the harvesting possibilities. The current depressed state of the shallow-water demersals suggests a need for stricter regulations, particularly for the Kru boats that mostly seem to thrive under open access.

4.2. Coastal Fleets Economics

In 2016, the small-scale and the industrial fisheries appear to have been profitable (Table 7). Total profits are estimated at around US$ 7.2 million with the Kru and Fanti boats accounting for nearly 99%. Estimated profits boat^{-1} were around US$ 510 for a typical Kru canoe, US$ 8000 for a Fanti boat and US$ 18,200 for an industrial vessel. While estimated profits as a share of revenues were reasonable for the coastal fleets, the average return on investments (ROIs) appear to be particularly encouraging ≥68% in the SSF. The industrial vessels were less profitable, which may explain the lack of investment in the coastal industrial fishery in Liberia.

Table 7. Estimated economic outcome of the fishery end of 2016.

	All Vessel				Vessel^{-1}		
Economics Status	**Total**	**Kru**	**Fanti**	**Industrial**	**Kru**	**Fanti**	**Industrial**
Revenue (US$ 1000)	39,012.9	12,562.0	24,315.1	2135.8	3.97	35.5	534.0
Cost (US$ 1000)	31,854.3	10,962.2	18,829.0	2063.1	3.47	27.5	515.8
Profits (US$ 1000)	7158.6	1599.7	5486.1	72.7	0.51	8.0	18.2
Profits/revenue	0.18	0.13	0.23	0.03	0.13	0.23	0.03
Return on investment	0.70	0.68	0.81	0.06	0.68	0.81	0.06

Source: Model and Authors 'calculations.

In general, world fisheries have been moving towards industrialization i.e., bigger motorized vessels are more effective [47,48], but this does not appear to be the case with the industrial fishery in Liberia. The introduction and increased enforcement of zoning regulations seem to have changed the profitability of the coastal fleet, benefiting the SSF by increasing their access to the coastal resources. This regulatory action appears to be in line with SDG 14B, which encourages states to protect the access rights of SSF [8].

Limited access to critical fishing inputs, i.e., fishing nets, outboard motors, big forest trees traditionally used to build the Fanti boats (as the length of these boats is determined by the size of the forest tree used for the keel), makes it somewhat difficult to invest in new boats and equipment, according to reports from NaFAA and Fanti fishermen. This may explain the current development trend in the Fanti fishery, as it would otherwise be expected for a profitable fishery.

Although the Fanti boats appear to be performing better relative to the Kru canoes and the industrial vessels, this does not imply that replacing all other vessels with the Fanti is a viable policy option. The vessel groups use different harvesting technologies and target different species. Such change may therefore be technically infeasible. Differences in profitability between vessel groups may have more to do with the profitability of harvesting different target species. It seems therefore that the overall best feasible utilization of coastal fishery resources in Liberia would be some combination of these fleets or the introduction of new technologies.

4.3. *Dynamic Fisheries Policy*

The evolution of the fisheries depends on the fisheries policy and how it is implemented, i.e., the number and types of vessels that are employed in the fishery and how their activities are regulated. Four fisheries policies scenarios (FPS) were examined: maintaining 2016 fishing effort levels, business as usual (BAU); optimal and realistic optimal policies. The average annual interest rate in Liberia was 13% at the end of 2016 [49]. This average interest rate is adopted in this analysis, although it may seem high for the analysis of the maximum net benefit.

4.3.1. Maintaining 2016 Fishing Effort

Under this fishery policy, we assessed what would happen if the 2016 initial biomasses (x_o), of the stocks modelled, and the number of Kru, Fanti, and industrial vessels are unchanged. The biomass and catch of small pelagics decline by about a third in the first four years but stabilize thereafter. The medium pelagic show a similar trend (Figure 2a). Once these species assemblages reached sustainable levels (equilibrium), they are just above their respective Xmsy.

Under this FPS, the shallow- and deep-water demersals show signs of recovery in the beginning and thereafter become stable ending up far above their 2016 levels (Figure 2b). The crustaceans initially decline moderately and stabilize after the 5th year (Figure 2c). This species assemblage is above its Xmsy after it reaches sustainable levels. Under this FPS, the aggregate profits decrease along with the stocks in the beginning years and afterwards become stable (Figure 2d). The Kru boats realized the most profits, after seven years of control.

This FPS is unlikely to materialize because the individual boats enjoy substantial profits and so there are incentives for expansion in the fisheries, i.e., invest in new boats and improvements of existing vessels. There are signs of this occurring already in 2019 according to reliable informal reports.

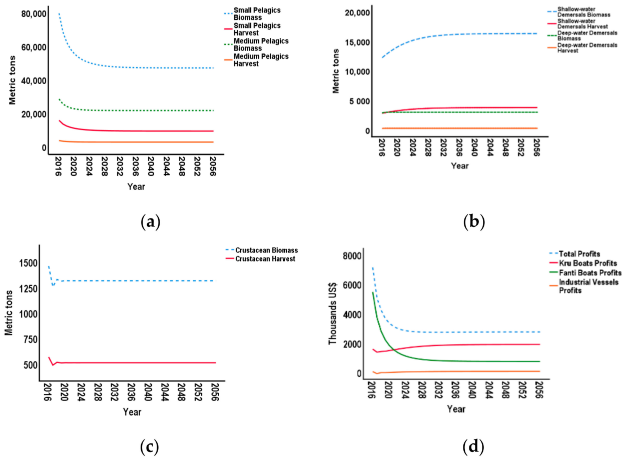

Figure 2. (**a**) Evolution of small and medium pelagic; (**b**) Evolution of shallow-and deep-water demersals; (**c**) Evolution of the crustacean; (**d**) Evolution of profits. Source: Model.

4.3.2. Business as Usual

The decision rule used here to assess the BAU FPS was if profits are greater than zero then they increase (i.e., average Δ effort), or else they decrease (average Δ effort). This rule was necessary to reflect the behaviour of commercial fleets in response to positive or zero profits by increasing or reducing fishing effort, based on historical changes in effort.

The small and medium pelagics fall far below their 2016 levels (Figure 3a). While the medium pelagics remain above their Xmsy, the small pelagics are 3% below their Xmsy. The sustainable yields of these species revealed similar trends. The shallow-water demersals fall below their 2016 levels to nearly 54% below Xmsy, whereas the deep-water demersals showed a similar trend but remain far above Xmsy (Figure 3b). The crustaceans decline severely below the 2016 levels and sustainable harvest also but remain 45% above Xmsy (Figure 3c). Aggregate profits decrease to zero (Figure 3d). Because of this, there will be no incentives for additional entries into the fisheries.

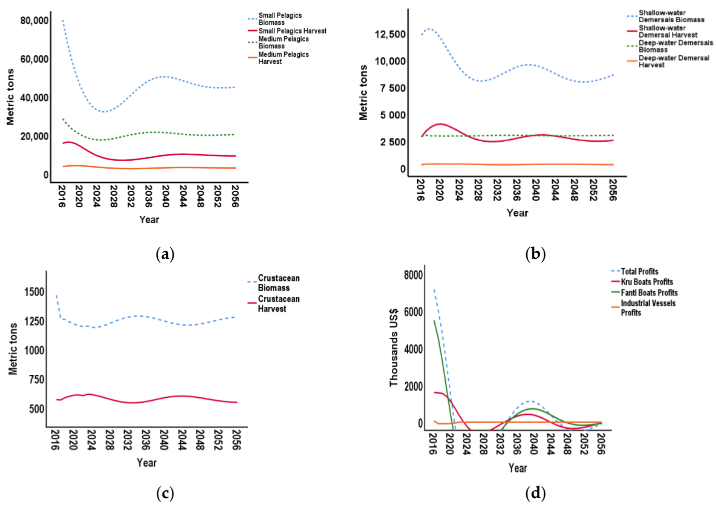

Figure 3. (**a**) Evolution of small and medium pelagics; (**b**) Evolution of shallow- and deep-water demersals; (**c**) Evolution of the crustacean; (**d**) Evolution of profits. Source: Model.

4.3.3. Maximum Net Benefits Policy

The objective, under this FPS, is to maximize the present value of profits. To locate the optimal dynamic fishery policies, the fundamental principle of dynamic optimization in fisheries was employed, using an iteration procedure [20–22].

To optimize profits in the coastal fisheries in Liberia, the model shows that the current number of boats should be reduced by around 58% for the Kru and 26% for the Fanti, whereas the industrial vessels should be increased by about 75% (Figure 4a). This large reduction in effort compared to the current situation has to do with the high costs and inefficiency of the vessels, suggesting in an optimal strategy of fewer vessels and much higher CPUE. This will lead to a speedy restoration of the shallow-water demersals and generation of substantial profits (Figure 4b–d). The biomass of all species assemblages is above their respective Xmsy.

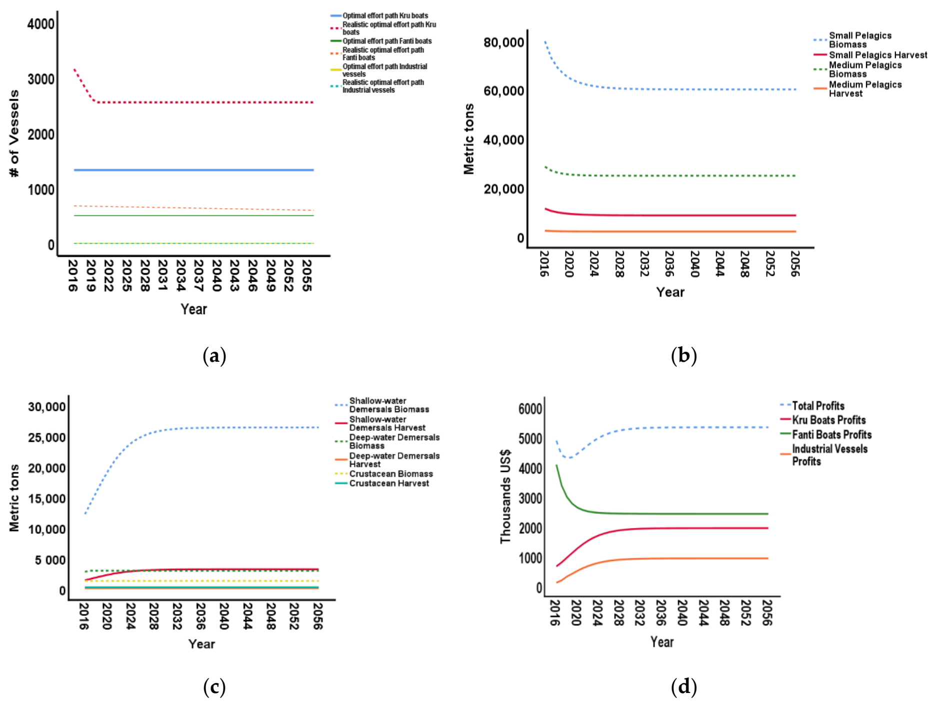

Figure 4. (**a**) Optimal and feasible Kru, Fanti and industrial effort paths; (**b**) Small and medium pelagics; (**c**) Shallow- and deep-water demersals and crustacean.; (**d**) Profits. Source: Model.

However, a realistic feasible optimal adjustment path which incorporates food and nutrition security and socio-economic and environmental considerations [47] might be more practical for Liberia's coastal fisheries. This realistic optimal fisheries policy indicates around 19% reduction of the current number of Kru canoes but no cut for the Fanti and industrial vessels and an overall reduction of 16% (Table 8). While profits vessel^{-1} for the small-scale fleets increase considerably, the total sustainable profits increased by nearly 29% compared to its 2016 (Figure 4d). Note that some loss of profits will occur during the early years of the fisheries control, due to sunken costs.

Table 8. Long-term economic highlights of the fisheries policies scenarios (FPS).

Policy Scenario	Employed Boats			Present Value of Profits (million US$)	Long-Term Annual Profits (million US$)	Profits Boat^{-1} (1000 US$)		
	Kru	Fanti	Trawler			Kru	Fanti	Ind.
Maintaining 2016 effort	3165	685	4	33.1	2.8	0.6	1.1	21.6
BAU	4710	687	0	12.8	−15.0	0.0	0.0	0.0
Maximum net benefits	1334	510	7	41.8	5.3	1.5	4.8	134.7
Realistic optimal	2561	685	4	35.8	3.6	0.9	1.6	63.2

A comparison of the long-term features, of the three FPSs assessed, indicate fleet size under the "BAU" is the greatest (Table 8). The present value of profits, sustainable long-run profits, and the profits boat^{-1} are highest under the maximum net benefits FPS but lowest under the "BAU" fisheries policy.

The maximum net benefits FPS indicates that the current fleet size should be reduced, even though the stocks are currently underutilized (Table 6). This is due to the low effectiveness and high cost of the current fleet. Note that the present value estimates for all four FPS simulated are sensitive to the rate of discount used. Discount rates below 13% would naturally generate higher present value estimates.

However, while it is possible to calculate the optimal combination of fleets for the Liberian coastal fisheries, it is currently an unrealistic policy option to implement. This is because of the crucial role of SSF in Liberia in terms of food security and poverty alleviation as reported elsewhere [50–56], the imperfect substitutability between the coastal fleets, the potentially detrimental effects of the poorly performing trawl fishery [28,57–61], and the poor state of the Liberian economy evidence by widespread poverty and limited employment opportunities [62].

A fisheries policy which considers maximizing the present value of profits, employment of the marginalized small-scale fishers, and the marine environment seem to be realistically optimal [63,64]. A major drawback, however, is the short-term costs (socio-economic) that are necessary to reduce the excess fishing capacity [63]. Note the trawlers are neither efficient nor profitable but technical infeasibility of harvesting the same resources with the Kru canoes make the trawlers a viable part of the coastal fisheries in Liberia. There is a need, therefore, for the coastal fisheries to undergo major technological development and investments as well as improved management.

4.4. Model Structural Uncertainties

Effects of non-harvesting anthropogenic alterations, technological change, and socio-economic and environmental fluxes were not incorporated in the bio-economic model, because the effects of structural uncertainty are not amenable to standard modelling approaches [65].

The economic downturn and prevalent poverty in Liberia [62] and harvesting externalities due to excessive fishing effort and disruptions between SSF and industrial fisheries resulting from competition for the same species may greatly affect the coastal marine fisheries. It is likely that these factors may have negative effects on the results (benefits) from the fisheries policies analyzed here. Lack of reliable data, however, impeded analysis of the impacts of these factors. Further analysis is required to shed light on the effects of environmental and other non-fishing anthropogenic influences on Liberian fisheries.

Catchability, marginal cost of fishing, and price of the landed catch, which may vary as the number of vessels in the fisheries, marine environment, and fish market conditions change, are assumed constant. Fishing grounds, which may change in accordance with seasonal fluctuations in the stocks' availability and overfishing of inshore stocks, in reality, are assumed unchanged. A constant discounting rate is assumed in this analysis but time preferences of individuals and groups, as well as their determinants, evolve overtime as societies change [66].

A key assumption in our fisheries policy analysis is that all the coastal fisheries vessels cooperate to realistically optimize the overall benefits of the fishery resources. Therefore, in some fisheries policy scenarios, the benefits of some fleets were optimized at the expense of others following Cheung and Sumaila [63]. While this assumption may influence the optimal fleet structure in the fisheries, the overall trade-offs, presented in this analysis, should remain valid [65,67].

5. Conclusions and Policy Recommendation

This analysis set out to shed light on the state of the coastal fisheries in Liberia, actions taken by the Government to effectively regulate harvesting to produce at MSY, and secure access rights for the SSF fishers aligned with SDG 14 targets 14.4 and 14 B.

The bio-economic model indicates that the shallow water demersals are overfished while most other species are not fully exploited. The most likely explanation for the observed under exploitation is the civil conflict in Liberia and the 2010 policy of extending the exclusion zone for trawlers. The coastal fisheries were profitable in 2016 but the distribution of profits was skewed to the small-scale fleets. ROIs were > 67% for the Kru and Fanti boats, while it was much lower (<7%) for the industrial vessels. The poor performance of the coastal industrial fishery can most probably be attributed to the introduction of zoning regulation in 2010, accompanied by increased enforcement. This seems to have led to a redistribution of benefits from industrial to small-scale fishers and to changes in the development of the coastal fleets.

It seems the Liberian Government zoning regulatory action taken in 2010 supplemented by increased enforcement has been successful in attaining certain parts of SDG 14 and targets 14.4 and 14B, in terms of stocks rebuilding and increasing SSF access to coastal resources but probably at the expense of economic efficiency.

There has in particular been an increase in the Kru fleet, which certainly is a contributing factor to the overfishing of the shallow water demersals that are primarily targeted by this fleet. Other stocks are underexploited, possibly because the SSF does not possess the appropriate technology to harvest other species complexes.

The results from dynamic simulation indicate that the current fleet size will over time lead to some stock decline in all species. Since both the Kru and the Fanti are currently operating with profits, there appear to be substantial incentives for new investments in the coastal fisheries. Regulatory actions, especially for the Kru and Fanti fleets, is therefore needed to manage the fishery sustainably. Designing an effective policy is however quite challenging.

The three coastal fleets are designed differently and employ different harvesting technologies targeting different species in different depths and zones. Some mixture of the different types or the introduction of new technology as the current fleet structure seems unlikely to effectively utilize the opportunities to expand fisheries of deep-water demersal and crustacean, i.e., crabs and lobsters as well as shrimp. In this case, it seems introducing some changes to make it possible to exploit the valuable coastal shrimp resources, while at the same time preventing interference between the industrial and SSF which may lead to the conflict would be worthy. A successful policy must address the issue of the SDG's, access for SSF's, sustainable management as well as the appropriate technology for the utilization of the different categories of marine species available in the Liberian EEZ. This is a considerable challenge.

