Challenges and Responses of the Nile Perch Fishery to Evolving Policies and Resource Base on Lake Victoria, with Emphasis on Uganda

Veronica Mpomwenda

Thesis for the degree of PhD
in Environment and Natural Resource Management

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Áskoranir í stjórnun veiða á nílarkarfa í Viktoríuvatni

Veronica Mpomwenda

Ritgerð til doktorsgráðu í Umhverfis- og auðlindafræði

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Janúar 2026

Félagsvísindasvið

HAGFRÆÐIDEILD

HÁSKÓLI ÍSLANDS

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Reykjavik, Iceland 2026

Ágrip

Ritgerð þessi inniheldur greiningu á fiskveiðum í Viktoríuvatni, með áherslu á veiðar smábáta á nílarkarfa. Áhersla er lögð á þróun veiðimynsturs, aðlögun veiðanna að breytingum í stjórnun veiðanna sem og þróun stofnstærðar og árgangasamsetningar nílarkarfa. Jafnframt er fjallað um árangur og skilvirkni ólíkra leiða við fiskveiðistjórnun. Gögn um veiðar í Úganda liggja til grundvallar þremur af fjórum greinum, meðan fyrsta greinin er samanburðarrannsókn um skilvirkni veiða á nílarkarfa í öllum þremur löndunum sem liggja að Viktoríuvatni. Gögnin sem rannsóknin byggir á eru meðal annars mat á afla og búnaði sem notaður er við veiðarnar, sem sótt voru í gagnagrunna Fiskveiðistofnunar Viktoríuvatns (LVFO) og Fiskirannsóknastofnunar Úganda (National Fisheries Resources Research Institute), gögnum um útflutning á fiski, sem og eigindlegum og megindlegum gögnum sem safnað var sérstaklega fyrir rannsóknina. Mismunandi aðferðum er beitt við úrvinnslu gagna eftir markmiðum hverrar greinar.

Grein 1 inniheldur greiningu á tæknilegri skilvirkni veiða á nílarkarfa í Viktoríuvatni. Greiningin nær til allra þjóða sem stunda veiðarnar, Úganda, Kenýa og Tansaníu. Niðurstöðurnar sýna umtalsverða fjölgun vélknúinna báta, sérstaklega í Úganda, samhliða fækkun árabáta, en mjög hefur verið barist gegn veiðum þeirra í bæði Tansaníu og Úganda á undanförnum árum með hertu eftirliti.

Í grein 2 er farið yfir þróun netaveiða á nílarkarfa í Úganda. Fjallað er um þær áskoranir sem veiðimenn standa frammi fyrir, s.s. varðandi möskvastærðir neta, samsetningu afla og fleira. Niðurstöðurnar sýna fram á mikilvægi þess að virkja notendur auðlinda í ákvarðanatöku um þróun fiskveiðistjórnunar.

Grein 3 fjallar um sýn veiðimanna á mismunandi sviðsmyndum fyrir framtíðarskipulag á veiðistjórnun í ljósi afskipta hersins á veiðieftirliti.

Grein 4 fjallar um áhrif þess að hverfa frá samvinnu yfir í valdbeitingu við stjórnun á nílarkarfaveiðum í Úganda, en stjórnvöld þar stigu það róttæka skref að fá herinn til þess að framfylgja reglum um veiðar. Sú aðgerð var ákveðin vegna minnkandi afla og offjárfestingu í vélknúna hluta flotans. Rannsóknin undirstrikar mikilvægi þess að fiskveiðistjórnun taki tillit til svæðisbundins efnahagslegs mismunar og flóknu samspili hegðunar fiskimanna, hversu vel þeir fylgja settum reglum og stöðu auðlindarinnar.

Á heildina litið veita þessar rannsóknir innsýn í skipulag og stjórnun smábátaveiða á Viktoríuvatni. Smábátaveiðar eru stundaðar um alla Afríku, og því er hægt að draga mikilvægan lærdóm af niðurstöðunum. Greiningin gefur til kynna að hvorki núverandi né sögulegar aðferðir við fiskveiðistjórnun í Viktoríuvatni hafi reynst nægjanlega árangursríkar. Hver aðferð hefur haft sína veikleika. Þörf er á nýjum leiðum til að tryggja sjálfbærni veiðanna og efnahagslega velferð fólksins sem er háð veiðunum sér til framfærslu.

Lykilorð:

Fiskveiðistjórnun, áhrif fiskveiða, sjálfbærni, Viktoríuvatn, smábátaveiðar og auðlindastjórnun.

Abstract

This thesis contains an analysis of Lake Victoria´s Small-Scale Fishery (SSF), aiming to provide a novel perspective and framework for understanding this intricate and dynamic system. The thesis is dedicated to evaluating the Nile perch fishery in Lake Victoria, focusing on the evolution of fishing patterns, adaptation strategies, and the effectiveness of fishery management institutions in implementing existing policies and legislation. The research focuses on Uganda in three out of four papers, while in the first paper, the technical efficiency of the Nile perch fishery provides a comparison among the three riparian countries. Data sources include Catch Assessment and Frame Survey datasets from the Lake Victoria Fisheries Organization (LVFO) and the National Fisheries Resources Research Institute databases, fishery export data, and cross-sectional qualitative and quantitative survey data.

Quantitative data, organized as panel datasets, are employed to analyse fish catch, fishing effort, and Nile perch exports, while qualitative data obtained through interviews with fishers and law enforcement officials supplement the available quantitative data. Data analysis methods vary depending on the objectives of each paper, including descriptive statistics and econometric analysis. Using diverse datasets, the thesis addresses four primary objectives across four papers.

Paper I delves into the analysis of the technical efficiency of the Nile perch fishing fleet on Lake Victoria across Uganda, Kenya, and Tanzania, highlighting the significant increase in the number of motorized vessels, particularly in Uganda, alongside a decline in paddled vessels due to stringent law enforcement targeting illegal gear and vessel sizes.

Paper II examines fishersperspectives on future fisheries management regimes in the context of the current military intervention on Lake Victoria.

Paper III analyses trends in fishing effort and catch variables among gillnet fishers on Lake Victoria, emphasizing adaptive strategies employed, based on the Nile perch population structure and economic needs, while underscoring the necessity of considering fisher behaviour in policymaking for sustainable resource use and livelihood development.

Paper IV investigates the effects of transitioning from cooperation to coercion in managing the Nile perch fishery in Uganda's Lake Victoria, highlighting concerns regarding declining catches and overcapacity in the motorized fleet. The study underscores the importance of tailored policies addressing regional economic disparities and the complex interplay between fisher behaviour, regulatory compliance, and resource health, referred to as the biological condition of the fishery resource and the broader ecological state of the lake.

Keywords:

Fisheries management, fishery dynamics, sustainability, Lake Victoria, small-scale fisheries, and resource management.

Acknowledgments

I want to extend my heartfelt gratitude to everyone who has supported me throughout my doctoral studies. I thank God for granting me the strength to complete this task, there would be no me without Him. I would like to express my deepest gratitude to my exceptional doctoral advisory team: Dr. Tumi Tómasson, Professor Daði Már Kristófersson, Professor Jón Geir Pétursson, and Dr. Anthony Taabu-Munyaho. Your guidance, patience, and unwavering support during this period have been truly invaluable. I am deeply indebted to you all.

I would also like to acknowledge the National Fisheries Resources Research Institute for paving the way for my career. Special thanks to Dr. John S. Balirwa and Dr Anthony Taabu-Munyaho for their mentorship and for opening doors to this fulfilling professional path. My sincere appreciation goes to the UNESCO-GRO Fisheries Training Programme for awarding me a scholarship that allowed me to pursue my studies in Iceland. This opportunity has been pivotal to my academic and professional development. I am grateful to my church family at Filadelfia Church in Iceland for their warmth and hospitality. Special thanks to Racheal Muhaye and all the sisters for their love and support, making my life in Iceland so much easier and more enjoyable.

I am eternally grateful for the unwavering support from the Director of the National Fisheries Resources Research Institute, Dr Winy Nkalubo and members of the Capture Fisheries and Biodiversity Conservation Program. Special thanks to Drs. Nakiyende Herbert, Dr. Bassa Samuel, and Mr. Elias Muhumuza for their continuous encouragement and assistance. I am deeply thankful to the fishers on Lake Victoria whom I interviewed, for providing me with steady employment and for being an integral part of this journey.

Special thanks go to my dedicated data collection team: Mr. Akol John Micheal, Mr. Nduwayesu Everist, and Mr. Kamya Ashraf from the National Fisheries Resources Research Institute; Mr. Eric Odari and Ms. Monica Achieng from the Kenya Marine and Freshwater Research Institute; and Ms. Sophia Shaban from the Tanzania Fisheries Research Institute. Your hard work and commitment have been invaluable.

To my family my parents Mr Wairagala N.P and Ms Ikima R.M mostly for understanding and support given through the tribulations of life I was going through during this period, my uncle Prof Isiko A. Paul for his support to the girl child in our extended family, and the courage he gave me through this process, and to my siblings for lightening my days and making me smile and laugh through the 5 years of my studies. All your prayers, support, and love have been my anchor during these years. A special

mention to my mother and siblings Eva, Paul, Moses, Arnold, Christine, and Steven, whose care for my little one allowed me to focus on my studies. I am profoundly grateful. Above all, I dedicate this work to my two grandmothers and my mother, who never had the chance to study this far. I give glory to God Almighty. For God and my country.

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List of abbreviations

AFALU	Association of Fishers and Lake Users
ANOVA	Analysis of Variance
BMU	Beach Management Unit
CAS	Catch Assessment Survey
COFI	Committee on Fisheries
CPUE	Catch Per Unit Effort
DiFR	Directorate of Fisheries Resources
EAFFRO	East African Freshwater Fisheries Research
GDP	Gross Domestic Product
FAO	Food and Agriculture Organization
FPU	Fisheries Protection Unit
FS	Frame Survey
KMFRI	Kenya Marine and Fisheries Research Institute
LP	Labor Productivity
LVBC	Lake Victoria Basin Commission
LVFO	Lake Victoria Fisheries Organization
LVFS	Lake Victoria Fisheries Service
NaFIRRI	National Fisheries Resources Research Institute
MAAIF	Ministry of Agriculture, Animal Industry and Fisheries
S.D.	Standard Deviation
S.E.	Standard Error
SDGs	Sustainable Development Goals
SFA	Stochastic Frontier Analysis
SSF	Small-scale Fisheries
TAFIRI	Tanzania Fisheries Research Institute
TE	Technical Efficiency
TL	Total Length
UPDF	Uganda Peoples Defence Force

List of figures

List of tables

List of original papers

This thesis is based on the following original publications;

I. Mpomwenda, V., Tómasson, T., Pétursson, J. G., Taabu-Munyaho, A., Nyamweya, C. S., & Kristófersson, D. M. (2024). Technical Efficiency of the Nile Perch Fishing Fleet on Lake Victoria: A Comparative Perspective on the Three Riparian Countries, Kenya, Tanzania, and Uganda. Fishes, 9(10), 414.

II. Mpomwenda, V., Kristófersson, D.M., Taabu-Munyaho, A., Tómasson, T., Pétursson, J.G., 2021. Fisheries management on Lake Victoria at a crossroads: Assessing fishers' perceptions on future management options in Uganda. Fisheries Management and Ecology 2, 1–16. https://doi.org/10.1111/fme.12526.

III. Mpomwenda, V., Tomasson, T., Pétursson, J.G., Taabu-Munyaho, A., Nakiyende, H., Kristófersson, D.M., 2022. Adaptation Strategies to a Changing Resource Base: Case of the Gillnet Nile Perch Fishery on Lake Victoria in Uganda. Sustainability 14, 1–20. https://doi.org/10.3390/su14042376.

IV. Mpomwenda, V., Tómasson, T., Pétursson, J.G., Kristófersson, D.M., 2023. From Co-Operation to Coercion in Fisheries Management: The Effects of Military Intervention on the Nile Perch Fishery on Lake Victoria in Uganda. Fishes 8, 563. https://doi.org/10.3390/fishes8110563.

Declaration of contribution

My contributions involved the planning, execution, and dissemination of research presented in this thesis. It includes my involvement in research design, fieldwork, data analysis, writing of the papers, and formulation of conclusions. Contributions are listed below.

1. Research planning and design:

I was responsible for conceptualizing and designing the research framework for this study. This involved identifying key research questions, developing methodologies, and coordinating with various stakeholders and institutions. My work was guided by discussions with my advisory team and the literature on fisheries management.

2. Fieldwork and data collection:

I actively led fieldwork operations across different sites on Lake Victoria. This included organizing and managing data collection efforts, conducting interviews with fishers, and overseeing the gathering of observational data. I collaborated closely with my data collection teams in Uganda, Kenya, and Tanzania to ensure accurate and comprehensive data collection.

3. Data analysis and interpretation:

Daði Már Kristófersson and I took primary responsibility for analysing the collected data, applying both statistical and qualitative methods to extract meaningful insights. This involved processing raw data, conducting statistical analyses, and interpreting the results within the context of fisheries management practices.

4. Writing and manuscript preparation:

I took the lead in writing the research papers included in this thesis. This involved drafting, revising, and finalizing the manuscripts based on feedback from my advisory team and peer reviewers. My writing aimed to communicate the research findings and their implications for fisheries management.

5. Drawing conclusions and implications:

I synthesized the findings from each paper to draw overarching conclusions about fisheries management on Lake Victoria. This synthesis considered the broader regional and ecological context, as well as policy implications. My work culminated in recommendations for sustainable fisheries practices and management reforms.

1 Introduction

Small-scale fisheries (SSF) play a crucial role in global food security and the livelihoods of millions. SSF, particularly inland fisheries, cover diverse aquatic ecosystems worldwide, spanning approximately 7.8 million km^2 (De Graaf et al., 2012). Small-scale fisheries display a range of characteristics that can vary widely based on the local context, practices, and economic conditions (Bartley et al., 2015; Cooke et al., 2016; Funge-Smith, 2018; Funge-Smith & Bennett, 2019; Lynch et al., 2016). This diversity positions them on a scale between subsistence and commercial operations, without fixed or universal boundaries separating them from large-scale fisheries, making it challenging to define or categorize them (FAO, 2022b; FAO et al., 2023; Rousseau et al., 2019).

The study focuses on small-scale inland fisheries, which include subsistence fisheries for household consumption, commercial fisheries for market sales, and artisanal fisheries that combine both, using traditional, low-tech methods (da Cunha et al., 2023; FAO et al., 2023; Funge-Smith & Bennett, 2019). In more developed regions, recreational fisheries often dominate inland waters, while in Africa and Asia, commercial and subsistence fisheries prevail (Cooke et al., 2016; Welcomme et al., 2010). Many fishers have diverse livelihoods, combining fishing with agriculture or small businesses, making classification difficult (FAO et al., 2023). Because of their varied goals and traditional practices, the term "artisanal" is commonly used and will be applied in this dissertation to describe such small-scale fisheries. Key inland SSF regions, including the Mekong River basin, Amazon River, and African Great Lakes, exhibit unique characteristics with numerous small-scale operators pursuing multiple species and operating under open access or common property regimes (Kolding & van Zwieten, 2014; Lynch et al., 2016, 2017).

Small-scale fisheries employ nearly 90% of the world's fishers and play a crucial role in supporting the livelihoods of millions, contributing significantly to food security, income generation, and national economies (FAO, 2023). In 2016, an estimated 60.2 million people were employed part-time or full-time in the SSF value chain. Of these, 27.5 million were involved in harvesting, with 53% (14.6 million) in inland fisheries (FAO et al., 2023). Inland fisheries are linked to the 2030 Agenda of the Sustainable Development Goals (SDGs) including SDG 1 (No Poverty), SDG 2 (Zero Hunger), SDG 5 (Gender Equality), SDG 8 (Decent Work and Economic Growth), and SDG 14 (Life Below Water) as they play a pivotal role in addressing poverty alleviation, enhancing food security and nutrition, promoting gender equality, supporting sustainable households, and conservation of aquatic ecosystems (Lynch et al., 2017; UN, 2015)

Inland fisheries in Africa contribute 29% to the global inland catch (FAO, 2024). FAO estimates global inland fish production at 11.3 million tons, while the Illuminating Hidden Harvests (IHH) report gives a slightly higher estimate of 11.8 million tons (FAO et al., 2023). This discrepancy likely arises from the IHH report's use of diverse data sources and a multidisciplinary approach to data collection, while FAO considers statistics provided by national governments, and data may not be fully captured (FAO, 2024; FAO et al., 2023). Although the figures differ slightly, both estimates highlight the significant contribution of African inland fisheries to global production. Despite this significant contribution, African inland fisheries face a range of challenges, both internal and external. Internally, issues such as underreporting, escalating fishing pressure, climate change impacts, pollution, habitat degradation, and governance problems persist (Bartley et al., 2015; Cooke et al., 2016; Elliott et al., 2022; Welcomme, 2011). Externally, inland fisheries compete with other sectors like aquaculture, hydropower, and tourism, often leading to conflicts over resource use (Cooke et al., 2016; Cowx & Ogutu-Owhayo, 2019; Musinguzi et al., 2019; Njiru et al., 2019).

While data availability and reliability for informing verifiable decision-making in SSFs have been questioned (Bartley et al., 2015; Fluet-Chouinard et al., 2018; Lorenzen et al., 2016; Pilling et al., 2009), Lake Victoria, the lake subject of this thesis, is an exception. The lake has been extensively studied, with significant efforts on data collection, analysis, and governance (Lawrence et al., 2023).

Despite the wealth of available knowledge, the most significant debate centres around the effectiveness of fisheries policies and their implementation in promoting the ecological sustainability, economic viability, and resilience of Lake Victoria's fisheries. Questions remain about whether current fishery policies, regulations, and their execution adequately address the evolving fishing patterns, fisher adaptation strategies, and management challenges within the sector (Kolding et al., 2016; Kolding & van Zwieten, 2014; Mkumbo & Marshall, 2015; Natugonza et al., 2020; Njiru et al., 2014; Nyamweya et al., 2023). This thesis explores these critical issues by evaluating how fishing practices have changed over time, the strategies fishers adopt in response to shifting conditions, and the effectiveness of policy frameworks in achieving sustainable fisheries management.

The primary focus of the study is on the Ugandan Nile perch fishery on Lake Victoria, but a comparative study with the other riparian countries of Kenya and Tanzania was also carried out. The comparative aspect of the research, novel to Lake Victoria, sheds light on the challenges in the regional management of transboundary fisheries resources. This research also addresses a gap in the literature and practice regarding the adoption of the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries, which aim to promote responsible governance and management of SSFs (FAO, 2015, 2022a). The SSF Guidelines provide a framework for sustainable SSFs with a focus on human rights (Chuenpagdee & Jentoft, 2015; FAO, 2022a; Nakamura, 2022). However, in Lake Victoria, fishing communities face regulatory and economic barriers, such as vessel size limits, gear restrictions, and high compliance costs, particularly on the Ugandan side (Kantel, 2019; Mpomwenda et al., 2021, 2023). These challenges marginalize artisanal fishers and restrict their access to resources. Weak legal frameworks and poor stakeholder engagement further undermine the human-rights-based approach, and the voluntary nature of the guidelines limits their effectiveness.

This thesis integrates four papers that utilize diverse datasets, including cross-sectional data, which captures a snapshot of different units at a single point in time, and panel data, which track the same units across multiple periods to observe temporal changes (Mastromarco et al., 2016; Verbeek, 2007). By employing a mixed-methods approach, combining both quantitative and qualitative data, the thesis captures the complexity of managing small-scale fisheries and provides a nuanced understanding of the challenges they face. The key objectives are:

- To determine the technical efficiency of the Nile perch fishing fleet by comparing vessel performance among the three Lake Victoria riparian countries.

- To evaluate the adaptation strategies of Nile perch gillnet fishers on Lake Victoria in Uganda using eight years of catch and effort data from 2005 to 2015.

- To assess how fishers in Uganda envision future management options for Lake Victoria fisheries amid strict law enforcement interventions.

- To examine the effects of shifting from cooperative management to coercive strategies in managing the Nile perch fishery in Uganda's Lake Victoria.

Together, these papers address these objectives and provide insights into the governance and management of SSFs, offering practical recommendations for improving sustainability and supporting the livelihoods of fishing communities. Beyond Lake Victoria, the findings hold relevance for other African inland fisheries and global contexts facing similar challenges. This work underscores the importance of adaptive, inclusive, and rights-based management approaches to ensure the resilience and long-term sustainability of SSFs, ultimately contributing to the well-being of fishing communities.

2 Lake Victoria overview

2.1 Fisheries resource base and key management challenges on Lake Victoria

In this thesis, the term "fisheries management" is used in a practical and policy-focused sense. It refers specifically to the regulatory, administrative, and enforcement measures implemented through government institutions and regional bodies, rather than to formalized management frameworks or theoretical governance models. This definition reflects the empirical and applied orientation of the study, which focuses on real-world policy interventions and their implications for small-scale fishers on Lake Victoria. While theoretical models of fisheries governance exist, such as Arnason's fisheries management regimes or interactive governance theory (Arnason, 2009; Kooiman et al., 2005), they were not used to frame the research design or structure the analysis. The study instead applies a grounded, field-based evaluation of how fishers and institutions respond to evolving policy regimes.

Lake Victoria's ecosystem, once home to over 500 endemic cichlid species, has undergone substantial changes over the past 50 years attributed to various stressors (Pringle, 2005; Witte et al., 1992). Habitat alterations, including the introduction of invasive species like Nile perch (Lates niloticus) and Nile tilapia (Oreochromis niloticus), is one of the key factors reported to have significantly impacted the native cichlid populations. Overfishing has been reported to further exacerbate the decline of indigenous species such as Oreochromis esculentus and Oreochromis variabilis (Marshall, 2018; Pringle, 2005; Taabu-Munyaho et al., 2016). With a growing human population in the catchment, nutrient loading from agricultural runoff and urban development has led to eutrophication, altering the ecosystem and affecting fish food availability and breeding grounds (Hecky et al., 2010; Kolding et al., 2008; Kolding & van Zwieten, 2006; Ngoepe et al., 2024; van Zwieten et al., 2016). In addition, climate change has intensified these stressors, altering water levels, temperature patterns, and seasonal dynamics (Cowx & Ogutu-Owhayo, 2019; Johnson, 2010; Nyboer et al, 2022).

Over time, the fisheries of Lake Victoria shifted, from a diverse multi-species fishery with over 500 species to three major species, including the pelagic Rastrineobola argentae (locally known as dagaa), and two introduced species, Nile perch and Nile tilapia, now dominating the fishery. The species composition of overall catches in Lake Victoria has undergone significant changes over time (Figure 1A). From 1980 to the mid-2000s, there was a notable increase in catches following the introduction of Nile perch and Nile tilapia, with Nile perch dominating the catches during this period. However, from the mid-2000s onward, a notable shift occurred, with dagaa becoming increasingly dominant, accounting for more than 60% of total catches. Additionally, a resurgence of Haplochromine species has been observed, coinciding with the rise in dagaa catches nearly 15 years ago. These shifts in species composition and the increasing catch also coincide with the increase in the number of boats and fishers, thus highlighting evolving dynamics within the lake's fishery system (Figure 1B). By 2022, the lake had a capture fish production of over 1 million tons, contributing over a quarter to Africa's inland capture fisheries, estimated at 3.3 million tons (FAO et al., 2023; LVFO, 2022). From a total ecosystem yield perspective, the trend in fisheries catch does not immediately imply unsustainable fishing, but rather reflects a structural shift in species composition, where smaller, faster-growing species dominate catches, a pattern that has been observed in tropical inland fisheries in Africa (Kolding et al., 2019).

Despite established governance rules under the Lake Victoria Fisheries Organisation (LVFO), which include gear restrictions and closed fishing seasons, fisheries management on the lake remains a challenge. Noncompliance with these regulations is widespread, largely due to the differing political environments and implementation strategies in Uganda, Tanzania, and Kenya. The open-access nature of the fisheries further complicates regulation, as fishers compete with stakeholders in cage farming, tourism, waste treatment, and mining for access to resources (Chimatiro et al., 2021; Jul-Larsen, 2003; Lawrence et al., 2023).

National policies alone are insufficient without harmonized regional efforts, which have not been effectively implemented despite the presence of regional institutions, including the Lake Victoria Fisheries Organisation and the Lake Victoria Basin Commission (LVBC). Recent efforts by Uganda and Tanzania to implement Monitoring, Control, and Surveillance (MCS) systems aim to reduce illegal fishing. However, Kenya has been more hesitant to adopt similar measures, reflecting the uneven policy implementation that hampers the lake's fisheries management. The fisheries management objectives of economic, social, and conservation are misaligned, complicating effective management (Hilborn, 2007; Njiru et al., 2014). Uganda prioritizes economic returns by restricting access; similar efforts have been applied in Tanzania to enforce regulations through a multi-sectoral approach (Natugonza et al., 2020). Kenya's approach to fisheries management, though perceived as more relaxed, appears to be a strategy aimed at balancing social objectives, particularly employment and livelihood support in fishing communities.

The lack of coordination between the three countries hinders harmonized efforts to manage Lake Victoria's shared ecosystem sustainably (Natugonza et al., 2020; Njiru et al., 2014). Moreover, fishing patterns and vessel performance play critical roles in the sustainability of the fishery. Intensified competition among fishers and technological advancements in vessel propulsion and gear efficiency have led to increased fishing pressure, particularly on commercial species. The following section will explore how these factors impact the sustainability of the fishery and how MCS efforts in Uganda and Tanzania have attempted to address these challenges.

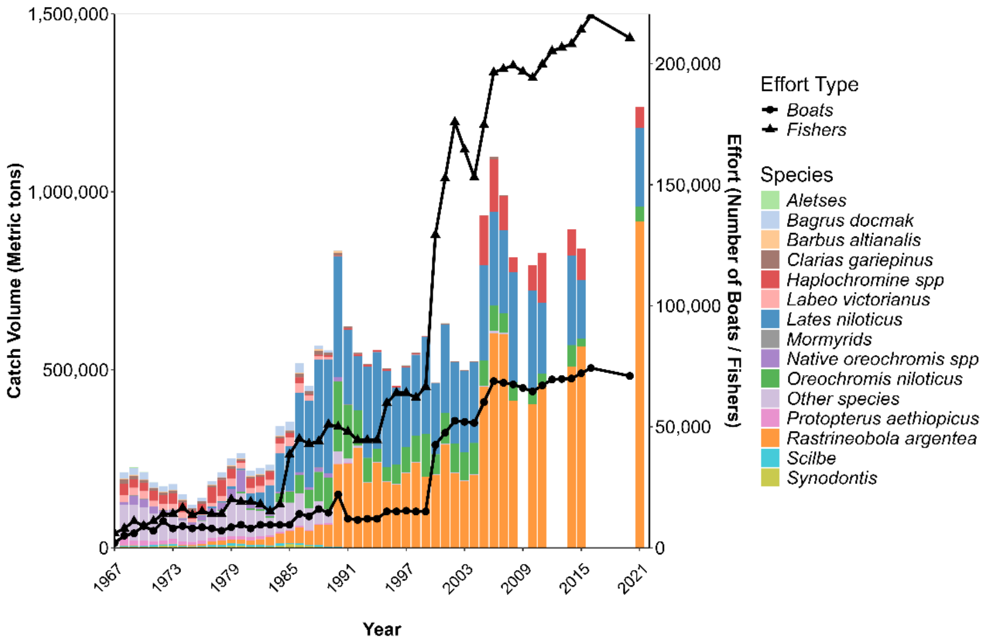


Figure 1: Changes in species catch composition (A) and the number of boats and fishers (B) on Lake Victoria, Source: LVFO database.

2.2 Fishing patterns, vessel performance, and their impact on fisheries sustainability

Lake Victoria's fishing patterns have significantly shaped fish catches, especially for key commercial species. Fishing patterns describe the likelihood of capturing specific species or sizes of fish based on their natural occurrence in the ecosystem, influenced by the combination of gear, methods, and effort used by fishers (Kolding et al., 2016; Natugonza et al., 2022).

Historically, fishing on Lake Victoria relied on traditional gear like spears, but the introduction of gillnets in the 1920s marked a pivotal shift in the commercial exploitation of the native tilapine species Oreochromis esculentus and Oreochromis variabilis, spurring trade (Graham, 1929; Msuku et al., 2011; Ogutu-Ohwayo, 1993). Technological advancements introduced by colonial administrations gradually replaced these traditional methods with more modern gear. The Nile perch boom in the 1980s further accelerated fishing activities through the adoption of multifilament nylon gillnets, longlines, and motorized outboard engines, which not only improved efficiency but also expanded access to distant fishing grounds (Kudhongania & Chitamwebwa, 1995; Taabu-Munyaho et al., 2016). The combination of growing global fish markets and improved processing infrastructure increased both fishing effort and efficiency, particularly in the Nile perch fishery. In 2020, 58% of the estimated 210,600 fishers and 71,000 fishing vessels on Lake Victoria targeted Nile perch (LVFO, 2020a).

Fisheries policies across Lake Victoria's riparian countries have sought to regulate fishing selectivity and pattern rather than effort through restrictions such as minimum mesh sizes and gear bans. However, fishing patterns often reflect natural fluctuations in species abundance (Kolding & van Zwieten, 2011). Since the mid-2000s, the use of illegal fishing gear (e.g., monofilament gillnets, beach seines, cast nets) has surged in response to the increased abundance of juvenile Nile perch (Mkumbo & Marshall, 2015; Msuku et al., 2011; Njiru et al., 2010, 2014). Concurrently, the dagaa fishery has gained commercial importance, accounting for over 60% of total catches in 2021, driven by increased fishing effort specifically targeting this species (LVFO, 2022). Despite concerns over declining Nile perch exports (Mpomwenda et al., 2023; UBOS, 2015), fishing communities have demonstrated resilience by adjusting their fishing effort from one species to another, thereby sustaining commercial fisheries (Kolding & van Zwieten, 2011).

In Uganda, evolving fishing patterns have prompted policy changes aimed at combating illegal harvesting of juvenile Nile perch. The Ugandan government has intensified enforcement of fishing regulations, with a focus on eliminating small fishing crafts linked to illegal gear use (Mpomwenda et al., 2022). The following section will explore the evolution of fisheries management regimes, with particular emphasis on policy and enforcement changes over time. In the context of this thesis, the fisheries management regime is defined as the institutions established to oversee policy formulation and enforcement of fishery regulations.

2.3 Fisheries management responses on Lake Victoria in Uganda

Historically, hierarchical self-governing systems played a key role in fisheries resource management (Alidri, 2016; Onyango, 2015). These traditional systems were disrupted during colonial times when science-based regulatory measures and formal centralized institutional structures were introduced (Chuenpagdee & Jentoft, 2015; Jentoft & Chuenpagdee, 2015; Kolding & van Zwieten, 2011). This came with the early restrictive measures in fishing, including the minimum mesh size of 5 inches for gillnets on the lake to regulate the early native tilapia fishery.

Following Uganda's independence in the early 1960s, the newly formed government maintained the colonial structures. Centralized management continued to be responsible for policy formulation and enforcement, but these efforts were hampered by inadequate resources for the development and implementation of regulations (Nunan, 2006). Relying solely on top-down, central government-driven fisheries management proved unsustainable, leading to the search for alternative approaches. In line with trends of decentralization and power devolution, co-management systems gained traction in the 1990s (Béné et al., 2009; Hara et al., 2015). These systems sought to distribute management responsibilities between governments and local communities, promoting a bottom-up approach (Béné et al., 2009; Sen & Nielsen, 1996). Fisheries co-management was widely promoted in small-scale fisheries and adopted in many African inland fisheries through various donor-funded initiatives (Jentoft et al., 1998; Kateka, 2010). Localized community-based user groups were established, on Lake Victoria known as Beach Management Units (BMUs), to manage fisheries at the community level, specifically to curb the use of illegal fishing gear and practices (Kolding et al., 2019; Nunan, 2018; Nunan et al., 2015).

The BMUs, formally mandated through national and regional policies to promote sustainable fisheries co-management at the local level, had functions such as registering of fishers and vessels, monitoring and reporting illegal activities, resolving conflicts, and supporting data collection (Nunan, 2006; Ogwang et al., 2009). However, the BMUs failed to fulfill their mandate due to inadequate funding, limited devolution of authority, and trust from the state. These challenges were compounded by corruption and elite capture, with BMU leaders implicated in rent seeking and collusion with illegal fishers, which led to an increase in the use of illegal gear and fishing practices (Béné et al., 2009; Cepić & Nunan, 2017; Kolding et al., 2019; Nunan et al., 2020).

In Uganda, the co-management system faced major challenges, including limited funding, bribery and corruption, and reliance on social and kin ties, which encouraged more illegal activities on the lake, ultimately leading to the abolition of the BMUs in November 2015. The BMUs were replaced by military-led law enforcement to curb the use of illegal gear, in particular those targeting juvenile Nile perch and tilapia (Kantel, 2019; Kolding et al., 2019; Mpomwenda et al., 2021).

Uganda's fisheries management framework is guided by laws and regulations, including the National Fisheries and Aquaculture Policy (2017) and the National Fisheries and Aquaculture Act (2022) (MAAIF, 2017; The Republic of Uganda, 2022). The Act aims to address challenges such as overcapacity, institutional weaknesses, excessive fishing effort, and destructive fishing practices, while also promoting investment in aquaculture. However, the policy continues to uphold existing gear-specific regulations, such as the minimum mesh size for fishing nets. The regulation, although intended to protect fish stocks, was ineffective in maintaining the populations of native tilapia species (Fryer, 1973; Taabu-Munyaho et al., 2016).

The military enforcement system maintains the use of two-member local committees as a way to incorporate co-management at landing sites, which are imbalanced in terms of power and whose primary role is to assist military enforcement by identifying hotspots of illegal activity and individuals involved (Mpomwenda et al., 2023). While the policies target both capture fisheries and aquaculture, the country's natural resource management approach tends to prioritize meeting market-driven goals, such as Nile perch exports, contributing to the decline of the BMU system.

3 Materials and methods

3.1 Study area: Lake Victoria

Lake Victoria is Africa's largest and the world's second-largest lake by surface area (68,800 km2). It is shared by Kenya (6%), Tanzania (51%), and Uganda (43%) (Figure 2). The lake and its catchment area of 194,200 km^2 support about 60 million people in Kenya, Tanzania, Uganda, Rwanda, and Burundi. The population around Lake Victoria is growing at a rate of 3.8% per year, significantly higher than Africa's average population growth rate of 2.5% (Nyamweya et al., 2020; World Bank, 2020). The rapid population growth reflects the lake's importance to the region, with several factors driving this increase. The high birth rate is a major contributor, especially among rural communities in the area (Bremner et al., 2013). The lake supports fishing, while the fertile riparian soils enhance agricultural productivity. Growing urban centers such as Kisumu, Kampala, and Mwanza stimulate trade and attract migrants seeking better services and employment. Migration from other regions driven by conflict or environmental changes also contributes to rapid population growth (Bremner et al., 2013; Downing et al., 2014; Nyamweya et al., 2020).

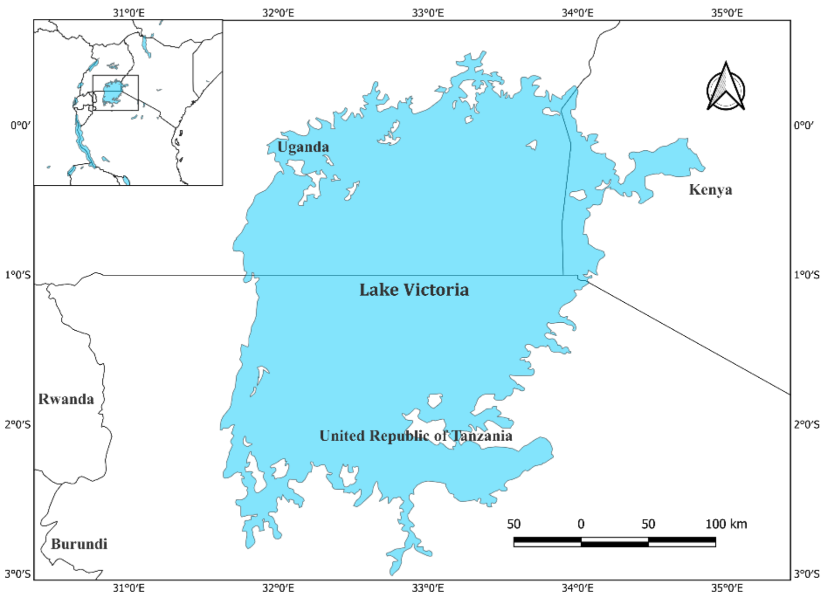


Figure 2: Lake Victoria in East Africa, bordered by the riparian countries of Kenya, Tanzania, and Uganda. Shoreline lengths of Lake Victoria: Uganda (1,750 km), Tanzania (1,150 km), and Kenya (550 km). Source: QGIS.

3.2 Ugandan fisheries on Lake Victoria

Uganda has large fisheries resources, as water covers 20% of its total surface area, which includes five major lakes, 160 minor lakes, wetlands, and reservoirs (NEMA, 2019). Uganda produced 570,000 MT of capture fish in 2020, 5% of the world's and 17% of Africa's inland capture fisheries, making it Africa's top inland capture fisheries producer (FAO, 2024). Inland capture production in the country predominantly derives from the five major water bodies: Lakes Victoria, Albert, Kyoga, Edward, and George. Nile perch is the country's most economically valuable fish species and contributed to 53% of the total economic value of the fisheries in 2015 (NaFIRRI, 2021). Lake Victoria's fisheries provide over 90% of Uganda's fish and fishery product exports, attracting policy and regulation attention (Mpomwenda et al., 2023; UFPEA, 2019). In 2021, Uganda's fisheries production, like that of other riparian countries of Lake Victoria, was predominantly composed of dagaa, accounting 54% (372,727 tons) of the total catch. Nile perch contributed 9% (61,774 tons), Haplochromines accounted for 4.8% (32,884 tons), Nile tilapia contributed 4.1% (28,364 tons), while other species contributed 28.1% (194,040 tons) (NaFIRRI, 2021).

The Ugandan part of Lake Victoria has an extensive shoreline of 1,750 km characterized by numerous islands, making it favourable for fisheries production (Mafuta et al., 2017; Muhoozi, 2002). Nile perch is mainly processed as a chilled or frozen product for export markets, Nile tilapia is primarily consumed locally, and dagaa is sold in both local and regional markets. In recent years, a lucrative trade in Nile perch maws has developed where the value of the maw of the largest fish exceeds the value of the flesh (Bagumire et al., 2018; Odongkara et al., 2018).

Although the BMUs were originally introduced to decentralize fisheries governance and promote community participation, in practice, they were embedded in a neo-patrimonial political context that limited autonomy and effectiveness (Kantel, 2019; Mpomwenda et al., 2021). Over time, the evaluation of BMUs shifted from participatory ideals toward national-level performance metrics, particularly their perceived failure to curb illegal fishing and support fishery exports. This mismatch between the original mandate of BMUs and the expectations imposed on them by the central government contributed to a policy turning point in Uganda's fisheries management. The abolition of BMUs and the subsequent shift toward militarized enforcement thus reflected a crossroads between participatory and coercive management regimes (Kantel, 2019). The co-management institutions, the BMUs on Lake Victoria, were disbanded through a presidential directive in 2015, and the Uganda Peoples Defence Force - Fisheries Protection Unit (UPDF-FPU) was tasked to undertake fisheries law enforcement. Although military involvement was intended to be a temporary measure, the need for a paramilitary fisheries enforcement unit having both trained law enforcement personnel, with the help of local community representatives, has been stated and is reflected in the Fisheries Act of 2022 (The Republic of Uganda, 2022).

3.3 Data sources and analysis

Empirical analyses presented in the papers included in this thesis are based on several key variables and datasets collected from Lake Victoria. Data for the variables involved both qualitative and quantitative methods of data collection.

3.3.1 Lake Victoria frame and catch assessment survey data

The main datasets used in the papers of the thesis include the Frame and Catch Assessment Survey data sets obtained from the Lake Victoria Fisheries Organization and National Fisheries Resources Research Institute databases.

Frame Survey (FS) data involves a complete census (count) of fishing inputs (fishers, fishing crafts by type and propulsion method, fishing gears by type and size) and infrastructure supporting fisheries at all landing sites (LVFO, 2020a). In 2020, a total of 1364 landing sites were reported, 329 in Kenya, 580 in Tanzania, and 455 in Uganda (LVFO, 2020a). On Lake Victoria, three vessel propulsion types were considered for the thesis as these were dominant on the lake and influenced their access to different fishing grounds. These were described as paddled, sailed, and motorized fishing vessels.

Catch Assessment Survey (CAS) data, as used in the thesis papers, included information that was used to estimate Catch Per Unit Effort (CPUE) based on catch per vessel and corresponding effort variables, such as vessel type, number of fishers, gear type, and fishing duration. Frame Survey data is used to select the landing sites for the CAS, with 10% of the total landing sites chosen for sampling. Access to the LVFO database enabled access to data from Kenya and Tanzania. Catch assessment data consisted of nine-year vessel-level CAS data (2005-2008; 2010-2011; 2014-2015; 2021) collected over 17 years.

