Nutrition-sensitive solutions for aquaculture development in Africa

A thesis submitted for the degree of
Doctor of Philosophy

By

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March 2023

Abstract

Commercial aquaculture in Africa has boomed in recent years. The capital-intensive growth of tilapia aquaculture in countries like Zambia and Kenya is supplying thousands of tonnes of fish to markets. This has caught the attention of governments, donors and experts who have renewed calls for greater efforts to develop aquaculture in the region. Much of the focus is on defining and measuring production systems and pushing for improvements in production efficiency. While such approaches are important, an overfocus on production and productivity threatens to overshadow approaches that may be more beneficial for human nutrition and health outcomes. A fixation on commercial growth can disaffect smallholders and lower-income consumers who struggle to access the value chain efficiently. This thesis argues for a refocus of the current productivist paradigm towards more nutrition-sensitive aquaculture. It begins with a quantitative assessment of smallholder tilapia farmers in Zambia, teasing out the role of aquaculture to household livelihoods, dietary diversity, and food security; going beyond production potential by assessing the value of fishponds to farming systems and human wellbeing. This is followed by a chapter that introduces a nutrition-sensitive pond polyculture technology trialled in the same rural communities. The results show that cultivating multiple species and promoting intermittent harvesting of various micronutrient-rich fish increases nutrition security for households. The second part of the thesis assesses the oft-overlooked consumer preferences for tilapia compared to other animal-source foods, and why they are important to incorporate into value chain developments. A quantitative consumer study set in Kenya shows how a preference for small tilapia, especially among poorer people, can allow producers to redesign their production systems and target markets. A follow up chapter introduces a nutrition-sensitive solution for commercially-oriented production systems in Kenya, based on the results of a trial that purposively grew small tilapia by increasing stocking densities and shortening production cycles. The thesis concludes with an argument for inclusive value chains and greater food sovereignty where the needs of poor and vulnerable communities are included, and where nutrition and health outcomes are prioritised.

For Katja

Acknowledgments

I thank Universities South Africa (USAf) for nominating me and kick-starting my PhD journey. Thank you to the Commonwealth Scholarship Commission (CSC) for enabling me to reach Stirling - a long-held dream in the making.

Funding for the Zambia component of the doctoral research was provided by the European Union under the program "Putting Research into Use for Nutrition, Sustainable Agriculture and Resilience", and administered by the International Fund for Agricultural Development (IFAD), under the project: *"Managing Aquatic Agricultural Systems to Improve Nutrition and Livelihoods in Selected Asian and African Countries: Scaling Learning from IFAD-WorldFish Collaboration in Bangladesh"* implemented by WorldFish One CGIAR. A special thanks to Dr. Gelson Tembo and Palm Associates for devising the sampling strategy and data collection for this project. I thank the staff of the WorldFish One CGIAR Zambia office and all the communities I visited in Zambia. A special thanks to Lulu and Muleya for roughing it out and collecting crucial pieces of data. I'm grateful to Dr. Shakuntala Thilsted for supporting me in this part of my research.

Funding for the Kenya component of the doctoral research was generously funded by Skretting and Tunga Nutrition, and I was wonderfully hosted by Victory Farms in Kenya. A special thanks to Thijs Berkers from Nutreco, Steve Moran from Victory Farms and Harrison Juma from Tunga Nutrition for joining us in putting the project together.

A special thanks to Tien Nguyen for assisting me in the field. And a very huge thank you to Alex Pounds for helping me put together and monitor the trial on Lake Victoria. The trial would not have happened without the support of Victory Farms staff, namely: Kimweri Fredrick Ajero; Omwange Dancan Omweno; George Dalmas Otieno; Maziga Stephen Odhiambo; Aomo Kevin Odhiambo; and Valentine Oketch.

Thank you to all the enumerators, Winnie, Winfred, and Nso, who assisted with the consumer survey and for the good times we had along the way.

A very special thank you to Daniel Quomsieh for setting me down the long and scary road of statistics and R programming. I cannot believe the progress I made in the last years. But none of the progress would have been possible without the amazing support and patience of Dr. Bruce McAdam. For any prospective PhD students reading this far into the acknowledgments, I cannot urge you enough to find a dedicated statistics tutor to work with you on your journey. For me, it was like learning a new musical instrument and I could not be more content. Thanks, Bruce.

I thank my colleagues and friends, Steph, Wes, Alex, Simao, and Arsenio for the chit-chat and coffees. It was a weird time with the COVID-19 pandemic hitting us smack-bang in the middle of our studies but somehow, we endured, and I think it was partly because we had each other.

Thanks to all the co-authors featured in the thesis for their contributions and support. Late night chats with Jacob across the pond were always worth it.

I have immense gratitude and appreciation for my supervisor, Prof. Dave Little, who I wanted to work with for a long time. Thank you for your dedicated and patient support through all the ups and downs and for pushing me to be my best.

I thank my family, and specifically my parents, Ania and Władysław, for their unwavering support of my education, and for pretending to enjoy my monologues on what I was doing all this time.

Finally, and with most adoration, to my biggest inspiration and supporter – Katja – your care, thoughtfulness, and dedication were a constant and steadfast light for me throughout this journey. I dedicate this work to you, for without you, I would not be where I am, and I only know what joy and love are, because of you. And as if to confirm it all, our baby, Nina, was the sunny and sparkling muse we needed to get this over the line. She couldn't' have come at a better time. Thank you to her and thank you to you.

Declaration

I, the undersigned, hereby declare that this thesis has been composed entirely by me and has not been submitted for any other degree. The work presented in this thesis, except where specifically acknowledged, is the result of my own investigations.

All primary and secondary datasets, and research protocols in this thesis were submitted to the University of Stirling Ethics Board. Surveys with households and individuals were approved by the General University Ethics Panel (GUEP). Research trials with fish were approved by the University of Stirling Animal Welfare Ethical Review Body (AWERB).

Ethical clearance for research in Zambia was provided by the Directorate of Research and Graduate Studies, Humanities and Social Science Research Ethics Committee at the University of Zambia.

Informed consent was obtained from each research participant for all surveys used in this thesis.

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March, 2023

This is to certify that this thesis for the degree of Doctor of Philosophy entitled "Nutrition-sensitive solutions for aquaculture development in Africa " submitted to the University of Stirling (UK), is an original work carried out by Alexander M. Kaminski under my supervision.

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Prof. David C. Little

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March, 2023

Thesis Outline

Nutrition-sensitive solutions for aquaculture development in Africa

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List of Abbreviations

ABW	Average Body Weight
AG	Agriculture group
ALA	α-linolenic acid
ANOVA	Analysis of Variance
AWERB	Animal Welfare Ethical Review
B_{12}	Cobalamin
B_2	Riboflavin
B_3	Niacin
B_9	Folate
Ca	Calcium
CGIAR	Consultative Group for International Agricultural Research
CLS	Crop and Livestock Score
CP	Crude Protein
Cr	Chromium
CSO	Central Statistics Office
Cu	Copper
DGLV	Dark Green Leafy Vegetables
DHA	docosahexaenoic acid
DO	Dissolved Oxygen
DoF	Department of Fisheries
DPC	Direct Production Costs
EPA	eicosapentaenoic acid
FAO	Food and Agriculture Organization
FCR	Feed conversion ratio
Fe	Iron
FFQ	Food Frequency Questionnaire
HDDS	Household Dietary Diversity Score
HFIAS	Household Food Insecurity Access Scale
Ibid.	ibīdem
IFAD	International Fund for Agriculture Development
K	Potassium

KES	Kenyan Shillings
KNBS	Kenya National Bureau of Statistics
L	Litres
Ltd.	Limited company
M1	Model 1
MCA	Multiple correspondence analysis
MDDW	Minimum Dietary Diversity for Women
MT	Metric Tonnes
Mg	Magnesium
MP	Monoculture pond group
NASEM	National Academies of Sciences, Engineering and Medicine
PCA	Principal component analysis
PDS	Production Diversity Score
PP	Polyculture pond group
PSU	Primary Sampling Unit
RNI	Recommended Nutrient Intake
Se	Selenium
SIS	Small indigenous species
spp.	Several species
SSU	Secondary Sampling Unit
T1	Treatment 1
T2	Treatment 2
T3	Treatment 3
TEOW	Terrestrial Ecoregions of the World
UoS	University of Stirling
USD	United States Dollar
WG	Wealth Group
WHO	World Health Organization
WWF	World Wildlife Fund
ZMW	Zambian Kwacha
Zn	Zinc

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Preface

CHAPTER 1

General introduction and methodology

1.1 Problem statement & research overview

As a food commodity, farmed fish has grown substantially in Africa in the last decade (Mapfumo, 2022). Tilapia farming particularly has experienced a commercial boom on some of Africa’s largest lakes (Kaminski et al., 2018; Njiru et al., 2018). Aquaculture has provided jobs for thousands of people and supplied fish for hundreds of thousands more (FAO, 2022). Rising urbanisation rates and a growing middle class has fuelled an appetite for high quality, fresh fish purchased mostly from supermarkets and retail outlets (Reardon et al., 2012; Tschirley et al., 2015). These emerging, high-end value chains for farmed fresh fish complement the traditional dried and smoked fish sourced from artisanal fisheries and sold in informal markets. Due to stagnating capture fisheries and population growth, aquaculture is strongly touted to play an important role in supplying fish on the continent in the future (Chan et al., 2019). Where this fish will come from and who will access it is a key question for many researchers and practitioners (Hicks et al., 2022; Lynch et al., 2016; Tran et al., 2019).

In 2015, an estimated 33% of all people involved in fish production globally were engaged in aquaculture (Lynch et al., 2017), and this is expected to rise to 52% by 2025, with most of the employment generated in lower-income countries (FAO, 2018). The share of fish that will come from aquaculture in Africa is expected to double by the year 2050, though the fish supply per capita is expected to decline due to rising population growth and stagnating production from capture fisheries (Chan et al., 2019). Since the turn of the millennium, aquaculture production in sub-Saharan Africa has grown by 11% annually on average — almost twice as fast compared with the rest of the world, with some countries reaching over 20% growth per year (Ragasa et al., 2022a). This expansion is evident mostly in inland water systems where there has been an increase from just 9 cages in 2006 to 20,000 in 2019 in lakes Victoria (Kenya, Tanzania, Uganda), Kariba (Zambia, Zimbabwe), Kivu (Rwanda, Democratic Republic of the Congo), Muhazi (Rwanda) and Volta (Ghana), which together comprise 91% of the total inland cage aquaculture in Africa (Musinguzi et al., 2019).

Most farmed fish today come from large commercial, capital-intensive cage farms with vertically integrated supply chains and distribution channels that target the top of the economic pyramid (Kaminski et al., 2018). There is some criticism that large-scale operators produce predominately large fish for export or for wealthier segments of society (Genschick et al., 2018; Marinda et al., 2018). There is a wealth differentiation in tilapia consumption in Zambia for example, where poorer segments of society purchase smaller tilapia imported mostly from Asia, while larger, domestically produced tilapia are purchased from supermarkets by wealthier consumers (Genschick et al., 2017).

The share of capture fisheries to total fish supply compared to aquaculture is projected to drop from 83% in 2015 to 46% in 2050, and most employment benefits are expected to rise in the aquaculture sector, especially in rural areas (Chan et al., 2021). Given the low value and decreasing availability of fish from capture fisheries compared to other animal-source products, farmed fish will need to become cheaper and target poorer people, especially those outside urban centres (de Bruyn et al., 2021). For aquaculture to become a growing supplier of fish, especially for those lower down the economic pyramid and living in remote rural areas, more smallholders will need to engage in fish cultivation (Beveridge et al., 2013). With a rapidly commercialising value chain, significant opportunities will emerge for smallholders and small-to-medium-sized (SME) operators, who will need to step up production to meet a growing fish supply deficit on the continent.

There has been some, albeit limited, evidence that aquaculture can alleviate poverty through employment and increased incomes for smallholder homesteads and other value chain actors in Africa (Mulokozi et al., 2020). Some subsistence-oriented smallholders and their immediate neighbours in rural areas benefit by consuming the fish they produce (Aiga et al., 2009). As aquaculture grows however, purely commercial farmers and subsistence-oriented producers diverge from each other supplying different markets and procuring different inputs, thus creating somewhat of a dichotomised value chain with small-scale and large-scale producers occupying different strands (Kaminski et al., 2018). Assessing how inclusive these value chains are, is only recently coming to the fore (Bush et al., 2019; Kaminski et al., 2020).

Economic growth is crucial for sustained poverty reduction though there is evidence that growth can bypass the poor and replicate or even exacerbate inequality (Ali & Son, 2007). Growth that is inclusive should emphasises the need to improve the economic opportunities of the poor, who are generally constrained by circumstances and market failures in the global economic system (Ali & Zhaung, 2007). The degree to which smallholder producers and other poorer value chain actors, including consumers, can participate in, and benefit from, aquaculture development is a contested topic (Stevenson & Irz, 2009; Beveridge et al., 2010). The diversity and dynamism of small-scale actors is rarely considered by policymakers and decision-makers leading to unrealistic assumptions of homogeneity and stasis (Short et al., 2022). Inequalities in food production, distribution and access to resources still underpin and perpetuate food and nutrition insecurity in fish value chains - evident still, in much of Africa (Simmance et al., 2021). How smallholders and SMEs adapt to the changing landscape and rapid commercialisation of the aquaculture industry in Africa is the central theme of this thesis.

The marginalisation of smallholders and poor consumers in aquaculture value chains has been documented before. Mialhe et al*.* (2016) for example, discuss the complex social hierarchies and power relations in the aquaculture sector in the Philippines showcasing how some of the poorest people resorted to gleaning by-products from aquatic food systems after primary species were sold and processed for export. In Tanzania, monopolies inflated market prices and increased competition for small-scale seaweed producers, which had detrimental social effects on poor communities that lacked alternative livelihoods (Bryceson, 2002). There were increasing conflicts over privatisation and intensifying aquaculture practices in Chilika Lake in India, where fishing communities fought for access to water resources (Adduci, 2009). Smallholders and traders in Vietnam struggled to benefit from the lucrative shrimp industry due to stringent standardisation requirements for export markets (Tran et al., 2013). Similar studies have documented the effects of rural transformations on social wellbeing in communities in Bangladesh due to the rapid introduction of brackish water shrimp ponds (Belton, 2016). Soft-shell mud crab farms, also in Bangladesh, went through boom-and-bust periods owing to farmers' reliance on global value chains and a shortage of trash fish as a feed ingredient (Lahiri et al., 2021).

In many of these instances, smallholders as both producers and consumers of aquaculture products, as well as rural populations at large, become marginalised from aquaculture development (de Roos et al., 2019). Genschick et al. (2018) showed how poor consumers in urban Zambia, for example, are mostly excluded from increased availability of farmed tilapia due to affordability and accessibility of these products. While there are many examples of small-scale aquaculture succeeding in places such as Egypt and Nigeria (MacFadyen et al., 2011; Miller & Atanda, 2011), without actively including and recognising the needs of poorer actors and evaluating power asymmetries in the value chain, commercial developments and intensification of aquaculture systems can result in the marginalisation of smallholders and other poor actors (Poole et al., 2013).

When diving deeper into academic literature, donor agency reports and accounts of failed aquaculture ventures in Africa, a different picture emerges from the optimistic one projecting the rise of aquaculture in Africa. This picture shines light on the plight of smallholder farmers and low-income consumers in their struggle to meet basic food and nutrition security, and where aquaculture provides seemingly little value (Harrison, 1996). Despite scientifically proven technologies that demonstrate approaches that can improve productivity, as well as millions of dollars spent from donors and governments in subsidy-based extension models, small-scale aquaculture is often presented as a failure (Limuwa et al., 2018; Matekenya & Ncwadi, 2022). This thesis aims to highlight the value and potential benefits of aquaculture for those that perhaps need it most, and which often gets overlooked. Following this, the thesis aims to provide sustainable solutions that respond to the needs of poorer populations and prioritises their food and nutrition security.

Part of the problem of why the marginalisation of people from aquaculture value chains may go unnoticed is that there is an overfocus on production and productivity of aquaculture systems as metrics of success and development. Such views are regarded as *productivist* and tend to prioritise yields and production over important social and ecological concerns (Tezzo et al., 2020). One can be amiss to assume that based on growing production figures, aquaculture is a rising and resounding success in Africa. Similarly, given dismal productivity figures for smallholder aquaculture systems, one may be forgiven to surmise that small-scale fish farming systems simply do not work and will not play a major part in the aquaculture story on the continent. Furthermore, little is done to try and understand farming livelihoods and the role of aquaculture in the context of larger food systems. Few studies look at the consumption and nutrition benefits of farmed fish on the continent as compared to studies looking at improving production efficiency. Fewer studies look at the multitude of species from capture fisheries and how they compete with farmed fish on the market. As a result, the nuances of how aquaculture affects food security, economic growth, or environmental stability is often lost. Moreso, by not including the views and perceptions of those that utilise and consume fish, there are missed opportunities in making value chains more inclusive.

Using tilapia farming as a case study, this thesis aims to address the imbalances created by a productivist paradigm that encapsulates how academics, donors, and governments often view and operationalise aquaculture on the continent. The thesis is presented in two parts. The first part addresses how smallholder tilapia farmers in Zambia are often relegated to the bottom of a production hierarchy but where fish ponds provide far more value to a household than what is generally measured or considered. Using various tools to quantify dietary diversity, production diversity and food security, this chapter shows the value of aquaculture to rural farming households in some of Zambia's poorest communities. The second part of the thesis considers the viewpoint from end users in fish value chains. This part of the thesis is set in Kenya and uses a quantitative study to understand consumer preferences for tilapia products in relation to other animal-source foods, offering lessons on how commercial tilapia farms can respond to different demands, particularly for people from lower-income communities.

Based on these findings, alternative production approaches to tilapia systems are introduced in both parts of the thesis. These “nutrition-sensitive solutions” are based on lessons from the preceding chapters, which were used to develop empirical trials with fish in smallholder ponds and commercial cages in Zambia and Kenya, respectively. By so doing, the thesis captures a broad range of tilapia farming systems in Africa. These two chapters advocate for the potential of mixed-species production in polyculture systems in Zambia, and purposively growing smaller tilapia in commercial cage-based ventures in Kenya. The thesis will show how these approaches are tailored to the characteristics of farming households and fish markets in the region – namely, that consumers often eat smaller fish; farmers intermittently harvest fish throughout production cycles; farmers grow a diversity of fish for shorter periods of time due to financial constraints; and that aquaculture plays a wider, interconnected role in food systems.

Informing potential approaches to redesigning aquaculture production systems is the hopeful outcome of this research. The lesson is that maximising yields and production efficiency should be done in a way that best responds to the nutritional and food security needs of people. This constitutes a nutrition-sensitive approach to food systems and fish value chains where the needs, nutrient requirements and health outcomes of poorer farmers and consumers are prioritised (Ruel et al., 2018). The thesis ends by promoting a food sovereignty approach to aquatic food systems – one that advocates for especially the vulnerable and poor to decide what kind of food system they want to establish, and which provides them with optimal benefits (social, economic, nutritional, and environmental). Food sovereignty promotes localised food systems where providers and consumers are at the centre of decision-making and where knowledge and skills are developed to fit local socio-economic contexts (Akram-Lodhi, 2015). The goal of food sovereignty in these systems is to improve choices around how people produce food and what they eat so that aquaculture systems better reflect their larger socio-economic and agroecological contexts. The final chapter reflects on food sovereignty discourse, providing some practical examples of how it can be operationalised in aquaculture. By adopting such views, already established commercial operators in the value chain can refocus their strategies and products to be more inclusive of poorer people, while smallholders have more freedom to make better choices on what they produce and consume. Efficacy of food production needs to be determined by human consumption and nutrition benefits in addition to production metrics. The inputs from and impacts on smallholder farmers and low-income consumers needs to be acknowledged. This is especially critical in areas where malnutrition and food security are still major development challenges.

1.2 The productivist paradigm in aquaculture

Agriculture is the predominant employment sector of poor people in underdeveloped countries and rural economies are responsible for feeding millions of people (Ruel & Alderman, 2013). Meeting the demand for staple grains is the primary challenge for less “productive” systems, especially those that are primarily subsistence-oriented (Pingali, 2012). Although productivity and crop yields have increased dramatically in the last decades, thanks to improvements in technologies and value chain developments, poverty and food insecurity persist across Africa (Gómes & Ricketts, 2013). A rise in calorie consumption has not always been accompanied by improvements in nutritional status despite a rise in demand for non-staple foods such as vegetables fruit, fish, meat and dairy (Pingali, 2015). While improvements in value chains have allowed for an increase in yields of non-staple foods by larger agri-food companies, the transaction costs of linking smallholder farmers into modern high-value commodity chains are still too high (McCullough et al., 2018). The high relative prices of non-staple foods has limited the impact of dietary diversification and nutrition outcomes for especially poorer people (Joshi et al., 2004).

The term productivism “refers to a discourse of agricultural organisation in which the function of farming was singularly conceived as the production of food and fibre, and which prioritised increasing agricultural production over all other considerations” (Woods, 2011, p. 67). Specifically, such views emphasised efforts in intensification, concentration and specialisation of practices and discourses that aimed to maximise production potential (Ilbery & Bowler, 1998). In aquaculture terms, this relates to improvements in feed efficiency, maximising productivity gains from breeding, water quality management and other techniques and technologies that optimise production and growth (Little et al., 2018). The productivist paradigm encapsulates not only how farmers optimise their production potential but this expands to the value chain where institutions, stakeholders, and governance arrangements focus primarily on producing fish and bringing it from farm to market with little consideration for how this reverberates socially or environmentally (Almstedt, 2013). Typically, this relates to all processes related to production, distribution and consumption of foods, often depicted in linear, one-way illustrations as value chains (Kaminski et al., 2020). There is less focus on the diversity, quality and social or ecological benefits of producing and consuming foods under such narratives (Woods, 2011).

Productivist narratives are rife in many assessments of the aquaculture industry in sub-Saharan Africa. Often, the main conclusion is that there is a limited supply of adequate feed and seed in the value chain, a narrative used time and time again to explain why smallholder farmers are underproductive (Brummett et al., 2008; Ragasa et al., 2022a). Smallholder tilapia farmers are subsequently relegated to the bottom of a production hierarchy based on their limited access to inputs, as well as on narrow and imprecise productivity statistics as indicators of their value chain membership and, indirectly, a verdict on their success as fish farmers. There is a belief that tilapia farmers must produce large, market-grade tilapia and can only be productive and efficient if they invest in capital-intensive modifications, such as monoculture systems, sex-reversed seed, and formulated feeds, the efficiency of which is monitored by feed conversion ratios, growth rates and profit margins.

Developing highly productive, commercial monoculture aquaculture systems is probably unattainable for most resource-poor farmers in Africa, yet development agencies and governments keep touting tilapia aquaculture as a poverty alleviation tool (Kaminski et al., 2019; Limuwa et al., 2018; Obiero et al., 2019). While there are calls to develop feed and seed supply chains, little is done on altering the production handbook entirely, and challenging the standard productivist paradigm.

Historically, government and donor-driven programmes have dictated the pace and alignment of aquaculture development in sub-Saharan Africa, targeting smallholder production with the goal of improving household food consumption and therefore, food and nutrition security (Brummett et al. 2008). Little evidence exists that such goals have been achieved via the cultivation of fish in rural communities. For the most part, this is due to a lack of research, however, there is a need to further understand the diverse characteristics and contribution that small-scale farmers make to sustainable and equitable food systems (Short et al., 2022). Aquaculture on the continent is transforming, much like what happened in Asia in the last decades (Hernandez et al., 2018; Filipski & Belton, 2018). Some countries in Africa have experienced commercial growth in feed and seed supply chains following the boom of commercial production systems. Market-led expansion of tilapia aquaculture specifically, is evident in countries such as Nigeria, Uganda, Kenya, Ghana, and Zambia, evidenced by upward trends in capital investment and commercially orientated enterprises with the development of high-quality supply chains and more established relationships in the value chain (Kaminski et al. 2020; Moyo & Rapatsa, 2021). In places such as Myanmar and Bangladesh, commercial transformations in the value chain led to increased adoption of technologies, knowledge, and skills in rural areas whereby smallholders were able to invest in aquaculture, which resulted in positive economic spillovers in local economies (Hernandez et al., 2018; Filipski & Belton, 2018).

In other words, feed and seed capabilities in Africa are improving and formal tilapia markets are emerging, yet this has seemingly done little for smallholder farmers, most of whom do not reap the supposed spillover benefits from commercial investments (Kaminski et al., 2019). In many ways, feed and seed is more readily available in the value chain today, though few small-scale farmers make use of higher quality inputs. While some SME cage farmers may benefit from recent commercial developments, many smallholder pond farmers still struggle to access commercial products (ole-MoiYoi, 2017; Kaminski et al., 2018).

The affordability and logistics of accessing these products is certainly part of the problem, but it also has as much to do with smallholder on-farm capacities and knowledge as it does with a failure by experts to understand the characteristics of these farming systems in the first place. While it may be true that, despite promising agroecological conditions, small-scale tilapia farms in sub-Saharan Africa produce below par what would be considered "standard" production metrics for earthen-pond or small-cage systems (Lundeba et al., 2022; Ragasa et al., 2022b), these narratives tend to ignore the fact that the majority of so called "fish farmers" are, in fact, regular crop and livestock farmers, and usually only cultivate fish as a secondary source of income and food. Understanding the food provisioning, purchasing power and consumption choices of rural households in these areas is rarely considered.

One study in Zambia found that most small-scale tilapia farmers produce less than 100kg of fish per year with a productivity of between 0.5 and 3 tons per hectare (Kaminski et al. 2019). By any tilapia farming handbook standards such statistics would suggest a dismal performance; and any private hatchery or feed producer would be wary to invest in supplying such farmers. The same study found that most of what is produced in homestead ponds goes to household consumption. This may perk the interests of food security practitioners; however, when the study asked farmers about their intentions, 78% said that they would prefer to sell tilapia for profit on the market if they could (Ibid.). What farmers want to do and what they end up doing seems to contribute to a dissociation that many policymakers, researchers and aquaculturists make when discussing the future potential of the sector versus farmers' own realities and objectives. This begs the questions whether the few nutritional wins at being able to self-grow some additional protein for the dinner table is sufficient or whether farmers should be doing more to make the type of profits that aquaculture is touted to be able to make. If we go by the latter, and only use productivity and fish yield as a proxy of success, it is easy, and convenient, to lay the fault at the "lack of feed and seed" as the reason why small-scale farmers cannot extract optimal production efficiency from their systems. If we go by the former, we create a false polarity of aquaculture systems as subsistence versus commercial without seeing potential for both. The choices presented to farmers are thus to either operate extensive systems for subsistence or make capital intensive modifications to upgrade their farms, and compete in commercial value chains dominated by multi-million dollar mega farms (Agarwal, 2014).

In any case, we have little evidence of the role aquaculture systems actually play in food security at an individual, household, or national level in Africa. We are left with little understanding of these systems, yet small-scale farmers keep persevering with “sub-optimal” ponds and cages for a reason, which we choose to interpret using a productivity discourse, thereby misunderstanding their roles and overall importance. In reality, aquaculture value chains in Africa are changing, driven by competing producers, traders and consumers, and the diversity and scale of production and trade goes far beyond traditional versus modern binaries (Bush et al., 2019).

Equally, the overfocus on yields and productivity has disaffected consumers living outside of areas where fish is produced. Farmed aquatic foods have generally been more expensive than wild aquatic foods globally (Villasante et al., 2013). In places such as Ghana, Zambia and Kenya, farmed tilapia is more expensive than wild tilapia (Ragasa et al., 2022b; Kaminski et al., 2018; Munguti et al., 2022). While the above mentioned problems facing smallholder farmers has left the door open for commercial farmers to produce thousands of tonnes of fish, the limited number of farms and competition from capture fisheries has allowed large-scale commercial producers to target their fish to high-end markets and retail outlets at premium prices (Chikowi et al., 2021). Since poor households in developing countries spend most of their income on purchasing food, and since deviations in food prices have considerable nutritional and health impacts, the ability for poor people to access and afford farmed fish is limited (Sahn, 2015). This is especially so for rural populations.

There is a growing recognition that including the needs and preferences of certain markets or value chain segments, such as poorer farmers, youth and women, into value chain developments can lead to improved adoption rates of agricultural technologies (Ashby & Polar, 2019). A study in Egypt found gender and wealth differences in consumer preferences for different morphological measurements and sizes of tilapia, suggesting better product targeting for these groups (Murphy et al., 2020). In Sri Lanka, smaller tilapia were preferred by poorer households because of its low cost (Murray & Little, 2022). In Bangladesh and India, Mehar et al., (2022) found different gender and geographical differences in preferences and overall ranking of different fish species. Similar studies on preferences for tilapia in Bangladesh concluded that farmers and breeders could respond to preferred traits such as freshness, taste, or size by improving farm management and value chain practices (Mehar et al., 2023). Expressing preferences into well-defined traits and assessing trade-offs in genetic improvement programmes can make fish value chains more inclusive (Mehar et al., 2019). Developing systems that increase access to safe and nutritious foods and the wellbeing of actors in the food system are critical to overcoming global challenges such as malnutrition, structural inequality, environmental sustainably and climate change (Simmance et al., 2021). Despite these challenges, there are ways in which aquaculture can improve access to nutritious foods. By researching people's livelihoods, market access, purchasing power and dietary preferences and consumption, we may be able to develop systems that can be both productive and sensitive to the nutritional needs of human populations (Golden et al., 2016).

1.3 Nutrition-sensitive food systems

Aquatic foods currently supply nearly 20% of animal protein for over 3 billion people, providing a rich source of vitamins, minerals, and omega-3 fatty acids that are essential to human health (Béné et al., 2016). Some 845 million people are estimated to be nutritionally dependent on aquatic foods (HLPE, 2014). Fish plays a vital role in addressing micronutrient deficiencies and is a key animal source protein for millions of households in Africa (Byrd et al., 2021, Thilsted et al., 2016). Almost two thirds of women of reproductive age are still affected by micronutrient deficiencies and hidden hunger, with the majority living in African countries (Stevens et al., 2022). Addressing such issues is the primary concern of nutrition-sensitive food systems.

Movements away from productivism, often referred to as post-productivism, look to shift away from quantity to quality in food production, improve diversification and off-farm employment, extensification, and the promotion of sustainable farming (Ilbery & Bowler, 1998). As economies and structural transformations occur, food systems and their contribution to nutrition outcomes need to adapt (Pingali & Sunder, 2017). The concept of food systems goes beyond simple linear depictions of value chains and looks at transdisciplinary social and environmental trade-offs and synergies across production, food provisioning and consumption activities (Tezzo et al., 2020). Central to food systems is thus, attaining food and nutrition security, which is understood as the condition related to the availability accessibility and utilization of food (Eakin et al., 2016). Understanding how food systems respond to and govern the interaction between these conditions of food and nutrition security is fundamental to nutrition-sensitive agriculture (Ericksen, 2008; Ingram, 2011). Contrary to the productivist paradigm, the focus goes beyond promoting production technologies and increasing output, by also looking at how foods are accessed, cooked, consumed, and even how nutrients are absorbed (Ickowitz et al., 2019; Béné et al., 2019)

Nutrition-sensitive agriculture seeks to maximize the benefits of farming by optimising diversification, improving nutrition, valuing the social significance of food, and supporting livelihoods (Uccello et al. 2017). The overarching aim of nutrition-sensitive agriculture is to enhance the diversity, quality and safety of food systems and make them more accessible and inclusive to all people at all times (Pingali & Suner, 2017). Nutrition-sensitive solutions require deliberate policy-oriented approaches in combination with infrastructure investments and incentives for consumers to either change their consumption behaviours or for producers to produce more nutritious foods at accessible prices (Ruel et al., 2018). Designing production systems, products and value chains to promote dietary diversity is a key objective. Diverse diets provide a balance in calories, protein and micronutrient intake (Arimond et al., 2010). In smallholder systems that may be deemed “less productive”, increasing farm production diversity is an important aspect of increasing household dietary diversity in addition to enabling access to purchased foods (Jones et al., 2014).

Elsewhere, value chain interventions that aim to balance food prices can be helpful, as are communication tools that empower consumers to make better food choices (Allen & de Brauw, 2016). Some examples of nutrition-sensitive agriculture can be found in the promotion of biofortified foods, homestead gardens, or improved animal husbandry and irrigation capabilities (Ruel et al., 2018). Behavioural change communication tools may include the promotion of optimal feeding practices for children or how to make better food choices (Mary et al., 2018; Di Prima et al., 2022). At the governance level, various policies and regulations can promote the production, distribution and consumption of nutritious foods via taxes, subsidies, certification, and standardisation (Pingali & Suner, 2017).