Finally, this analysis acknowledges that the harvesting function (expression 6), assumed here, restricts effort elasticity to unity i.e., 1% increase in effort leads to a 1% increase in the profits. More flexible functional forms exist, e.g., the Cobb-Douglas production function e.g., [68]. Further, surplus production models are restrictive in their assumptions and do not include factors that have been shown to be important to management, e.g., the biological relationship between the size or age composition of the stocks, e.g., [69]. Recent analyses e.g., [70,71] have shown, that when the age-structured information is considered, optimal harvesting strategies may be different from those found when optimization is based on conventional surplus production models. The simplicity of the surplus production model makes it applicable in cases where data is scarce. This analysis is an example of such a case where a bio-economic model can be estimated and realistic optimal harvesting paths identified in a complex but data-poor fisheries context.

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Paper III

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Technical Efficiency Analysis of Coastal Small-Scale Fisheries in Liberia

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Abstract: The coastal fisheries in Liberia comprise small-scale Kru and Fanti low technology canoes and open boats, as well as industrial trawlers. At the end of the war in 2003, foreign industrial trawlers dominated the coastal fisheries in Liberia. After the war, the industrial fleet declined rapidly from 60 in 2004 to 15 in 2010. Over the same period the local Kru canoes grew from <400 to over 2400 and the motorized Fanti boats increased from <200 to about 800. Since 2010, when the government established a six nautical mile inshore exclusion zone, the industrial fleet has continued to decline, the Fantis have remained fairly constant, but the Kru fleet has continued to expand, reaching 3800 canoes by 2019. This paper analyzes the technical efficiency and productivity of the SSF fleets in Liberia. Data were collected from 46 randomly chosen Kru and 86 Fanti boats. There is a considerable difference between the Kru and the Fanti boats in terms of quantities of inputs used and output produced. Mean efficiency of the Kru canoes was 0.53, while for the Fanti boats it was 0.70, indicating considerable inefficiencies and scope for technical improvement. Vessel length and skipper's age are the two main factors significantly influencing technical efficiency of the Kru and Fanti boats. The younger Kru operators (≤40 years) using newer and smaller dugout canoes (≤6.1 m) were more efficient than the older fishers in older and larger canoes, while the opposite was true for the Fantis. There were efficient boats and inefficient vessels among the Kru and Fanti but on average they were profitable. However, the design of these vessels offers limited scope to introduce improved fishing technology. To address the current technological regress and increase productivity in the fisheries, it is recommended that the Liberian government explore new harvesting technologies such as fiberglass reinforced plastic in the coastal fisheries.

Keywords: small-scale fisheries; stochastic production frontier analysis; Liberia

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1. Introduction

Liberia, located on the west coast of Africa, has a coastline of around 590 km and an exclusive economic zone (EEZ) of 246,000 km^2, which harbors valuable demersal and pelagic fishery resources. Liberian fisheries are a major source of food and jobs for several thousand Liberians and provides government revenue, accounting for around 10% of the Gross Domestic Product [1]. The marine fishery resources are currently exploited by the offshore and coastal fisheries, which use different vessels and fishing methods [2,3].

The offshore fleet consists of around 40 industrial tuna vessels, operating under a sustainable fisheries partnership access agreement with the EU, deploying purse seines and surface longlines [4]. Their catch, which has been estimated to be 10,000 tons year^{-1}, is not landed in Liberia.

The coastal fisheries consist of industrial and small-scale fisheries (SSF) targeting both pelagic and demersal fish species and crustaceans [4,5]. There are two distinct demersal communities on the continental shelf where the water is permanently stratified, namely above and below the thermocline, which fluctuates between 40–60 m depth [6]. These are referred to as shallow- and deep-water demersals.

The industrial coastal fishery comprises trawlers, averaging around 180 gross registered tonnage, using bottom- and mid-water trawls targeting demersal fish and shrimp stocks [3]. The trawlers are mostly foreign owned and operate through joint ventures with Liberian registered fishing agencies [2,3]. Before the end of the civil war in 2003, 60 such trawlers operated in Liberian waters, but their numbers have declined rapidly after 2004 and have continued to decline following a fisheries management reform by the Government of Liberia in 2010. In 2019, this fleet only counted six vessels (Figure S1) [4,7]. High levels of illegal (unlicensed) fishing activities were observed and reported in the industrial fisheries before the end of the civil war and the economic loss to Liberia has been estimated at around USD 12 million per year [8,9].

Before the end of the war (2001–2003), the estimated catch of the trawlers ranged between 13,464 to 15,560 tons year^{-1}, and averaged around 14,441 $\pm$ 1055 tons year^{-1}; from 2010 to 2016, their total catch varied between 75 to 3028 tons year^{-1} and averaged around 1310 $\pm$ 1154 tons year^{-1} (Figure S2), according to NaFAA statistics. Management of the industrial coastal fisheries is through a range of input controls such as effort, gear and area restrictions, fishing licenses, and output controls such as catch restrictions [10,11]. The catch is landed in Liberia and consumed locally, although a part is exported [2,3].

Since 2010, the SSF have had exclusive access within a six nautical mile inshore exclusion zone (IEZ), although they may also fish further offshore [11]. The majority of SSF consist of non-motorized dugout canoes averaging about 6.7 m with 1–4 crew, operated by local Kru fishers (Figure 1a). However, in practice Kru fishers may be a mix of people comprising Kru, Vai, Bassa, Grebo and other tribes [3].

(**a**) A typical small-scale Kru canoe in Liberia (**b**) A typical small-scale Fanti boat in Liberia

Figure 1. A typical small-scale Kru canoe and Fanti boat in Liberia.

In 2019, the Kru constituted about 83% of the SSF fleets, having increased from less than 400 in 2004 to 2459 in 2010 and roughly 3815 canoes in 2019 (Figure S1). The Kru mainly use hook and line, longlines, gill nets, cast nets and traps [12]. They primarily target shallow and deep-water demersal species and some crustaceans, mainly crabs and lobsters [4,5].

The Fanti operate larger open wooden boats, averaging 10.1 m and typically powered by 9–40 hp outboard and inboard engines with a crew of 4 to 26 people (Figure 1b) [7]. The number of Fanti boats grew steadily from 168 in 2004 to 737 in 2010. Since then, their number has been fairly stable and in 2019 they numbered 774 (Figure S1). Ring net is the most common gear used to target small pelagics inshore, but some also occasionally deploy other types of gear such as gill nets, set nets, hooks and lines targeting shallow and deep-water demersal species [7,12]. Before the war ended from 2001 to 2003, the SSF total catch varied between 6303 to 6842 tons year^{-1} and averaged around 6598 tons year^{-1}, but from 2010 to 2016, it ranged between 9700 to 32,298 tons year^{-1} and averaged around 19,498 tons year^{-1} (Figure S2), according to NaFAA statistics.

About 11,000 full-time fishers and 22,000 fish processors and traders depend on the SSF for their livelihoods [9]. Between 2004–2016, the total domestic catch averaged around 19,849 $\pm$ 7079 metric tons, of which the SSF produced around 67% (Figure S2). Most catch is landed during the dry season in October–April when the weather and fishing conditions are favorable, whereas during the rainy season (May–October), periods of strong ocean currents and heavy storms impede the boats from going out to sea [3].

The coastal small-scale fleets were more profitable than the industrial trawlers and accounted for nearly 99% of the USD 7.2 million total profits generated in the Liberian coastal fisheries in 2016 [4]. The development and composition of the coastal fleets since 2004 have been mostly driven by differences in profitability. The Kru and Fanti boats outperform the industrial trawlers [4].

However, the sourcing of raw materials (i.e., big forest trees) used for building these small-scale traditional fishing vessels has been a major challenge in Liberia, as is commonplace in African SSF and elsewhere [13–15]. One of the important features of the SSF in Africa is their use of dugout canoes, the size of which is limited by the availability of suitable trees [13,16]. Over-exploitation of forest resources is commonplace and current harvesting rates are unsustainable [13,16]. Traditional canoe building is at the center of conflicts between forest conservation and traditional boat building in Africa [13]. This certainly has implications for the production performance of small-scale operators, a phenomenon which appears to manifest itself in the SSF in Liberia.

This paper aims to determine and understand the difference in performance within the SSF fleet segments in Liberia, analyzing technical efficiency. To proceed, we asked: What is the current state of the harvesting technology? Are the small-scale fleets in the coastal fisheries technically efficient? The following section presents the data and variables, and a summary of the theory underlying Stochastic Production Frontier (SPF) analysis used to estimate technical efficiency of individual vessels. The results and discussion are provided in Section 3, while the conclusion and policy recommendations are presented in Section 4.

2. Methods

2.1. Study Site and Data

Data for this analysis were collected at three landing sites, Robertsport (Grand Cape Mount), Point four (Montserrado) and Marshall (Margibi) beaches (see, Figure 2). Both Kru and Fanti operated from all three beaches, which are considered representative of the coastal SSF in Liberia [4,5,17].

A total of 48 Kru and 90 Fanti were randomly selected and interviewed at the start of the rainy season during April and May of 2018 using a structured questionnaire (see, SA1). The data collected included landed catch and sales price as well as quantities and cost of inputs including the costs of boats, outboard engines, fuel, fishing gear and bait, and the number of crew. Other operator information collected included skipper's age and nationality, as well as vessel length. The reliability of the data was evaluated, and outliers removed from the observations [18]. This left valid observations for 46 Kru canoes and 86 Fanti boats for the technical efficiency analysis.

Figure 2. Map of study area. (FreeMapViewer. Accessed on 06.21.2021).

2.2. Stochastic Production Frontier Conceptual Framework

The estimation of technical efficiency is well established in production theory [19–21]. Technical efficiency was measured using stochastic production frontier analysis [22,23], where random variability is separated from inefficiency [24,25]. The production frontier is specified as

$$q_k = f(x_{k1}, x_{k2}, \ldots, x_{kn}) \tag{1}$$

where q_k refers to the catch of vessel k, x_{ki} refers to input quantity of input i for vessel k. Transcendental logarithmic (translog) functional specifications are commonly used in applied estimation of SPF due to their flexibility for approximating unknown technology [24,25]. The unknown technology is approximated by a translog function, expressed as

$$ln(q_k) = \alpha_0 + \sum_i \beta_i ln(x_{ki}) + \frac{1}{2} * \sum_i \sum_j \beta_{ij} ln(x_{ki}) ln\left(x_{kj}\right) + (v_k - u_k) \tag{2}$$

where α_0, β_i and β_{ij} are parameters. The expression further contains a composite error term where v_k is a random error term and u_k captures technical inefficiency [26,27]. Technological inefficiency is assumed to be enterprise-specific, non-negative and identically and independently distributed as non-negative truncations of the normal distribution, $u_k \sim \left|N\left(0, \sigma_u^2\right)\right|$ [19,28]. The error term v_k is the statistical noise assumed to be identically and independently distributed $v_k \sim N\left(0, \sigma_v^2\right)$ and independent of u_k. The parameters of the frontier in Equation (1) are estimated using a maximum likelihood method.

Based on Battese and Coelli [24], the technical inefficiency distribution parameter can be extended to include covariates as

$$u_k = \delta_0 + \sum_i z_{ki}\delta_i + w_k \tag{3}$$

where z_{ik} are variables of enterprise-specific explanatory variables linked to the technical inefficiency of the k^{th} enterprise, δ refers to the unknown vector of parameters to be estimated, and w_k is distributed $w_k \sim \left|N\left(0, \sigma_u^2\right)\right|$. The likelihood function is expressed in terms of the variance [24] and, following Battese and Corra [27], Battese and Coelli [26], and Kompas et al. [25], we parameterized the variance terms by substituting σ_v^2 and σ_u^2

with $\sigma = \sigma_v^2 + \sigma_u^2$ and $\gamma = \frac{\sigma_u^2}{(\sigma_v^2+\sigma_u^2)}$. The technical efficiency score for the k^{th} enterprise is specified as

$$TE_k = \exp(-u_k) = \exp\left(-\left(\delta_0 + \sum_i z_{ki}\delta_i\right) - w_k\right) \tag{4}$$

where TE_k is the relative technical efficiency of the enterprise, which lies between zero and unity [0 < TE < 1]. The output elasticity of the k^{th} enterprise, which measures the degree of responsiveness of output in response to a percentage change in input, is given as

$$\varepsilon_i = \frac{\partial lnq}{\partial lnx_i} = \beta_i + \sum_j \beta_{ij} lnx_j \tag{5}$$

By centralizing the data at average, the expression simplifies, and the parameters estimate for β_i becomes an estimate of the elasticity at the mean. The elasticity of scale, which measures the percentage change in the expected output due to a relative change in the application of all input variables, is calculated as the sum of the output elasticities for all input variables [29].

2.2.1. Analysis of Technical Efficiency

In this analysis, the output variable 'catch trip^{-1}' was elected based on the two main species assemblages 'shallow-water demersal' (e.g., *Psedotolithus* spp., locally referred to as cassava-fish) and the 'small pelagics' (*Sardinella* spp.), given that they were the major target species of the Kru and Fanti boats, respectively. During the survey though, some boats harvested other species. In cases where more than one species assemblages were targeted, catch trip^{-1} was standardized as a cassava-fish equivalent, using

$$q_c = \sum_{i=1}^{i=n} \frac{q_t \cdot p_t}{p_c} \tag{6}$$

where q_c refers to the aggregate trip-level catch represented in terms of species 'c' cassava-fish of a specific boat, q_t is catch of other species caught (e.g., grouper or grunter) by that same boat, p_t is the average price kg^{-1} of the species (i.e., grouper or grunter) and p_c is the average price kg^{-1} for cassava-fish of the boat.

2.2.2. Econometric Specification

The catch variable, q_k, is the catch weight landed in kg per trip of cassava fish equivalent. The inputs are capital stock (USD) (sum of value of vessel and equipment), labor (the number of crew per boat including the skipper), bait cost (USD per trip for the Kru canoes only), and fuel cost (USD per trip for Fanti boats only). The operators and boat-specific factors in the technical inefficiency parameters for the Kru and Fanti vessels were the overall length, age of the skipper, nationality of skipper, and size of outboard engine. The FRONTIER 4.1, package in R was used to estimate the parameters of 2, 3, and 4. For the Kru canoes, the parameters were capital, labor, and bait in Equation (2), overall length and the skipper's age in Equation (3), and estimate of technical efficiency in Equation (4). The parameters for the Fantis were capital, labor, and fuel in Equation (2), skipper's age and nationality, small and medium size engine and small and medium size boat in Equation (3), as well as the estimate of technical efficiency in Equation (4). The translog functional specifications were tested against the simpler Cobb–Douglas definition by a likelihood ratio (*LR*) test.

3. Results and Discussion

There was considerable heterogeneity in terms of the operational and technical aspects of the small-scale fleets, such as the cost of capital stock, labor, bait, fuel, the skipper's age, overall length, and the outboard engine (Table 1). The mean catch for the Kru canoes was

16 ± 25 kg trip^{-1}, varying from 1.9 to 123 kg trip^{-1}. Capital stock ranged from USD 136 to USD 600 and averaged 330 ± 89 USD canoe^{-1}. While the crew size averaged 2 ± 1 persons and varied between 1 to 4 people canoe^{-1} for the Kru, the bait cost trip^{-1} varied between 1.6 to 8 USD and averaged around 4.5 ± 1.8 USD. The average age of Kru skippers was estimated at 38 ± 11 years, but ranged from 22 to 70 years, while overall length ranged between 3.7 to 10 m, with an average of 6.7 ± 1.5 m (Table 1). Catch for the Fanti boats averaged 166 kg trip^{-1}, varying between 1 to 1287 kg trip^{-1}, while mean capital stock was estimated at 8650 ± 10,775 USD, but ranged between 550 to 60,000 USD boat^{-1}. Crew size ranged between 4 to 26, with an averaged 14 ± 5 boat^{-1}. Fuel cost by the Fanti boats varied from USD 1.8 to 90, averaging 15.3 ± 15.2 USD trip^{-1}. The mean age of Fanti skippers was 41 ± 8 years but ranged from 25 to 60 years, and the overall length varied between 4.6 and 21.6 m, averaging 10 ± 3.9 m (Table 1). The mean cost of the outboard engines was estimated at 3152 ± 896 USD and varied between USD 950 to 4500. The average catch trip^{-1} and input of labor for the Fantis exceeded that of the Kru canoes, as has been observed elsewhere for motorized and non-motorized boats in SSF [30].

Table 1. Summary statistics for key variables in the SPF and technical inefficiency models for the Kru and Fanti vessels in Liberia.

Output	Measure	Stats	Kru Canoes	Fanti Boats
Catch	kilogram	Mean	16.0	165.5
		SD	25.0	271.0
		Min	1.9	1.0
		Max	122.5	1287.4
Inputs				
Capital stock	USD	Mean	330.2	8649.8
		SD	88.8	10,774.7
		Min	136.0	550.0
		Max	600.0	60,000.0
Labor	# of persons	Mean	2.0	14.0
		SD	1.0	5.3
		Min	1.0	4.0
		Max	4.0	26.0
Bait	USD	Mean	4.5	
		SD	1.8	
		Min	1.6	
		Max	8.0	
Fuel	USD	Mean		15.4
		SD		15.2
		Min		1.8
		Max		89.1
Boat & operators specific variables				
Skipper's age	Year	Mean	38.0	41.0
		SD	11.0	7.88
		Min	22.0	25.0
		Max	70.0	60.0
Length overall	meter	Mean	6.7	10.0
		SD	1.5	3.9
		Min	3.7	4.6
		Max	10.0	21.6
Outboard engine	USD	Mean		3151.8
		SD		896.0
		Min		950.0
		Max		4800.0
Observations (n)			**46**	**86**

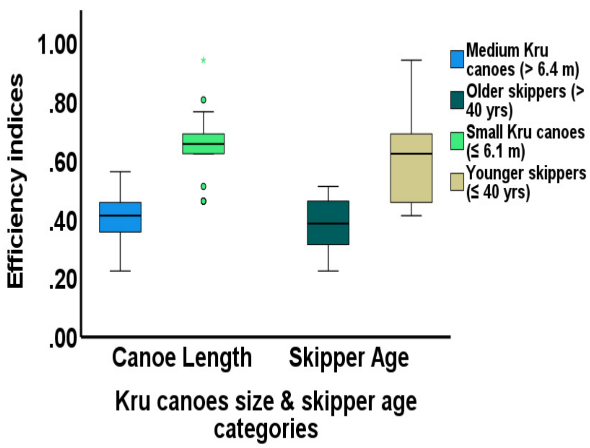
Source: Constructed from survey and NaFAA statistics (2018) compiled by Authors.