The collection of catch assessment data follows a two-stage sampling procedure (LVFO, 2007, 2021b). In the first stage, approximately 10% of all landing sites are selected for sampling based on frame survey data (Table 1). The sample sizes in the table represent the spatial and temporal trends in the total landing sites and sampled CAS sites lake wide. Landing sites should be selected randomly with probability proportional to their size measured in terms of the total number of vessels landing at the site. In the second stage, vessels are randomly selected from those landing at each site. Catch and effort are sampled for four days each month. Catch refers to the total weight of fish landed (in kilograms), while effort refers to variables such as vessel type, number of fishers or crew, number or size of different gear types, and hours fished.

Table 1: Total number of landing sites and the corresponding number of sites sampled for the Catch Assessment Survey (CAS) in the indicated years. The CAS sampling proportion is derived from the Frame Survey (FS) conducted in the preceding year. Source:(LVFO, 2022).

FS Year	2002	2004	2006	2008	2010	2012	2014	2016	2020
Total landing sites	1452	1433	1431	1327	1443	1481	1530	1535	1364
Count of CAS-sampled landing sites	145	143	143	133	144	148	153	154	136

3.3.2 Additional survey data

The thesis also relied on the collection of data from independent surveys to fulfill its objectives. Three separate surveys were conducted, each answering different objectives (Table 2). Additional survey data for Paper I, fuel consumption data for motorized fishing vessels, were collected in all three riparian countries, an existing gap in the catch assessment data set. Data collection took place between June and August 2017 in Uganda, and from April to September 2020 in Kenya and Tanzania. The landing sites selected for data collection were purposefully chosen from existing CAS sites, ensuring a representative sample of vessels across the lake from the landing sites (LVFO, 2020a, 2022). At each site, enumerators randomly collected data from the vessels during the first and last week of the data collection period for three months in Uganda and six months in Kenya and Tanzania. The data for Kenya and Tanzania were collected using the same format as in Uganda, incorporating the fuel variable into the catch assessment data form (LVFO, 2021b). This consistency ensured that the survey data could be reliably linked to the available panel data and used to predict the missing fuel variable. A description of the data and fuel model is given in Appendix 1.

For Paper II on fishermen's perceptions, data was collected from June to August 2017 from six landing sites. A two-stage sampling design was employed. In the first stage, six landing sites were stratified based on dominant (>80%) vessel propulsion type (motorised or paddled) and targeted species (Nile perch or dagaa). This stratification was informed by FS data from 2014. The selected landing sites were comprised of three motorised vessel landing sites (two targeting Nile perch and one targeting dagaa) and the other three with fishers predominantly using paddles (two targeting Nile perch and one targeting dagaa). These strata were chosen to ensure representation of the diverse fishing practices on Lake Victoria, while also adhering to budgetary constraints. In the second stage, a systematic random sampling approach was used to interview 273 respondents (fishers/boatowners) using a semi-structured questionnaire. Every other fisher/boatowner was selected based on their self-identification to participate in the study and this ensured minimal selection bias and ensured that the sample was representative of the population (Gorard, 2003). Interviews were conducted during two distinct times, tailored to the operational patterns of different fisher groups. At landing sites dominated by Nile perch (and tilapia), fishers were typically interviewed from midmorning to late afternoon. After landing and selling their catch, they engaged in net preparation during which the interviews were held. Dagaa fishers who usually landed their catches in the very early morning hours and left immediately after selling were targeted in the afternoon to evening hours as they prepared to go out fishing. This adaptive approach enabled the collection of perceptions on future fisheries management while accommodating landing site and species specific dynamics.

Table 2: Key variables and corresponding data sources used for the papers in the thesis.

No	Key variable	Data source	Data structure	Paper
1	Fishers' perceptions of management	Interviews with fishermen from a cross-sectional survey conducted by the student.	Cross-sectional data	Paper II
2	Fish catch	Catch Assessment Survey data from LVFO, NaFIRRI 2005-2008; 2010-2011; 2014-2015, and 2021.	Panel data	Papers I, III, and IV.
3	Fishing effort	Biennial Frame Survey reports from LVFO, NaFIRRI 2000-2016 and 2020.	Panel data	Papers I, II, III, and IV
4	Effects of policy interventions	Qualitative key informant interviews with FPU.	Cross-sectional	Paper IV
5	Illegal gear count	Records of illegal vessel and gear confiscations made by the FPU.	Panel data	Paper IV
6	Fuel use estimates	Cross-sectional survey using a semi-structured questionnaire	Cross-section data	Paper IV
7	Nile perch export data	Data from the Directorate of Fisheries Resources, Uganda Bureau of Statistics abstracts, and Bank of Uganda statistics for 2005-2021	Panel data	Paper IV.

In the first part of the questionnaire, fisher-specific information like age, fishing experience, status of the respondent (whether boat owner, crew member or manager), gender, full or part-time involvement in fishing, target species and gear used were asked. In the second part, fishers were asked to rate the status of the catches of their targeted species based on the severity of common challenges they faced in their operations, their level of knowledge and perception of regulations, and their effectiveness. Finally fishers were asked questions about alternative management regimes. Replies were either categorical yes/no responses to a statement or rated on a 3-point Likert scale from better off (1), constant (2), and worse off (3). The 3-point Likert scale was used as it was easier for respondents to distinguish their responses around a neutral point and for ease of analysis (Johns, 2010).

Paper II employed a mixed methods approach involving both quantitative data (FS and CAS already described) and qualitative data. Qualitative data was collected from eight senior military officials, each in charge of a distinct FPU sector. These were purposefully contacted and selected for interviews to provide a comprehensive understanding of the military intervention in law enforcement. A checklist of interview questions was used; however, depending on the situation, divergences were allowed from one respondent to another to allow respondents to talk freely. Interviews were conducted from December 2019 to August 2020, recorded, and each lasted 45–60 minutes. Permission to collect data was sought from the FPU head office. During the fieldwork, the purpose of the study and emphasis on ethical principles of anonymity and confidentiality guiding the research were explained to the respondents, with their consent to participate confirmed before the interviews were conducted. In addition, records of confiscations of illegal vessels and gear covering the period from February 2017 to August 2020 were obtained from each sector and compiled for further analysis. FPU officials are tasked with recording every confiscation made per operation, which is sent to the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF).

3.3.3 Other supplementary data sets

Fish export data were sourced from the statistical databases of the Bank of Uganda and the Uganda Bureau of Statistics to cross-reference and validate the information retrieved from these sources. Data verification was conducted using an additional dataset provided by the Directorate of Fisheries Resources (DiFR).

3.3.4 Data structure

The Catch Assessment and Frame Survey data sets were structured as panels by organizing a series of independent cross-sectional surveys conducted in different years. Vessels with common characteristics (such as vessel propulsion or gear type) were grouped into cohorts and treated as panel observations (Deaton, 1985; Verbeek, 2007).

A key limitation of using repeated cross-sectional surveys as panel data is that the same individuals are not consistently tracked over time, since vessels on Lake Victoria are sampled randomly for each cross-section, unlike in traditional panels. However, grouping vessels based on common characteristics reduces issues like participant dropouts and non-responses, and it often includes a larger number of observations across both individuals and periods (Verbeek, 2007).

3.4 Data analysis

The data analysis varied according to the type of data used for each paper and the objectives of the paper.

3.4.1 Descriptive analysis

Descriptive analysis involved summarizing data to provide insights into the general patterns and characteristics of the key variables in the data sets. Summary statistics were made for the three pre-determined vessel propulsion types for all the papers. For Paper I, summary statistics were based on the central tendency (mean, SD, and range) to describe key variables such as catches, labour, fuel use, and gear numbers. In Papers II and IV, graphical and tabular trends of vessel propulsion type count and other key characteristics, such as target species and gear type count per vessel type, were also described. For Papers I, III, and IV, descriptions were based on the FS and CAS data, whereas in Paper II, summary statistics were based on an independent survey, and these were presented as percentages of counts still based on the major vessel propulsion types in Uganda.

3.4.2 Quantitative metrics

1. Nile perch equivalent

The study focused on vessels targeting Nile perch, particularly for Papers I, III, and IV. In cases where bycatch of one or more species was recorded, the total catch for the vessel was standardized to the Nile perch equivalent weight, based on the value of the bycatch. For instance, if a vessel caught both Nile perch and Nile tilapia, the output was adjusted to reflect the Nile perch equivalent using the following formula:

$$Y_{Np} = NP + \sum_{1}^{n} \frac{y_t p_t}{P_{Np}} \quad \text{...Equation 1}$$

Where, Y_{Np} is the Nile perch equivalent total catch of a particular vessel

NP is the weight of Nile perch in kilograms for that vessel.

y_t Represents the catch weight (in kilograms) of another species (e.g., tilapia) obtained by the same vessel.

p_t Is the price per kilogram of the other species, say tilapia, in that vessel

P_{Np} Is the price per kilogram for Nile perch in the same vessel

Thus, the summation accounts for all species t (from 1 to n) in the vessel's catch to compute the total catch in terms of Nile perch equivalent.

2. Stochastic Frontier Analysis (SFA)

In Paper I, SFA was employed to assess the Technical Efficiency (TE) of the Nile perch fishing fleet in each of the riparian countries. Technical efficiency is derived from a production function specified as;

$$Y_i = f(X_i \beta).\exp(v_i - u_i) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \text{Equation 2}$$

Where:

Y_i = Output (Nile perch equivalents)

X_i= Inputs (Labor, gear, fuel, catch by species)

β = Parameters

v_i = Random error, e.g. due to measurements or randomness in weather

u_i = Inefficiency term

Full details of the model specifications are given in Appendix 2.

The primary objective of this framework is to estimate technical efficiency across fishing units. Using a stochastic frontier approach, we model the maximum attainable output given set of inputs, such as gear number, fuel, and labour, and catch by species, using a production function. The model incorporates a composite error term that captures random deviations v_i and inefficiencies u_i in the system. TE, ranging from 0 to 1, is derived using the stochastic production function, here 1 represents the efficiency frontier at the maximum possible output (catch) a vessel could achieve given its input levels are below the best observed conditions in the sample. A TE value approaching 0 implies that the vessel is highly inefficient, producing very little output relative to the inputs used compared to the most efficient vessels in the data set (Morrison et al., 2010). The output variable is the vessel's total catch standardized into Nile perch equivalents (see equation 1 above). This standardization enables consistent cross-vessel comparison by converting mixed-species catches into a single, price-weighted metric. To estimate the maximum possible output under best-practice conditions, the model considers key input variables, including labour (a product of the number of crew and hours fished), gear number, and fuel usage (in litres, where applicable), and catch composition.

In this study, country-specific heterogeneity, such as differences in macroeconomy (like GDP), regulatory enforcement, and institutional arrangement, among other factors, was accounted for by the inclusion of country dummy variables in the inefficiency component u_i of the stochastic production function. This specification captures the proportion of inefficiency attributable to a vessel's country of operation (e.g., Uganda, Kenya, or Tanzania), allowing cross-country performance comparisons without assuming uniform operating conditions (Battese & Coelli, 1995).

3. Labour productivity

Labour productivity (LP), as applied in the thesis, is defined as the total fish catch (standardized to Nile perch equivalents) divided by the product of crew size and hours fished per day (up to 24 hours). This measure captures the output generated per unit of human labour over time and serves as an indicator of labour efficiency (Alani, 2012; Carlaw & Lipsey, 2003; Nugent & Radicic, 2023). LP reflects how technological changes, such as motorisation, affect labour requirements relative to output, offering important insights into employment dynamics, investment decisions, and the economic performance of fishing units. TE and LP were thus used together in the paper to understand not just how much is caught, but how efficiently labour and inputs are utilised, supporting a more policy-relevant interpretation of fleet performance across countries. While acknowledging that small-scale fishers often engage in diversified livelihood strategies, LP remains a practical, measurable indicator of efficiency at the vessel level, particularly when comparing vessel types and country-level variations in input use and output.

4. Catch Per Unit of Effort (CPUE)

In Paper III, CPUE was used to assess the performance of gillnets. Firstly, data were filtered to include only vessels operating with a single mesh size per trip to ensure consistency in mesh size comparisons. Two proxy variables were computed: the average weight of fish and CPUE.

1. The average weight of fish landed per vessel was determined as;

$$\text{Average weight per fish (kg)} = \frac{\text{Total catch (kg)}}{\text{Total number of fish caught}}$$

2. CPUE was then calculated as;

    a. CPUE by number of fish:

$$\text{CPUE}_{\text{Number}} = \frac{\text{Total number of fish caught}}{\text{Number of gillnet panels x Hours fished}}$$

    b. CPUE by weight (kg):

$$\text{CPUE}_{\text{weight}} = \frac{\text{Total catch weight (kg)}}{\text{Number of gillnet panels x Hours fished}}$$

This dual method provided a detailed understanding of fishing efficiency, accounting for both the weight and number of fish to effort.

In Paper IV, CPUE was similarly calculated but included both gillnets and hooks as gear types. While Paper III was limited to the period 2005 to 2015, Paper IV included data collected in 2021.

While both labour productivity and CPUE measure fishing output, they capture different analytical dimensions and serve distinct purposes. CPUE is primarily used as a biological indicator to infer stock availability relative to effort (gear or vessel-based), reflecting resource conditions over time (Nyamweya et al., 2020). Labour productivity, on the other hand, defined as catch per fisher time, functions as an economic indicator, assessing efficiency at the fisher level, revealing insights into crew dynamics, technology adoption (e.g. motorisation), and labour intensity of different vessel types. In this study, labour productivity is used to explore how human effort translates into output across vessel categories and countries, whereas CPUE is interpreted more cautiously, given its ecological connotations and variability.

5. Parametric test – ANOVA and post hoc Tukey test

In Paper III, an analysis of the means between variables, namely mesh size, the number of vertical panels, and fish size, was performed using a one-way Analysis of Variance (ANOVA). This statistical test was used to determine whether there were significant differences in fish size based on variations in mesh size and vertical panels. The level of significance for the test was set at $p = 0.05$, meaning that differences between the groups were considered statistically significant if the p-value was less than 0.05.

In Paper IV, a two-way ANOVA was applied to compare how CPUE varied between two vessel propulsion types (e.g., motorized vs. paddled) over the study years. This analysis focused on evaluating differences in CPUE associated with propulsion type and time.

Following the ANOVA, a Tukey post hoc test was conducted to pinpoint which vessel propulsion and year groups differed significantly from each other. The post hoc test is critical for understanding pairwise differences between means when ANOVA indicates overall significance.

6. Non-parametric tests - Fisher's exact test

In Paper II, we employed Fisher's Exact Test to analyse the differences in fishers' responses based on their target species and the type of vessel propulsion they used. This test was chosen for its precision in handling small sample sizes and categorical data. The significance level was set at $\alpha = 0.05$, ensuring our findings were statistically robust and reliable.

3.4.3 Qualitative analysis

Qualitative analysis was used in Paper IV to analyse the transcripts of interviews conducted with FPU senior commanders. A deductive coding approach, where codes are developed in advance based on the study's predetermined objectives, was applied to guide the identification of relevant information from the interviews (Charmaz, 2006; Saldana, 2015). This involved authors carefully examining the transcripts to identify and code specific direct quotes from the respondents that addressed the paper's objectives. This involved systematically reviewing each line of the interview text to find statements that discussed how the military intervention was organized and the rules imposed during its implementation. The coding process helped categorize and link these insights to broader themes related to the study objectives, facilitating a deeper understanding of the commanders' perspectives on the intervention's structure and regulatory enforcement.

3.4.4 Statistical and graphical analysis

All statistical and graphical analyses for Papers II-IV were conducted using R software (R Core Team, 2022), version 4.0.3, while Paper I utilized version 4.2.2. Specific packages were employed for particular analyses, including the plm package for panel data management and the sfa package for Stochastic Frontier Analysis in Paper I. For data manipulation and visualization, the dplyr and ggplot2 packages were used, respectively.

3.5 Contribution of the thesis

This thesis contributes to the growing body of knowledge on fisheries management on Lake Victoria, particularly in Uganda, by offering empirical, analytical, and methodological insights across four interlinked studies. These contributions are synthesized along three dimensions: (1) Knowledge of fisheries management in Lake Victoria, (2) Analytical innovations, and (3) Methodological advancements.

3.5.1 Contribution to knowledge on fisheries management in Lake Victoria

Paper I presents the first comparative assessment of fishing fleet performance across the three riparian countries on Lake Victoria: Kenya, Tanzania, and Uganda. It identifies motorisation as a key factor in driving both technical efficiency and labour productivity, while exposing country-specific disparities linked to enforcement intensity and investment capacity. The study provides new regional benchmarks and reveals structural inefficiencies that undermine sustainability.

Paper II deepens understanding of fishers' perceptions and institutional trust under different management regimes. It highlights a clear shift in fishers' preferences towards user-defined, species-based groups over traditional local government and BMU-led systems. The findings introduce the idea of species-specific, hybrid co-management regimes that reflect user identities and shared interests.

Paper III provides longitudinal insights into how different vessel types (paddled and motorised) adapt to declining stocks, spatial constraints, and policy changes. It presents clear patterns in the gillnet gear adjustments, including mesh sizes and net depth, showing how both ecological feedbacks and economic realities shape fisher behaviour.

The study clarifies the behavioural logic underlying gear choices in small-scale fisheries.

Paper IV investigates the outcomes of militarised enforcement through Uganda's Fisheries Protection Unit. While rule compliance improved, the findings suggest that such coercive strategies did not yield corresponding ecological or economic gains. The study documents the changes in enforcement and its unintended consequences for fisher participation, particularly among paddled vessels. It challenges the assumed link between top-down control and improved fishery outcomes.

Collectively, these studies offer a fuller picture of Lake Victoria's fishery management realities linking fleet performance, fisher activity, institutional trust, and enforcement impacts. They also contribute context-relevant knowledge for designing equitable, adaptive, and effective inland fisheries policies.

3.5.2 Analytical contribution

Paper I applies a transboundary lens to evaluate TE and LP across Lake Victoria, distinguishing national patterns and linking them to regulatory and fleet characteristics. While Stochastic Frontier Analysis (SFA) has been used in other global fisheries, its comparative application to multi-country, inland fishery data in this context is new. The paper reveals how policy enforcement and fleet structure mediate efficiency, offering cross-country performance diagnostics.

Paper II uses fishers perceptions to interrogate governance and, through its findings, aligns with core tenets of legitimacy theory, particularly around institutional trust, perceived fairness, and governance preferences. Although not explicitly framed within this theory in the standalone paper, the synthesis draws on it to interpret the empirical patterns and inform broader governance debates.

Paper III analyses adaptation through the lens of vessel-gear interaction, demonstrating that behavioural responses to resource decline are not uniform but differ by technology and economic capability. It incorporates ecological and socioeconomic signals to understand gear reconfiguration, making the case for behaviourally informed regulations.

Paper IV introduces a political economic perspective to enforcement, framing coercion not just in terms of rule compliance but also in its implications for access, legitimacy, and long-term sustainability. It problematizes the assumption that increased compliance equals improved fishery health.

3.5.3 Methodological contribution

The thesis adopts a mixed-methods approach, combining longitudinal fisheries data with perception-based surveys and institutional interviews. While such combinations are not novel in a global sense, the thesis adapts and operationalises this integration for Lake Victoria's data-scarce and institutionally complex context.

Paper I demonstrates how SFA can be applied to compare TE and LP at national levels across an inland fishery, integrating gear and effort data to diagnose overcapacity and regional disparities.

Papers II and IV rely on structured and semi-structured interviews to generate data on governance and enforcement. The use of fishers perception surveys to model institutional trust and governance preference adds interpretive depth to standard regulatory assessments.

Paper III uses disaggregated catch and effort data (by gear and vessel) to reveal adaptation over time. It integrates ecological indicators (CPUE, fish size) with behavioural data to produce an understanding of gillnet use strategies on Lake Victoria.

The methodological value lies in tailoring these approaches to Lake Victoria's realities, demonstrating how combining diverse datasets can yield actionable insights even in data-poor, multi-use fisheries. The framework can be adapted to similar inland fisheries across Africa and beyond.

In addition, the thematic mapping in Table 3 demonstrates how each paper contributes distinctly to key areas of fisheries research: efficiency, governance, adaptation, enforcement, and policy relevance, highlighting their cumulative value to Lake Victoria's management discourse.

Table 3: Thematic contributions of the four papers to core fisheries management domains.

Theme	Paper I	Paper II	Paper III	Paper IV
Vessel efficiency	√		√	√
Governance		√		√
Adaptation			√	√
Enforcement		√		√
Policy relevance	√	√	√	√

3.6 Limitations

This thesis makes a significant empirical and conceptual contribution to fisheries management.

First, the analysis is constrained by data gaps in the CAS, which is the primary data source for Papers I, III, and IV. Specifically, data were not collected for eight out of the seventeen years considered in Papers I and IV, and for three out of eleven years in

Paper III. These gaps, due to inconsistent funding and logistical issues, may affect the continuity and comparability of some trend analyses.

Second, the qualitative component of Paper III involved a purposive selection of respondents, focusing primarily on senior army officers involved in fisheries enforcement. While these perspectives provide insights into high-level decision-making, they may not fully capture the lived experiences and operational views of lower-ranking officers or other enforcement actors. This limits the breadth of inference possible from the findings.

Third, the perception-based survey in Paper II was conducted in the early phases of heightened enforcement efforts on the lake. As such, respondents' views may have been shaped by immediate reactions to recent events, introducing potential response bias. Artisanal fishers using paddled vessels, particularly those targeting Nile perch and tilapia, were underrepresented in the sample, which may skew the generalisability of the results to the broader fisher population.

Lastly, the analysis assumes that gear specifications, particularly mesh and hook sizes, remained constant over time. Due to the absence of detailed annual records, this assumption could introduce error, especially in Papers I and IV, where gear performance is a key variable. This limitation is mitigated through disaggregated analysis by vessel and gear type, but it still warrants caution in interpreting temporal shifts.

Despite these constraints, the thesis offers robust and context-sensitive insights. The limitations identified here are common in inland fisheries research and underscore the need for sustained investment in consistent, multi-source data collection to inform future policy and scholarly work.

4 Synthesis of the main findings

4.1 The status and trends of vessel propulsion types on Lake Victoria.

A comparison of vessel composition in the Nile perch fishery across the three East African countries bordering Lake Victoria over the past two decades reveals changes in the adoption and use of propulsion technologies. The dominance of paddled vessels on the lake is primarily associated with their accessibility and affordability for economically disadvantaged communities (Muhoozi, 2002). In Uganda and Tanzania, the number of paddled vessels fluctuated but followed a generally increasing trajectory over time. However, in Uganda, a significant enforcement-driven decline occurred in 2020. In Kenya, the number of paddled vessels declined moderately over the period, with minor fluctuations. After an initial rise in the early 2000s, the trend plateaued and then gradually decreased, indicating a slow but steady shift away from paddled propulsion over time (Figure 3). On the other hand, the number of motorized vessels increased across all three countries over the past two decades, as fishers sought to explore more distant waters. While sailed vessels are most common in Kenya, there has been a slow but steady declining trend of such vessels in all countries.

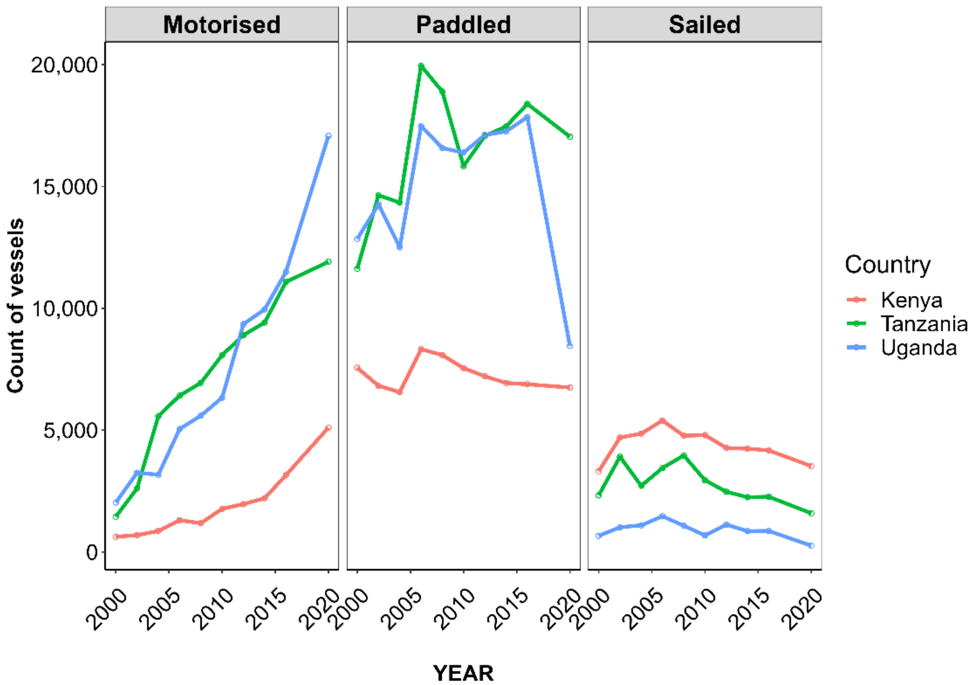


Figure 3: Vessel propulsion trends on Lake Victoria (2000-2020). Source: Frame Survey data.

4.2 Vessel propulsion and target species on Lake Victoria, Uganda

The increase in the number of motorized vessels in Uganda is primarily driven by the Nile perch fish export industry, as the species contributes to the majority (>90%) of the country's export of fish and fish products (UFPEA, 2019). These vessels are larger (approximately 10-12 meters) than the paddled vessels (≤6 meters) and can access more distant fishing grounds and carry larger catches (Mpomwenda et al., 2022). Additionally, the dagaa fishery has expanded, marking a large increase in the number of motorized vessels targeting this species, reflecting its growing regional market (Odongkara et al., 2018). In contrast, tilapia is predominantly harvested using smaller paddled vessels (Figure 4), with this fishery mainly supplying the domestic market. There was a slight increase in motorized vessels targeting tilapia in 2020. Enforcement measures have had a marked impact on vessel type changes, with a decline in the use of paddled vessels across all fisheries and a corresponding increase in motorized vessels.

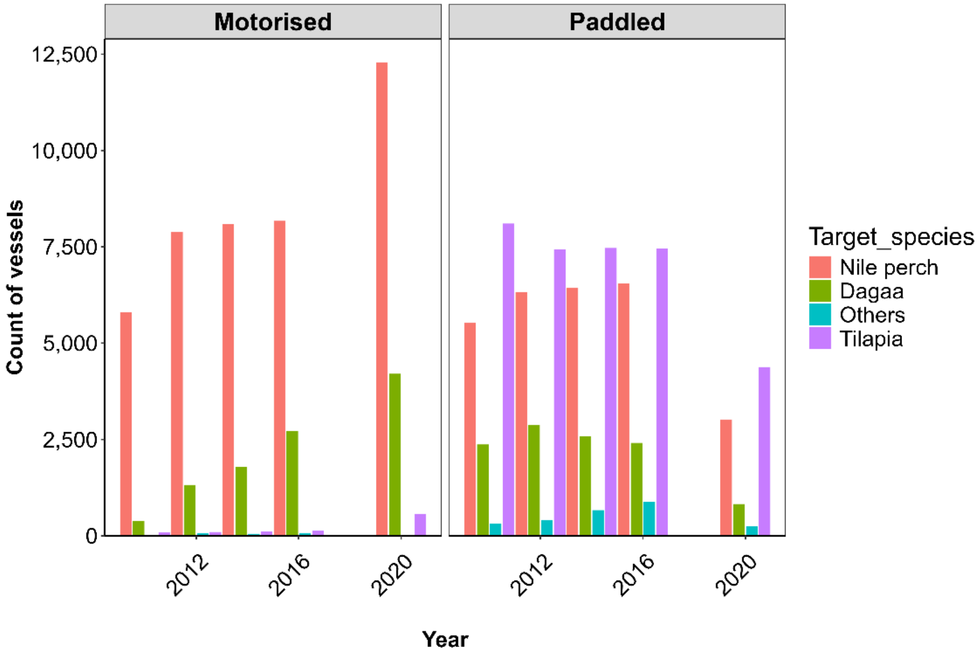


Figure 4: Vessel count by mode of propulsion per target species in Uganda (data only available from 2010 onwards) (Mpomwenda et al., 2022).

4.3 Fishing gears - Lake Victoria, Uganda

The primary fishing gears used to target Nile perch in Lake Victoria include gillnets and longlines. Gillnets are also used to target Nile tilapia and other larger fish species, as are cast nets. The Fishing Rules (MAAIF, 2010) specify which gears are legal to use in Uganda. For example, multifilament gillnets with mesh sizes ≥5″ and hooks larger than size 10 are considered legal. Gillnets, especially, are more likely to catch fish within the allowable size range, such as Nile perch (≥50-85 cm TL) and Nile tilapia (≥25 cm TL) (Ogutu-Ohwayo et al., 1998). While gillnets are highly selective, with a minimum mesh size of ≥5 inches set to target these species, they can also have an entangling effect. This may result in larger fish than intended being caught, sometimes exceeding the target size range (Asila, 2001). Beach seines are illegal, and widely regarded as a low-selectivity gear due to its tendency to capture a variety of species and sizes (Bjordal, 2002). However, recent studies (Tilley et al., 2019) suggest they disproportionately catch smaller fish, as larger individuals often escape during hauling. Monofilament nets, by contrast, have gained popularity for their high catch efficiency, low visibility, lightweight nature, rot resistance, and affordability (Ogutu-Ohwayo et al., 1998; Okeyo, 2014; Ssempijja et al., 2024). Notably, before enforcement measures were strengthened, the use of legal gear did not increase (Table 4). Instead, fishers adapted by using illegal small-size hooks and monofilament nets since 2006, to effectively maximize their harvest of the available fish (Table 4). In 2020, a surge in the use of legal multifilament gillnets and hooks was observed, a shift in fishing gear use in response to enforcement efforts. The increase in hook use can also be attributed to fishers targeting Nile perch for the lucrative fish maw trade. While the data from the frame surveys show a relatively stable or declining trend in the use of illegal gear such as monofilament gillnets, the confiscation records present a contrasting perspective, indicating that the actual use of illegal gear may be underreported in these surveys (Mpomwenda et al. 2024). Between February 2017 and August 2020, authorities confiscated approximately 540,000 monofilament gillnets, a number 5 times higher than the combined FS statistics since 2004. This discrepancy suggests that illegal fishing activities may have been much more prevalent than the survey data indicated, and the confiscation efforts reveal the scale of non-compliance with fishing regulations.

It is also important to understand why fishers would resort to illegal gear. Natugonza et al., (2022) observed that juvenile Nile perch, despite being highly productive, remain largely underexploited, with exploitation rates below 10%. The underutilization of juvenile Nile perch despite their high productivity could have led some fishers using paddled vessels, who are confined to inshore waters, to adopt illegal gears that more effectively target these smaller, accessible fish. These gears, especially monofilament nets and small hooks, are more catch-efficient in the nearshore areas and are also cheaper and more accessible, making them a viable option for fishers facing economic hardship (Mpomwenda et al., 2022).

Table 4:: Trends in the use of legal and illegal fishing gear in Lake Victoria in Uganda from 2000 to 2020 (LVFO, 2020a; Mpomwenda et al., 2023).

Variable	2000	2002	2004	2006	2008	2010	2012	2014	2016	2020
Legal gears										
Gillnets- Multifilament gillnets ≥5''	243,209	374,642	402,351	498,037	327,098	307,052	423,155	384,849	355,348	556,767
Handline	4,585	6,547	8,335	15,860	19,629	17,071	27,780	27,004	37,785	20,669
Longline hooks < 10				1,681,048	1,657,458	1,389,548	1,525,810	850,493	479,767	3,178,446
Illegal gears										
-Multifilament gillnets <5''	54,454	52,846	56,246	91,740	76,908	66,532	59,585	78,571	79,473	8,676
Beach/Boat seine	811	880	954	1,425	1,649	1,451	1,233	1,819	1,968	1,093
Cast net	1,276	858	659	631	1,000	1,095	1,372	1,359	1,342	873
-Monofilament gillnets			845		11,203	12,115	15,148	21,793	31,876	15,204
Basket traps	11,349	5,781	5,361	499	7,615	10,331	7,082	9,000	6,144	3,341
Longline hooks ≥10				604,561	1,106,341	1,169,807	2,892,575	3,737,273	3,998,352	1,057,646

4.4 Vessel performance – Technical efficiency

The study assessed the efficiency of Nile perch fishing fleets in utilizing resources such as labour, fuel, and gear to optimize catch rates. Vessel performance was measured through technical efficiency (TE) and labour productivity across Kenya, Tanzania, and Uganda, revealing regional differences (Mpomwenda et al., 2024). Motorized vessels, increasingly dominant in Lake Victoria, outperformed non-motorized ones, with TE scores ranging from 0.60 to 0.66, compared to 0.29 to 0.49 for paddled vessels and 0.24 to 0.35 for sailed vessels (Table 5). Tanzania showed the highest TE across all vessel types, while Uganda ranked second in efficiency for sailed and paddled vessels but had the lowest TE for motorized vessels. The declining use of sailed vessels, and for paddled vessels in Kenya, can be partly explained by their lower efficiency.

Table 5:: Mean TE values per country and vessel propulsion. (Mpomwenda et al., 2024).

Country	Kenya				Tanzania				Uganda			
Statistic	Mean	Max	Min	N	Mean	Max	Min	N	Mean	Max	Min	N
Paddled	0.290	0.800	0.037	1463	0.490	0.880	0.036	13719	0.440	0.870	0.045	11877
Sails	0.240	0.830	0.030	9087	0.460	0.890	0.020	8283	0.350	0.830	0.040	2259
Motorized	0.640	0.89	0.06	2372	0.660	0.890	0.050	12406	0.600	0.870	0.040	15260

Country-specific factors, including economic growth and fisheries policies, could account for the observed differences in vessel performance. Labour was identified as the most critical factor (elasticity to catch of 0.317 compared to fuel 0.089 and gear units 0.158 based on motorized vessel estimates (see Table 2 in Mpomwenda et al., (2024)), in improving efficiency, reinforcing the labour-intensive nature of Lake Victoria's fisheries. Labour productivity followed similar trends to TE across the countries, further highlighting this relationship. Uganda and Tanzania experienced significant declines in TE across all vessel types, with Uganda seeing the steepest drop from 0.65 in 2005 to 0.50 in 2021. In contrast, paddled vessels in Kenya, despite their overall low efficiency, improved by 50%, from 0.24 in 2011 to 0.38 in 2021. Motorized vessels in Kenya also saw slight improvements, while Uganda and Tanzania experienced continuous declines, particularly between 2015 and 2021 (Figure 5).

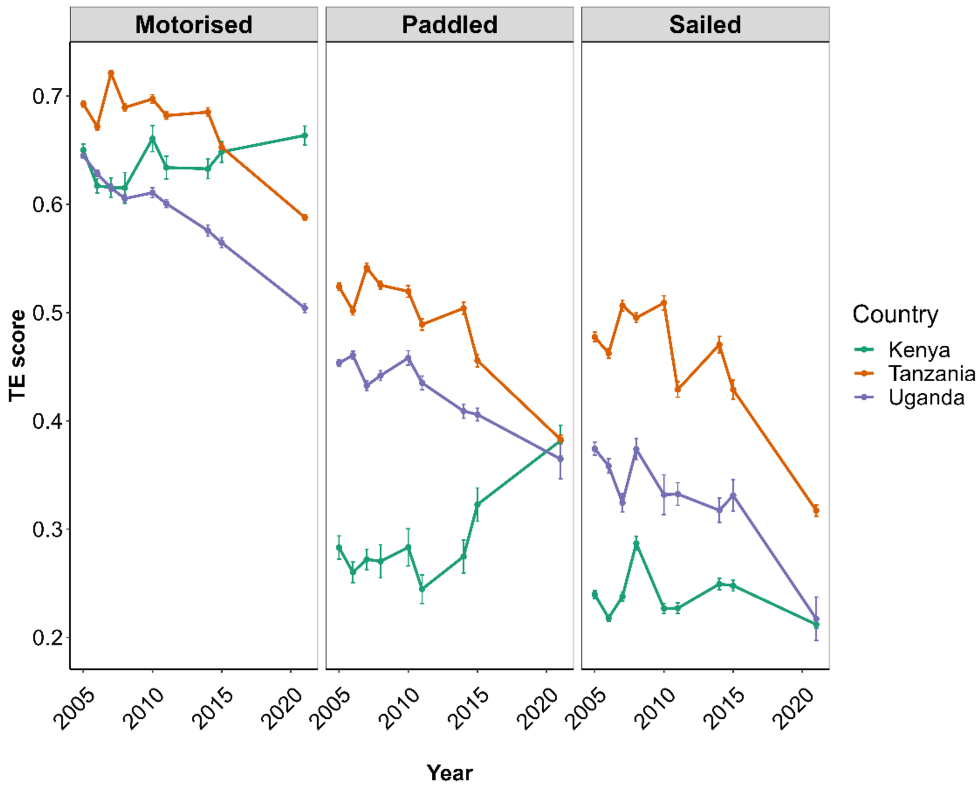


Figure 5: Mean Technical efficiency (TE) estimates across vessel groups and countries over the study period. Line plot with error bars representing mean TE ± standard error (S.E.) (Mpomwenda et al., 2024)

The similarities between Uganda and Tanzania, compared to Kenya, can be traced to differences in the political economy priorities, fisheries management, economic development, and labour opportunities. Uganda and Tanzania implemented stricter fisheries policies after 2015, focusing on gear type and size restrictions. This coincided with declining vessel efficiency, suggesting unintended negative impacts of these policies, particularly given Kenya's improved TE during this period. Similar results between regulated and unregulated fisheries have been noted in other transboundary systems in Africa, like Lake Kariba (Kolding & van Zwieten, 2014).

Economic development and alternative labour opportunities may also influence labour productivity. Countries with large populations relative to their capital and natural resources (Lewis, 1954; Sadik-Zada, 2021) tend to experience declining labour productivity, as can be seen in Uganda and Tanzania (Mpomwenda et al., 2024). Labour productivity can signal employment patterns and skill development in fisheries, but further analysis is required to fully unpack these dynamics.

Kenya's gain in paddled and motorized vessels TE suggests that the stricter enforcement of fisheries policies in Uganda and Tanzania contributed to the decline in vessel performance there. In Kenya, where there were no strict restrictions, catches were maintained and increased, possibly through the use of smaller mesh and hook sizes, despite fewer paddled vessels. While Nyamweya et al., (2023) reported minimal stock impacts from gear size restrictions, such regulations appear to have constrained fishers' ability to optimize catches, reducing vessel technical efficiency in Uganda and Tanzania. Uganda's rapid growth in motorized vessels coincided with the lowest TE among the three countries, showing that fleet expansion alone does not improve performance when vessels operate below capacity.

The decline in paddled vessels across the region reflects both enforcement and economic pressures. In Uganda, strict military-led enforcement disproportionately affected paddled operators, even though fisheries remain a fall-back source of employment for low-income groups during economic hardship. Tanzania adopted a multi-sector task force (Operation Sangara), which produced moderate vessel reductions (LVFO, 2020a). Kenya's relatively stable paddled fleet, by contrast, points to weaker enforcement and the presence of alternative livelihoods.

At the regional level, the Lake Victoria Fisheries Organisation (LVFO) plays a key role in harmonizing management policies, promoting cooperation among the three riparian countries (LVFO, 2021). Yet uneven national enforcement capacities and limited resources constrain local uptake of regional management measures, limiting their effectiveness at the community level (Lawrence et al., 2023). This highlights the need for complementary, country-specific implementation that accounts for socio-economic realities, as regional measures alone may not fully address localized challenges of livelihoods, compliance, and sustainability. Economic pressure, particularly in Uganda, has made fisheries an essential source of livelihood, especially among low-income groups historically engaged in paddle-vessel operations. However, the enforcement efforts in Uganda have disproportionately affected these operators, limiting their access to the fishery. In contrast, the number of paddled vessels in Kenya remained relatively stable over the study period, possibly reflecting a different enforcement approach or less dependence on enforcement. These contrasts underscore that local challenges are shaped more by national enforcement strategies than by regional regulations, whose influence on domestic implementation remains limited.

4.5 Fishing patterns and adaptation strategies of fishers in Lake Victoria, Uganda

Fishing patterns and adaptation strategies were analysed for gillnet fishing vessels on Lake Victoria, Uganda, with a focus on understanding the dynamics of gillnet use, identifying fishing strategies, and evaluating their effects on sustainability, as outlined in Paper III. Gillnets play a crucial role in the Nile perch fishery, originally introduced to enhance fishing efficiency. They also formed the foundation for the first fisheries regulations on Lake Victoria, driven by Graham's recommendation of a minimum mesh size of 5 inches (Graham, 1929). This regulation aimed to selectively harvest mature Nile tilapia, thereby safeguarding juvenile fish from premature capture.

Currently, gillnets target both Nile perch and Nile tilapia, with the minimum mesh size limit of 5 inches aimed at targeting legal fish sizes set at ≥50-85 cm TL for Nile perch and ≥ 25 cm TL for tilapia. The dynamics of gillnet use are characterized by mesh size and the number of vertical panels joined together, from one panel, also termed single, up to four panels termed quadruple (Figure 6). By 2015, the Nile perch fishers could be classified into two main groups: those employing motorized vessels targeting factory-size Nile perch with large mesh nets (6-7 inches) with triple gillnet panels, and those operating paddled vessels using smaller mesh (less than 5 inches) single-panelled nets targeting juvenile fish.