There are examples of nutrition-sensitive solutions in aquaculture and fisheries. In Ghana, efforts at improving the quality of “trash fish” caught by industrial trawlers improved per capita consumption of fish in poor areas (Nunoo et al., 2009). There are further examples of nutrition-sensitive products such as fish chutney or fish powder used to improve the diets and nutrition of especially women and children in the first 1000 days of life (Mamun et al., 2022; Banna et al., 2022). Peñarubia et al., (2022) details how value addition of tilapia by-products can be used to create alternative food products or even non-food products such as leather or fertilizer, thus improving human nutrition but also livelihood opportunities. Studies in Zambia have shown how gender inclusion and improved fish processing technologies can impact on gender relations, making value chains more inclusive and producing higher quality fish products (Cole et al., 2020). In Bangladesh, the promotion of backyard pond farming in polyculture with multiple small indigenous species has promoted greater micronutrient intake in farming households (Bogard et al., 2015; Castine et al., 2017). While many of these interventions deal with improving products and making value chains more inclusive, few aim to redesign the actual production system - with the exception of the last polyculture example. Challenging the productivist paradigm at the production node of a value chain is a key focal point of this thesis.

Aquaculture specifically encompasses a range of species and cultivation methods, resulting in diverse social, economic, nutritional, and environmental outcomes (Gephart et al., 2021). In recent years the trade-offs between the environmental and nutritional performance of fish production have been considered in the broader context of sustainability, human nutrition, and climate change (Halpern et al. 2019; Fry et al., 2016). The contribution of aquaculture to nutrition outcomes varies widely, depending not only on the species produced but also on how this influences human wellbeing and environmental health outcomes in local contexts (Thilsted et al., 2016; Fisher et al., 2017). Recognition of this has spurred a push for nutrition-sensitive aquaculture, the goals of which are to (i) support public health outcomes through the production of diverse aquatic foods, (ii) provide multiple, rich sources of essential, bioavailable nutrients, and (iii) support equitable access to nutritionally adequate, safe, and culturally acceptable diets that meet food preferences for all populations, without compromising ecosystem functions, other food systems, and livelihoods (Gephart et al., 2021). The same study concludes that: “Key to nutrition-sensitive aquaculture is the shift from looking at aquaculture as primarily a means to produce seafood [aquatic foods] toward a means to create wellbeing, which necessitates accounting for socio-economic, environmental, and cultural dimensions” (Ibid.).

1.4 Objectives of the thesis

In the context of the historical development of aquaculture in Africa and the above-mentioned goals of nutrition-sensitive agriculture, the thesis aims to move beyond assessing productivity of aquaculture systems by finding practical solutions for smallholder and commercial aquaculture, enabling greater responsiveness to the food and security needs of human populations. The thesis thus has four broad objectives, the first two which focus on assessing linkages between aquaculture and food security in rural smallholder systems; while the last two focus on how commercial aquaculture can respond to the preferences of different market segments:

i. To assess smallholder aquaculture systems in Africa and highlight the value of pond culture to the food and nutrition security of rural households.
ii. To redesign smallholder aquaculture in food insecure regions to be more nutrition-sensitive by introducing pond-based polyculture and intermittent harvesting.
iii. To assess consumer preferences for animal-source foods with a focus on tilapia size differentiation, in the context of a rapidly commercializing cage aquaculture sector in the region.

iv. To redesign commercial cage systems to be more nutrition-sensitive by increasing stocking densities and shortening production cycles and/or introducing partial harvests for greater product size differentiation and targeted marketing.

The thesis uses the case of tilapia farming in Zambia and Kenya to illustrate and evidence these objectives. The subsequent chapters have their own set of research questions, all of which aim to satisfy the above overarching objectives.

1.5 Methodology overview

The thesis relied on a mixed methods approach using various tools from social and natural sciences to assess and reconfigure aquatic food systems. The thesis aimed to bridge some of these approaches by looking primarily at the social and biophysical dimensions of aquaculture in line with the above overarching objectives. Below is a brief description of the study areas and justification of why they were selected. This is followed by a background on the projects and timeline of the doctoral research, as well as a brief description of the methods and units of study that make up the focus of this thesis. Since all subsequent chapters have their own *Materials & Methods* sections, only a brief overview is presented here.

1.5.1 Background to study areas

Zambia and Kenya both provide ideal case studies for understanding the problems and potential solutions for aquaculture development in Africa, as depicted in the preceding sections. Both countries have a long history of aquaculture development, primarily led by governments and the donor community, which has resulted in low level adoption and retention of low input pond aquaculture in geographical clusters (Kaminski et al., 2018; ole-MoiYoi, 2017). There is a burgeoning small-scale cage sector around some of the lakes found in both countries, though total yields from these operators are still relatively small (Avadí et al., 2020; Musa et al., 2021). Tilapia is the primary fish cultivated in both countries though capture fisheries still contribute the overwhelming bulk of total fish supply, with aquaculture making-up less than 20% and 30% in Zambia and Kenya, respectively (Kaminski et al., 2018; Munguti et al., 2022). In terms of total yield produced per annum, both countries are among the top five aquaculture producers in Africa (FAO, 2020). This is mostly due to the tremendous growth in tilapia yields, particularly from large capital-intensive investments in cage production on Lakes Kariba and Victoria, specifically (Avadí et al., 2020; Njiru et al., 2018). In both countries a handful of large-scale operators dominate the total yield of aquaculture products. Even though both countries have recently experienced a rise in tilapia consumption, most tilapia still comes from capture fisheries, and increasingly more tilapia are imported from Asian farms (Genschick et al., 2018; Opiyo et al., 2018).

As described above, the value chains in both countries are somewhat dichotomised, where wealthier segments of society enjoy the recent influx of large, fresh tilapia in supermarkets, while poorer segments of society rely on small dried fish value chains or cheaper wild tilapia that are dried/smoked or imported from Asia (Kaminski et al., 2018; Munguti et al., 2022). The fish supply from small-scale aquaculture (ponds and cages) is still too low to mark any significant shift in consumption habits, especially in poorer urban suburbs or rural areas (Marinda et al., 2018; Obiero et al., 2014). Other than households who grow fish in more subsistence-oriented farming systems and their immediate neighbours, few other Zambians and Kenyans below the poverty line consume farmed tilapia.

This suggests, as presented above, that consumers and small-scale farmers are yet to benefit adequately from the commercialising aquaculture value chain, or at least there is little data evidencing what the true benefits are. Despite persistent donor and government-funded programmes and the development of commercial supply chains for feed and seed, small-scale farmers still struggle to grow fish efficiently to turn a profit (ole-MoiYoi, 2017). Extension officers and NGO practitioners often encourage techniques and technologies to try and maximise production efficiency. While there are some promising results (see Lundeba et al., 2022), these approaches are rarely scaled-out and many farmers are unable to adopt such approaches due to financial constraints.

The methods used in this thesis aim to view the development of aquaculture from different perspectives. Contrary to studies that try to assess the productivity of smallholder systems, the thesis aims to understand the role of aquaculture systems to farming households. The thesis also relies on the views and preferences of consumers at the end of the value chain, to further understand tilapia markets in the context of other competing animal source food products. This is done with the view of incorporating these preferences into the redesign of value chains and production systems. The results and potential solutions depicted in this thesis are specific to both countries, but could be easily transferred to other tilapia producing countries in the region, such as Uganda, Rwanda, Tanzania, Malawi, Nigeria or Ghana, to name a few.

1.5.2 Project background and timeline of doctoral research

The PhD student, a Commonwealth scholar nominated by Universities South Africa[1] (USAf), commenced his doctoral studies in October of 2018. After spending half a year on campus the student travelled to Zambia in May 2019, hosted by WorldFish, an international research institute part of the Consultative Group on International Agricultural Research (CGIAR). Under an agreement with WorldFish, the PhD student provided research support on a project entitled *"Piloting inclusive business and entrepreneurial models for smallholder fish farmers and poor value chain actors in Zambia and Malawi"* led by WorldFish in partnership with the Institute of Aquaculture at the University of Stirling (UoS) and funded by the Federal Ministry of Economic Cooperation and Development (BMZ) in Germany. The first months in the field were spent familiarising the student to WorldFish programmes and collecting secondary data sources in addition to conducting a literature review and preparing for the implementation of the project.

In this time, the PhD student collected several unpublished raw datasets from WorldFish in Zambia and Malawi. The student worked with several other researchers at WorldFish to set up a polyculture pond experiment in northern Zambia under a project funded by the International Fund for Agricultural

[1] https://www.usaf.ac.za/

Development (IFAD). The above mentioned BMZ project was delayed and ultimately the agreement between UoS and WorldFish never materialised. This was compounded further by the outbreak of the COVID-19 pandemic in March 2020. By this time, the PhD student returned to Stirling. Under an agreement with WorldFish, the student began analysing the secondary datasets collected during his time in Zambia, including the data from the polyculture trial set up under the IFAD programme. Two of these datasets would ultimately form chapters 2 & 3 of his thesis. By this time, the student had shifted his topic focus from inclusive business models in aquaculture to nutrition-sensitive aquaculture, despite publishing a review paper on the former by the end of 2019 (see Table 3). Only brief excerpts from this first publication are used in this thesis.

The two quantitative datasets from Zambia were part of a project funded by the European Union (EU) and administered by IFAD, with WorldFish as the implementing partner. The project was titled *“Managing Aquatic Agricultural Systems to Improve Nutrition and Livelihoods in Selected Asian and African Countries: Scaling Learning from IFAD-WorldFish Collaboration in Bangladesh”*. The first dataset was collected by WorldFish scientists at the end of 2017, but due to unforeseen circumstances was yet to be analysed. This dataset detailed the livelihood and dietary characteristics of 382 households in northern Zambia, of which around half were made up of households that practiced aquaculture, and the other half that did not. Data for the second dataset, although designed by the student in partnership with WorldFish during his stay in Zambia, was collected in the field by WorldFish staff between September 2019 and March 2020. This dataset comprised of a pond trial in the same study sites as the first dataset. The trial introduced the concept of pond polyculture with multiple species to 20 farming households. Food diaries were used over a 6-month period noting households’ frequency of consumption of fish species from polyculture ponds as compared to different sources of fish (e.g. markets or lakes). The results were compared to 20 other households over the same period that did not practice aquaculture and 17 households that practiced only monoculture farming of tilapia.

The COVID-19 pandemic severely impacted research and funding activities for over two years. Students and university staff were unable to travel and many funding opportunities ceased. Fortunately, the student had access to these datasets from Zambia and spent this time analysing the data.

By the end of 2021, the student and his supervisor applied for funding to the Knowledge Transfer Network (KTN) of Innovate UK, funded by United Kingdom Research and Innovation (UKRI). The proposal set out to collect a consumer survey of tilapia preferences in rural and urban Kenya. The key focus was to determine consumer preferences for different type of fish products, including specifically size of tilapia. The second component of the proposal was to conduct a trial in commercial cages on Lake Victoria to assess the production and economic efficiency of purposively growing small tilapia by increasing stocking densities and shortening production cycles. The project partners included a local commercial fish farm (Victory Farms Ltd.) and a local feed supplier (Tunga Nutrition, a subsidiary of Skretting). Although much time was spent on securing partners and establishing project objectives, the entire funding grant was withdrawn due to the impact of COVID-19 on government budgets in the UK.

Fortunately, the student and his supervisor were able to convince the project partners that the study should commence and funding was successfully sought directly from Skretting as a private sector funder. The student travelled to Kenya in May of 2022 and spent three weeks in Nairobi and Kisumu to conduct the consumer survey. With the assistance of a master's student from the Institute of Aquaculture, additional surveys were administered to consumers in rural areas around Lake Victoria. The PhD student spent time at Victory Farms Ltd. setting up the trial and monitoring the results. The trial commenced under the student's supervision in partnership with Victory Farms staff who collected the data. The trial finished in July of 2022. The above mentioned KTN project was eventually funded by the end of 2022. However, since the original trial was now complete, a novel adaptation using mixed-sex fingerlings was included as an additional component of the trial. Although still involved with this project, the student had enough primary data to complete his PhD thesis and the trial was implemented by other colleagues at the Institute of Aquaculture. An overview of the thesis timeline can be seen in Table 1.

Table 1.1. *Overview of projects and timeline*

Country and time in field	Project partners & funders	Objective in the field	Data for chapter
Zambia May – August 2019	Hosted by WorldFish, funded by International Fund for Agricultural Development (IFAD)	Analyse secondary datasets collected by WorldFish in 2017	Chapter 2
Zambia September 2019		Assist in setting up pond trial and analyse data collected by WorldFish in 2019	Chapter 3
Kenya May – June 2022	Hosted by Victory Farms Ltd., funded by Skretting and Tunga Nutrition	Design and collect primary data from urban and rural consumers	Chapter 4
Kenya February – June 2022		Design and collect primary production data from caged fish trial	Chapter 5

1.5.3 Brief overview of materials and methods

Part 1 of the thesis depicts the smallholder and rural homestead nodes of a typical aquaculture value chain in Africa, where small-scale earthen pond farmers are both producers and consumers of fish. This part of the thesis is set in rural Zambia and aims to provide an in-depth view of pond farming, focusing on the many impacts the system has on livelihoods and food security of rural homesteads. Here, the thesis introduces the concept of small-scale tilapia farming in smallholder systems, its challenges, and its potential value to crop diversification, diets and overall food security status. The study was conducted in northern Zambia with 382 households with just under half of the sample having practiced aquaculture in the preceding 12 months. The other half of the sampled households never practiced aquaculture. The sampling was done intentionally to assess the benefits of adopting aquaculture into a household's livelihood portfolio. The study used dietary metrics typically found in public health sciences to measure the dietary diversity of households. Improving dietary diversity is a key focus of nutrition-sensitive agriculture interventions (Pingali & Sunder, 2017). The survey asked respondents what they ate and how often they ate it, focusing on several food groups and specifically the many different types of fish species consumed. The study also attempted to understand crop diversification on the farm and how aquaculture plays a role in farming systems. Two regression analyses were used to predict dietary diversity and food security status with various livelihood and dietary characteristics as predictors. This chapter concludes with an overview of how adopting aquaculture offers different pathways to achieving food and nutrition security.

The second chapter in Part 1 of the thesis also takes place in Zambia, in the same district to be exact, and introduced a nutrition-sensitive solution to small-scale pond farming that is more responsive to the needs and characteristics of rural smallholder farms, as found in the preceding chapter. This study tested the efficacy of a pond polyculture intervention with farming households in northern Zambia. Longitudinal data on fish consumption and the associated nutrient intake of households (N = 57) were collected over a six-month period (September 2019–March 2020). One group of households tested the intervention while another group that practiced monoculture tilapia farming, and a third group that did not practice aquaculture, acted as control groups. By knowing the specific fish species and weight (grams) consumed in a household the study was able to measure the amount of micronutrients, vitamins and fatty acids consumed per capita per household. This is in line with nutrition-sensitive approaches that attempt to evidence how agricultural interventions lead to nutritional outcomes (Ruel et al., 2018). The study further assessed the consumption of fish from capture fisheries and markets to see what role aquaculture and specifically pond polyculture played in fish supply compared to these other sources of fish.

Part 2 of the thesis is set in Kenya and also comprises of two chapters. In keeping within food systems framings and nutrition-sensitive approaches, the first chapter in Part 2 (i.e. Chapter 4) takes into account the perceptions and preferences of end users in the value chain, namely consumers in urban and rural areas. The survey was conducted with 729 consumers from urban areas (Nairobi and Kisumu) and several rural areas around Lake Victoria. Many fish farms, by default, end up producing small tilapia almost as a by-product of their growth cycle (due to grading, mixed-sex fingerlings, feeding hierarchies, etc.). There are different sizes of tilapia found in Kenyan and Zambian markets that are usually imported from Asia or caught as juveniles in lakes and rivers (Genschick et al., 2017; Munguti et al., 2022). Since small tilapia are produced and consumed in Kenya, the thesis aimed to establish who was eating this fish and why. The study asked respondents to choose from different sizes of tilapia. Using a decision-tree analysis, the study determined which attitudinal and behavioural drivers influenced the choice of tilapia based on size and price. The findings have important implications for the aquaculture sector in Kenya as farmers can actively target their products to different market segments.

In response to the findings of the consumer survey, a trial was set up in commercial cages in Lake Victoria. The aim was to purposively grow small tilapia in cages by changing two distinct production strategies. One strategy was to increase stocking density to maximise the biomass of the cage. The other strategy was to shorten the production cycle and harvest smaller fish. This was done either through a partial harvest or by reducing the number of days of culture. The trial looked at the biological and economic efficiencies of producing small tilapia with relevant findings for the Kenyan aquaculture sector. This approach was found to be novel and helps to redesign production systems that can be more responsive to different market segments, especially for those who are poor or suffer from hunger and malnourishment. While these changes are productivist in a sense, as they deal with productivity metrics and yields, they offer a rather radical divergence from the typical production view of tilapia aquaculture systems.

A justification for redesigning production systems towards greater food sovereignty and to achieve nutrition-sensitive agriculture objectives is made in the final chapter. An overview of the methods for each chapter can be found in Table 1.2. A final list of publications, both published, under review or planned for submission are presented in Table 3 below.

Table 1.2. *Overview of methods for each chapter*

Chapters	Unit of analysis	Objective of research	Overview of methods
Chapter 2: Zambia	Smallholder pond aquaculture households vs. non-aquaculture households	To understand the livelihood and dietary predictors of food security for rural households, and what role aquaculture plays in achieving this	• N = 382 households • Household dietary diversity questionnaire and Food Frequency questionnaire • Livelihoods questionnaire • Food security status questionnaire
Chapter 3: Zambia	Smallholder households with polyculture ponds vs. monoculture ponds vs. no ponds	To monitor a trial of polyculture ponds with various smallholder farmers and assess the role ponds play in fish consumption compared to other sources of fish	• N = 57 households • Trial with 20 smallholder pond farmers and multiple species in ponds vs. 37 farmers (control group) • Food diaries and nutrient intake of all fish consumption over 6 months
Chapter 4: Kenya	Urban and rural tilapia consumers	To understand the drivers and preferences for small tilapia	• N = 729 consumers • Consumer questionnaire on preferences for tilapia and other animal-source foods • Decision-tree analysis
Chapter 5: Kenya	Small-scale cages	To monitor a trial in commercial cages on how to purposively grow small tilapia	• N = 18 cages x 3 treatments • Measuring production and economic efficiency of cages with various stocking densities and cycle lengths

Table 1.3. *List of papers and publications*

List of papers	**Status**
First author papers prepared during doctoral research	
A review of inclusive business models and their application in aquaculture development *[not included in thesis*]*	Published in *Reviews in Aquaculture,* 12(23): 10091. (2020)
The role of aquaculture and capture fisheries in meeting food and nutrition security: Testing a nutrition-sensitive pond polyculture intervention in rural Zambia *[Chapter 3]*	Published in *Foods,* 11(9): 1334. (2022)
Smallholder aquaculture diversifies livelihoods and diets thus improving food security status: Evidence from northern Zambia *[Chapter 2]*	Published in *Agriculture and Food Security*, 13(1). (2024)
Growing smaller fish for inclusive markets? Evidence from a trial that increased stocking density and shortened the production cycle of Nile tilapia in Lake Victoria *[Chapter 4]*	Published in *Aquaculture*, 581: 740319. (2024)
Consumer preferences for small tilapia: Implications for aquaculture development in Kenya *[Chapter 5]*	In prep.
Moving on from the productivist paradigm: a food sovereignty and nutrition-sensitive approach to tilapia farming in sub-Saharan Africa [*Chapters 1 & 6*]	To be drafted after PhD submission
Co-author papers published during doctoral research	
Pounds et al., (2022). More Than Fish – Framing aquatic Animals within Sustainable Food Systems	Published in *Foods,* 11(10), 1413. (2022)
Stetkiewicz et al., (2022). Seafood in food security: a call for bridging the terrestrial aquatic divide.	Published in *Frontiers in Sustainable Food Systems* 5, 703152
Short et al., (2021). Harnessing the diversity of small-scale actors is key to the future of aquatic food systems.	Published in *Nature Food, 2*, 733-741

* Due to the impact of Covid-19 pandemic, the thesis changed focus from inclusive business models to nutrition-sensitive solutions. This paper does not feature as a chapter in this thesis but elements of it are integrated into Chapters 1 & 6.

Part 1

Rural homesteads and smallholder systems in Zambia

CHAPTER 2

Smallholder aquaculture diversifies livelihoods and diets thus improving food security status: Evidence from northern Zambia

Published in **Agriculture and Food Security** 2024, 13(1);
https://doi.org/10.1186/s40066-023-00452-2

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Abstract

Much has been made of the potential for aquaculture to improve rural livelihoods and food and nutrition security in Africa, though little evidence exists to back such claims. This study, conducted in northern Zambia, assessed the benefits of aquaculture by comparing a sample of households with (n=177) and without fishponds (n=174). On-farm food production was assessed by summing all crop and livestock activities and calculating a production diversity score (PDS) of key food groups. Aquaculture households had greater crop diversification and were more associated with key nutritious foods grown on the farm, possibly due to additional water irrigation capabilities. A greater diversity of cultivated crops led to better household dietary diversity scores (HDDS). We further assessed the frequency of consumption of 53 food items (including 30 fish species) over a period of four weeks via a Food Frequency Questionnaire (FFQ). Using the Simpson's Index, aquaculture households had greater diversity and evenness in the distribution of foods and fish species consumed, particularly foods grown on the farm. Using livelihood and dietary factors in a multilevel probit regression on the Household Food Insecurity Access Scale (HFIAS), we found that adopting aquaculture gave households almost two times more likelihood of improving their food security status. Households could further improve their food security outcomes by growing and consuming certain vegetables, especially those that could be integrated along pond dykes. Aquaculture should be promoted in the region for its crop diversification and food security benefits, so long as it fits the local farming system and livelihood context. The study suggests three clear pathways to food security. 1) Increasing wealth and income from the sale of fish and integrated vegetables and/or crops, which can be used to purchase a diversity of foods. 2) Increasing food and nutrition security via the direct consumption of fish and vegetables grown on the farm. 3) Improving irrigation capabilities in integrated aquaculture-agriculture systems that has direct impact on pathways 1 and 2. Aquaculture should be promoted in the region for its crop diversification and food security benefits, so long as it fits the local farming system and livelihood context. Moving away from productivist approaches to nutrition-sensitive aquaculture widens the scope of uncovering the many benefits of pond farming in smallholder systems.

Key words: aquaculture; crop diversification; dietary diversity; production diversity; tilapia; Zambia

2.1 Introduction

Aquaculture is often touted to be able to alleviate poverty and improve food and nutrition security for small agricultural homesteads (Beveridge et al., 2013; Béné et al., 2016). Farmers in Africa cultivate a variety of aquatic species; however, the most frequently farmed fish are tilapias, farmed by smallholders and large commercial enterprises alike (Moyo & Rapatsa, 2021). The proliferation of smallholder tilapia farming in Africa has had direct and indirect impacts on poverty reduction and improving food and nutrition security (Macfadyen et al., 2012; Kassam & Dorward, 2017; Dey et al., 2006). Pinpointing the exact pathways by which aquaculture leads to improved food security and nutrition outcomes are notably difficult to discern (Lightfoot et al., 1993).

Given that aquaculture is a relatively new agricultural activity in much of Africa, it is worth assessing it as an agricultural intervention in the same way that biofortified crops or homestead gardens aim to improve household diets and food and nutrition security (Ruel & Alderman, 2013). Aquaculture provides multiple pathways to food and nutrition security by 1) increasing purchasing power via the sale of fish to access more diverse diets (Irwin et al., 2020); and 2) increasing fish consumption via harvesting from ponds (Kaminski et al., 2022). A third, and less acknowledged pathway, is that ponds provide water for irrigation capabilities and thus additional opportunities for horticulture (Ahmed et al., 2014). These pathways aim to contribute to two key pillars of food and nutrition security, namely, improving the access and availability of certain foods via the interplay between farm production diversity and dietary diversity, as well as the diversity (and affordability) of purchased foods (Nandi et al., 2021). The interconnection in understanding the benefits of farming systems is a particularly important and often under-researched component in assessments of smallholder tilapia farmers in sub-Saharan Africa (Hichaambwa et al., 2015). While crop diversification has been shown to benefit rural livelihoods and household diets in Africa, aquaculture as a livelihood activity is notably absent from this body of work (Jones et al., 2014; Sibhatu & Qaim, 2018a; Singh et al., 2020)

In Asia, where aquaculture production has a longer tradition than in Africa, the links between food and nutrition security, incomes, and aquaculture are more explicit (Toufique & Belton, 2014). Aquaculture has had positive effects on income levels, employment and raising fish consumption levels in Bangladesh (Jahan et al., 2010; Ahmed & Waibel, 2019, Khanum et al., 2022). Fishponds contributed to rural economies by improving retail and labour opportunities in Myanmar (Filipski & Belton, 2018). Intercropping fish with rice and vegetables diversified livelihoods and improved incomes of households in the Philippines and Bangladesh (Irz et al., 2007; Belton et al., 2012). The adoption of aquaculture led to crop diversification in farming households in Bangladesh who adopted both aquaculture and horticulture actives, thus leading to better diet quality (Ahmed et al., 2014; Akter et al., 2020). Similar pathways to food security and poverty alleviation surely exist in Africa, meaning that small-scale tilapia farming has the potential to significantly improve the lives of farming households (Chan et al., 2019).

In Zambia, a burgeoning aquaculture sector has had positive effects on fish supplies, commercialising supply chains, and providing opportunities for fish farming among rural populations (Kaminski et al., 2018). Much of the perceived positive impacts of aquaculture can be attributed to the fast-growing, capital-intensive commercial sector (Avadí et al., 2022; Genschick et al., 2018). Many donor-led organisations and the government of Zambia look favourably at aquaculture as a potential solution to poverty and food and nutrition insecurity in rural areas. Zambia is amongst the poorest and most food-insecure countries in the world, with one of the lowest rankings in the global Hunger Index (von Grebmer et al., 2020). Making the linkages between agricultural livelihoods, diets and food and nutrition security is thus critical. Smallholder aquaculture in Zambia is, however, limited by low productivity, lack of markets, and underdeveloped supply chains, with little evidence of its impact on food and nutrition security (Kaminski et al. 2018). Despite these barriers, farming households still persevere with tilapia pond farming, with anecdotal evidence that this provides some additional income or the occasional fish for dinner (Kaminski et al., 2019; Kaminski et al., 2022). The goal of this study is to assess the potential benefits of aquaculture to rural households.

Quantifying the benefits of aquaculture adoption is a difficult task given the vast social, economic, and agroecological differences in tilapia farming systems in the region, and even within villages in Zambia (Kaminski et al., 2019). Previous approaches often failed to consider that many fish farmers in sub-Saharan Africa, and Zambia specifically, are primarily terrestrial crop and/or livestock farmers and only partake in fish farming as a secondary or tertiary livelihood activity (Short et al., 2021). Ponds are often studied in isolation, rather than looking at how they fit into diverse livelihood portfolios or how they are integrated with other agricultural activities, thereby missing important linkages in the farming system. Aquaculture farmers are rarely compared to their neighbours, who do not cultivate fish, which would provide more accurate assessments of food security and income benefits as compared to those who do not adopt aquaculture (Karim & Little, 2017). Finally, many studies overfocus on measuring (estimating) fish productivity in extensive systems through recall methods that are rarely accurate (Lundeba et al., 2022). Such approaches further fail to account for the different ways and reasons why fish are cultivated and harvested, or the different benefits ponds provide throughout the year (Kaminski et al., 2019).

Our assessment begins with the assumption that the true value of tilapia pond farming lies not necessarily in how much fish is produced or how productive a pond is per se, but rather, in the total value ponds provide to a household, based on direct and indirect pathways to food and nutrition security (Stevenson & Irz, 2009). To achieve a more accurate assessment, we selected a randomised and representative sample of aquaculture and non-aquaculture households. We employed several methods to quantify household livelihoods, diets, and food and nutrition security by assessing the role of aquaculture in food production and consumption. The overall objective was to assess whether aquaculture contributes to dietary diversity and food and nutrition security via the above-mentioned pathways. Our specific research questions were: 1) do aquaculture households have more diverse livelihoods (i.e., crop diversification and/or non-farm activities?); 2) do aquaculture households have better access to foods (including fish) and more diverse diets? And 3) if aquaculture affects livelihoods and/or dietary diversity, does this ultimately improve food and nutrition security?

2.2 Materials and methods

2.2.1 Study location

The study was conducted in Luwingu District in the Northern Province of Zambia in September 2017 (see Figure 2.1). Luwingu has a total population of approximately 80,000 people as of the last census conducted in 2014 (CSO, 2015). Over 80% of households are classified as rural agricultural households (CSO, 2019). Most households engage in some form of farming, typically growing a combination of maize, cassava, beans, and groundnuts (Mulungu & Mudege, 2020). Farmers in the north of Zambia rarely engage in livestock and poultry, generally favouring traditional crops in a rotational system throughout the year (Grogan et al., 2013). The district is home to Lake Bangweulu, a major source of capture fisheries in the region, which is critical to the diets of local households (O'Meara et al., 2021). According to the Department of Fisheries (DoF), approximately 400 households were officially registered as practicing aquaculture in 2017, accounting for around 3% of all households in the district. This was later verified by an updated census of fish farmers conducted by WorldFish in 2019 where 412 farmers were officially registered as practicing aquaculture (Kakwasha et al., 2020).

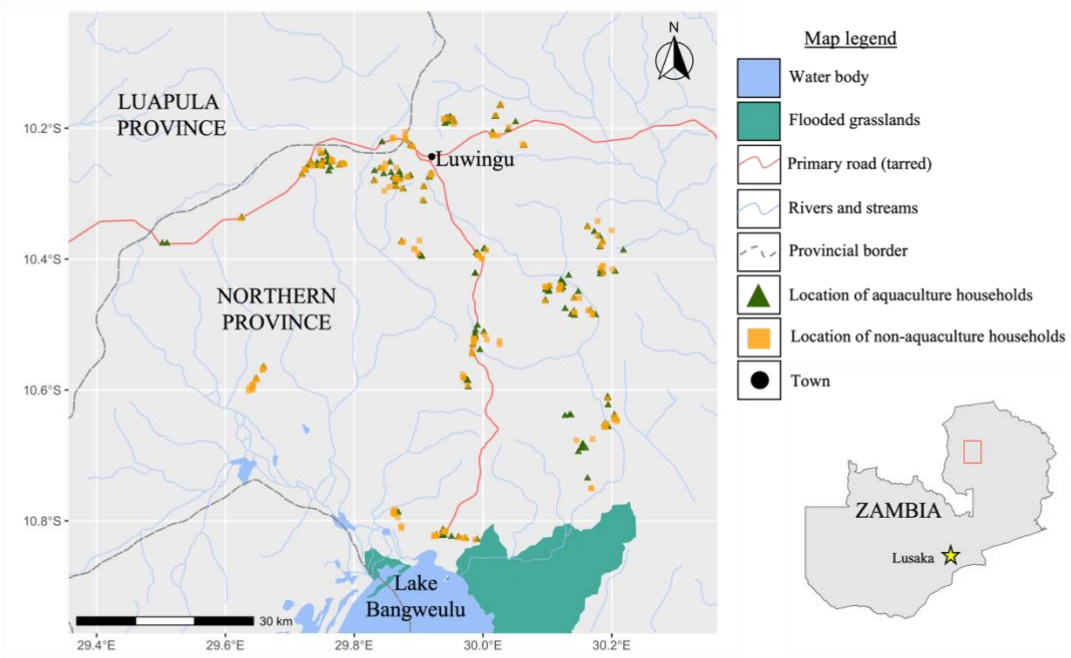


***Figure 2.1**. Map of study site locations in Northern Province, Zambia. Data for the flooded grasslands biome is from Terrestrial Ecoregions of the World (TEOW) (Dinerstein, et al., 2017); rivers and water bodies are from the HydroATLAS (Linke et al., 2019) and HydroATLAS-Zambia (Lehner, 2020)*

Northern Province is home to 3,255 fish farmers, more than a third of all fish farmers in the country, of which around 13% were registered in Luwingu

(4.3% of all fish farmers in the country) (CSO, 2019). Luwingu District has been the target of many donor-led aquaculture interventions over the last years, providing a suitable site to assess the benefits of adopting aquaculture (Kaminski et al., 2018; Lundeba et al., 2022; Kaminski et al., 2022). The province has some of the highest rates of households living in poverty, with over 43% of households reported to belong to the lowest wealth quintile, according to the National Demographic and Health Survey (CSO, 2015). Rural households in Zambia suffer from high levels of hunger and micronutrient malnutrition, with an estimated 19% of women and children suffering from critical micronutrient deficiencies (Harris et al., 2019; Kaliwile et al., 2019).