Technical Efficiency

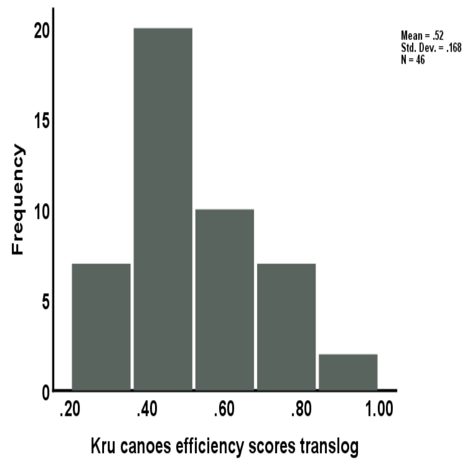
There was not sufficient evidence to reject the null hypothesis that technical inefficiency effects are absent in the models (γ = 0 and δ_i = 0 for all k) for the Kru and Fanti boats. The second null hypothesis that the appropriate functional forms for the SPF models are of the Cobb–Douglas form, imposed by removing the square and cross product terms, was rejected at the 5% significance level for the Kru and at the 1% significance level for the Fanti boats. This indicates that the translog production functions are the most appropriate functional specifications for the analysis of the small-scale Kru and Fanti vessels in Liberia (see, Table S1).

Lastly, the null hypothesis that $\gamma = \frac{\sigma_u^2}{(\sigma_v^2+\sigma_u^2)} = 0$ (when the variance of the inefficiency effects is zero) or that technical inefficient effects are not stochastic, was also strongly rejected at 5% significance level and better for both fleets (see, Table S1). For both estimated models, the results thus indicate that stochastic effects and technical inefficiency are major factors explaining the performance of the Kru and Fantis.

The technical efficiency score for the Kru canoes averaged 0.53 $\pm$ 0.12 and seems to follow observation for SSF fishers elsewhere [31]. The efficiency indices for the Kru canoes significantly decreased ($p < 0.00$) along with an increase in canoe length, which may be attributed to the cost of larger canoes and skipper age (Figure 3a). This suggests that small Kru canoes ($\leq$6.1 m) and younger skippers ($\leq$40 years) are more efficient than larger canoes (>6.1 m) and older skippers (>40 years). About 46% of the observed Kru canoes' technical efficiency score ranged between 0.41 and 0.60, followed by 28% of the canoes with efficiency indices in the range 0.61–0.80 (Figure 3b), indicating that most of the Kru canoes are inefficient.



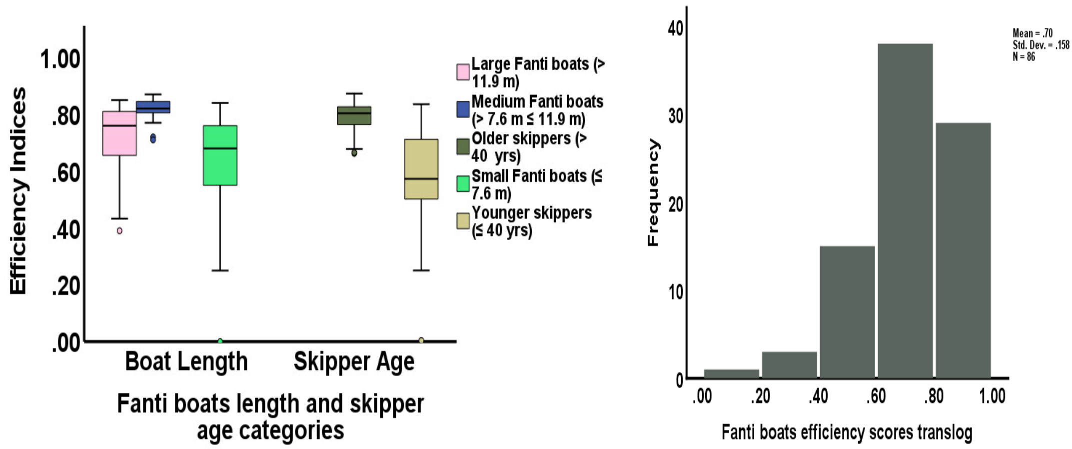
(**a**)



(**b**)

Figure 3. Differences in technical efficiency and frequency distribution of efficiency: (**a**) Differences in technical efficiency scores by Kru canoe size and skipper age; (**b**) Frequency distribution of efficiency indices for small-scale Kru canoes in Liberia.

Technical efficiency score of the Fanti boats averaged 0.70 $\pm$ 0.16 and increased significantly with boat length ($p < 0.00$) and skipper age (Figure 4a). This indicates that larger Fanti boats (>7.6 m) and older skippers ($\geq$40 years) were more efficient than small boats ($\leq$7.6 m) and younger skippers ($\leq$40 years), which is contrary to what was observed with the Kru canoes. It seems, for Kru operators who mostly use hook and lines, that the length of the boat does not matter as much as it does for the Fantis, which mainly deploy large ring nets and require a large crew (manpower) to pull them. Fantis, therefore, cannot operate in the same way a typical small boat does, which might be more important than the skipper's age. Approximately 44% of the Fanti boats technical efficiency scores were in the interval of 0.61–0.80, followed by 34% with efficiency scores greater than 0.80 (Figure 4b). Based on these estimates, the Fanti boats are on average 17% more efficient than the Kru canoes.



(**a**) (**b**)

Figure 4. Differences in technical efficiency and frequency distribution of efficiency: (**a**) Differences in technical efficiency scores across Fanti boat size and skipper age. (**b**) Frequency distribution of efficiency indices for small-scale Fanti boats in Liberia.

The parameter estimates evaluated at the sample mean are output elasticities which indicate the magnitude of the responsiveness of output to a percentage change in the models' endogenous input variables. The output elasticities of capital, labor, and bait for the Kru canoes are 1.45, 0.42, and 0.35, respectively, and the return to scale is estimated at 2.22 at the sample mean (Table 2). The output elasticity is highest for capital but lowest for bait used (Table 2). The coefficient for capital is statistically significant at 1% significance level, while they are insignificant for labor and bait used. The positive signs associated with the coefficients of capital, labor, and bait indicate that these inputs variables have positive effects on the Kru canoes output, as expected (Table 2).

Vessel length overall has significant ($p < 0.05$) negative effect on technical efficiency of Kru canoes, but the dummy variable "younger skipper" had a positive but not statistically significant effect (Table 2). Gamma (γ) for the Kru canoes model was statistically significant at 5% significance level (Table 2), indicating that all deviations are entirely due to technical inefficiency and random noise but most importantly to technical inefficiencies [24,29].

The Fanti boats output elasticities of capital, labor, and fuel are 0.42, 0.46, and 1.09, respectively, and the elasticity of scale is estimated to be 1.97 at mean-scale (Table 2). The output elasticity is greatest for fuel used per trip, but lowest for capital. The Kru canoes return to scale is relatively higher (0.25) than the Fanti boats. The estimates of elasticities of scales indicate an increasing return to scale (IRS) for both Kru and Fanti vessels. The coefficients of capital and fuel are significant ($p \leq 0.05$), but labor is insignificant (Table 2). All coefficients are positive, as expected, indicating that capital, labor and fuel have positive effects on the output of the Fanti boats. The positive signs associated with capital, labor, and fuel (for Fanti) in both Kru and Fanti boat models follow those reported elsewhere [32,33].

Estimates for the Fanti boats inefficiency model indicates that none of the covariates (dummy variables z_1–z_6) were statistically significant (Table 2). The negative signs linked to the coefficients of dummy variables z_1, z_3, z_5, and z_6 indicate that older skippers, small sized outboard engines, and medium and large size boats have positive effects on the production efficiency of Fanti boats (Table 2), whereas foreign skippers and medium sized outboard engines have a negative effect on the technical efficiency of these boats. Gamma in the Fanti boats model is statistically significant ($p < 0.00$) (Table 2), indicating that both statistical noise and inefficiency are significant in explaining deviations from the SPF, though inefficiency is more significant than noise [24,29].

Table 2. Parameter estimates of the Kru canoes and Fanti boats SPF and technical inefficiency models.

(a) Kru Canoes			(b) Fanti Boats		
Stochastic Production Frontier	**Coefficient**	**Asymptotic t-Ratio**	**Stochastic Production Frontier**	**Coefficient**	**Asymptotic t-Ratio**
Constant	2.75 [0.25]	0.11	Constant	4.2 *** [0.22]	18.54
ln (capital)	1.45 ** [0.51]	2.84	ln (capital)	0.42 * [0.20]	2.05
ln (labor)	0.42 [0.47]	0.88	ln (labor)	0.46 [0.49]	0.92
ln (bait)	0.35 [0.34]	1.00	ln (fuel)	1.09 *** [0.20]	5.31
ln (capital)^2	−0.76 [2.63]	−0.29	ln (capital)^2	−0.14 [0.41]	0.35
ln (labor)^2	4.05 ** [1.53]	2.64	ln (labor)^2	0.92 *** [1.05]	3.75
ln (bait)^2	0.76 [1.04]	0.72	ln (fuel)^2	0.82(*) [0.49]	1.66
ln (capital) * ln (labor)	2.06 [2.61]	0.78	ln (capital) * ln (labor)	0.36 [0.45]	0.79
ln (capital) * ln (bait)	1.07 [1.06]	1.01	ln (capital) * ln (fuel)	0.03 [0.45]	0.08
ln (labor) * ln (bait)	−1.91 [1.28]	−1.49	ln (labor) * ln (fuel)	−1.52 ** [0.54]	−0.21
Technical inefficiency model			**Technical inefficiency model**		
Constant	−0.21 [0.26]	−0.01	Constant	$-1.93 \times 10^{+3}$ [$3.45 \times 10^{+3}$]	−0.56
Z_1(length overall)	1.14 * [0.50]	2.21	Z_1(skipper-age)	$-2.95 \times 10^{+3}$ [$5.25 \times 10^{+3}$]	−0.56
Z_2(skipper-age)	−0.35 [0.25]	−1.42	Z_2(skipper-nationality)	$5.8 \times 10^{+2}$ [$1.04 \times 10^{+3}$]	0.56
			Z_3(small-outboard-engine)	$-9.3 \times 10^{+2}$ [$1.65 \times 10^{+3}$]	−0.56
			Z_4(medium-outboard-engine)	$5.14 \times 10^{+2}$ [$9.13 \times 10^{+2}$]	0.56
			Z_5(medium-boat)	$-2.89 \times 10^{+3}$ [$5.16 \times 10^{+3}$]	−0.56
			Z_6(large-boat)	$-5.74 \times 10^{+2}$ [$1.03 \times 10^{+3}$]	−0.56
Sigma-square (σ^2)	0.42 *** [0.09]	4.84	Sigma-square (σ^2)	$1.38 \times 10^{+3}$ [$2.44 \times 10^{+3}$]	0.56
Gamma (γ)	2.68×10^{-4} *** [1.12×10^{-5}]	23.79	Gamma (γ)	9.99×10^{-1} *** [1.50×10^{-3}]	667.54
Ln (likelihood)	−45.53	-	Ln (likelihood)	−136.1608	-

Note: (*), *, ** and *** denote statistical significance at the 10%, 5%, 1% and 0% level, respectively. Numbers in brackets are asymptotic standard errors.

There are efficient and inefficient Kru canoes and Fanti boats in the SSF in Liberia, but, on average, they are profitable, earning between USD 510 and USD 8000 for a typical Kru and Fanti, respectively [4]. This may explain why there has been a continuous increase in the number of Kru canoes since the end of the civil war and following the introduction of the six nm IEZ policy in 2010 to protect the SSF and control illegal fishing by industrial trawlers (Figure S1) [7]. The number of Fanti boats, however, has been relatively stable since 2011.

This raises the question of why the industrial vessels left the coastal fishery, declining from 60 vessels in 2004 to just 6 in 2019. One plausible explanation for their decline, specifically starting from 2003, could be attributed to the new government policies after a long period of instability. There was a complete lack of governance in the fishing industry, as was generally the case with most sectors in the economy, and harvesting was largely unregulated, resulting in rampant illegal unregulated and unreported fishing [8]. Since 2004, successive governments have focused on governance of the fisheries sector, with a significant fishery reform introduced in 2010 [7]. Another possible reason for the industrial vessels' departure could be due to the decline of catches (Figure S2), after a prolonged period of high levels of illegal (unlicensed) fishing activities during the civil war that started in 1989 and ended in 2003 [8,9]. Before the civil war ended in 2003, the industrial vessels total catch was on average nearly 11 times what it has been since 2010 (Figure S2) [4].

The departure of the industrial vessels from the coastal fisheries in 2004 coincided with an increase in both the catch and the number of Kru and Fanti boats. For instance, between 2004 and 2016, the average annual total catch of the Kru and Fantis doubled compared to what it was before 2004 when there were around 60 industrial vessels. For this same period, the average number of Kru canoes in the coastal fisheries is approximately 11 times what they were before 2004, whereas for the Fanti boats, it is around 6 times (Figure S1). Although the current number of Kru canoes and Fanti boats together have, on average, increased in the SSF by around 9-fold, their total catch has only doubled over these years (Figure S2). This indicates how inefficient and archaic the harvesting technology employed by the Kru and Fanti boats in Liberia is. This also indicates overfishing due to increased fishing pressure (effort), which has implications for the sustainability of the fishery resources in Liberia. Jueseah et al. [4] and MRAG [5] recently found that, the shallow- and deep-water demersals, the Kru canoes main target species were overfished, and suggested a need for stricter regulations, particularly for the Kru canoes that mostly seem to thrive under open access. It seems that the fishery is characterized by both considerable inefficiency and use of low-level harvesting technology among Kru canoes and Fanti boats in Liberia and unsustainable utilization of the fish stocks [4,5]. In an unregulated fishery, there is an inverse relationship between efficiency and biological sustainability, i.e., the more efficient the vessels are, the less biologically sustainable the fishery becomes [34]. Economic sustainability is, however, positively related to efficiency [34,35]. Improved fisheries management will improve both biological and economic sustainability but will lead to fewer fishers being involved in the sector [34–37] and might limit the ability of the sector to act as a buffer for unemployed young men, perhaps reducing social sustainability. This is the challenge of fisheries management [34]. Increased efficiency will certainly generate wealth [34–37]. The overall social impact will depend on government policy and the distribution of benefits. This suggests that any measure to increase the efficiency of the small-scale fleet must also consider all aspects of sustainability of the resources and socio-economic implications.

To keep the number of Kru canoes at sustainable levels, it seems fisheries management measures should be considered to change the current incentive in the SSF, although management of SSF can be quite complicated. Still, substantial benefits could be obtained by introducing proper fisheries management measures for the sustainable utilization of the fishery resources in Liberia [38–40].

Jueseah et al. [4] found that all the fish stocks in the Liberian coastal waters, except the shallow-water demersals, were underutilized. This was attributed to the prolonged civil conflict, underinvestment in the coastal fisheries, and the changes in policy in 2010 [4]. After the end of the civil war and the departure of the industrial vessels, the coastal fishery resources in the Liberian coastal waters have mostly been exploited by the Kru and Fanti that seem to be generally inefficient and lacking in appropriate harvesting technology to fully utilize the fish resources in the Liberian coastal waters. During the civil war, there was a long period of underinvestment in new harvesting technology in the coastal fisheries. A considerable proportion of the small-scale Kru and Fanti boats are old (i.e., ≥10 years) (see, Figures S3 and S4) and in bad shape, because they have passed what can be considered their average lifespan (i.e., 6–7 year) [41] and gained extra weight over time by absorbing water, which makes them difficult to paddle. There has been a considerable growth in the Kru fleet, albeit with smaller canoes. The Fanti boats are larger and, given that their keel must be made of a single piece of big forest wood, is a major problem which may explain why there has been no growth in this fleet in recent years [4]. It seems that the investment of small-scale Kru operators over recent years has been in low technology that is not working so well, whereas the Fantis find themselves in a situation where they do not have access to the required raw materials for new boats. This indicates a technical regression which impacts the livelihoods of all those involved in the SSF in Liberia.

However, the limited scope these traditional boats offer to improve harvesting technology indicates a significant need for a technological leap in the SSF in Liberia. Alternative technologies that might be employed in the coastal fisheries that will both improve the profitability and livelihoods of the small-scale operators should be explored. In this case, therefore, it seems advisable for the government to introduce new harvesting technology such as fiberglass reinforced plastic (FRP) vessels comparable to those in Iceland, Nigeria, and elsewhere in the SSF sector [15,42–44]. In recent decades, FRP fishing vessels have gradually been introduced into fishing communities globally as alternative material for shrinking forest resources used to build traditional small-scale fishing boats [15,42,43]. FRP boats are reported to have a longer hull life, less maintenance costs, and are 27% lighter than comparable traditional wooden boats [15,42,43]. The question is whether the small-scale operators will be willing to adopt new technology. Small-scale operators' attitudes toward changes are usually positive if they are convinced that the change will have positive effects on their fishing and livelihoods [44]. Inputs such as capital stock and fuel have significant positive effects on productivity (Table 2). These results could be presented and discussed with operators in the SSF to improve their understanding of efficiency.