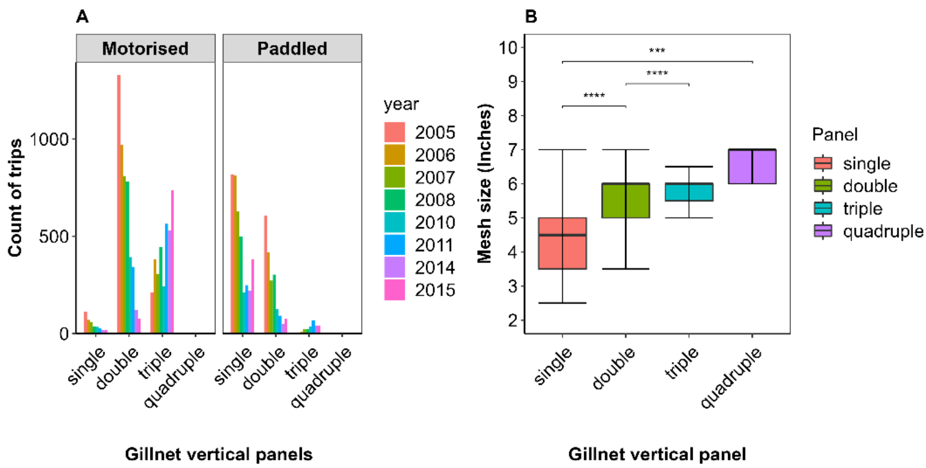


Figure 6: Gear panel characteristics: **A**- trend in the number of gillnet panels during in the study period; **B**-Comparison of mesh size across different gillnet panels. The boxplot illustrates the distribution of mesh sizes (in inches) across single, double, triple, and quadruple gillnet panels. The horizontal line inside each box indicates the median mesh size. The interquartile range (IQR), representing the middle 50% of the data, is shown by the height of the boxes, with whiskers extending to the smallest and largest values within 1.5 times the IQR. An ANOVA test revealed statistically significant differences in mesh sizes across the gillnet panel groups, with larger mesh sizes used in more gillnet panels ($p < 0.05$). (Mpomwenda et al., 2022)

The adaptations observed in gillnet use, both in mesh size and panelling, are largely a response to changes in the distribution, population structure, and abundance of Nile perch in Lake Victoria. Motorized vessels used larger gillnets with more panels to maintain the harvest of factory-sized fish (≥50-85 cm TL) purposely for export, extending their operations offshore to avoid areas of higher concentration of juvenile Nile perch. Meanwhile, paddled vessels targeted the abundant juvenile fish inshore with wider local and regional markets (Kimani et al., 2018; Medard, 2015). While adult

Nile perch are distributed over all habitats, high juvenile densities are common in shallow coastal areas (Peter & van Zwieten, 2018; Taabu-Munyaho et al., 2013).

The fishing patterns had a clear effect on CPUE. CPUE as measured in kilograms per panel-hour remained relatively stable for paddled vessels, which was maintained by catching a larger number of smaller fish (Figure 7). This reflects a shift to smaller mesh sizes and single vertical panel nets. While motorized vessels maintained their catch numbers per panel by increasing net depth (i.e., more vertical panels), they too targeted smaller fish, which suggests that these adjustments were insufficient to counteract broader declines in catch levels. These trends, based on CAS data for 2005–2015, reflect the collective adaptation strategies of fishers attempting to sustain catches under changing ecological and regulatory conditions. While this study did not investigate fishers' adaptations in the form of alternative livelihoods directly, existing literature indicates that most small-scale fishers on Lake Victoria rely heavily on the fishery, with limited viable livelihood options outside the sector (Dannenberg et al., 2024; Mbabazi et al., 2018; Musinguzi et al., 2016; Nyboer et al., 2022). This context helps explain the persistence of certain fishing strategies, for example, the reliance of paddled vessels on nearshore juvenile stocks as a means of sustaining income and access under spatial and enforcement constraints.

The long-standing debate on Lake Victoria fisheries concerns whether reduced fish catch rates in legal gear drive the adoption of illegal fishing gear, or whether the use of illegal gear has itself led to stock decline and lower catches. Several studies have explored this causality dilemma in small-scale fisheries (Cinner et al., 2009; Dannenberg et al., 2024; Kolding et al., 2014; Kolding & van Zwieten, 2014; Magego et al., 2021; Mkumbo & Marshall, 2015; Onyango, 2015). While both dynamics likely coexist, the findings of this study (Mpomwenda et al., 2022, 2024) suggest that declining individual catch rates have prompted many fishers, especially those with limited options, to adopt the use of smaller mesh sizes in nearshore areas. These behaviours highlight the need to understand fisher strategies not just as regulatory violations, but as livelihood responses shaped by access and economic context.

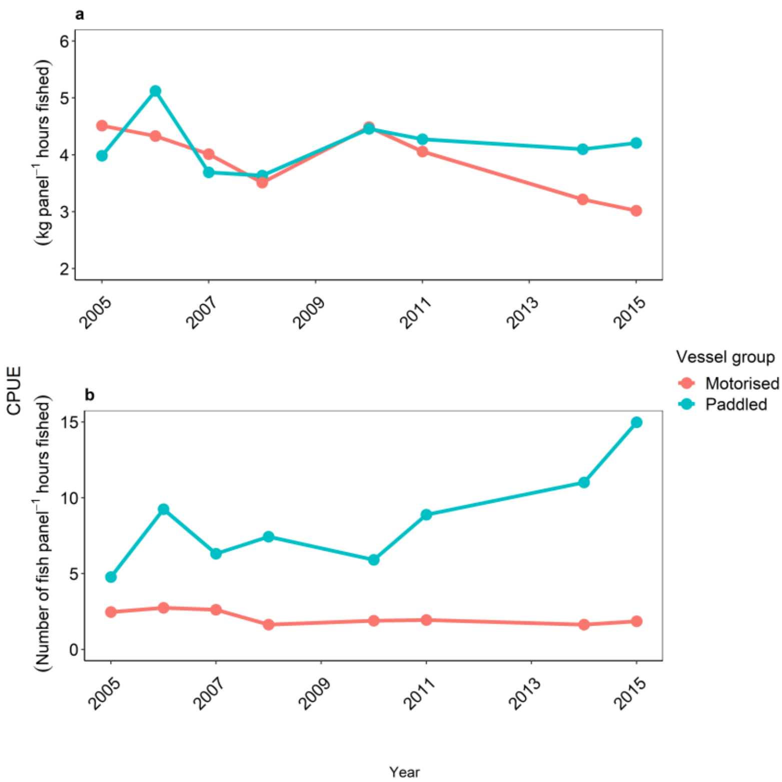


Figure 7: CPUE as kg per panel hour fished (a) and number of fish per panel hour (b). Note: CPUE values as reported in NaFIRRI (2017) are point estimates derived from national Catch Assessment Survey summaries and do not include associated variance measures such as standard errors or confidence intervals.

Fishery managers need to develop adaptive policies tailored to the specific challenges faced by Lake Victoria's fishers. Key strategies could include flexible mesh size regulations that respond to shifts in fish population structure and distribution, support for sustainable fishing practices, and promote alternative livelihoods during periods of stock depletion (Kolding & van Zwieten, 2011; Natugonza et al., 2022). The importance of incorporating fisher knowledge and participation into management decisions has long been a cornerstone of co-management approaches, and it formed the foundation for the establishment of BMUs on Lake Victoria (Geheb et al., 2008; Jentoft et al., 1998; Onyango, 2015). However, as discussed in this study and elsewhere, BMUs fell short of their goals due to political interference, elite capture- where influential fishers dominate decision making, sidelining the interests of poorer fishers, and weak enforcement structures (Luomba, 2014; March & Failler, 2022; Mudliar, 2021; Nunan, 2020).

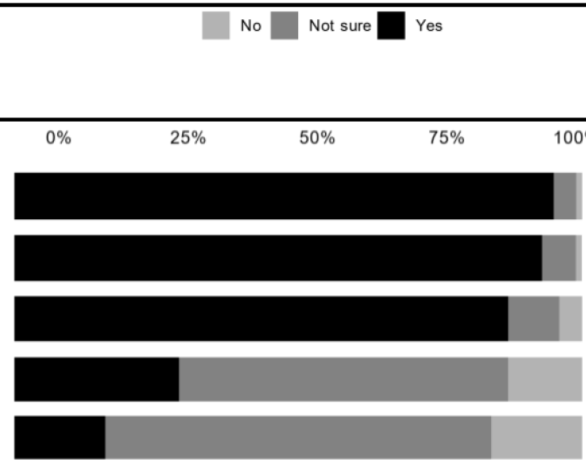
The co-management system requires addressing structural weaknesses and restoring legitimacy through mechanisms such as transparent fisher consultations, the creation of species- or vessel-gear specific subcommittees, local knowledge integration into management, and participatory adaptation within a reformed governance structure that is both context-sensitive and institutionally credible.

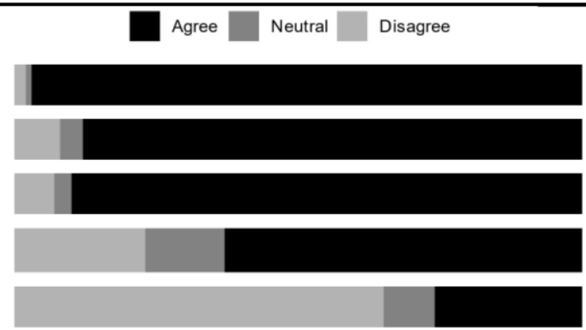
4.6 Fisheries management policies: Fisher perceptions and effects of management interventions in Lake Victoria, Uganda

The management of Lake Victoria's fisheries in Uganda has evolved through different regimes, ranging from traditional self-governing communities to top-down management systems, a co-management system, to a more stringent, militarized enforcement of regulations (Alidri, 2016; Mpomwenda et al., 2021). This section draws insights, particularly from Mpomwenda et al. (2021) and Mpomwenda et al. (2023). The papers explore the perceptions of fishers and law enforcement officials on fisheries management, respectively, with Mpomwenda et al. (2023) extending to examine the effects of different management interventions on fish catches in the fishery. Similarly, Mpomwenda et al. (2021) examines fishers' perceptions of regulations alongside their fishing practices and catch strategies.

Fishers frequently cited minimum mesh size requirements, gear bans, and licensing as the most well-known and nominally accepted rules (Table 6). However, this perceived effectiveness did not always translate into full compliance, particularly among operators of smaller paddled vessels, where illegal gear use persisted despite enforcement (LVFO, 2020b; Mpomwenda et al., 2023). This discrepancy may reflect strategic conformity (expressing support without full adherence), fear of sanctions, or contested legitimacy of the rules. Enforcement officials, for their part, continued to highlight the widespread use of illegal gear, particularly on the smaller paddled vessels. Other measures, such as closed seasons or fishing area restrictions, were generally unpopular among Nile perch fishers and not actively enforced by military officials. This gap between stated perceptions and observed behaviour underscores the need for management approaches that address both regulatory legitimacy and the socio-economic realities of compliance.

Questions	N	Mean response	Target species	Vessel propulsion
			P-value	
i) Do you know of the following fishery regulations?				
Mesh size	245	1.10	ns	ns
Gear ban	242	1.13	ns	ns
Licensing	210	1.23	ns	ns
Closed areas	225	2.25	ns	ns
Closed seasons	216	2.29	*	ns
ii) Rate the regulations in ensuring effective fisheries management?				
Mesh size	245	1.04	ns	ns
Gear ban	242	1.16	ns	ns
Licensing	214	1.17	*	ns
Closed areas	228	1.60	ns	ns
Closed seasons	229	2.38	ns	ns





The military succeeded in confiscating large quantities of illegal gear especially monofilament nets and small hooks, and paddled vessels that used them, Consequently, a shift in fishing practices was observed, with 90% of the catches being made by motorized vessels using longlines and gillnets in 2021 (Figure 8A) and more compliance with regulations (Figure 8B). However, instances of catches from illegal gear were also noted in 2021 (Figure 8B).

Recent shifts in gear composition indicate a growing reliance on the longline fishery, which depends heavily on bait fish (Bassa, 2018; Chitamwebwa et al., 2009; Mkumbo & Mlaponi, 2007). This transition is reflected in 2021, which recorded notable beach seine catches in paddled vessels and boat seine catches in motorized vessels, suggesting intensified bait harvesting to support longline operations (Figure 8B). Consequently, the increased importance of beach seines in artisanal fisheries may be linked to this demand, as fishers adapt to supply bait for the expanding longline sector.

While motorized vessels accounted for 90% of Nile perch catches in 2021, the CPUE of gillnet vessels declined from 4.5 kg/panel-hr in 2015 to 1.8 kg/panel-hr in 2021, indicating overcapacity and reduced efficiency (Mpomwenda et al., 2023). In contrast, CPUE in gillnet paddled vessels remained stable, suggesting no detectable change in the density of small Nile perch in coastal waters (Mpomwenda et al., 2023). Acoustic surveys support this, showing that over 80% of detected fish consisted of individuals between 10–50 cm TL (LVFO,2020c). Despite high CPUE, monofilament gillnets contributed only 1% to total catches in 2021, reflecting a decline in their relative importance due to enforcement. Longline CPUE showed a slight increase in the paddled vessels and no statistically significant decline in the motorized vessels ($p = 0.113$), with similar size distributions of Nile perch harvested by both motorized and paddled vessels (Mpomwenda et al., 2023). These trends underscore the resilience of small-scale paddled vessel operations. Small vessels, and illegal gear persist due to low capital requirements and quick returns, despite ongoing military confiscations. The continued capture of illegal gear by the army suggests that rule evasion is not abating. This highlights a critical governance challenge that enforcement alone may not be able to suppress illegal fishing effort without addressing the structural drivers of non-compliance, particularly the lack of alternative livelihoods and the economic incentives embedded in gear and vessel choices.

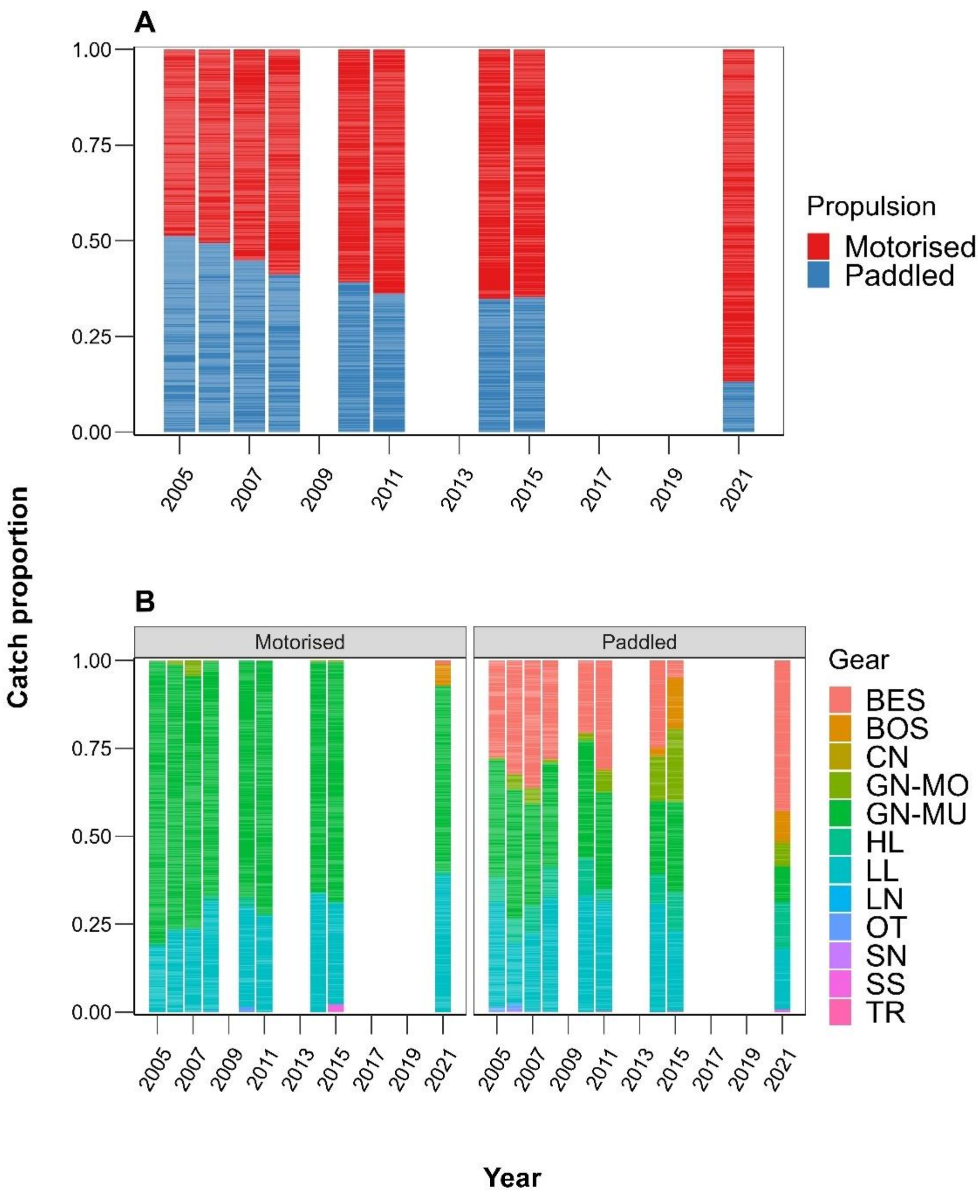


Figure 8: Proportion of Nile perch catches from vessels reported in the study period by A) vessel propulsion as paddled and motorized, and B) by gears BES- Beach Seines, BOS-Boat Seines, CN- Cast nets, GN-MU- Multifilament gillnets, GN-MO- Monofilament gillnets, HL- Hand line hook, LL- longlines, LN-Lift nets, and OT-other unidentified gears, SN- Scoop net, SS- Seine nets, TR- Basket traps. Illegal gears among these include BES, BOS, GN-MO hooks size 10 and above, and basket traps (Mpomwenda et al., 2023).

Some fishers appear to be adopting a mix of strategies that allow them to target different species and size classes based on availability and enforcement pressure (Figure 8B). While beach seines primarily capture juvenile or small-bodied species, other gear types, such as long lines or handlines, are used to target larger Nile perch. These shifting strategies reflect the adaptive behaviour of fishers in response to ecological, economic, and policy dynamics. Although Peter and van Zwieten (2022) focused on Tanzania, their concept of "bet-hedging," where fishers diversify their approaches to manage daily catch variability, helps frame this pattern. Employing multiple strategies allows fishers to remain active in the fishery, even when constrained by enforcement or changing resource conditions. Another development was the increase in the catch proportion of motorized longline vessels, which increased from less than 25% in 2005 to over 40% in 2021 (Figure 8B), indicating a shift in gear preference for targeting Nile perch. The increased use of longlines on Lake Victoria has been noted in other similar studies (Mkumbo & Mlaponi, 2007; Peter & van Zwieten, 2018, 2022).

Reflecting on the various fisheries management institutions establihed on Lake Victoria, including co-management under the BMUs, decentralized local governments, and top-down military interventions, it becomes evident that the enforcement of regulations has been inconsistent and often ineffective. The military enforcement regime involves landing site committee members to assist with enforcement efforts. However, this approach lacks the participation of actors across other major target species, as the appointed members are primarily from the Nile perch-leaning Association of Fishers and Lake Users Association [AFALU] (Kantel, 2019; Mpomwenda et al., 2023).

The failure of the BMUs to eliminate illegal fishing gear does not invalidate the concept of co-management but rather highlights deeper systemic challenges that need to be addressed. Several factors contribute to the shortcomings of co-management in the Lake Victoria fishery. Research points to the limited capacity of local institutions, power imbalances among stakeholders, insufficient government support, and inadequate funding (Cepić & Nunan, 2017; Kolding et al., 2019; Medard, 2015). The misalignment between centralized policies, focusing on only one species- the Nile perch, and local community needs has exacerbated these issues, limiting the effectiveness of co-management frameworks.

The regulations enforced, for example, the minimum mesh size of gillnets have remained static despite significant ecological and economic changes in the fishery. Over time, the fisheries have shifted from primarily targeting larger-bodied species in the 1980s to increased fisheries for the dagaa and juvenile fish, necessitating changes in fishing gear and strategies. BMUs, which were intended to provide adaptive and locally led governance, struggled to respond to these changes. This was partly due to institutional weaknesses but also because their operational capacity depended heavily on donor-funded projects (Béné et al., 2009; Hara et al., 2015; Nunan et al., 2015). Without a sustainable funding model or strong local institutional support, BMUs became vulnerable to collapse once external funding ended. This limited their ability to independently adapt or respond to the evolving challenges in the fishery.

Based on fishers' perception towards fisheries management, Nile perch fishers predominantly favoured fisher groups, followed by state-led management [FPU]. The dagaa fishers, on the other hand, had a preference for BMUs and fisher groups (Figure 9). Fisher groups are defined as management based on fishery stakeholders organised by target species (Poon & Bonzon, 2013). Unlike other management regime options, fisher groups offer an opportunity for management decision-making based on target species specific shared interests and goals. On Lake Victoria, the existence of such a group has been evident with the Nile perch fishers under the AFALU, whose membership is dominated by commercial Nile perch fishers. With the ban on BMUs, AFALU nominated a two-person committee at every major landing site to collaborate with the military law enforcement through the reporting of illegal fishing activity. It is, therefore, no surprise that the AFALU has been identified as one of the major actors behind the suspension of the BMUs (Kantel, 2019; Mpomwenda et al., 2023). At the time of the study in 2017, the dagaa fishery was less regulated, so preference for BMUs could have been based on their ability to strengthen social ties and co-operation among these fishers.

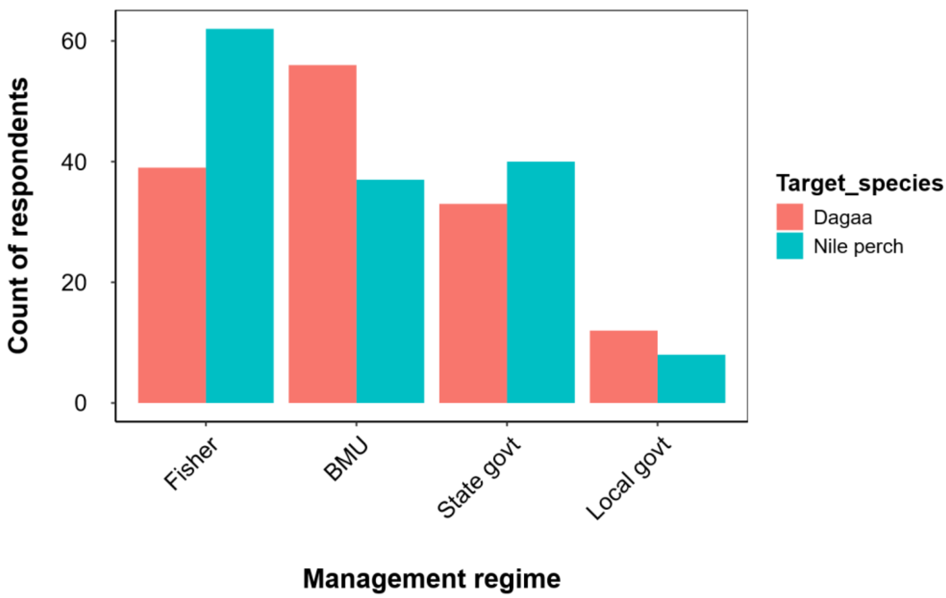


Figure 9: Fisher's response to the suggested management regime based on their target species. Response counts based on those who indicated yes to the stated management regime.

However, a growing competition between dagaa and Nile perch fishers has become a notable challenge on the lakes in Uganda. In February 2024, the "hurry-up" seine-netting method used to fish dagaa was banned, due to concerns that it was capturing significant amounts of juvenile Nile perch (The Daily Monitor, 2024). The method involves using a seine net with a 5-10 mm mesh size, operated at night with a light source, typically 5-6 kerosene lanterns, to attract fish, which are then encircled by the net. This technique is used by 97% of vessels targeting dagaa and is preferred over other gears like scoop nets (2%) and lift nets (1%) due to its ability to cover a larger area (LVFO, 2020). Fishers often extend the depth of the nets to encircle larger schools of Rastrineobola argentea in offshore areas, a strategy supported by acoustic survey data showing significant dagaa presence below the upper layers of the water column (Mangeni-Sande et al., 2019; Proud et al., 2020). While effective, this method has been associated with bycatch, particularly of juvenile Lates niloticus, when deployed inshore.

Fisheries managers and scientists have pointed out that the harvesting of juvenile Nile perch impacts the population of Nile perch (Geheb et al., 2008; Ogutu-Ohwayo, 1990; Ogutu-Ohwayo et al., 1998; Schindler et al., 2013), which could threaten the sustainability of the export market, particularly due to international size regulations and long-term stock viability.

The "hurry-up" seine-netting method was therefore banned, with enforcement efforts directed at transitioning fishers toward less popular alternatives, such as scoop net fishing. While intended to protect Nile perch stocks, the ban has had substantial economic impacts on the dagaa value chain, especially fishers who now find themselves blamed for illegal fishing practices, a role previously attributed to paddled fishers; however, the subject requires further study. The core issue lies in the enduring rigidity of enforcement rules, many of which trace back to colonial-era regulations that have remained largely unchanged, even as the management structure itself has evolved. (Kolding et al., 2019; Kolding & van Zwieten, 2011, 2014).

Enforcement practices often fail to account for the socio-ecological conditions, such as changing dynamics of fishing strategies and vessel patterns, environmental stressors such as pollution leading to eutrophication, climate variability, and the exacerbating tensions among fisher groups, thus complicating efforts to achieve sustainable fisheries management. This suggests that, beyond simply creating fisher groups, what is needed is stronger institution coordination concerning other fishery emerging stressors such as eutrophication and climate variability, clearer species-specific governance mandates, and conflict resolution mechanisms that recognize the ecological interdependence of different fisheries on the lake.

5 Conclusions and recommendations.

This thesis evaluated the Lake Victoria Nile perch fishery by analysing fishing patterns, adaptation strategies, and the effectiveness of fishery management institutions in implementing policies. It provides insights into fisheries management, including the roles of institutions and the enforcement of regulations.

The analysis revealed a significant increase in motorized vessels across Uganda, Tanzania, and Kenya, indicating a rise in commercial fishing operations lake-wide. Conversely, the number of artisanal paddled vessels, predominantly found in Tanzania and Uganda between 2000 and 2016, sharply declined by 2020, particularly in Uganda, due to stringent law enforcement.

In Uganda, the fishing of juvenile Nile perch is understood by both fisheries scientists and managers to pose a threat to the sustainability of the Nile perch export market, which contributes approximately 3% to the national GDP. To sustain the existing export market and to meet growing local and regional demand for juvenile Nile perch, gillnet fishers developed adaptive strategies in response to shifts in the Nile perch population and market dynamics. However, the increasing fishing of juvenile Nile perch prompted calls for more stringent law enforcement efforts to sustain the Nile perch exports. While the export industry did not directly displace small vessels, fishing policies have primarily focused on curbing illegal activities, which are predominantly associated with fishers operating these smaller vessels. The strict enforcement aimed at eliminating illegal fishing has not only displaced fishers using small vessels but has also impacted vessel efficiency and productivity. However, it remains unclear how those excluded by regulatory measures, particularly in Uganda, have adapted their livelihoods amid economic pressures from the export industry and stricter regulations. The rise in motorized vessels corresponds with the decline of paddled vessels, suggesting former paddled fishers may have transitioned to motorized vessels or shifted to alternative species like dagaa, which constitutes nearly 60% of Uganda's fish production.

With Uganda's population growth rate at 3.0% and high poverty levels, fisheries resources are crucial for local communities. While export revenue from fisheries contributes to national growth, it is essential to evaluate the impact of enforcement efforts on local livelihoods.

Co-management presents a promising approach, but its success hinges on addressing systemic barriers such as elite capture, weak institutional autonomy, lack of sustainable financing, and inconsistent enforcement. Strengthening local accountability structures, improving coordination among species-specific fisher groups, and establishing stable funding mechanisms are critical for enabling more effective and equitable co-management. While sustaining Nile perch exports remains a priority, it is vital not to overlook other species like dagaa, which are crucial for local food security and nutrition. This raises an important challenge for fisheries management: how to balance the short-term economic gains from Nile perch exports with the broader societal and ecological benefits of sustainably managing a more diverse set of species. The findings of this study suggest that achieving this balance will require flexible, species-sensitive policies that account for local livelihood dynamics, while ensuring long-term resource sustainability and equitable access across fisher groups.

To promote sustainable management of the Nile perch fishery on Lake Victoria, particularly within the Ugandan context, this study offers the following recommendations:

I. Strengthen species-specific fisher organizations within co-management systems, and establish inclusive conflict resolution mechanisms:

Although groups like AFALU already exist, power imbalances and ongoing tensions, such as claims of juvenile Nile perch bycatch during dagaa light fishing, underscore the need for structured intergroup dialogue. Supporting fisher organizations with clearer mandates, equitable representation, and collaborative platforms can foster trust and reduce conflict. While scientific investigations into gear impacts have already been conducted on issues of the dagaa fishing gear and fishing (Unpublished NaFIRRI reports), continued engagement is essential to ensure fishers' concerns are evidence-based and integrated into adaptive policy frameworks.

II. Update fisheries policies to reflect current catch realities, not outdated assumptions.

Although the Nile perch stock remains stable (Nyamweya et al., 2023), the dominance of juvenile fish and dagaa in landed catches has shifted the operational structure of the fishery. Policies must reflect what is being caught and the gear types being used, rather than relying solely on biomass assessments. This calls for a more dynamic regulatory framework that aligns with fishers' day-to-day realities.

III. Assess the social and economic impacts of enforcement efforts, especially on vulnerable groups.

The 2017 enforcement reforms were successful in cracking down on illegal fishing activities, particularly through the removal of prohibited gear. However, their effects have been uneven, especially for non-motorized and small-scale fishers who faced heightened vulnerability. A systematic assessment is needed not only to understand these disparities but also to examine how affected groups adapt to enforcement as a stressor, informing strategies that protect sustainability without deepening social inequities.

IV. Institutionalize co-monitoring between fishers and scientists to support adaptive management.

Rather than relying solely on top-down data collection, closer collaboration between fishers and scientists through participatory stock monitoring, gear trials, and data-sharing can build trust and enhance responsiveness. Lake Victoria's precolonial fisheries management practices, shaped by local ecological knowledge, could offer valuable insights into species behaviour, seasonal patterns, and habitat use. Institutionalizing local knowledge alongside ecological science would not only empower fishers but also support conservation strategies that are locally grounded, historically informed, and adaptive to current challenges.

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Paper I

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Article

Technical Efficiency of the Nile Perch Fishing Fleet on Lake Victoria: A Comparative Perspective on the Three Riparian Countries Kenya, Tanzania and Uganda

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Abstract: Lake Victoria, which is shared by Kenya, Tanzania, and Uganda, faces escalating concerns over sustainable fisheries amidst expanding fishing efforts. This study aims to investigate how technical efficiency (TE) and labor productivity (LP) of the Nile perch fishing fleet vary across the three riparian countries. Using a nine-year dataset spanning from 2005 to 2021 and employing Stochastic Frontier Analysis, this study evaluates the TE of the fleet, where LP is determined as catch per crew hour fished in a day for three vessel types: motorized, paddled, and sailed. Motorized fleets had the highest mean technical efficiency (0.60–0.66), compared to paddled (0.29–0.49), and sailed vessel categories (0.24–0.46). Sailed vessels declined in all countries owing to their low TE. In Kenya, TE and LP increased for paddled vessels, especially in the period from 2015 to 2021, and a slight increase was also indicated for motorized vessels. Conversely, Uganda and Tanzania experienced gradual declines in TE and LP, particularly from 2015 to 2021, a period of rigorous law enforcement that led to declines in the number of paddled vessels by 50% and 7%, respectively, and a contrasting increase in motorized vessels. By 2021, the number of Ugandan motorized vessels had increased greatly but TE had declined compared to Kenya and Tanzania, a sign of overcapacity. The findings underscore the need for region-specific policies that address economic differences, policy implementation impacts, and resource health to promote sustainable transboundary fisheries management on Lake Victoria.

Keywords: fisheries management; fisheries technical efficiency; labor productivity; catch assessment; over capacity

Key Contribution: This study presents a novel cross-border comparison of technical efficiency and labor productivity in Lake Victoria's fishing fleet. Differences in vessel performance and labor output are shaped by factors such as economic growth, technology use, and regulations, with motorization emerging as a key driver of improved fleet efficiency.

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Citation: Mpomwenda, V.; Tómasson, T.; Pétursson, J.G.; Taabu-Munyaho, A.; Nyamweya, C.S.; Kristófersson, D.M. Technical Efficiency of the Nile Perch Fishing Fleet on Lake Victoria: A Comparative Perspective on the Three Riparian Countries Kenya, Tanzania and Uganda. *Fishes* **2024**, *9*, 414. https://doi.org/10.3390/fishes9100414

Academic Editors: Mohamed Samy-Kamal and Célia M. Teixeira

Received: 22 September 2024
Revised: 15 October 2024
Accepted: 16 October 2024
Published: 17 October 2024

1. Introduction

Fisheries on Lake Victoria, Africa's largest freshwater lake, are an important socio-economic activity. The fisheries contribute significantly to regional food security and provide employment and livelihoods for the large lakeside populations [1]. The fisheries sector is of major economic importance and integral to the economies of the three riparian countries, contributing approximately 0.8%, 1.7%, and 3% of the Gross Domestic Product (GDP) in Kenya, Tanzania, and Uganda, respectively [2]. Lake Victoria's fisheries operate under limited restrictions on access. The three countries of Kenya (6%), Tanzania (51%), and Uganda (43%), which share the transboundary lake, have imposed regulations on fishing gear, registrations, and type of vessels to regulate fisheries efforts, but allow entry to the fishery after payment of a nominal access fee [3]. Fisheries management efforts suffer from access to reliable data and are plagued by data scarcity in both spatial and temporal dimensions, as well as irregular data collection practices. It is therefore important to seek ways in which the existing although limited data can be used [4].

The evolution of landed fish catches in Lake Victoria reflects notable shifts toward the focus on the Nile perch in the 1990s, which remains the most valued species and the primary fish export for the past three decades [5,6]. The significance of the Nile perch fishery is further underscored by the distribution of fishing effort, with up to 58% of the 210,620 fishers targeting the species, along with a comparable proportion of the 70,995 fishing crafts [7,8].

On the lake, fishery-related technological changes introduced by the early colonial governments replaced the inefficient and ancient traditional fishing methods. Modern fishing equipment, including synthetic gill nets and trawls, were used to increase catches per input, and outboard engines were introduced to expand access to fishing grounds [5,9]. The commercial importance of capture fisheries grew alongside increased markets and infrastructure development, leading to increased fishing efforts. This evolution has led to a shift in efficiency.

Technological advancements have led to reduced costs and transformed fishing fleets' performance in Lake Victoria. Three main types of vessel propulsion are used on the lake: motorized vessels with outboard engines, paddled vessels, and sail-powered vessels. The introduction of outboard engines in the 1950s led to sizeable changes in efficiency [9,10]. However, investment capacity is limited, and a small section of sailed vessels remains. The final vessel type, paddled vessels, is generally smaller than the other two, and its activities are limited to areas close to the shoreline [11].

While comparative studies on fleet performance have been conducted for some of the African lakes [12,13], no comparative study has been undertaken to assess the technical efficiency of the fishing fleets across the three riparian countries sharing Lake Victoria. Previous studies on technical efficiency have been conducted in individual countries, including research by [14] in Uganda and studies by [15,16] in Tanzania using cross-sectional data. In contrast, this study extends its analysis to nine years of panel data collected over 17 years (2005–2008; 2010–2011; 2014–2015; 2021). The utilization of panel data provides a unique opportunity to capture the dynamic and heterogeneous nature of fleet production units over time, considering factors such as country-specific technology adoption and economic and policy changes that may influence fleet technical efficiency. In addition to evaluating technical efficiency, the study also provides estimates of labor productivity (LP) for each vessel type across the three countries. LP, defined as the output (fish catches) per fisher over a specific period, is important in understanding the development of the fishery, given that Lake Victoria's fishery remains labor-intensive [17–19].

This study's objective is to assess the technical efficiency (TE) and labor productivity (LP) of the fishing fleet on Lake Victoria, comparing performance across Kenya, Tanzania, and Uganda, while identifying the key factors influencing these metrics.

The guiding research objectives are:

- To evaluate the status and historical development of the fishing fleet on Lake Victoria across the three riparian countries.
- To analyze the TE and LP scores of the fishing fleet across Kenya, Tanzania, and Uganda.
- Assess the impact of fleet development, regulatory frameworks, and fish stock health on TE and LP scores, and their influence on sustainability in Lake Victoria fisheries.

2. Materials and Methods

2.1. Measuring Technical Efficiency

Measurement of productive efficiency is commonly applied to fisheries to evaluate outcomes, policies, and development [20–24]. The Stochastic Frontier Approach (SFA) is used to estimate the technical efficiency of the Nile perch fleet. It models the relationship between outputs, such as fish catch, and inputs, such as fuel and labor, using a flexible functional form that represents underlying technology. The model is well-suited for single-species fisheries with multiple inputs and a single output, such as the Nile perch catches evaluated in this study [20,21], is flexible in dealing with complexity, and is versatile with respect to analyzing external factors of inefficiency [20,25,26]. The general approach is discussed in [27,28]. The model contains a composite error term, a random deviation, and an inefficiency term. The inefficiency term can contain a model of explanatory variables linking independent variables to the level of inefficiency [29]. Figure 1 shows a representation of the model terms.

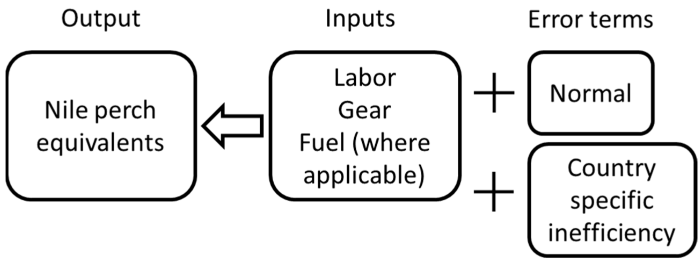

Figure 1. Representation of the empirical model used in the analysis, with output, inputs, and a composite error term.

2.2. Data Sources and Treatment

Two main datasets were used, a frame survey (FS) and catch assessment (CAS), with both obtained from the Lake Victoria Fisheries Organisation (LVFO) database. Frame survey data are generated from a complete census of all fishery variables, including the vessels, gears, and landing site facilities along the lake [7]. The data collected biennially on Lake Victoria was available for the period from 2000 to 2020 and was specifically used to answer this study's first objective, namely, to evaluate the status and historical development of the fishing fleet on Lake Victoria, including trends from 2000 to 2021 across the three riparian countries.

The second dataset and main dataset used to estimate TE and LP comprised the CAS data. It consists of nine-year vessel-level catch data (series of catch assessment surveys conducted with support from the Implementation of Fisheries Management Plan (IFMP) project during 2005–2008; and Lake Victoria Environmental Management Program (LVEMP1) 2011 and 2014 and 2015 by LVEMP2.) (2005–2008; 2010–2011; 2014–2015; 2021), collected over 17 years. The LVFO periodic survey data usually follows a two-stage sampling procedure where 10% of the landing sites in each country are identified as strata in the first stage and then vessels are randomly sampled at the landing sites in the second stage [30,31]. To address the missing variable of fuel use for motorized vessels, a supplemental survey was conducted: in Uganda between June and August 2017, and in Kenya and Tanzania from April to September 2020. Data were collected following the CAS data collection form, including vessel fuel use in liters as a variable. Fuel is a crucial input, especially for motorized vessels, as it is used to power engines and enable vessels to access their desired fishing grounds. The data obtained from the survey was used to predict fuel use for nine of the years in the period between 2005 and 2021. Details of the model are provided in Supplementary Materials.

The panel data, which consists of repeated observations of the same subjects over time [32], was organized as a series of independent cross-section surveys conducted between 2005 and 2021. Observations were grouped based on vessel propulsion as paddled, motorized, or sailed using gillnets and longlines and harvesting Nile perch. Initially, the CAS datasets were assessed independently to understand their structure, variables, coding, and measurements across different years. To ensure consistency throughout the nine years of sampling, data variables were renamed and re-coded wherever necessary, specifically to consolidate changes made in the standard operating procedures used for data collection in 2021 [30,31].

2.3. Variable Selection

Inputs included in the model were the number of units of gear, fuel (liters per fishing trip, where applicable), and labor (crew hours per trip), with the catch as the output variable. A single output measure (Nile perch quantity) was used for consistency [33,34]. In cases where bycatch such as Nile tilapia was present in the catch, the output was standardized to a Nile perch equivalent by dividing the catch value by the price of Nile perch.

2.4. Labor Productivity Computation

Labor productivity was calculated as the ratio of total fish catches (standardized to Nile perch equivalents) to the total labor input (measured as a product of the number of fishing crew in a vessel and hours fished in a day—24 h) for each vessel type [17]. The analysis was conducted separately for each country to identify differences in LP across the riparian states.