2.2.2 Study design and sample

Study participants were selected using convenience sampling methods. Given the small proportion of fish farmers to the general population in the district, probability sampling methods were deemed inappropriate. First, a sampling frame of all wards with registered fish farmers was established through consultations with DoF registrars (13 wards in total, with over 70 individual villages, 24 of which had registered farmers). To have a comparative sample, we aimed to interview close to 50% of all fish farmers in the district. The aim was to have half the study sample represented by aquaculture households and the other half represented by non-aquaculture households. Inclusion criteria for aquaculture households were either to have 1) stocked ponds at the time of survey, or 2) harvested fish in the preceding 12 months. For each selected village, the sampling frame for the households was generated by using the village household registrar, in consultation with village authorities. A random number generator was used to select up to eight aquaculture households per village for inclusion in the study. In some villages, there were less than four households that conducted aquaculture, which meant some discretion was used to combine villages (if they were in proximity). The same sampling process was administered for non-aquaculture households based on how many aquaculture households were chosen.

A total of 382 households were selected to participate in this study, with around half represented by fish farmers. We dropped 9 non-aquaculture households from the analysis, due to inaccurate responses. A further 22 aquaculture households were removed for not meeting the selection criteria. This meant that 9.5% of the sampled aquaculture households had abandoned production prior to the study and were removed from the analysis. A similar rate of pond abandonment in the region was found in other studies (Kaminski et al., 2018; Kakwasha et al., 2020). The final sample size used in the analysis, therefore, was 351 households: 177 aquaculture households and 174 non-aquaculture households.

2.2.3 Quantitative scores and indices

All data were collected using tablets and coded in KoBo Toolbox (www.kobotoolbox.org). All analyses and graphical illustrations were computed using R Studio software (ver. 1.3.1056).

2.2.3.1 Household and livelihood characteristics

The first part of the survey was administered, in the local language, to the person responsible for agricultural production, who, in all cases, was the head of the household. Individual and household characteristics were obtained: sex and age of the household head, their marital and educational status, along with household size and estimated yearly income of the household. Given the skewed distribution of income (in Zambian Kwacha), this was converted to a logarithmic scale for analysis.

Using key informant interviews with government agricultural extension officers, we developed a list of livelihood activities, including farming and non-farming activities for the area. Farmers answered “Yes” or “No” if they participated in a livelihood activity in the previous 12 months, regardless of whether it generated an income or not. There were three quantitative scores developed from this list. The first was a total Crop and Livestock Score (CLS), which represents the total sum of all on-farm activities, excluding aquaculture. Crop diversity has been associated with better household diet quality in subsistence-orientated farming households (Jones, 2017). Livestock and poultry were combined into one score given that few households engaged in these activities while all other individual crops and vegetables received their own score. The list did not include the number of animals on the farm, production yields or the amount of land under cultivation. Past studies have shown that a higher diversity of on-farm production activities (food and cash crops) led to improved dietary diversity and food security (Jones et al., 2014; Sibhatu & Qaim, 2018b).

The second score was the sum of all non-farm activities. The third score was a Production Diversity Score (PDS), which grouped only the food crops and livestock/poultry grown on the farm into key nutritional food groups for human consumption (Muthini et al., 2020). In places such as rural Zambia where subsistence food production is key to household food security, the PDS was determined to be an appropriate measure of the diversity of self-produced foods (Jones, 2017).

Notably in our study, we did not discern which of the foods captured in the PDS were consumed in the household and which were sold in markets. Based on the list of foods produced at household level we grouped these into 12 common food groups for human consumption: i) cereals and grains; (ii) white roots tubers; (iii) pulses; (iv) nuts and seeds; (v) dairy; (vi) meat; (vii) fish; (viii) eggs; (ix) dark green leafy vegetables (DGLV); vitamin-A rich vegetables; (xi) fruit (xii) other vegetables (e.g., tomatoes, onions, okra, cabbage, etc.). We focused on the nutritional importance of these food by separating animal-source foods into dairy, meat, fish and eggs, while also highlighting the nutritional importance of vitamin-A rich foods and DGLV, thus borrowing from several commonly used food group scores (Arimond et al., 2010). Some of these scores, such as the Minimum Dietary Diversity for Women (MDDW) group roots and tubers with grains and cereals. We separated white roots and tubers from those considered vitamin-A-rich to highlight the importance of the latter to nutritional outcomes. In the absence of staple grains, many households often depend on white roots and tubers instead, which has important nutritional consequences given that they are less nutritious than certain key staple grains consumed in Zambia (Harris et al., 2019).

2.2.3.2 Dietary characteristics

The second part of the survey was made up of three components designed to assess dietary diversity. This part of the survey was administered to the person in charge of food preparation in the household. The first component was measured by the Household Dietary Diversity Score (HDDS). The HDDS is a continuous score (0-12) based on the total sum of food groups consumed in the past 24 hours: (i) cereals; (ii) roots and tubers; (iii) vegetables; (iv) fruits; (v) meat, poultry, offal; (vi) eggs; (vii) fish and seafood; (viii) pulses/legumes/nuts; (ix) milk and milk products; (x) oil/fats; (xi) sugar/honey; or (xii) miscellaneous (condiments, sodas, sweets, etc.). Notably, the HDDS food groups differ from the PDS food groups as they contain oils/fats, sugar, and other miscellaneous food categories not typically cultivated on a farm.

The HDDS is a globally recognised score that reflects a household's economic access to different foods (self-grown and purchased), including food categories that may be considered as micronutrient-poor (Headey & Ecker, 2013). The HDDS has been validated against caloric availability, though it is not a measure of nutrient adequacy, therefore, there is no official recommendation of how many food groups households should consume (Kennedy et al., 2011). The HDDS score is used as an independent and dependent variable in two separate regressions in this study, discussed in further detail below. For our study, we categorized households into three groups based on the HDDS score for comparative purposes: "Low HDDS" (≤ 4 food groups); "Average HDDS" (5-6 food groups); and "High HDDS" (≥ 7 food groups). This was determined by the fact that just over 50% of respondents (upper and lower quartile range) in both study groups consumed 5-6 food groups. These categories are not used in any predictive models but rather they serve as a useful categorical variable to visualise exploratory analyses, discussed in detail below. In addition, the number of meals consumed in the previous 24-hrs was also recorded as an indicator of a household's access to foods.

The second component in our assessment of dietary diversity used a Food Frequency Questionnaire (FFQ). The FFQ recalled the number of times certain foods were consumed by a household over a 4-week period (28 days). A total of 23 food items were listed (see Appendix 2.1), including an additional list of 30 fish species that are typically consumed in the region (see Appendix 2.2). The list of fish species, like the livelihood activities presented above, was determined through key informant interviews and a literature search (Huchzermeyer, 2013).

Seven different frequency options were provided in the FFQ and then converted into a proportion of the number of times a food item was consumed: (i) 1 time in the past 4 weeks (e.g., 1/28 = 0.036); (ii) 2-3 times in the past 4 weeks; (iii) 1 time per week; (iv) 2 times per week; (v) 3-4 times per week; (vi) 5-6 times per week; or (vii) 1 or more times per day. The conversion to a continuous variable was necessary for statistical analyses, discussed in more detail below. The benefit of the FFQ is that it provides greater detail on the quality of diets by including more food items and recording frequencies of consumption over time. FFQ methods have been validated as a measure of dietary diversity (Rodríguez et al., 2002; Cade et al., 2002). We were further interested in individual fish species consumed in the household given that they each have different micronutrient profiles (Nölle et al., 2020; Kaminski et al., 2022). The food items in the FFQ were grouped into the same food groups as the PDS above for better reflection of nutritional quality and diversity in the diet. Here we combined all fish into one category when compared to other food groups, though we maintained the longer list of individual fish species and analysed that separately.

We used the Simpson's Index (Simpson, 1949) to analyse the diversity of the food groups and fish species. The Simpson's Index is often used by ecologists to measure biodiversity in ecosystems (Baumgärtner, 2006). The index acts as a diversity score though notably different to the HDDS since it reflects the frequencies captured in the FFQ and attempts to understand if there is any overdependency on fewer food groups over time. The score has been regularly used in analyses of dietary and agricultural diversity (Jones et al., 2014; Lachat et al., 2018). First, the index sums the number of food groups consumed, often referred to as species richness, though in this case refers to richness of different food items. The index then uses the frequency of the consumption of these items as a continuous variable. The Simpson's Index is used as a calculation of species evenness, which in this case refers to the distribution of the frequency of foods consumed. The main goal is to ascertain whether the household diet relied on a higher frequency of less food groups or whether the frequency of consumption was more evenly distributed across food groups. The results are bound between zero and one, indicating whether the number of foods were distributed and consumed evenly. This is interpreted as the probability of any two foods selected at random from a single household and the likelihood that they will be different.

The consumption of specific fish species was treated separately as its own score using the Simpson's Index again. The total sum of all fish species consumed is considered (species richness), as well as the evenness of the distribution of consumption. These 30 fish species are later grouped into 10 categories for ease of analysis and interpretation based on their genus, family, size and/or source of capture (see Appendix 2.2).

2.2.3.3 Food security status

The third and final part of the survey measured food security status using the Household Food Insecurity Access Scale (HFIAS) (Swindale & Bilinksy, 2006). The scale consisted of nine occurrences related to food security and hunger, such as: "Did you or any household member go to sleep at night hungry because there was not enough food?" A recall period of four weeks is used offering three frequency options: (i) Rarely (1-2 times); (ii) Sometimes (3-10 times); and (iii) Often (>10 times), or zero for non-occurrence. The responses are used to calculate the HFIAS score, a continuous measure of the degree of food insecurity in the household, ranging from 0 to 27. This is calculated into one of the following ordinal categories: (i) severely food insecure; (ii) moderately food insecure; (iii) mildly food insecure; (iv) food secure. Of the four pillars of food security (access, availability, utilization, and stability), the HFIAS score has been used successfully to measure the access component of food insecurity (Becquey et al., 2010; Knueppel et al., 2010; Mohammadi et al., 2012). The HFIAS categories are used as the dependent variable described in a regression analysis below.

2.2.4 Data analysis

There were four multivariate analyses that assessed if household, livelihood, and dietary characteristics differed between aquaculture and non-aquaculture households, and whether any of these characteristics predicted dietary diversity and/or food security status. Differences between the two groups were calculated using chi-square tests, Welch's t-tests, and analysis of variance (ANOVA) for categorical and continuous variables, respectively. Bivariate correlations and multivariate regressions were computed to determine associations.

There were two exploratory multivariate analyses which developed indices that were used as factors in two multivariate regressions (see Figure 2.2 for analytical flow). The first of the multivariate analyses was a multiple correspondence analysis (MCA), used to assess the associations between livelihood activities. The MCA provided an index of food production and diversity based on how food groups were correlated in a geometric space. The MCA is not a predictive model but rather an exploratory analysis of how livelihood activities are clustered. An indicator matrix of all livelihood activities as binary categories (0= "no", 1= "yes") was assessed by way of cross-tabulation and covariance. The cumulative percentage of inertia, explained mostly by the first and second dimensions were adopted into the results. Using aquaculture and non-aquaculture groups we further tested for differences in livelihood activities with a one-way ANOVA, presented below the 5% level.

The second multivariate analysis assessed the dietary characteristics captured in the FFQ. Here, a principal component analysis (PCA) was used to explore the relationships and associations of the frequency of consumption of different food groups. Like the MCA, but with continuous data, the PCA is an exploratory analysis that clusters variables in a way that identifies patterns and associations of foods in the diet over time (Newby et al., 2004). This is presented as two additional indices (components 1 and 2) based on the eigenvectors of the data's covariance matrix and where most of the variance can be explained. Differences between aquaculture and non-aquaculture groups, and between low, average, and high HDDS groups were computed with a one-way ANOVA and presented below the 5% level.

The first multivariate regression aimed to determine the factors that predicted household dietary diversity. A stepwise multivariate linear regression was used to model the effect of household and livelihood characteristics on the HDDS. We included a household's involvement in aquaculture as a dummy variable (0= "no", 1= "yes"). Bivariate analyses were used to test associations between household and dietary characteristics, and only the results of significant associations were reported ($p < 0.05$). Independent variables included household characteristics: age, gender, education (of household head), and main income source. We further included the livelihood characteristics: CLS, PDS, number of non-farm activities, and the MCA dimensions.

Once understanding the relationships and associations between household and livelihood characteristics and their impact on dietary diversity, we assessed whether the same factors, and additional dietary characteristics (including the HDDS as an independent variable this time), explained food security status. Here, a multilevel probit regression was used to assess which factors predicted food security status (HFIAS). The ordinal category (4 levels) of the HFIAS from "severely food insecure" to "food secure" constituted the observable dependent variable. The same independent variables from the linear regression were used, and in addition we added the dietary characteristics: HDDS, number of meals, Simpson's Index of both food groups and fish species, and the PCA dimensions. All covariates were computed at the same time and then eliminated one by one if they were not significant below the 5% level. We then calculated the odds ratios to present which factors increased the likelihood of achieving a higher food security category.

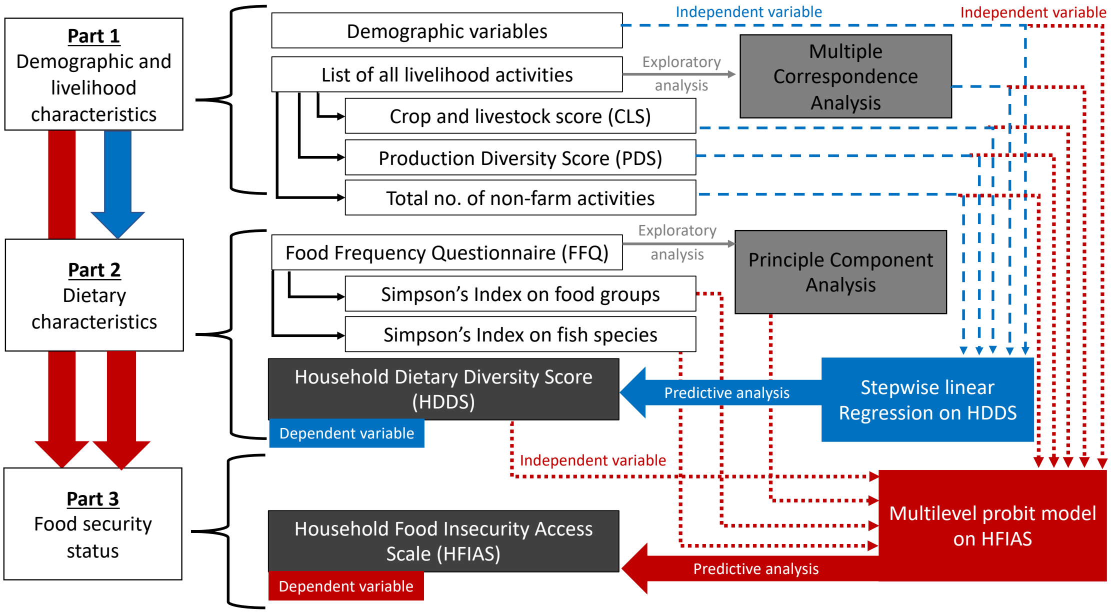


Figure 2.2. *Analytical flow and summary of all survey tools, scores, and analyses, depicting the logical flow of the study [left of diagram] with the demographic and livelihood characteristics predicting dietary characteristics and both, in turn, predicating food security status, while the four multivariate analyses [right of diagram] show the analytical flow of the study*

2.3 Results

2.3.1 Household and livelihood characteristics

All households in the sample were involved in agricultural activities of some kind and just under half made their main income from selling staple crops such as maize and cassava (see Table 2.1). Aquaculture households were significantly wealthier on average than non-aquaculture households ($p < 0.05$). Only 13% of aquaculture households made their main income from aquaculture. Deriving the main income from vegetables (e.g., tomatoes, onions, and okra) was important for more aquaculture households (14.1%) than non-aquaculture households (4%). More non-aquaculture households made their main income from formal employment (teaching, civil service) and “other” non-farm activities, such as charcoal burning, brick making and house rentals, than aquaculture households.

Table 2.1. *Household and livelihood characteristics*

Household Characteristics	Aquaculture n = 177		Non-Aquaculture n = 174		
	Freq.	**%**	**Freq.**	**%**	
Sex of household head					
Female	12	6.8%	27	15.5%	*
Male	165	93.2%	147	84.5%	
Marriage status †					
Married male household head	159	89.8%	140	80.5%	
Unmarried female household head	12	6.8%	27	15.5%	
Unmarried male household head	6	3.4%	7	4.0%	
Age of household head					
< 35 years old	32	18.1%	58	33.3%	**
35-60 years old	117	66.1%	86	49.4%	
> 60 years old	28	15.8%	30	17.2%	
Household size					
Small (< 3 people)	17	9.6%	27	15.5%	**
Average (4 – 7 people)	85	48%	100	57.5%	
Large (> 8 people)	75	42.4%	47	27%	
Education level of household head					
Partial primary school	87	49.2%	105	60.3%	
Partial high school	76	42.9%	57	32.8%	
Finished high School	14	7.9%	12	6.9%	
Yearly income – Zambian Kwacha (ZMW)					
Median (interquartile range 25% - 75%)	3000 (1200 – 6000)		1900 (800 – 4000)		*
Main income source					
Aquaculture	23	13.0%	0	0.0%	***
Staple crops (maize, cassava, millet)	79	44.6%	85	48.9%	
Beans	28	15.8%	26	14.9%	
Groundnuts	16	9.0%	21	12.1%	
Vegetables (tomatoes, okra, etc.)	25	14.1%	7	4.0%	
Fisheries	1	0.6%	15	8.6%	
Employed	3	1.7%	12	6.9%	
Other	2	1.1%	8	4.6%	
Livelihood Characteristics	**Mean ± SD**		**Mean ± SD**		
Total number of crops & livestock (CLS)	6 ± 2.65		4.47 ± 2.18		***
Total number of non-farm activities	0.21 ± 0.44		0.37 ± 0.56		*
Production diversity score (PDS)	5.26 ± 1.66		3.59 ± 1.46		***

All p-values on mean differences between aquaculture and non-aquaculture groups calculated with chi-square tests or Welch's t-tests for categorical and continuous variables, respectively – statistical significance marked with * ($p < 0.05$) or ** ($p < 0.01$) or *** ($p < 0.001$).

† "Unmarried" signifies single, widowed, or divorced household-head. In all married male households, the main food preparer was the spouse (female). Only one elderly woman of all the female unmarried households had another person (daughter) cook for the household, while eight unmarried male households cooked for themselves (all young, single men); and the rest had a female household member cook for the household (e.g., sister, daughter).

When all livelihood sources were listed together (see Figure 2.3), it was clear that cropping activities such as cassava, maize, beans, and groundnuts were the mainstay of household livelihoods in both study groups. More aquaculture households grew different vegetables such as rapeseed leaf, sweet potato, tomato, Chinese cabbage, onion, orange sweet potato, cabbage, and potato. More non-aquaculture households participated in fisheries activities than aquaculture households. Overall aquaculture households participated in more crop and livestock activities ($p < 0.001$), while non-aquaculture households participated in significantly more non-farming activities ($p < 0.01$). Aquaculture households had a significantly higher PDS ($p < 0.001$), meaning they grew a higher diversity of food groups that would be considered important for nutrient adequacy.

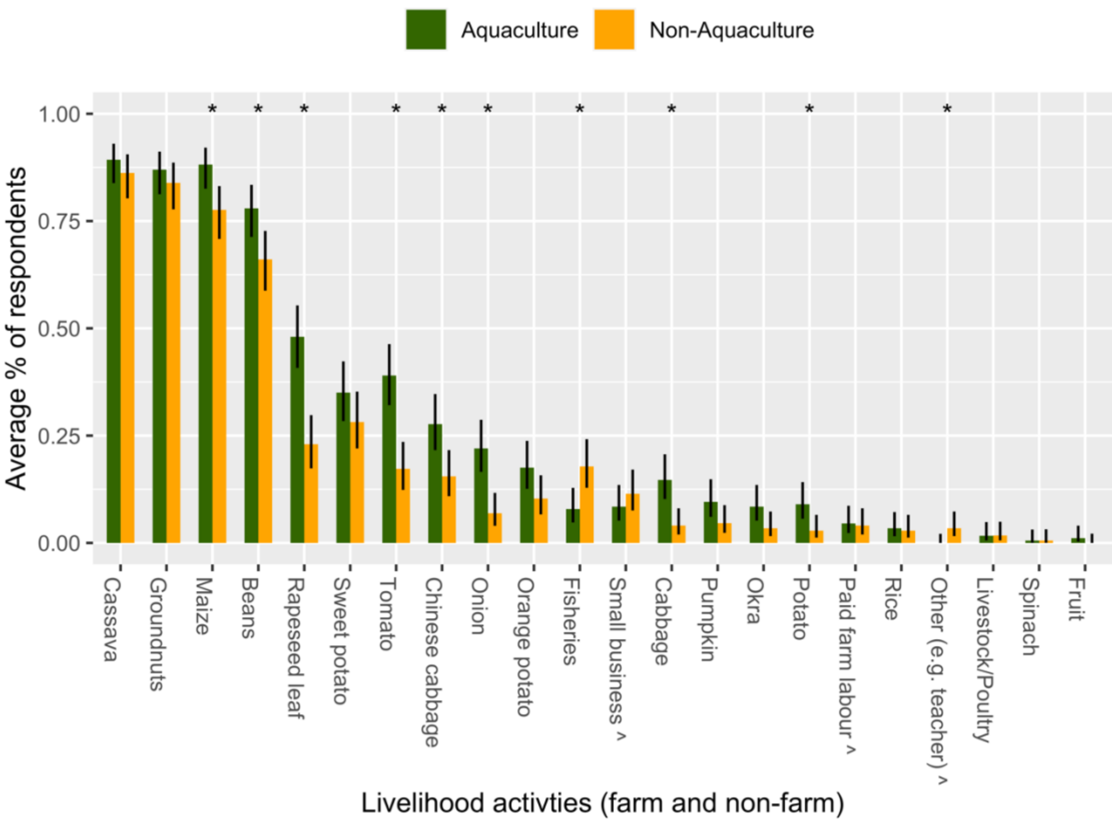


Figure 2.3. *Number of households (%) participating in various farming and non-farming activities with standard error bars. Statistical significance at or below the 5% indicated with asterisk (*) and calculated using chi-square test. Non-farm activities indicated with caret (^).*

2.3.2 *Dietary characteristics*

There was no significant difference in the total HDDS between aquaculture (5.73 ± 1.34) and non-aquaculture households (5.46 ± 1.48) (see Table 2.3). The former group, however, consumed significantly more meals in the 24-hr recall than the latter group ($p < 0.05$). A higher percentage of aquaculture households consumed seven or more food groups while a higher percentage of non-aquaculture households consumed four or less food groups, statistically significant at the 5% level. When viewing individual food groups in the 24-hr dietary recall, a significantly higher percentage of aquaculture households consumed cereals and grains while more non-aquaculture households consumed roots and tubers (see Appendix 2.3). This validates separating roots and tubers into their own food group as it shows that some households relied more on the latter. There were no differences in the consumption of other food groups. Across the sample it was evident that all households relied on cereal, grains, and dark green leafy vegetables (DGLV); while fish was by far the most important animal-source protein compared to meats, eggs, or dairy.

When grouping the frequency of consumption of the 53 food items into 12 key food groups, we see significant differences (see Figure 2.4). Aquaculture households consumed nuts and seeds, white roots and tubers, fruit, and meat, more frequently than non-aquaculture households ($p < 0.05$). Aquaculture households also consumed more “other vegetables”, made up of onions, tomatoes, okra, and cabbage. Many of these vegetables were the same ones that more aquaculture households cultivated as compared to non-aquaculture households (see Table 2.1). Both groups consumed a similar frequency of fish over the previous 28 days ($p > 0.05$).

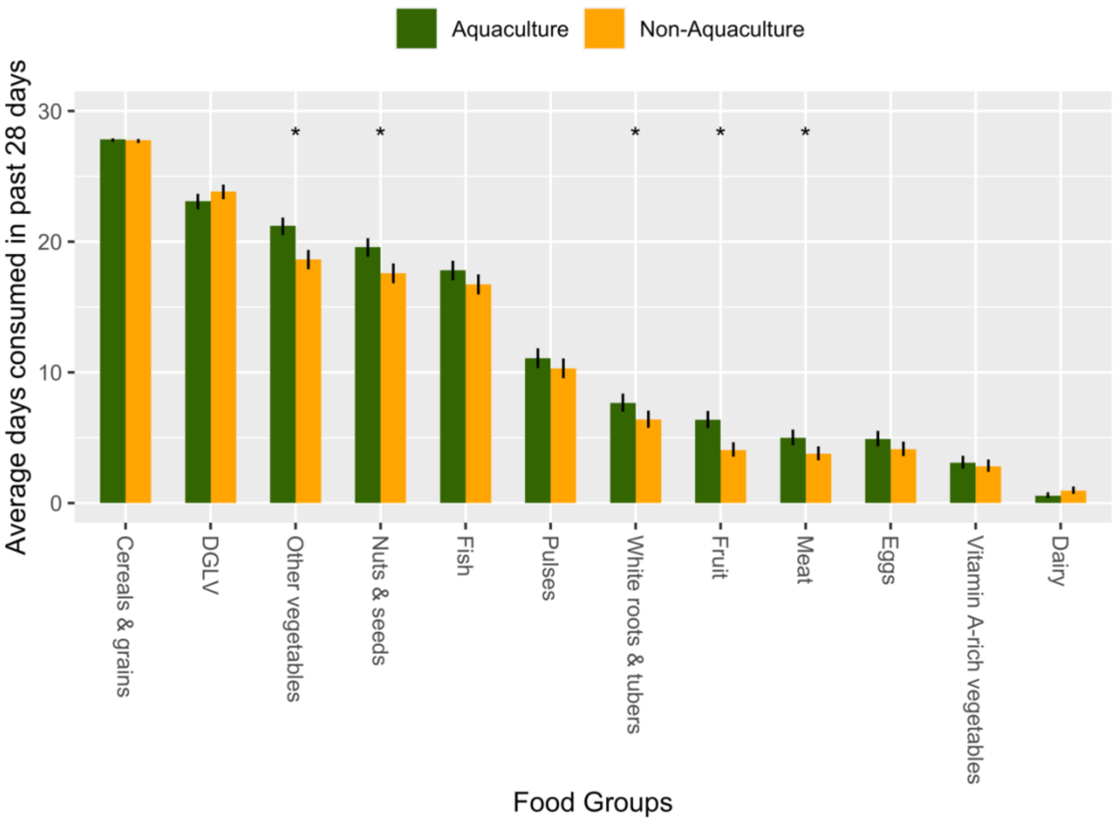


Figure 2.4. *Average daily rate (in past 28 days) of key food groups consumed in household with standard error bars. Statistical significance at or below the 5% level indicated with asterisk (*) and calculated using a one-way ANOVA. DGLV = Dark green leafy vegetables.*

When viewing the total sum of the 12 food groups (species richness) the aquaculture households consumed more food groups on average over the previous 28 days than non-aquaculture households ($p = 0.007$) (Table 2.2). The aquaculture households had a significantly higher average Simpson's Index than the non-aquaculture households, indicating more diversity and evenness in the frequency and distribution of food groups consumed over time ($p = 0.001$)

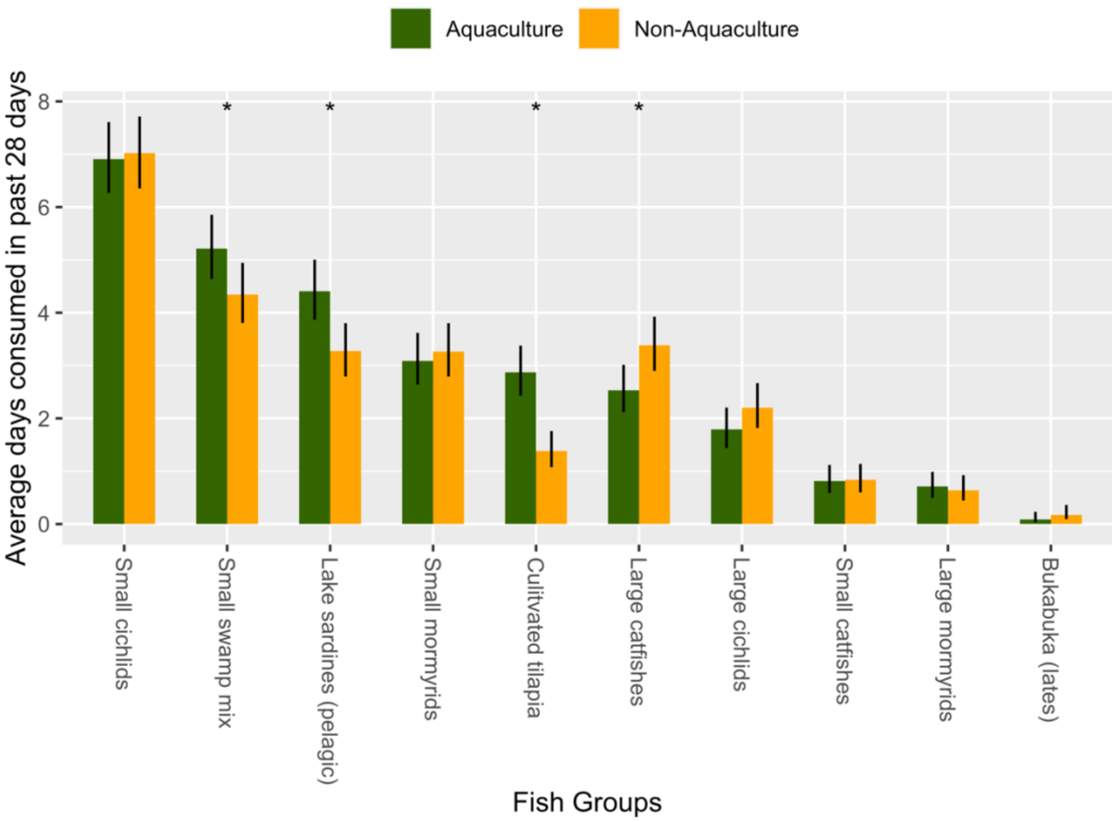


Figure 2.5. *Average daily rate (in past 28 days) of fish species consumed in aquaculture and non-aquaculture households with standard error bars. Statistical significance at or below the 5% level indicated with asterisk (*) and calculated using a one-way ANOVA*

When the individual fish species were grouped into broader categories, significant differences in the frequency of the consumption were evident (see Figure 2.5). Aquaculture households consumed cultivated tilapia more often than non-aquaculture households, as well as smaller fish such as lake sardines and other wetland species (small swamp mix). Non-aquaculture households meanwhile consumed significantly more catfish. This was verified at the individual species level where aquaculture households consumed cultivated tilapias more frequently than non-aquaculture households, while one common catfish was consumed more frequently by the latter households (see Appendix 2.4). There were no significant differences in the sum of fish species (species richness) consumed on average, though aquaculture households had a significantly higher

Simpson's Index for fish species consumption than the non-aquaculture households (p = 0.011).