4. Conclusions and Policy Recommendation

Analysis of the differences in technical efficiencies of the Kru and Fanti fleets in Liberia indicates considerable heterogeneities in terms of the operational and technical aspects such as the quantity of inputs used and output produced. Input quantities such as capital stock and labor (crew) used, and output produced by the Fantis were on average much higher than their Kru counterparts. The technical efficiency scores of about 28% of the observed Kru canoes ranged between 0.61 and 0.80, whereas approximately 44% of the Fanti boats' technical efficiency indices falls into the same bracket. A considerable proportion of the small-scale fleets appear to have potential for improvement in their productivity, considering the present low level of technologies and the state of the fishery resources.

There were efficient boats and inefficient boats among the Kru and Fanti, but on average they were profitable [4]. This may be the reason for the growth trend in the Kru fleet at the end of the war and following the Liberian government's establishment of a zoning policy in 2010, although the Fantis have remained quite constant. The trawlers' exit from the coastal fisheries after the war and the Liberian government's zoning policy in 2010 seems to correspond with an increase in both the catch and number of small-scale Kru and Fanti vessels. While the small-scale fleets increased by nine times on average, their catch only doubled for the period, indicating a significant level of inefficiency in the SSF. However, given the traditional dugout construction of these boats, a low-level technology that has not been working very well, and the problem associated with the sourcing of raw materials used for their construction, there is a risk of technological regression in the SSF. This again leads to an ever more limited ability to invest in and adopt improved harvesting technologies. It seems, therefore, that there is a need for a technical leap in the coastal fisheries in Liberia.

Vessel length and skipper age appear to be the two major factors that influence the technical efficiency of the small-scale fleets. The technical efficiency of the Kru canoes decreases significantly with an increase in canoe length and skipper age, whereas for the Fanti boats it increases with an increase in boat length and skipper age. This indicates that younger skippers ($\leq$40 years), employing newer and smaller dugout Kru canoes ($\leq$6.1 m), seem to be more efficient than older operators (>40 years) using older and larger canoes. Although it is possible to fish with hook and line from small canoes, it is more difficult to use small vessels when ring nets are deployed. This is intriguing and suggests it might be easier to operate Kru canoes, since running a typical Kru canoe just requires muscle power to propel, which is why younger skippers do better than older skippers. It is more difficult to run a Fanti boat, therefore experience and the size of the vessel matter.

Capital stock, labor, and bait used had positive effects on the output of Kru canoes, but only capital stock had a significant effect. For the Fanti boats, capital and fuel used had significant positive effects on their output. There seems to be IRS for the Kru and Fanti boats, but the Kru canoes were observed to be 0.25 higher. This indicates that when use of all three input variables (i.e., capital stock, labor, bait or fuel) were to be increased by around 10%, output (i.e., catch trip^{-1}) would increase by around 15%, assuming constant stock abundance.

Jueseah et al. [17] found that Kru operators received a price premium from hoteliers for high quality (fresh) cassava fish landed in Liberia. In order to land high quality fish, the small-scale vessels need space onboard for chillers, but the evolution of Kru and Fanti fleet is moving towards smaller vessels (see, Figures S3 and S4). Larger and more efficient vessels, such as FRP boats, would make it possible to improve the quality of the landed fish and efficiency (profitability). There is, however, a likely trade-off between quantity and quality of the landed fish, that would, in turn, affect prices and profitability e.g., see [45]. For instance, it is possible that the technically most efficient vessel may land large quantity of low-quality fish, but may still be more profitable than a less efficient vessel that lands fish of high-quality and receive better prices e.g., see [45]. This certainly has implications for value-adding and marketing in subsequent links of the value chain [45] and calls for further research when examining alternative fishing vessels and harvesting technologies for the current traditional Kru and Fanti boats in Liberia.

Certain policy interventions might be feasible to improve technical efficiency and profitability of the small-scale fleets in Liberia. For instance, the government could explore, promote, and introduce new harvesting technology such as FRP boats to both increase the productivity and profitability of the SSF. We think such intervention might help to address the current technical regression in the fisheries and utilize the coastal fishing resources better in Liberia. Nevertheless, problems arise when it comes to accepting the socio-economic costs embedded in the technological innovation. For example, a change towards the use of new FRP vessels or increased motorization is not just a question of technically managing the capital stock but also means changing the management of finances in terms of savings for future reinvestment and perhaps altering the labor patterns to maximize the employment of the capital stock [44]. Moreover, it may mean a need to produce (harvest) more and sell most of the catch. It normally leads to modifications in the attitudes towards technological innovations when these hidden features become evident [44].

To deal with the challenge associated with the introduction of a new harvesting technologies, it is best at the pilot level to elect an entrepreneur strategy. The government could select individual boat owners/skippers who, to a certain extent, are marginal in the fishing community [44]. They could be teachers, farmers, carpenters, traders, among others, and they should be allowed to choose their own crew. They must, at the onset, demonstrate clear interests in investing in the fishing industry. This strategy is largely based on the assumption that, as entrepreneurs, individuals (i.e., boats owners/skippers) would typically act economically more easily and in accordance with the requirements of the new harvesting technology [44]. This strategy has been reported to be successful in northern Angola [44]. The government should also endeavor to train Kru and Fanti operators in the technical and business management aspects of their fishing enterprises. Small-scale boat operators require enhanced enterprise management knowledge and skills as fishing becomes more market driven [46]. In this case, the government needs to improve the working environment for the small-scale fleets to operate in, aiming to make them willing and able to invest in new harvesting technologies that improve efficiency and safety.

Supplementary Materials: The following are available online at https://www.mdpi.com/article/10.3390/su13147767/s1, Figure S1: Changes in coastal fleets in Liberia, Figure S2: Catch development of the Liberian coastal fleets, Figure S3: Variability in length by age of Kru canoes, Figure S4: Variability in length by age of Fanti boats, Table S1: Generalized likelihood test ratio tests of hypothesis for parameters of SPF.

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Paper IV

Paper IV

A CRITICAL REVIEW OF THE LIBERIAN FISHERIES SECTOR: A TECHNICAL REPORT

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EXECUTIVE SUMMARY

Liberia is amongst the poorest countries in the world with an exclusive economic zone (EEZ) of 246,000 km^2 and a 579 km coastline. Fisheries are a source of food and nutrition security, livelihoods for several thousand Liberians, revenues and foreign exchange for government and account for 3% of GDP. Six major exploitable fish stock complexes include small, medium and large pelagics, shallow- and deep-water demersals as well as crustaceans. These stock complexes are exploited by two small-scale fleets i.e. Kru and Fanti, a costal industrial fleet, and an offshore industrial fleet at various extents.

Over the years, major policy documents have been prepared and adopted to guide development in the fisheries sector in Liberia, primarily focusing on sustainable management of the fisheries resources and value-addition. Recent empirical analyses have, however, shown that the sector has not been performing well in terms of profitability, fleet development, and value-addition in the post-harvest sector. This paper reviews the evolution of the Liberian fisheries and evaluates the performance of the sector in light of the current policies.

Fisheries statistics, both catch and effort data prior to and during the civil war period (1989-2003) are unreliable but appear to have been improving in recent years. The small and medium pelagic stocks in the Liberian coastal waters are considered to be moderately to lightly exploited. Even so the Fanti fleet which is generally profitable and targets the small pelagics has remained fairly constant in recent years, possibly because of limited availability of large trees needed for their construction. The offshore large pelagic fishery resources such as the tuna and tuna-like species are managed at the regional level by the International Commission for the Conservation of Atlantic Tunas and Liberia practically has no control over this stock.

The shallow-water demersals have been found to be overexploited, while the deep water demersal are considered to be moderately to fully exploited. The fleet of Kru canoes who primarily target shallow-water demersals has grown fast and was in 2020 around 11 times larger than it was at the end of the civil war in 2003, which may be the reason for the current overutilized state of this stock.

Crustacean species of commercial importance include shrimps, crabs, and lobsters. The collapse of the Liberian lucrative shrimp fishery in the early 1980s appears to be more associated with security and political issues as opposed to a fishery collapse. Today there is hardly any industrial shrimp fishery operating in Liberia perhaps because of the less availability of shrimp due to

environmental changes or because of the changes in policy in 2010 which restricts industrial trawling inside six nm where the coastal shrimp resources are most abundant. This seems to have resulted in underutilization of the coastal shrimp resources in Liberia.

The coastal shrimps and deep-water demersals are valuable stocks that are possibly underutilized in Liberia. In the 1970s, maximum economic yield (MEY) for the coastal shrimp resources was estimated at 800 tons for 14 vessels, valued at US$ 5.7 million. Today, the landed value of 800 tons of shrimp at US$ 10,200 ton^{-1} would be around US$ 8.2 million. It seems the same applies to the deep water demersals. The deep water demersal seem to be underutilized, but it is uncertain whether the stock is of economic quantity to benefit the Liberian society. It is possible that there may be some more stock there than recently estimated. This is something the government might want to look into and would probably be money well spent.

In this report, a conceptual model for evaluating the cost and benefit of management for different types of fisheries (fleets) is presented and management options discussed in this light. It is argued that it may be difficult to implement an economically efficient management for SSF, where the cost of management may be greater than the benefit. This may explain why SSF seem generally to be unmanageable, and this may also be the case for the Liberian coastal SSF. The design and nature of the Kru and Fanti vessels in terms of the small size boats, the primitive harvesting technology used, their disperse and sheer numbers as well as the unpredictable nature of informal operations, make practical economically efficient management quite challenging. There seem to be a substantial efficiency problem in the SSF in Liberia. However, empirical analysis only gave an indication that vessel length and skipper's age may be the cause of this observation in the SSF in Liberia.

Due to the open access nature of SSF, incremental improvements are unlikely to generate long-term net benefits for the society. Economically efficient management of many small-size unsophisticated small-scale vessels, such as the Kru canoes in Liberia, may therefore not be worth the required effort. All costs and benefits associated with management of each fishery (fleet) need to be estimated before a decision to manage is taken. This certainly would, however, depend on the government's intended management outcome(s) i.e. biological (maximum fish production) or social (short-term employment) or economic efficiency (rent generation/efficiency), for the fishery right from the outset. Still, fisheries managed successfully for economic efficiency have been reported to increase value-addition and the sector's contribution to GDP and growth as well as better biological and social outcomes.

Progress is noted in most of the policy areas in Liberia including (i) fisheries improvement (ii) sustainable management of fisheries resources and ecosystems (iii) strengthening of fisheries management and development capacities; and (iv) enhancement of value-addition, marketing and fish trade. Despite the progress made in these four policy areas, empirical analyses have shown there is lot more to do and suggest certain policy measures be adopted to improve the fisheries sector performance. Annual catch in the SSF has increased by 58% year^{-1} between 2018-2020. This increase, however, can also be attributed to a new data collection system implemented for the SSF and makes it difficult to gage the real improvement. There have been improvements in sustainable fisheries management (governance) in terms of licensing and vessels registration, regulated harvesting, establishment of Co-Management Associations (CMAs), engagement with Regional Fisheries Management Organizations (RFMOs) and effective Monitoring Control and Surveillance (MCS).

Fisheries management and development capacities have been strengthened by the establishment of the National Fisheries and Aquaculture Authority (NaFAA), an autonomous authority, which replaced the former Bureau of National Fisheries. Human resource capacity and administrative processes have somewhat improved although it still persists as a major constraint, and new fisheries law and new fisheries regulations have been approved. Financial stability to some extent has been achieved at NaFAA through engagement with the European Union (EU) Sustainable Fisheries Partnership Agreement (SFPA) among other sources, although the SFPA with the EU was not renewed on December 15, 2020, due to a yellow card issue.

For progress made in the enhancement of value-addition, marketing and fish trade, a fish landing site cluster has been established and there are plans to establish new ones in selected coastal counties under Liberia Sustainable Management of Fisheries Project (LSMFIP). The strategies to achieve the goal(s) of increasing domestic fish supply by 2023 are not outlined in the Pro-poor Agenda for Prosperity and Development (PAPD), while the current development trend of the small-scale fleet, especially the Kru canoes, seem inconsistent with sustainable management of fisheries resources and ecosystems. The fish value chain in Liberia is typified by poor handling of the catch both onboard and ashore, with implications for value-adding and marketing in subsequent links, and lack of transparency which stems from power asymmetries and lack of information flow in the SSF value chain.

The policy action framework lacks implementation costs, which makes it difficult to determine the management costs linked to these improvements. Typically, fisheries management costs linked to implementing fisheries policy and enforcement of rules can be quite substantial ranging between 3-25% of the gross value of the landings. While implementing management may be regarded as progress for the fishery based on past experiences, it could be a net cost to society for certain fisheries (fleets) such as the SSF as management costs seem to be sensitive to the number and size of the vessels as argued in the conceptual model. In order to improve the performance of the Liberian fisheries sector, the following recommendations are advanced for the government (NaFAA) to look into.

Conduct stock and economic assessments for coastal shrimp and deep-water demersal stocks

The coastal shrimp resources and the deep water demersals may be larger than previous analyses have indicated, and they are almost certainly under-exploited. It seems, therefore, worthwhile that the government look into conducting national stock assessments (survey) and economic analyses for the coastal shrimp resources and the deep water demersals to determine both stocks abundances and value of these resources. If the survey for the coastal shrimps shows the stock is abundant i.e. there is good economic quantity of the resource, then the government can determine a way to optimally exploit the shrimp stock. In this case, the management of the resource should be organized in such a way that the fishery (fleet) is manageable as argued in the conceptual model, using few well equipped vessels for the operation. The goal here is to focus on a management structure that generates greater benefits for the Liberian society. The same applies to the deep water demersals. If a survey establishes that there is economic resource (quantity) that could be exploited, the management of the resource should be arranged in such a way that the fishery (fleet) is manageable as illustrated in the conceptual model.

Management of the small-scale fisheries and fleets

While it has been shown that substantial benefits could be derived from management of the small-scale fleet (i.e. reducing the number of Kru canoes) in Liberia, managing small-size primitive vessels with unpredictable informal operations may not be worth the economic effort that would be required. The option to phase out the Kru canoes should be looked into due to conflict with forestry or perhaps because they are unmanageable economically. The first step could be to stop issuing new fishing licenses and registration numbers to Kru canoes. If the Kru can be phased out, the government should explore the feasibility of introducing new harvesting technology like fiberglass reinforced plastic (FRP) vessels to both increase productivity and profitability in the Liberian fishing industry. There should, however, be an economic evaluation of any option to phase out the current small-scale fleet to shed light on the socio-economic implications of this policy. There are indications that most of the Kru and Fanti boats are inefficient and lacking appropriate technologies to harvest the valuable deep-water demersals and the coastal shrimp resources in Liberia as well as the medium and large pelagics offshore. The introduction of FRP vessels might help to address the current technical regress in the fishing industry and utilize the coastal fishery resources i.e. deep water demersals, coastal shrimps, medium and large pelagics, better in Liberia. Larger and more efficient vessels, such as FRP vessels, might make it possible to improve efficiency and the quality of the landed fish. Still, if there is going to be a technological leap in the fishery, one has to remember that this leap should be within the manageable area as argued in the conceptual model. This means the vessels have to be sufficiently big so that the fishery that emerges is manageable and capable of generating greater benefits for the Liberian society.

Establish basic fisheries infrastructure

The absence of basic fisheries infrastructure contributes to the poor handling of the landed catch in the SSF value chain. Interventions such as provision of basic fisheries infrastructure might address issue related to poor handling of the catch both onboard and ashore and improve value-addition services in the SSF value chain. It is, therefore, advisable that the government look into establishing critical fisheries infrastructure such as ice and chill facilities, suitable sanitary facilities, and hands-on training, to enhance value-addition services in the SSF value chain.

Establish access to financial services

Lack of transparency in the SSF value chain has resulted in captive or hierarchy relationships, and lower price and benefits for fishermen than if they were in a market relationship with the middlemen. In order to tackle the lack of transparency in the value chain, government could create access to financial services for the SSF subsector such as less demanding and restrictive microloans as an alternative source of finance and increase access to information in the value chain from end-markets to the fishermen. The establishment of a single fish selling desk that represents the interests of the fishermen might address the current lack of information. Access to financial services might also give the fishermen access to the necessary investment finance to purchase improved harvesting technologies which are needed in the fisheries to increase efficiency and profitability.

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1.0 INTRODUCTION

Liberia, situated on the west coast of Africa, is bounded with Sierra Leone to the west, Cote D'Ivoire to the east, Guinea to the north and the Atlantic Ocean to the south with a coastline of 579 km. Liberia is among the poorest countries in the world and has an exclusive economic zone (EEZ) of 246,000 km^2, slightly larger than its closest neighbors Sierra Leone and the Ivory Coast (MRAG 2013, Chu et al. 2017). The fisheries are conducted in the coastal and offshore waters at small and industrial scales, using multiple fishing craft and methods (Ministry of Agriculture 2014; MRAG 2014; Chu et al, 2017).

The coastal fisheries are conducted on the continental shelf, which is on average 36 km wide, narrower in the north between Monrovia and Robertsport with trawling grounds down to 800 m, and wider in the south between Monrovia and Ivory Coast (Ssentongo 1987). The coastal waters are within the Guinea Current Large Marine Ecosystem and are generally warm (>24 °C) and permanently stratified with low salinity levels (< 35‰). The lack of vertical mixing of waters and low nutrient levels are reflected in relatively poor productivity (Ssentongo 1987).

There are six exploitable fish stock complexes in the Liberian waters including small, medium, and large pelagics, shallow- and deep-water demersals and crustaceans (MRAG 2014). The stock complexes are targeted by two coastal small-scale fishing fleets i.e. the Kru and Fanti vessels, a coastal industrial fleet as well as an offshore fleet.