2.5. Data Summary Statistics

Table 1 provides a comprehensive overview of essential statistics for the output and input variables examined in this study. Sampled motorized vessels were highest in Uganda (50.8%), paddled vessels in Tanzania (52.1%), and sailed vessels dominated (45.9%) in Kenya.

Table 1. Summary statistics for the SFA model variables for the different vessel groups.

	Vessels			
	Motorized (N = 30,052)	**Paddled (N = 26,147)**	**Sailed (N = 19,192)**	**Total (N = 75,391)**
Country				
Kenya	2375 (7.9%)	1321 (5.1%)	8809 (45.9%)	12,505 (16.6%)
Tanzania	12,417 (41.3%)	13,631 (52.1%)	8252 (43.0%)	34,300 (45.5%)
Uganda	15,260 (50.8%)	11,195 (42.8%)	2131 (11.1%)	28,586 (37.9%)
Vessels by gear type				
GN	25,122 (83.6%)	14,026 (53.6%)	7659 (39.9%)	46,807 (62.1%)
LL	4930 (16.4%)	12,121 (46.4%)	11,533 (60.1%)	28,584 (37.9%)
Gear units				
Gillnets	61.373(20.058)	35.719 (24.877)	47.603(23.559)	51.433 (24.932)
Long lines	951.140 (740.370)	580.912 (559.374)	791.651 (452.081)	729.800(573.630)
Catch				
Mean (SD)	32.286 (37.101)	23.426 (25.704)	24.484 (29.592)	27.227 (31.904)
Range	0.000–705.000	0.000–470.000	0.000–1000.000	0.000–1000.000
Labor				
Mean (SD)	27.333 (14.231)	28.740 (15.609)	42.439 (20.462)	31.667 (17.658)
Range	2.000–299.000	1.000–282.000	2.000–168.000	1.000–299.000
Fuel				
Mean (SD)	20.429 (6.370)			20.429 (6.370)
Range	1.000–125.000			1.000–125.000

2.6. Technical Efficiency Empirical Model

The production frontier model for the three vessel groups was specified as the translog production. The SFA model and prediction of technical efficiencies for the fishing fleet were then performed using R version 4.2.2 with packages plm applied to organize a panel structure of the data and frontier to run the SFA model [35–38].

3. Results

3.1. The Status and Trend of Vessel Types on Lake Victoria

Motorized vessels exhibited a consistent increase in numbers, with the highest count of these recorded in 2020 in all three countries: around 17,000 in Uganda, 12,000 in Tanzania, and 5000 in Kenya (Figure 2). In contrast, paddle vessel usage in Uganda and Tanzania displayed parallel fluctuations from 2000 to 2016, followed by a decline of 53% and 7%, respectively, in 2020. Conversely, Kenya experienced a distinct trajectory, with a 19% decrease from its 2006 peak of 8324 vessels to 6749 in 2020. Sailed vessels steadily declined in use across all three countries during the same period.

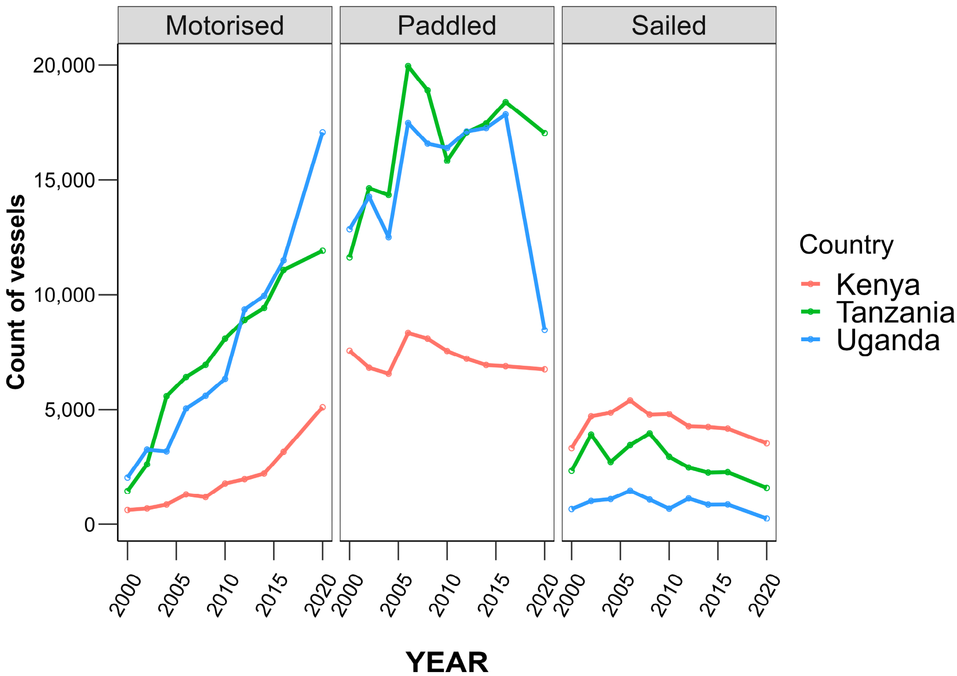

Figure 2. Status of vessel development by propulsion on Lake Victoria [7].

3.2. Technical Efficiency Estimation

Motorized fleets had the highest mean technical efficiency (0.60–0.66) compared to the paddled (0.29–0.49) and sailed vessel categories (0.24–0.46). Table 2 presents the estimates from the Translog stochastic production frontier analysis. The first-order parameters of vessel inputs (gear units, labor, and fuel for motorized vessels) and technical efficiency parameters (gamma and sigma squared) were all positive and significant across all vessel groups. These parameters represent output elasticities, with labor showing slightly higher elasticity than gear units and fuel. The gamma values were significant for all vessel groups (85% for motorized, 75% for paddled, and 70% for sailed vessels). The significant sigma squared σ^2 values further confirm the model's fit and the correctness of the composite error term's distributional assumption.

Table 2. Maximum likelihood estimates for the parameters of the stochastic frontier production function (SFPF).

SFA	Parameter	Motorized		Paddled		Sailed	
		Estimate	Standard Error	Estimate	Standard Error	Estimate	Standard Error
Intercept	β_0	0.217	0.022 (***)	0.685	0.032 (***)	0.967	0.043 (***)
InUnits	β_1	0.158	0.005 (***)	0.169	0.0058 (***)	0.102	0.009 (***)
Ifuel	β_2	0.089	0.030 (**)				
ILabor	β_3	0.317	0.017 (***)	0.294	0.014 (***)	0.216	0.017 (***)
I(0.5 * InUnits^2)	β_{11}	0.071	0.007 (***)	0.042	0.004 (***)	0.007	0.008
I(0.5 * Ifuel^2)	β_{22}	−0.036	0.044				
I(0.5 * ILabor^2)	β_{33}	0.338	0.038 (***)	−0.089	0.026 (***)	−0.096	0.033 (**)
I(InUnits * Ifuel)	β_{13}	−0.034	0.020				
I(InUnits * ILabor)	β_{12}	0.086	0.012 (***)	0.038	0.007 (***)	−0.010	0.009
I(Ifuel * ILabor)	β_{23}	0.054	0.049				
Country-specific inefficiency effect							
Z_(Intercept)	z_0	−4.218	1.353 (**)	1.401	0.080 (***)	1.679	0.051 (***)
Z_CountryTanzania	z_1	−0.626	0.175 (**)	−1.292	0.082 (***)	−1.114	0.038 (***)
Z_CountryUganda	z_2	0.813	0.218 (***)	−0.966	0.067 (***)	−0.585	0.038 (***)
Variance variables							
sigmaSq	σ^2	3.391	0.656 (***)	1.561	0.072 (***)	1.128	0.026 (***)
gamma	γ	0.853	0.027 (***)	0.748	0.008 (***)	0.696	0.016 (***)

Significance denoted: 0 '***'; 0.001 '**'; 0.01 '*'.

The technical inefficiency model revealed significant z_0 values across all vessel groups, indicating country-specific inefficiencies. The signs of the z_1 and z_2 variables determined whether a vessel group was inefficient (positive sign) or efficient (negative sign). For instance, in Uganda, an increase in the number of motorized vessels was associated with increased inefficiency, while in Tanzania, more motorized vessels were likely to increase technical efficiency with respect to the Kenyan motorized vessels. For other vessel groups, negative z-variable signs indicated a reduction in inefficiency as vessel numbers increased.

3.3. Technical Efficiency Distribution and Change

Technical efficiency score indicates that vessels are fully efficient at score 1 and inefficient tending to 0. From the TE estimation, vessels across all groups were inefficient as the maximum efficiency values were less than 0.90 (Table 3). Across countries, the estimated mean TE values for all vessel groups were highest in Tanzania, while Uganda had the lowest estimated mean TE for motorized vessels. The lowest mean TE values for paddled and sailed vessels were recorded in Kenya.

Table 3. Mean TE values per country and vessel propulsion.

Country	Kenya				Tanzania				Uganda			
Statistic	**Mean**	**Max**	**Min**	**N**	**Mean**	**Max**	**Min**	**N**	**Mean**	**Max**	**Min**	**N**
Paddled	0.290	0.800	0.037	1463	0.490	0.880	0.036	13,719	0.440	0.870	0.045	11,877
Sails	0.240	0.830	0.030	9087	0.460	0.890	0.020	8283	0.350	0.830	0.040	2259
Motorized	0.640	0.89	0.06	2372	0.660	0.890	0.050	12,406	0.600	0.870	0.040	15,260

The TE distribution shows that at least 63% of motorized vessels operated with efficiency levels above 0.6. A similar proportion of paddled vessels operated from >0.41, while sailed vessels of the same proportion operated at <0.40, indicating that the latter were utilizing less than half of their capacity to maximize catches (Figure 3).

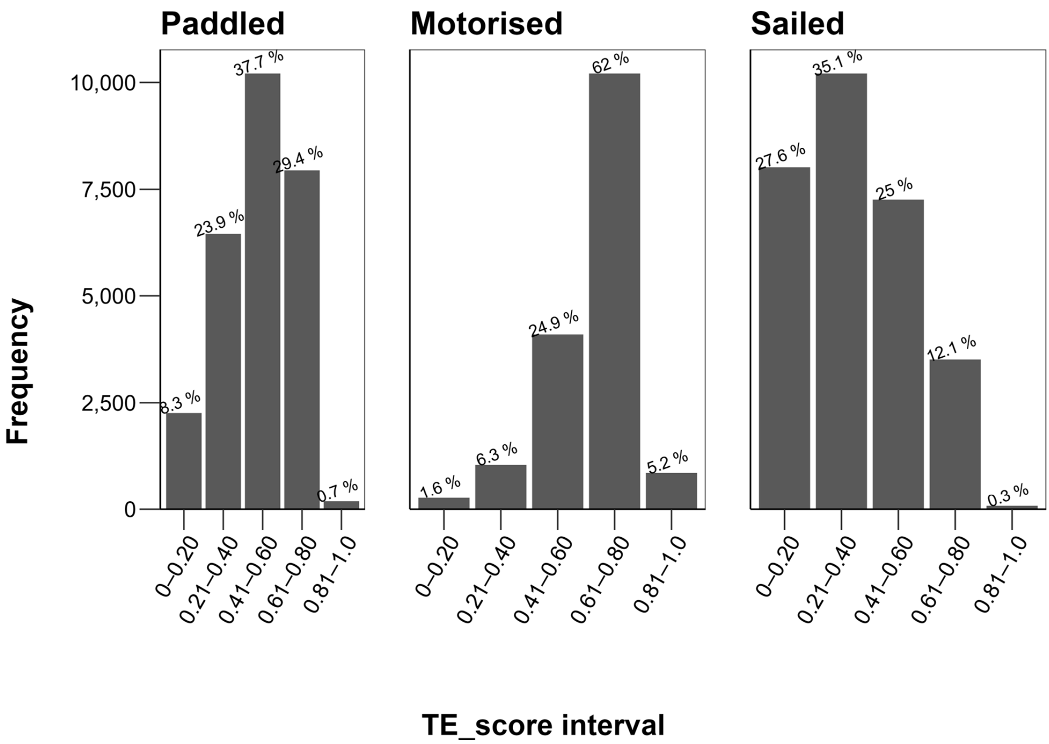

Figure 3. Distribution of TE scores for the three vessel groups, with scores categorized into groups.

Exploring the variations in technical efficiency (TE) throughout the study period (Figure 4) shows that both Uganda and Tanzania witnessed a noticeable reduction in technical efficiency (TE) across all vessel groups. The null hypothesis that there is no country-specific technical inefficiency was tested for each fleet segment. The hypothesis was always rejected, indicating that country-specific inefficiency differences exist for all vessel types. The most significant and consistent decline was observed in Ugandan motorized vessels, where the capacity to maximize catches for their given input and technology dropped by 22%, decreasing from 0.65 TE in 2005 to 0.50 in 2021. In Kenya, TE showed variations among different vessel types. Paddled vessels demonstrated an improvement in TE, increasing from 0.24 in 2011 to 0.38 in 2021, marking a substantial 50% enhancement in efficiency for this vessel category. Motorized vessels, on the other hand, exhibited a modest 2% increase in TE, while TE for sailed vessels declined by 12% between 2015 and 2021.

3.4. Labor Productivity

Labor productivity, defined as catch per hour fished, serves as a measure of fishers' productivity. From 2005 to 2015, all vessel groups experienced minor fluctuations in labor productivity. However, a significant increase in labor productivity was observed for motorized and paddled vessels in Kenya from 2015 to 2021 (Figure 5). In contrast, the same categories of vessels in Uganda and Tanzania showed minimal changes, with a slight downward trend from 2015 to 2020. Sailed vessels maintained a consistent level of labor productivity across all countries throughout the entire study period.

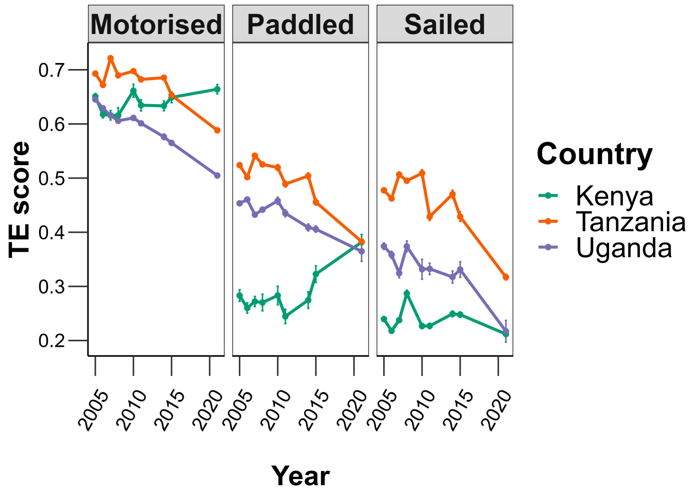

Figure 4. Technical efficiency (TE) estimates across vessel groups and countries over the study period.

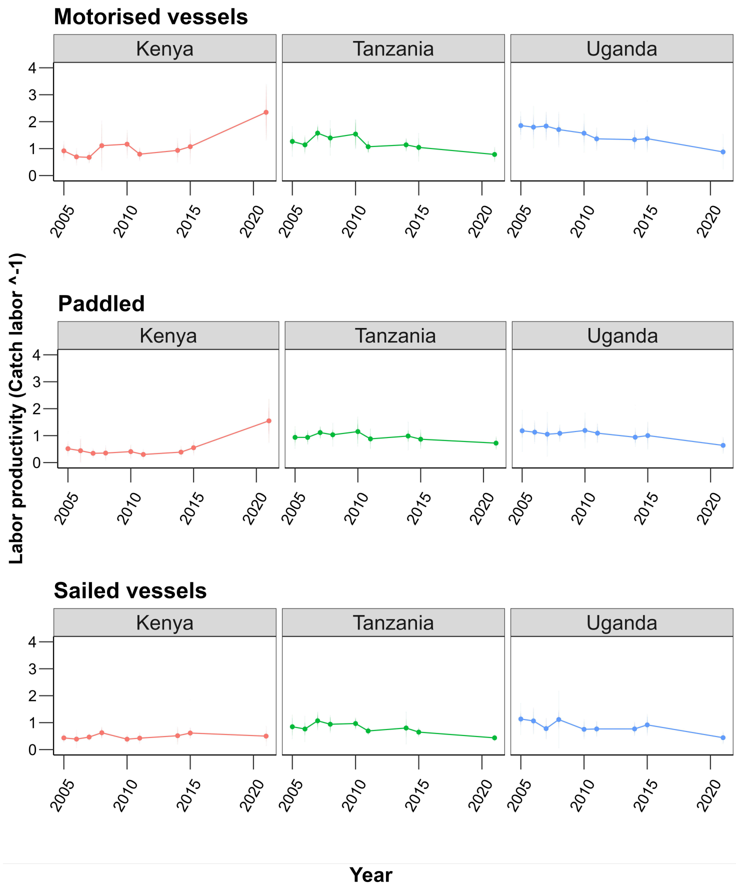

Figure 5. Comparison of labor productivity (LP) by vessel type and country (2005–2015).

4. Discussion

4.1. Vessel Group Fleet Changes and Technical Efficiency (TE)

The results show that efficiency and productivity vary between vessel groups, countries, and over time. This sheds light on the effects of technological development, policies, and natural and social conditions on economic outcomes in the fishing industry.

The finding that motorized fleets had the highest mean technical efficiency compared to the paddled and sailed vessel categories aligns with the research conducted by Kateregga and Sterner [14] in Lake Malawi [22], who highlighted the significance of vessel motorization in enhancing fish productivity. Similar effects have been observed by Branch et al. [39] regarding the motorized Fanti vessels in Liberia compared to their unmotorized counterparts [40]. The natural progression within the fishing industry is that fishers strive for more efficient operations, and this is evidenced by the general increase in the number of motorized vessels for all of Lake Victoria's riparian countries.

Motorized and paddled vessels form the two most important vessel types in the fishery. While the significant decline in paddled vessels in Uganda and Tanzania from 2016 to 2020 can be attributed to rigorous enforcement efforts to eradicate illegal fishing gear, the consistent decrease in these vessels in Kenya warrants further investigation to uncover the underlying factors.

On the other hand, sailed vessels have been declining in number. The low TE values in Kenya (<0.30) may explain the decline in sailed and paddle vessels. Motorized vessels across the three countries, with a TE of ≥ 0.60, could boost catches by 40% on average with current technology, while sailed vessels, the least efficient, have on average over 60% capacity for improvement. The motorized and paddled vessel groups were earlier described as commercial and artisanal, respectively, on Lake Victoria in Uganda [41,42]. Therefore, the shift to commercial fisheries indicates a within-sector improvement toward productivity growth [43–45], as fishers shift to motorized fishing vessels, the most technically efficient vessel type.

4.2. Comparative Analysis of Technical Efficiency and Labor Productivity across Countries and Vessel Groups

Country-specific comparisons show a difference in fleet development in Kenya versus Uganda and Tanzania. A shift towards more commercial vessel operations was observed across all countries, which is indicative of a boost in vessel productivity over time. In Tanzania and Uganda, the pattern for artisanal (paddled) vessels was similar, showing fluctuations for the first 15 years and a sharp decline between 2016 and 2020 due to fisheries enforcement. In contrast, Kenya has seen a consistent decrease in the use of paddled vessels since 2008, even though efficiency has been improving for this segment, a unique development for the fishery. This difference might be due to several factors, such as differences in fisheries management, economic development, and the different alternative values of labor in the three countries [39]. The three counties have had different fisheries policies in effect during the period. However, the most stringent policies have been found in Uganda and Tanzania, where technical efficiency and labor productivity have declined between 2015 and 2020. At the same time, improvements in technical efficiency and labor productivity were observed in Kenya. It is therefore difficult to attribute the development to fisheries management. Other forces could be at play. For example, countries where the population is large relative to capital and natural resources, the most productive sectors of the economy, are likely to have negligible to zero marginal productivity of labor and declining labor productivity, as is indicated in Uganda and Tanzania in this study [43,44]. Labor productivity results can highlight trends in labor markets such as increasing or decreasing employment and skills indicative of economic sustainability for the fishers; however, further analysis is needed on this issue.

The objective of the stringent fisheries enforcement in Uganda and Tanzania was to raise stock sizes of Nile perch by reducing illegal fishing activity, thereby improving fish exports [45]. The reported biomass estimates for the Nile perch before and after enforcement have followed a similar variable trend for all countries. Gear size and type had a small influence on fish stocks, as the Kenyan side maintained its biomass [8]. Successful policy implementation should lead to improved vessel efficiency, but the evidence for such effects regarding Uganda and Tanzania is weak [8,11,45–47]. This is in line with substantial literature that shows that policies that prioritize maximizing productivity may negatively impact the long-term sustainability of fish stocks, leading to depletion and even collapse of certain species [48–50]. The Ugandan and Tanzanian model of fisheries management illustrates the difficulty of regulating activities that people are compelled to undertake given their negative economic situation.

While the study demonstrates that the data used in this study can be effectively used to assess fishing fleet performance and inform fishery management in data-deficient contexts, it is important to recognize that the application of stochastic frontier production requires larger datasets to yield more robust results. As such, interpretations should be approached with caution, given the potential limitations in the data's scope of this study. Nevertheless, the findings still provide valuable insights into fleet efficiency and management strategies in resource-limited fisheries.

5. Conclusions

This study focuses on evaluating the technical efficiency of the Nile perch fishing fleet on Lake Victoria, categorizing vessels into three distinct groups based on their technology. Motorized vessels exhibited the highest efficiency (mean 0.60–0.66), showcasing their significant growth throughout the study. The declining trend observed in sailed vessels is reflected in their low technical efficiency across all countries, with specific variations observed for paddled vessels between Kenya and the other riparian countries.

The study acknowledges that vessel development mirrors the economic progress of the East African economies. The prevalence of paddled vessels in Uganda and Tanzania underscores their importance in artisanal fisheries, driven by a low opportunity cost of labor compared to Kenya. The improvement in technical efficiency and labor productivity in Kenyan vessels indirectly highlights gaps in fisheries management, questioning the effectiveness of enforcement, consideration of fish population status, and socio-economic conditions for alternative employment.

Overall, this study's primary contributions involve showing how sparse and deficient data can be utilized and interpreted in fisheries management, illustrating the application of technical efficiency in evaluating economic outcomes and fish stock health. It emphasizes the importance of incorporating CAS data into econometric models for resource assessment and policy evaluation, underlining the significance of monitoring fishery statistics. By analyzing transboundary fisheries data from Kenya, Uganda, and Tanzania, this study offers a unique perspective on factors impacting these fisheries, contributing to comparative studies on fishery performance in the African Great Lakes region.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes9100414/s1, Table S1: Summary statistics of fuel model key variables; Table S2: Fuel model regression results for motorized vessels in Kenya. Remba and Kokach are landing sites; Table S3: Fuel model regression results for motorized vessels in Uganda; initial starting with L represents selected landing sites i.e., L_NK for landing site Nakatiba, V_SF is for Vessel type Ssese Flat and GG_Number is the number of gillnets; Table S4: Fuel model regression results for motorized vessels in Tanzania. G_GN for Gear_Gillnets, GG_number is Gillnets number.

Author Contributions: V.M.; conceptualization, methodology, investigation, visualization, writing—original draft: T.T.; supervision, funding acquisition, methodology, writing—original draft: D.M.K.; data curation, supervision, funding acquisition and writing—original draft: J.G.P.; conceptualization, methodology, data curation, supervision writing—original draft; C.S.N.; writing—review and editing A.T.-M.; writing—review and editing. All authors have read and agreed to the published version of the manuscript.

Funding: This study did not receive any external funding; however, the student was supported by the Research fund of the University of Iceland and the UNESCO-GRO Fisheries Training Programme (FTP) scholarship.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data for the study have restricted access; however, considerable explanation could be made available upon request from the Lake Victoria Fisheries Organisation.

Acknowledgments: I want to extend my gratitude to the Fisheries Resource Monitoring and Research Section staff of the Lake Victoria Fisheries Organisation, particularly Robert Kayanda, for providing the Regional Lake Victoria Catch Assessment data used in this study. Appreciation to JS Balirwa for earlier insights into this manuscript, and Herbert Nakiyende, Basa Samuel, and Muhumuza Elias of the National Fisheries Resources Research Institute for their continued support. I extend my appreciation to Monica Ochieng Eric Odari of the Kenya Marine and Fisheries Research Institute, and Sophia Shaban of the Tanzania Fisheries Research Institution for their invaluable support in data collection amidst the challenges of the COVID-19 pandemic.

Conflicts of Interest: The authors declare no conflicts of interest.

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Paper II

Fisheries management on Lake Victoria at cross-roads: Assessing fishers' perceptions on future management options in Uganda.

Article in Fisheries Management and Ecology · December 2021

DOI: 10.1111/fme.12526

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Received: 22 May 2021 | Revised: 30 November 2021 | Accepted: 1 December 2021

DOI: 10.1111/fme.12526

ARTICLE

Fisheries Management and Ecology | WILEY

Fisheries management on Lake Victoria at a crossroads: Assessing fishers' perceptions on future management options in Uganda

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UNESCO-GRO Fisheries Training Program

Abstract

Fishers' perceptions on the state of fisheries and the applicable fisheries management system in Lake Victoria (LV), Uganda, were assessed. Fisheries management in the lake is currently at a crossroads. The government abolished a co-management system in November 2015 and installed the military to temporary enforce management. The objective of this study was to explore how fishers envisage future management options by assessing past management regimes and analysing perceptions of alternative regimes. A total of 273 semi-structured interviews at six selected landing sites on LV in Uganda were conducted. Fishers targeted two dominant species, Nile perch, *Lates niloticus* (L.), mainly on motorised vessels representing the commercial fishers and dagaa, *Rastrineobola argentea* (Pellegrin), using both motorised and paddled vessels. The dominance of motorised fishing vessels depicted a consequence of the army operations and represents government priority to protect rather than regulate commercial fishing operations. Fishers mainly perceived regulations they knew about as effective, strongly opposed local governments as a management entity and assigned management to fisher groups as expected. The results support a management regime of key resource users organised by common interest groups to participate in decision-making and combined government structures to regulate and enforce sustainable fisheries measures.

KEYWORDS
fisheries management, fishers' perceptions, Inland fisheries, Lake Victoria, Uganda

1 | INTRODUCTION

Inland fisheries are of particular importance in Africa, providing employment and income, food and nutritional security to millions of rural households (Funge-Smith, 2018; Jentoft & Chuenpagdee, 2015). The fisheries, however, suffer from significant challenges, especially related to poor governance systems and management (Cowx & Ogutu-Owhayo, 2019; Jentoft & Chuenpagdee, 2015).

Over time, different fisheries management paradigms have evolved with various efforts to advance sustainable outcomes. However, few successful examples can be found in African inland fisheries (Béné et al., 2009). Historically, hierarchical self-governing systems existed in fisheries resource management (Onyango, 2015). These traditional systems were disrupted with the colonial conquest, where science-based regulatory measures and formal centralised institutional structures were adopted (Jentoft & Chuenpagdee, 2015). During the post-independence period from the mid-1950s, most of the newly developed African governments maintained colonial structures as centralised management continued to be responsible for crucial policy formulation and enforcement. These faced many challenges due to inadequate resources to develop and implement regulations (Nunan, 2006).

However, basing fisheries management on top-down approaches from central governments did not become a recipe for sustainability, resulting in a search for alternative management approaches. These were commonly based on decentralisation and co-management, following a trend of the devolution of powers from central governments to lower [local] management levels (Béné et al., 2009; Nunan et al., 2015). Fisheries co-management systems were widely promoted in small-scale fisheries (SSF) as early as the 1990s and adopted in most African inland fisheries through various donor-funded initiatives, commonly creating localised community-based user groups (Hara et al., 2015; Nunan et al., 2015). There is little evidence that co-management has improved fish catches in African waterbodies (Béné & Neiland, 2006; Béné et al., 2009).

Fisheries on Lake Victoria (LV) are particularly productive, contributing about one per cent to global capture fisheries (FAO, 2016; Funge-Smith & Bennett, 2019). In Uganda, fisheries on the lake account for half of the country's total fish production and are of considerable economic importance.

Failure of co-management systems to meet specific national goals has put fisheries management at a crossroads in Uganda. In November 2015, the co-management institutions, the Beach Management Units (BMUs), were deemed ineffective in enforcing fishery regulations and abolished through a presidential directive. Through the Uganda Peoples Defence Force-Fisheries Protection Unit (UPDF-FPU), the military is now in charge of fisheries enforcement as a temporary measure in response to the declining fisheries (National Fisheries & Aquaculture Policy, 2017).

Militarisation of natural resources management does not necessarily guarantee good governance and demonstrates how politics and power shape socio-ecological relations. It is, however, on the rise in many African countries framed as “green militarisation.” Green militarisation is much driven by scarcity discourses related to forest and wildlife resources, manifested in heavily militarised operations of government agencies and their paramilitary approaches (Duffy et al., 2019; Massé et al., 2018).

This raises the question whether Uganda is out of options to create a viable and sustainable fisheries management system. The military intervention in its current form is expected to be a short-lived option. The pertinent question revolves around what management system can become a viable option once the military has been pulled out. Important insights can be gained from the primary resource users, the fishers.

As resource users, fishers are directly affected by resource changes, such as the decline in fish stocks (Poon & Bonzon, 2013). Any management or policy changes imposed on the fisheries affect their activities and quality of life and, more importantly, the livelihoods of fishing communities. Assessing perceptions is one way to gain insight into fishers pre-existing knowledge, experience and attitudes, as this can be an essential ingredient for efficient, effective and equitable management (Jentoft et al., 1998; Nunan, 2014). Management should not only be left to experts and government officials drawing on lessons from past interventions. The ideas of resource users could be embedded as part of a proactive approach in developing sustainable fisheries management for Uganda.

The overall objective of this study was to understand how fishers in Uganda envisage future management options for LV fisheries in light of the current military intervention. The study was conducted in 2017, once the military intervention was fully operational, 2 years after the BMUs were abolished. The study aimed to answer the following research questions as a way of voicing fishers' concerns on the LV resources and their perceptions on management issues.

- What are the fishers' perceptions of their production environment and the management regulations in place?
- What are the fishers' perceptions of existing and future management regime?
- What do fishers' perceptions in the study imply for future fisheries management efforts in Uganda?

2 | FISHERIES MANAGEMENT IN UGANDA IN TRANSITION

Uganda is endowed with rich inland fisheries resources producing about 500,000 metric tons annually, >50% from LV, contributing about 3% to national GDP (UBOS, 2016).

Fisheries management efforts in Uganda have proven to be a challenging transitional exercise (Table 1). Fundamental documentation of the fisheries in the country took place in colonial times. In the pre-colonial era, patriarchal tribal chiefs all around the lake who managed different lake sections within their jurisdictions and had exclusive rights to make decisions, including punishments, were appointed (Alidri, 2016; Onyango, 2015; Opondo, 2011). Tribal chiefs in the Buganda subregion in Uganda locally known as *gabunga* overtook leadership of the fleet. The chiefs were selected by popular vote or self-assertion and led fishers based on traditional authority and customs (Barratt et al., 2015). However, such management phased out with the British protectorate government in Uganda at the end of the 19th Century.

With the British colonial rule, central government efforts to manage fisheries started and the first formal regulation, the Fish Protection Ordinance, was introduced in 1908. The Uganda Game Department was established to enforce regulations and oversee the country's fisheries. Regulations included vessel licencing and registration for non-native Africans and the prohibition of using nets with meshes smaller than 2 inches. In 1929, the first fish stock assessment was carried out on LV, recommending a minimum mesh size of gillnets to be five inches to sustain the native Tilapia gillnet fishery (Graham, 1929). The mesh size regulation was included in the fish protection ordinance in 1933 (Kyangwa & Geheb, 2000). Subsequently, the protectorate government established the Lake Victoria Fisheries Service (LVFS) to enforce fisheries regulations lake-wide following the Uganda Game Department's dissolution. Other fishery regulations were developed in subsequent years

TABLE 1 Fisheries management in transition

No.	Era	Description of governance and fisheries management regimes	Timeline	Legal framework	References
1	Pre-colonial era	Self-governing communities, property rights vested in clan leaders and kinship systems	<1890s	Traditional norms and customs	Alidri (2016), Onyango (2015)
2	Colonial-era	Top-down management British colonial government Uganda game department Lake Victoria Fisheries Service (LVFS) East African Freshwater Fisheries Research Organisation (EAFFRO)	1890–1962	Fish protection ordinance 1908 Sleeping sickness rules 1908 Fish Protection Ordinance 1933	Kyangwa and Geheb (2000)
3	Independent Uganda Phase I	Top-down management- The first independent government- Obote, I Uganda Fisheries Department	1962–1971	The Fish and Crocodile Act of 1964	Nunan et al. (2015)
	Phase II	East African Economic disintegration period Idi Amin government Obote II government Uganda Fisheries Department	1971–1986	The Fish and Crocodile act of 1964	
	Phase III	NRM government period Lake Victoria Fisheries Organisation (LVFO) Ministry of Agriculture, Animal Industry and Fisheries Department of Fisheries Resources Fisheries Research Institute District fisheries officers	1986 to date	The Fisheries Act Cap 197,2000	
	Phase IV	Co-management- Beach Management Units (BMUs)	2003–2015	The fish-Beach management rules 2003	Nunan et al. (2015)
	Phase V	UPDF-FPU	2017-present	Presidential directive on law enforcement for fisheries National Fisheries and Aquaculture Policy 2017	Kantel (2019)

Note: Chronology of evolving management in Uganda.

(Table 1) and implemented lake-wide by the LVFS. By 1960, catches had declined as LVFS was unable to manage the fishery resulting in an upsurge in fishing effort, leading to the establishment of the East Africa Freshwater Fisheries Research Organisation (EAFFRO; Beverton, 1959; Kyangwa & Geheb, 2000).

At independence in 1962, the Ugandan government introduced a subsidy scheme encouraging larger and more efficient fishing vessels to enable access to distant fishing grounds (Kudhongania & Chitamwebwa, 1995). The Fish Act was passed in 1964 as independent legislation from the consolidated colonial legislation. The legislation maintained the earlier mesh size regulations, vessel licencing was extended to all fishers, and closed seasons were instituted in fisheries management. The new policies, especially the subsidy policy, almost doubled fish catches from 24,384 tons in 1965 to 46,271 tons in 1969 (Kyangwa & Geheb, 2000). During this period, the Chief Fisheries Officer under the Minister of Fisheries was tasked with enforcing fisheries regulations.

In 1971, the government expelled all non-native fishermen, leading to a significant reduction in catches. The Amin and the post-Amin period 1971–1986 was characterised by political turmoil that led to the dissolution of the East African Community in 1977 under which EAFFRO operated, affecting regional trade policies. Consequently, no substantial fisheries management was implemented as people resorted to non-selective and destructive fishing practices such as beach seines, cast nets and poisoning (Lawrence & Watkins, 2012).

In 1986, the National Resistance Movement (NRM) came to power, bringing relative political stability to Uganda. The change in government also led to the expansion of the fisheries sector through an economic liberalisation programme and increased international demand for Nile perch (Beuving, 2013). Annual catches grew from ≈30,000 tonnes in the period 1971–1983 to 146,600 tonnes in 1989 (Kyangwa & Geheb, 2000). Nile perch contributed over 60% of the total catch, and a number of fish processing companies came into being, exporting Nile perch fillets (Beuving, 2013, 2015; Kjær et al., 2012). The NRM government also initiated reforms of most government sectors, and in 1992, the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) was established, under which the Department of Fisheries (DFR) was reinstated. DFR's primary objective was to ensure sustainable, market-oriented fish production; and quality control and safety of fisheries products for improved food security and household income (Kjær et al., 2012; Lawrence & Watkins, 2012). The Fisheries Research Institute was also restructured under the National Agriculture Research Organisation to conduct research and guide the policymakers at the department and ministry levels. Uganda joined the other two riparian countries, Kenya and Tanzania, at the regional level to form the Lake Victoria Fisheries Organisation (LVFO) to oversee research and management. The Fisheries Act Cap 197 of 2000 was approved as a new fisheries legislative instrument (Table 1).

It is essential to understand the transitions and current developments in Uganda's fisheries within its overall governance and political profile. Uganda has been portrayed as a neo-patrimonial state under the current government that has been in power since 1986 (Kantel, 2019; Nunan, 2020). What generally characterises policy and decision-making is the neo part, an aspiration for modernisation in governance and a reform agenda. Simultaneously, the patrimonial part seeks to consolidate power that revolves into more narrow leadership circles, not limited to the management of natural resources.

In 1995, Uganda's government was part of the global drive towards decentralising the government, manifested in the creating of multiple new district governments (Béné et al., 2009; Green, 2010). Management was carried out at local levels by creating by-laws, collecting revenues and involving community members in resource management (Barratt et al., 2015; Lawrence & Watkins, 2012). Fishery department units were set up at the local government level but without sufficient resources, resulting in significant constraints in implementing fishery regulations. Local governments focussed on collecting revenues at major fishing hubs by issuing fishing vessel licences and fish movement permits. However, no revenue redistribution was made back to the fishing communities, thus creating distrust between the local government officials and fishers (Barratt et al., 2015; Nunan, 2020). Decision-making was still in the central government's hands as it funded and dictated action areas to the districts (Lawrence & Watkins, 2012). District officials resorted to corruption and taking bribes from fishers resulting in the widespread and rampant use of illegal fishing methods. This culminated in the fish poisoning crisis in 1998 and 1999 that led to a ban of Nile perch exports resulting to the closure of fishing activities and a decline in catch (Kyangwa & Geheb, 2000).

In the wake of the fish poisoning crisis, local participation in resource management was sought as national task force teams were appointed and created at every landing site, mandated to control the use of poison in fishing. When the export ban was lifted and fishing reopened in 2001, the teams became landing site management committees (LMCs) led by the g*abunga* (head fishermen; Allison, 2003; Nunan, 2006).

With the BMUs being instituted lake-wide in 2003, Uganda had a conducive realm for a fisheries co-management system with fishery institutions existing at the national management level with the Department of Fisheries Resources (DFR) under the MAAIF, Departments of Fisheries at the district levels and LMCs at the riparian community level. However, unlike the LMCs, committee members of the BMUs were democratically elected rather than appointed, and roles were allocated through a legislative instrument, The Fish (Beach Management) Rules (2003), thus appeared to be a suitable co-management system. Although democratically elected, there is evidence that leaders were elected based on power and influence thus some *gabunga* retained their positions as BMU leaders (Barratt et al., 2015). The key function of the BMUs was to undertake fisheries management on LV coordinated by top government and district officials. This meant that key activities such as the issuing of fishing permits and boat licences, registration of vessels, quality assurance and sanitation, and fishery law enforcement were vested in the BMU committees in collaboration with the district and central government operatives. The lake-wide guidelines for BMUs stipulated the co-management institutional structure and linkages to include a wide range of stakeholders (Ogwang et al., 2005).

Like the decentralisation policy, the BMU structure displayed a highly instructive rather than participatory co-management system as fishers were supposed to follow instructions and implement regulations set by the central government (Lawrence & Watkins, 2012). Social connections and lack of economic empowerment made it quite hard to eliminate non-compliance with regulations and illegal fishing increased (Cepić & Nunan, 2017; Nunan et al., 2018).

Significant and abrupt management changes were made through a Presidential Directive in November 2015. The BMU structures were abolished and replaced by a specialised military unit – UPDF-FPU mandated to enforce fishery regulations according to the Fish Act of 2000, assisted by a two-person committee appointed by senior officials in MAAIF at every landing site (Kantel, 2019). The FPUs activities commenced in 2017, focussing on eliminating illegal fishing gear such as beach seines, cast nets, monofilament gillnets, multifilament gillnets <5 inches and hooks ≥10. The FPUs also participate in licencing of fishing vessels and through enforcement ensuring that all fishers use vessels ≥28 ft.

The official political explanation for the military intervention in Uganda was that the BMU co-management system had failed to eliminate illegal fishing and reverse the decline of the fish stocks. Nile perch exports fell from 36,000 tonnes in the export peak year 2005 to 17,500 tonnes in 2014 (UBOS, 2015), resulting in the closure of more than half of the 23 fish processing factories, with the remaining ones operating at below 30% of installed capacity. Ideally, BMUs were to devolve an effective fisheries management system at lower management levels to ensure the sustainable harvest of fish stocks through enforcement of fisheries regulations. Instead, the institutions resorted to rent-seeking behaviour through revenue collection and promoted local political empowerment to consolidate power to the central government (Green, 2010; Nunan, 2020). There are also suggestions that the motive behind military enforcement might have been to consolidate power around the most economical part of the fisheries (Kantel, 2019; Nunan, 2020). Lawrence and Watkins (2012) note that the institutional arrangement in the fisheries management in Uganda was structured to favour market values rather than local cultural and subsistence values and uses. Accordingly, prioritising fisheries management to favour a more export-orientated direction and an NRM achievement describes fisheries management in Uganda into the earlier notion of a neo-patrimonial state (Kantel, 2019; Nunan, 2020).

Fisheries management in Uganda is, therefore, at a crossroads with the current military intervention ongoing. As elaborated earlier, the military involvement in the fisheries cannot be understood as anything but temporary. A question would then arise on what prospects would facilitate future fishery management on LV whose attempts on decentralisation and co-management policies have been systematically unsuccessful (Béné et al., 2009; Greene, 2010). Therefore, policy options for future and legitimate fisheries management options should be discussed. There are many options open to policymakers that can partly draw from lessons learned from the country's earlier transitional fisheries management policies.