Table 2.2. *Dietary characteristics of aquaculture and non-aquaculture households*

Characteristics	Aquaculture n = 177		Non-Aquaculture n = 174		
	Mean ± SD		Mean ± SD		
Total dietary scores from 24-hr HDDS §					
Total HDD score	5.7 ± 1.3		5.5 ± 1.5		
Total meals	3.1 ± 0.9		2.9 ± 0.9		*
Diversity of key food groups from FFQ #					
Simpsons Index for diet (0 to 1 indicating more diversity)	0.83 ± 0.04		0.81 ± 0.07		**
Richness of diet (total no. of Food Groups out of 12)	8.5 ± 1.6		8.0 ± 1.9		**
Diversity of fish from FFQ (28 days)					
Simpsons Index for fish species	0.65 ± 0.23		0.58 ± 0.29		*
Richness of fish (total no. of species)	5.1 ± 3.3		4.4 ± 3.3		
Total frequency of consumption of fish (daily rate)	1.1 ± 1.2		1.0 ± 1.4		
	Freq.	**%**	**Freq.**	**%**	
Household dietary diversity groups †					
Low HDDS: ≤ 4 food groups	28	15.8	45	25.9	*
Average HDDS: 5-6 food groups	96	54.2	91	52.3	
High HDDS: ≥ 7 food groups	53	29.9	38	21.8	

§ Household Dietary Diversity Score
# Food Frequency Questionnaire
† Statistical difference calculated with chi-squared test on 6 groups – aquaculture and non-aquaculture respondents in the three groupings based on HDDS.
All other p-values on mean differences between aquaculture and non-aquaculture groups calculated with one way ANOVA, statistical significance marked with * (p < 0.05) or ** (p < 0.01) or *** (p < 0.001)

2.3.3 Multivariate analysis of livelihood characteristics

The MCA revealed three distinct patterns and associations of livelihood activities on two dimensions (explaining 26.6% of the variance) (see top panel in Figure 2.6). Households that grew tomato were clustered closely with onion, rapeseed leaf and Chinese cabbage; and these crops contributed to most of the variance on the first dimension of the MCA, suggesting households that grew these foods were the most different to the other households in the sample. Households that caught wild fish were more associated with groundnut and beans, though the latter two crops were common across the sample. Most households grew maize, closely clustered with sweet potato, cassava, and potato, meaning that these crops did not contribute much to the variance across the sample. Certain notable outliers such as pumpkin, okra and cabbage indicated that some households specialised in these crops, though this was notably a minority.

When disaggregated by farmer group and HDDS group (bottom left and right panels in Figure 2.6), there were clear differences, especially on dimension 1 of the matrix. Many of the households that relied on staple crops such as maize and cassava were made up of households from both study groups, but also from the lower HDDS group. Households with higher or average HDDS, and those that engaged in aquaculture, were more associated with crops such as tomato, onion, rapeseed leaf, okra, pumpkin, and cabbage, which contributed to most of the variance on dimension 1. When viewed together with Figure 2.3 above, the MCA verified that significantly more aquaculture households cultivated a cluster of these latter crops than non-aquaculture households. A one-way ANOVA of MCA dimension 1 comparing the aquaculture households (mean = 0.12 $\pm$ 0.46) and non-aquaculture households (mean = -0.13 $\pm$ 0.35) was statistically significant at the 1% level. There were no significant differences on dimension 2. The same was found with a one-way ANOVA comparing the low HDDS (mean = -0.19 $\pm$ 0.26), average HDDS (mean = 0.04 $\pm$ 0.45) and high HDDS groups (mean= 0.07 $\pm$ 0.40), statistically significant at the 1% level. There were no statistical differences on dimension 2. This suggests that the ability to grow crops such as tomato, Chinese cabbage, rapeseed leaf and onion (which more aquaculture households cultivated – see Figure 2.3 above) may be a factor in explaining household dietary diversity. This validates the inclusion of the MCA dimensions as independent variables in the regression analyses presented below.

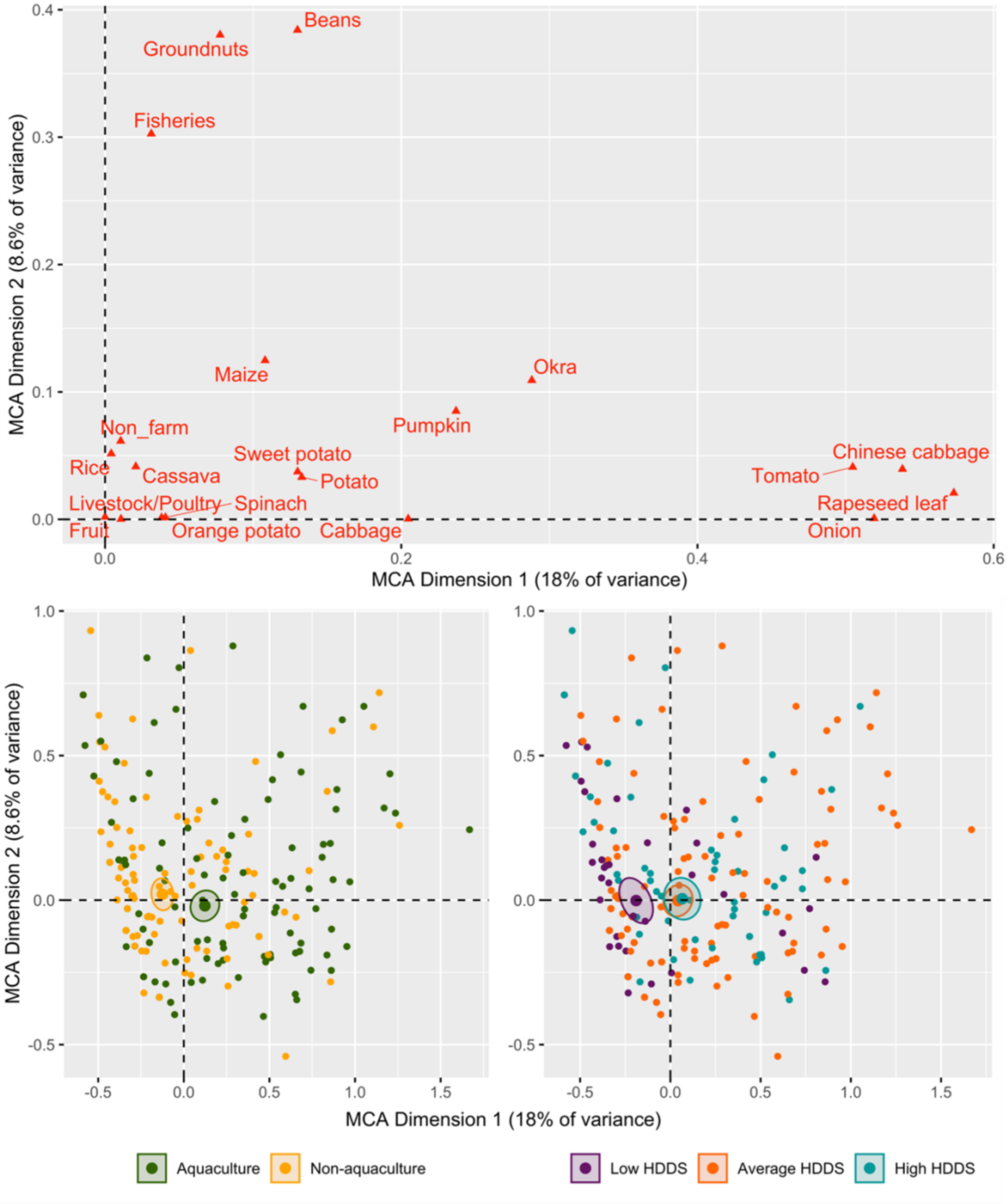


Figure 2.6. *Livelihood activities (farming and non-farming activities) using Multiple Correspondence Analysis (MCA) (top panel) and plotted by farmer group (bottom-left panel) and HDDS group (bottom-right panel), only showing contribution of top 200 farmers to total variance*

2.3.4 Multivariate analysis of food frequency

The PCA results of the food frequency should be interpreted by the magnitude and direction of the coefficients (Figure 2.7). The larger the coefficient the more important the corresponding variable is in calculating the components (which together explain 33% of the variance in the diet over the previous 4 weeks). The direction of the coefficient indicates a positive or negative association with components. In Figure 2.7, nuts and seeds, meat, vitamin-A-rich vegetables, pulses, and white roots and tubers had negative loadings on component 1, and positive loadings on component 2. Fruit, dairy, egg, DGLV, and other vegetables such as tomato, okra, and onion were positively associated with both components. Only cereals and grains were negatively associated with component 2. When looking at the disaggregated results by farmer group and HDDS groups, we see that many non-aquaculture (and lower HDDS) households were negatively associated with component 1 and positively associated with component 2, suggesting that these households strongly relied on cereals and grains in their diet. The higher HDDS households meanwhile had a higher prevalence of dairy, fruit, eggs, and other vegetables in their diet, in addition to roots, tubers, nuts and seeds. A one-way ANOVA of component 1 and aquaculture households (mean = 0.21 $\pm$ 1.52), and non-aquaculture households (mean = -0.21 $\pm$ 0.21), was statistically significant ($p = 0.0128$). There was no significant difference on component 2 between these groups. The same was found when using a one-way ANOVA to compare differences between the low HDDS (mean = -0.97 $\pm$ 1.14), average HDDS (mean = 0.152 $\pm$ 1.68) and high HDDS groups (mean = 0.056 $\pm$ 1.31), statistically significant at the 1% level. There were no differences between HDDS groups on component 2.

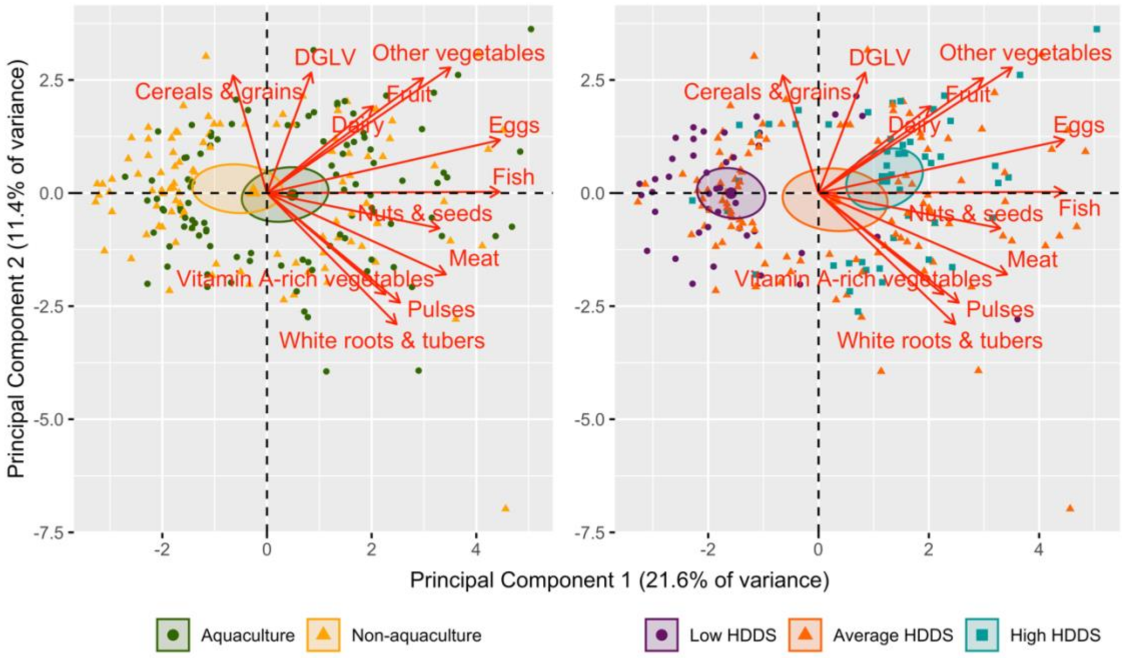


Figure 2.7. *Principal Component Analysis of food frequency and diet over 28 days using 12 key food groups, disaggregated by farmer group (left panel) and HDDS group (right panel). DGLV = Dark green leafy vegetables.*

2.3.5 Stepwise linear regression with Household Dietary Diversity Score (HDDS)

Bivariate regressions were computed for each household characteristic and livelihood factor against the HDDS. Dimension 1 of the MCA (β= 0.58, SE= 0.18) and the PDS (β=0.15, SE= 0.04) were statistically significant at the 1% level, but not significant in the multivariate analysis. This means that the types of crops grown may have had an impact on HDDS but not when accounting for other variables. The multivariate analysis with the household and livelihood characteristics, including aquaculture as a dummy variable, showed no significant results. After a backward elimination process, the only factors that had significant positive effects on the HDDS was the log of income and the CLS. The results in Table 2.3 should be interpreted as the log of income having the largest effect with a 0.19 increase in HDDS for every unit increase in income. The effect of the CLS was smaller but still significant. The HDDS improved by 0.08 points for every additional CLS category that was added to a household's livelihood portfolio.

Table 2.3. *Final model results of stepwise linear regression with HDDS explained by household and production characteristics that were significant (p < 0.05)*

	Coef	SE	P
Log (income + 1)	0.19	0.05	< 0.000
No. crops & livestock (CLS)	0.08	0.03	0.011
All other factors were not significant, including household characteristics: sex, age, household size, education level, and main income source; as well as livelihood characteristics including the PDS, number of non-farm activities and MCA dimensions 1 and 2.			

2.3.6 Household food insecurity access score (HFIAS) and multilevel probit model

Table 2.4 presents the food security status of the aquaculture and non-aquaculture households as represented by the HFIAS. Aquaculture households had slightly better food security status, although the overwhelming majority in both samples were found in the moderately and severely food insecure categories. A chi-squared test of HFIAS categories with the aquaculture versus non-aquaculture groups was statistically significant at the 1%, though this does not account for household, livelihood, or dietary differences between the two groups, hence the need for the multilevel probit regression.

Table 2.4. *Household Food Insecurity Access Score (HFIAS) of respondents*

HFIAS Category	Total sample N=351		Aquaculture n=177		Non-aquaculture n=174	
	Freq.	%	Freq.	%	Freq.	%
Food Secure	54	15.4%	36	20.3%	18	10.3%
Mildly Food Insecure	48	13.7%	31	17.5%	17	9.8%
Moderately Food Insecure	117	33.3%	58	32.8%	59	33.9%
Severely Food Insecure	132	37.6%	52	29.4%	80	46.0%

The regression was first calculated with bivariate analyses of each factor against the HFIAS. The factors that were significant in the bivariate analyses were MCA dimension 2 (β=0.76; SE=0.33: p= 0.0232), the PDS (β=-0.13; SE=0.06; p= 0.017); and PCA component 1 (β=-0.15; SE=0.06; p=0.0167). This suggests that the types of crops grown, as seen in the MCA and the PDS indices, mattered in predicting food security. The food groups that explained most of the variance along component 1 of the PCA also mattered in predicting food security. However, when we included these variables in a multivariate analysis, they did not have a significant impact.

Figure 2.8 presents the calculated odds ratios of the multilevel probit regression model. The coefficients, standard error and confidence intervals can be found in greater detail in Appendix 2.5. The results should be read attentively, as a negative correlation with food insecurity translated to a positive association with food security. The main finding was that aquaculture as a livelihood activity had a significant positive effect on food security outcomes (p = 0.003). This gave households with ponds a 1.88 odds ratio of being more food secure even when accounting for income and other livelihood activities. Income (based on a logarithmic scale) was a significant predictor of household food security: for every double increase in Zambian Kwacha the log of odds of improving household food security increased by 0.21, meaning wealthier households were 0.81 times more likely to have a better food security outcome given that other variables were held constant (p = 0.003).

The age of the head of the household was negatively correlated with food insecurity. When the head of the household was above the age of 35 there was a higher likelihood of food security, which almost doubled when the head of the household was 61 years or older (p = 0.032). The effect of household size, however, had a greater effect on food security. Households with an average number of members were 1.83 times more likely to be in worse food security categories and this almost doubled to 2.86 times if there were more than eight household members.

Certain dietary characteristics further affected the likelihood of reaching a better food security outcome. A household's dietary diversity score had a negative effect on food insecurity, meaning that for every 0.24 change in the HDDS score, there was a 0.79 odds ratio of improving food security (p = 0.003). The Simpson's Index score was the greatest predictor of food security in the model. For every 10% increase in the Simpson's Index, there was a two times higher likelihood of improving food security (p = 0.006). This could be further improved with a unit increase on PCA component 2, which gave a 0.82 odds ratio of improving food security (p = 0.0308). PCA Component 2 was mostly defined by cereals and grains but also by dairy, fruit, and other vegetables such as tomato, onion, and okra, that were less frequently consumed across the population sample, but also farmed by more aquaculture households.

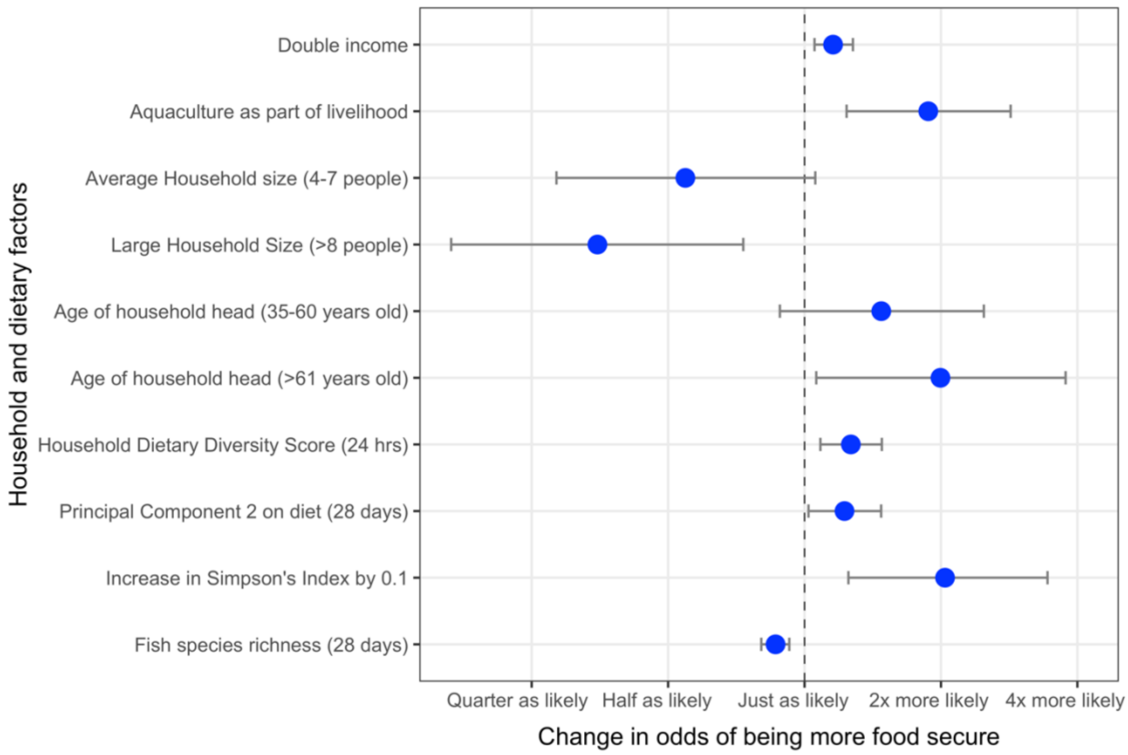


***Figure 2.8**: Odds ratios and likelihood of food security using a multivariate probit regression with HFIAS categories (from severely food insecure to food secure)*

2.4 Discussion

The study evidenced that aquaculture households had a higher diversity of crops, more diverse diets, consumed a greater frequency and diversity of fish species, and that adopting aquaculture as a livelihood strategy improved food and nutrition security compared to non-adopters. The mechanisms by which aquaculture plays a role in food and nutrition security is explored below via three distinct pathways.

The first pathway to food and nutrition security that aquaculture enables is that the sale of fish can provide additional income, which improves purchasing power, food provisioning and dietary diversity. Our study showed that adopting aquaculture increased household food security even after accounting for income, meaning that fish farming may have contributed to household wealth through the sale of fish. While we did not investigate the actual income derived from the sale of fish directly, aquaculture households in our sample were, on average, wealthier than non-aquaculture households. Certain demographic factors like family size and age of the household-head influenced food security outcomes, in addition to income. The results suggest that younger households had not amassed the assets, wealth, and knowledge to increase their food provisioning and on-farm resources, however, smaller families reduced the likelihood of food insecurity. Larger households were more likely to be food-insecure, though this was lessened with increasing age as households gained more experience, wealth, and on-farm resources. If households further invested in aquaculture and increased their incomes, they were even more likely to improve their food security status.

Whilst we are unable to say whether aquaculture was a key activity that contributed to household income, it is likely that wealthier farmers had the capital needed to be able to invest in aquaculture (Obiero et al., 2019). Few aquaculture households in our sample made their main income from the sale of fish (only 13%) and aquaculture was clearly a supplementary source of income. Few farming households make their main income from aquaculture in sub-Saharan Africa, in general (ole-MoiYoi, 2017; Limuwa et al., 2018). Studies in Malawi and Ghana reported that aquaculture provided 12% and 8% to the total incomes of rural households, respectively (Dey et al., 2006; Kassam & Dorward, 2017). Another study in Malawi found that aquaculture households were generally better-off and had greater dietary diversity than non-aquaculture households due to incomes derived from fish farming (Aiga et al., 2009). One study in Zambia showed that fish farmers did not follow regular harvesting schedules and intermittently harvested and sold fish when certain immediate expenses arose (e.g., paying school fees) (Kaminski et al., 2019). Most extensive aquaculture households in northern Zambia (over 70%) were estimated to produce less than 100 kg of fish per year, suggesting that the incomes derived from the sale of fish are minimal, though potentially not insignificant when measured as a contribution to diets (Kaminski et al., 2019). Around half of the fish harvested from rural homestead ponds in Zambia are estimated to be sold while the rest are consumed in the household (Nsonga, 2015).

It is likely that the second pathway to food and nutrition security, namely, the direct consumption of fish from ponds may have played a larger role in improving food security. In the case of rural Zambia, in the same district to be exact, there is evidence of farming households consuming small tilapia and a range of other small indigenous species (which gain entry into farmers' ponds) as compared to households without fishponds (Kaminski et al., 2022). In our study sample, aquaculture households had higher dietary diversity as seen in both the Simpson's Index of food groups and the HDDS results. Aquaculture households consumed a greater variety of foods more frequently than non-aquaculture households, especially meats, nuts, and vegetables, many of which were likely purchased. Overall, both household types consumed a similar frequency of fish, yet aquaculture households consumed more different fish species over a period of four weeks. The Kaminski and colleagues (2022) study showed that ponds played an important role in overall fish supply and nutritional quality, though aquaculture and non-aquaculture households consumed a similar quantity of fish. Aquaculture households, as in our study, consumed a greater diversity of fish species, especially small fish that were richer in micronutrients.

Almost half of all households in both groups consumed fish in the previous 24-hours, suggesting that fish consumption in the area is very high, likely driven by proximity to large capture fisheries (O'Meara et al., 2021). Aquaculture households in our study had higher frequencies of tilapia consumption than non-aquaculture households suggesting that, should fish supplies from capture fisheries dwindle, aquaculture could potentially provide a steadier source of fish. While our model showed that an increase in fish species diversity was negatively associated with food security, this may imply that wealthier, more food secure families depend on less diversity, but a greater frequency of fish species consumed (and probably purchased). This could mean that food-insecure households relied on whatever species of fish they could access whilst more food-secure households relied on more consistent sources of fish products they could afford, though this cannot be verified by our study.

The third and final pathway to food security is how ponds enable the growth and consumption of other foods on the farm via improved irrigation capabilities, i.e., crop diversification. Aquaculture households farmed a higher diversity of crops and food groups as compared to non-aquaculture households. These households were also more associated with a particular cluster of crops often found in homestead gardens (Rosenberg et al., 2018). The total number of crops cultivated by a household increased dietary diversity, which in turn was a positive predictor of food security. This has been verified by other studies in Zambia which suggest that crop diversification (and specifically crops produced for subsistence) had positive effects on dietary diversity, which translated to greater nutrient adequacy (Kumar et al., 2015; Nkonde et al., 2021). Growing more diverse food groups seemed to matter less in our model and while production diversity is important to diet quality (Mofya-Mukuka & Hichaambwa, 2018), access to markets for buying food and being able to sell farm produce can have a larger effect on dietary diversity (Koppmair et al., 2017). The ability to diversify from a reliance on staple grains and improve homestead gardens and on-farm livestock management can have the highest impacts on dietary diversity (Gupta et al., 2020).

From our study, the effect of aquaculture on food security was greater than crop diversity alone, and greater than engaging in non-farm activities. While there was a correlation between aquaculture and crop diversification, we did not assess to what extent the former impacted on the latter, and we did not determine which agricultural activities were more significant to wealth generation. One study in

Zambia found that crop diversification had a positive and significant impact on income derived from the farm, as well as on household dietary diversity (Mofya-Mukuka & Hichaambwa, 2018). Such income diversification can make households more resilient to market and climate fluctuations (Abdulai & CroleRees, 2001). And while households that adopted homestead gardens managed to increase crop diversity, and thus increase access to diverse foods, this did not always translate to an overall increase in nutrient adequacy for young children and mothers, specifically (Rosenberg et al., 2018). These nuanced benefits for different population groups may exist because of imbalances in gender roles, unequal food allocation and poor knowledge on nutrition and child feeding, for example (Islam et al. 2018). Such issues were regrettably not included in this study. Certain social and cultural norms act as barriers to adopting and realising the benefits of agricultural interventions and future studies or development programmes should critically include gender transformative and behavioural change approaches when promoting and/or studying aquaculture (Kumar et al. 2018; Irwin et al., 2020).

The specific crops that more aquaculture households in our sample diversified into were Chinese cabbage, tomato, onion, rape, and okra. While this study did not investigate how crops were planted, total yields, or the share of crops consumed in the household, there is evidence in the region of homestead garden crops planted close to or even around pond dykes (Dey et al., 2006). Studies show that crops irrigated with pond water produced almost three times higher yields (Limbu et al., 2016). Rape, Chinese cabbage, tomato, and onion are typically planted in the late dry season gardens (September – November) and farmers with improved water irrigation would benefit by diversifying their crop selection and being able to grow these vegetables all year round (Burney & Naylor, 2012). Other crops like sweet potato and pumpkin are planted later in the rainy season after staple foods like maize and cassava are planted around December. Home gardens have been found to improve food security and dietary diversity in a wide range of settings (Rammohan et al., 2019; Cabalda et al., 2011; Galhena et al., 2013).

In Zambia, seasonal fluctuations can have large repercussions on dietary quality for rural households and especially for pregnant and lactating women and children (Ahern et al., 2021). The rainy period starting around November is associated with variable levels of dietary diversity and the beginning of the lean period, which is at its peak by March (Caswell et al., 2020). This period also coincides with a national fishing ban starting in December till the end of February when fish resources become scarce (Kaminski et al., 2022). Due to such fluctuations farmers often resort to harvesting their crops early or depend on the woodland systems for charcoal burning as a coping mechanism (Anderson et al., 2017). The ability to produce and sell more cash crops, such as tomatoes and onions, using water from the pond, especially in times of seasonal rain fluctuations, may provide farmers with an additional coping mechanism.

Integrating aquaculture and agriculture has proven to be a sound livelihood strategy in other parts of the world, which allows farmers to diversify their food sources and income-generating activities (Dey et al., 2006; Ahmed et al., 2014). Adopting and integrating fishponds into farming systems is an important and often undervalued contributor to food security in the African context. During times of severe drought, ponds can provide enough residual moisture and nutrients to produce vegetable crops (Prein & Ahmed, 2000; Dey et al., 2010). Wetland gardens have been shown to be a lifeline for farmers during lean periods in Africa (Lightfoot & Noble, 2001), while farmers who successfully integrate agriculture with aquaculture reported better cash flows, especially in drought years (Brummett & Jamu, 2011). Promoting the integration of agriculture and aquaculture in sub-Saharan Africa and greater efforts at finding the right combination of crops and local species of flora that complement fish cultivation, and vice versa, should be made (Belton & Little, 2011). Improving agroecological diversity and the additional ability to retain water in ponds may also provide farmers with increased resilience against climate shocks such as droughts and floods, though more effort needs to be made to evidence this (Troell et al., 2014; Radeny et al., 2022).

Given that many households in both groups in our study were still severely or moderately food insecure, aquaculture could be playing a vital role in preventing households from slipping further into food insecurity and poverty (Krishna, 2004; Little et al., 2012). Fishponds become more than just production systems of single species but operate as a sort of “bank” or “insurance policy” allowing households to sell fish to pay for immediate costs, consume a vital animal-source protein, or provide water irrigation to diversify cropping strategies extend growing seasons.

2.5 Conclusion

This study surveyed rural agricultural households in northern Zambia to better understand their household, livelihood, and dietary characteristics and determine which of these factors influenced household food security. The results suggest that aquaculture households had higher crop diversity, which was a key factor in increasing dietary diversity. Aquaculture households grew certain additional crops, possibly because of improved water supply on the farm in the form of ponds. Aquaculture households had more even distribution and higher diversity of key foods in their diets compared to non-aquaculture households, particularly a higher frequency of consumption of different fish species. Finally, aquaculture was a key predictor of food security, along with diversity in diets, incomes, and other demographic factors such as age and household size. Farming households that invest in aquaculture can increase their food and nutrition security by improving incomes, consuming more fish, and diversifying their crops – three key pathways to achieving food and nutrition security.

Development practitioners, policymakers and government programmes should look to promote aquaculture for smallholders. However, it should be realised that ponds can bring more benefits than just the cultivation of single fish species. Studies have shown that tilapias mixed with other wetland fish species in polyculture systems have improved nutritional diversity in homestead ponds (Castine et al., 2017, Kaminski et al., 2022). Productivity parameters in ponds can no doubt be improved in the region, however, this needs to be done in a manner that is both feasible and achievable for agricultural households, especially considering the crops already cultivated on the farm including the role of off-farm nutrients (fertilizers and feed) that can boost productivity. The nuances in time, labour, and complex social and gender issues that may increase work burdens for women need to be critically factored into efforts at improving productivity. Fish farming in ponds can improve livelihoods, well-being, and food and nutrition security in a myriad of different ways. Quantifying the total yields of crops over different seasons as well as the share that are self-produced compared to the share of purchased foods would provide greater insight into the direct linkages between different crops, foods, dietary diversity and/or food and nutrition security. Understanding which foods are consumed when, and which foods, crops and livestock activities provide the most income would help to understand how aquaculture is placed within the farming system but also offer a better understanding of whether wealth status precedes aquaculture adoption or aquaculture adoption leads to wealth accumulation, or both. Further research in how ponds play a role in retaining water and improving water irrigation capabilities in the face of potential climate shocks should be urgently investigated.