The local Kru fleet consists mainly of non-motorized (paddle/sails) canoes 12-33 ft long with a crew of 1-4 (Jueseah et al. 2021). Operators of Kru canoes mostly deploy handlines and gillnets and target shallow-water demersal stocks above the thermocline, and deep-water demersal stocks below the thermocline (Ssentongo 1987). Kru canoes, using traps and gillnets, also to a lesser extent target some crustaceans, primarily lobsters and crabs (Jueseah et al, 2020b). The Fanti fleet, mostly operated by migrant fishermen from Ghana, consists of larger open wooden boats around 15-71 ft long generally propelled by outboard or inboard engines with 4-26 crew (Chu et al, 2017; Jueseah et al, 2021). Fantis mainly employ ring nets and target small pelagic stocks. Operators of Kru and Fanti vessels, to a much lesser extent, also catch some large and medium size pelagic species. Since 2010, the small-scale Kru and Fanti vessels have had exclusive access up to six nautical miles (nm) offshore, although they also may fish further out.

The coastal industrial fleet consists mostly of trawlers that employ bottom and mid-water trawls and target shallow- and deep-waters demersal finfishes, such as those targeted by the Kru, and coastal shrimp (MRAG 2013). The coastal trawlers have in recent years increasingly used mid-water trawls targeting small- and medium pelagics. The offshore fleet comprises large industrial tuna vessels that employ multiple fishing methods but primarily purse seines and target mostly large pelagic species (MRAG 2014). Most of these vessels are from EU countries fishing under Sustainable Fisheries Partnership Agreement (SFPA).

The fishing industry plays a major role in the Liberian economy. Today, fisheries are a prime source of food and nutritional security, where fish provides 65% of the animal protein consumed with average annual consumption per capita of 6 kg,[1] livelihoods for several thousand Liberians, revenues and foreign exchange for government and accounts for around 3.2% of GDP (Ministry of Agriculture 2014; Yokie 2019; Sherif 2019). Because of the high rate of unemployment and the open access regime of the SSF, the fisheries sector is regarded as a buffer for many jobless young Liberians (Togba 2008; Belhabib et al. 2016). In the past two decades, the coastal fisheries catch has ranged between 7,083 to 32,373 tons year^{-1} and averaged around 20,803 tons year^{-1}. The local catch is mostly supplied to the domestic markets but shortages in fish supply are supplemented by imports (MRAG 2013).

When the fisheries expanded in the early 1980s and before the civil war started in 1989, the governments had weak administrative capacity, was lacking trained personnel and managerial competence, and corruption was widespread. During the periods of the prolonged civil war which lasted until 2003, fisheries monitoring and research basically came to a halt resulting in a situation where very little was known about the fisheries and the status of stocks or the marine ecosystem in general (World Bank 2007; Ministry of Agriculture 2014; Belhabib et al. 2016). Data from this time are at best unreliable.

Over the years, key policies have been formulated and adopted by the government to guide developments in the fisheries sector (see e.g., Ministry of Agriculture 2014; Republic of Liberia 2018). Policies have mostly aimed at sustainable management of the fishery resources, strengthening of fisheries governance capacities, and improvement in value-addition activities (Ministry of Agriculture 2014; Republic of Liberia 2018). Recent studies by the author have

[1] FAO Fisheries & Aquaculture - Fishery and Aquaculture Country Profiles - The Republic of Liberia. Accessed 06.18.2021.

indicated that the Liberian fishing industry has not been performing well in terms of profitability and fleet development, level of harvesting technology used and value-addition in the post-harvest sector (see, Jueseah et al, 2020a, Jueseah et al, 2020b; Jueseah et al, 2021).

This paper aims to critically review the development of the Liberian fisheries and evaluate the performance of the sector in light of current policies. Key national development policy documents will be reviewed, i.e. the Pro-poor Agenda for Prosperity and Development (PAPD), which outlines a five-year (July 2018-June 2023) development plan priorities for Liberia (Republic of Liberia 2018), and the current Fisheries and Aquaculture Policy and Strategies (FAPS) (Ministry of Agriculture 2014), which states the overall goals and key objectives for sustainable utilization of the fisheries resources.

The report is in five parts. Section 2 describes and gives a background of the fisheries sector in Liberia. The main fish stocks and catches, development of the fleets, the status of stocks, the fishery value chain and governance of the fisheries sector are presented and discussed. A conceptual model of the costs and benefits of fisheries management is developed and discussed in section three. This model is then used to evaluate management options of the different fisheries (fleets). In section four, the performance of the existing national fisheries policies and supporting strategies are presented. The PAPD goals are first reviewed followed by the vision for the fisheries sector. This is followed by the review of the goal and key objectives of the current FAPS for sustainable utilization of the fisheries resources in Liberia. The progress made since the implementation of the policies in 2014 is reviewed. The conclusions and policy recommendations are presented in section five.

2.0 FISHERIES BACKGROUND

In this section, the key stocks and development of the fleets are first presented and discussed, followed by the state of the stocks, the fishery value chain, and the governance of the fisheries sector.

2.1 MAIN FISH SPECIES AND CATCH

The small, medium, and large pelagics, shallow- and deep-water demersal and crustaceans are groups of species that occur only within the Liberian waters or are part of larger sub-regional or reginal stocks (MRAG 2014). Small-pelagics range between 12-25 cm total length and are primarily caught in coastal waters mostly where the depth is around 40–70 m (Boyer et al, 2017) and include bonny (*Sardinella spp.*), porjoe (*Chloroscombrus chrysurus*) and flying fish (*Cheilopogon melanurus*) (MRAG 2014). The medium pelagics, vary between 18-55 cm with a modal length of 41 cm, are found in turbid coastal and offshore waters and typically caught in areas straddling the thermocline around 0-40 m depth and include pike fish (*Sphyraena spp.*) and barracuda (*Sphyraena barracuda*) (Boyer et al, 2017). The large pelagics typically occur in offshore waters at 0-300 m depth and include tuna and tuna-like species such as yellowfin (*Thunnus albacares*), bigeye (*Thunnus abesus*) and skipjack (*Katsuwonus pelamis)* tunas, swordfish (*Xiphias gladius*), marlin (*Istiophoridae*), hammerhead shark (*Sphyrnidae*) and ray species (Fonteneau and Marcille 1993; MRAG 2014)

The main shallow-water demersal species are cassava fish (*Pseudotolithus spp.*), butternose (*Galeoides decadactylus*), solefish (*Cynoglossus spp.*) and catfish (*Arius spp.*), whereas deep-water demersals include groupers (*Epinephalus spp.*), snappers (*Lutjanus spp.*), grunts (*Pomadasys spp.*) and sparids (*Dentex spp*) (MRAG 2014). The shallow water demersals are usually caught at ≤ 30 m depth, but the deep water demersals are primarily found at depths ≥30 m (MRAG 2014). Crustaceans primarily occur in inshore waters mostly at 30–60 m depth (FAO 2001). Main species include the coastal shrimp (*Penaeus notialis*), deep-water shrimp (*Parapenaeus longirostris*), marine crab (*Callinectes sapidus*) and tropical spiny lobster (*Panulirus ornatus*) (MRAG 2014).

Based on published FAO data, catch landed in Liberia ranged from 6,463 to 18,731 tons year^{-1} in 1980-2019 (Figure 1). Total catch increased in the 1980s reaching a peak in 1987 of about 18,700 tons. Landings then decreased sharply, especially following the onset of the civil war to a low of 6,500 tons in 1990. Since then FAO has reported catches ranging from 7,000 to 16,000 tons, ranging from 12,000 to 16,000 tons in the last nine years (Figure 1). NaFAA catch statistics available from 2001 indicate similar catches as reported by FAO in 2009-2012, but about double the catches reported by FAO in all other years (Figure 1). The biggest catches of about 32,000 tons reported by NaFAA, have been attributed to changes in the data collection system for the SSF (MRAG 2014).

During and immediately after the civil war, Liberia's capacity to monitor its fisheries was almost non-existent (MRAG 2005; Ministry of Agriculture 2014; Belhabib et al. 2016). Catch data reported by FAO for Liberia, during these periods, can be said to be educated guesses (Belhabib et al. 2016). Reconstruction of the small-scale fishing effort from 1950-2010 based on ethnic affiliation i.e. Kru and Fanti fleet, and their catch per unit effort was 66% higher than estimates of the coastal catches supplied by Liberia (NaFAA) to FAO (Belhabib et al. 2016).

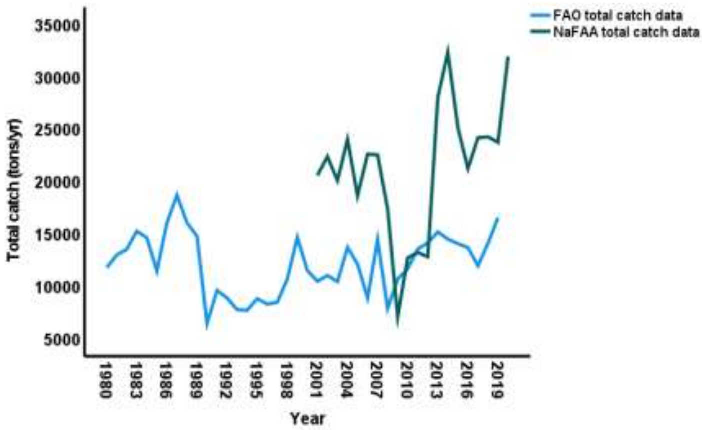

Figure 1. Liberia marine fishery production between 1980-2020.
Source: FAO[2] (1980-2019), NaFAA statistics (2001-2020)

In the sections that follow, the fleets targeting the fishery resources and the state of the main stocks in the Liberia coastal waters are described in detail. Because the total catch data from FAO are generally not disaggregated by fleets, the disaggregated catch and vessel data used in the sections that follow were obtained from multiple sources as indicated in the text.

2.2 FISHING FLEETS

This section discusses the structure and development of the fishing fleets in Liberia which can be divided into the small-scale Kru and Fanti and the coastal and offshore industrial vessels. The types of vessels, fishing methods use, major species targeted, and annual catch developments of the fleets are presented and discussed.

[2] FAO Fisheries & Aquaculture - Fishery and Aquaculture Country Profiles - The Republic of Liberia. Accessed 29.03.2021.

2.2.1 SMALL-SCALE FLEET

There are two main types of small-scale fishing fleets i.e. Kru and Fanti, that operate in the coastal waters of Liberia. The Kru operate on average 22 ft dugout canoes with 1 to 4 crew typically propelled by sails and/or paddles (Chu et al. 2017). Most authors refer to them as Kru fishermen mainly because of the type of dugout canoe they operate but they may be a mix of people belonging to several local tribes such as Kru, Bassa, Grabo and Vai (MRAG 2013). Operators of Kru canoes employ a range of fishing methods but mostly use hook and lines, longlines, gill nets, cast nets and traps and mainly target the shallow and deep waters demersal fish species such as cassava fish, butter-nose, sole-fish above the thermocline and sparids groupers, snappers, and grunters below the thermocline (Ssentongo 1983; MRAG 2014; World Bank 2015). They also target some crustacean species, mostly crabs and lobsters, using gill nets and traps (Chu and Meredith 2015; Jueseah et al. 2020b).

Today, there are over 3,800 Kru canoes operating in the SSF in Liberia, having increased from <50 canoes in 1960 to around 3,815 in 2019 (Figure 2a). Development of the Kru fleet has mainly been driven by profitability (Jueseah et al, 2020b). Kru canoes have limited ability to exploit deep-water demersal stocks and coastal shrimp resources as they are not able to apply appropriate harvesting technologies to do so (Jueseah et al, 2021).

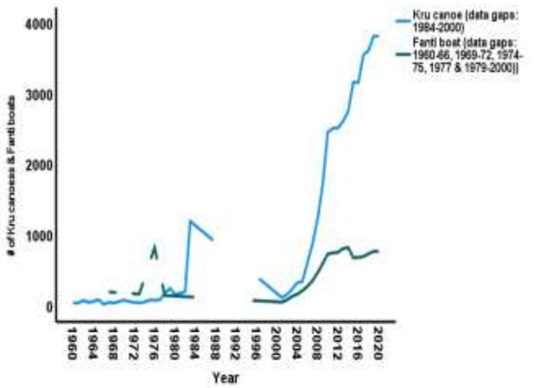

Figure 2a. Small-scale Kru and Fanti boats development trend.
Source: Shotton (1983), Ssentongo (1983), NaFAA Statistics (2001-2020)

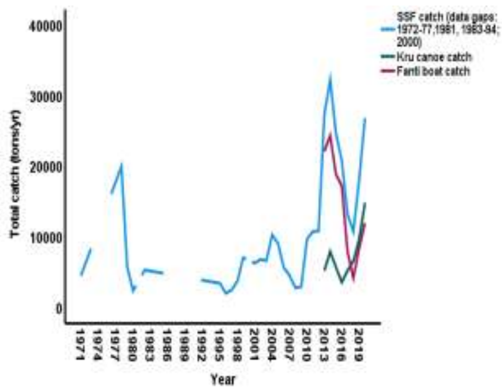

Figure 2b. Liberia SSF total catch overtime.
Source: Shotton (1983) (1971-1980, 1982), FAO[3] (1995-1999) NaFAA Statistics (2001-2020)

[3] FAO fishery country profile - the republic of Liberia (africanmarineatlas.org). Accessed 29.03.2021.

The Fantis are mainly Ghanaians who operate larger open wooden boats, with the keel and lower part of the boat constructed from a single tree trunk. These vessels mostly range from 15-71 ft in length. They have 4-26 crew and are propelled by 9-40 hp outboard and/or inboard engines (Chu et al, 2017). The Fantis mostly deploy large ring nets and target small-pelagics like bonny, porjoe, and Atlantic flying fish (MRAG 2014; Chu and Meredith 2015; Chu et al, 2017). Operators of Fanti boats also target some shallow- and deep-waters demersals using gill nets, set nets and handlines, (Chu and Meredith 2015; Chu et al, 2017). Kru and Fanti operators also catch some medium and large pelagics, but to a much lesser extent (MRAG 2014; Chu and Meredith 2015; Chu et al, 2017). The number of Fanti boats grew steadily from 200 in 1967 to 737 in 2010 but since then their numbers have been fairly stable (Figure 2a). The Fanti fleet is quite profitable, but its expansion since 2011 has been constrained by the lack of access to the required raw materials (big forest trees) used to build the keel of the boats (Jueseah et al, 2021).

There are large fluctuations in the SSF catch which can mostly be attributed to fluctuations in catches of small pelagics targeted by the Fanti (Figure 2b). Small pelagic species are short-lived and their stock sizes fluctuate greatly. These species are sensitive to environmental variations, such as upwelling, salinity and temperature, which can cause large fluctuations in year class strength. The entire catch from the SSF is consumed locally. Between 2013-2020 the Fanti accounted for around 63% of the total SSF catch and great fluctuations in the pelagic stocks have thus considerable impact on the food security of the local population which is further accentuated by poor post-harvest handling (Jueseah et al, 2020a).

2.2.2 INDUSTRIAL FLEET

The industrial fleet consists of coastal trawl and offshore large pelagic (tuna) vessels (MRAG 2013; Ministry of Agriculture 2014). Since 2008, however, there has been a marked decrease in the number of coastal trawlers and since 2013 there have been on average five coastal industrial vessels (Figure 3a) which are mostly owned by foreigners from Europe i.e. Spain, Greece and Russia, and China, who operate through joint ventures with locally registered fishing firms (MRAG 2013)

During the civil war, governance in the fisheries sector was nonexistent and fishing was generally unregulated resulting in rampant IUU fishing (Braimah 2012). Since 2004, successive governments have concentrated on governance of the fisheries sector resulting in considerable disinvestment (exits) in the coastal industrial fishery (Figure 3a) (Chu et al, 2017; Jueseah et al, 2020b). Due to a key policy change in 2010, reserving a 6 mile zone for the SSF, the trawlers have no access to most of their main target species such as shallow water demersals and the coastal shrimp (Chu et al, 2017; Jueseah et al, 2020b). This has caused the coastal trawlers to increasingly target pelagic species resulting in a large increase in the trawlers total catch (Figure 3b). The coastal trawlers supply most of their catch to the local market as frozen whole fish, but some is also exported (MRAG 2013; Ministry of Agriculture 2014).

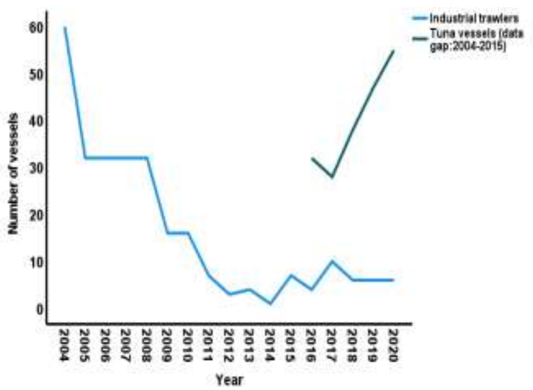

Figure 3a. Number of registered coastal trawlers and tuna vessels in Liberian waters 2004-2020.
Source: NaFAA Statistics

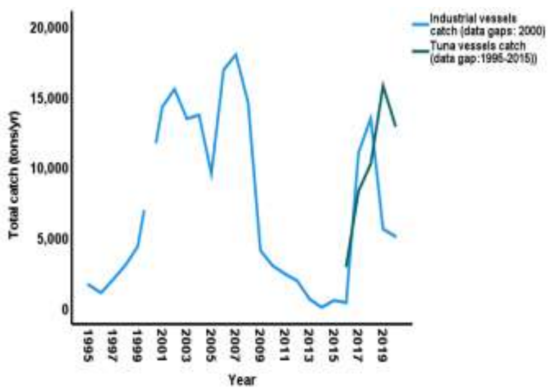

Figure 3b. Total catch of coastal trawlers and tuna vessels (1995-2020)
Source: FAO[4](1995-1999) & NaFAA Statistics (2001-2020).