3 | MATERIAL AND METHODS

3.1 | Study area

The Ugandan part of LV covers a total surface area of 29,584 km^2 representing 43% of the total area of the lake. The country has an extensive shoreline of 1,750 km characterised by numerous islands, making it favourable for fishing. The study was carried out at six landing sites, two on Kalangala Island in the south and four on the mainland (Figure 1).

Target species and vessel operation mainly characterised the selection of the study landing sites. LV fisheries are SSF. In the study, those using paddled vessels were classify as artisanal fishers and those using motorised vessels as commercial fishers (Branch et al., 2002; FAO, 2016). There are operational differences between these groups. Paddled vessels are smaller, use fewer gear units, and mainly fish inshore purposely for domestic consumption and local markets (Mpomwenda, 2016; Muhoozi, 2002). The motorised vessels involve substantial capital investment in buying engines, fuel and large quantities of gear units to operate, aiming at higher commercial returns than paddled fisheries. Based on frame survey data from 2014, the majority of vessels that operated from Kiyindi (86%, N = 713) and Kikondo (78%, N = 208) targeted dagaa using motorised and paddled vessels respectively. Motorised vessels targeting Nile perch dominated in Nakattiba (75%, N = 189) and Gaba (69%, N = 72), while about a third of the vessels at the two Kasenyi sites were motorised targeting Nile perch [Kalangala = 35%, N = 87; Wakiso = 29%, N = 279], and the rest were paddled vessels targeting Nile perch, dagaa and tilapias.

3.2 | Data collection

Face-to-face interviews using a semi-structured questionnaire were carried out from June to August 2017, following a pilot study to identify potential problem areas and deficiencies in the questionnaire. The questionnaire was adjusted accordingly before implementing the complete survey. Fishers and boat owners were randomly selected and interviewed at the landing sites in the afternoon to evening hours as they prepared to go out fishing and gave interviewers ample time.

In the first part of the questionnaire, fisher-specific information was asked. In the second part, fishers were asked to rate the status of the catches of their targeted species, rate the severity of common challenges they faced in their operations, and their

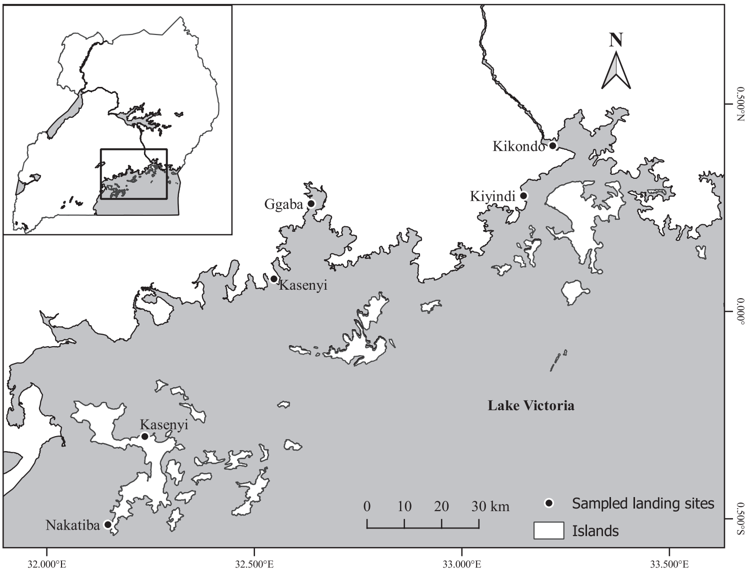


FIGURE 1 Map of Lake Victoria, Uganda, showing selected landing sites (filled circles) where fishers were interviewed

level of knowledge and perception of regulations, and their effectiveness. Replies were either categorical yes/no response to a statement or rated on a 3-point Likert scale from positive (1), average (2) and negative (3). The 3-point Likert scale was used as it was easier for respondents to distinguish their response around a neutral point and for ease of analysis based on accurate responses (Johns, 2010).

Finally, respondents were asked to specify their preferred fisheries management regime. For this question, four regimes were specified, that is fisher groups, BMUs, local government and central government. All regimes, except fisher groups, are specified in LV's fishery co-management structure (Ogwang et al., 2005). Fisher groups were defined as fishers or even boat owners organised according to target species, adopted from Poon and Bonzon (2013) who define fisher groups as social units organised at a given fishing jurisdiction based on a biological unit, that is target species. This trait demonstrates fisheries under a territorial user fisher rights management scheme (Poon & Bonzon, 2013), which might be an option for the LV fishery.

3.3 | Data analysis

The quantitative survey data were analysed using RStudio Team (2020) version 4.0.3. In addition, descriptive statistics of the respondent's profile and vessel characteristics were obtained based on frequencies. Finally, differences in fishers' responses based on the two dominantly targeted species of Nile perch and dagaa, and vessel operation were tested to understand distinctions between paddled and motorised fishers. Differences were compared using the Fisher's exact tests with the level of significance (α) determined at $\alpha = 0.05$.

4 | RESULTS

4.1 | Respondents characteristics

Respondents were predominantly male (99%) with a mean age of 34 years. The majority of respondents were crew (86%), while others were vessel owners (13%) and managers (1%). New entrants with 5 years' experience or less constituted 44% of respondents, 34% had six to 15 years of experience, and 22% were very experienced fishers with more than 15 years of experience.

Engagement in fishing activities was considered a full-time activity by the majority (88%) of the respondent's, while the rest were part-time fishers.

Over 80% of the Nile perch fishers fished in motorised vessels. Operators owned on average eight vessels with the highest owning 25 vessels and hired managers to run their fleets. Respondents in the dagaa fishery operated in both motorised (67%) and paddled vessels (33%), and vessel owners had at most two vessels per person and individually managed vessel operations.

Most Nile perch fishers used gill nets and longlines, whereas dagaa fishers predominantly used seine nets. Some Nile perch fishers also targeted other species such as tilapia, lungfish, catfish and dagaa, whereas dagaa fishers were also likely to target haplochromine species (Table 2).

4.2 | Changes in the proportion of fishers; population versus sample

In 2014, dagaa fishers predominantly used motorised vessels (68%), while motorisation was less common in the Nile perch (42%) and tilapia (23%) fisheries (Figure 2). However, this had changed in 2017

TABLE 2 Summary statistics of respondents' demographic characteristics by vessel operation and target species

Variable	Description	Motorised			Paddled			
		Nile perch (*N* = 111)	Dagaa (*N* = 88)	Tilapia (*N* = 3)	Nile perch (*N* = 23)	Dagaa (*N* = 44)	Tilapia (*N* = 4)	Total *N* = 273
Status of the respondent (%)	Boat manager	1.8	–	–	–	–	–	0.7
	Boat owner	7.2	18.2	33.3	–	25.0	–	13.2
	Crew member	91.0	81.8	66.7	100.0	75.0	100.0	86.1
Gender (%)	Men	100.0	97.7	100.0	100.0	97.7	100.0	98.9
	Women	–	2.3	–	–	2.3	–	1.1
Age (years)	Average	33.4	32.3	27.7	36.5	34.9	39.3	33.6
	SD	9.2	8.7	2.1	11.8	9.4	14.5	9.6
Involvement in fishing (%)	Fulltime	90.1	89.8	100.0	82.6	84.1	75.0	88.3
	Part-time	9.9	10.2	–	17.4	15.9	25.0	11.7
Experience in fishing (%)	1–5 years	39.6	55.7	100.0	39.1	34.1	–	44.0
	6–15 years	42.3	28.4	–	17.4	31.8	50.0	33.7
	Above 15 years	18.0	15.9	–	43.5	34.1	50.0	22.3
Vessel ownership (number)	Maximum	25.0	3.0	3.0	–	2.0	–	25.0
	Average	8.0	1.25	3		1.18		3.05
	Minimum	1.0	1.0	3.0	–	1.0	–	1.0
Gear used (%)	Gill nets	85.6	–	–	65.2	–	100.0	41.8
	Longline	10.8	–	–	30.4	–	–	7.0
	Small seine	3.6	96.6	100.0	4.3	100.0	–	50.2
	Others	–	3.4	–	–	–	–	1.1
Target other species (%)	Haplochromines	–	2	–	–	9	–	2
	Lung and catfish	1	–	–	13	–	–	1
	dagaa	5	–	–	4	–	–	2
	Tilapia	15	–	–	39	–	–	10
	Synodontis	–	–	–	–	–	25	–

when 62% of the Nile perch fishers sampled used motorised fishing vessels. Tilapia fishers mainly used paddled vessels, but a smaller proportion of them was sampled in 2017 compared with the targeted population in 2014 (Figure 2).

4.3 | Fisher's perception of catches and challenges in fishing

Fishers were most likely to rate their Nile perch catches as worse (Mean = 2.89), while dagaa catches were rated relatively constant with a mean of 2.01 (Table 3).

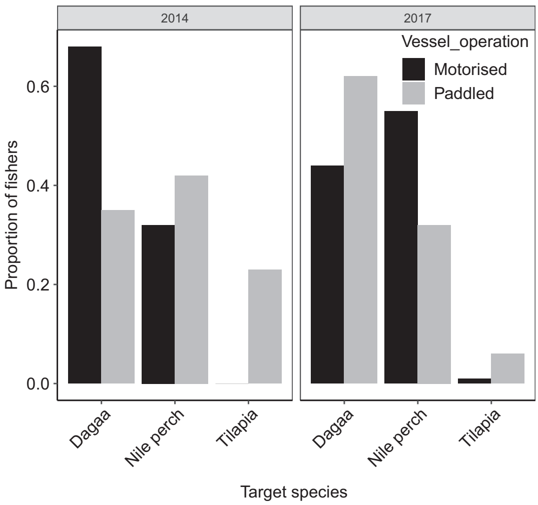


FIGURE 2 Comparison between the proportion of fishers' population by vessel operation and target species in 2014 versus sampled fishers in 2017

Dagaa fishers operating motorised vessels (51%, $N = 88$) were more likely to rate the catches as worse, while fishers in the paddled vessels were more likely to rate them as better (50%, $N = 44$).

Fishers rated all challenges as severe (Table 4). The most severe challenges, viz. reduced catches, high costs, reduced fish size and long fishing hours, could reflect declining stocks. In contrast, challenges like unregulated gear and illegal gear that could cause declining stocks were indicated to be less of a challenge.

Fishers targeting dagaa were more likely to rate bad weather as a challenge than Nile perch fishers who rated conflicts and long fishing hours as more severe (Figure 3).

4.4 | Fisheries regulations; Level of knowledge and perception of effectiveness

Fishers, irrespective of their target species or vessel operation, knew about minimum mesh size (95%), gear ban (93%) and licencing (87%). However, few fishers knew whether closed fishing seasons (16%) and closed fishing areas (29%) were fisheries regulations. Fishers also perceived mesh size (97%), licencing (90%), gear ban (88%) and closed fishing areas (63%) to be effective fishery regulations. However, few (26%) fishers perceived closed fishing seasons as an effective regulation (Table 5).

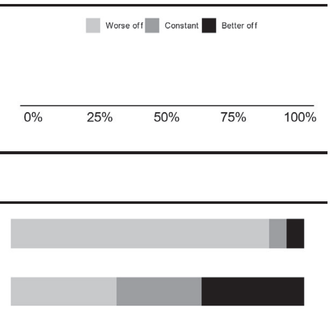
Irrespective, most dagaa fishers knew about closed fishing seasons (>50%) and fishers that disagreed with licencing as a practical measure were mostly (>70%) Nile perch fishers (Figure 4).

4.5 | Preferred fisheries management regimes

Opinions on different management regimes varied (Table 6). However, fisher groups and BMUs were suggested as effective by 42% and 38% of the respondents, respectively, while only 21% and

TABLE 3 Fisher's perception of fish catches' status by target species and vessel operation

Question	N	Mean	Target species (P-value)	Vessel operation	
Rate the status of catches of the following species when you started fishing and now.					
Nile perch	141	2.83	ns	ns	
Dagaa	147	2.01	ns	***	

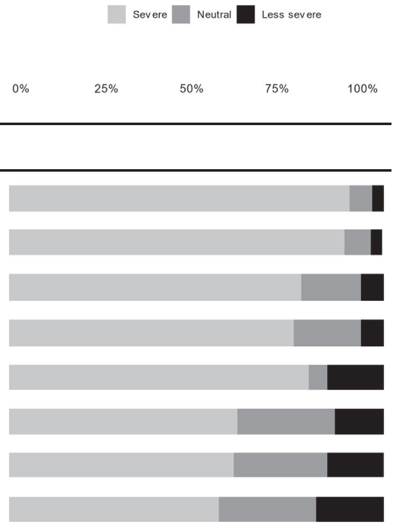


Notes: **** p ≤ .0001, ***p ≤ .001, **p ≤ .01, *p≤ .05, ns p> .05

Notes: The mean response rate calculated from left to right given as 1 = Better off, 2 = Constant and 3 = Worse off; and the *p*-value of Fisher's exact tests of independence shows differences between fisher's response to the status of catches by target species and vessel operation.
****$p \le 0.0001$, ***$p \le 0.001$, **$p \le 0.01$, *$p \le 0.05$, $^{ns}p > 0.05$.

TABLE 4 Fisher's responses to the severity of the challenges faced in their fishing activities

Question	N	Mean	Target species (P-value)	Vessel operation (P-value)
Please rate the following challenges in affecting fishing activities				
Reducing catch	220	1.12	ns	ns
High input costs	208	1.14	ns	ns
Reducing fish size	192	1.27	ns	ns
Long fishing hours	163	1.30	****	ns
Conflicts	241	1.35	*	ns
Unregulated entry	227	1.53	ns	ns
Increased illegal gears	199	1.56	ns	ns
Bad weather	158	1.62	*	ns



Notes: **** p ≤ .0001, ***p ≤ .001, **p ≤ .01, *p≤ .05, ns p> .05.

Notes: The mean response was calculated from left to right for each challenge: 1 = Severe, 2 = Neutral and 3 = Less severe; and the *p*-value of Fisher's exact tests of independence shows differences between fisher's response to the status of catches by target species and vessel operation. ****$p \leq 0.0001$, ***$p \leq 0.001$, **$p \leq 0.01$, *$p \leq 0.05$, $^{ns}p > 0.05$.

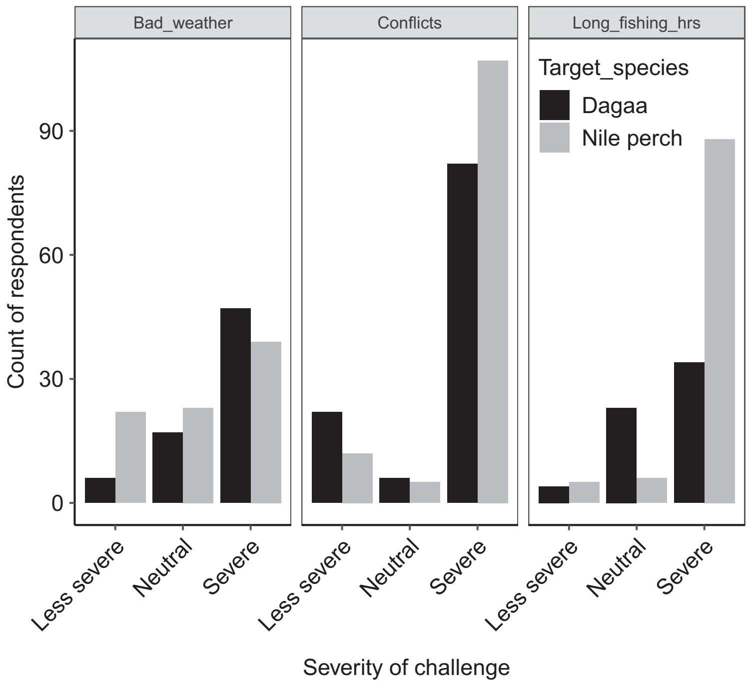
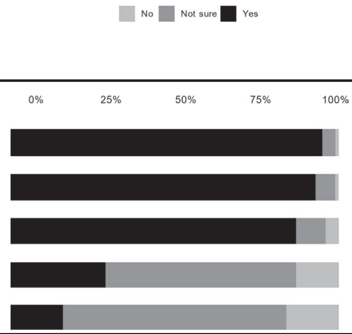
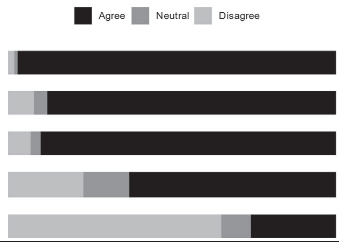


FIGURE 3 Perception of fishers towards the severity of selected fishery challenges by target species; bad weather, conflicts and long fishing hours

TABLE 5 Fisher's level of knowledge and their perception of regulation effectiveness

Questions	N	Mean response	Target species	vessel operation
			P-value	
i). Do you know of the following fishery regulations?				
Mesh size	245	1.10	ns	ns
Gear ban	242	1.13	ns	ns
Licensing	210	1.23	ns	ns
Closed areas	225	2.25	ns	ns
Closed seasons	216	2.29	*	ns
ii). Rate the regulations in ensuring effective fisheries management?				
Mesh size	245	1.04	ns	ns
Gear ban	242	1.16	ns	ns
Licensing	214	1.17	*	ns
Closed areas	228	1.60	ns	ns
Closed seasons	229	2.38	ns	ns





Notes: **** p ≤ .0001, ***p ≤ .001, **p ≤ .01, *p≤ .05, ns p> .05.

Notes: The mean response was calculated for both knowledge and perception as (i) 1 = Yes, 2 = Not sure and 3 = No; and (ii) 1 = Agree, 2 = Neutral and 3 = Disagree; and the *p*-value of Fisher's exact tests of independence shows differences between fisher's response to the status of catches by target species and vessel operation.
****$p \le 0.0001$, ***$p \le 0.001$, **$p \le 0.01$, *$p \le 0.05$, $^{ns}p > 0.05$.

8% of the respondents suggested the state and local government as effective, making the latter the least preferred regime.

About half of the respondents targeting Nile perch (48%, $N = 110$) preferred fisher groups over other regimes, while dagaa fishers preferred BMUs (46%, $N = 113$; Figure 5). Neither group wanted local governments to manage the fisheries (2–4%).

5 | DISCUSSION

5.1 | Fisher's perceptions on the productive environment, challenges faced and fishery regulations

Fishers' perceptions of fisheries management in LV based on their targeted species and vessel operation were analysed. Most fishers targeted Nile perch or dagaa, the lake's two main commercial species (LVFO, 2016). Only 3% of the respondents targeted Nile tilapia, while 15% targeted at least two species, including one dominant commercial species.

LV fisheries are best described as artisanal SSF, best depicted by paddled fishers, and larger vessel commercial SSF, depicted by the Nile perch fishers (Branch et al., 2002; Funge-Smith & Bennett, 2019). A majority of respondents that targeted Nile perch operated in motorised vessels (>80%), vessel owners had eight fishing vessels on average, and fishing was a full-time activity of most respondents.

A commercial Nile perch fishery has existed for over three decades, driven by high international market demand for whitefish since the early 1990s, attracting heavy investment in fishing operations, including vessels motorisation and efficient fishing gear (Beuving, 2015; Kudhongania & Chitamwebwa, 1995). However, the expansion of commercial dagaa exploitation is relatively recent in Uganda, with intensive motorisation of vessels observed since 2011 (LVFO, 2014; Mpomwenda, 2018). Commercial dagaa harvesting is enhanced by growing local and regional market demand (Odongkara, 2018). The dagaa fishery, formerly less regulated, is now being regulated under the UPDF-FPU to include a maximum number of panels (eight for the small mesh seine net and minimum vessel length of 28 ft, which explains the dominance of motorised vessels (67%) at the time of the study).

Fishers were generally knowledgeable about the minimum mesh size and gear ban that have been implemented longer than any other regulations (Kolding et al., 2013; Kolding & van Zwieten, 2011). Nile perch fishers perceived these and vessel licencing to be positive and effective for their operations. Before the military involvement in enforcement, existing legislation in Uganda did not specify rules for the dagaa fishery; thus, implementation mainly affected the Nile perch fishery. However, it is still questionable how effective mesh size and gear ban regulations have been in sustaining fish catches (Kolding & van Zwieten, 2011). According to fishers, Nile perch catch has declined while the dagaa catches have remained relatively stable.

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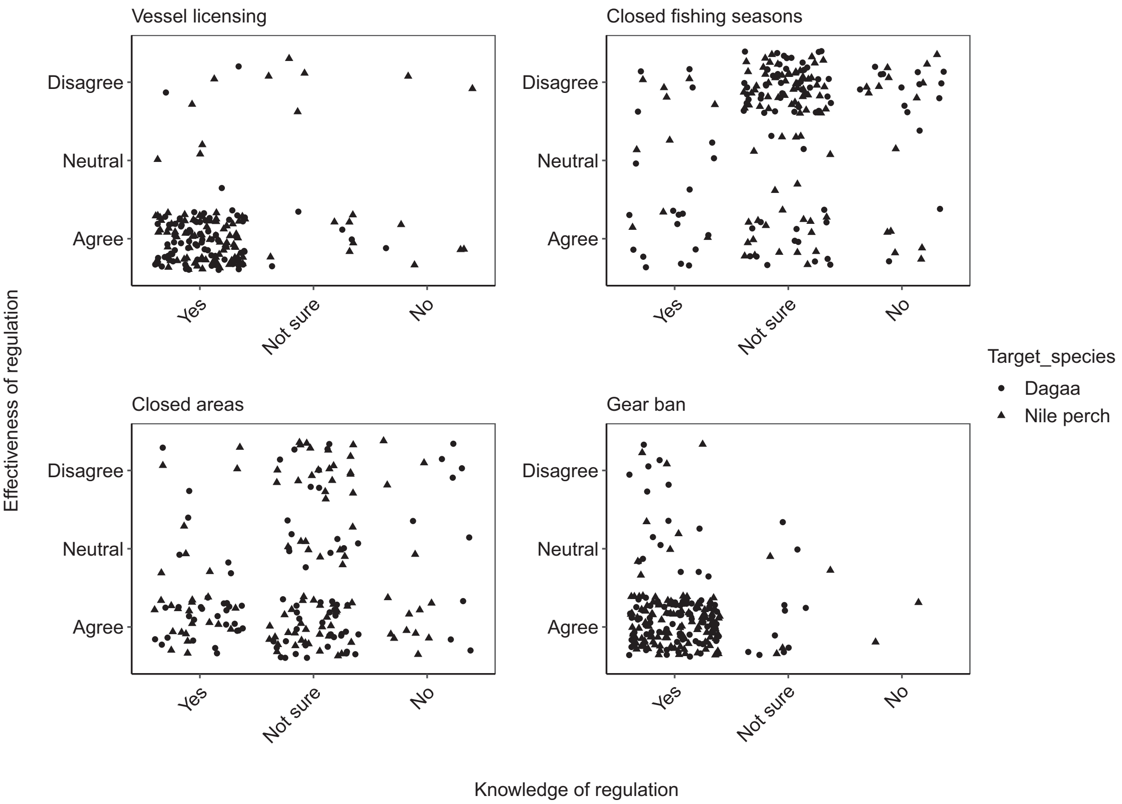
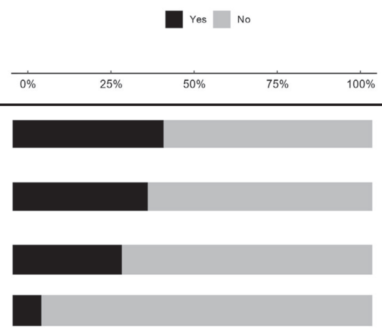


FIGURE 4 Relationship between respondents' knowledge of a regulation and perception on its effectiveness by target species. Fishers' knowledge [x-axis] based on a Likert scale measured as 1 = Yes, 2 = Not sure or 3 = No while perception of regulation effectiveness [y-axis] based on 1 = Agree, 2 = Neutral or 3 = Disagree

TABLE 6 Fisher's perception of the effective fisheries management by target species and Landing site

Do you think the following institutions would manage fisheries effectively	N	Target species	vessel operation
		(P-value)	
Fishers	250	*	ns
BMU	250	**	ns
State government	250	ns	ns
Local govt	250	ns	ns



Notes: **** p ≤ .0001, ***p ≤ .001, **p ≤ .01, *p≤ .05, ns p> .05.

Notes: The *p*-values of Fisher's exact tests of independence show differences between fisher's response to the status of catches by target species and landing site.

****$p \le 0.0001$, ***$p \le 0.001$, **$p \le 0.01$, *$p \le 0.05$, $^{ns}p > 0.05$.

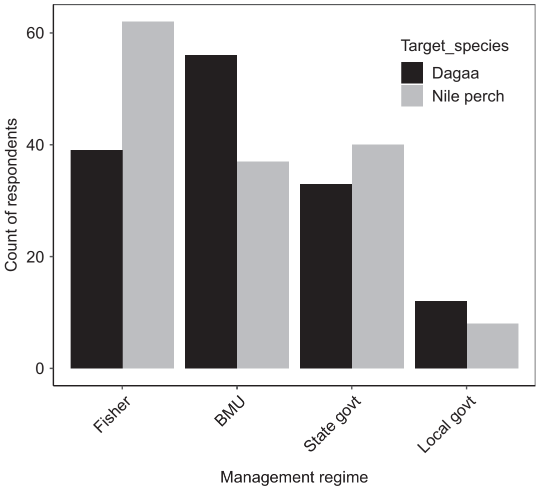


FIGURE 5 Fisher's response to suggested management regime based on their target species. Response counts based on those who indicated yes to the stated management regime

Illegal mesh sizes and non-selective gear have always been seen to cause reduced catches (Nunan, 2014). Vessel licencing, however, has never imposed any effort restrictions as there are no limits to the number of licences issued (Lawrence & Watkins, 2012; Nunan, 2014). Therefore, it pays off for fishers and boat owners to increase investment in legal fishing gear if they can afford the licence fees. Fishers do not consider unregulated entry and illegal fishing gear as being as severe as other challenges, disregarding that these could be the actual causes of reduced fish catches (Table 6), a classical outcome of the tragedy of the commons. Fishers' perception of declining catches is not a new notion in LV. It has been reported in other socio-economic studies (Cepić & Nunan, 2017) and is borne out by the decline in Uganda's fish exports in 2014 (UBOS, 2016). Nile perch fishers indicated reduction in fish catch as the most pressing challenge in their operations. Although the catches control all operations of fishers, an increase in catches often results in further investments and vice versa.

Closed fishing seasons and areas were largely unknown to fishers, and these regulations have not been enforced. Nevertheless, fishers who felt that closed fishing seasons could be effective were mostly dagaa fishers (Figure 4). Dagaa fishing is linked to the lunar cycle giving fishers between 14 and 24 fishing days in a month. For dagaa fishers, a closed season would likely entail the days when the moonlight is too bright for the light attraction fishery to be effective. Periodic dagaa closed seasons are implemented in the Kenyan part of the lake, thus influencing the perceptions of some dagaa fishers on the Ugandan portion of LV (Njiru et al., 2014).

Most of the respondents (88%) were fully occupied in fishing with no alternative employment. Thus, it would be unpopular to impose a closed fishing season. The negative perception of closed fishing seasons has also been reported by fishers in other SSF (Kincaid et al., 2014; Musiello-Fernandes et al., 2017). On the other hand, closed areas gained support from over 60% of the respondents, making it more feasible to implement than seasonal closure (Table 5).

The productive fishery environment directly associates with the policy and regulatory environment existing in the fishery. Most regulations known to the fishers were those that have been implemented and enforced for the Nile perch fishery: mesh size regulation and gear ban are the most common ones. An earlier law was implemented for the indigenous tilapia species (Graham, 1929) and later recommended for Nile perch. For Nile perch, it is essential to address the impact of implemented regulations on fisher activity and implications for sustainable fisheries management.

5.2 | Perceptions towards fisheries management options

Fishers' perceptions towards four alternative fisheries management regimes – fisher organisations, BMUs, central and local government institutions – are diverse. Except for fisher groups, all institutions are part of the lake-wide co-management structure (Ogwang et al., 2005). However, at the time of the study, BMUs in the Ugandan part had been replaced by the UPDF-FPU.

No single institution gained the majority support of the respondents, but fisher groups and BMUs received moderate support of around 40%. The state government was supported by 21% of respondents, while only 8% supported the local government option. It was evident that there is a strong dissatisfaction with vesting fisheries management in the local governments. The disapproval of local government in fisheries management is not new as this has been established in other studies (Kjær et al., 2012; Lawrence & Watkins, 2012; Nunan et al., 2015). However, it is worth noting that the disapproval of local government structure reflects an unsuccessful neo-patrimonial institution based on the global drive towards decentralisation. Earlier studies indicated that local governments lacked enough support to enforce fishery regulations. Officials instead resorted to corruption and bribery, which perpetuated illegal fishing, thus failing to serve the interests of both the central government and the fishing communities (Nunan, 2020).

Nile perch fishers were more likely to select fisher groups and state government than the dagaa fishers, who were likely to have a preference for BMUs and fisher groups. Unlike other management options, fisher groups offer an opportunity for fishers' decision-making based on their specific shared interests (target species) and goals (profitability). The central government's mandate on fisheries management has always been towards eliminating illegal fishing gear and practices and fish quality assurance, which enables commercial export-based Nile perch fishery. The central government has enabled these through policy formulation and research, developing appropriate strategies and technologies for fisheries management. It must be noted, however, that fisher responses could give a biased view of the overall fishery as the artisanal fishers targeting Nile perch and tilapia constituted only a small proportion of the respondents (Figure 2).

Commercial fishers by their operational areas [offshore] can fish the acceptable fish sizes mainly target fish for the export-oriented processing factories, using legal gears. Artisanal fishers are limited to fishing in nearshore areas, mainly targeting fish for local markets where lack of large fish leaves them with little alternative than to fish with illegal fishing gears such as gillnets <5 inches and cast nets (LVFO, 2014; Mpomwenda, 2016). Thus, these fishers have been the main target of the UPDF-FPU operations.

The BMU structure encouraged the engagement of many fishery stakeholders (Ogwang et al., 2005). When the BMUs were established, they encouraged various stakeholders, irrespective of targeted species and position in the value chain (fishers, traders and processors). However, the multi-stakeholder structure of the BMUs might have failed to address all the stakeholders' interests, causing mistrust among members. In this study, fishers targeted either dagaa or Nile perch (Figure 2); thus, one could assume that BMUs were addressing fishers' interests targeting the dominant harvested species at a landing site, thus gaining fishers' support. However, this was not the case for the Nile perch fishers. It is important to note that the disbandment of BMUs in Uganda resulted from the declining Nile perch exports tagged to the rampant use of illegal fishing gears and methods, which could explain why Nile perch fishers had also lost trust in the BMU regime.

The former BMU co-management structure on LV in Uganda has been described as an instructive rather than participatory fisheries co-management system (Nunan et al., 2015). Information was shared with fishers only at the end of the planning process rather than having them participate in the process: thus, fisher views were rarely considered at the planning stage (Cowx and Ogutu-Owhayo, 2019; Nunan et al., 2015). Other challenges also contributed to its failure, such as the disproportionate return of fishing rents to fishing communities, inadequate funds to enforce fishery regulations, limited judicial power to apprehend offenders leading to a distrust in the system and the general failure of the system to implement its core objective on the fishery (Lawrence & Watkins, 2012; Nunan, 2014; Nunan et al., 2018). Unlike the Nile perch, the dagaa fishery has always been less regulated, so it is likely to still thrive with BMUs or even fisher group institutions given the status quo regulatory system under the BMUs is maintained.

BMUs have been credited with strengthening social ties and cooperation in the fishery. Nunan et al. (2018) indicated that fishers grouped mainly by kinship, ethnicity or gear could create a more robust organisational bond than the BMU system offers. Based on this study, management that involved smaller fisher institutions and BMUs received more support than other structures.

Unlike other government institutions, BMUs and fishery-based organisations provide flexible conditions and an environment for consultations, negotiations and participation in decision-making, given that the co-management structure is participatory rather than instructive. However, total control of resources in the hands of local communities makes them complacent: thus, fisheries management needs to consolidate both top and bottom management structures. This would also encourage cooperation and information sharing between fishers and management institutions to ensure sustainable fisheries management.

The BMU structure on LV has been described largely as unsuccessful (Béné & Neiland, 2006; 2009; Nunan, 2014, Nunan et al., 2015). The dagaa fishers' preference for the BMU at the moment may reflect that they are less regulated than the Nile perch fishers. Overall, fishers supported the hypothetical fisher group institution of management, based on right-based management of the fisheries.

Right-based management is aimed at increasing fishers' social responsibility towards sustainable use of the fisheries resources by strengthening fishing rights through avenues, such as defining individual or community catch shares or managing designated fishing areas (Poon & Bonzon, 2013). For SSF, such as is the case in this study, a shared system would be impractical given the vast number of fishers operating in the fishery, insufficient political support and government capacity to implement such an approach (Béné & Neiland, 2006; Cooke et al., 2016; Nunan, 2014). On the other hand, designated fishing territories requires improving the current capacity to govern through traditional ecological knowledge, traditional user rights and traditional governance structures, such as self-organised fisher associations (Cooke et al., 2016; FAO, 2015), a depiction of the pre-colonial fisheries management structures (Onyango, 2015). Nunan (2014) also noted that upholding designated fishing rights could be difficult in terms of attracting government investment in fisheries infrastructure, improving living conditions and access to services, but suggested that steps could be taken by the recognition of rights and investment in fishing communities. It is evident that fishers have quite different operational and regulatory needs depending on the species they target. Establishing species specific management units with an appropriate set of management instruments could be a step towards an inclusive management regime.

6 | CONCLUSIONS AND IMPLICATIONS FOR POLICY

This study examined and compared fishermen's perceptions of LV's fisheries management concerns in Uganda and, particularly, on future fisheries management options for the lake. The study was conducted during a transitional period after the government abolished the BMUs as an approach to governance and had installed military operations on the lake to enforce fisheries regulations.

The study distinguished the fishery operations of the major commercial target species on LV in Uganda. Nile perch as a developed commercial fishery, dagaa fishery as a developing commercial fishery, and a small portion of the artisanal paddled Nile perch and tilapia fishery. Importantly, a significant change in landing site operations was noted. Before the study, landing sites were purposely selected to include respondents from commercial Nile perch operations, commercial dagaa operations and smaller-scale [artisanal] mixed species-based landing sites. The latter group (small scale mixed landing) also adopted commercialised operations to include operating in motorised fishing vessels with possibly larger vessels

(>28 ft). Much as acknowledged in this study is a response to the FPU enforcement, but is noted that the onset of the military operations amplified the distinction between the artisanal and commercial SSF fishers by eliminating the former favouring the latter. This might imply that the increased commercialisation of the fishery will perhaps eliminate small artisanal operators. Besides, the FPU operations truly consolidate government control over the fisheries resources, albeit portrayed as a technical fisheries management exercise to drive more sustainable fishing. It can be understood as a manifestation of the patrimonial politics around natural resources, which Uganda has experienced in recent years. It truly has a strong focus on advancing the outputs of the most valuable fish species for export, the Nile perch, which has proven to be of significant economic value.

Fishers do not know all fisheries regulations except those enforced to maintain catches of commercially important species. This is not surprising as fishers rarely comply with regulations, instead operationalise them to their benefit of maximising catches and profits. For those who cannot invest in efficient fishing vessels, non-compliance with the fisheries management rules is a significant livelihood opportunity. Management has always been oriented towards the market-driven fisheries regulation towards local fishers than towards external factors. However, policymakers could regulate the fisheries beyond just the commercial fleet and offer appropriate regulations to accommodate other fisher groups, whose rationale for fishing differs from the commercially intensive fishing fleet. Accordingly, the dagaa fishery on the lake supports the livelihoods through employment, a cheaper source of fish nutrients and, most importantly, the species dominates in lake catches and is traded widely for human consumption both locally and regionally (LVFO, 2016; Odongkara et al., 2018).

Natural resource management in Uganda is not entirely separate from military-related law enforcement. This is displayed in the country's forestry and wildlife sectors, whose legal framework includes trained paramilitary units to enforce regulations. Therefore, it is not a surprise to see the government resorting to this approach during the crisis with the fisheries decline and allegations of lax performance of the BMUs. However, given the LV fisheries economic potential, military fisheries enforcement presence indicates significant policy priority of promoting commercial fisheries production, specifically the export-based fisheries. The paramilitary approach to law enforcement in natural resources also needs to be vested in the respective legislative and policy frameworks to secure legitimacy and transparent application of power. However, it is argued that this should not ignore management at lower levels as they play a significant role in fisheries governance.

The fishermen strongly oppose fisheries management being vested in the hands of local government and showed preferences for more inclusive models. This can give directions for policymakers and help narrow down their management options.

Bringing the findings together, an alternative fisheries management model that would opt for inclusive local management based on well organised common interest groups for decision-making and recognition of the different scales and economic interests in the LV fisheries is suggested. Nunan's (2014) suggestion of recognition of fishing rights, which could be based on the needs of varied target species fisher groups targeting different species, might be a good option for the management of fisheries. Besides, a legally backed central government agency/s be mandated to develop, implement and enforce fisheries regulations according to sustainability criteria (FAO, 2015). However, there are indeed foundations from the former co-management system attempts and essential lessons from other natural resources sectors that can inform such an approach and the needed legislative and policy reforms.

Fisheries management in Uganda is truly at a crossroads with the military enforcing regulations on the lake, a dire need for a new fisheries management system and, yet, not with a clear policy direction where to go. This study argues that policy options are available and essential to draw lessons from the fishermen's perceptions and earlier management regimes to envisage an efficient and legitimate fisheries management system.

ACKNOWLEDGEMENTS

All fishermen who gave of their valuable time and information: and staff at the National Fisheries Resources Research Institute, especially Herbert, Elias, Sam, Esther, Ashraf, Everist, Bairon and John-Michael, are gratefully acknowledged. Also, we acknowledge the three anonymous reviewers who spared their time to review the manuscript.

DATA AVAILABILITY STATEMENT

The data that support the findings of this study are available from the corresponding author upon reasonable request.

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How to cite this article: Mpomwenda, V., Kristófersson, D.M., Taabu-Munyaho, A., Tómasson, T. & Pétursson, J.G. (2021) Fisheries management on Lake Victoria at a crossroads: Assessing fishers' perceptions on future management options in Uganda. *Fisheries Management and Ecology*, 00, 1–16. https://doi.org/10.1111/fme.12526

Paper III

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Article

Adaptation Strategies to a Changing Resource Base: Case of the Gillnet Nile Perch Fishery on Lake Victoria in Uganda

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Abstract: Sustainable management of fisheries has proven to be a daunting exercise for Lake Victoria. Exploitation patterns in the fishery are driven by fishers who adopt different strategies as a response to changing economic, management, socio-economic, and resource conditions. Fisheries managers, however, seldom consider these changes in management policies. The aim of the study, therefore, was to evaluate the adaptation strategies of the Nile perch gillnet fishers on Lake Victoria in Uganda using 8-year catch and effort data collected in the period from 2005 to 2015. Trends of the selected effort and catch variables in the study period identified two adaptive fishing strategies by gillnet fishers on the lake. The first group, the paddled fishermen whose gillnet use varied in the first half of the study, diverted to harvesting juvenile Nile perch by using smaller, mesh sizes, monofilament nets and gillnets of less depth in the second half of the study. Motorized fishers, on the other hand, maintained their mesh size, using multifilament gillnets, however, they increased the depth of their nets in the second half of the study period to maintain their targeted fish size. Fishers on Lake Victoria adapted strategies to cope with their constraints and opportunities based on the Nile perch population structure and their economic needs. It is important for fishery managers to consider that the fishers are an integral part of the fisheries ecosystems, and considering their behavior in management decisions will aid in devising adaptive policies for sustainable resource use and sustainable livelihood development of the fishers' communities.

Keywords: small scale inland fisheries; sustainability; fisheries management; fisher's strategies

Citation: Mpomwenda, V.; Tómasson, T.; Pétursson, J.G.; Taabu-Munyaho, A.; Nakiyende, H.; Kristófersson, D.M. Adaptation Strategies to a Changing Resource Base: Case of the Gillnet Nile Perch Fishery on Lake Victoria in Uganda. *Sustainability* **2022**, *14*, 2376. https://doi.org/10.3390/su14042376

Academic Editors: Liontakis Angelos, Tzouramani Irene and Just Tomàs Bayle-Sempere

Received: 15 November 2021
Accepted: 6 February 2022
Published: 18 February 2022

1. Introduction

1.1. Background

Sustainable management of fisheries has proven to be a daunting exercise for most African inland water fisheries which are largely small-scale (SSF), employing about 12% of world fishers and also playing a crucial role as a source of livelihoods, food security, and income for millions of people and national economies [1]. SSF fisheries are characterized by multiple harvesting patterns, being open access or common property resources with a growing population dependent on them, makes them complex and difficult to manage [2–5]. SSF are vulnerable to overexploitation, and they face environmental degradation as well as poor management outcomes [6,7].