2.6 Appendices for Chapter 2

Appendix 2.1. *Food items used in the FFQ to develop 12 food groups calculated in overall diet in last 28 days*

Food items in FFQ – 28 days	Food Groups
1. Maize 2. Cassava 3. Rice 4. Millet 5. Wheat	A. Grains and cereals
6. White/Yellow Sweet Potato 7. Irish Potato	B. White roots and tubers
8. Beans and/or other lentils	C. Pulses
9. Groundnuts	D. Nuts and seeds
10. Milk products	E. Dairy
11. Organ meat 12. Poultry (chicken) 13. Beef 14. Pork 15. Goat/Lamb 16. Insects 17. Other meat (bush meat)	F. Meat
18. Small mormyrids 19. Small swamp mix 20. Small cichlids 21. Lake sardines 22. Small catfishes 23. Typically cultivated tilapia 24. Large catfishes 25. Lates (*Buka-buka*) 26. Large mormyrids	G. Fish

27. Large cichlids	
28. Eggs	H. Eggs
29. DGLV (rape, cassava, pumpkin leaves, spinach)	I. Dark Green Leafy Vegetables
30. Orange sweet potato 31. Carrots, pumpkin and squash	J. Vitamin A-rich vegetables
32. Fruit (mango, lemon, oranges)	K. Fruit (mostly Vitamin A-rich fruits)
33. Vegetables (onion, tomatoes, cabbage, okra, Chinese cabbage)	L. Other vegetables

Excluded from the list: oils and fats; savoury and fried snacks; sweets; sugar-sweetened beverages; condiments and seasonings; other beverages and foods
The 10 fish categories (Food items: 18-27) are made up of 30 fish species asked in the FFQ (see Appendix 2.2)

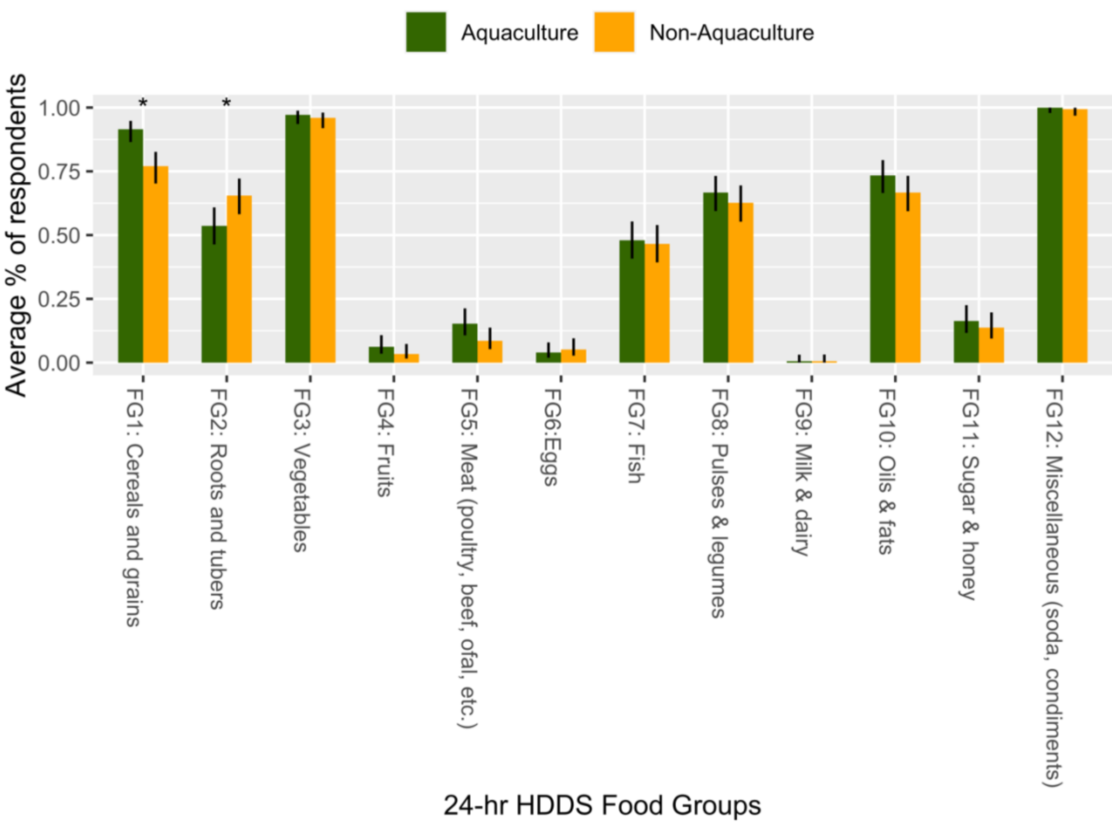
Appendix 2.2. *Fish species classification and groups used in the study*

Classification	Bemba name	Scientific name	Common name	Size
Small mormyrids	Icele	*Petrocephalus & Cyphomyrus*	Elephant fishes / Parrot fishes	Small
	Ishimba	*Pollimyrus cf. isidori/castelnaui*	Elephant Fish / Dwarf stonebasher	Small
	Mintesa	*Marcusenius macrolepidotus*	Bulldog	Small
Small swamp mix (clupeidae, cyprinidae and alestidae)	Bwelele	*Micropanchax johnstoni*	Banded lampeye or topminnow	Small
	Itala	*Rhabdalestes spp.*	African tetras (robbers	Small
	Kasepa	*Mixed barbus species*	barbinidae (minnows)	Small
	Misenga	*Barbus paludinosus*	Straightfin barbs	Small
	Mushipa	*Barbus trimaculatus*	Threespot barb	Small
	Misebele	*Alestes macrophthalmus*	Torpedo robber	Small
	Other small fish	Range of small mixed species		Small
Small & medium sized cichlids	Cifinsa	*Tilapia ruweti*	Okavango tilapia	Small
	Cikundu	*Pseudocrenilabrus philander*	Southern mouthbrooder	Small
	Matuku	*Tilpia sparrmanii*	Banded tilapia	Small
	Imbelya	*Sargochromis mellandi*	Snaileater or Greenbream	Small
Lake sardines	Dagaa	*Rastrineobola argentea*	Silver cyprinid	Small
	Kapenta	*Limnothrissa miodon*	Lake Tanganyika sardine	Small
	Chisense	*Potamothrissa acutirosis*	Sharpnosed sawtooth pellonuline	Small
Small catfishes	Lupata	*Schilbe mystus*	African butter catfish	Small

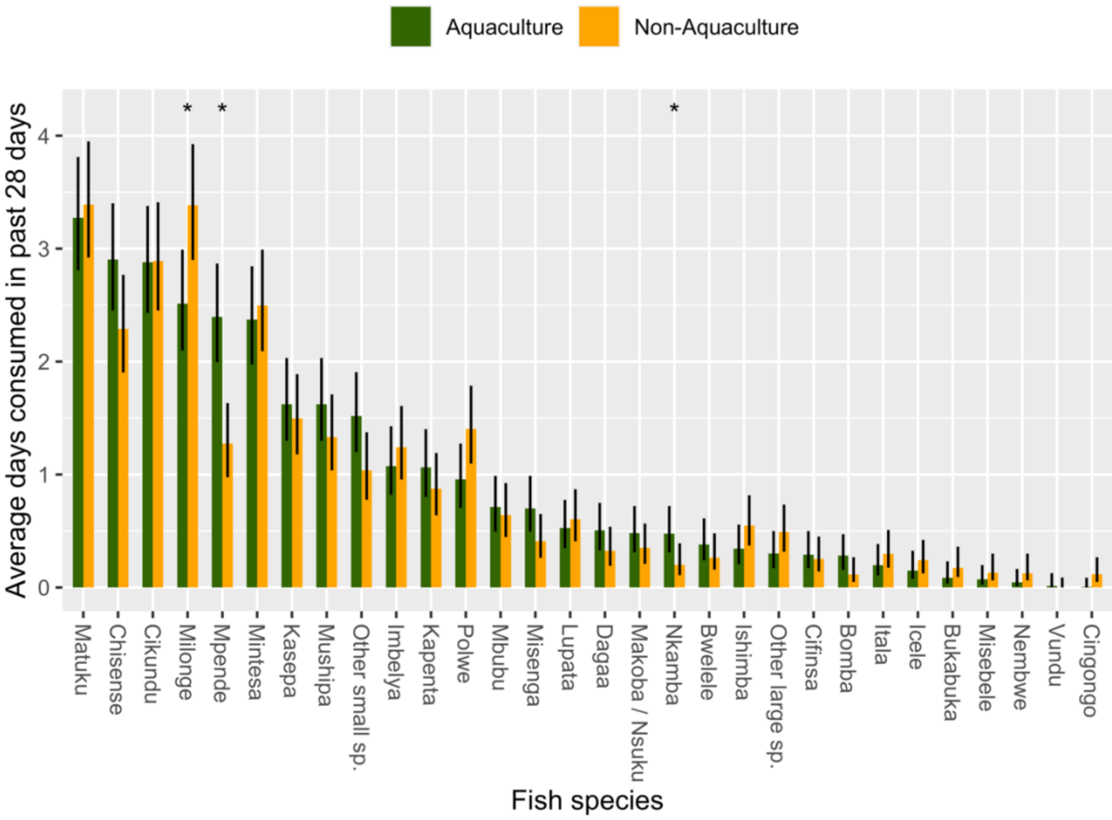
	Bomba	*Clarias stappersii*	Blotched catfish	Small
	Cingongo	*Syndontis spp*	Squeakers	Small
Typically cultivated tilapia†	Mpende	*Coptodon rendalli*	Red-breasted tilapia	Large
	Nkamba	*Oreochromis machrochir*	Greenhead tilapia	Large
Large catfishes	Milonge	*Clarias gariepinus*	Catfish	Large
	Vundu	*Heterabranchus longifilis*		Large
Lates (perch)	BukaBuka	*Luciolates stappersii*	BukaBuka	Large
Large mormyrids	Mbubu	*Mormyrus longirstris*	Bottlenose	Large
Large Cichlids	Makoba / Nsuku	*Serranchromis robustus*	Yellowbelly Bream	Large
	Nembwe	*Serranochromis spp.*	Largemouths	Large
	Polwe	*Serranochromis angusticeps*	Thinface Largemouth	Large
	Other large fish	Range of large serranchromis	Large	

† While these two tilapias are technically cichlids, they differ in that they are bred in government hatcheries and promoted in aquaculture development plans. All other cichlids in this list are not promoted for aquaculture, although some, such as *Matuku*, can be found frequently in farmers' ponds as they enter through the inlet systems.

Appendix 2.3. *Number of households (%) that consumed 12 food groups in the 12-hr HDDS Statistical significance at or below the 5% indicated with asterisk (*) and calculated using chi-square test*



Appendix 2.4. *Average daily rate (in past 28 days) of fish species consumed in aquaculture and non-aquaculture households. Statistical significance at or below the 5% indicated with asterisk (*) and calculated using a one-way ANOVA*



Appendix 2.5. *Results of multilevel probit regression on HFIAS categories*

Variables	B	SE	p-value	Exp(B) - OR -	95 CI for OR	
					Lower	Upper
Log (income +1)	-0.209	0.072	0.003	0.811	-0.355	-0.073
Non-aquaculture	0.629	0.212	0.003	1.875	0.214	1.047
HH size: 4-7 people	0.605	0.335	0.070	1.832	-0.055	1.260
HH size: 4> 8 people	1.052	0.378	0.005	2.864	0.311	1.795
Age: 35-60	-0.341	0.264	0.14	0.677	-0.911	0.125
Age: 61-years old	-0.691	0.323	0.032	0.501	-1.326	-0.061
Dietary diversity score	-0.235	0.081	0.003	0.790	-0.393	-0.08
PCA Dimension 2	-0.203	0.094	0.0308	0.816	-0.389	-0.020
Simpsons index for diet	-7.139	2.573	0.006	0.001	-12.346	-2.228
Richness fish species	0.147	0.036	<0.000	1.159	0.077	0.221

B = beta, SE = Standard Error; OR = Odds Ratios

CHAPTER 3

The role of aquaculture and capture fisheries in meeting food and nutrition security: Testing a nutrition-sensitive pond polyculture intervention in rural Zambia

*Published in **Foods** 2022, 11(9), 1334; https://doi.org/10.3390/foods11091334*

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Abstract

This study tested the efficacy of a pond polyculture intervention with farming households in northern Zambia. Longitudinal data on fish consumption and the associated nutrient intake of households (N = 57) were collected over a six-month period (September 2019–March 2020). One group of people tested the intervention while another group that practiced monoculture tilapia farming, and a third group that did not practice aquaculture, acted as control groups. A similar quantity of fish was consumed on average; however, the associated nutrient intake differed, based on the quantity and type of species consumed, particularly for those who had access to pelagic small fish from capture fisheries. There was a decrease in fish consumption from December onward due to fisheries management restrictions. The ponds provided access to micronutrient-rich fish during this time. Pond polyculture can act as a complementary source of fish to capture fisheries that are subjected to seasonal controls, as well as to households that farm tilapia. Assessments of how aquatic foods can improve food and nutrition security often separate aquaculture and capture fisheries, failing to account for people who consume fish from diverse sources simultaneously. A nutrition-sensitive approach thus places food and nutrition security, and consumers, at the centre of the analysis.

Keywords: aquaculture; fisheries; small-scale; nutrition-sensitive; food systems; polyculture; food and nutrition security; Lake Bangweulu; Zambia; Africa

3.1 Introduction

There is a growing recognition that freshwater lakes and rivers in sub-Saharan Africa are crucial to the food and nutrition security of millions of people (Fluet-Choinard et al., 2018; Funge-Smith & Bennett, 2019). Pelagic small fish and wetland species are among some of the cheapest sources of animal foods and are seen as a lifeline for rural households that struggle to meet their food and nutrition needs (O'Meara et al., 2021). Many of these fish are rich in essential long-chain polyunsaturated fatty acids (PUFAs), which are crucial for cognitive development in children during the first 1000 days of life (Kawarazuka & Béné, 2011; Thilsted et al., 2016). The amount and frequency of consumption of individual species are often underrecognized, as they are frequently lumped into larger categories of "fish" or "seafood".

There are few records of the true extent of yields and distribution of freshwater fish species for human consumption in sub-Saharan Africa (de Bruyn et al., 2021). It is largely believed, however, that total yields in many of these capture fisheries are declining or stagnating, which, coupled with population growth, means that countries need to increasingly rely on other sources of fish to achieve food and nutrition security, either by importation or developing a domestic aquaculture industry (Hicks et al., 2019; Lynch et al., 2017). The latter has long been touted as a solution to supplement fish supplies on the continent; however, yields are still far too small to mark significant shifts in consumption (Chan et al., 2019). Aquaculture in sub-Saharan Africa is still mostly driven by large, commercial farms that supply expensive fish for high- and middle-income consumers in urban areas (Chikowi et al., 2021; Genschick et al., 2018). While there is some evidence that smallholder fish farmers manage to improve household food and nutrition security through the direct sale and/or consumption of fish, most farmers still struggle to produce fish (especially tilapia) successfully and consistently (Aiga et al., 2009; Obiero et al., 2019). This is particularly the case for smallholder tilapia farmers in Zambia (Kaminski et al., 2018).

Aquaculture in Zambia is expanding and rapidly commercializing. The total production is made up exclusively of tilapia species. Certain indigenous tilapia species are farmed throughout the country, but most of the production is dominated by one non-native tilapia (*Oreochromis niloticus*) (Avadí et al., 2022). Most of the fish consumed by Zambians come from freshwater capture fisheries, not from aquaculture, and are eaten as dried and/or smoked products (Kaminski et al., 2018). Zambia has a high diversity of indigenous species available in markets throughout the year, constituting a critical animal-source food for most of the population (Harris et al., 2019; Longley et al., 2014). Fish consumption is stratified along economic lines and poorer people tend to consume small, dried, cheap fish, while well-off people tend to consume large, fresh fish, such as farmed tilapia (Marinda et al., 2018).

The potential of small indigenous fish species (SIS) is increasingly recognized as crucial to food and nutrition security in low- and middle-income countries, due to their superior micronutrient composition compared to common commercial species, such as tilapia (Hasselberg et al., 2020; Roos et al., 2002). Such perspectives emerged from studies in Bangladesh, where SIS contributed significantly to increases in micronutrient intake, particularly for pregnant and lactating women (Bogard et al., 2015; Roos et al., 2007). Greater benefits were realized when multiple species were produced in small homestead ponds, i.e., polyculture production (as opposed to single species in monoculture production) (Castine et al., 2017).

The principle of polyculture is to stock compatible fish species that occupy different trophic niches in a pond ecosystem, thereby utilizing the available resources more efficiently (Milstein, 1992; Wahab et al., 2011). Such approaches usually consider sustainability issues, with the aim of improving production per unit per land/water and using less energy, resulting in lower feed conversion ratios (FCR) and lower production costs (Robinson & Li, 2010). In commercial systems, polyculture is implemented with the intended outcome to increase fish growth, achieve higher yields, and gain greater profitability (Ahmad et al., 2010). In many extensive systems in rural areas, however, the unintentional entry of wild self-recruiting species is an outcome of the system itself, e.g., rice-field fisheries in Bangladesh. Such extensive polyculture systems have since been noted for their ecological and nutritional outcomes (Karim et al., 2011). The systems provide many benefits, such as allowing for shorter production cycles, faster cash flows, and the intermittent harvesting of highly nutritious fish throughout the season, which do not need to be purchased and restocked from hatcheries (Castine et al., 2017). This type of mixed-fish production is better suited for extensive systems that rely on natural rather than formulated feeds usually operated by poorer farmers as a means of livelihood (Karim et al., 2011).

In sub-Saharan Africa, few studies have incorporated SIS into polyculture systems, probably because, at face value, they offer little in the way of economic reward. One study did find that small fish generated more gross income because the biomass of small barbs was larger than tilapias in a pond (Brummett & Katambalika, 1996), though this may speak more to the difficulties farmers face in rearing tilapia. There is very little commercial incentive to establish hatcheries for SIS, and due to their fragility, recruiting and stocking can be problematic (Ibid.). The knowledge of the number and diversity of species suitable for aquaculture is, thus, extremely limited in the region.

In many cases, however, SIS already exist in household ponds in small-scale systems, especially in northern Zambia (Kakwasha et al., 2020). This is largely an unintentional consequence of the design of extensive pond systems that allow fish to enter and breed in the pond. Most ponds are also dug in local wetlands where there is an abundance of SIS. The benefit is that farmers can bypass the issue of procuring species from hatcheries or recruiting stock from larger capture fisheries. Smallholder farmers in northern Zambia, therefore, operate de facto polyculture systems. This fact is frequently unacknowledged in assessments of extensive, small-scale aquaculture systems in the region. Farmers are, however, actively encouraged by the government and development organizations to establish monoculture systems with local tilapias purchased from government hatcheries (there are almost no private hatcheries) to maximize the potential growth of single species for markets. As was the case in Bangladesh in the past, the SIS are treated as competitors with tilapia for pond resources. Farmers are encouraged by extension officers to eliminate these small fish. Meanwhile, farmers struggle to maintain strict tilapia growth levels in a monoculture system for long periods, meaning that total yields and productivity remain critically low (Lundeba et al., 2022).

In essence, as tilapia species in much of Africa are indigenous, compared to Asia where they are exotic, farmers end up growing small tilapias and/or a mix of other species throughout the year. Most of these farmers intermittently harvest fish from their ponds throughout the production cycle, almost exclusively for household consumption (Kaminski et al., 2019), thereby not allowing the tilapias the possibility of growing to full size. Public health statistics, meanwhile, highlight the urgency of improving food and nutrition security in rural Zambia and the critical role that SIS can play in supplying multiple nutrients including minerals, vitamins, essential fatty acids, and protein (Marinda et al., 2018; Nkonde et al., 2021).

Farmers balance the needs of harvesting fish for food and generating cash. Governments and development organizations favour the latter commercialization narrative, which fails to recognize that many smallholder farmers simply do not have the financial means to grow tilapia unabatedly for the six or more months required to produce large fish (Kaminski et al., 2018). In turn, the failure of these systems to improve livelihoods is often blamed on the lack of infrastructure and inputs (i.e., seed and feed) (Brummett et al., 2008). While the lack of input supply chains is a definitive barrier in sub-Saharan Africa, many policy and development practitioners fail to see aquatic ponds as a potential bank of highly nutritious foods that make up one part of a larger food system operated by a farmer. The vast supply of fish from capture fisheries, which dwarfs that of farmed fish in the region, is rarely acknowledged by studies that look to assess the role of ponds in improving food and nutrition security, despite an obvious overlap of competing fish products on the markets (wild versus farmed tilapia), and people's fish consumption choices and preferences.

There are calls for greater recognition of smallholder pond polyculture as a technology to help reach nutrition and health goals in Zambia (Genschick et al., 2017). For example, having learned from Bangladesh and Cambodia, WorldFish, an international research organization, funded polyculture trials in the north of the country, with promising results (Gellner et al., 2017). However, no studies tested such approaches directly with Zambian smallholder farmers, and none collected panel data that traced the consumption of fish from all sources to see how such a technology may fit into people's fish-sourcing strategies.

We investigate whether a polyculture system with various SIS could increase the supply of fish and the frequency of consumption. The polyculture systems introduced in this study are intentionally designed to grow several self-recruiting species in one pond. The objective of this research is to establish the potential contribution of aquaculture, and polyculture production specifically, to address household micronutrient sufficiency through the improved seasonal availability of fish. This requires looking at aquaculture in terms of the nutrients it can provide as opposed to solely producing large fish for markets. In a nutshell, this can be summarized as a nutrition-sensitive approach to rural smallholder farming in Zambia (Ruel & Alderman, 2013; Ruel et al., 2018). In other words, this entails placing nutrition at the centre of the system rather than focusing on quantities produced and monetary outcomes. This approach prioritizes the food and nutrition security of poor households in addition to the productivity of farming systems, thus looking at access to and diversity of foods to ensure that food and nutrition security is met. To get a better sense of fish consumption choices that households make, we assessed all sources of fish in the region, including capture fisheries and dried fish markets. Therefore, we placed aquaculture and capture fisheries together in one aquatic food system that is interconnected, with many different types of aquatic foods and temporal benefits (Simmance et al., 2022; Tezzo et al., 2021).

3.2 Materials and methods

3.2.1 Sampling and site selection

Key informant interviews with extension officers from the government's Department of Fisheries (DoF) were used to select the study sites in Luwingu District in northern Zambia. The extension officers were primarily responsible for all aquaculture development projects in the province and helped guide the site selection process. The intervention group was made up of people who trialled the pond polyculture intervention (referred to as the PP group), whereas the two control groups included people who practiced conventional "monoculture" pond farming (referred to as the MP group), and people who had no ponds at all and only practiced terrestrial agriculture (referred to as the AG group). The PP and AG groups were selected from the same villages (Luena and Isansa). This area was selected because the residents were new to aquaculture and the researchers did not want to interfere with, or contradict, established fish farming systems in the region. The MP group was selected from a village (Fisonge) close to the district capital, Luwingu, 78 km away from the other two groups, where there were more established fish farmers (see Figure 3.1). All households were primarily agricultural households. We aimed to recruit 20 households in each group, using focus-group discussions with village authorities to request volunteers. We were only able to recruit 17 households for the MP group. A total of 57 households were selected for the study.

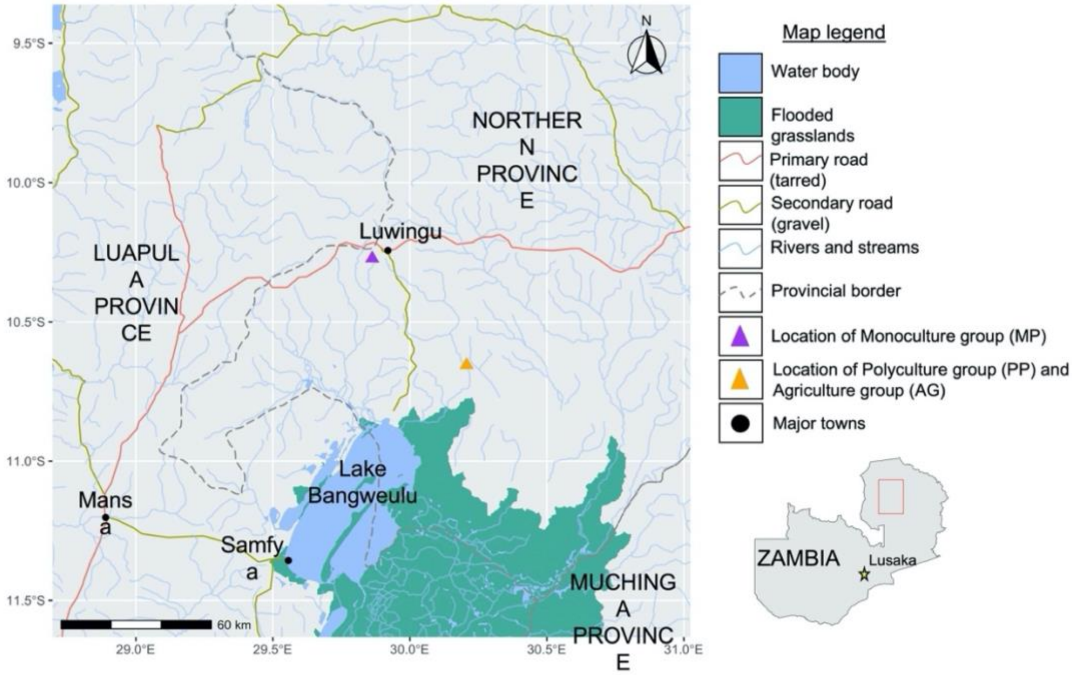


Figure 3.1. *Map of study site locations in Northern Province, Zambia. Data for the flooded grasslands biome is from Terrestrial Ecoregions of the World (TEOW) (Dinerstein et al., 2017). Rivers and water bodies are from the HydroATLAS (Linke et al., 2019)) and HydroATLAS-Zambia (Lehner & WWF-Zambia, 2020).*

3.2.2 Intervention: Polyculture pond farming and nutrition training

The main intervention included stocking self-recruiting species in polyculture ponds. The species were selected based on a screening process that relied on a literature review of commonly consumed fish species, their nutrient profiles, and any evidence of pond trials in the region (details of the screening process are given in Appendix 3.1). In brief, the fish species selected for the trial were chosen because (1) they were often found in farmers' ponds, (2) they had a high nutrient composition in the edible parts, and (3) there was some, albeit limited, information on their suitability for production in earthen ponds.

Farmers in the region typically cultivate the indigenous tilapias, *Oreochromis macrochir* and *Coptodon rendalli* (Kakwasha et al., 2020). *O. macrochir* and three other species were stocked in the PP group's ponds as part of the intervention: a small adult-sized tilapia (*Tilapia sparrmanii*), another small cichlid (*Pseudocrenilabrus philander*), and a small barb (*Barbus trimaculatus*, which has since been changed to *Enteromius trimaculatus*). The *T. sparrmanii* and *O. macrochir* were sourced from local farmers' ponds, while the *P. philander* and *B. trimaculatus* were sourced from the surrounding water bodies with the help of local fishermen. The number and stocking densities of the fish species are provided in Table 3.1. The *O. macrochir* were stocked as juveniles, while the SIS were mostly adult fish. Due to high mortality rates during the handling of the *P. philander* and *B. trimaculatus*, their weight and length measurements were combined.

Table 3.1. *Stocking data for polyculture trial including one commercial tilapia species (O. macrochir) and three small indigenous species (SIS)*

Species	**Total fish**	**Number of fish stocked in ponds (n=20)**		**Stocking density (fish/m^2)**		**Weight of fish (g)**		**Length of fish (cm)**	
		M	**SD**	**M**	**SD**	**M**	**SD**	**M**	**SD**
O. macrochir	8554	427.3	11.6	2.0	1.0	13.4	4.6	8.6	1.0
<u>Small Indigenous Species</u>									
T. sparrmanii	2000	100	0.0	0.5	0.2	5.0	1.0	5.9	0.6
P. philander	2000	100	0.0	0.5	0.2	1.8*	0.8	4.1	0.8
B. trimaculatus	1000	50	0.0	0.2	0.1				

* *P. philander* and *B. trimaculatus* were combined at the time of stocking; weight and lengths reflect a random sampling of the species mix

The PP intervention group received additional training on pond management and on how human nutrition is improved through the consumption of fish, particularly on the benefits of consuming small fish whole for children and pregnant or lactating women, especially in the first 1000 days of life. The pond management training focused on three key issues that contradict the advice given to farmers by DoF extension officers and development workers. Participants were encouraged to:

1. Take fish from their ponds whenever they wanted to, rather than at the end of the growth cycle (promoting intermittent harvesting).
2. Cultivate a diversity of species and not eliminate SIS (promoting polyculture).
3. Use natural rather than formulated feeds since the aim did not require maximizing the growth of a single species in a pond (promoting natural feeding regimes).

The trial was planned from the beginning of September 2019 to the end of March 2020. This constituted the beginning of spring moving into summer when air temperatures begin to warm and farmers in the region typically prepare their ponds for the coming rains. By the end of November, an annual national fishing ban implemented by the government prohibits all capture fisheries activities for three months (December, January, and February). The fishing ban is enforced every year during the spawning season as part of the Zambian government's attempt to manage fish stocks, and is applicable to all fisheries in Zambia except for Lakes Tanganyika and Kariba (Huchzermeyer, 2013). The fishing ban allowed for an additional seasonal dimension to ascertain whether fish supplies decreased during the ban and whether ponds might act as a substitute source of fish. This period, which is typically when farmers wait for the rains and start sowing their fields, is the time when food stocks from the previous year's harvest are depleted, also known as the "hunger season" (Birbeck et al., 2007). This, too, provides an additional seasonal dimension to the analysis from a food availability and access perspective.

3.2.3 Data collection

3.2.3.1 Primary data: Demographic information and fish food diaries

We collected demographic data, including household size, the age of the household head, marital status, years of education, disposable income, and the number and age of all children. Participants were trained on how to use fish food diaries to record the consumption of fish (but not other types of food) for the whole household, including the source of fish, to allow for comparisons between aquaculture and capture fisheries. Participants noted every instance when they consumed fish, including the species and form (dried/smoked/fresh), as well as the weight of fish. Participants used several household items, for example, cups, bowls, handfuls, and buckets to determine the quantities of fish. We converted these units of measurement for each fish species into kilograms. These conversion units were used throughout the study. The quantity of fish provided by participants referred to the total weight of all fish cooked and consumed on the day and not the weight of the edible portions. To validate quantities and descriptions, enumerators visited every month from September 2019 to March 2020, making a total of seven visits to each participating household. On visiting the household, enumerators discussed each entry to ensure accuracy. During this process, qualitative data were collected on how fish was sourced, cooked, portioned, and consumed, to provide a holistic view of people's consumption habits and patterns.

3.2.3.2 Secondary data: Nutrient composition of fish species and Recommended Nutrient Intake (RNI)

A data set compiled by Hohenheim University includes the nutrient profiles of 43 species that are commonly consumed in Zambia (Nölle et al., 2020). The study collected multiple samples of each species, mostly from the Lake Bangweulu area, including both the dried and fresh forms. Fish were divided into "small", "medium", and "large" categories, based on size and edible portion (whole or filleted). The data set includes nutrient composition data per 100 g of edible portion for calcium (Ca), potassium (K), magnesium (Mg), iron (Fe), zinc (Zn), selenium (Se), chromium (Cr), and copper (Cu), as well as riboflavin (B_2), niacin (B_3), folate (B_9), Cobalamin (B_{12}), crude protein and omega-3 fatty acids: eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA), and α-linolenic acid (ALA). The authors determined that these nutrients and omega-3 fatty acids were commonly found in fish compared to other animal-source foods and their contribution toward growth and development in the first 1000 days of life was a key focus.

We used the recommended nutrient intake (RNI) for adults and children, as stipulated by the World Health Organization (WHO) and the Food and Agriculture Organization of the United Nations (FAO) (WHO/FAO, 2004), as a measure of nutrient security. Data for the intake of potassium was taken from the National Academies of Sciences, Engineering, and Medicine (NASEM, 2019). An RNI is the daily suggested amount of nutrients in grams for healthy individuals in specific age and sex groups, expressed as a percentage of reaching the daily target. In this case, the RNI averages for females across five age groups were used (see Appendix 3.2). The RNI values for omega-3 fatty acids were derived from an expert consultation report (WHO/FAO, 2010). There is no consensus on the RNI of omega-3 fatty acids for children and the RNI for adults differ, depending on contexts (Zhang et al., 2018). We established the RNI for omega-3 fatty acids by using the average energy requirements of females in different age groups (NASEM, 2005), and then calculated the percentage of the energy requirements for each age group, as stipulated by the expert consultation report (WHO/FAO, 2010).

3.2.4 Analysis of longitudinal fish consumption and individual nutrient intake

The quantity of individual fish species consumed by a household on a given day is the key unit of analysis in this study. Quantitative data were analysed on how much fish was consumed, which species were cooked, in what form, and from which source, over a period of six months. The average consumption of fish per capita, per household, per day, was calculated by adding all the quantities of fish together and dividing by the number of people in each household, as well as the total number of days in each month.

Dried and fresh fish weights are not directly comparable, since consuming the equivalent weight of dried fish to wet fish requires more units of fish to be caught/purchased. We calculated the difference in moisture content of wet fish compared to dry fish for every species using the study by Nölle and colleagues (2020). In some cases, where data were missing, we used similar fish species based on size and genus as a substitute (see Appendix 3.3). By doing so, we calculated a wet weight equivalent in kilograms to be able to better compare the consumption of species. Given the small sample size in each farmer group and the non-normal distribution of fish weights, any statistical methods to compare differences in total fish weights between groups did not prove useful.

There was no need to use a wet weight equivalent regarding the RNI calculations since the study by Nölle and colleagues (2020) collected the nutrient compositions of species in both dry and wet forms, respectively. We used the nutrient composition profiles of each species per 100 gram (g) edible portion (dry and wet values) to calculate the nutritional content of the fish consumed so that we could compare the total nutritional contributions between the groups. We multiplied the nutrient composition (in grams, milligrams, and micrograms of different nutrients) by the quantity of fish (in kilogram) consumed in a household each day (see Appendix 3.3). We then divided each nutrient by the number of people in the household, subtracting infants (0–1 years old) that were still breastfeeding. The quantity of fish among all household members was divided equally.

We acknowledge that adults and children consume different portion sizes of fish; however, we were regrettably unable to achieve this level of nuance for each unit of fish consumed in our approximation, given the vast diversity and sizes of fish species that came in both fresh and dried form. The nutrient composition for 100-gram edible portions was calculated for whole fish, including those parts of the fish that may have been discarded or thrown away, meaning that the results should be read with caution since we did not establish exactly which parts of the fish were consumed by whom. For larger fish, we used the nutrient composition of fillets, as per the study by Nölle and colleagues (2020), when in fact some people in a household may have been eating different parts of a larger fish (i.e., head or tail). We only know the total quantity of fish consumed by a household and not the size of the individual units of fish consumed by each person. Where possible, we used qualitative interviews to determine whether certain species were likely to be consumed as adults or juveniles and either whole or filleted, and then used the corresponding nutrient values from the study by Nölle and colleagues (2020) (see Appendix 3.3 for more detail). Based on these data, we present the quantity of fish consumed on a given day and the contribution of this portion to meeting daily nutrient recommendations for each age group. This is calculated as a percentage of the daily RNI of all the nutrients assessed in this study for each age group and is then averaged for the household.