Prior to 2016, all activities of the offshore tuna vessels operating in the Liberian EEZ were regarded as IUU mostly due to poor governance (Braimah 2012). Due to the governance reforms introduced by the Liberian Government in 2010, government revenues from fisheries grew from U$ 400,000 in 2011 to U$ 6 million in 2013, derived mainly from fines for violations of the new fisheries regulations (Ministry of Agriculture 2010).

Since 2016, the offshore tuna fleet has mostly consisted of large industrial vessels operating through SFPA with the EU (EU et al, 2020). They deploy multiple fishing methods including purse seines, longlines and pole and lines and mainly target tropical tuna and tuna-like species all year round (EU et al, 2020). The total catch of the offshore tuna fleet rose from 3,025 tons in 2016 to

[4] FAO Fishery Country Profile - the republic of Liberia (africanmarineatlas.org). Accessed 29.03.2021.

15,798 tons in 2019 but declined again to 12,993 tons in 2020 (Figure 3b). The catch is not landed in Liberia mostly due to limited infrastructure and weak local demand for tuna. Due to an unresolved yellow-card issue between Liberia and the EU, the EU tuna fleet left Liberian waters on December 8, 2020[5].

2.3 STATE OF THE RESOURCES

Information on the status of stocks and their productivity can be inferred from the analysis of data collected from the fisheries and from fisheries independent surveys reviewed in this section.

2.3.1 PELAGIC STOCKS

In 1981, surveys using the Soviet R/V Belagorsk and the Norwegian R/V Dr. Fridtjof Nansen were carried out to estimate the fish stocks on the continental shelf of Liberia (shotton 1983; Ssentongo 1983). The Soviet estimated the biomass of the pelagic stocks at 43,000 tons, while the Norwegian survey estimated it at 136,700 tons (Shotton 1983; Ssentongo 1983). Further surveys conducted by the Nansen program in 2006, 2007 and 2017 showed a reduction by an order of magnitude in the biomass of medium and small pelagics from 2006 to 2007 which cannot be explained by fishing according to the available catch statistics. Biomass estimates of the small pelagic species *Sardinella* and *Anchovy* mainly targeted by the Fantis vary less but the estimates doubled from 2006 to 2007, but were again reduced to 13000 tons in 2017, a third of the 2007 estimate (Table 1). The variation in abundance estimates of the pelagic stocks may be because of poor coverage. For instance, the most recent Nansen survey in 2017 lasted for only six days (i.e. August 11-17, 2017) (Boyer et al, 2017), but it can also to some extent be due to the different time of year the surveys were conducted and partly due to the migratory nature of the stock (Boyer et al, 2017). However, this may also be due to differences in recruitment, environmental variability or harvesting strategies of the fleets (Boyer et al, 2017), although the stark differences between the small and medium pelagic stocks do not support this suggestion.

[5] Liberia (europa.eu). Accessed 07.13.2021.

Table 1: Biomass estimates of pelagic fish stocks in Liberia based on R/V Dr. Fridtjof Nansen surveys in 2006, 2007 & 2017.

	Biomass estimate (tons)		
Stock	**2006**	**2007**	**2017**
Sardinella & anchovy	25,000	48,000	16,000
Carangids, scombrids, barracudas and hairtails	127,000	16,000	13,000
Total	**152,000**	**64,000**	**29,000**

Source: Boyer et al, (2017)

Biomass estimates of small and medium pelagics based on catch and effort data from 2013-2014 (MRAG 2014) and 2013-2016 (Jueseah et al 2020b) were similar, 70,000-80,000 tons for small pelagics and 25,000-30,000 tons for medium pelagics (Table 2), which is much higher than was indicated from the survey in 2017 (Boyer et al, 2017), with small pelagic stock of 16,000 tons and medium pelagics with 13,000 tons (Table 1).

Table 2: Biomass and MSY estimates of pelagic fish stocks in Liberia using catch & effort data in 2014 & 2020

Stock	**Biomass estimate (tons) 2014**	**Biomass estimate (tons) 2016**	**MSY estimate (tons) 2014**	**MSY estimate (tons) 2016**	**Stock status 2014/2016**
Small pelagic	79951	68830	17011	9520	moderately exploited
Medium pelagic	28688	25750	4912	3560	lightly exploited
Subtotal	**108,639**	**94,580**	**21,923**	**13,080**	

Source: MRAG (2014) & Jueseah et al, (2020b)

Since 2013 the catch of coastal pelagics has varied between 11,000 and 27,000 tons according to NaFAA data which is roughly four time greater than that reported by FAO (Figure 4) reflecting the lack of quality data on the Liberian fisheries. The pelagic stocks in the Liberian coastal waters have been found to be moderately to lightly exploited (Table 2).

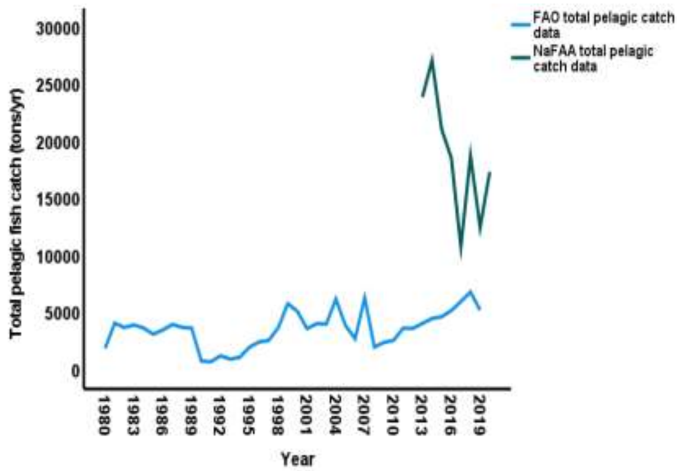

Figure 4. Pelagic species catch over time.
Sources: FAO[6] (1980-2019), NaFAA Statistics (2013-2020)

2.3.2 DEMERSAL STOCKS

The total biomass estimate for the demersal stock in the Liberian coastal waters, based on the Soviet survey in 1981 (AtlantNIRO 1981; Shotton 1983; Ssentongo 1983), was about 11000 tons (Table 3). It seems the survey was mainly carried out at depths below the thermocline. The main shallow-waters demersal species today such as cassava fish (*Pseudotolithus spp.*), butternose (*Galeoides decadactylus*) and solefish (*Cynoglossus spp.*) were not recorded and deep water demersals constituted about 90% of the biomass (Table 3).

Table 3. Biomass estimates of demersal stocks in Liberia based on
Soviet R/V Belagorsk **survey 1981**

Stock	Biomass estimate (tons)
Boops boops (bream) (shallow-water)	800
Pteroscian peli (sparid) (shallow-water)	126
Penthroscion mbisi (shallow-water)	982
Dentex angolensis(deep-water)	3500
Dentex congoensis (deep-water)	3100
Pegellus coupei (deep-water)	200
Epinepheleus gigas (grouper)(deep-water)	185
Epinepheleus aeneu (grouper)(deep-water)	2010
Total	**10,903**

Source: Shotton (1983) & Ssentongo (1983)

[6] FAO Fisheries & Aquaculture - Fishery and Aquaculture Country Profiles - The Republic of Liberia. Accessed 05.25.2021.

In 1981 the biomass estimate of shallow water demersals was only about 1,000 tons, while it was about 9,000 tons for the deep water demersals. This contrasts strongly with biomass estimates for 2014 and 2016 based on catch and effort data where biomass of deep water demersals was estimated at about 3,000 tons and shallow water demersals at 12,000 – 13,000 tons (Table 4). Catch and effort data series used in MRAG (2014) and Jueseah et al, (2020b) are from periods when the coastal trawlers were in relatively poor condition and not well equipped to operate in deeper waters. The low biomass estimate may thus more reflect the status of the fleet than the state of the resource. Ssentongo (1983), based on FAO (1978) and Troadec and Garcia (1980), estimated that the potential yield of the demersal fish stocks in the Liberian waters varied between 9,000 to 15,000 tons year^{-1}.

Table 4: Biomass estimates of demersal fish stocks in Liberia using catch & effort data in 2014 & 2016

Stock	Biomass estimate (tons) 2014	Biomass estimate (tons) 2016	MSY estimate (tons) 2014	MSY estimate (tons) 2016	Stock status 2014/2020
Shallow-water demersal	12342	12870	5812	3910	over-exploited
Deep-water demersal	2952	3050	1323	900	moderately/fully exploited
Total	**15,294**	**15,920**	**7135**	**4810**	

Source: MRAG (2014) & Jueseah et al, (2020b)

In the 1980s, there was an industrial fleet targeting the demersal stocks (Shotton 1983). Total catch, however, from the industrial demersal fishery from 1957 and 2020 varied largely (Figure 5). For instance, from 1957 to 1965, it increased steadily varying between 1,080 to 6,728 tons year^{-1} but large fluctuations occurred between 1971-1979 with the highest demersal catch recorded in 1977 (Figure 5). The increase at the end of the data period (i.e. 2013-2020) is mostly due to the demersal catches of the SSF especially the Kru canoes and the new sampling scheme for the SSF as mentioned earlier. The prolonged civil war, weak administrative capacity to properly monitor the fisheries, and policy changes in the Liberia fishing industry at the end of the civil war could partly explain the large fluctuations in the trawlers total demersal catch. However, today because of the Government's zoning policy (Ministry of Agriculture 2010) only few trawlers operate in the coastal industrial fishery in Liberia (Figure 3a) (Jueseah et al, 2020b).

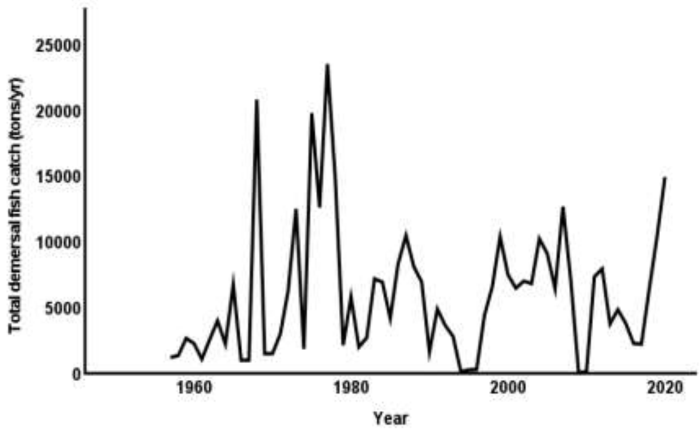

Figure 5. Total demersal fish catch of the coastal industrial fleet overtime.
Sources: Shotton (1983) (1957-65,68, 1971-79, 1981-82),
FAO [(1994-2010), 1966-67,69,70,80,1983-93, 2011-12, SSF total catch included].
NaFAA Statistics (2013-2020).

Total demersal fish catch for the trawlers between 2013 to 2020 varied from 57.3 to 3,974 tons year^{-1} (Figure 5). It is worth noting that between 2013-2016, the SSF catch of demersal fish ranged between 2,041 to 4,783 tons year^{-1} with the Kru accounting for about 85% (Jueseah et al, 2020b). Note that between 1957-1965 the total demersal catch reported by Shotton (1983) for the trawlers was on average four times the total demersal catch reported by FAO for Liberia, and between 1971-1979 it was roughly three times the total demersal catch reported by FAO. The conflicting information about the demersal resources and in particular the deep water stocks indicate a high level of uncertainty, but also the possibility that the deep water demersal resources may be more abundant than the most recent estimates indicate.

2.3.3 CRUSTECEAN SPECIES

Historical biomass estimates are scanty for the crustaceans in the coastal waters of Liberia (Ssentongo 1983). Today only a small amount of shrimp is being caught by the coastal trawlers mostly due to changes in policy in 2010, while Kru canoes catch some crabs and lobsters (Jueseah et al, 2020b). Jueseah et al, (2020b), estimated a total biomass for the crustacean including crabs, lobster, and shrimps, to be around 1,260 tons. It is worth noting that this estimate suffers similar limitations as observed with the deep-water demersal stocks. The coastal trawlers, due to the zoning policy initiated by the government in 2010, has had no access within six miles where the coastal shrimp resources are most abundant (Ministry of Agriculture 2010).

FAO (1977) estimated the MSY of shrimp to be around 1,870 tons year^{-1}, assuming the shrimp stock was shared between Liberia and Sierra Leone (Ssentongo 1983). In 1983 potential yield of shrimp in the coastal waters of Liberia was estimated between 1,200 to 1,600 tons year^{-1} (Shotton 1983; Ssentongo 1983).

In the 1970s, there was an industrial shrimp fleet mainly targeting coastal shrimp (Shotton 1983). Total catch of shrimp increased from about 400 t in 1969 to around 1500 tons in 1974 to 1980 before collapsing in 1981 (Figure 6). The collapse of the lucrative shrimp fishery in Liberia appears to be more associated with security and political issues as opposed to a fishery collapse. It seems because the fishing company (i.e. Mesurado Group of Companies) that owned and operated the shrimpers targeting the coastal shrimp resources in Liberia was owned by the then first family, the company was forced to shut down following the 1980 military coup (Drammeh 2007).

According to Shotton (1983), the shrimp fishery during the 1970s was profitable and maximum economic profits of 14 shrimpers, catching around 800 tons year^{-1}, were estimated at around US$ 5.7 million. Today, the landed value of 800 tons of shrimp at US$ 10,200 ton^{-1}would be around US$ 8.2 million.

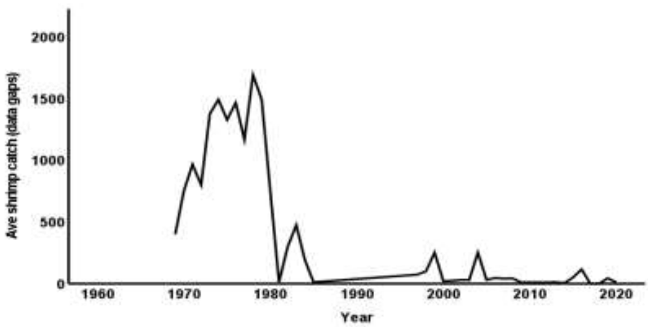

Figure 6. Shrimp fishery annual catch overtime.
Sources: Shotton (1983) (1969-83), Ssentongo (1983) (1984-85), FAO (2017) (1997-2012), NaFAA Statistics (2013-2020).

However, today there is hardly any industrial shrimp fishery operating in Liberia possibly because of the changes in policy in 2010 that restricts industrial trawling inside six nm (Ssentongo 1983). The shrimpers, in the 1970s, were allowed to trawl inside three nm, where the main coastal shrimp resources are concentrated (Shotton 1983; Ssentongo 1983). The few trawlers operating today catch just a small amount of shrimp and between 2013-2020 total catch ranged from 0 to 116 tons year^{-1} and averaged around 30 tons year^{-1} (Figure 6).

The small-scale Kru canoes that operate inside the six nm today between 2013-2016 caught on average 343 tons year^{-1} of crustacean mainly crabs and lobsters, using gillnets and traps. It seems, therefore, the potential yield for shrimp could be much higher than the current catches indicate.

2.4 FISHERY VALUE CHAIN

The SSF value chain in Liberia is characterized by multiple actors participating in fish production (harvesting) and purchasing either for processing or for distribution and consumption (Jueseah et al, 2020a). When the weather is good the sea is calm and fishing conditions are favorable, during the dry season October-April, catches can be very high. The occasional arrival of large shoals of small pelagics in the inshore waters can lead to huge harvest and substantial increase in post-harvest activities (MRAG 2013; Jueseah et al, 2020a). Due to inadequate infrastructure, fish traders and processors don't have the means to buy and process all the landed catch typically resulting in large post-harvest losses (MRAG 2013; Jueseah et al, 2020a). On the other hand, during the rainy season May-October, unfavorable conditions strong ocean currents, heavy storms, and rainfall, inhibit small-scale operators from going to sea (MRAG 2013; Jueseah et al, 2020a). Consequently, fish supply, during the rainy season, can be six times less than during the dry season (Jueseah et al, 2020a).

In the SSF, there is little or no use of ice or chillers onboard the traditional boats which are too small to accommodate isolated boxes for storing ice and fish which leads to post-harvest loss due to spoilage (Drammeh 2007; Jueseah et al, 2021). Basic infrastructure to preserve, process and store fish onshore are also limited while onboard industrial vessels, fresh fish is packaged in cartoons and frozen to preserve the quality of the fish (Drammeh 2007). Note that the industrial fishery fish value chain is not discussed in detail, because the fishing firms are generally vertically integrated.

Generally, the actors engaged in the fishery value chain are fishermen, fish traders, who are predominantly women, and Korean traders (Drammeh 2007; Jueseah et al, 2020a). The main financiers of small-scale fishermen are the middlemen (i.e. fishers' wives and large-scale Korean traders[7]). Middlemen provide informal loans to fishermen to purchase fishing inputs such as boats and equipment and occasionally pre-finance fishing trips (Jueseah et al, 2020a). Operational dependencies between small-scale fishermen and middlemen are commonplace in the SSF in Liberia (Jueseah et al, 2020a). Fishermen's main sponsors exercise greater power and control major portions of the total quantities of fish landed and traded (Jueseah et al, 2020a).

The fishery value chain is characterized by considerable power asymmetries and information externality. For instance, Jueseah et al, (2020a), found that Kru fishermen were unable to estimate the real costs of fishing inputs provided to them by the Koreans who take advance of their bargaining position to increase their benefits by providing fishermen with fishing inputs on credit. The lack of transparency in the value chain makes it difficult to determine the actual price fishermen obtain. This also applies to the fishermen's wives who offer support to the fishermen and pay lower price compared to prices based on market relationships (Jueseah et al, 2020a). Jueseah et al (2020a) argued that there was a quality incentive in the market that fishers were not receiving probably due to the lack of information flow along the value chain. The lack of transparency in the SSF value chains has resulted in captive hierarchical relationships and lower prices for fishermen compared with market relationship (Jueseah et al, 2020a).