To enable sustainable management of SSF, international legal and policy frameworks (e.g., FAOs code of conduct, voluntary guidelines for small scale fisheries, and Sustainable Development Goal (SDG) 14b) encourage the Ecosystem Approach to Fisheries (EAF) as a guiding principle to management. The EAF approach denotes the need for fisheries management as a holistic linkage across human and natural systems, identifying conflicts between competing ecosystem services and the direct and indirect impacts of fishing activities. The approach considers that the health of the aquatic ecosystem and associated biodiversity are a fundamental basis for fisher community livelihoods, recognizing the contribution of SSF to global food security and nutrition, equitable development of fishing communities and poverty eradication [8–10]. However, the international legal and policy frameworks do not guarantee any requirement for the SSF to adopt the approach unless this is specifically mandated in the individual country's legal and policy frameworks.

Fishing is a highly uncertain activity and managers in SSF are still faced with the challenge of managing the dynamic and unpredictable interdependance between resource users and the fisheries resource. Understanding the interactions between the fishers and the fisheries resource can provide insights to enable holistic and sustainable fisheries management of SSF. Fishers are able to re-organize and develop strategies to adapt to resource changes, opportunities, and even address uncertainity associated with fishing activities [11–13]. Fishery managers, on the other hand, have focused on understanding biological fishery processes, neglecting fisher responses to changes in resource availability, market conditions, and also management regulations [12–14]. Managers therefore need to identify and understand the dynamics of fisher strategies, based on the contraints, goals and opportunities, to generate relevant information necessary to design sustainable fisheries management frameworks.

It is a common assumption that data or information on inland SSF are limited, and if they are available then they are considered to be highly unreliable in guiding authorities towards sustainable decision making in fisheries management [7,15–17]. However, a complete lack of data is not always the case for African inland fisheries. Lake Victoria accounts for more than 1% of global capture fisheries and the lake and its fisheries have been studied widely [18,19]. Substantial support has been provided for data collection, analysis, and governance structures. It is, however, still open to debate as to whether the acquired knowledge and information has led to the intended improvements in the fishery. Recurring challenges on the lake, such as perceived reduced catches, use of illegal gear and governance issues, have been reported in some studies [4,19]. Notwithstanding some inconsistencies in the data, the available information can be used to assess fishery management issues, such as the effectiveness of regulations and to explore different fisher strategies and their influence on fisheries production.

The aim of the paper was to evaluate the adaptative strategies of the Nile perch gillnet fishers and operators using 8-year catch and effort data collected in the period 2005 to 2015. The specific objectives of the study included determining the dynamics of gillnet use by vessel groups, identifying fishing strategies and evaluating the effects on the sustainability of the Nile perch fishery on Lake Victoria in Uganda.

Firstly, we looked at the trends in vessel characteristics in the Nile perch fishery based on mode of propulsion, i.e., paddled or motorized vessels. Secondly, fishing strategies were defined to include how the use of gillnets has changed over time in terms of mesh size, set up of the gillnet (adjusting depth), type of material, i.e., monofilament versus multifilament nets, and how changes in gillnet use affected the size and quantity of the Nile perch catch. The resultant adaptive strategies of fishers in the eight-year period were then used to reflect on the policy and livelihood implications of gillnet use in fishing Nile perch on the lake.

In the following sub-section, the paper illustrates the general context of the status of fisheries and a description of gillnet use on Lake Victoria in Uganda. Section 2 describes the data used for the study, the data attributes selected for analysis, and the method used for data analysis. Section 3 presents the study results, Section 4 presents the discussion, and finally the study's conclusions are presented in Section 5.

1.2. Overview of the Lake Victoria Fisheries in Uganda

1.2.1. Background

In Uganda, Lake Victoria lies in the nation's north-western quadrant, covering 31,000 km^2 and a shoreline length of 1750 km. In 2014, the fisheries on the lake contributed more than half (54%) of the 467,000 MT of landings in Uganda. There were about 65,000 fishers, 16,745 boat owners (12% female), and many others involved in fisheries on the lake through trading, processing, transportation, and provision of fishing inputs and regulation [20]. Fishing vessels are locally made and operated using paddles (17,164), outboard engines (10,057), or sails (856). In addition, 162 fishers do not rely on vessels for their operation. Three species dominate commercial catches, including the small pelagic silver cyprinid, locally known as dagaa, *Rastrineobola argentea* (Pellegrin, 1904), Nile perch (*Lates niloticus;* Linnaeus, 1758), and Nile tilapia (*Oreochromis niloticus;* Linnaeus, 1758), all of which serve different markets. Nile perch is processed as chilled and frozen products to Europe, the Far East, the Middle East, the USA, and South America, while Nile tilapia is mainly consumed locally, either fresh or sundried. Dagaa is sundried and utilized as human food and in industrial feed mills as a raw material for production of feeds for poultry, fish, and livestock. The species is consumed locally and also exported regionally to the Democratic Republic of Congo, Kenya, South Sudan, and Rwanda [21–23]. Processing fish for local consumption is largely artisanal involving women mostly [24–26].

The number of fishing vessels targeting each species reflects their economic importance. Out of 28,239 vessels enumerated in 2014, 54% targeted Nile perch, 27% Nile tilapia, 16% dagaa, and 3% other species [20]. Consequently, most management measures on fishing are enforced on the lake mainly to protect the Nile perch, such as a ban on indiscriminate fishing gears and methods such as cast nets, beach seines, poison, <5 inch gillnets, and >9 hook size. Other regulations include licensing, closed seasons, and areas; however, these are seldom enforced [27].

Fisheries management on Lake Victoria has undergone institutional changes. In Uganda, the co-management system was disrupted when the local level Beach Management Units (BMUs) were abolished in November 2015 and replaced by military law enforcement. This was after a reportedly rampant increase in the use of illegal gears on the lake and the failure of BMUs in eliminating illegal fishing [27–29]. Military enforcement on the lake includes eliminating indiscrimanate fishing gears, vessels <28 ft and seine nets > eight panels for the dagaa fisheries. Natural resource management in the country, including in the fisheries, is reportedly structured to favour market values and revenue generation than social values. Therefore the need to protect Nile perch could explain the disbandment of the BMU system in Uganda [28,30,31]. The policy framework in the country relies on the Fish Act cap 197 of 2000 and its amendment in 2011, the Fisheries policy of 2004, and currently the fisheries and aquaculture bill of 2017, which will provide management measures in both capture fisheries and aquaculture.

1.2.2. Gillnets on the Lake

Gillnets were introduced into Lake Victoria fisheries over a century ago due to their catch efficiency, replacing native fishing gears in exploiting the endemic tilapia species *Oreochromis esculentus* [32], which at the time was the most important commercially exploited fish species. However, with increased effort, catches soon declined. Surveys on the major fishing grounds showed a decline from 25 fish per net in 1925 to 5 fish in the late 1930s, which led to the introduction of a minimum mesh size of 5 inches for the fishery [33]. Nile perch was introduced into Lake Victoria in the 1960s, and the 5-inch minimum mesh size regulation was maintained for the developing Nile perch fishery [34] However, the circumstances for adopting the same regulation for the Nile perch were unclear, especially once the native tilapia stocks collapsed [35,36]. In the 1990s, a slot size of 50–<85 cm TL was introduced for commercial catches, aimed at protecting the juvenile and spawning stock of the Nile perch [32,34]. About half of the fishing vessels on the lake in Uganda target Nile perch, primarily using longlines and gillnets. In 2014, gillnets were the dominant fishing gear used by 40% of the fishing vessels, followed by hooks (32%), seine nets (21%), and 7% of vessels used other gear such as basket traps [20]. Boat ownership on the lake varies between species, with large boat owners mainly venturing more into fishing Nile perch than other commercial species. Boat owners in the perch business supply mainly to factories and employ their fishing crew mainly through kinship. Boat owners have a background in fishing or fish trading, and in cases where they own several vessels, they employ a boat manager and crew to fish on their behalf [37–39].

1.2.3. Description of Gillnet Use on the Lake Victoria

A gillnet on Lake Victoria consists of a series of panels, each being about 50 m long depending on the hanging ratio and 26 meshes deep. Panels can be joined, both horizontally to increase the length of the gillnet or vertically to increase the depth [height] of the net [20,40].

A net of one panel deep is recorded as a single panel net. As panels are joined vertically, the nets are recorded as double, triple, and so forth (Figure 1). The overall set is then a gillnet that is either bottom set or set at a certain depth in the water column using anchors like rocks, which must be sufficiently heavy to neutralize the buoyancy of the floats.

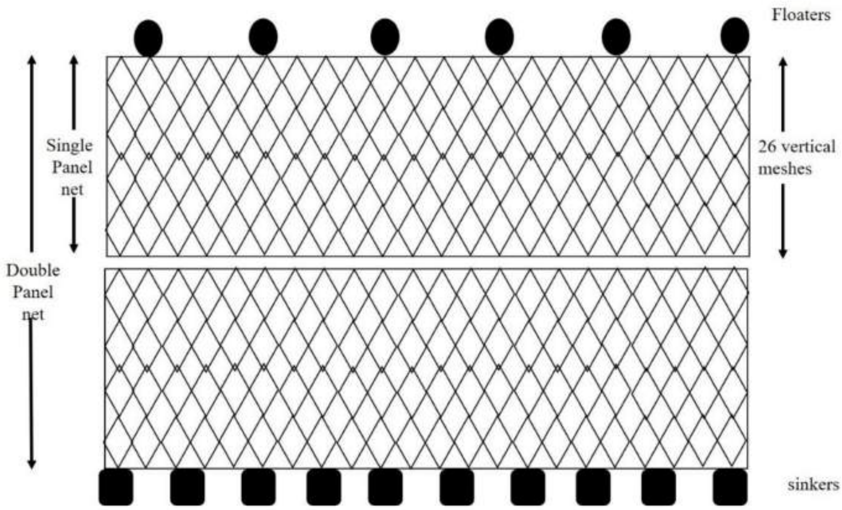

Figure 1. Schematic illustration of a gillnet assemblage. Illustrated from descriptions in [40–42].

Fishers operate their gillnets in three main ways: firstly, through active fishing, where fishers, by beating the water using a heavy hardwood club, scare fish into the net and several hauls are made at different sites in one night. The second method is passive fishing, whereby a gillnet is set at the bottom of the lake, anchored at one site overnight, and the third method is drift fishing, where the net is set either in-surface or mid-waters and allowed to drift with the current throughout the fishing period. Active fishing is illegal and fishers using active fishing are reported to operate in the shallow inshore waters using monofilament nets <5″, which are also illegal [40,41,43]. Drift and set (passive) nets are mainly multifilament. Fishers using these two methods have also been known to connect nets vertically, enabling them to fish up to 50 m deep from the surface to the bottom. Multiple panel nets are mainly used on vessels equipped with outboard engines or sails, which are able to navigate in the coastal and deeper offshore parts of the lake [40,41].

2. Materials and Methods

2.1. Data Collection

Data for the study were selected for vessels using gillnets at 54 landing sites (Figure 2). The Lake Victoria Fisheries Organisation (LVFO) monitors catch rates through periodic frame surveys when a census is made of the number of fishers, and the number, size, and propulsion mode of vessels and gear used. These surveys are termed frame surveys, which are then complemented with catch assessment surveys, where catch data from a sample of individual vessels are collected throughout the year at representative landing sites.

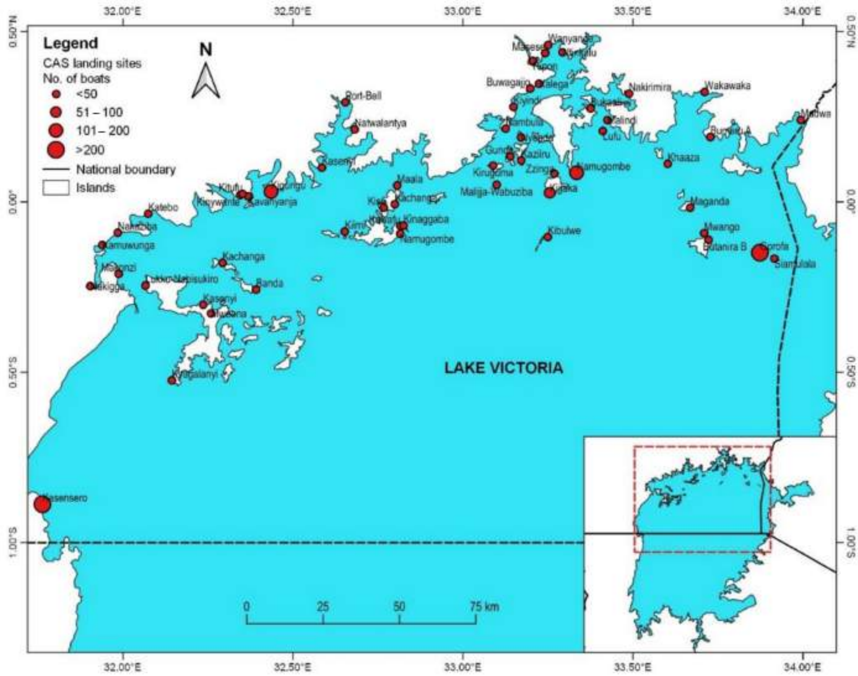

Figure 2. Distribution and number of gillnet vessels targeting Nile perch at landing sites included in catch assessment surveys on Lake Victoria, Uganda. Data from LVFO Catch assessment survey.

In this study, data were sourced from six frame surveys conducted every second year from 2004 to 2014. Catch assessment surveys were conducted at 54 landing sites in eight years, 2005–2008, 2010–2011, and 2014–2015. Both datasets were collected by trained enumerators and based on the Lake Victoria Fisheries Organisation (LVFO) harmonized Standard Operating Procedures and data forms [44].

From the frame survey, we selected two key vessel variables: mode of propulsion (paddled, motorized, or sailed) and target species. From the catch assessment survey, we selected gillnet vessels targeting Nile perch and data relating to effort and catch. These included the following:

(i) vessel-specific characteristics, such as vessel length and mode of propulsion;
(ii) gear specific information i.e., gillnet type [monofilament or multifilament], mode of operation [active, drift or stationary], mesh size, number of panels, and if panels were vertically joined;
(iii) hours fished and catch specific information, such as the number of Nile perch caught and the total weight of the catch.

From the resulting set of data, we selected trips that operated with gillnets of only one mesh size (e.g, only 6 or 7 inches). This was done to eliminate any bias due to the uncertainty of identifying which mesh was used to capture fish at the time of sampling. Outliers and missing information rows were removed from the dataset. The final dataset comprised 14,630 trip records for eight years in the period 2005 to 2015.

2.2. Data Analysis

To analyse the data, we employed the trend analysis recommended in [45], and applied to compare catches between the recreational and commercial fishermen on Lake Annecy in France [46]. The trend analysis is based on a time series of catch, effort, and the catch per unit effort (CPUE) of the focal fishery. The catch and effort variables collected from the independent cross-sectional surveys in the eight-year period were merged to form time-series data to be used for further analysis. The selected variables were repeatedly sampled in the specified period, and this allows for the assessment and interpretation of effort in relation to catch trends and vice versa.

In the first stage of the analysis, we identified variables that would adequately describe operational differences (and later strategies) among the gillnet fishing vessels. These are specified in 2.1 above. Variables concerning general vessel characteristics were selected from the frame survey data, and gear characteristics, fish catch, hours fished, and vessel length were obtained from the catch assessment data.

In the second stage, two proxy variables were calculated—the average weight of fish landed, calculated as the recorded total weight of the catch divided by the number of fish, and illustration of CPUE (per kg and number of fish) using the number of gillnet panels and hours fished as measures of effort.

Lastly, interpretation of the trends was presented in graphs and tables, where changes in effort, catch and CPUE were used to explain the changing patterns of exploitation in the fishery.

Statistical analysis and graphical displays were performed using R software [47]. We compared the mean between variables i.e., mesh size and numbers of vertical panels versus fish size. The mean differences were tested using Analysis of Variance (ANOVA) and the level of significance (p values) denoted as; **** = <0.001, *** = 0.001, ** = 0.01, * = 0.05, not significant = >0.05.

3. Results

3.1. Vessel Characteristics on Lake Victoria in Uganda

Fishers on the lake operate their vessels using two dominant modes of propulsion, paddles, and outboard engines, while few operate using sails (Figure 3a). From 2004 to 2014, the number of motorized vessels more than trebled from around 3000 to over 10,000. The number of paddled vessels, on the other hand, increased by 40% between 2004 and 2006, but their numbers remained relatively constant for the rest of the study period. The number of sailed vessels was relatively low, with about 1000 vessels recorded with no significant changes over time.

Motorized vessels predominantly targeted Nile perch (>80%) throughout the study period, although the proportion of motorized dagaa vessels increased from 6% to 18% over the period 2010 to 2014 (Figure 3b). Paddled vessels targeted tilapia and Nile perch in almost equal proportions, with no significant changes in the number of vessels per target species from 2010 to 2014. The average length of a motorized vessel was approximately 10 m, about 4 m longer than a paddled vessel. Vessel length remained constant for both groups of vessels throughout the period of study (Appendix A, Table A1). Nile perch vessels dominate in the fishery and thus were considered for further analysis.

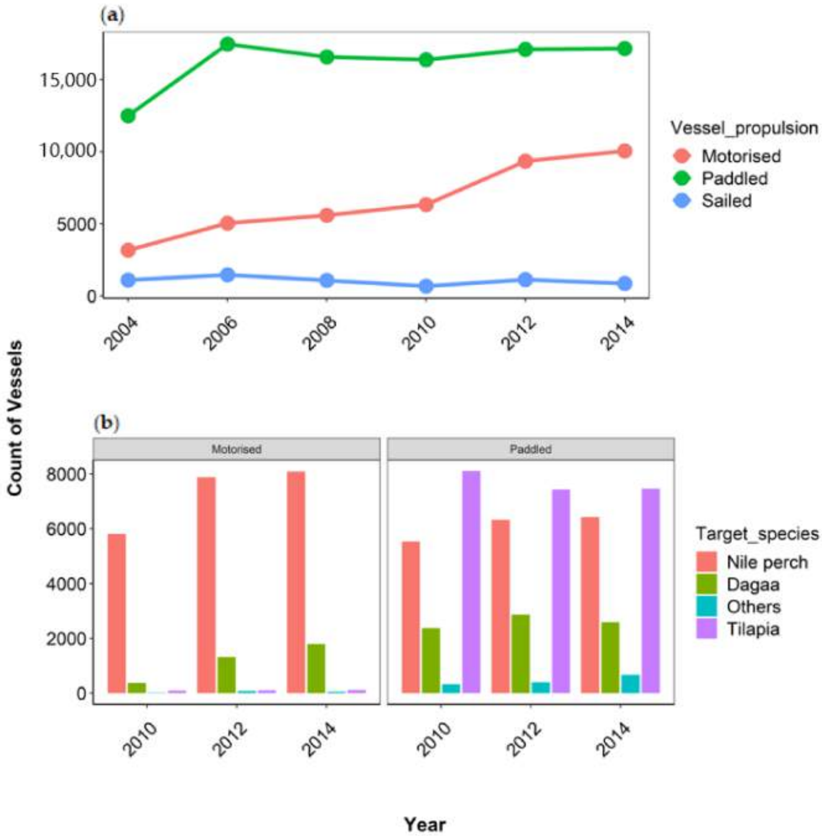

Figure 3. Fishing vessel characteristics (**a**) total count of vessels on Lake Victoria Uganda grouped by mode of propulsion; (**b**) vessel count by mode of propulsion per target species (data only available from 2010 onwards). LVFO Frame survey data.

3.2. Gillnet Use in the Nile Perch Fishery

Motorized vessels used mesh sizes up to 8″ and only rarely <4″ with the modal mesh sizes between 5″ and 6″. The use of nets >6″ became less common over time. Paddled vessels in all years used a much wider range of mesh sizes, from 2.5″–8″. With time, two modes of mesh size used become apparent in the paddled fleet, a larger mode at 2.5″–3.5″ and a smaller mode at 5–6″ (Figure 4).

At the beginning of the study period, both vessel groups predominantly (>90%) used multifilament gillnets. However, from 2010, an increase in the proportion of the monofilament gillnets was evident for the paddled vessels, rising from 16% in 2011 to 42% in 2015 as paddled operators were increasingly using smaller meshes (Appendix A, Table A1, Figure 4). Motorized vessels, on the other hand, maintained the use of multifilament gillnets and maintained the modal mesh size of 6″. The use of monofilament gillnets was dominant in mesh sizes <6″ (Appendix A, Figure A1).

More than half of the paddled vessels operated using passive [stationery] set gillnets, followed by drift nets, however, in 2014–2015, there was a decline in fishers using drift nets. Motorized vessels primarily used drift and passively set gillnets, though, by 2015, sampled vessels using drift nets declined (39%) and were exceeded by those using passive nets (61%) (Appendix A, Table A1).

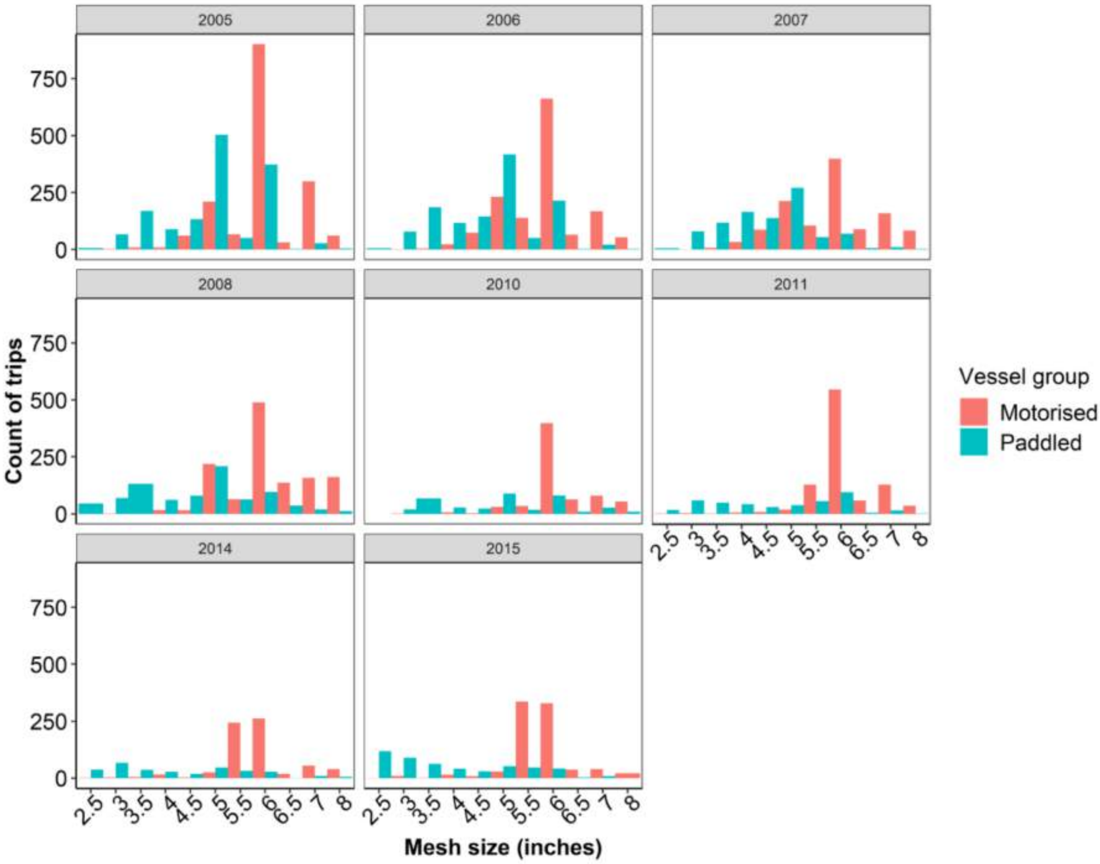

Figure 4. Gillnet meshes size distribution between motorized and paddled vessels over the study period. LVFO Catch assessment survey data.

Gillnets are made from panels of a standard dimension, but different mesh sizes. Motorized vessels, on average, used 60 panels while paddled vessels used 40 panels (Figure 5a). No increase in the number of panels per gillnet was observed throughout the study period for either vessel group, however, fishers were observed to alter the depth of the gillnets. Motorized vessels predominantly (>80%) used double vertical panel gillnets in 2005 and shifted to triple vertical panel gillnets in 2015. Paddled vessels, on the other hand, were observed to fish using both the single vertical and double vertical panel gillnets in the first four years of the study, but, a gradual shift to the use of single vertical panel gillnets occurred, with these constituting >80% of the sampled vessels in 2015 (Figure 5b).

The median mesh size between panels was significantly ($p < 0.05$) different as the number of gillnet panels increased with mesh size (Figure 6). Single panel nets had a wide range of mesh sizes from 2.5″ to 7″, double panel nets varied between 3.5″ to 7″, while the triple and quadruple nets were comprised of a narrow range of mesh sizes mainly >5″ to 8″ and 6″ to 7″, respectively.

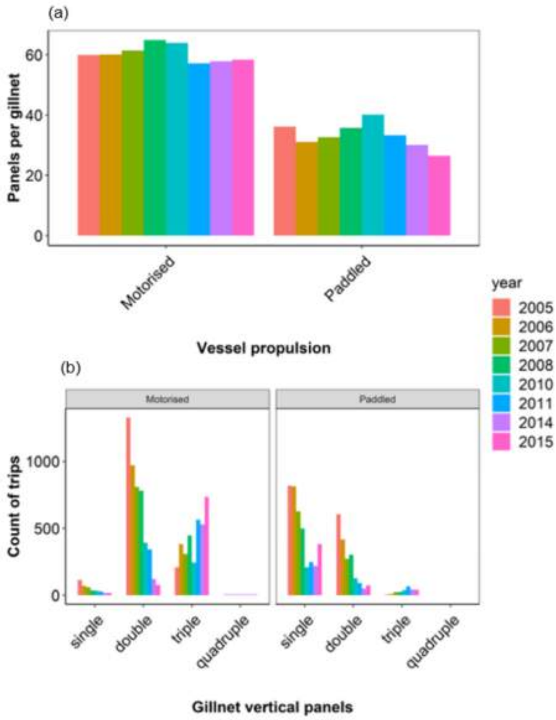

Figure 5. (**a**) Average number of panels per gillnet, irrespective of either vertical or horizontal joining (**b**) modal distribution of gillnet panel vertical joining for the motorized and paddled vessels. The latter is specified in the CAS survey data. LVFO Catch assessment survey data.

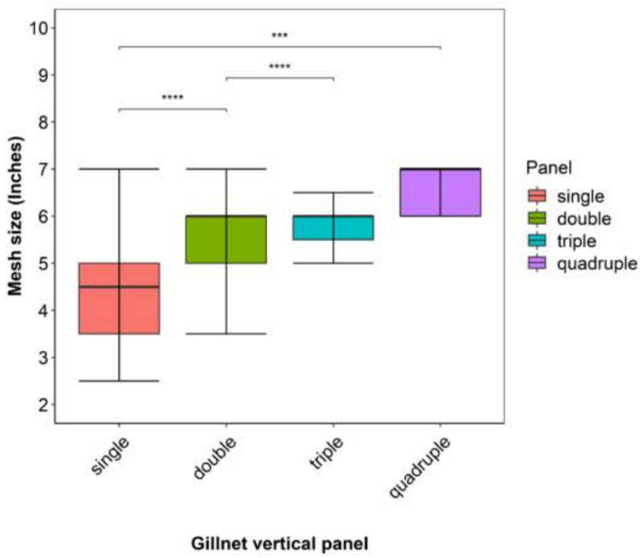

Figure 6. Relationship between the number of gillnet panels and mesh sizes. Mean difference between gillnet panels and mesh size tested using ANOVA significant level at $p < 0.05$.

3.3. Fish Catches

The average weight of fish harvested increased with increased mesh size (p value < 0.05), although the variation in average weight of individuals caught also increased with increasing mesh size. Fish sizes harvested with the 7- and 8-inch nets varied widely, with the largest average fish sizes of about 6 kg and 9 kg, respectively. The average catch per trip increased with mesh size, with vessels using 2.5″–4″ nets on average harvesting about 15 kg per trip. Those using 4.5″–5.5″ harvested on average around 20 kg, while the increase is greatest for the two largest mesh sizes, with about 25 kg in 7″ nets and 35 kg in 8″ nets (Figure 7b).

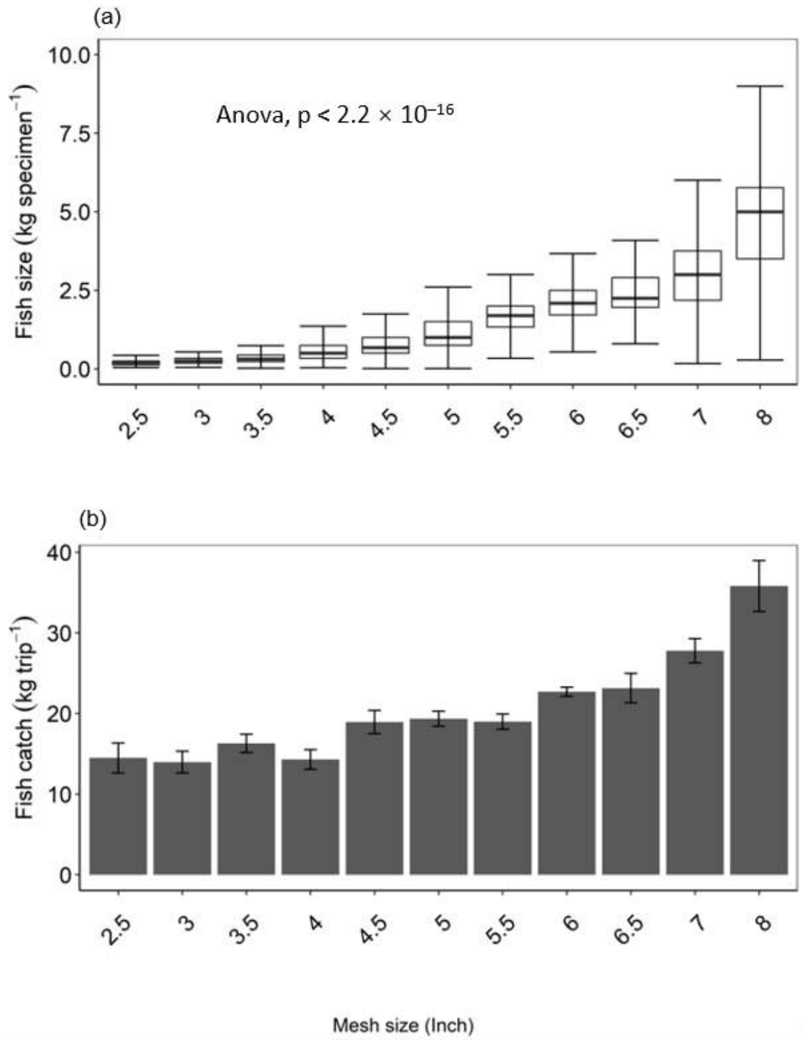

Figure 7. Fish catches (**a**) the average fish size (kg specimen^{-1}) per mesh size, comparison of mean size of fish between mesh sizes performed using Analysis of Variance (ANOVA) and (**b**) fish catch (kg trip^{-1}) in the different mesh sizes indicated with mean catch and ± standard error.

The average weight of individual fish caught increased significantly and differed (p < 0.05) from one to two and from two to three-panel gillnets (Figure 8). The average fish size in triple and quadruple gillnet panels was not significantly different (p > 0.05). Single panelled nets harvested fish sizes <2.5 kg, while the fish sizes in double panel gillnets varied most among all panels, with average fish sizes of up to 4.5 kg harvested.

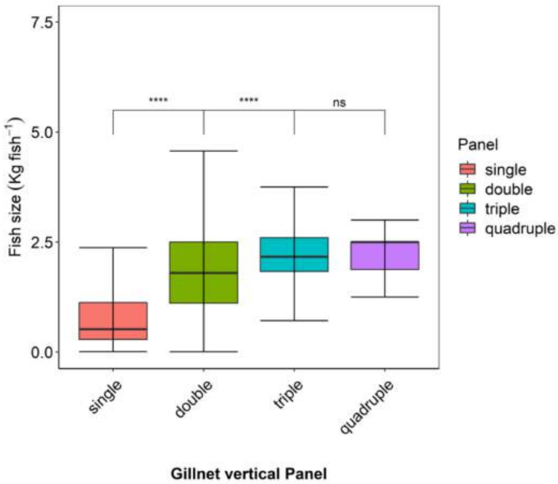

Figure 8. Relationship between gillnet panel and fish size. Mean difference between gillnet panels and fish size tested using ANOVA, significant level at $p < 0.05$.

From 2005 to 2007, there was a wide range of Nile perch weight harvested by motorized vessels, with modal weights observed at 1 kg, 2 kg, and 3 kg, however, from 2011 to 2015, the modal average fish size harvested by this vessel group was maintained at about 2 kg (Figure 9a).

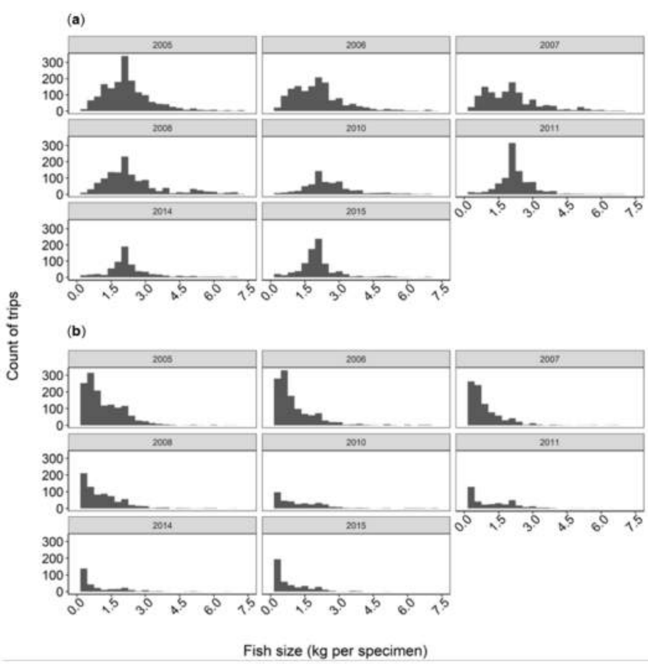

Figure 9. Frequency distribution of the estimated average size of Nile perch in commercial catches between (**a**) Motorized fishing vessels and (**b**) paddled fishing vessels in the survey period.

Paddled vessels also caught a wide size range of Nile perch at the beginning of the study period, with the modal weights of about 1 and 2 kg. However, this is followed by a gradual decline over time, as the overall distribution became narrower, and by 2015 the modal average fish size was <1 kg (Figure 9b).

Fish catch per trip and hours fished was higher in motorized vessels than paddled vessels. Catches for both vessel groups show the same trend, though this fluctuated until 2010, followed by a continuous decline, especially for the motorized fishing vessels (Figure 10). By 2015, catch per trip and catch per hour reduced to almost half from about 30 kg per trip and approximately 4 kg per hour at the beginning of the study to less than 20 kg per trip and 2 kg per hour in 2015, respectively. The catch per trip and hours fished in paddled vessels, on the other hand, fluctuated throughout the study period, ranging between 10 to 15 kg per trip and 1.5 to 2 kg per hour, respectively.

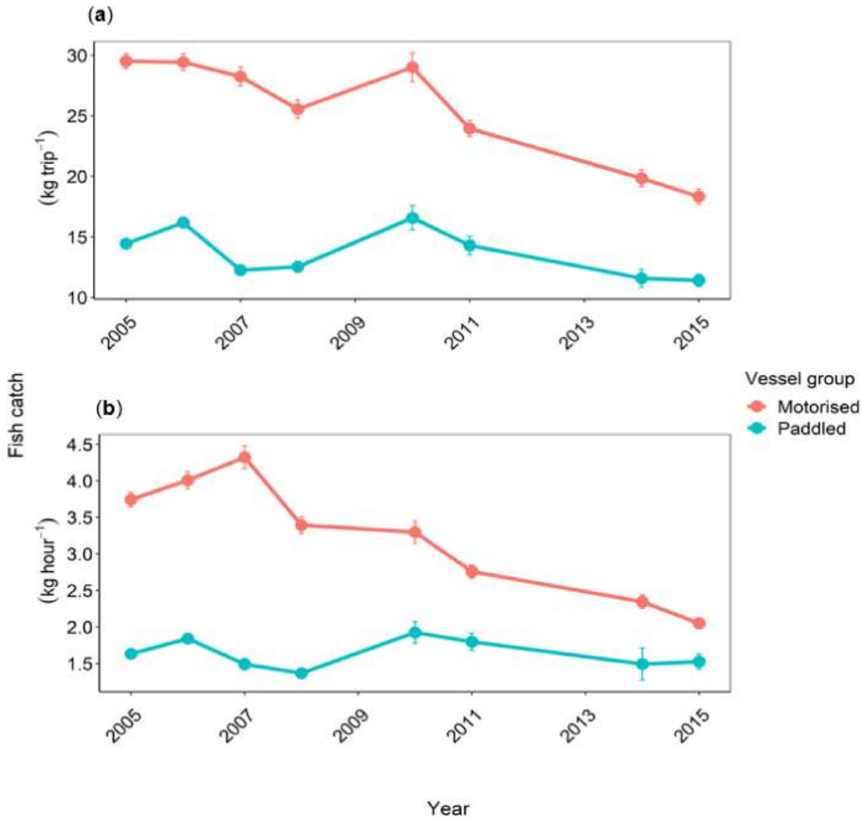

Figure 10. Fish catch in terms of (**a**) kg per trip and (**b**) kg per hour fished in motorized and paddled vessels for the study period 2005–2006; 2010–2011 and 2014–2015. Mean catches per vessel are represented as mean and standard error.

Similar to the catches depicted in Figure 10 above, the CPUE kg per panel hours fished fluctuated for both vessel groups between 2005 to 2010. For motorized vessels, there was then continuous decline until 2015, when the vessels' CPUE was <3 kg per panel compared to about 4.5 kg at the beginning of the study period. In contrast, the CPUE for paddled vessels stabilized at 4 kg per panel hours fished (Figure 11a). Motorized fishing vessels harvested about 3 fish per panel hour fished throughout the study period, with the number of specimens harvested per panel for the paddled vessel increasing gradually; in 2005, each panel of the gillnet captured about 5 fish, and by 2015 vessels harvested about 15 Nile perch specimen per panel (Figure 11b).

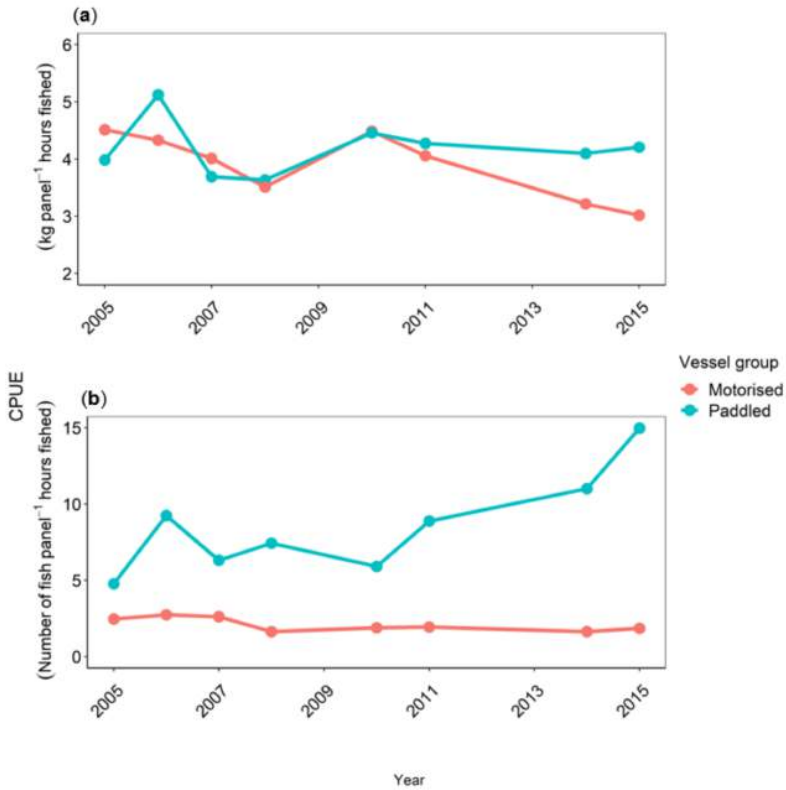

Figure 11. CPUE per panel hours fished (**a**) measured as the catch per panel and (**b**) number of fish per panel.

4. Discussion

4.1. Gillnet Use and Adaptive Fishing Strategies

To improve the understanding of fisher adaptive strategies in the gillnet Nile perch fishery, we analyzed the trends of selected effort and catch indicators to evaluate changes in the fisher's exploitation environment. Evaluation of catch and effort statistics can help fisheries' policies to become more consistent, acknowledging the diversity of fishing practices and identifying appropriate points of intervention, especially the formation of policies aimed at reducing fishing effort or even improving adaptive capacity within the fishing communities [45,48]. In the study, we identify fisher adaptive responses (changes in gillnet use) as a result of changes in the population structure and abundance (catches) of Nile perch in Lake Victoria. The comparison made between vessel groups in the study, i.e., motorized and paddled, was derived from earlier studies indicating spatial differences, with the motorized vessels mainly operating in the offshore and coastal areas of the lake, while the latter operate largely inshore [23,41]. The operational differences between the two vessel groups in the Nile perch gillnet fishery further reinforce the distinction between artisanal and commercial SSF [27,49]. Artisanal Nile perch fishers target fish sold to local and regional markets; here the fish is sold fresh, smoked, or deep fried, while commercial fishers target Nile perch purposely for the fish factories who process Nile perch as fillets destined for the export market [21–23]. Other distinctions include boat/vessel ownership. Owners of paddled vessels engage in fishing themselves, while owners of motorized vessels mostly employ their fishing crew. Irrespective, both are considered as fishers in this study, which assumes that a fishing strategy is a collective effort and the owners of motorized vessel are experienced fishers [38].