We compared the quantities of fish consumed, the species, and the source between the three groups over time. We also compared the average amount, i.e., portion, of fish (for each species) per capita per day; by doing so, we can compare the contribution these fish made to the RNI of various nutrients, expressed as daily averages for the study period.

3.3 Results

The trial started on 9 September 2019 and ended on 31 March 2020, lasting for a total of 209 days. By November, one person from the PP group and one from the MP group had dropped out of the experiment. By January, two more people had dropped out of the AG group for undisclosed reasons. All subsequent analyses are based on the sample size of 53 households that provided complete data.

Households from the PP and AG groups were from the same area and shared similar characteristics, although the MP group members were slightly older and wealthier on average, while the AG group members were notably younger and with smaller households (see Table 3.2). The PP and AG groups were located further down the escarpment, closer to Lake Bangweulu (see Figure 3.1). The Luena River flows through the area where the AG and PP groups were located and provides a local wetland fishery for these two groups. The MP group was slightly wealthier on average and was located further away, closer to markets and trade routes.

Table 3.2. *Household descriptive statistics*

	Total *(N = 53)[a]*	**Polyculture (PP)** *(n = 19)*	**Monoculture (MP)** *(n = 16)*	**Agriculture (AG)** *(n = 18)*
Age *(Mean Years ± SD)*	40.6 ± 11.4	39.9 ± 10.1	44.9 ± 12.2	37.4 ± 11.5
Education *(Mean Years ± SD)*	7.6 ± 2.0	6.7 ± 2.3	7.7 ± 1.9	8.5 ± 1.3
Household size *(Mean No. of People ± SD)*	6.3 ± 2.5	6.2 ± 2.6	7.2 ± 2.4	5.6 ± 2.5
Number of Children (Mean No. ± SD)	4.3 ± 2.4	4.3 ± 2.4	4.7 ± 2.6	3.9 ± 2.4
Marital status *(Freq. & % Single)*	14 (26%)	6 (32%)	1 (6%)	6 (33%)
Head of Household *(Freq. & % Female-headed)*	13 (25%)	6 (32%)[b]	1 (6%)	6 (33%)
Average disposable *income* *(Mean ZMW [c] ± SD)*	5 265 ± 7 982	5 237 ± 10 943	6 215 ± 6 200	4 449 ± 5709

All values are mean and standard deviation unless otherwise specified.
[a] Original sample was N=57 but four participants dropped out of the experiment.
[b] Only one woman was married and the head of the household. All single women were head of the household.
[c] ZMW = Zambian Kwacha

Each household consumed on average 40.6 kilograms (kg) of fish over 6 months. When considering the wet weight equivalent of fish, this resulted in 69.4 kg of fish on average or 0.3 kg of fish per household per day. With a total of 332 people in 53 households, this means a total of 11.1 kg of fish was available per person in each household over this period, resulting in just over 1.8 kg of fish per person per month and around 0.05 kg of fish per person per day. In total, all three groups consumed roughly the same amount of fish: the AG group consumed the total wet weight equivalent of 1243 kg of fish; the PP group consumed 1247 kg, while the MP group consumed 1191 kg. When dividing the quantity of fish by the number of people in the households, the AG group consumed 12.4 kg of fish per capita over 6 months, the PP group consumed 10.7 kg, and the MP group consumed 10.36 kg. The AG group had smaller household sizes on average. The average and ± standard deviation portion size of wet-weight-equivalent fish for a household on any given day was around 1.2 kg ± 1.7, which was portioned between 6.3 people on average, resulting in an average portion per person of 0.2 kg of fish per day. This was around 1 kg ± 1.6 for AG households, compared to 1.1 kg ± 1.6 for PP households, and 1.7 kg ± 1.8 for MP households.

Figure 3.2 shows the average fish (wet weight equivalent in kilograms) per capita per day for each month, disaggregated by group. There was a general rise in the daily per capita average from September to November (note that the trial did not start on 1 September). The increase was sharpest for the AG and PP groups, who exponentially increased their consumption of fish just before the national fishing ban started in December. Coincidentally, there was a gradual decrease in fish consumption during the latter period, with the sharpest decrease reported by the AG group. The PP group started to harvest more fish from their ponds during this period. The MP group maintained a steadier per capita average of fish per day throughout the whole study period.

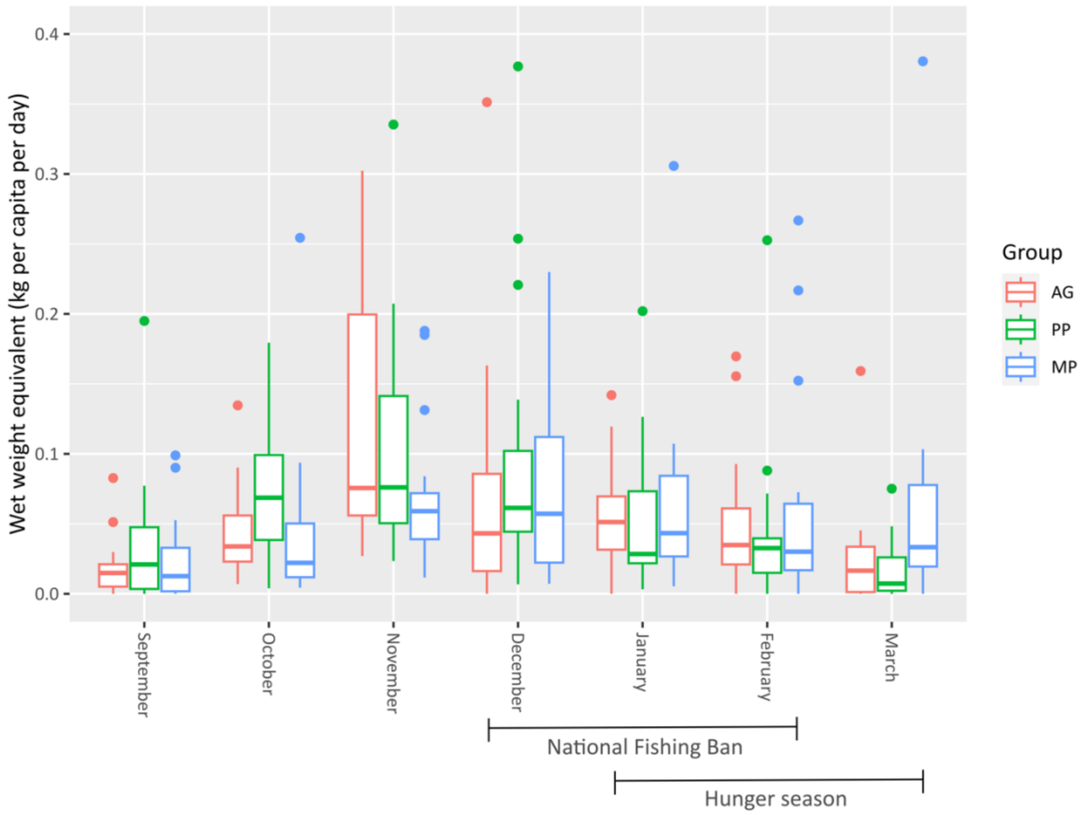


Figure 3.2. *The monthly quantity of fish consumed, with the wet weight equivalent in kilograms per capita per day, for the three treatment groups. Outliers above 0.4 kg have been truncated for clarity, removing 4 observations.*

A total of 21 species were consumed across all households. Since some species were consumed less frequently than others, they were combined into a single species based on family and genus (see Appendix 3.4 for more detail). We categorized all these species into the 15 most frequently consumed species (see Table 3.3).

Table 3.3. *Categories and names of the fish species consumed, including total frequency (number of times consumed) and total quantity (kilograms consumed), represented as the measured weight and wet weight equivalents.*

Category*	Scientific name	Local name	Freq.	Weight (kg)	Wet weight equiv. (kg)
A: Mormyrids and barbs (wetland species)	*Mormyrus longirstris*	Mbubu	38	13.7	33.9
	Marcusenius macrolepidotus	Mintesa	278	119.6	234.1
	Barbus trimaculatus	Mushipa	243	122	242.5
B: Pelagic small/medium fish	*Luciolates stappersii*	Buka-Buka	59	63.3	141.8
	Limnothrissa miodon & *Stolothrissa tanganicae*	Kapenta	138	71.9	197.6
	Potamothrissa acutirostris & *Poecilothrissa moeruensis*	Chisense	133	66.3	214.1
C: Catfishes (large and small)	*Clarias* spp.	Milonge	465	333.4	350.7
	Syndontis spp.	Cingongo	79	44.9	70.3
	Schilbe mystus	Lupata	41	70.7	120
D: Large cichlids	*Sargochromis mellandi*	Imbelya	89	75.1	139.8
	Serranochromis angusticeps	Polwe	133	157.7	274.4
E: Tilapias (often cultivated)	*Coptodon rendalli*	Mpende	326	388	508.4
	Oreochromis machrochir	Nkamba	121	178	193.3
F: Small cichlids from local capture fisheries	*Pseudocrenilabrus philander*	Cikundu	384	165.2	480.2
	Tilapia sparrmanii	Matuku	553	282.3	479.1

* Letters A-F in Category column correspond to fish groups in Figure 3.3 below

The most frequently consumed fish were catfishes (*Clarias* spp.), as well as the smaller *T. sparrmanii* and the larger, and frequently cultivated, *C. rendalli*. These latter two tilapias were the most consumed fish in terms of total weight. However, as many of the small species were consumed dried, the wet weight equivalent of these fish far exceeded the total weight of *Clarias* spp. This means that a greater quantity of these small fish species was actually produced and consumed.

This is better represented in Figure 3.3, which shows the same average quantity of wet weight equivalent (kg) fish per capita per day, disaggregated by group and source. The total weight of fish consumed and not the weight of the edible portions is given, although small fish were generally consumed whole. The PP and MP group members sourced between 10 to 20 g of fresh fish per capita per day from their ponds. The AG group members, who did not have ponds, sourced roughly double that from capture fisheries, and many of the species were the same as the ones found in the ponds of the PP and MP groups.

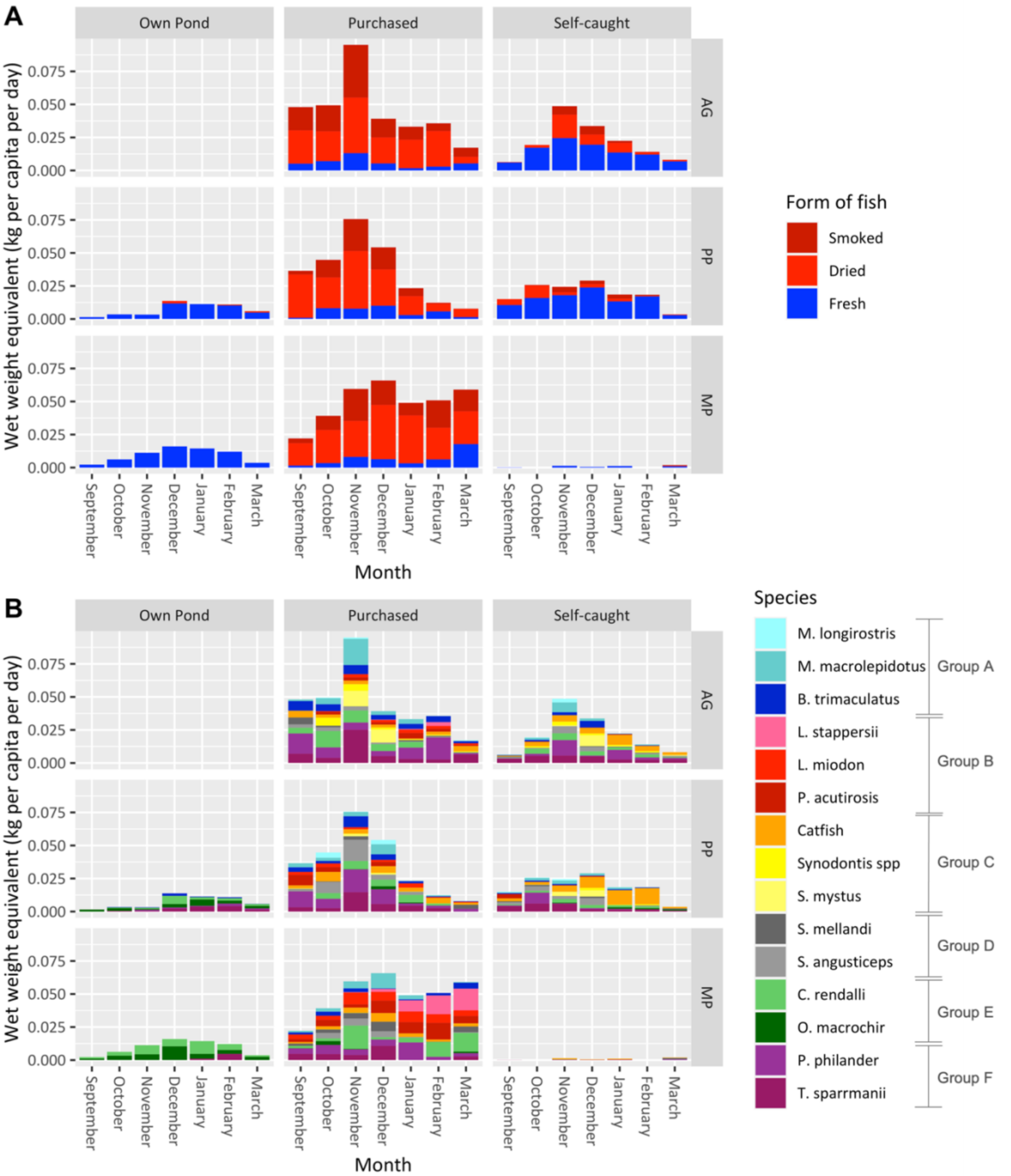


Figure 3.3. *Monthly quantity of fish consumed as a wet weight equivalent (kg/capita/day) according to the three study groups and sources of fish: (**A**) form of preparation of fish; (**B**) species. Group A: mormyrids and local barbs, generally consumed as juveniles and caught in small lagoons and channels in wetlands. Group B: caught in the pelagic zones of large, further-away fisheries and frequently traded throughout Zambia. Group C: catfishes of all sizes and some of the most frequently consumed fish in the region. Group D: large, robust cichlids caught in nets or with handlines. Group E: widely consumed tilapias that are frequently cultured in ponds*

but are mainly sourced from capture fisheries. Group F: small, wild cichlids that are widely consumed and usually enter farmers' ponds.

The MP group hardly caught any fish from capture fisheries, compared to the other two groups; however, they did purchase a large quantity of dried fish from the market that were originally caught in capture fisheries located further away. Discussions with farmers revealed that these species were more available in the markets closer to the MP group, compared to the markets closer to AG and PP groups. Half of the fish consumed across all groups was either dried or smoked, especially fish purchased from local markets. In total, 1288.5 kg of fish was consumed fresh, whereas 863.7 kg was consumed dried and/or smoked, and the wet weight equivalent of the latter was far greater than that of fresh fish (2391.7 kg). Most of the fish (60%) was purchased, although there was a notable decrease in purchased fish from December onward, coinciding with the national fishing ban, meaning that households had to find alternative sources of fish.

This decrease in fish consumption during the fishing ban was not as large for members of the MP group as it was for the AG and PP groups. The MP group started sourcing pelagic small fish and *L. stappersii* (Buka-Buka — a medium-sized perch) from capture fisheries further away; namely, from Lake Tanganyika, which was unaffected by the national fishing ban. According to interviews with farmers, despite the ban applied to Lake Bangweulu, where *Potamothrissa acutirostris*/*Poecilothrissa moeruensis* (chisense) is common, much of this fish was dried and stockpiled in November and illegally traded throughout the fishing-ban months. This fish was caught in the deeper pelagic zones on the western shore of the lake and landed in Samfya, meaning that it was processed in Luapula Province and then traded via road. When asked from which specific markets or vendors fish was accessed from, it was evident that the MP group had greater access to chisense and other pelagic small fish species as they were located along the main road by Luwingu, where fish was more frequently traded and sold (see Figure 3.1).

During the fishing ban period, both the MP and PP groups increased the quantity of fish that they harvested from ponds. This gave these households a small additional source of fish during the closed fishing season. The PP group only started sourcing fish from their ponds in greater quantities once the fisheries were closed since the same species were readily available from capture fisheries in the open fishing season. During the closed fishing season, there was an increase in catfishes sourced from capture fisheries. When discussing the location whence fish was sourced, farmers stated that catfishes were widespread and were commonly found in rivers, streams, and ponds that were not usually monitored by DoF extension officers during the national fishing ban.

Figure 3.4 provides more information on the quantity of fish consumed throughout the study period and how this varied between species and the three groups. The tilapia, *C. rendalli*, is the most consumed fish species (wet weight equivalent: kg/capita/day), and the MP group sourced almost a third of this from ponds. While this is one of the most widely cultivated fishes in the region, most of this fish was sourced from capture fisheries. The AG group consumed a larger quantity of *P. philander*, *T. sparrmanii* (two small cichlids), and *B. trimaculatus* (a small barb) than the PP group, despite these species being chosen for the polyculture intervention. The AG group consumed no *O. macrochir*, in contrast to the other two groups, as this was largely a cultivated tilapia species.

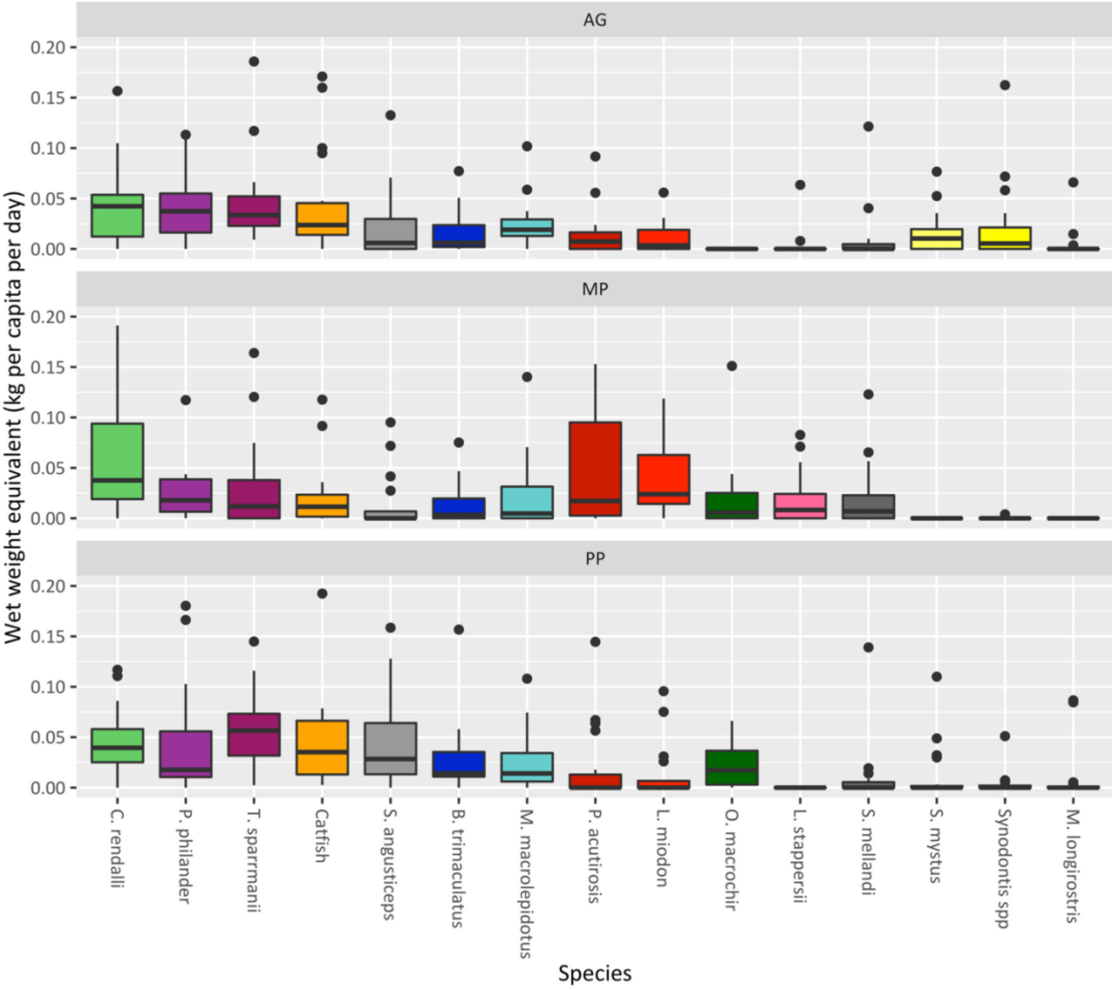


Figure 3.4. *The average quantity of fish consumed (wet weight equivalent: kg species/capita/day), disaggregated by the three study groups. From left to right: the species are ordered as the most to least consumed fish on average for the whole sample of households over the entire study period, in terms of the total wet weight equivalent (kg). Outliers above 0.2 kg/capita/day have been truncated for clarity, thus removing 18 observations.*

The species of fish have varying nutrient compositions per 100 g edible portion (see Appendix 3.3). This varies depending on the type of fish: for example, differences in fat content or micronutrients, whether the fish were consumed whole (including viscera and bones), or whether they were dried/smoked, all of which affect nutrient content. The catfishes and large tilapias are often consumed fresh after cooking. The small cichlids, such as *T. sparrmanii* and *P. philander*, if self-caught from capture fisheries were consumed fresh, although most are caught in large quantities and processed for sale in markets. Other small fish, such as *M. macrolepidotus*, *L. miodon*, and *P. acutirostris,* were almost exclusively consumed dried. Compared to larger fish, these smaller fish were consumed whole, including the viscera and bones. This is evident, for example, in the low amount of calcium provided by catfishes compared to the pelagic small fish species, because the latter were consumed whole with the bones (see Figure 3.5). Catfishes and larger cichlids, meanwhile, played an integral part in providing protein, mainly because of the size of the fillets that were consumed. The pelagic small fish species, such as *L. miodon* and *P. acutirostris*, provided far more omega-3 fatty acids per 100 g than the larger catfishes and tilapias. The smaller cichlids, such as *P. philander*, contributed the most omega-3 fatty acids, not because they have a particularly high concentration of fats but because of how much (total weight) was consumed. These small cichlids played an important role in contributing to the average RNI of calcium, riboflavin, and zinc, whereas catfishes provided fewer micronutrients despite being one of the most consumed fish species. Other notable fish species (*M. macrolepidouts* and *B. trimaculatus)*, although consumed in smaller quantities than the cichlids, still contributed high amounts of nutrients.

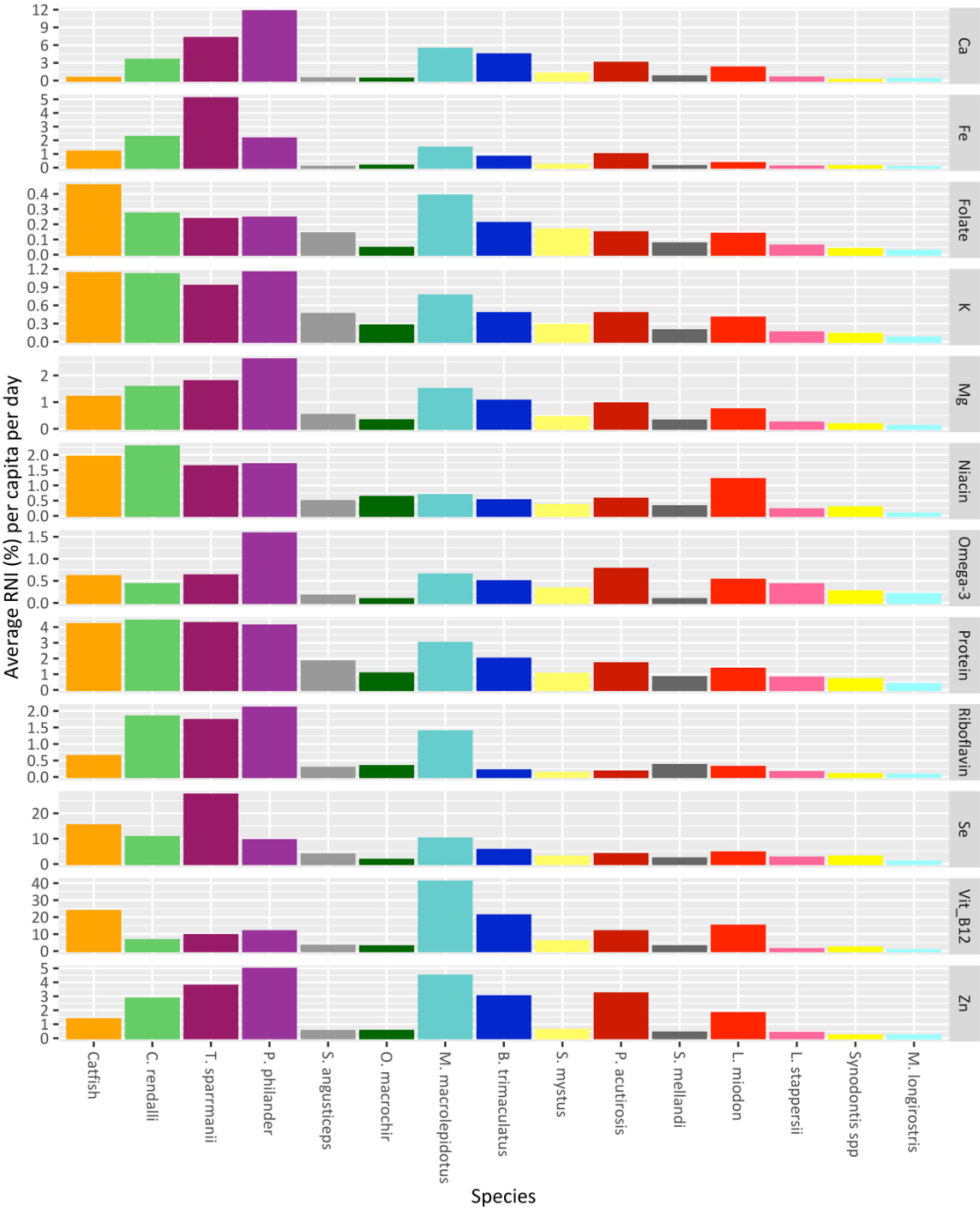


Figure 3.5. *Average consumption of each nutrient per species as a percentage of the recommended nutrient intake (RNI) achieved for each nutrient per capita per day. From left to right, the species are ordered as the most to least consumed fish for the whole sample of households over the entire study period, in terms of the total weight (kg) of fish (i.e., not the wet weight equivalent).*

Figure 3.6 shows the percentage of the RNI reached for each nutrient over time as an average per person per day for each study group. Overall, the entire sample achieved a daily average of 34.6% of their recommended protein intake, 8.6% of their recommended omega-3 fatty acids intake, and 48.2% of their recommended calcium intake. Participants in the study achieved almost double the daily recommended intake for vitamin B_{12} and selenium, on average. Since fish is known to contain high concentrations of these micronutrients, it is common for people to overreach the daily recommendation (Hallström et al., 2019). Over time, during the study period, the percentage of RNI achieved for most nutrients decreased, with the AG and PP groups experiencing the largest decreases from December onward. The MP group managed to avoid such a decrease, especially in their intake of omega-3 fatty acids. This was because of the high contribution of the pelagic fish, purchased from stocks caught from capture fisheries that are located further away, and because of the overall quantity consumed by the MP group (see Figure 3.3 and Figure 3.4).

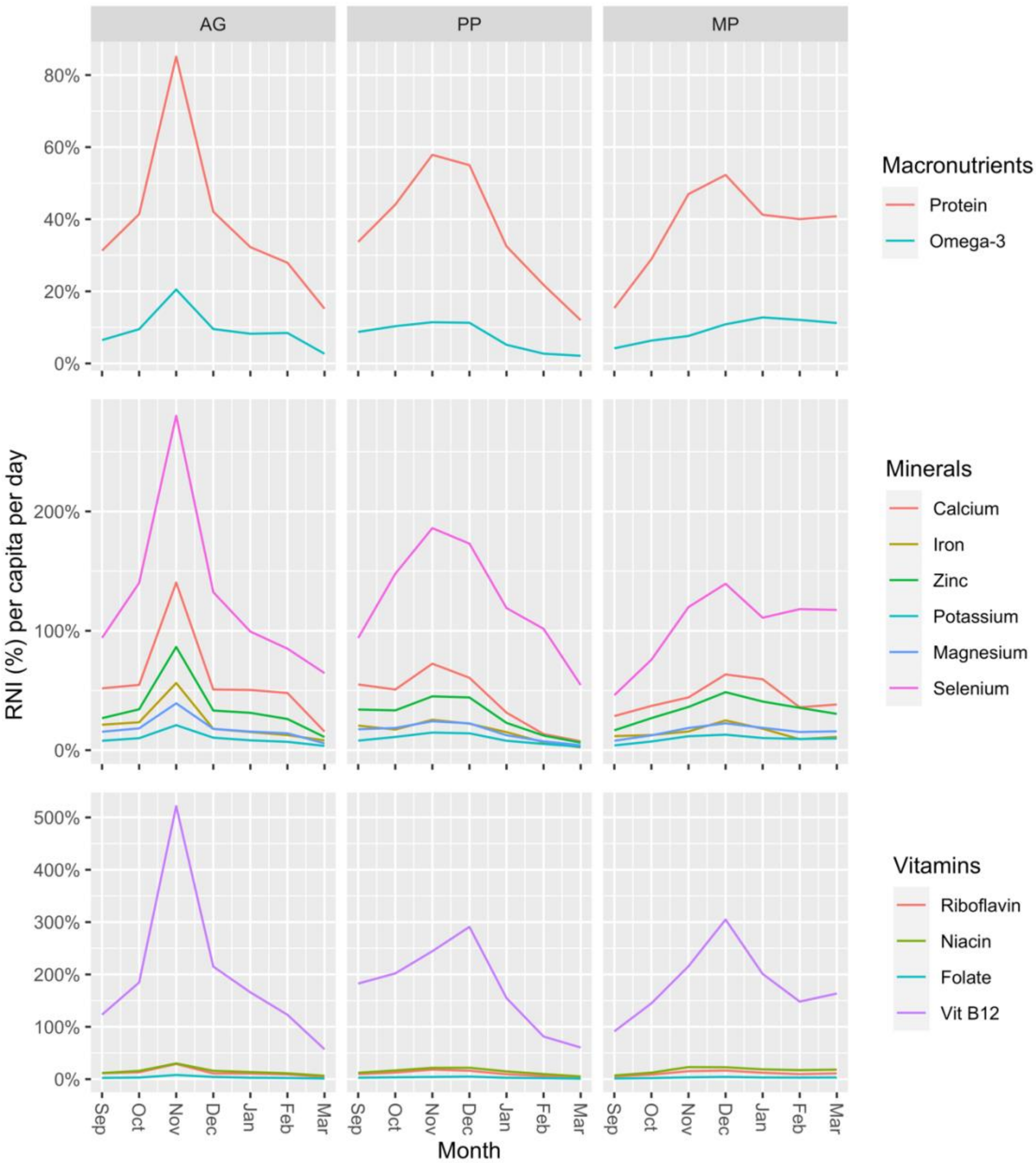


Figure 3.6. *The percentage of the recommended nutrient intake (RNI) reached per capita per day of selected nutrients: minerals, vitamins, and omega-3 fatty acids derived from the consumption of fish over 6 months (September 2019–March 2020), disaggregated according to the three study groups.*

3.4 Discussion

The total quantity of fish consumed per capita over the whole study period was relatively the same for the three groups, pointing to people's ability to find ways to satisfy their protein needs, in this case in the form of fish. The MP group managed to maintain a more consistent consumption of fish compared to the decreasing consumption experienced by the AG and PP groups. As a result of the national fishing ban, the latter groups almost doubled their fish consumption per capita in November in preparation for the inevitable decline in fish supplies starting in December, or for other unknown reasons to do with food availability during this time. This may be seen as indirect proof that fisheries management strategies are, indeed, successful in decreasing fishing activities and supplies. In anticipation of the ban, however, fishing pressure seems to increase in November, thus affecting the net impact that the ban may have on fish stocks. This study did not aim to assess the impact of the national fishing ban and other causes for this decline should be considered, such as the reduced catch per unit effort, resulting from an increase in rain and water levels making it difficult to access fishing grounds, especially in wetland swamps. Regardless, there was a clear trend of decreasing fish supplies experienced by all groups during this time, which is also regarded as the beginning of the "hunger season" for many poor and vulnerable Zambian families (Birbeck et al., 2007). Such a drop in fish supplies, a primary animal-source food in this area, could exacerbate food and nutrition insecurity.