2.5 GOVERNANCE OF THE FISHERIES

In this section, the fisheries management system (FMS) that is employed to manage the main fisheries and the legal basis of the system as well as the institutional framework supporting the fishing industry governance are presented. The FMS is described first followed by the description of the institutional framework supporting the sector governance.

2.5.1 THE FISHERIES MANAGEMENT SYSTEM

The overall objective of the Liberian FMS is to ensure the long-term sustainable utilization of the fisheries resources and associated environments for the benefit of Liberia (Ministry of Foreign Affairs 2019. section 2.1). The coastal industrial fisheries are managed through individual vessel catch quota, fishing licenses and technical measures such as minimum mesh size, area and gear restrictions, among others, while the SSF are managed through licensing and fishing rights such

[7] A large-scale Korean trader typically buys > 300 kg day^{-1} of cassava fish from Kru fishers and uses privately organized vehicles, to transport the fish to Monrovia, before exporting (Jueseah et al, 2020a).

as community fishing rights and territorial user rights fisheries (TURFs) as well as other technical measures like minimum size of fish, gear restrictions, among others (Ministry of Foreign Affairs 2019).

The legal framework supporting the Liberian fisheries management regime are the Natural Resources Law (1958), National Fisheries and Aquaculture Authority Act (2017), Fisheries and Aquaculture Management and Development Law (2019) and the FAPS (Ministry of Agriculture 2014). NaFAA in collaboration with the Liberian Coast Guard implements a monitoring control and surveillance (MCS) system to monitor and control all fishing activities in the Liberian EEZ (Ministry of Foreign Affairs 2019).

NaFAA operates a fisheries monitoring center (FMC) and implements a fisheries observer program to support its MCS function particularly with regard to the coastal industrial and offshore tuna fisheries, but MCS is limited in the SSF (Chu et al, 2017). The judicial system processes violations of the fisheries laws (and regulations) and issues appropriate sanctions to those judged to have broken the fisheries laws (Ministry of Foreign Affairs 2019). In 2013 Liberia generated around US$ 6 million, as administrative fines through negotiated settlements, for violations of the 2010 fisheries regulations (Chu et al, 2017).

2.5.2 INSTITUTIONAL STRUCTURE

The National Fisheries and Aquaculture Authority (NaFAA), established by an act of legislation in 2017, is an autonomous agency of government solely responsible for fisheries management and development in Liberia (National Fisheries and Aquaculture Authority Act 2017; Fisheries Management and Development Law 2019). NaFAA has a nine member Board of Directors, appointed by the President of Liberia, that serves as its governing body. The Board is chaired by the Minister of Agriculture and includes representatives from other ministries and agencies of government. There is also a 15 member Fisheries Advisory Council (FAC), appointed in 2020 by the Director General of NaFAA, based on nominations from several government ministries and agencies. The primary function of FAC is to advise the Director General on policy and related matters concerning the conservation, management, sustainable utilization and the development of fisheries and aquaculture in Liberia in accordance with international law and agreements (Fisheries Management and Development Law 2019).

Today, NaFAA is funded by revenues raised from license (access) fees, fish import permit fees, fish export permit fee, transshipment authorization (permit) and certificate fees, fines for violation of the laws and regulations, grants (or donations) among others (National Fisheries and Aquaculture Authority Act 2017). The total fisheries revenue collected is distributed between NaFAA and the Government on a percentage basis. Currently 60% of the total fisheries revenues generated remains with NaFAA and 40% is remitted to the government consolidated bank account.

NaFAA is supported by the Liberia Sustainable Management of Fisheries Project (LSMFIP), financed by the World Bank, whose objective is to improve the management and utilization of selected fisheries (World Bank 2019). LSMFIP services to NaFAA include support to strengthen and build NaFAA's capacity through improving the sector's governance framework and the national MCS functionality, and mobilization of regional technical experts who will support implementation of project funded activities at the national and community levels (World Bank 2019). LSMFIP is divided into two key components, and each consists of two sub-components for implementation of its activities at the national level (World Bank 2019). The first component is "management of selected fisheries" which includes sub-components (i) institutional strengthening and capacity building; and (ii) improving management of selected fisheries (World Bank 2019). The second component is "improving handling of fish and fish products" and includes sub-components (i) strengthening national post-harvest value systems; and (ii) support focused on women (World Bank 2019). There is a list of planned activities under these two components of LSMFIP that are expected to be financed by project funds.

At least three Co-management associations (CMAs) have been established by NaFAA, to support community-led fisheries management (Fisheries Management and Development Law 2019; EU et al. 2020) and this initiative is expected to be scaled up to support establishment of co-management and co-administration mechanisms between CMAs and the Liberia Artisanal Fishermen Association, a community-based SSF advocacy group (World Bank 2019).

3.0 CONCEPTUAL MODEL OF FISHERIES MANAGEMENT

Small scale fisheries management in the developing world has proven very challenging. Good fisheries management seems to be very difficult to achieve (World Bank 2017). Liberia is no exception. This raises questions like "what can really be managed?" and "what level of management is optimal?" One way to address these questions is to view fisheries management from the angle of costs and benefits of management actions. Might the reason for generally poor management be that benefits of good management simply do not justify the costs?

In figure 7, revenues, biomass, and costs curves of a fishery are illustrated as a function of fishing effort according to a classic bioeconomic model. Here fishing effort may be construed as the employment of the fishing vessels, with differences in sophistications (efficiencies) to harvest, from least efficient (I) to most efficient (III). The revenues and biomass functions illustrate how different levels of fishing effort result in different points of equilibria between costs and revenues, termed sustainable biomass or sustainable revenues and costs. To achieve an equilibrium one must assume a constant environment and that the fishing fleet efficiency and price of fish remains constant.

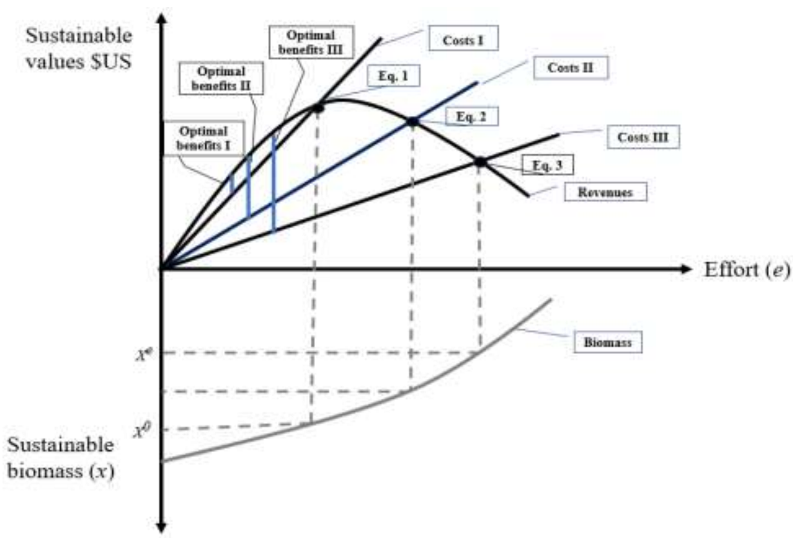

Figure 7: Sustainable fisheries model (adapted from Arnason 2009). See text for further explanation.

The upper section of figure 7 describes the well-known sustainable fishery model adapted from Arnason (2009) but first introduced in the literature by Gordon (1954). The fishing costs are highest (i.e. costs I) the fishing fleet that is applied in the fishery is less efficient (unsophisticated) and the impact of harvesting on the biomass (natural capital) is at a minimum. As the fishing fleet efficiency increases, the costs of harvesting are reduced from costs I to costs II. If the fishing fleet gets more sophisticated the costs of fishing decline further from costs II to costs III. However, without proper management, long term profits are still zero as competition between fishermen leads to increased effort and decreasing biomass. This may eventually lead to stock collapse if costs are sufficiently low, as it will continue to be profitable to harvest even at very low levels of biomass, as seen in the lower part of figure 7. The three vertical blue bars show the optimal net benefits, or sustainable rents, that can be obtained from the fishery at different levels of cost. Management is required to reach this, and management is not without cost. The question becomes: what is the optimal strategy for government to apply under different levels of fleet sophistication? Should it apply management or not?

Figures 8-10 are derived from figure 7 and illustrate costs and benefits curves as a function of vessel size. Vessel size may be regarded as a proxy for efficiency of the fleet characterized e.g. by the fishing power, technology, engine capacity or gross registered tonnage (GRT) of a typical fishing vessel. Figure 8 describes the costs and benefits of implementing practical fisheries management. As depicted in the figure, fisheries management cost (grey curve) is sensitive to the number and size of vessels. Managing many small and primitive vessels is much more expensive than managing few large vessels. The figure indicates that it may not be economically feasible to apply any fisheries management for the very smallest vessels because the benefits are simply not big enough to cover management cost (i.e. area A in Figure 8). The net social benefits (green curve) are less than zero, as seen by the net social benefits curve to the right of the broken vertical red line, for implementing a functioning fisheries management for these small size vessels.

On the other hand, if the vessel size is increased beyond this point (i.e. area B in Figure 8), the net social benefits for applying any practical economic efficient fisheries management are positive (green curve in area B). Note that the positive net social benefits for implementing fisheries management for large size vessels in figure 8, correspond to the net difference between the revenues and costs curves (i.e. optimal benefits and management costs) in the upper part of figure 8 (vertical blue bars in Figure 7).

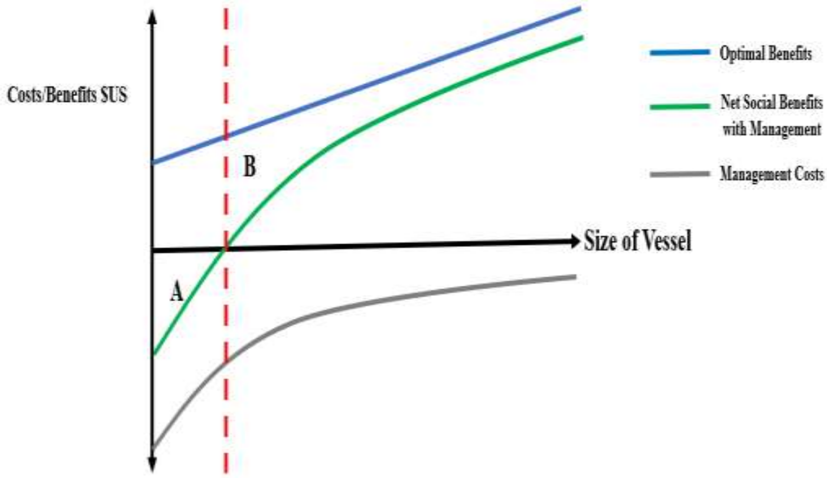

Figure 8: Conceptual model of the costs and benefits when applying practical fisheries management for many unsophisticated small-size vessels in area "A" and sophisticated big-size vessels in area "B" in a typical fishery.
Source: Author's

Figure 9 illustrates the conceptual model for not implementing any fisheries management. If no fisheries management is applied regardless of the size and number of vessels, the net benefits are zero to private operators (fishermen) (i.e. green dotted horizontal line in diagram corresponding to the open access equilibriums in figure 7). The net social cost (brown line) for no management is a reduced natural capital (biomass) (brown curve in area A). This cost increases with vessel size as natural capital stock in open access equilibrium declines, as seen in figure 7.

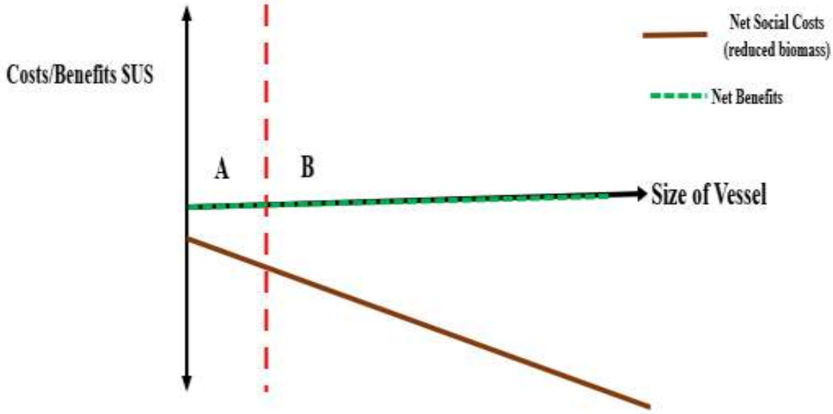

Figure 9: Conceptual model for not implementing any fisheries management derived from figure 8. Note the y-axis represents costs/benefits to fishermen and the society for no management and x-axis represents vessels size as in figure 8. In area B the vessels have become large enough to make management feasible (Figure 8). “
Source: Author’s

Figure 10 illustrates the optimal choice for whether to apply economic efficient fisheries management or not, drawn from figures 8 and 9. As depicted, there are three options indicated by areas A, B and C in the diagram. It shows that the optimal strategy for the smallest vessels (area A in diagram) is no management, since the negative net social benefits (brown curve in area A) of a reduced natural capital stock, as seen in figure 9, is smaller than the negative net benefits of management, as seen in figure 8. If the size of the unsophisticated smaller vessels is increased above area A in diagram, the net social benefits (brown curve in area B) for no fisheries management is more negative than the net social benefit of management. The fishery is still a net-cost to society, but the cost is smaller with management than without management. At the other end as illustrated, if the vessel size is increased beyond area B into area C in diagram, the net social benefits (green curve in diagram) are positive for applying fisheries management. The fishery becomes a net source of revenue for society.

The optimal least-cost strategy for society, therefore, is no fisheries management as in area A, and management in areas B and C. The fishery is a net cost to society in areas A and B but a net source of revenue in area C. The best point in area A, from society’s perspective, is associated with the smallest least sophisticated vessels. Area A in figure 10 is associated with better short-term employment (social outcomes) in the fisheries but low biological and economic outcomes (Danielsen and Agnarsson 2020). The best points in areas B and C are associated with larger more sophisticated vessels. The optimal strategy for society in area A is to keep cost up, while it is to keep cost down in areas B and C. In areas B and C, the fishery should be managed to increase economic efficiency. While studies have shown that high employment is not typically associated with economically efficient managed fisheries such as ITQ fisheries (Hilborn 2007; Abbott, Garber-Yonts, and Wilen 2010; Gunnlaugsson and Saevaldsson 2016), Danielsen and Agnarsson (2020) have shown that a fishery managed successfully for better long-term economic outcomes can employ just about the same amount of people as an unsuccessful fishery and pay their fishers a higher wage. The wealth (resource rent) generated, for an economically efficient managed fisheries, can be redistributed for the rest of the society and used to fund and improved existing welfare services such as free health care and education among others (Cunningham et al. 2009; Danielsen and Agnarsson 2020). This approach to fisheries management increases value added and the sector's contribution to the GDP and growth (Cunningham et al. 2009) and has been reported to result in better biological, economic and social outcomes of the fisheries (Danielsen and Agnarsson 2020).

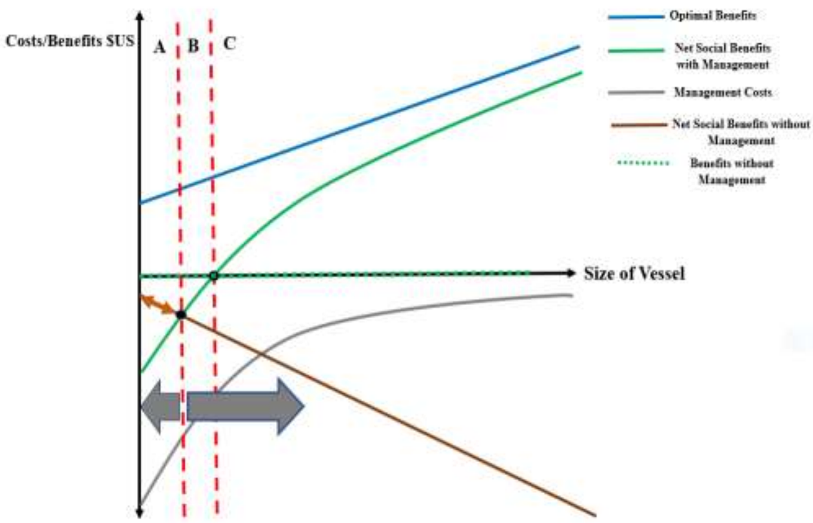

Figure 10: Conceptual model optimal choice for whether to apply economic efficient fisheries management or not derived from figures 8 and 9. Note y-axis represents the costs/benefits (US$) to private operators & the society and x-axis is vessels size. "A" represents the area for many unsophisticated small-size vessels, "B" is the area for many medium-size vessels with higher sophistication than vessels in area "A", and "C" signifies the area for large-size sophisticated vessels in a typical fishery.

Source: Author's

This may be highly relevant for the fisheries in Liberia. The small scale Kru and Fanti vessels operating in the Liberian SSF are examples of small and unsophisticated vessels (Jueseah et al, 2021). Because of their small size, Kru and Fanti can take their vessels ashore anywhere along the coast in Liberia. Operators may leave for a fishing trip and on return land their catches anyplace through informal (unregulated) channels along the coast and the departure and landing points may be different in most cases (MRAG 2013). This makes them practically difficult if not impossible to monitor, control, and manage. It seems the design and nature of the Kru and Fanti boats in terms of the small size boats, the archaic (unsophisticated) harvesting technology used (Jueseah et al, 2021), their disperse and sheer numbers as well as the unpredictable nature of their informal operations, make practical economic efficient fisheries management quite challenging. In this case, the small-scale Kru and Fanti boats fit quite well with the small size vessels description captured in the conceptual model (figures 8 to 10).