For the two vessel groups, fishers over time adapted their fishing operations according to resource constraints, i.e., their ability to harvest large fish or small Nile perch, and also as a result of opportunities availed to them to maximise their objectives. Operations of the motorized and paddled vessel groups reflect the dynamics behind the commercial gillnet fishery, which target the export market, and the artisanal fishers who focus on local and regional markets [22,38,49]. These are further described as follows.

4.1.1. Paddled Vessels

During the first four years of the study, gillnet use among the paddled fishers was diversified as some fishers employed larger mesh sizes, double vertical panels, and multifilament gillnets, characteristics observed in the motorized (commercial) fleet. However, over time, the fishers switched their gillnet use to smaller meshes and dominantly adapted to single vertical panels. The rationale for this development is two-fold. Firstly, it represented a resource opportunity based on the abundant stock of juvenile Nile perch; secondly, there was a constraint, with an inability to raise sufficient capital to compete with the motorized vessel group.

Generally, the status of Nile perch fish stocks (resource health) on Lake Victoria have been widely studied, with mixed opinions on abundance. Some argue that they are overfished [50–52] and some that they are not overfished [4,53]. Nile perch biomass estimates in the hydroacoustic surveys conducted in this period indicated that the population structure of Nile perch was by 2015 dominated (>90%) by small-sized Nile perch (<10 cm TL) found in shallow inshore areas [54]. In the study, paddled vessels switched to smaller meshes and changed depth of their gillnets and were able to maintain their fish catch and also increase the number of fish per panel (Figure 11). The strategy to target smaller fishes by the paddled vessels signifies an opportunity response of utilizing the abundant stock of the population to remain in the fishery. Paddled vessels operate mainly in inshore areas and also target Nile tilapia (Figure 3b), whose distribution is mostly areas that are < 10 m deep [52,55]). Juvenile Nile perch and Nile tilapia have a high market demand in the local and regional markets in the DRC and South Sudan, markets that provide an opportunity for fishers to maintain their livelihood [21,22].

It is also worth noting that the use of small mesh sizes (<5″) and monofilament nets is prohibited on the lake: however, enforcement of regulations was challenging, with the co-management system providing a comparative advantage for paddled fishers to shift strategy [39,56]. In terms of capital constraints, an average artisanal fisher, due to his largely intensive fishing methods and limited capital, can scarcely afford to match the efficiency of larger vessels, more nets, and an out board engine [38,57].

4.1.2. Motorized Vessels

A rapid increase in vessel motorization was observed since 2004 (Figure 3a), and this was particularly evident for the Nile perch fleet (Figure 3b), indicating a technological intensification in response to available resources and market opportunities [58]. Fishing pressure can directly affect a target species' population; however, changes in market prices, management regulations and environmental and socio-economic conditions also generate synergies that affect fishing pressure over time, impacting the availability of resources [12,14,59]. In Uganda, the need for economic growth in terms of foreign exchange revenue is a major driver of resource exploitation.

Nile perch products are the major (>90%) fish exports in Uganda, thus fishers in this vessel group equip themselves to harvest for the export market. This is observed in the study as these fishersmaintained mesh size, used multifilament gillnets, and used double and triple panels of their gillnet, and on average caught 2 kg Nile perch throughout the study period. A development in the fishing strategy in this vessel group was observed, with the shift of gillnet panels from two to three vertical panels in the second half of the study (Figure 5). The increase in vertical panels is directly related to an increase in fishing depth and could be attributed to the increased competition in the fishery and a need to search for new fishing grounds. Large sized Nile perch (>40 cm TL) are mainly located in the deeper parts of the lake. Notwithstanding this, the size structure of large Nile perch in biomass estimates in that period reflected a small proportion of this population [55,60,61]. Salas et al., 2004 indicates that fishers tend to shift strategies if they perceive an increase in uncertainity in their catches and profits, especially when competition increases.

It is important to note that the development of the commercial Nile perch industry has existed for about 4 decades since the 1980s and this has been exacerbated by international market demand of white fish and donor-driven improvement in fish processing and exporting policies in the country [37,62]. In 2006, the factories established self-regulating policies, which included processing only of fish 50–85 cm to suit the demands of international markets. This meant that factory agents were only permitted to purchase fish sizes of 50–85 cm total length [37,62]. In a study of the Nile perch value chain, Bagumire et al., (2018) indicates that in the first stage of the value chain, at the beach, fish of processable quality and allowable slot-size is sold directly to factory agents, whilst poor quality fish and fish below and beyond the allowable size are then sold to the local traders. The allowable fish slot sizes of 50–85 cm correspond to about 2–10 kg fish from fish sampled in other commercial vessels [63,64], which also coincides with the modal fish size of the motorized fishers in this study. Fishers have mastered strategies, and with the use of triple panel gillnets, they were able to obtain fish sizes within this range (Figure 8). Besides, currently in Uganda and Lake Victoria, there is an emerging fish maw industry, where the value of the fish maw increases with the size of the Nile perch. Nile perch beyond the factory allowable size limit >85 cm TL are targeted for the fish maws and their price per kg (50 USD) is 10 times more than that of fish fillets (5 USD) [64]. Unregulated fishing of large fish sizes threatens the population of the spawning stock.

4.2. Effects of Strategies on Catch and CPUE

CPUE is a basic fisheries science measure used as the first-order evaluation of broad trends in the likely relative abundance or biomass of underlying fish stocks over time [7,65]. However, it is important to note that catches and CPUE are a resultant effect of the fishing strategies to maintain catches. Paddled vessels switched to smaller mesh sizes and single vertical panels to maintain their catch, while the motorized vessels aimed at maintaining a particular fish size by increasing the depth of the gillnet.

In terms of catches, the abundance of the small-sized fish enabled paddled vessels to maintain their catches over time while a decline was observed for the motorized vessels. By 2015, about half of the 20 fishing factories in Uganda had closed and those still in the business operated below their capacity due to the inadequate supply of fish [36]. The observed decline in the catches of the motorized vessels had a direct effect on the factories. The shift in fishing strategy from double to triple panels is also indicative of the measures the fishers devised to maintain their catch and supply the factories. CPUE as a measure of abundance assumes that changes in catch rates directly reflect the abundance and disregard the development of productivity due to improvements in technology or any changes in fishers' behavior [45]. The fishers here were endogenously reacting to changes in the environment by changing their strategy on how they set their nets, and such responses in the future could greatly affect subsequent CPUE interpretations.

Individual fishermen will invest in new vessels, technology or methods of fishing if they will make more money by doing so or even fish illegally when it is profitable [14,16,66]. In the case of the Nile perch gillnet fishery, the motorized group is an example of increased investment and effort, while the paddled vessel group have resorted to illegal methods; however, both groups are reacting to changes in the size structure of Nile perch, leading possibly in both cases to negative resource impacts. Hydroacoustic surveys conducted in the period 2005–2015 indicated that Nile perch biomass estimates on the lake increased from about 500,000 MT in 2007 and more than doubled by 2015 [61]. Even if the total biomass of Nile perch appears to have increased, the absolute number of larger perch (>50 cm TL) decreased over the same period and constituted less than 5% of the total biomass, reflecting the resultant catch for the two vessel groups in this study. The strategy of the commercial fishers leads to the progressive harvest of larger individuals (spawning stock) while the artisanal fishers increase the fishing mortality of juvenile fish stocks [67,68]. Consequently, the paddled vessels have been a targeted group in enforcing fishery regulations in Uganda [27]. In terms of fisheries management, it is important to note that the regulations (e.g., mesh sizes) support the existence of the commercial export-oriented fishery, whose benefits are squandered if fish are instead sold to local markets and food chains [3,10,14,59]. Besides, the question of whether reduced fish catches on Lake Victoria are caused by illegal gears or reduced catch leads to the use of illegal gears could probably be explained by understanding the dynamics of fisher strategies on the Lake [23,36,52,53]. The impact on the fishery resource due to the collective effort of fishers adapting to operational strategies to maintain their fishery objective is an element that is seldom considered in fisheries management on Lake Victoria. Most fishers on the lake depend on the fisheries with limited alternative livelihood options available, necessitating adaptive strategies to fishing [22,27]. The sustenance of the fishery benefits to the fishing communities should be the goal of fisheries management.

Sustainable fisheries management must address the need to maintain and improve the economic, social, and ecological benefits of a fishery [8–10]. In the case of the Nile perch fishery, the fundamental question should be what the objective of fisheries management is, and why and how the stated objective can be achieved. The type of management system greatly influences the performance and overall sustainability of the fishery [7,69].

5. Conclusions

The study evaluates the adaptive strategies of Nile perch gillnet fishers on Lake Victoria, using 8-year data over the periods 2005–2007, 2010–2011, and 2014–2015. We note that the gillnet Nile perch fishery evolved over this period, with two fishing strategies evident on the lake. The artisanal fishers on paddled vessels adopted a safe strategy of harvesting the large numbers of juvenile Nile perch over time, mostly for local or regional markets, and the small-scale commercial gillnet fishers deployed motorized vessels, specializing their fishing effort to target larger fish purposely for the export market.

The use of catch and effort data in the study provides a means of understanding fisher behavior and its impact. It should also be noted that the study considers fishers as key decision makers; however, their behavior could be dependent on the vessel owners, especially for the larger vessels. Irrespective of whether it is the decision of the crew or the vessel owner, both aim to maximize the benefits from the fishery.

It is important to acknowledge that the Nile perch fishery is a source of livelihood to over 30,000 (50%) fishers on lake Victoria in Uganda and many fishing communities on the shores of the Lake are involved in its value chain [20]. Therefore, any negative effects on the Nile perch fish stocks directly affect the livelihoods of these fishers, their dependents, and everyone involved in the value chain.

The strategies used by both motorized and paddled fishers on Lake Victoria have driving factors that can mostly be attributed to the economic value of the Nile perch. Based on the fisheries' legal and policy framework, motorized vessels in the study fish legally ($\geq 5''$ mesh size multifilament), while paddled vessels fish illegally ($<5''$ mesh size, monofilament) [70]. Managing the lake's fishing effort, however, should offer a balanced view of not only eliminating illegal fishers but also managing the capacity of legal ones and what drives changes in the strategies employed by the two groups. The key to maintaining or improving the biological health of fish stocks necessitates studying and restricting fisher behaviour, which is expected to reduce profitability in the short run but improve profits in the long run [10,14]. The expansion of motorized fishing leads to competition, and increasing the depth of the gillnet indicates a strategy that reflects the need for short-term profit margins at the expense of sustaining the Nile perch stocks.

It is important for fishery managers to understand the changes in fisher strategies as these provide important insights for envisioning fishers responses to other factors, such as management measures and resource uncertainities. Additionally, it is important to consider that people (fishers) are an integral part of the fishery ecosystem. Considering their behavior in management decisions will aid in devising adaptive policies to fishery conditions for sustainable resource use, as well as ensuring the livelihood development of the fishers' communities.

Author Contributions: Conceptualization, V.M., H.N., A.T.-M. and D.M.K.; methodology, D.M.K. and V.M.; validation, D.M.K., T.T. and J.G.P.; formal analysis, V.M.; investigation, V.M.; data curation, V.M. and H.N.; writing—original draft preparation, V.M.; writing—review and editing, D.M.K., T.T., A.T.-M., H.N. and J.G.P.; visualization, V.M.; supervision, D.M.K., T.T., A.T.-M. and J.G.P. All authors have read and agreed to the published version of the manuscript.

Funding: The data provided in this paper accrued from Catch Assessment and Frame surveys conducted under the Implementation of a Fisheries Management Plan (IFMP) project for Lake Victoria and the Lake Victoria Environmental Management Plan II (LVEMP II), both funded by the EU through NaFIRRI and the LVFO. Article written under a PhD scholarship from the UNESCO affiliated GRO-Fisheries Training Programme in Iceland.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data for the study will be available upon request from the author.

Acknowledgments: All staff at National Fisheries Resources Research Institute, Directorate of Fisheries Resources and Lake Victoria Fisheries Organization that contributed to the collection and collation of data used in the study are hereby acknowledged. The article benefited from comments of two anonymous reviewers and language review by David Cook of the University of Iceland, much appreciated.

Conflicts of Interest: The authors declare no conflict of interest.

Appendix A

Table A1. Trend of vessel length and gillnet construction code for the paddled and motorized vessel groups.

Vessel Group	Variable	Description /Measure	Survey Years							
			2005	2006	2007	2008	2010	2011	2014	2015
Motorized	Vessel length	meters	9.81	10.03	9.99	10.00	10.24	9.72	10.11	10.03
	Gillnet construction code	Monofilament	2 (0.2%)	27 (2%)	62 (5%)	4 (0.6%)	0 (0%)	3 (0.3%)	5 (0.7%)	11 (1.3%)
		Multifilament	1649 (99.8%)	1396 (98%)	1115 (95%)	1258 (99.6%)	671 (100%)	932 (99.7%)	668 (99.3%)	819 (98.7%)
	Gillnet operation code	Active	5 (0.3%)	10 (0.7%)	2 (0.3%)	3 (0.2%)	0 (0.0%)	27 (3.1%)	3 (0.4%)	2 (0.2%)
		Drift	8634 (49.1%)	778 (56.0%)	697 (59.5%)	719 (56.8%)	323 (47.0%)	537 (56.9%)	367(54.7%)	322 (38.7%)
		Passive	812 (50.6%)	635 (43.3%)	478 (40.2%)	540 (42.9%)	348(53.0%)	371 (40.1%)	303 (44.9%)	506 (61.1%)
	Sample size	Sub-total	1651	1423	1177	1262	671	935	673	830
Paddled	Vessel length	meters	6.69	6.58	6.44	6.48	6.73	6.80	6.58	5.91
	Gillnet construction code	Monofilament	21 (2.1%)	138 (11.3%)	139 (15.6%)	25 (3.1%)	23 (7.1%)	65 (16.1%)	107 (35.2%)	211 (42.4%)
		Multifilament	408 (97.9%)	1103 (88.7%)	783 (84.4%)	800 (96.9%)	351 (92.9%)	343 (83.9%)	204 (64.8%)	287 (57.6%)
	Gillnet operation code	Active	121 (8.7%)	184 (14.9%)	144 (15.5%)	100 (12.0%)	31 (9.2%)	46 (11.0%)	40 (13.2%)	86 (17.3%)
		Drift	439 (28.9%)	313 (24.2%)	252 (26.6%)	178 (21.4%)	105 (27.0%)	110 (26.4%)	57 (17.9%)	63 (12.5%)
		Passive	869 (62.5%)	744 (61.9%)	526 (57.9%)	547 (67.6%)	238 (64.4%)	255 (64.3%)	214 (68.9%)	349 (70.1%)
	Sample size	Sub-total	1429	1241	922	825	374	408	311	498
	Total trips sampled		3080	2664	2099	2087	1045	1343	984	1328

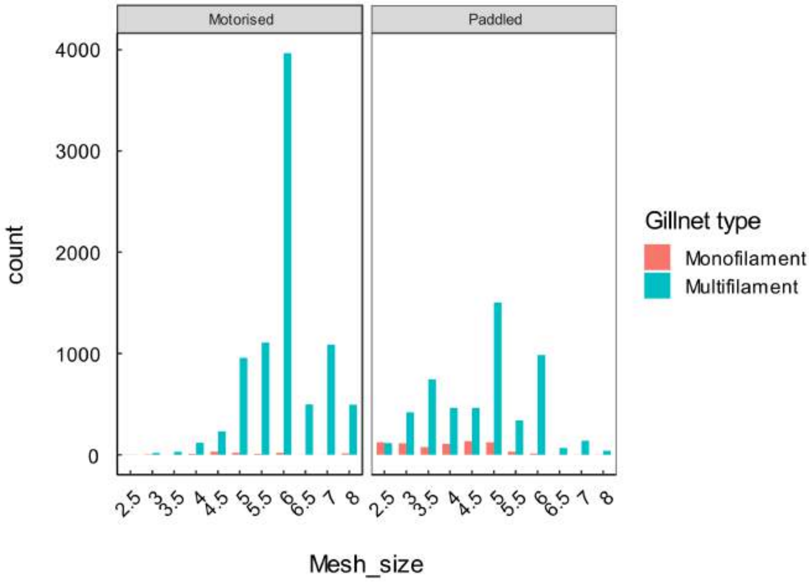

Figure A1. Gillnet construction type across mesh sizes for the paddled and motorized vessel groups.

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Paper IV

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From Co-Operation to Coercion in Fisheries Management: The Effects of Military Intervention on the Nile Perch Fishery on Lake Victoria in Uganda

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Abstract: In 2017, Uganda's small-scale inland fisheries underwent a significant transformation, shifting from local co-management to state military enforcement owing to ineffective enforcement of regulations and declining exports. Employing a mixed-methods approach and blending qualitative and quantitative data, we assessed the impact of military intervention on Lake Victoria's Nile perch fishery, focusing on fishing effort, catch, and exports. Our findings indicate that military operations adhered to regulations, gaining primary support from key stakeholders, specifically motorized fishing operators. Consequently, between 2016 and 2020, legal fishing activities experienced substantial growth. By 2021, approximately 90% of Nile perch catches were made by motorized vessels using longlines and gillnets, despite a declining trend in catch-per-unit effort. Between 2015 and 2021, the Nile perch fishery saw changes: boat seines made up about 5% of motorized fleet catches in 2021, while catches in paddled vessels increased from 20% to over 50%, suggesting a potential role in the growing longline fishery. Therefore, the current management approach does not increase catches or exports compared with the co-management period. The observed decline in catch-per-unit effort among motorized gillnets suggests overcapacity. Further research is needed to comprehend the broader sociological and ecological impacts of the present enforcement strategy for sustainable fishery management.

Keywords: rule compliance; law enforcement; fisheries management; Nile perch; Lake Victoria; Uganda

Key Contribution: This study assesses the effectiveness of military enforcement of fishery management rules in improving fishery performance and outcomes in the Ugandan part of Lake Victoria, replacing the existing co-management approach. However, this military enforcement approach did not result in increased catches or exports compared with the co-management period. The observed decline in catch-per-unit effort among motorized gillnets suggests overcapacity. Further research is needed to fully understand the broader sociological and ecological impacts of the current enforcement strategy for achieving sustainable fishery management.

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Citation: Mpomwenda, V.; Tómasson, T.; Pétursson, J.G.; Kristófersson, D.M. From Co-Operation to Coercion in Fisheries Management: The Effects of Military Intervention on the Nile Perch Fishery on Lake Victoria in Uganda. *Fishes* **2023**, *8*, 563. https://doi.org/10.3390/fishes8110563

Academic Editor: Ben Drakeford

Received: 3 October 2023
Revised: 15 November 2023
Accepted: 16 November 2023
Published: 20 November 2023

1. Introduction

African small-scale inland fisheries are in transition. Fisheries co-management as a cooperative instrument to secure sustainable fisheries has not proven as successful as hoped, and some African countries have been exploring more coercive enforcement measures to ensure rule compliance and regulate access in their inland fisheries, which have traditionally been open access [1–4].

Further, there is an increased emphasis on export-oriented, commercial fisheries and less focus on artisanal fisheries as a source of local livelihoods [5–8]. These two policy directions are often mutually exclusive and have important political and economic implications [9]. This is amplified by the growing and globally integrated African national economies that impact both fisheries and other natural resource sectors [10]. Other common-pool natural resources on the continent, such as forestry and wildlife, have also seen a drive from cooperation towards more high-handed, coercive approaches to enforce rule compliance [11,12]. This has resulted in multiple paramilitary approaches and, in more extreme cases, the deployment of full-scale military operations.

Uganda conducted an interesting study of such a transition in small-scale inland fisheries. In November 2015, bold reforms were introduced to fishery management. Local-level fisheries co-management systems, the Beach Management Units (BMUs), were dissolved through a presidential directive, as well as the military, in the form of the Fisheries Protection Unit (FPU). This was installed to enforce rule compliance on Ugandan lakes, including the territorial waters of Lake Victoria [13]. The suspension of local-level BMUs was due to the alleged prevalence of mismanagement under the BMUs, resulting in widespread illegal fishing, bribery, and corruption [13,14]. Fishery landing site committees were established to enforce fishery regulations alongside the military, contrary to the mandate of the co-management structure, disrupting the involvement of government officials, such as district and sub-county officers who had earlier been involved in the co-management structure [13,15,16]. An extensive military operation commenced in Lake Victoria in February 2017 and is still being implemented in 2022. When the FPU was established, it aimed to eliminate all forms of illegal fishing gear and practices in the hope of reversing the trend of declining catches and exports [15]. Peak Nile perch catch and export values were achieved in 2006, 3 years after the installation of the BMUs. However, by 2015, catches had decreased by 20% to 117,600 MT, and exports had dropped by 50% to 18,408 MT [17]. Some authors argue that the political agenda is also to consolidate access to valuable fishery resources to the ruling elites [11,12,18,19].

Fishing effort on Lake Victoria has been growing steadily through new entrants, technological improvements, and increased use of illegal gear, such as small mesh monofilament nets, small hooks, and beach seines, in response to the reduced availability of large fish and growing demand for fish in national, regional, and global markets [8,20]. Nile perch fishers, which predominantly target global export markets, must invest in larger vessels and engines to access deeper waters where the likelihood of catching legal-sized fish is better, while those using smaller paddled vessels have traditionally been fishing for domestic consumption, and local or regional markets fish close to shore using small mesh gillnets and monofilament nets. Similar trends in the development of fishing efforts have been observed in other small-scale fisheries (SSFs), classified as commercial or artisanal, respectively [21,22]. The FAO voluntary guidelines for small-scale fisheries, the FAO code of conduct for responsible fisheries, and the United Nations' Sustainable Development Goal 14 highlight the need to increase economic benefits while protecting the access rights of artisanal small-scale fishers [23]. However, it is difficult to reconcile increased economic benefits while preserving access rights in some inland fishing nations, such as Uganda, where economic growth and development is a key agenda in the productive sectors.

The objective of this study is to analyze whether the strong enforcement of fisheries management rules has enhanced the fisheries performance and outcomes in the case of a productive African inland fishery. This study examines the effects of a shift from cooperation to coercion in managing the Nile perch fishery in Uganda's Lake Victoria. It assesses the impacts on fishing effort and catches after five years of military involvement. Our research questions are as follows.

- How was the military intervention on Lake Victoria organized, and what rules were enforced?
- To examine how coercive rule enforcement has impacted the fishing effort and fish stocks of the Nile perch on Lake Victoria over time;

- To understand the fishery policy implications of these interventions.

2. The Challenge of Rule Compliance in African Inland Fisheries

Institutions matter, and to avoid the tragic outcomes of open access to common-pool natural resources, an institutional framework involving formal and informal rules, norms, and conventions related to a particular resource is required [24,25]. Resource users are generally driven by individual interests and without definitive rules on resource use and accountability, resources typically suffer from degradation [26]. This is a key challenge with common-pool resources, such as inland Small-Scale Fisheries (SSF), where excluding access is difficult, and there is a high degree of competition among users. A key aspect of the effective governance of common-pool resources is that users adhere to the rules and institutions enforcing them are perceived as being effective and legitimate [27–29]. Two major challenges concerning compliance in inland fisheries exist: the inadequacy of rules and weak law enforcement mechanisms to guide sustainable management [30–32].

Rules governing resource use in African inland fisheries are mostly centred on managing fishing effort through gear limitations, such as mesh regulations and gear bans [33–35]. These are perceived as easier to implement in fisheries characterized by many users with varying fishing effort. However, non-compliance remains high among resource users [30,36]. Fisheries management faces insufficient financial and personnel capacity to enforce rules. In addition, there is also a growing uncertainty being expressed in the literature about whether these types of effort limitations are indeed effective in ensuring the sustainable management of SSF [34,35]. Most of the existing rules in African inland fisheries are dated and based on scientific principles perceived to address the political and economic interests of the state, commonly ignoring the needs of the fishing communities [30,34,37]. However, successful governance of common pool resources requires institutional frameworks to evolve, change, and adapt [28]. Over time, fishermen tend to diversify and evolve their activities, and with rigid rules, resources are susceptible to degradation in the long term.

Successfully co-managed, common-pool resources are mostly found when communities are characterised by well-defined boundaries, shared norms and rules, low levels of mobility, appropriate leadership, and accountability of users [24,38]. Inland fisheries are often transboundary, fishers are multicultural and highly mobile, and the nature of imposed co-management is instructive, as fishers are expected to adhere to the rules rather than participate in their formulation. Fisheries face challenges, such as inadequate resources to manage the fishery, bribery, corruption, and lack of political will and genuine enforcement to sustain the fisheries [4,14,39]. Thus, co-management to govern fisheries has found difficulties in ensuring compliance with the rules [40]. Consequently, nations such as Uganda have resorted to coercive powers to enforce rule compliance. The shift to coercive enforcement, coming in the form of the military in Uganda, also depicts the drive of individual states to control the fisheries sector. The co-management structures had a weak law enforcement mechanism characterised by inadequate resources, poor coordination among the BMU structures, and a lack of political will to empower enforcement activities [40–42]. Consequently, fishing practices remained contrary to government regulations, as BMU operations were mainly based on social ties rather than active law enforcement [14,42]. The challenges of the co-management structures to enforce fishery rules among fishers were used as arguments for the military to enforce rule compliance in Uganda. While cooperation failed to foster rule compliance among fishers, it is also argued that reliance on military approaches indicates a lack of social control since the state fails to facilitate collective control over common resources [43]. Military coercion, being inherently costly and prone to triggering violent conflicts, is not a sustainable approach, especially for low-income countries. On the other hand, cooperation relies on voluntary compliance, introducing the risk of free-rider problems. Therefore, there is a need to examine both coercive and cooperative approaches, as they present different but interesting opportunities for effective rule compliance in inland African fisheries.

3. Materials and Methods

3.1. Study Area and Context

Lake Victoria is a 68,600 km^2 transboundary water body, of which 29,584 km^2 (43%) belongs to Uganda. The country's share has an extensive shoreline of 1750 km characterised by numerous islands, making it favourable for fishing [44]. Fishing is primarily based on three key commercial species: the small pelagic silver cyprinid, locally known as dagaa (*Rastrineobola argentea* Pellegrin, 1904), Nile perch (*Lates niloticus*; Linnaeus, 1758), and Nile tilapia (*Oreochromis niloticus*; Linnaeus, 1758). Nile perch is processed as a chilled and frozen product for export markets, Nile tilapia is consumed locally, and dagaa is consumed in both local and regional markets. In recent years, a lucrative trade in Nile perch maws has developed where the value of the maw of the largest fish exceeds the value of the flesh [45].

Fisheries management in Lake Victoria evolved from self-governing communal arrangements before colonial times (<1890) to centralised top-down management for over a century [1890–2002]. A bottom-up co-management structure was introduced on the lake in 2003 [13]. The co-management system was established in the early 1980s as part of the global movement to decentralise governments. The shift was prompted by challenges faced by the centralised management system in effectively regulating fisheries [4,42]. In 2015, the co-management system was suspended in Uganda and replaced by military operations as the FPU was effective in 2017. At the time of data collection, the FPU had established eight operational areas around the lake, commonly known as sectors (Figure 1). Each sector includes a minimum of two adjacent districts. The operations in each sector are headed by a senior military commander commanding a cadre of 8–17 military personnel.

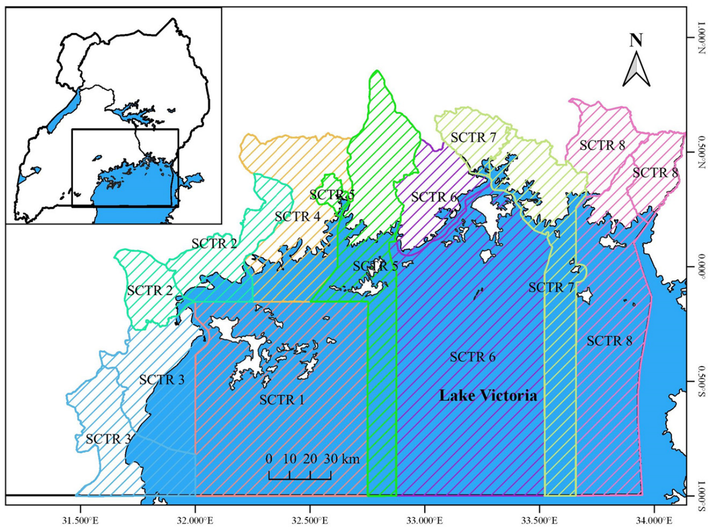

Figure 1. Boundary demarcation among the eight areas (sectors) of FPU operations along the Lake Victoria riparian districts in Uganda. Different colour patterns represent where each of the eight sector commandants conducts law enforcement on the lake.

3.2. Data Sources

To analyse the structure and effects of the current military fisheries management in the Ugandan waters of Lake Victoria, a sequential exploratory and explanatory mixed-method approach were used, using qualitative and quantitative data. The data were gathered and analyzed sequentially. The findings from the initial exploratory/qualitative dataset are substantiated by a subsequent dataset, which comprises explanatory or quantitative data in the study [46,47]. Qualitative data were obtained from the FPU personnel, while quantitative data were obtained from the National Fisheries Research Resources Institute

(NaFIRRI) and the Lake Victoria Fisheries Organisation (LVFO). Qualitative data were used to provide background information, the context of the study, and to discover the structure of the law enforcement operations, while quantitative data were used to explain the effects of the operations on fisheries effort and catch. We chose this approach to mitigate the comparative weakness of qualitative research, add richer detail to their conclusions, and make the results more credible by using different methods to collect data on the same subject as has been carried out in several other studies [46,48,49].

3.2.1. Data on the FPU Operation

Eight senior military officials, each in charge of a distinct FPU sector, were purposefully contacted and selected for interviews. They were highly ranked and had pivotal roles in law enforcement. Selected for their extensive expertise, these individuals were to provide a comprehensive understanding of military intervention in law enforcement and articulate the regulatory challenges, operational intricacies, and practical insights into maintaining law enforcement activities on the lake. The decision to engage with these key stakeholders was driven by the goal of capturing a holistic and authoritative perspective on the law enforcement dynamics in the lake. A checklist of interview questions was used; however, depending on the situation, divergences were allowed from one respondent to another to allow respondents to talk freely. Interviews were conducted from December 2019 to August 2020, recorded, and each lasted 45–60 min. Permission to collect data was sought from the FPU head office. During the fieldwork, the purpose of the study and emphasis on ethical principles of anonymity and confidentiality guiding the research was explained to the respondents, with their consent to participate confirmed before the interviews were taken [47]. In addition, records of confiscations of illegal vessels and gear covering the period from February 2017 to August 2020 were obtained from each sector and compiled for further analysis. FPU officials are tasked with recording every confiscation made per operation, which is sent to the Ministry of Agriculture, Animal Industry, and Fisheries (MAAIF) for recording purposes.

3.2.2. Fishery Effort, Catch, and Export Data

Catch and effort data were sourced from technical reports and databases at the National Fisheries Resources Research Institute (NaFIRRI) and the Lake Victoria Fisheries Organisation (LVFO). Since 2004, LVFO, in collaboration with partner fisheries research and management institutions in Uganda, Kenya, and Tanzania, has been monitoring fishing effort and catches on Lake Victoria through periodic frame surveys and continuous catch assessment surveys. Frame surveys (FS) are conducted biennially, with logistics permitting, and involve a complete census of all fishing effort variables, such as the enumeration of active landing sites, fishing vessels, gears, and fishers. Catch Assessment Surveys (CAS) involve the collection of catch data from a sample of vessels and landing sites throughout the year. Through the FS, an effective sampling frame is used to determine a representative sample of landing sites within the districts to be sampled [50,51]. Landing sites were selected randomly with a probability proportional to their size (PPS) measured in terms of the total number of vessels landing at the site, and catch data were obtained from vessels at random. The final data are representative of approximately 10% of all landing sites on the lake. These datasets are collected by trained enumerators, following the LVFO harmonized Standard Operating Procedures and data forms [50,51]. For this study, the time-series data were segregated into three discrete periods: the BMU management system era (2004 to 2015), the year of transition (2016), and the FPU period (2017 to 2021). The transition period in the study describes the period during which the BMU structures were disbanded until the commencement of FPU operations in 2017. Catch assessment data were sorted, and trips where either legal or illegal gillnets or/hooks were deployed, but not both, were selected for further analysis. This was carried out to eliminate any bias due to the uncertainty in identifying which catches or fish sizes were caught using legal or illegal gear by a specific vessel.

Fish export data were sourced from the statistical databases of the Bank of Uganda and the Uganda Bureau of Statistics [17,52], to cross-reference and validate the information retrieved from these sources. Data verification was conducted using an additional dataset provided by the Directorate of Fisheries Resources (DiFR).

3.3. Data Analysis

Interviews with the FPU senior commanders were transcribed and, in the analysis, the authors sought to find and analyse direct quotes from the interview respondents that discussed aspects related to the study objectives on how the military intervention was organised and the rules imposed. Quantitative data obtained from the sectors included records of confiscations, which were collated, summarised, and presented by year. The catch and effort data were analysed according to different types of gear and vessels.

Yearly average total catches were computed from the LVFO catch assessment survey data, whereas CPUE was computed based on vessel-level catch assessment data. For the latter, a proxy variable, the average weight of fish landed (kg $fish^{-1}$), was computed as a fraction of the total weight of the catch and the number of fish in a vessel for each observation. The CPUE was then presented as the kg per gear unit hours fished with gear units and hours fished as the effort variables over the study period from 2005 to 2021. The analysis and presentation of findings aimed at comparing the BMU (2005–2015) with the FPU period (2017–2021), where changes in effort, catch, CPUE and the average size of fish caught were used to explain changes related to the change in management. We compared the CPUE between vessel propulsion types and years using a two-way Analysis of Variance (ANOVA) and a post hoc Tukey test. All statistical and graphical analyses were performed using R software (4.0.3) [53] Packages dplyr and ggplot2 were used for data manipulation and visualization, respectively [54].

3.4. Limitations

Despite the study's strengths, it is essential to acknowledge its limitations, including its relatively small sample size. Qualitative data were collected from eight officials, and the quantitative data covered 10% of the total landing sites. The non-random, purposive selection of the qualitative sample limits generalizability and caution is warranted when interpreting the broader impact of military activities on the lake. Additionally, missing data in the quantitative analysis were non-random, affecting 8 out of the 17 years due to limited funding. Therefore, the findings should be cautiously interpreted, avoiding generalizations of catch trends for the entire 17-year period.

4. Results and Discussion

4.1. The Military Operation on the Lake

In 2014, 409 BMUs were recorded in the Ugandan part of Lake Victoria. In November 2015, the BMUs were suspended, and the FPU was installed to enforce rule compliance among fishers, starting its operations in February 2017. Most of the fisheries management rules that have been implemented are based on the fisheries legislation of Uganda, the most fundamental one being the Fish Act Cap 197 of 2000 and its amendments in the fish (fishing) rules of 2010, which did not change with the transition from the BMU system to the FPU. Sector commanders indicated that they had prior experience in operating in a marine environment under the Uganda Peoples Defence Force (UPDF) and this was part of the criteria for deployment in the FPU. In 2016, members of the FPUs received a 2-week orientation by the Ministry of Agriculture, Animal Industry and Fisheries (MAAIF) officials on the fisheries rules to be enforced, as noted by one respondent: "*Most of us were or are part of the UPDF marine. . .we undertook training with the ministry officials at the fisheries training institute and taught on what is acceptable on the lake, so whatever is prohibited on the lake according to the rule of law we abolish it (. . .)*".

Some of the equipment used for enforcement such as vessels and engines were provided by the MAAIF through the Directorate of Fisheries Resources (DiFR) and in some cases, additional equipment was supplied by prominent commercial fishers who supported strict enforcement. Under the FPU, fishers and vessels on the lake have to be registered and licensed, Fishers targeting Nile perch, Nile tilapia, and other larger species are prohibited from using gillnets < 5″, cast nets, beach/boat seines, monofilament nets, hooks size ≥ 10 (the naming of hook sizes is such that the hooks become smaller as the size number increases), and indiscriminate fishing methods and the use of vessels smaller than 28 ft/8.5 m. Dagaa fishers are allowed to fish with a maximum of 8 small seine net panels and with vessels ≥ 28 ft/8.5 m (Table 1). The use of illegal fishing gear and practices had been prevalent among smaller fishing vessels operating in the inshore areas of the lake [55–57]. Military officials also observed this, and hence, the eradication of small fishing vessels has been a major target throughout the enforcement work of the FPU.

Table 1. Rules enforced by the Fisheries Protection Unit (FPU).

Legislation	Rules
Fish Act Cap 197 of 2000 The fish (fishing) rules of 2010	• Vessel registration and licensing. • Prohibit indiscriminate methods of fishing, e.g., poisoning, tycoon (forcing fish into the nets by beating the water), etc., cast nets and beach seines. • Prohibit the use of gillnets < 5 inches, hook size > 10, and monofilament nets. • Acceptable fish slot size 50→85 cm TL for Nile perch and ≥25 cm TL for Nile tilapia. • Vessel size < 28 ft (8.5 m) prohibited for fishing. • Maximum of 8 panels for the seine nets for dagaa fishers.

Although the BMUs had been suspended, military officials consulted and engaged stakeholders at the local level in their activities to ensure the success of the enforcement operations. In one case, a respondent said: *"We work closely with the AFALU* (Association of Fishers and Lake Users) *and some former BMU chairmen help, we collaborated with them from the start, they gave us people to work with, in navigating the lake from the start…they gave us their boats and engines…they also feed us with information on the illegal activity hotspots"*. Engaging local stakeholders enhanced law enforcement, as the stakeholders ensured the acceptability of the regime shifts from the BMU to the FPU at the landing sites. With the suspension of the BMUs, the AFALU, whose membership is dominated by commercial Nile perch fishers, nominated two persons at every major landing site to report illegal fishing activities to the military. It is, therefore, no surprise that the AFALU has been identified as one of the major actors behind the suspension of the BMUs. Such a swift change in management in Uganda was possible because transition powers remained with government actors rather than resource users [15,16]. Mpomwenda et al. [13] indicate that commercial Nile perch fishers were dissatisfied with the local-level BMU structure and local fisheries officials. The enforcement of the rules is perceived to favour commercial Nile perch fishers over artisanal fishers using small vessels.

4.2. Enforcement Activities of the FPU and the Effect on Fishing Effort

4.2.1. Effect on Fishing Effort

At the beginning of the 21st century, most fishing vessels on Lake Victoria were unmotorised and mainly paddled (80%), while some used sails. Over the first two decades of the century, there was no growth in paddled or sailed vessels from 2006, while an exponential growth in the number of motorized vessels was recorded, with an average annual growth rate of 11% from 2000 to 2020 (Table 2).

Table 2. Fishing effort indicators on Lake Victoria in Uganda during periods of different management regimes 2000–2020. Source frame survey reports.

Management Regime	**Pre-BMU**		**BMU**						**Transition Period**	**Military Enforcement**	**Average Yearly Change**			
Variable	**2000**	**2002**	**2004**	**2006**	**2008**	**2010**	**2012**	**2014**	**2016**	**2020**	**2002–2004**	**2014–2016**	**2016–2020**	**2000–2020**
Landing sites	597	552	554	481	435	503	555	567	556	446	0%	−1%	−6%	−1%
Fishers	34,889	41,674	37,721	54,148	51,916	56,957	63,921	64,617	66,869	60,552	−5%	2%	−2%	3%
Motorised vessels	2031	3250	3173	5047	5156	6334	9351	9955	11,495	17,075	−1%	7%	10%	11%
Paddled vessels	12,848	14,262	12,506	17,475	15,602	16,389	17,111	17,260	17,260	8460	−7%	0%	−18%	−2%
Sailed vessels	665	1074	1096	1466	1078	682	1125	857	864	260	1%	0%	−30%	−5%
Towed vessels							17	51	28	18		−30%	−11%	1%
Foot fishers						50	367	100	463	350		77%	−7%	19%
Legal gears														
Multifilament gillnets ≥ 5″	243,209	374,642	402,351	498,037	327,098	307,052	423,155	384,849	355,348	556,767	4%	−4%	11%	4%
Hand line hooks [1]	4585	6547	8335	15,860	19,629	17,071	27,780	27,004	37,785	20,669	12%	17%	−15%	8%
Longline hooks < 10				1,681,048	1,657,458	1,389,548	1,525,810	850,493	479,767	3,178,446		−29%	47%	5%
Illegal gears														
Multifilament gillnets < 5″	54,454	52,846	56,246	91,740	76,908	66,532	59,585	78,571	79,473	8676	3%	1%	−55%	−9%
Beach/boat seine	811	880	954	1425	1649	1451	1233	1819	1968	1093	4%	4%	−15%	1%
Cast net	1276	858	659	631	1000	1095	1372	1359	1342	873	−13%	−1%	−11%	−2%
Monofilament gillnets			845		11,203	12,115	15,148	21,793	31,876	15,204		19%	−19%	18%
Basket traps	11,349	5781	5361	499	7615	10,331	7082	9000	6144	3341	−4%	−19%	−15%	−6%
Longline hooks ≥ 10				604,561	1,106,341	1,169,807	2,892,575	3,737,273	3,998,352	1,057,646		3%	−33%	4%

[1] The size of handline hooks was not specified in the frame survey reports.