There is very little reliable information on the total fish yields in Zambian capture fisheries. Little is known about whether fisheries management strategies are successful; although, in general, there seems to be evidence of declining fish supplies from capture fisheries (Tweddle et al., 2015). While the data in our study show a decline in the quantity and number of fish species from December onward, the MP group managed to shift their consumption of fish to dried pelagic species from other freshwater capture fisheries outside of Zambia, which were unaffected by the national fishing ban. Much of this fish is sourced from Malawi or Tanzania (Mussa et al., 2017). Such fish trade corridors along main roads allowed the MP group to access these fish species and, thus, maintain a higher intake of key micronutrients and omega-3 fatty acids. The MP households were made up of established fish farmers and are likely to be generally wealthier than non-fish farmers (Kaminski et al., 2020), another reason why this group could afford to purchase fish from markets more regularly. Many of the pelagic small fish species were not commonly traded in the AG and PP groups' villages, given the poor condition of the roads; thus highlighting the importance of the accessibility of fish products.

All three groups experienced a dip in protein intake over time, owing to a decrease in fish supplies; however, the omega-3 intake was variable between the three groups, owing to differences in species consumption. The pelagic small fish species contained high amounts of fatty acids, and they were consumed whole including the viscera and bones. This points to the importance of these species and capture fisheries in providing access to key nutrients. While these fishes may not be available in certain areas, other small fishes, if consumed whole and in sufficient quantities, can also be a critical source of omega-3 fatty acids. The small cichlids *T. sparrmanii* and *P. philander* contributed much of the omega-3 fatty acids for the AG and PP groups, suggesting that they may be good candidate species for polyculture systems. It is important to consider the nutrient composition of edible portions, as well as the total quantity consumed. While some fish species may have exceptionally high concentrations of certain micronutrients and fatty acids, they may be consumed less frequently. This points to the importance of assessing not only edible portions correctly but also the total quantity and frequency of fish species consumed.

A large quantity of fish was consumed by these households (over 11 kg of fish per capita during a six-month period). Fish was consumed almost every second day. This is above the annual average for Africa (10.8 kg/capita/year) and far above the annual average of East Africa (4.8 kg/capita/year) but below the annual average for West Africa (15.3 kg/capita/year) (Chan et al., 2019). Considering that we measured this consumption for half a year and during the time of the national fishing ban, we can assume that people in our study consumed higher amounts of fish on an annual basis. It is worth mentioning that this study did not evaluate other animal-source foods that households consumed, nor did we assess whole diets—for example, how much, in terms of cereals, dark green leafy vegetables, and fruits, was consumed. It is, therefore, unclear what other foods people consumed during this time; however, there is evidence that people in this region have little access to other animal-source foods and that fish is the primary protein source throughout the year (Harris et al., 2019).

The primary purpose of this research was not to establish which aquatic food system provided a better source of fish and nutrients, per se, but to establish whether polyculture fish farming can provide a significant and alternative source of fish. When looking specifically at the role of ponds in supplying fish, it was clear that they served a similar purpose for the MP and PP groups. The MP group claimed to grow tilapia for markets by operating strict monoculture systems for several months; however, most of these farmers harvested fish from their ponds sporadically throughout this period. This group even harvested *P. philander* and *T. sparrmanii* from their ponds (two fish that were selected for the polyculture intervention), suggesting that some, if not most, farmers in the region probably operate polyculture ponds by default. The fact that most small-scale ponds are, in fact, polyculture systems is rarely acknowledged in assessments of small-scale aquaculture in sub-Saharan Africa.

The PP group consumed a slightly larger quantity of fish from ponds than the MP group did, which was important from a food and nutrition security perspective, as they did not have the same access to fish markets as the latter group. The PP group, then, had an additional source of fish that the AG group did not have. The ponds provided an important source of fish, particularly during the months of the national fishing ban when both the PP and MP groups increased their consumption from ponds. The PP group tended to harvest less fish from capture fisheries during this time, as fish was available from their ponds. Polyculture ponds that can provide fish all year round, but especially during the national fishing ban, may be beneficial for fisheries management as well as food security objectives. It is also likely that the PP group spent less money on buying fish from markets as they had access to fish from their ponds. The PP group sourced notably less fish from markets than the other two groups. Therefore, ponds can provide additional fish, but low yields from ponds mean that they cannot substitute fish from capture fisheries.

Since the PP and MP groups harvested fish from their ponds for consumption, it stands to reason that polyculture may provide two production strategies for farmers: (1) they can use ponds exclusively, and almost daily, as a source of diverse fish for human consumption; or (2) they can integrate polyculture with the aim of additionally producing larger fish (tilapia) for markets, since there may be niche opportunities for growing both tilapia and SIS at the same time (Ahmad et al., 2010). Though the biophysical aspects of the latter were not tested in this study, some farmers from the sample expressed their interest in operating ponds with diverse fish species for household consumption whilst at the same time operating ponds with single species strictly for sale. Other farmers saw an opportunity to do both at the same time in one pond. The intentional recruitment of SIS species into ponds can be a sound livelihood activity for semi-controlled pond systems, as they are in Bangladesh (Karim et al., 2011). The value of polyculture ponds is to provide more fish and a diversity of fish species—small and large—for consumption and for sale, and to extend the season of consumption, minimizing the reliance on capture fisheries and the negative effect of the fishing ban.

An extensive, low-input system with multiple highly nutritious fish species enables not only management techniques, such as phytoplankton-based or periphyton-based growth, but also allows for partial harvesting throughout the production cycle. This may be more complementary to the conditions and characteristics of smallholder aquaculture in sub-Saharan Africa. A high diversity of fish species, the inclusion of indigenous species, and polyculture production methods are likely to be more compatible with smallholder aquaculture at this stage of aquaculture development on the subcontinent. This is especially the case for poorer farmers who struggle to produce for markets and in areas where malnutrition and food and nutrition security are major development challenges. The potential to widen the parameters for diverse species selection must be considered, to allow for the growth and development of aquaculture in the region.

3.5 Conclusion

By using a food systems lens in assessing the contribution of various aquatic systems, we were able to ascertain a more complete picture of how households in rural Zambia consumed fish. We achieved this by looking at all aquatic food systems in the region and placing human nutrition at the centre of the analysis. We considered, specifically, the individual species produced in various systems with the goal of improving access to these species. The study took place during seasonal shifts, including weather changes as well as fisheries management interventions and food scarcity fluctuations, which helped to better understand fish consumption trends.

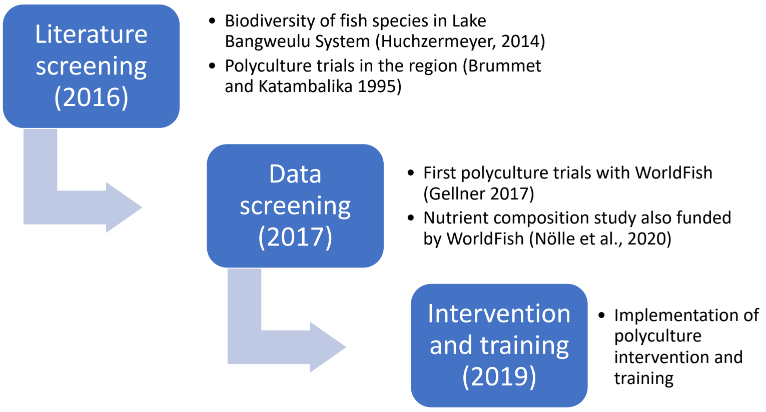
This research provided evidence that people's ability to shift their sourcing strategies of fish, due to various circumstances, was the most important factor in meeting their overall nutritional needs. A diversity of fish species, a diversity of sources, and the ability to adapt and change sourcing (and expenditure) strategies provided households with a more flexible pathway to food and nutrition security.

Polyculture ponds can play a complementary role to the current tilapia production paradigms implemented in Zambia and other sub-Saharan countries, which tend to focus on the productivity of tilapia under supposedly monoculture systems. Aquaculture development must be positioned within the larger aquatic resource system. This should encompass assessing the contribution of diverse fish species from a vast array of different inland water bodies, including lakes and rivers, especially because pelagic small fish species contributed significantly to micro-nutrient and fatty acid intake compared to other species in this study. Development projects should continue to develop the infrastructure and supply chains associated with the tilapia industry in Zambia so that more small-scale farmers can participate successfully (see Kaminski et al., 2020). Some farmers may opt for more intensive and commercial forms of aquaculture that rely on the monoculture production of individual species; however, farmers who are unable to consistently produce single species to commercial sizes could adopt polyculture pond farming as a potential solution, to better utilize water resources on the farm and maximize nutrient yield.

The best way to assess the efficacy of a food system is to assess how well it provides nutritious foods in comparison to other, similar systems in the area. This further provides a strong justification to continue placing aquaculture and capture fisheries in an interconnected continuum, rather than as separate systems, with a focus on the diversity of species and systems (Thilsted, 2021). Nutrition-sensitive approaches must avoid the same trap of "productionist" approaches that only look at the potential of a single system or single food, without considering complementary or competing systems. Assessing these systems is not only about the bioavailability or economic accessibility of diverse foods but also about the choices and strategies that people make, based on varying contexts and drivers that differ from season to season. While the polyculture pond approach aims to improve access to a diversity of fish species, thereby improving dietary diversity and nutrition and health outcomes, there are dimensions of the approach that require further investigation to properly assess how nutrition-sensitive these systems truly are. Namely, this means assessing the potential income of these systems and also whether the approach empowers and improves women's access to and control over resources, ultimately lifting their social status (Ruel et al., 2018). While the latter was not the focus of this research, studies in Bangladesh suggest that backyard-style pond farming has been beneficial for women's empowerment (Castine et al., 2017). Coupled with the potential of integrating aquaculture with agricultural activities on smallholder farms, the pond polyculture system can have a positive impact on livelihoods as well as food and nutrition security.

3.6 Appendices for Chapter 3

Appendix 3.1 *Species screening and selection process (2016-2019)*



Appendix 3.2 *Recommended Nutrient Intake (RNI) for females in five age groups for 13 nutrients in grams (g)*

Nutrient	**Toddler 1-3 years**	**Children A 4-6 years**	**Children B 7-9 years**	**Adolescent 10-18 years**	**Adult 19-50 years**
Protein (g)[1]	13	19	34	46	46
Fat (g)	29	34.8	40.6	69.6	58
n-3 fatty acids (g)[2]	1.25	1.75	1.75	3	2.5
Riboflavin (g)	0.0005	0.0006	0.0009	0.0011	0.0011
Niacin (g)	0.006	0.008	0.012	0.016	0.014
Folate (g)	0.00015	0.0002	0.0003	0.0004	0.0004
Vit_B12 (g)	0.0000009	0.0000012	0.0000018	0.0000024	0.0000024
Ca (g)	0.5	0.6	0.7	1.3	1
Fe (g)[3]	0.0058	0.0063	0.0089	0.031	0.0294
Zn (g)[4]	0.0041	0.0048	0.0056	0.0072	0.0049
K (g)[5]	2	2.3	2.3	2.3	2.6
Mg (g)	0.06	0.076	0.1	0.22	0.22
Se (g)	0.000017	0.000022	0.000021	0.000026	0.000026

[1] Based on grams per kg of body weight, e.g., for adults 0.8 g/kg body weight for the reference body weight (NASEM 2005)
[2] Calculated as 1.25 E% of female in age group, recommended intake is 0,5-2 E% and refers to the adult population (age ≥ 18 years of age): 1000 kcal for toddler, 1400 kcal for Child A, 1400 kcal for Child B, 2400 kcal, for adolescents, 2000 kcal for adults.
[3] Based on 10% bioavailability
[4] Based on Moderate bioavailability
[5] Based on Adequate Intake (AI) for potassium from NASEM (2019).

Appendix 3.3 *Nutrient composition of fish species by form (source: Nölle et al., 2020)*

Species	Form from survey	Form of fish in lab	Substitute Species	Portion (100g)	Protein (g)	Fat (g)	Water (g)	ALA (% of fat)	EPA (% of fat)	FHA (% of fat)	Riboflavin (mg)	Niacin (mg)	Folate (mcg)	Vit B12 (mcg)	Calcium (mg)	Iron (mg)	zinc (mg)	Potassium (mg)	Magnesium (mg)	Selenium (mcg)
B. trimaculatus	Fresh	Fresh	B. radiatus	whole	21.8	8.6	65.3	2.2	0.7	1.3	0.1	1.8	21.7	14.9	1324.4	6.7	5.2	282.5	56.1	43.9
	Dried	Dry	None	whole	56.2	23.6	8.9	1.5	0.4	1.7	0.1	4.9	52.4	30.6	3001.3	11.3	12.1	920.7	131.0	100.7
	Smoked	Dry	None	whole	56.2	23.6	8.9	1.5	0.4	1.7	0.1	4.9	52.4	30.6	3001.3	11.3	12.1	920.7	131.0	100.7
Catfish	Fresh	Fresh	None	filleted	16.5	1.4	81.4	2.5	0.4	2.9	0.1	2.9	20.7	3.9	10.2	0.7	0.7	296.3	21.5	36.4
	Dried	Dry	None	filleted	67.9	19.1	9.1	3.3	1.1	2.0	0.2	8.4	48.9	33.8	482.8	9.0	3.1	1243.5	104.7	222.4
	Smoked	Smoked	None	filleted	29.8	2.8	66.8	1.5	0.2	2.7	0.1	4.3	21.6	5.3	15.1	13.7	1.5	500.0	29.5	43.0
L. miodon	Fresh	Fresh	None	gutted	16.5	1.8	77.6	2.4	2.8	7.8	0.1	3.6	14.1	9.7	823.8	2.9	3.7	340.4	41.6	35.4
	Dried	Dry	None	whole	67.5	11.0	9.0	3.4	3.9	7.8	0.4	20.7	63.0	41.1	2713.8	9.1	13.4	1421.3	162.7	158.5
	Smoked	Dry	None	whole	67.5	11.0	9.0	3.4	3.9	7.8	0.4	20.7	63.0	41.1	2713.8	9.1	13.4	1421.3	162.7	158.5
L. stappersii	Fresh	Fresh	None	filleted	23.2	2.4	73.7	0.9	0.7	2.6	0.1	7.6	14.0	5.6	30.1	0.8	0.6	326.4	28.1	128.2
	Dried	Smoked	M. Lacerde	body	64.1	22.8	9.8	2.7	0.7	6.9	0.3	4.0	44.0	3.8	1169.3	3.7	5.0	806.1	84.1	107.7
	Smoked	Smoked	M. Lacerde	body	64.1	22.8	9.8	2.7	0.7	6.9	0.3	4.0	44.0	3.8	1169.3	3.7	5.0	806.1	84.1	107.7
M. longirostris	Fresh	Fresh	None	filleted	13.6	2.5	83.4	1.1	1.6	2.4	0.1	0.5	5.6	2.6	37.2	0.5	0.4	159.5	16.7	25.4
	Dried	Smoked	M. Lacerde	body	64.1	22.8	9.8	2.7	0.7	6.9	0.3	4.0	44.0	3.8	1169.3	3.7	5.0	806.1	84.1	107.7
	Smoked	Smoked	M. Lacerde	body	64.1	22.8	9.8	2.7	0.7	6.9	0.3	4.0	44.0	3.8	1169.3	3.7	5.0	806.1	84.1	107.7
M. macrolepidotus	Fresh	Fresh	None	filleted	17.1	8.1	71.9	2.5	0.6	1.1	0.4	1.3	7.4	4.8	692.2	1.2	3.4	291.0	35.7	34.0
	Dried	Dry	None	gutted	66.0	12.1	10.5	3.5	1.0	2.2	0.7	4.9	84.1	52.8	2882.5	20.0	13.8	1156.5	151.8	149.4
	Smoked	Dry	None	gutted	66.0	12.1	10.5	3.5	1.0	2.2	0.7	4.9	84.1	52.8	2882.5	20.0	13.8	1156.5	151.8	149.4
O. macrochir	Fresh	Fresh	None	filleted	18.4	1.4	79.3	1.7	0.2	2.3	0.1	4.0	6.0	2.3	41.9	0.4	1.2	335.1	23.6	19.5
	Smoked	Smoked	T. Rendalli	body	67.3	10.5	19.7	1.4	0.0	0.1	0.7	12.5	33.7	4.3	323.1	1.8	4.9	1116.8	84.3	105.6

	Dried	Dry	T. sparmanii	whole	57.3	19.7	7.7	5.2	0.5	1.9	1.0	6.6	42.2	29.6	3463.8	38.0	9.4	1083.7	136.9	44.5
P. acutirosis	Fresh	Fresh	L. miodon	whole	16.5	1.8	77.6	2.4	2.8	7.8	0.1	3.6	14.1	9.7	823.8	2.9	3.7	340.4	41.6	35.4
	Dried	Dry	None	whole	67.9	12.7	7.3	3.4	3.7	8.6	0.2	7.3	53.3	25.0	2975.3	22.1	19.3	1325.5	171.2	106.5
	Smoked	Dry	None	whole	67.9	12.7	7.3	3.4	3.7	8.6	0.2	7.3	53.3	25.0	2975.3	22.1	19.3	1325.5	171.2	106.5
P. philander	Fresh	Fresh	T. Rendalli / sparrmanii	filleted	19.7	1.2	78.6	4.1	0.6	3.0	0.1	2.3	9.2	1.5	54.9	0.4	1.0	226.1	21.5	132.2
	Dried	Dry	None	whole	57.0	17.3	8.7	2.7	1.3	4.4	0.8	8.1	31.1	9.2	4361.0	17.3	10.9	1134.8	168.7	65.7
	Smoked	Dry	None	whole	57.0	17.3	8.7	2.7	1.3	4.4	0.8	8.1	31.1	9.2	4361.0	17.3	10.9	1134.8	168.7	65.7
S. angusticeps	Fresh	Fresh	None	filleted	17.7	0.8	80.9	1.1	0.2	2.7	0.1	1.6	23.3	0.9	19.9	0.2	0.6	314.1	24.2	23.9
	Dried	Smoked	S. Robustus	body	76.9	6.8	13.5	1.9	0.3	6.2	0.3	6.9	27.6	8.6	527.5	1.6	3.2	1128.2	96.1	99.8
	Smoked	Smoked	S. Robustus	body	76.9	6.8	13.5	1.9	0.3	6.2	0.3	6.9	27.6	8.6	527.5	1.6	3.2	1128.2	96.1	99.8
S. mellandi	Fresh	Fresh	None	whole	18.0	4.2	73.9	2.6	0.8	2.5	0.2	2.2	27.1	4.5	1028.4	3.0	2.2	260.5	42.8	38.8
	Dried	Smoked	None	body	70.4	15.6	12.0	1.1	0.2	0.8	0.8	9.3	46.7	12.1	899.1	3.0	4.6	1081.7	102.0	116.3
	Smoked	Smoked	None	body	70.4	15.6	12.0	1.1	0.2	0.8	0.8	9.3	46.7	12.1	899.1	3.0	4.6	1081.7	102.0	116.3
S. mystus	Fresh	Fresh	A. occidentalis	filleted	17.0	1.1	81.5	2.0	1.5	2.3	0.1	3.1	19.2	2.5	13.7	0.4	0.4	280.8	20.3	15.2
	Dried	Dry	S. intermedius	body	59.6	9.5	10.4	4.0	1.3	4.5	0.2	6.4	125.0	24.0	2781.2	9.1	6.6	1157.2	142.9	143.8
	Smoked	Smoked	S. intermedius	body	62.0	20.8	13.7	7.8	1.3	2.3	0.2	4.2	33.3	15.8	978.1	7.7	4.1	1084.4	116.6	103.4
Synodontis spp	Fresh	Fresh	None	whole	16.5	14.4	67.9	1.1	0.2	0.2	0.1	2.7	13.5	3.7	26.8	0.6	0.5	189.9	16.2	76.9
	Dried	Smoked	None	body	62.9	28.0	8.2	2.8	0.9	2.6	0.1	7.7	19.0	8.4	304.8	7.2	2.8	806.3	70.6	111.1
	Smoked	Smoked	None	body	62.9	28.0	8.2	2.8	0.9	2.6	0.1	7.7	19.0	8.4	304.8	7.2	2.8	806.3	70.6	111.1
T. rendalli	Fresh	Fresh	None	filleted	19.7	1.2	78.6	4.1	0.6	3.0	0.2	3.6	11.7	1.0	58.6	0.4	1.1	333.5	26.6	23.6
	Dried	Dry	T. sparrmanii	whole	59.7	14.0	9.0	3.9	0.3	1.0	0.8	8.1	31.1	9.2	4225.8	70.1	10.8	991.5	150.6	139.2
	Smoked	Smoked	None	body	67.3	10.5	19.7	1.4	0.0	0.1	0.7	12.5	33.7	4.3	323.1	1.8	4.9	1116.8	84.3	105.6
T. sparrmanii T	Fresh	Fresh	T. Rendalli / sparrmanii	filleted	19.7	1.2	78.6	4.1	0.6	3.0	0.1	2.3	9.2	1.5	54.9	0.4	1.0	226.1	21.5	132.2
	Dried	Dry	None	whole	59.7	14.0	9.0	3.9	0.3	1.0	0.8	8.1	31.1	9.2	4225.8	70.1	10.8	991.5	150.6	139.2
	Smoked	Dry	None	whole	59.7	14.0	9.0	3.9	0.3	1.0	0.8	8.1	31.1	9.2	4225.8	70.1	10.8	991.5	150.6	139.2

Appendix 3.4 *Total frequency of species that were combined into one species*

Species	**Freq.**	**Combined species**	**Freq.**	**New total**
C. stappersii	7	Catfish	458	465
C. multispine	26	Synodontis	53	79
R. argentea	4	L. miodon	133	137
P. mueruensis	26	P. acutirosis	107	133
S. robustus	10	S. mellandi	79	89
T. ruweti	10	T. sparrmanii	543	553

Part 2

Consumers and commercial aquaculture systems in Kenya

CHAPTER 4

Consumer preferences for small tilapia: Implications for aquaculture development in Kenya

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Abstract

The study set out to understand consumer preferences for tilapia as compared to other animal-source foods in urban and rural Kenya (N=729), with a specific focus on what drives choices of different sizes of tilapia. The study was devised in the context of the growing aquaculture industry in Kenya, showing how tilapia of different sizes and price points are available on the market. The results showed that consumption and purchasing preferences of tilapia differed across urban and rural geographies, with the former preferring fried tilapia from street vendors while the latter preferred fresh tilapia from open-air markets. Tilapia was frequently consumed across the study sample (almost weekly), and people made choices on tilapia size in the context of other available animal-source foods and the attributes they favoured when deciding what food to purchase. More than 80% of people chose large tilapia (>200 g) in our choice experiment, however, the probability of choosing small tilapia (<200 g) increased for people with lower economic status. Principle component analysis (PCA) with food frequencies of various animal-source foods showed that people tended to cluster in what we refer to as “fish-eaters” versus “meat-eaters” and “expensive” versus “less-expensive” foods. A second PCA on food attributes showed how people cluster between preferring utilitarian attributes (price and portioning) versus hedonic attributes (quality and taste). A decision-tree analysis based on people's choice of small or large tilapia showed that, after accounting for wealth, consumers increased their probability of choosing small tilapia based on their association with being "fish-eaters" and/or ranking utilitarian attributes as the most important, in addition to their association with less-expensive foods and lower overall rankings of tilapia quality. Socio-demographic factors such as age, ethnicity, and household size did not affect the model. The findings suggest that lower income areas may have greater potential for a small tilapia market.

Key words: "tilapia"; "small fish"; "aquaculture"; "value chain"; "consumer"; "Kenya"

4.1 Introduction

Fish is an important and frequently consumed animal-source protein for millions of Kenyans (Cornelsen et al., 2016; Obiero et al., 2014). Kenya is made up of diverse tribal ethnicities, and those with a stronger "fish-eating" culture have higher fish consumption rates resulting in greater nutritional outcomes than non-fishing eating ethnicities (Hansen et al., 2011). The consumption of certain fish species, particularly smaller pelagic fish, are critical to the fatty acid composition of breast milk, which is vital for child development (Fiorella et al., 2018). This is important, as roughly 50% of Kenyans are regarded as food insecure with 10% needing food relief (Kenya National Bureau of Statistics [KNBS], 2015). Catching, farming, trading, and selling fish is central to many people's livelihoods and incomes, making up a key part of the Kenyan economy (Fiorella, et al., 2014; Obiero et al., 2019a). Consumer preferences for fish are largely driven by socio-economic circumstances, and especially the availability and accessibility of fish as compared to other animal-source foods (Obiero et al., 2014; Githukia et al., 2014). Such foods in Kenya are a key source of essential amino acids, vitamins, minerals, protein, and fatty acids that prevent micronutrient deficiencies including stunting and anaemia in food insecure communities (Adesogan et al., 2020). These foods, and particularly fish, are vital to dietary quality and diversity in much of the country (Dominguez-Salas et al., 2016). Understanding people's perceptions and preferences for animal source foods, and the drivers that allow people to make food choices are thus critical (Bukachi et al., 2021).

While studies in Kenya have assessed the drivers of consumers' choices of fish species, often comparing preferences across species (Ayuya et al., 2021), few studies have looked at size variation of single species, especially of widely consumed fish such as tilapia. The tilapia value chain in Kenya is complex, as tilapia come in different sizes and price points, sourced from different actors in the value chain (aquaculture, capture fisheries, imports), and can be bought from informal markets, street vendors and high-end supermarkets in fresh, frozen, smoked, or fried forms (Munguti et al., 2022). Understanding who eats tilapia and why is a key objective of this research, with a particular focus on tilapia size differentiation.

Fish consumption in Kenya has changed substantially over the years. Since non-native Nile perch (*Lates niloticus*) and Nile tilapia (*Oreochromis niloticus*) were introduced into Lake Victoria in the 1950s, the species composition of the lake changed entirely (Kitchell et al., 1997). Today perch and tilapia are some of the most consumed fish in Kenya, in addition to small pelagic species and other small cichlids, while many local indigenous species have been eradicated through predation by these invasive species (Geheb et al., 2008). Kenyan aquaculture until recently, added little to total fish supply (Njiru et al., 2008). Today, an expansion of commercial aquaculture on Lake Victoria is transforming the value chain again. Thousands of tonnes of fresh, cultivated tilapia is transported through improved cold chain logistics and retail capabilities to growing urban centres (Munguti et al., 2022). The largest market for farmed tilapia is in the capital city, Nairobi, where a growing middle class of people from different ethnic backgrounds consume fish, and specifically tilapia. The country imports tilapia from Asia to meet demand and narrow the fish supply deficit (Awuor et al., 2019).

Tilapia in Kenya comes in different sizes, partly because juvenile fish are caught in seine nets from capture fisheries, but also because of how tilapia is produced in aquaculture systems (Yongo et al., 2016). Despite efforts at grading and sex-reversing tilapia fingerlings, size variation is an inevitable part of the production cycle in many aquaculture systems (Palada-de Vera & Eknath, 1993). This is even more pronounced in earthen pond farming where mixed-sex tilapia fingerlings breed multiple times a year (Opiyo et al., 2021). In Zambia, Genschick et al. (2017) point to the lower price of smaller size categories of tilapia and the high demand from poorer segments of society, which is currently filled by imported tilapia from Asia. Zambia has a bourgeoning aquaculture sector too, and people who can afford larger tilapia generally consume domestically produced tilapia rather than larger imported tilapia (Genschick et al., 2018). In contrast to European markets where larger fish and fillets are preferred (Nielsen et al., 1997), Kenyan consumers enjoy whole fish, and at times prefer or are limited to consuming small tilapia (Obiero et al., 2014). Kaminski et al., (2018) note that countries such as China are exporting larger tilapia (whole or filleted) to western markets while sending smaller tilapia, treated as a by-product of production, at cost-price to African countries. There seems to be a missed opportunity for local producers in Kenya to satisfy a market niche for smaller, cheaper fish.

Small tilapia it seems, makes up a key part of the growing tilapia value chain in Kenya, yet we have little understanding of who buys this fish and why. Studies have shown that consumers in Kenya favour tilapia highly compared to most fish in terms of taste, though small pelagic fish are more widely consumed because of their price point (Obiero et al., 2014; Fiorella et al., 2018). Where small tilapia fits into the market or people's food choices is unclear. Understanding the production and consumption of tilapia at different sizes has ramifications for who can afford this fish and who is producing and/or catching it. This is especially pertinent against the backdrop of a growing tilapia aquaculture industry in the country.

The study uses a consumer survey with Kenyan consumers from urban and rural areas to assess tilapia preferences. The study introduces a choice experiment with different sizes of tilapia to see who buys this fish and why, noting how people make choices in the context of other available animal-source foods and the attributes they ascribe in making these choices. The study is intended to provide insights on tilapia market segmentation in Kenya so that fish farmers, fishers and traders can make more informed marketing decisions.

4.2 Theoretical framework of consumer preferences for fish

Factors that affect how consumers evaluate and chose food products can be divided into three broad categories (Shepherd & Sparks, 1994): the products (e.g., flavour, texture, brand, and taste); the individual (e.g., personality, attitudes, behaviours, perceptions); and the environment (e.g., availability, economic status, culture). The effects of these categories will vary between consumers and products and thus understanding the motives and barriers of food usage is essential (Brunsø et al., 2009). Food consumption choices can be explained by people's purchasing intentions, driven by their behaviours and attitudes, which are further shaped by their social environment (Ajzen, 1991). Such determinants include personal preferences for taste and texture; cultural preferences for specific foods; or practical preferences around price and cooking methods, for example (Honkanen et al., 2005; Olsen, 2003; Olsen et al., 2007).

Hedonic aspects such as taste or smell of food have always been of high importance to most consumers as food is generally a matter of pleasure (Verbeke, 2006). How foods are produced, transported, stored, and presented to consumers further informs people's preferences (Steenkamp, 1990). Depending on how much information is provided or how knowledgeable people are on these processes, they may fall back on hedonic attributes to evaluate foods based on appearance (smell, texture, colour, etc.). Price and the convenience of consuming a product are critical to the food choices people make, as it means the saving of time, money, physical or mental energy but also planning, shopping, storing, and cleaning of products (Olsen et al., 2007; Gofton, 1995). Such utilitarian attributes are rooted in instrumental functionality as people make judgments on foods based on aspects such as affordability, low calorie content, or high nutritional value (Maehle et al., 2015). The time people spend purchasing and cooking products as well as meal planning for families and portioning of food products is a major factor in their food choices (Beck, 2007). Most products aim to provide benefits of both hedonic and utilitarian products.

Previous studies in Western societies have shown that people's choices around fish are strongly affected by consumers' evaluation of hedonic attributes, especially taste, odour, and colour (Juhl & Poulsen, 2000). People who are traditional fish eaters tend to rely on hedonic attributes such as taste and smell to evaluate products, while those who occasionally eat fish rely more on utilitarian attributes, such as information on where the product is sourced from or price, to make a choice (Ibid.).

Comparing how people evaluate and choose between different animal-source foods can give us additional insights into their cultural and dietary habits and routines (behaviours), but also reveals their preferences for various attributes (attitudes) (Perry & Grace, 2015). Comparing tilapia, for example, to other animal source foods helps to locate the market value of the product within a group of similarly priced and/or sought-after foods. While people may make choices between tilapia and other fish, some studies have shown tilapia's relative competitiveness with broiler chicken, for example (Ragasa et al., 2020).

Preferences for fish over other animal-source foods in Africa are largely driven by their low cost (de Bruyn et al., 2021). This is true in western Kenya and lakeside communities in Tanzania (Hotz et al., 2015; Ekesa et al., 2019). Tilapia however, and especially farmed tilapia, is more expensive than most fish on the market but cheaper than most meats in many African countries (Darko et al., 2016). In Kenya, consumer preferences for fish are driven by cultural and social-economic factors such as ethnicity and wealth (Ayuya et al., 2021). Preferences for tilapia specifically, have been driven mostly by its taste (hedonic attributes) compared to other fish (Obiero et al., 2014). Some studies show that preferences for fish over other animal-source foods in Kenya are driven by their perceived health and nutritional value (utilitarian attributes) (Githukia et al., 2014; Esilaba et al., 2017).