On the other hand, the industrial vessels, because of their large size and intensive scale, operate through authorized formal channels-fishing harbor, where they must depart for a fishing voyage and on return are required to land their catches. This makes the coastal trawlers relatively easy to monitor, control and manage. Arguably, the same applies to the offshore industrial tuna vessels, except that they are not currently landing their catch in Liberia due to limited capacity and the extensive operations of the tuna vessels which span several EEZs along the Atlantic Ocean. The design and nature of operation of the industrial vessels in terms of the large size vessels, the sophisticated harvesting technology typically employed, and their contained formal operation make practical economic efficient fisheries management (e.g. catch quota) (Arnason 2009) quite possible for this size of fleet. In this sense, the industrial vessels seem to fit quite well with the large size vessels described in figures 8 to 10.

4.0 FISHERIES POLICY PERFORMANCE

The key national policy documents, guiding the Liberian fisheries sector development since 2014 are the Pro-poor Agenda for Prosperity and Development (PAPD) and the Fisheries and Aquaculture Policy and Strategies (FAPS). These policy documents are reviewed to assess the performance of the fisheries sector since their adoption and make recommendations to strengthen the performance of the Liberian fishing industry where needed. The vision and goals of the PAPD is first reviewed followed by the review of the current FAPS vision and objectives.

The PAPD goals are to build more competent and trusted state institutions and improve income security of the Liberian people (Republic of Liberia 2018). The overarching objective of the PAPD is consolidation of the peace and reconciliation efforts (Republic of Liberia 2018). The Government's vision for development of the fisheries sector is captured under the governance and transparency pillar and "increasing the competitiveness of existing industries-fisheries improvement" development outcome (Republic of Liberia 2018. page, 55). The government, under the "fisheries improvement" of the PAPD intends to "support artisanal communities to increase domestic fish supply from 8,000 tons to 16,000 tons annually by 2023" (Republic of Liberia 2018. page, 55). Government plans to facilitate private investment in the construction of a modern fishing harbor complex with facilities for repair and maintenance of fishing vessels and for storage, preservation, and processing of fish (Republic of Liberia 2018. page, 55).

Following this, the PAPD envisages increase employment and incomes, enhanced human and institutional capacity and creation of export opportunities. Government plans to tackle IUU fishing in its marine waters, to make the fishing industry viable and profitable, by establishing robust MCS systems in Liberia. The government intends to continue and expand its SFPA with the EU aiming to attract other interested and capable partners. Fishery managers at NaFAA regard the offshore tuna fishery to be a major contributor to the Government's fisheries income and therefore important to the Liberian economy. The PAPD activities is to increase fisheries contribution to Liberia's GDP from 3% in 2018 to 6% in 2023 (Republic of Liberia 2018.p 45).

While the Government's vision and goal(s) as described in the PAPD for improvement in the fisheries sector seem promising, the strategies for realizing its vision and goal(s) are not clearly outlined. It is not clear in terms of the strategies, for instance, how the government intends to support the artisanal communities to increase domestic fish supply, to achieve its fisheries improvement development outcome by 2023. For example, does the government plan to manage the coastal fisheries at maximum sustainable yield (MSY) as opposed to maximum economic yield (MEY) level i.e. produce more fish and more employment but less profits from harvesting activities? It is important to be quite clear about the management reference point such as MSY or MEY right from the outset of any management action. This is because it seems rather quite clear that the most inefficient fleet (fishery) such as the Kru and Fantis will reach an equilibrium at a biomass below that which would sustain MSY or MEY stock levels as observed by Jueseah et al, (2020b).

Nonetheless, based on recent empirical analysis, the catch from the SSF sector alone between 2018-2020, according to NaFAA statistics, increased from around 10,780 tons in 2018 to 18,126 tons in 2019 and in 2020 it was around 26,856 tons. This represents an average annual increase of around 58% and indicates some progress towards the Government's goal for increasing domestic fish supply. This raises further question about the sustainable utilization of the fishery resources in the Liberian coastal waters

The FAPS overall goal is a "sustainably managed and economically viable fisheries that generate prosperity for the present and future generations" by 2030 (Ministry of Agriculture 2014). The FAPS has four specific objectives and 19 strategies describing pathways to achieving the objectives of the FAPS (see, Appendix 1a). Liberia has made progress in implementing the current FAPS, although its framework action plan lacked implementation costs (EU et al. 2020). There have been major improvements in the licensing and vessel registration regime, IEZ has been established to protect access of SSF and space to allow the coastal fishery resources to rebuild, inter-agency collaboration, establishment of CMAs although at early stages and routine boat registration. Furthermore, Liberia is a member (and/or cooperating non-member) of regional fisheries management organizations (RFMOs), establishment of vessel monitoring system /automated identification system tracking of fishing vessels and cooperation agreement with Liberia Maritime Authority. This indicates major improvements in international engagement on responsible fisheries (EU et al, 2020). These improvements are associated with the six strategies i.e. biomass restoration, stakeholders' participation in fisheries management, international cooperation, implementation of effective MCS and conflict management mechanism, aimed at achieving FAPS objective one "sustainable management of fisheries resources and ecosystems".

However, the current development trend of the small-scale Kru canoes (Figure 2a) in the coastal fisheries does not seem to be in line with sustainable management of fisheries resources and ecosystems as well as the accompanied strategies. The number of small-scale boats, especially the Kru canoes, is expected to continue to increase since both Kru and Fanti boats were found to be profitable at the end of 2016 (Jueseah et al, 2020b). Regulatory actions, especially for the Kru and Fanti fleets, are therefore needed to manage the fishery sustainably. Any management (regulatory) action needs to weigh the costs and benefits associated with such management action for small-size vessels like the Kru and Fanti as illustrated in the conceptual model**.** This indicates designing an effective policy for small-scale boats is quite challenging considering the socio-economic implications.

Major improvements have been made towards policy objective three “strengthening of fisheries management and development capacities”. For instance, NaFAA an independent institution was created by law, replacing the former Bureau of National Fisheries, for fisheries matters in Liberia (National Fisheries and Aquaculture Authority Act 2017). There have been improvements in human capacity and administrative processes, new detailed fisheries law has been approved (Ministry of Foreign Affairs 2019) and new draft regulations are being reviewed (EU et al. 2020). Also, some level of financial stability at NaFAA has been achieved through engagement with the EU SFPA, collection of other access fees and engagement with the World Bank (EU et al. 2020). Due to unresolved fisheries governance issue (yellow card), the SFPA between NaFAA and the EU, which expired on December 15, 2020, was not renewed. This has delved a serious blow to NaFAA’s revenues according to fisheries managers and indicates a major setback to the government’s intent for improvements in the fisheries sector as envisioned in the PAPD. However, discussions are still ongoing to resolve the yellow card issue and, thereafter, renew the SFPA with the EU. Human capacity persists as a major constraint, despite the improvements made so far (EU et al, 2020).

For progress made towards realizing policy objective IV i.e. “enhancement of value addition, marketing and fish trade”, a fish landing site cluster has been established in Robertsport financed by the World Bank WARFP project and there are plans by NaFAA to establish new ones in selected coastal counties under LSMFIP component two i.e. improving handling of fish and fish products (World Bank 2019). Furthermore, under component two of LSMFIP, there are plans to expand the Mesurado Pier to include import and export terminals. Under this component, LSMFIP will finance fish landing sites and improvements of post-harvest processing facilities in selected small-scale fishing communities i.e. Buchanan, Greenville, Rivercess and Harper (World Bank 2019). Training and provision of financial and technical assistance to fishers on basic hygiene practices and sanitary procedures, value-addition, product branding and certification to adhere to standards and sustainability requirements are planned under this component (World Bank 2019).

It seems the needed financial resources, to implement the policy strategies associated with “enhancement of value addition, marketing and fish trade”, have been secured by the Liberian

Government. On the other hand, research has shown that the SSF value chains in Liberia are typified by low value-addition services and poorly developed and that fishers receive less economic benefits in both dry and rainy seasons compared to other actors (Jueseah et al, 2020a). Jueseah et al, (2020a) argued that in order to raise fishers' benefits and increase overall efficiency in the small-scale fish value chains in Liberia, interventions such as provision of basic fisheries infrastructure and training to fishers would be needed as well as provision of microloans. While the former would serve to improve quality handling and processing in the small-scale fish value chains, the latter would serve as an alternative source of finance and help to break fishers' financial dependency on dominant middlemen and consolidate their ability to sell their fish at market prices. In this case, the planned interventions by the Government under the LSMFIP seem to be crucial steps in the right direction (World Bank 2019).

5.0 CONCLUSION AND RECOMMENDATIONS

This section concludes and summarizes the review and recommendations drawn out of this report. The conclusion is presented first, followed by the recommendations. The recommendations mostly focus on the way forward for improvements in the Liberian fishing industry.

5.1 CONCLUSION

The fishing industry is very important in the Liberian economy. Fisheries are a source of food and nutrition security, employment for several thousand Liberians, revenues, and foreign exchange for government. Fisheries catch and effort data prior to the civil war are largely unreliable although in recent years there has been improvements in the fisheries statistics. Small pelagic species are short-lived and likely to fluctuate quite a lot. The pelagic stocks in the coastal waters of Liberia annual potential yield estimate range between 13,000-22,000 tons year^{-1} and are considered to be moderately to lightly exploited. The Fanti fleet is largely profitable and mostly targeting the small pelagics in recent years, however, has remained fairly stable, perhaps due to limited availability of big trees required for their construction. Increased exploitation of small pelagics by the industrial coastal fleet may change the outlook for the Fantis and should be monitored closely.

The shallow-water demersals are found to be overexploited most probably because of the continuous increase in the number of Kru canoes in the SSF (Jueseah et al, 2020b). The Kru canoes increased in the SSF and by 2020 their numbers were around 11 times greater than what they were at the end of the civil conflict (Jueseah et al, 2021). However, the design and nature of the Kru canoes make monitoring and controlling them quite challenging. Biomass of deep water demersals considered to be moderately exploited (Jueseah et al, 2020b) may be underestimated due to inappropriate harvesting technologies in the SSF and perhaps the relatively poor state of the coastal trawlers (Jueseah et al, 2021).

Crustacean species in the Liberian coastal waters includes shrimp, crabs, and lobsters. In the 1970s, there was a flourishing industrial shrimp fishery (Shotton 1983; Ssentongo 1983). This fishery today is nonexistent in Liberia possibly because of the 2010 policy changes which prohibits trawling within six miles where the coastal shrimp resources are abundant (Ministry of Foreign Affairs 2019). In the 1970s the MEY for the coastal shrimp resources was estimated at 800 tons for 14 vessels, valued at US$ 5.7 million (Shotton 1983). The landed value today for 800 tons of shrimp at US$ 10,200 ton^{-1} would be about US$ 8.2 million. The actual abundance and value of the coastal shrimp resources today is practically unknown. Between 2013-2020, the total shrimp catch of the few trawlers operating in Liberia averaged around 30 tons year^{-1} (Jueseah et al, 2020b). The total catch of crabs and lobsters between 2013-2016 of the Kru canoes operating inside the six miles average 343 tons year^{-1} (Jueseah et al, 2020b). Information on the state of these stocks is sparse.

A conceptual model used to evaluate the cost and benefit of management for different types of fisheries (fleets) indicates that the cost of management of the SSF is higher than the expected benefits. Therefore, implementing an economically efficient management for SSF may be quite difficult. This may be the reason why SSF seem generally to be unmanageable, and this phenomenon seems to manifest itself in the SSF in Liberia. The Liberian Government should consider this in its choice of management strategies and development of their fisheries sector. Still, SSF have been reported to contribute to both poverty alleviation and food security in economies of developing countries (FAO 2005). Keeping them may therefore be a necessity. In the Liberian SSF, there seems to be a substantial efficiency (Jueseah et al, 2021). Due to the open access nature of SSF, there is a problem generally that incremental developments are not likely to produce long-run net benefits for the society. Therefore, economically efficient management of many small-size primitive small-scale vessels like the Kru canoes in Liberia is simply not worth the required effort. The associated costs and benefits of management of each fishery (fleet) should be evaluated prior to a management decision taken. However, this would certainly depend on the envisaged or desired management outcome(s) i.e. biological, social or economic efficiency, of the government for that fishery right at the outset.

Considerable progress has been made in most of the PAPD and FAPS policy areas (Ministry of Agriculture 2014, Republic of Liberia 2018). In spite of this, studies showed there is a lot more to do to improve the performance of the fishing industry (Jueseah et al, 2020a; Jueseah et al, 2020b; Jueseah et al, 2021). There are post-harvest losses in the fishery value chains due to poor handling of the catch both onboard and on land. There is lack of transparency which emerges from power asymmetries and lack of information flow in the SSF value chain. In the sections that follow, the key recommendations stemming from this review are summarized and justified as possible avenues forward for improving the fisheries sector in Liberia.

5.2 RECOMMENDATIONS

This analysis gives rise to several recommendations. The main one's are elaborated below:

5.2.1 Conduct stock and economic assessments for coastal shrimp and deep water demersal stocks

The coastal shrimp resources and the deep water demersals may be larger than previous analyses have indicated, and they are almost certainly under-exploited. It seems, therefore, worthwhile that the government look into conducting national stock assessments (survey) and economic analyses for the coastal shrimp resources and the deep water demersals to determine both stocks abundances and value of these resources. If the survey for the coastal shrimps shows the stock is abundant i.e. there is good economic quantity of the resource, then the government can determine a way to optimally exploit the shrimp stock. In this case, the management of the resource should be organized in such a way that the fishery (fleet) is manageable as argued in the conceptual model, using few well equipped vessels for the operation. The goal here is to focus on a management structure that generates greater benefits for the Liberian society. The same applies to the deep water demersals. If a survey establishes that there is economic resource (quantity) that could be exploited, the management of the resource should be arranged in such a way that the fishery (fleet) is manageable as illustrated in the conceptual model.

5.2.2 Management of the small-scale fisheries

While it has been shown that substantial benefits could be derived from management of the small-scale fleet (i.e. reducing the number of Kru canoes) in Liberia, managing small-size primitive vessels with unpredictable informal operations may not be worth the economic effort that would be required. The option to phase out the Kru canoes should be looked into due to conflict with forestry or perhaps because they are unmanageable economically. The first step could be to stop issuing new fishing licenses and registration numbers to Kru canoes. If the Kru can be phased out, the government should explore the feasibility of introducing new harvesting technology like fiberglass reinforced plastic (FRP) vessels to both increase productivity and profitability in the Liberian fishing industry. There should, however, be an economic evaluation of any option to phase out the current small-scale fleet to shed light on the socio-economic implications of this policy. There are indications that most of the Kru and Fanti boats are inefficient and lacking appropriate technologies to harvest the valuable deep-water demersals and the coastal shrimp resources in Liberia as well as the medium and large pelagics offshore. The introduction of FRP vessels might help to address the current technical regress in the fishing industry and utilize the coastal fishery resources i.e. deep water demersals, coastal shrimps, medium and large pelagics, better in Liberia. Larger and more efficient vessels, such as FRP vessels, might make it possible to improve efficiency and the quality of the landed fish. Still, if there is going to be a technological leap in the fishery, one has to remember that this leap should be within the manageable area as argued in the conceptual model. This means the vessels have to be sufficiently big so that the fishery that emerges is manageable and capable of generating greater benefits for the Liberian society.

5.2.3 Establish basic fisheries infrastructure

The absence of basic fisheries infrastructure contributes to the poor handling of the landed catch in the SSF value chain. Interventions such as provision of basic fisheries infrastructure might address issue related to poor handling of the catch both onboard and ashore and improve value-addition services in the SSF value chain. It is, therefore, advisable that the government look into establishing critical fisheries infrastructure such as ice and chill facilities, suitable sanitary facilities, and hands-on training, to enhance value-addition services in the SSF value chain.

5.2.4 Establish access to financial services

Lack of transparency in the SSF value chain has resulted in captive or hierarchy relationships and lower price and benefits for fishermen than if they were in a market relationship with the middlemen. In order to tackle the lack of transparency in the value chain, government could create access to financial services for the SSF subsector such as less demanding and restrictive microloans as an alternative source of finance and increase access to information in the value chain from end-markets to the fishermen. The establishment of a single fish selling desk that represents the interests of the fishermen might address the current lack of information. Access to financial services might also give the fishermen access to the necessary investment finance to purchase improved harvesting technologies which are needed in the fisheries to increase efficiency and profitability.

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APPENDIX 1

Table 1: Fisheries and aquaculture policy and strategies (FAPS) 2014

Objective	Strategies
Sustainable management of fisheries resources and ecosystems	i. Restoring fish biomass capacities to produce at maximum sustainable yield levels. ii. Conserving of aquatic ecosystems associated with fish production. iii. Encouraging community and stakeholder participation in fisheries management iv. Promoting International cooperation for management of shared stocks v. Implementing effective MCS mechanisms to prevent IUU fishing. vi. Developing and promoting conflict management mechanisms and structures for sustainable management of the fisheries resources.
Development of aquaculture to meet local fish demand deficits and for foreign exchange	i. Establishing the legal framework for development of responsible aquaculture. ii. Strengthening the institutional framework for development of aquaculture. iii. Setting up an enabling environment for development of Aqua- business for growth of the sub-sector. iv. Improving capacity for aquaculture promotion through human resource development and training.
Strengthening of fisheries management and development capacities for sustenance of a vibrant fisheries sector	i. Revising the legislative framework to support fisheries management and development. ii. Up-scaling the capacity of the Bureau of National Fisheries (BNF). iii. Implementing a comprehensive adaptive research program for improvement of the industry. iv. Implementing comprehensive capacity building and advisory programs for the fisheries sector. v. Promoting sustainable fisheries investments vi. Setting up sustainable funding mechanisms for fisheries development and management.
Enhancement of value addition, marketing and fish trade for improved foreign exchange earnings and employment opportunities	i. Improving economic returns through establishment of post-harvest infrastructure ii. Establishing national safety and quality assurance systems to enhance safety and quality of fish. iii. Promoting value addition, fish marketing and trade opportunities.

Source: Ministry of Agriculture (2014)