The use of legal gillnets ≥ 5″ and longline hooks size < 10, which are mostly confined to motorised vessels, did not reflect the increase in the number of motorised vessels. The number of legal gillnets increased steadily from the beginning of the century until reaching a peak of about 500,000 in the 2006 census. The number of legal gillnets then fluctuated around 360,000 but increased again sharply to about 560,000 in 2020 after 4 years of military enforcement. The use of illegal multifilament gillnets fluctuated between 50,000 and 90,000 until 2016 and reduced to less than 9000 by 2020. The relative importance of multifilament gill nets < 5″ in the Nile perch fishery decreased over time, and thus military enforcement was effective in reducing the use of illegal multifilament gill nets.

Monofilament nets and basket traps are highly efficient gears on Lake Victoria and are mainly associated with the artisanal fishery targeting juvenile Nile perch near the shore. Monofilament nets were first recorded in the 2004 frame survey when less than 1000 nets were recorded. No monofilament nets were recorded in the 2006 frame survey, but in 2008 about 11,000 nets were recorded. Their numbers then grew in subsequent frame surveys and reached almost 32,000 in 2016. In 2020, they were down to about 15,000, a reduction of 52%. Over the same period, the number of paddled vessels had been reduced to 8500, a reduction of 51% from the survey in 2016. Reductions in effort variables such as landing sites, monofilament nets and beach seines are consistent with results given in [58], which indicated a general decline in these effort variables.

Longlines were first recorded in the 2006 frame survey, although longlining had already been practised to some extent earlier, both by commercial and artisanal fishers. In the beginning, the majority of longlines had legal-sized hooks, but with time, illegal smaller-sized hooks became increasingly dominant as the number of hooks increased (Table 2). The use of illegal hooks was especially prominent in commercial fisheries (Figure S1). In 2020, there had been a large drop in the use of illegal hooks from about 4 million in 2016 to 1 million in 2020. At the same time, the number of legal hooks increased from about 500,000 in 2016 to 3.3 million in 2020.

The increased use of small hook sizes (>10) and monofilament nets during the BMU period had been attributed to the decline in large-sized Nile perch, prompting fishers to shift to gear with greater fishing efficiency [55]. Illegal fishing gear usually targets immature fish, which is then thought to result in the reduction in larger fish. We note that before enforcement there was no increase in legal gear but rather illegal hooks and monofilament nets, which can be seen as an adaptation for fishers to effectively harvest the available sizes of the perch.

4.2.2. Confiscation of Illegal Gear and Vessels

During the first 3.5 years of operations, the FPU confiscated a total of 27,880 vessels (Table 3). These were mostly of the parachute type (80%) (Table 3). Unlike other vessel types, the parachute vessels are paddled and less than 6 m in length, and with their small size, can only access shallow inshore areas where they target juvenile and spawning fish [55,59]. The Ssesse-type vessels can be fitted with an outboard motor and range from 6 m to 15 m, thus including illegal ones of < 8.5 m, which were confiscated, and vessels larger than 8.5 m operating with illegal fishing gear were also confiscated, albeit with the military officials noting that the latter were given back to the owners after a fine. Despite these massive confiscations, the number of paddled vessels recorded in the frame survey in 2020 had only dropped by 8800 from the 2016 survey (Table 2).

The reduction in most illegal fishing gear from the frame surveys in 2016 to 2020 was proportional to the reduction in small fishing vessels, at around 50%, irrespective of the amount of gear confiscated. Thus, a total of about 540,000 monofilament gillnets were confiscated, which is 35 times the reduction recorded between the two last frame surveys in 2016 and 2020. The number of confiscated seines was 7 times, cast nets 3 times, and basket traps 0.6 times. The easiest and most effective gear to replace is the monofilament gillnets and this could be attributed to the low cost of doing so, which respondents also affirmed, "*these manyala [monofilament] nets and little hooks are the worst to eliminate, they are cheap to* *obtain. . .one can just get three nets and use his small boat at the shores, so they incur less capital and then within a few days, they have recovered their money back*".

Table 3. Vessels and fishing gear were confiscated by the FPU during law enforcement operations on Lake Victoria in Uganda. Data provided by sectoral commanders for the period February 2017 to August 2020.

Effort Variable	Year	February 2017	2018	2019	August 2020	Total
Fishing vessels	Parachute (≤6 m)	6136	3622	7154	5434	22,346
	Ssesse vessels (6–12 m)	924	2374	649	649	4596
	Unspecified		318	555	65	938
	Total of vessels	**7060**	**6314**	**8358**	**6148**	**27,880**
Fishing gears	Hooks size > 10	1,123,863	2,413,174	3,400,299	775,111	7,712,447
	Multifilament gillnets < 5″	22,400	15,322	44,630	2500	84,852
	Monofilament gillnets	147,331	244,949	99,992	47,391	539,663
	Basket traps	290	631	474	538	1933
	Beach/boat seines	2014	2377	1862	1185	7438
	Cast nets	1278	967	324	382	2951

Overall, the elimination of illegal gear used both by paddled and motorized vessels, such as illegal multifilament nets and small hooks, appears to have been quite effective. Confiscated multifilament nets do not appear to have been replaced and their use dropped by almost 90% between frame surveys. The use of small hooks was reduced by 73% between surveys and while these are readily replaced, the large increase in the use of legal hooks has reduced the incentive to replace confiscated small-size hooks (Table 2).

To the military officials, the confiscations have been successful, and the need for surveillance has dropped with time. A challenge, though, could be the cost of surveillance, which was mentioned by officials, in addition to the reduced intensity in conducting operations; "*Initially operations were held frequently and randomly with more support, however, this has changed because the rate at which crime is detected, and arrests made have also reduced. . .operations are now conducted based on information received*". There was however no detectable reduction in the confiscation of small vessels during the first 4 years of military intervention.

4.3. Changes in Catches during the BMU and FPU Management Regimes

During the BMU period, there was a consistent decline in overall Nile perch catches from ~90,000 t in 2005 to <50,000 t in 2015, and fish exports declined by 50% from 2005 to 2008, after which they remained relatively constant until increasing in 2018 (Figure 2). Fisheries on Lake Victoria supply more than 90% of Uganda's total exports [60]. Exports continued to increase in 2019 when they were 60% higher than at the end of the BMU period. The observed decline in exports in 2020 and 2021 could be attributed to the stringent COVID-19 pandemic restrictions, where few fishery actors were required to work thus affecting the quality and quantity of Nile perch available for processing and export [61].

With the FPU in charge of law enforcement, it is reported that six more factories for processing Nile perch had opened by 2019, adding to the five existing in 2015. This has been reported as the major achievement of the FPU by the Uganda Fish Processors and Exporters Association (UFPEA) [60]. Moreover, UFPEA and AFALU have been reported to support military activities on the lake, the latter being confirmed by the FPU officials in this study [15]. Rightly or wrongly, the implication is that the shift in management enhanced the survival of the commercial Nile perch trade's value chain by imposing strict measures on illegal fishers. The surge in mechanized fishing operations, concurrent with the opening of six new factories, aimed to yield higher catch volumes. This rise in motorized vessels was driven by the demand to supply fish to the newly established processing facilities. However, the study findings indicate a non-significant increase in catch volume post-enforcement, prompting inquiries into the efficiency of vessels in meeting industry supply. Moreover, there is a deliberation on the cost-effectiveness of the enforcement measures, considering the observed outcomes.

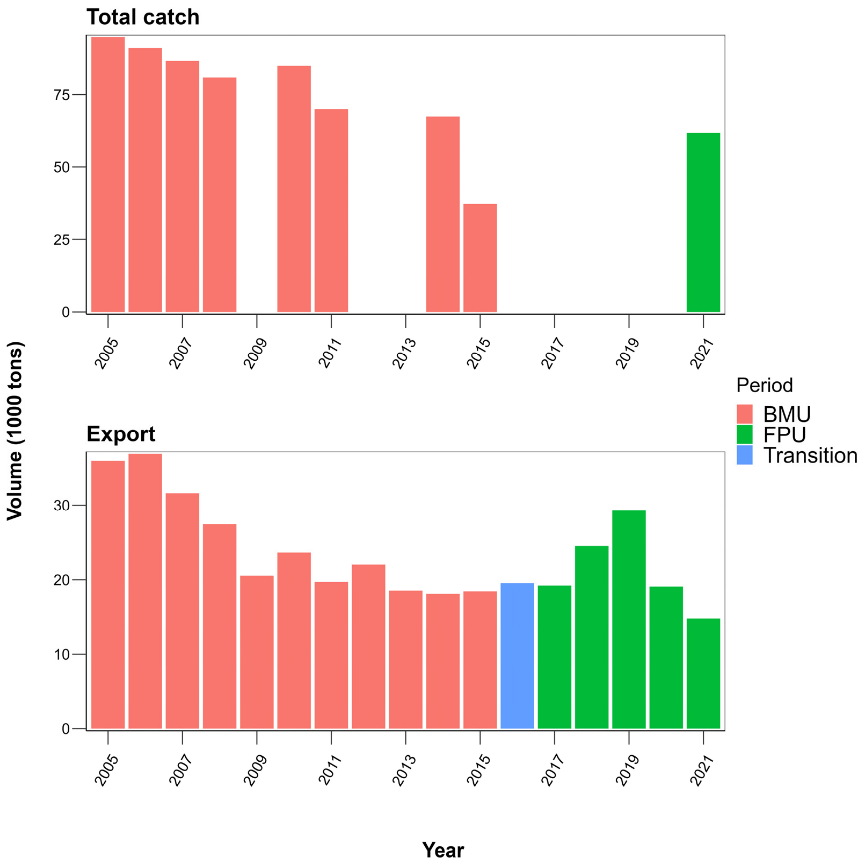

Figure 2. Annual Nile perch catch and exports as volume (1000 tons) during the BMU and FPU period.

In 2005, paddled vessels accounted for just over half of the total Nile perch catch at about 48.5 thousand tons. Thereafter, there was a gradual decline in the importance of paddled vessels, and by 2015 they accounted for about 13,000 t, equivalent to 35% of the total catch. By 2021, their catch of Nile perch was about 8000 t, around 13% of the total (Figure 3A). These changes correspond to the changes in the fleet, with rapid growth in the number of motorised vessels since 2016 and a halving of the number of paddled vessels due to the confiscation of vessels (Table 2).

In 2005, about 80% of the Nile perch caught in the commercial fishery was taken in gillnets and the rest by longlines. The proportion of Nile perch caught by longlines increased to about 30% by 2008 and remained about that figure until 2015. In 2021, longlines accounted for about 40% of the catch, gillnets for 52%, and the rest was caught using mostly illegal gear including beach seines, cast nets, and basket traps. Paddled vessels used a greater variety of gear to catch Nile perch, but gillnets and hooks (longlines and handlines) accounted for around 60–80% from 2005 to 2015. In 2021, the use of gillnets by paddled vessels had dwindled to a mere 10%, while catches were dominated (51%) by beach and boat seines followed by hooks (long and handline) at 30% (Figure 3B).

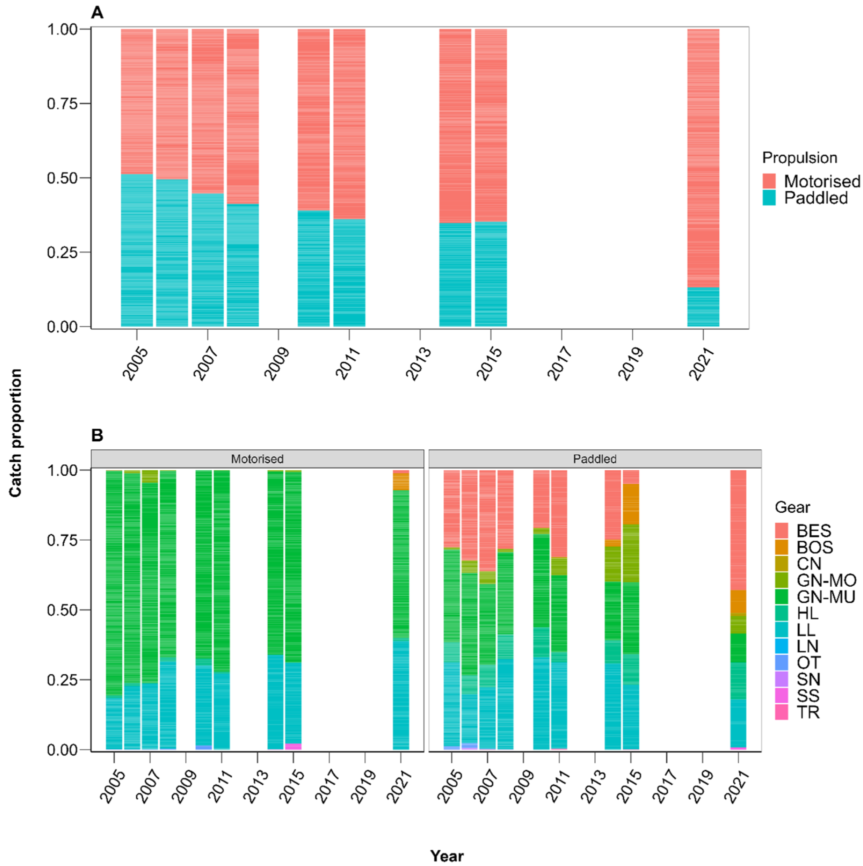

Figure 3. The proportion of Nile perch catches from vessels sampled in the study period by (**A**) vessel propulsion as paddled and motorised and (**B**) and gears; BES—Beach Seines, BOS—Boat Seines, CN—Cast nets, GN–MU—Multifilament gillnets, GN–MO—Monofilament gillnets, HL—Hand line hook, LL—Longlines, LN—Lift nets, MF—Monofilament, and OT—Other unidentified gears, SN—Scoop net, SS—Seine nets, TR—Basket traps.

Since 2015 there has been a marked reduction in the use of illegal gear and small unmotorised vessels, while the number of motorized vessels has continued to grow. There has been some increase in the use of legal gillnets, but the main increase has been in the use of legal-size hooks in both the artisanal and commercial fishery. The increased use of larger hooks has led to an increase in catches of large-sized Nile perch (Figure S2), as has also been reported in other studies [45,62,63]. This shift in the fishery has increased the demand for bait fish, which is likely the reason for the increased importance of beach seines in the artisanal fisheries (Figure 3B, [45]).

Increased effort targeting large Nile perch reflects the emergence of a lucrative fish maw business, where the economic returns are in favour of capturing the largest Nile perch individuals [45,64,65]. The Nile perch fishery, which is now mostly composed of motorised fishing vessels, does not only aim at targeting the high-value factory-sized Nile perch (≥50–85 cm TL), but much larger specimens for the fish maw trade which also appears to be attractive to the artisanal fishers with 30% of them operation long-lines and hand lines. Larger fish sizes are reported to have larger maws for instance the length of fresh maws for the 50 cm and 80 cm TL Nile perch individuals was estimated at 17 and 28.5 cm respectively, price per kg was also higher for larger maws at USD 210–270 while smaller maws were valued at USD 40–55 [45,64]. Thus, fishing for maws is economically attractive for fishers and other actors along the Nile perch value chain.

Nile Perch CPUE

A significant decline in the CPUE for the motorised gillnet Nile perch vessels was observed throughout the study period, from 4.5 kg panel^{-1} h fished at the beginning of the study period, to 3 kg panel^{-1} h fished in 2015, and further down to 1.8 kg panel^{-1} h fished in 2021. The CPUE for the artisanal gillnet fishers, who primarily use monofilament gillnets [56], declined from 4.2 kg panel h^{-1} fished in 2015 to 3.5 kg panel h^{-1} fished in 2021, but there has, however, not been a significant decline throughout the study (Figure 4, Tables S1 and S2), indicating that there has not been a detectable change in the density of small Nile perch in coastal waters. Small Nile perch of 10–50 cm TL are the most abundant (>80% of the sampled individuals) in the inshore areas of Lake Victoria, as measured in acoustic surveys [66]. A high abundance of small-sized Nile perch has long been reported on the lake [58,66,67]. Although the CPUE of monofilament gillnets has remained high, the importance of this gear in the Nile perch fisheries has dwindled as it only accounts for 1% of the total catches among all gear in 2021.

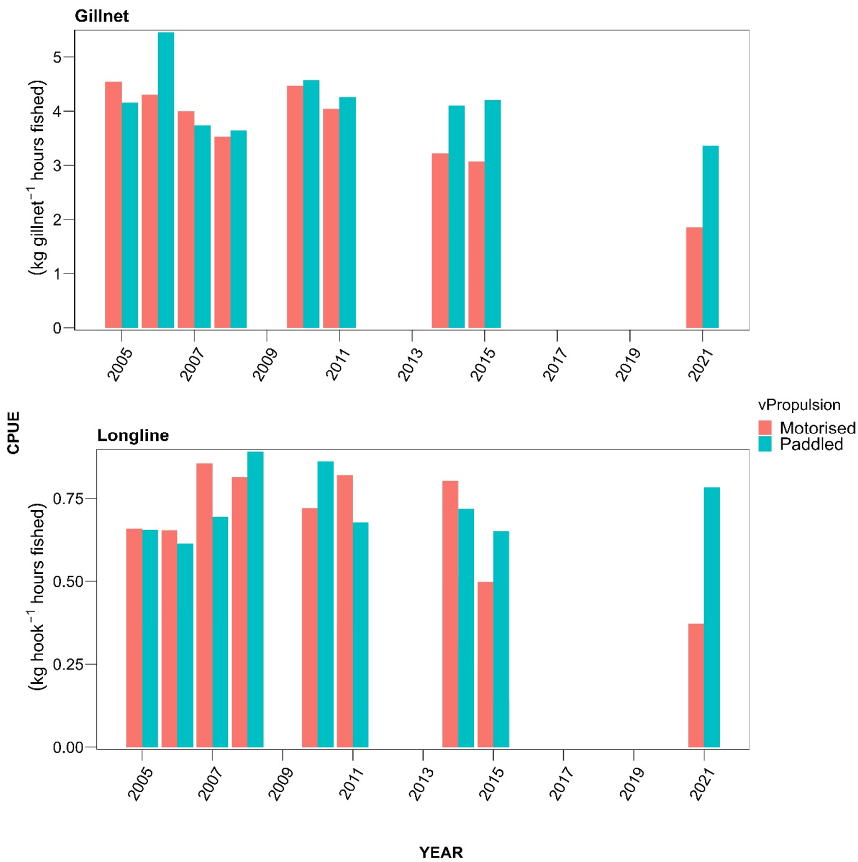

Figure 4. CPUE for Nile perch gears in kg per unit hours fished for motorised and paddled vessels for the catch assessment survey period 2005–2007, 2010–2011, 2014–2015, and 2021 [56].

Legal hooks dominated both paddled and motorised vessel groups at the beginning of the study period, with a shift to illegal hooks by the end of the BMU period. With the FPU setting in, a dominance of legal-size longline hooks was observed in the frame survey in 2020 and the catch assessment survey in 2021. (Table 2, Figures S1 and S2). A slight increase in the average CPUE was observed in the artisanal fishery from 2015 to 2021, and a reduction in the commercial fishery was not found to constitute a statistically significant difference ($p = 0.113$) (Table S2).

The CPUE in the longline fishery did not indicate a significant difference between vessel groups from the beginning of the study period and throughout the BMU period (Figure 4, Table S2). Changes over time in the use of illegal longline hooks were quite similar for both motorised and paddled vessels, which is also reflected by the similar size distribution of Nile perch harvested by motorised and paddled vessels (Figures S1 and S2).

5. Conclusions and Implications for Policy

The study examined the structure and effects of military law enforcement on the Nile perch fisheries on Lake Victoria in Uganda. The results show that the Nile perch fishery on Lake Victoria in Uganda is highly dynamic and responds rapidly to changes in the biological, social, and economic environment in which it operates.

After the first 5 years of military intervention, there has been an increased emphasis on the long-line fishery and catches of large Nile perch have increased substantially, both in absolute terms and regarding the proportion of larger fish caught. Exports of Nile perch increased rapidly from 2016 to 2019 but declined significantly in 2020 and then reached the lowest point in 2021. Although this can be attributed to the COVID-19 pandemic, it is also possible that national and regional markets have become more important, and that a substantial part of the catch is comprised of individuals that are too large for the factories.

The fishing rules that have been enforced were specified in Uganda's fisheries legislation; however, these rules foster more commercial fishery operations than subsistence ones. In the early 20th century, regulations, including the imposition of a minimum gillnet mesh size, were implemented to promote sustainable harvesting of commercial tilapia fisheries on Lake Victoria. However, these measures proved ineffective in preserving the native Oreochromis esculentus, the targeted tilapia species at that time. [67]. The Nile perch fleet alone makes up almost half of the fishing fleet on Lake Victoria in Uganda, and thus, to the commercial fleet owners and stakeholders along the value chain, the rules could be perceived as effective and legitimate. The institution and operation of the FPU in Uganda addressed the perceived "laxity" of co-management in enforcing rules, and the military has confiscated large numbers of small vessels and illegal gear since 2017. However, the results indicate that the goals to increase catches and exports relative to the BMU period may not be achieved in the long term. An increase in catch and exports was also realised in the early years of the BMU regime. Based on the findings of this study, there are no indications that the current regime has achieved the stated goals of increasing catch and exports relative to the preceding co-management period. A continued decline in catch-per-unit effort was observed for the motorized gillnet fleet, indicative of the overcapacity of the fleet. Driven by individual interests, the Nile perch stocks could suffer from resource degradation, as evidenced by the proportion of larger specimens being sought for economic benefits. It remains to be seen how the increased fishing pressure on the largest Nile perch may change the population structure, but most likely lead to reduced size at maturity and the maximum size attained [67]. Such a scenario would have serious implications for both the export of Nile perch and the maw trade.

On the side of the paddled vessels, we notice that in the first 4 years of military intervention, around 8000 small vessels were confiscated annually. Meanwhile, the use of illegal monofilament gillnets decreased, and most surveyed paddled vessels in 2021 were engaged in longlines and handlines to target large Nile perch or beach seines. This shift is likely due to the increased demand for bait fish in the expanding longline fishery. By 2020, the number of paddled vessels declined from approximately 17,000 in 2016 to 8500 in 2020, while almost 28,000 vessels were confiscated, indicating a persistent incentive to operate them. This is expected as no alternative incentive was given to the "illegal" artisanal fishers before the commencement of law enforcement.

The research provides valuable insights into the complex interactions involving military law enforcement on Lake Victoria, Uganda. It reveals the challenges associated with enforcing regulations, particularly in developing countries where the local socio-economic fabric is deeply intertwined with these vital natural resources. Two significant findings of the study are worth highlighting. Firstly, the study raises concerns about regulations inadvertently promoting excessive growth in fishing capacity in the commercial Nile perch sector. This, along with size-selective fishing, contributes to ongoing declines in catch levels of the commercial fleet. Secondly, the removal of smaller vessels implies a risk of social disruption in fishing communities, potentially causing the breakdown of social structures. This disruption may impact fisheries management, employment, and livelihoods. Hence, an assessment of the effectiveness of the current fishery laws concerning fish population dynamics and deliberate economic diversification may provide viable solutions to address these issues.

While our study has limitations, we acknowledge the need for future research to address these concerns. Diversifying interviewees to include fishers, local government actors, and fishing communities can provide a more comprehensive understanding of the social implications of military rule. Further research should explore the potential ecological effects of size-selective fishing and the necessity for revising fishery regulations considering the shifting fish population structure. Lake Victoria, a eutrophic lake, faces challenges exacerbated by a rapid increase in the human population in its catchment. Algal blooms in coastal areas lead to reduced dissolved oxygen, making these zones less suitable for larger fish [68–70]. Consequently, decreasing fishing effort in these areas may not necessarily increase larger fish. Although the study did not explore fish–environment interactions, such dynamics should be considered in formulating fisheries management plans. These efforts contribute to sustainable fishery management practices, which are crucial in addressing the complex issues related to law enforcement and fisheries.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/fishes8110563/s1, Figure S1: Legal/illegal hook size use between paddled and motorised gillnets for the study period based on catch assessment surveys in 2005–2008; 2010–2011; 2014–2015 and 2021, Figure S2: Comparison of the fish size distribution for the vessel groups; motorised and paddled and gears; gillnets and longlines; Table S1: ANOVA results for CPUE of the gillnets and longline vessel trips, Table S2: CPUE post hoc tests for gillnet and longline vessel trip comparisons.

Author Contributions: V.M.; conceptualization, methodology, investigation, visualization, writing—original draft: T.T.; supervision, funding acquisition, methodology, writing—original draft: D.M.K.; data curation, supervision, and writing—original draft: J.G.P.; conceptualization, methodology, data curation, supervision writing—original draft. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: The study did not involve any animal or human experimentation, and thus the declaration statement, approval code and date from the University of Iceland and Helsinki declaration are not applicable to this article.

Informed Consent Statement: Informed consent was obtained from all subjects involved in the study.

Data Availability Statement: Data for the study have restricted access; however, considerable explanation could be made available upon request from the corresponding author.

Acknowledgments: All staff of the FPU who participated in the interviews, staff of the National Fisheries Resources Research Institute, Directorate of Fisheries Resources and Lake Victoria Fisheries Organization that contributed to the collection of data used in the study are hereby acknowledged. Special thanks to Anthony Taabu Munyaho for the invaluable support rendered concerning data collection with the FPU, Nakiyende Herbert for providing us with guidance and feedback on the paper, and Bairon Mugenyi and Basooma Anthony. Lastly, we would like to express our gratitude to the UNESCO-GRO Fisheries Training Program that provided funding to the corresponding author for PhD studies at the University of Iceland.

Conflicts of Interest: The authors declare no conflict of interest.

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Appendices

Appendix 1: Analysis of fuel usage data

Data collection

We conducted an additional survey across the riparian countries of Lake Victoria to gather fuel consumption data for motorized fishing vessels, addressing gaps in the existing dataset (Table 1). Data collection took place between June and August 2017 in Uganda, and from April to September 2020 in Kenya and Tanzania. The landing sites selected for data collection were purposefully chosen from existing CAS sites, ensuring a representative sample of vessels from both inland and island locations (LVFO, 2021b, 2022). At each site, enumerators collected data from randomly selected vessels during the first and last week of the data collection period—three months in Uganda and six months in Kenya and Tanzania. The data for Kenya and Tanzania were collected using the same format as in Uganda, incorporating the fuel variable into the catch assessment data form (LVFO, 2021b). This consistency ensures that the survey data can be reliably linked to the available panel data and used to accurately predict the missing fuel variable.

Table 1: Summary statistics of key model variables.

Variables	Tanzania	Kenya	Uganda
Landings sampled	6	5	6
Average gear numbers			
LL	1069.11	2337.35	352.46
GN	62.07	82.07	64.90
Fuel use (ltrs)	12.94	24.39	11.62
Crew	3.36	3.35	2.35
Hours fished in a day	12.09	13.55	11.79
Average vessel length	7.89	10.69	8.79
N	**339**	**343**	**242**[1]

[1] The Ugandan survey was conducted in 2017, while the surveys in Kenya and Tanzania were done in 2020.

Variable selection

In our model selection process, we followed a forward stepwise approach—a statistical method that systematically identifies a subset of variables explaining the variance in the dependent variable (James et al., 2014). Specifically, we applied the stepAIC method from the MASS package to define the fuel model for each country. This method starts with an empty model and incrementally adds variables based on their contributions to improving model fit. The selection process continues iteratively until a predetermined stopping criterion is met. In our study, we used the Akaike Information Criterion (AIC) as the guiding measure. The AIC strikes a balance between model fit and complexity, favoring more parsimonious models. Its utility in facilitating model comparison sets it apart from the Bayesian Information Criterion (BIC) and adjusted R-squared, making AIC a widely adopted metric for effective model selection (James et al., 2014). This systematic procedure aids in identifying the most pertinent variables while avoiding the inclusion of unnecessary or redundant predictors, thus ensuring the final model is both interpretable and parsimonious. Based on the empirical estimation of the cross-sectional data, selected data variables for fuel prediction are specified as follows:

Uganda:

$$\text{Fuel (Litres)} = -5.45 + 4.69\ \text{crew} + 0.18\ \text{hoursfished} + 12.66\ \text{V}_{\text{SF}} - 11.70\ \text{K}_{\text{Kalangala}} - 9.38\ \text{K}_{\text{Wakiso}} - 10.75\ \text{Kiyindi} - 7.77\ \text{Nakatiba} - 10.75\ \text{Kikondo} - 0.03\ \text{GN}_{\text{Number}} \ldots\ldots \text{....Equation 2.}$$

Kenya

$$\text{Fuel (Litres)} = 7.13 + 1.71\ \text{hoursfished} - 5.62\ \text{crew} + 17.72\ \text{LL} - 0.005\text{LL}_{\text{number}} + 20.80\text{Remba} - 32.16\ \text{Kokach} \ldots\ldots\ldots \text{ Equation 3}$$

Tanzania

$$\text{Fuel (Litres)} = -12.41 - 7.66\text{GN} + 3.67\text{V}_{\text{length}} + 0.63\text{hoursfished} + 0.035\text{GN}_{\text{Number}} - 7.36\ \text{Shoka} - 8.72\text{Zabaga} + 5.17\ \text{Nyamikoma} \ldots\ldots\ldots \text{ Equation 4}$$

Explanation of variables in the fuel models

In our study, we investigated fuel consumption in motorized fishing vessels across three countries: Kenya, Uganda, and Tanzania (Tables 2, 3 & 4). The primary focus was to understand the relationship between fuel usage and specific variables within each country. We discuss these variables separately for comparative analysis.

Fishing hours and Fuel Consumption. Across all three countries, there was a direct correlation between fuel consumption and the length of the fishing trip. Longer fishing hours translated to increased fuel usage due to extended travel time to and from fishing grounds.

Fishing crew size. In Kenya, larger fishing crews were associated with lower fuel consumption, suggesting operational efficiency. Conversely, in Uganda, a larger crew was linked to higher fuel consumption. Contextual factors, such as vessel size or fishing practices, likely contribute to these differences.

Vessel type (V_SF) and Fuel Consumption. The use of Ssesse flat vessels (V_SF) showed a positive association with fuel consumption. In Uganda, where 90% of motorized vessels are Ssesse flat vessels, their larger size contributes to higher fuel requirements. Similarly, in Tanzania, vessel length (V_length) positively correlated with fuel consumption, aligning with the understanding that larger vessels consume more fuel.

Gear and gear numbers. In Kenya, we observe a positive connection between the use of longlines (LL) and fuel consumption, as highlighted in Equation 2. Essentially, when longlines are employed, fuel usage tends to increase. Considering gear numbers, in Uganda (Equation 1), we find a negative coefficient associated with gillnet numbers (-0.03 GN_number). Similarly, in Kenya (Equation 2), the negative coefficient for longline numbers (-0.005 LL_number) suggests that there exists an optimal range of gear usage for vessels. Beyond this range, we encounter fuel inefficiency. Interestingly, Tanzania's Equation 3 reveals a positive relationship between gillnet numbers and fuel use. This aligns with our expectation that larger vessels employing more gillnets would indeed exhibit higher fuel consumption.

Locations/Landing sites; For all three countries, fuel use was location-specific. In Uganda, all landings where data was sampled had a negative association with fuel use. Locations could be fuel efficient and associated with shorter travel distances to fishing grounds, this is specifically to coastal island locations such as Nakatiba and Kasenyi Kalangala. Landings with positive coefficients to fuel use such as Remba in Kenya and

Nyamikoma in Tanzania suggest that fishing operations from these landing sites may demand more fuel and potentially navigate longer distances to the fishing grounds.

The adjusted R-squared values for the fuel consumption models underscore their effectiveness in explaining the observed variations. Specifically, the models exhibited a good fit in Uganda (adjusted R-squared of 0.64), a moderate fit in Kenya (adjusted R-squared of 0.54), and a relatively weaker fit in Tanzania (adjusted R-squared of 0.45). Full model specifications are specified below.

Table 2: Fuel model regression results for Motorized vessels in Kenya. Remba and Kokach are landing sites.

Coefficients	Estimate	Std. Error	t value	Pr(>|t|)
(Intercept)	7.131	10.619	0.672	0.502
Hours fished	1.711	0.131	13.020	2e-16
crew	-5.626	3.294	-1.708	0.089.
Longlines	17.725	6.607	2.683	0.00765
Longline number	-0.005	0.002	-2.052	0.041
Remba	20.804	2.833	7.342	1.54e-12
Kokach	-32.161	7.715	-4.169	3.88e-05
Signif. Codes: 0 ''	0.001 ''	0.01 ''		0.05 '.'

Residual standard error: 16.72 on 343 degrees of freedom

Multiple R-squared: 0.537, Adjusted R-squared: 0.529

F-statistic: 66.31 on 6 and 343 DF, p-value: < 2.2e-16

Table 3: Fuel model regression results for motorized vessels in Uganda; SF is for Vessel type Ssese Flat .

Coefficients:	**Estimate**	**Std.Error**	**t value**	**Pr(>|t|)**
(Intercept)	-5.454	5.034	-1.083	0.280
crew	4.690	1.927	2.434	0.016
Hours_fished	0.184	0.133	1.379	0.169
Vessel type_SF	12.661	2.446	5.177	4.75e-07
Nakatiba	-7.769	1.477	-5.261	3.16e-07
Gillnet number	-0.026	0.016	-1.651	0.100
Kasenyi_Wakiso	-9.386	1.981	-4.738	3.69e-06
Kiyindi	-10.747	5.592	-1.922	0.056.
Kasenyi_Kalangala	-11.707	2.002	-5.849	1.60e-08

Signif. codes: 0 ' 0.001 '' 0.01 '' 0.05 '.' 0.1 ' ' 1

Residual standard error: 5.529 on 242 degrees of freedom

Multiple R-squared: 0.641, Adjusted R-squared: 0.629

F-statistic: 53.91 on 8 and 242 DF, p-value: < 2.2e-16

Table 4: Fuel model regression results for motorized vessels in Tanzania.

Coefficients:	**Estimate**	**Std. Error**	**t value**	**Pr(>|t|)**
(Intercept)	-12.416	6.625	-1.874	0.062.
Vessel length	3.672	0.718	5.116	5.30e-07
Hours fished	0.634	0.182	3.492	0.001
Gillnet	-7.656	1.113	-6.882	2.97e-11
Gillnet number	0.035	0.019	1.786	0.075.
Shoka	-7.359	1.218	-6.043	4.06e-09
Zabanga	-8.719	1.656	-5.265	2.52e-07
Nyamikoma	5.172	1.987	2.603	0.010
Signif. Codes:	0 ''	0.001 ''	0.01 ''	0.05 '.'

Residual standard error: 8.016 on 331 degrees of freedom

Multiple R-squared: 0.4533, Adjusted R-squared: 0.4418

F-statistic: 39.21 on 7 and 331 DF, p-value: < 2.2e-16

Appendix 2: SFA Model Specification

Theoretical framework

Earlier models by Battese & Coelli (1995) and Huang & Liu (1994) proposed the general stochastic model for estimating TE and identifying its determinants:

$\text{In}(y)_{it} = x_{it}\beta + v_{it} - u_{it}, i = 1,2, \ldots\ldots, N \text{ and } t = 1,2, \ldots\ldots, T$ ………Equation 1, which is the SFA model. and $u_{it} = \delta_0 + z_{it}\delta + w_{it}$ ……….. Equation 2, which is the inefficiency model. Where, $\text{In}(y)_{it}$ represents the output of the i th firm (vessel) at the t th time; f ($x_{it}\beta$) is the deterministic part of the model, representing the production or efficiency frontier. It is a function of input variables x_{it} and parameters β. v_{it} are assumed to be independent identically distributed-i.i.d) N (0, σ_v^2) random errors which capture the effects of statistical noise, measurement errors, and exogenous shocks beyond the control of the firm.

In Equation 2, z_{it} is a (1XM) vector of explanatory variables associated with technical inefficiency of production of firms over time,

δ is a (MX1) vector of unknown coefficients to be estimated,

Random variable w_{it}, is defined by the truncation of the normal distribution with mean zero and variance σ_w^2, so that at the point of truncation $w_{it} \geq -\delta_0 - Z_i\delta$. The latter is consistent with u_{it} being a non-negative truncation of the $N(u_{it}, \sigma_w^2)$ distribution, where $\mu_{it} = \delta_0 + z_{it}\delta$. When $\mu_{it} = 0$, production lies on the stochastic frontier and the firm is technically efficient; when $\mu_{it} \geq 0$, production lies below the frontier, and the firm is inefficient. Given that the actual production level is $x_{it}\beta + v_{it} - u_{it}$, while the efficient level is $x_{it}\beta + v_{it}$, the TE score for the i th firm at the t th time is given by.

$TE_{it} = e^{-u_{it}} = e^{-(\delta_0 + z_{it}\delta + w_{it})}$ ……Equation 5

The prediction of the technical efficiencies is based on its conditional expectation, given the model assumptions.

The study also employs the parameterization of (Battese & Corra, 1977) who replace σ_v^2 and σ_u^2 with $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and $\gamma = \sigma_u^2 / (\sigma_v^2 + \sigma_u^2)$. This helps in decomposing the error components with significant emphasis on the inefficiency term u. The parameter gamma (γ) must lie between zero and 1. If $\gamma = \text{zero}$, it indicates that the deviations from the frontier are due to entirely random noise (v) whereas if $\gamma = \text{one}$ indicates that the deviations from the frontier are entirely due to inefficiency effects (u) in the model.

Extension of the empirical model

The production frontier model for the three vessel groups is specified in two forms.

i. Cobb Douglas

$\ln Y_{it} = \ln \alpha + \beta_1 \ln G_{it} + \beta_2 \ln F_{it} + \beta_3 L_{it} + \epsilon_{it}$……Equation 3.

ii. Translog functional form.

$\ln Y_{it} = \ln \alpha + \beta_1 \ln G_{it} + \beta_2 \ln F_{it} + \beta_3 L_{it} + \frac{1}{2}\beta_{GG} \ln N_{it}^2 + \frac{1}{2}\beta_{FF} \ln F_{it}^2 + \frac{1}{2}\beta_{LL} \ln L_{it}^2 + \beta_{NF} \ln G_{it} \ln F_{it} + \beta_{NL} \ln G_{it} \ln GL_{it} + \beta_{FL} \ln F_{it} \ln L_{it} + \epsilon_{it}$……. Equation 4.

where i and t refer to the $i - th$ vessel observation in a particular district at time t.

α**,** is the production frontier intercept common to all vessels in the period t

Y_{it} represents the catch in kilograms for two main gears that is Nile perch for the longline (LL) and gillnet (GN) vessels, both of which mainly target Nile perch.

G_{it} represents the total number of gears.

F_{it} represents the quantity of fuel used in liters.

L_{it} represents the labor used as a product of the number of crew per boat and hours fished.

t represents a time trend used as a proxy for technical change for a given vessel group.

Technical change, in this case, is used to describe the ability of a vessel to produce more (or less) with a given vector of input quantities in the period t in comparison to the levels feasible in periods (Coelli et al., 2005).

The model contains the term ϵ_{it} represented as the error term. This is further decomposed into two components specified as.

$\epsilon_{it} = v_{it} - u_{it}$ … … … … … … …Equation 5

v_{it} representing the random noise and u_{it} representing the technical inefficiency component. Since the study aimed to determine vessel technical efficiency for a given period, a model specification (Battese & Coelli, 1995) was specified for the function. This as presented in the section above is given as.

$u_{it} = \delta_0 + z_{it}\delta + w_{it}$ … … ….Equation 6. This has been explained in Equation 2.

Hypothesis testing

Different hypotheses were tested to obtain a more definite functional form of the model fit for the Lake Victoria fishing fleet as indicated below.

The structural form of the production function is the Cobb-Douglas specification or the

Translog specification.

The presence of country-specific inefficiency effects ($z_{it}\delta$)

These were tested using a generalized likelihood ratio test specified.

$$\lambda = -2\{\log[L(H_0)] - \log[L(H_1)\} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \text{Equation 7.}$$

Table 1: Statistics for the hypothesis tests of the stochastic frontier production model.

Vessel Group	**Hypotheses**	**Log-Likelihood**		**Chi-square**	**p-value**	**Decision**
		$\log[L(H_0)]$	$\log[L(H_1)]$			
The production function is Cobb-Douglas, H_0: $\beta_{jk} = 0$	Motorized	-38829	-38580	497.8	< 2.2e-16	Reject H_0
	Paddled	-37120	-36961	318.59	< 2.2e-16	Reject H_0
	Sailed	-27841	-27794	95.3	< 2.2e-16	Reject H_0
Country-specific technical inefficiency effects are absent from the model, H_0: γ= 0	Motorized	-38831	-38475	710.7	< 2.2e-16	Reject H_0
	Paddled	-37335	-36655	1361.3	< 2.2e-16	Reject H_0
	Sailed	-28015	-26510	3010.9	< 2.2e-16	Reject H_0