Few studies in Kenya have looked at how attributes for tilapia compare to other fish and animal-source products, or how people's consumption behaviours around different animal-source foods inform their preferences. Assessing how these attributes and behaviours affect choices for tilapia size is a key factor in this study. We used quality and taste as key hedonic attributes people use to evaluate fish species in Kenyan markets. Fish products in Kenya differ vastly in their taste but also in how they are produced, processed, and presented in markets. We used price and portioning as key utilitarian attributes given their instrumental value in Kenya. We included portioning specifically, based on the assumption that the convenience of portioning small versus large tilapia as part of a family meal may be a key factor in people's preferences for size. We then compared people's ranking of the same attributes for other animal source foods (including other fish species) and how they compete with tilapia. We include some demographic and environmental factors that may affect people's food choices too.

4.3 Materials and methods

4.3.1 Sample and procedure

Survey data with consumers were collected through questionnaires from May to June 2022 in Kenya. Enumerators surveyed two urban centres (Nairobi and Kisumu) over a period of three weeks and thereafter surveyed a rural area (Homa Bay and Migori counties) located close to Lake Victoria for another three weeks (see Figure 4.1). The most common way of classifying "rural" and "urban" in Kenya is based on population characteristics and the existing economic environment (KNBS, 2019). For this study, we used the KNBS classification of a "rural" county if more than half of the population were associated with agricultural activities and limited access to certain services (Wiesmann et al., 2016).

Using a stratified sampling technique, we delineated the target markets and shopping centres in the urban areas into suburbs based on socio-economic status: "high-income, "middle-income" and "lower-income" (see Appendix 4.1). We determined these delineations through several key informant interviews with fish traders and retailers. The target sample sought to include an equal number of participants from two locations under each socio-economic delineation (a total of 6 suburbs in Nairobi). The same procedure was repeated in Kisumu, the third largest city in Kenya, situated on the shores of Lake Victoria in Kisumu county (see Figure 4.1).

In rural areas, wealth delineations were notably harder to discern and key informants from the fish retail sector pointed to several small peri-urban centres where a mixture of high-income and low-income fish markets existed. Enumerators visited markets in and around these areas, which we classified as “rural” to differentiate from the “urban” sample, but also because people from the rural countryside travel to and from these peri-urban centres to purchase fish (Mbita, Homa Bay, and Oyugis in Homa Bay county, and Rongo and Awendo in Migori county). In addition, each site selected for this study was close to retail outlets for fresh, farmed tilapia.

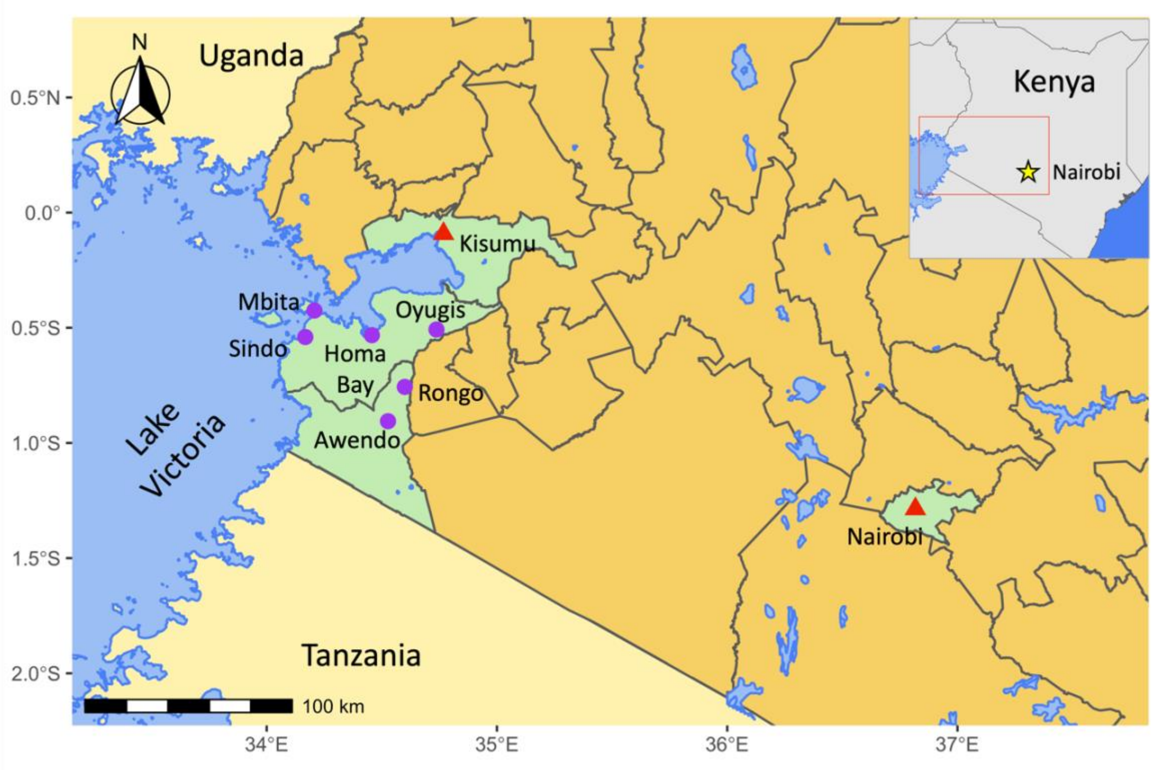


Figure 4.1. *Map of administrative national and county boundaries in Kenya (black lines), including major water bodies. Study counties shaded in green with red triangles representing urban study sample (Nairobi and Kisumu counties) and purple points representing rural study sample (Homa Bay and Migori counties). Data from GADM database of Global Administrative Areas, version 2.0, www.gadm.org. Map is authors’ own.*

Respondents were selected through a door-by-door random walk procedure. Enumerators visited markets and shopping centres where fish were regularly purchased from vendors and retail shops, respectively. Enumerators randomly approached shoppers and asked permission to conduct the survey. Of the whole sample, 64% of respondents were responsible for foods purchased within their household, and 26% said they shared this responsibility, meaning that most people surveyed were a reliable source of information for this study.

The total sample consisted of 759 people. Thirty people (4%) did not complete the survey because they did not consume fish and were removed from the analysis. All these people were from the urban sample and most cited allergies and taste as reasons for not consuming fish.

The final sample size used in subsequent analyses in this study consisted of 305 rural consumers and 424 urban consumers (N = 729). The non-probability sampling method and respondent selection procedure did not yield a statistically representative sample and does not allow for generalisation to the overall population.

4.3.2 Measurements of construct

The survey consisted of four parts that aimed to characterise individual preferences for tilapia, with a specific focus on product size. The drivers of choice of size, we argue, are made in the context of other available foods, as well as preferences around how people evaluate these products based on certain attributes. After establishing some basic demographic information, including a proxy of wealth, as well as general purchasing preferences for tilapia, we establish measurements of construct of people's consumption behaviours of tilapia versus other animal source foods, and the attributes they favour (utilitarian and hedonic) when making food choices.

4.3.2.1 Demographics and material wealth indicators

The first part of the survey asked general demographic questions (gender, age, household size, tribe/ethnicity, and whether the participant was responsible for grocery shopping in the household). This part of the survey also included the construction of a wealth index by asking people which assets they owned (see Table 4.1). The wealth index is a composite measure of a household's cumulative living standard, calculated by the ownership of selected assets. A wealth index, described in more detail below, places people within a wealth group, which is a key factor determining the affordability of a product (Ajzen, 1991). Given the many differences in living standards and socio-economic status in Kenya, the assets listed were particular to urban and rural geographies (Egede et al., 2017). The assets in the survey were determined through a literature search of previous studies, as well as through key informant interviews with researchers, and finally, checked through several rounds of pre-testing with consumers.

***Table 4.1**: Asset ownership for wealth index construction with first option signifying wealthier asset ownership*

Asset	Urban	Rural
Electricity	• Connected to main grid • No connection (candles, paraffine/kerosene, etc)	• Connected to main grid • Solar or generator • Candles, paraffine/kerosene
Water	• Piped water direct into dwelling • Communal tap, well, stream, etc.	• Piped water or tank • Delivered water • Communal tap, well, stream • Buy from vendors
TV	• Yes • No	• Yes • No
Fridge	• Yes • No	• Yes • No
Gas	• Electric coil or gas (jikokoko) • Stove (meko) or charcoal (jiko)	• Electric coil or gas (jikokoko) • Charcoal / firewood (collected) • Charcoal / firewood (purchased)
Smartphone	• Yes • No	• Yes • No
WIFI	• Yes • No	- *Not asked* -
Car	• Yes • No	- Not asked -
Material of walls	- *Not asked* -	• Cement, stone, bricks, plaster • Mud & cement, stone, or brick • Mud only, plywood, iron sheets
Motorcycle	- *Not asked* -	• Yes • No

4.3.2.2 Attribute comparison with other animal source foods

Participants were asked to rank taste and quality (hedonic attributes) as well as price, and portioning (utilitarian attributes) of fish in terms of the most important to least important attribute when making a choice of which fish to buy. The additional fish species considered in this study were omena (*Rastrineobola argentea*), fulu (*Haplochromis spp.*), and mbuta (*Lates niloticus* or Nile perch). These freshwater species are the most consumed fish in Kenya (Munguti et al., 2014). Participants were asked to compare tilapia versus these other fish species. Broiler chicken was included as an additional category for its similar price point to tilapia. Participants were asked to consider the same attributes as above and indicate whether tilapia fared "better", "the same", or "worse" than these other food items based on each attribute, e.g., "Is tilapia easier, the same, or harder to portion in the household than chicken?". Tilapia was scored as +1 if it ranked better, 0 if it was the same, or -1 if it was worse than each food item per attribute.

4.3.2.3 Animal-source food preferences and frequency

The survey used a Food Frequency Questionnaire (FFQ) to recall the number of times certain foods were consumed by a household over a 4-week period (28 days). The FFQ is used here to indicate consumer behaviour around dietary patterns of animal-source foods (Rodríguez et al., 2002). We used the same foods from the attribute rankings in the preceding section: tilapia, mbuta, fulu and omena, but this time added chicken into a "white "meat" category, and included "red meat", "catfish", and "tinned fish" as additional categories. Eight different frequency options were provided in the FFQ and then converted into a proportion of the number of times a food item was consumed: (i) zero times in the past 4 weeks; (ii) 1 time in the past 4 weeks (e.g., 1/28 = 0.036); (iii) 2-3 times in the past 4 weeks; (iv) 1 time per week; (v) 2 times per week; (vi) 3-4 times per week; (vii) 5-6 times per week; or (vii) 1 or more times per day.

4.3.2.4 Tilapia size choice experiment and purchasing preferences

Finally, the survey looked at fish purchasing and consumption preferences, including a visual choice experiment. This part of the survey asked participants their favourite fish to eat, followed by whether the person eats tilapia or not. The choice experiment was used to analyse people's stated preferences for size and price. This method is rooted in traditional microeconomics theories of consumer preference theory and is used to estimate attribute utilities based on an individual's response to combinations of decision attributes (Louviere et al., 2000).

Each enumerator was equipped with a cooler box that contained a sample of frozen tilapia in four distinct size categories that doubled in weight for each category: Grade 0 = 50-99 grams (g); Grade 1 = 100-199g; Grade 2: 200-299g; Grade 4: 400-500g (see panel A in Figure 4.2). The size grades were based on standard product categories of farmed tilapia with different price points per kilogram. Fish were kept frozen in plastic food bags and participants were asked to choose the size of tilapia they preferred to consume and how many they needed for one meal in their household. Participants were then introduced to four visual cue cards that depicted tilapia in the same size categories, but this time with information on the price and number of fish per kilogram (see panel B in Figure 4.2). Participants were asked whether they would change their initial choice based on this new information if they were to buy tilapia for a meal in their household on the same day. Using visual representations of choices has been recognized as one of the most effective ways to promote the comprehension and evaluability of a studied object (Mathews et al., 2006)

The study then asked participants to consider the size of tilapia they had chosen and complete the remainder of the questionnaire. Respondents were asked their purchasing preferences, such as what form this tilapia was usually bought in (fresh, frozen, smoked/dried), if it was processed (gutted and scaled), where they would usually buy it from, etc. Some questions around consumption preferences were asked, such as, how they would prepare and cook tilapia, and which parts of the fish they would eat, etc.

A) Picture of fish samples	Fish size categories
	Very small (<100g) – Grade 0
	Small (100-200g) – Grade 1
	Medium (200-300g) – Grade 2
	Large (>400g) – Grade 4

B) Cue cards depicting price of tilapia

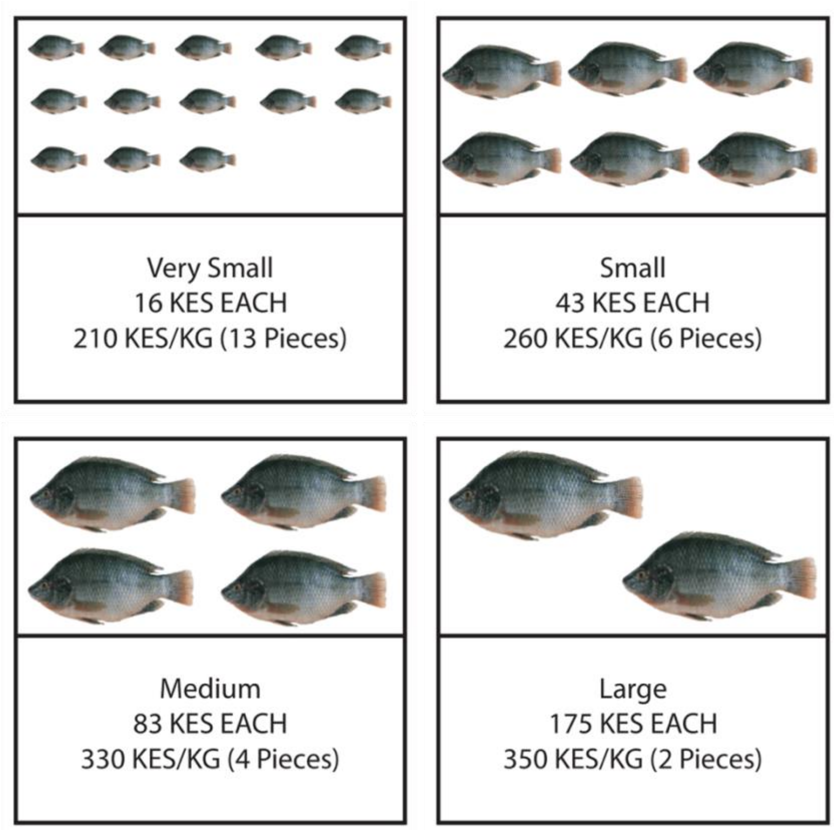


Figure 4.2. *(A) Photograph of physical fish samples used as visual aid when asking participants which size of tilapia they preferred to consume before price information was given. (B) Visual cue cards used to present price in Kenyan Shillings (KES) and number of fish per kilogram of different size grades.*

4.3.3 Analysis procedures

Data were analysed using R Studio, version 1.3.1056 (R Core Team, 2020). Given the differences in assets and living standards in rural and urban populations we analysed these samples as two separate datasets. We did not attempt to make any statistical comparisons between the sub-samples as they constituted entirely different segments of the fish market in Kenya.

The wealth index was constructed using principal component analysis (PCA). The composite index of asset ownership is used as a proxy indicator of wealth. The PCA standardised all asset variables through a covariance matrix identifying the principal components where most of the variance was explained (see Appendix 4.2). A wealth percentile was calculated by standardising the eigenvalues between 0 and 1. We also divided the component range into quartiles to create four ordered discrete variables labelled Wealth Group 1 (WG1), the least wealthy group, up to Wealth Group 4 (WG4), the wealthiest group.

We used PCA again to assess associations with people's preferences for tilapia versus other food items based on the four key attributes discussed above. Each food group and ranking created a matrix of values positioning tilapia as "better", "the same" or "worse" than other food groups for each attribute. These values were computed into a covariate matrix using PCA to discover the basic structure underlying attribute rankings of tilapia compared to other animal-source foods (see Appendix 4.3).

PCA was used again to explore the relationships and associations of the frequency of consumption of different animal-source food items from the FFQ. This provided an index of the frequency of consumption of animal-source foods and their correlation in a geometric space, which was assessed by way of covariance (see Appendix 4.4).

The components of all three PC analyses were used as factors in a decision-tree analysis. Decision-tree learning aims to portray the data in a pattern from a set of independent instances (Witten & Frank, 2005). A decision tree is an analysis where each branch node represents a choice between several alternatives, and each leaf node represents a classification or decision (Wan &

Lei 2009, p. 583). The decision tree is constructed by partitioning a dataset (as the root node) into subset nodes. Decision tree analysis segments the heterogenous groups of data into smaller homogenous groups based on selected variables (Byrd & Gutske, 2007). The model uses a linear regression with a response rate as the dependent variable at each node, with all other factors as predictors, segmenting the population into two sub-samples based on a factor value that predicts the choice. This procedure is repeated at each node until the sample size is too small to make meaningful predictions.

In our analysis we used tilapia size (after price information was given) as the dependent variable and then used the demographic variables (including wealth percentile), the attribute rankings (termed "Rank PC 1 & 2") and the animal source food frequencies (termed "FFQ PC 1 & 2") as predictors. To create a binary outcome, we combined the "medium" and "large" categories from the choice experiment to make one category: "Large". We combined the "small" and "very small" categories to make one category: "Small". We further calculated the probability of choosing small fish based on wealth status (percentile) as a predictor in a separate analysis.

4.4 Results

4.4.1 Demographic characteristics

Although the study sample is not generalizable to the whole population, it did cover a wide range of respondents and the similarities between urban and rural samples were notable. In the sub-samples, 62% and 61% of participants were females in rural and urban areas, respectively. The mean age ± standard deviation was 36 ± 9 years, and 35 ± 11.6 years for the rural and urban samples, respectively. There were 5 ± 9 people on average in a rural household, while urban households had an average of 4 ± 12 people in a household. In rural areas, 74% of people were married while 62% were married in urban areas. In both areas, 4% of people were widowed or divorced with the rest indicating single or cohabiting households. Table 4.2 depicts a summary of the tribal/ethnic identities of the sub-samples as this can inform cultural preferences for fish.

Table 4.2. *Tribe and ethnic identity as a proportion of urban and rural sample populations (%)*

Tribe	**Urban (n = 424)**	**Rural (n = 305)**
Luo	47%	67%
Kisii	4%	15%
Luhya	17%	7%
Kikuyu	13%	5%
Kamba	10%	3%
Kalenjin	2%	0%
Other	7%	3%

4.4.2 Tilapia purchasing and consumption habits

Respondents indicated their tilapia purchasing and consumption habits. In Table 4.3, we can see the summary of these habits as a proportion of the urban and rural samples, respectively. Most people in both geographies chose tilapia as their favourite fish to eat. Notably, almost twice the proportion of the rural population said that mbuta (Nile perch) was their favourite fish compared to the urban population. Two thirds of people from both sub-samples made this statement based on taste. More people in the rural population consumed fish in fresh form, bought from open markets, while the urban sample purchased and consumed fried fish from street vendors. The rural population were more concerned with the availability of products while the urban sample considered proximity and convenience as primary factors in choosing where to buy fish. More people from the rural sample bought unprocessed tilapia than the urban sample (gutted and scaled), and more also consumed whole fish, including bones, than the latter group.

Table 4.3. *Tilapia consumption and purchasing habits as a proportion of urban and rural sample populations (%)*

Tilapia consumption habits	**Urban n = 424**	**Rural n = 305**
	(%)	(%)
Your favourite fish to eat?		
Tilapia (ngege)	82%	65%
Nile perch (mbuta)	12%	23%
Small fish (omena / fulu)	2%	7%
Other	4%	5%
Why is this your favourite?		
Taste	67%	66%
Convenience	13%	16%
Health benefits	7%	8%
Traditional dish	8%	0%
Price (affordable)	5%	10%
Is the tilapia processed?		
Yes (gutted & scaled)	90%	79%
No	10%	21%
What form is the tilapia in?		
Fresh	40%	57%
Fried	57%	39%
Dried/Smoked	0%	3%
Frozen	2%	1%
Where do you buy from?		
Fish monger (mama samaki)	63%	14%
Open market (gikomba)	14%	42%
Retail outlet	11%	28%
Direct from fisher	3%	15%
Supermarket	6%	0%
Other	3%	1%
Main reason why you buy here?		
Availability of products	5%	41%
Best prices	21%	24%
Freshest products	24%	15%
Proximity and convenience	42%	18%
Trust and familiarity	7%	3%
Preparation/cooking of tilapia?		
Stew or fry fresh fish myself	22%	31%
Stew fried fish (wet fry)	58%	55%
Warm up fried fish (dry fry)	18%	13%
Grill / BBQ / Oven	1%	1%
Parts of the tilapia you eat?		
Only fillets and flesh	83%	71%
Everything (incl. bones)	17%	29%
How do you portion the tilapia?		
Everyone gets a whole fish	38%	38%
Fish is split	62%	62%

4.4.3 Preferences that drive tilapia choice compared to other foods

4.4.3.1 Consumption rates of different animal-source foods

We wanted to assess how tilapia compared to other similar animal-source foods on the market in terms of frequency of consumption in a four-week period (Figure 4.3). We found that tilapia was the second and third most consumed food for the urban and rural samples, respectively. Both sample populations had a similar average number of days they consumed tilapia in the preceding month. Omena was the most consumed product in both groups, and almost double for the rural sample. Respondents in the rural sample also consumed fulu almost four times as much as the urban sample. The urban sample meanwhile had higher rates of white and red meat consumption.

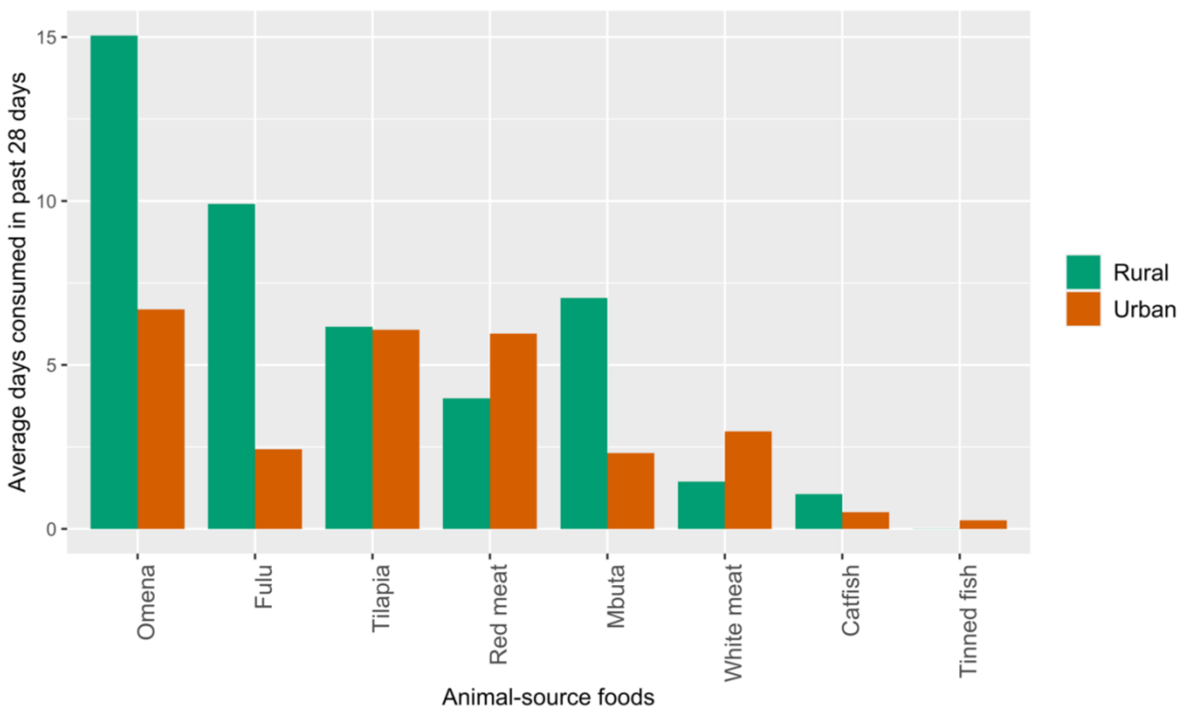


Figure 4.3. *Average daily rate (in past 28 days) of key animal-source protein products for rural and urban sample populations. Food items listed in order of most consumed to least consumed food items as an average of both rural (n= 305) and urban (n = 424) samples.*

4.4.3.2 Preferences for attributes of tilapia compared to other animal-source foods

We aimed to assess how tilapia ranked for each attribute in comparison to other food items. Figure 4.4 shows that, in general, the urban and rural sample ranked tilapia similarly. When it came to utilitarian attributes (portioning and price), tilapia ranked worse than almost all other foods. The only exception was that tilapia seemed to have a more affordable price point than chicken. When it came to hedonic attributes (quality and taste), tilapia ranked better overall compared to all the food items. For the smaller fish (fulu and omena), there were almost no respondents who indicated that tilapia was worse in terms of quality and taste.

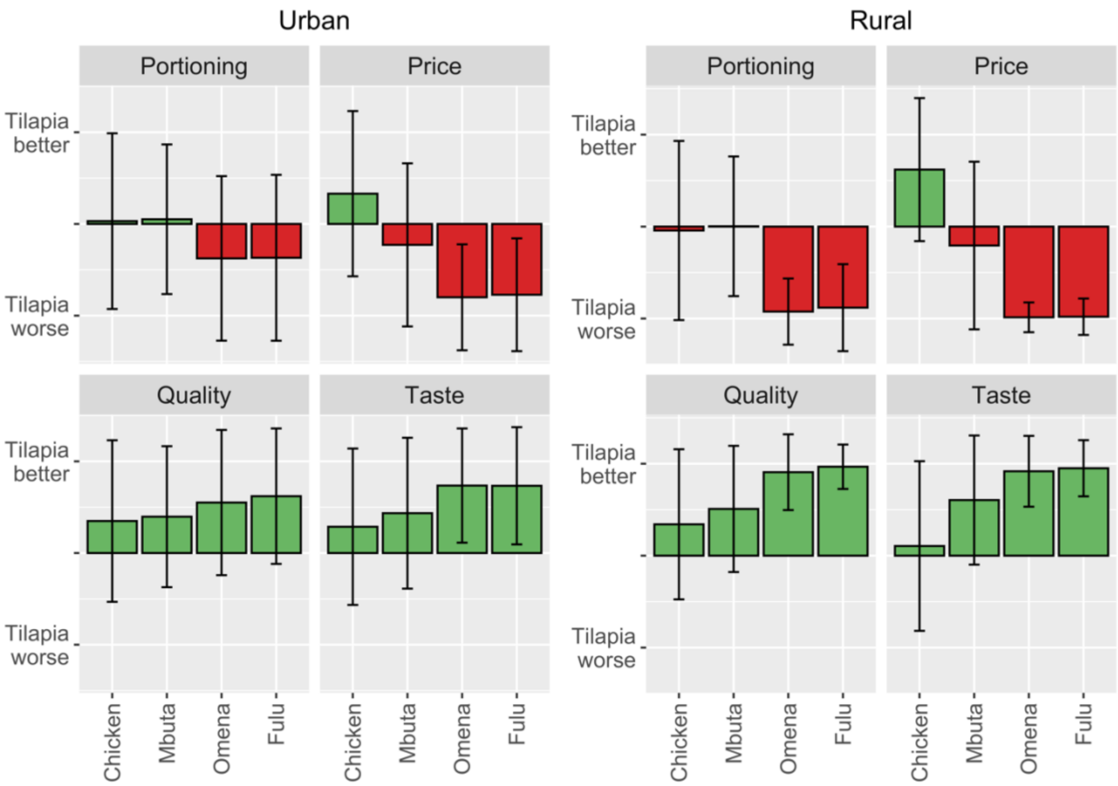


Figure 4.4. *The average score (and standard deviation bar) ranking tilapia as "better", "same", or "worse" than each other food item based on portioning and price (utilitarian attributes), and taste and quality (hedonic attributes), disaggregated by rural (n= 305) and urban (n = 424) sub-samples.*

Respondents were asked which attributes were the most to least important when making a food choice. We assessed this choice by wealth groups (see Appendix 4.1). Most people ranked quality and taste (hedonic attributes) as the most important attributes in both samples, regardless of wealth (Figure 4.5). However, in the less wealthy groups, more people valued portioning and price (utilitarian attributes), as the most important when considering fish products for consumption. Fewer people in the rural sample regarded taste as an important attribute, while they regarded price as more important. This was in stark contrast to the urban sample, where taste was highly regarded as an attribute.

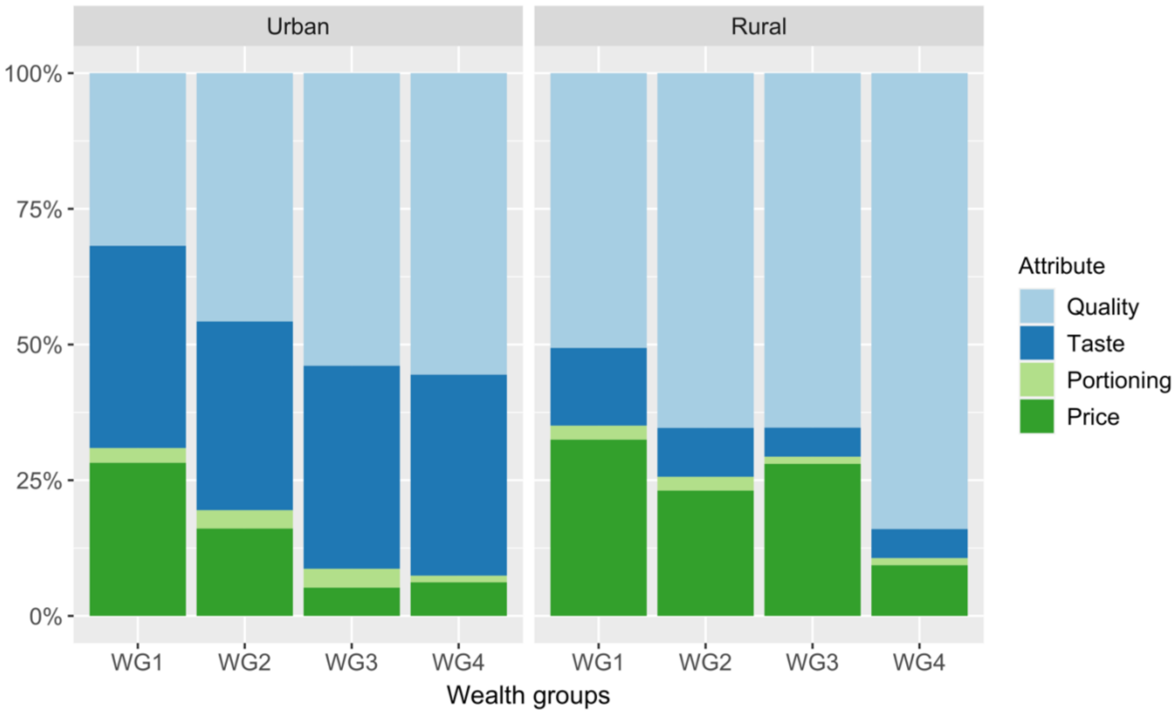


Figure 4.5. *Proportion of respondents ranking the most important attribute when making food choices in each wealth quartile for rural (n= 305) and urban (n = 424) sub-samples (WG1 = least wealthy group; WG4 = wealthiest group).*

4.4.3.3 Principle Component Analyses (PCAs) of animal-source food consumption and attributes of tilapia versus these foods

The PC analysis of the FFQ data (Figure 4.6) looked for associations between the frequency of consumption of the different food items used in this study. In general, both the urban and rural samples had similar results, in that, certain foods were grouped the same way. The data was grouped by people that frequently consumed fish (mbuta, fulu, omena), and those that consumed meat (along dimension 1 of both PCAs). We refer to this dimension as “meat eaters vs. fish eaters”. There was a clear association of wealth with dimension one of both PCAs. An increase in wealth percentile or a higher wealth group was more associated with the “meat eaters”.

Tilapia remained neutral along the first dimension in both samples, with it leaning closer to the meats for the rural sample. The results along dimension 2 were grouped on the price of food items for the urban sample with omena at the lowest price point and red meat at the highest price point. A wealth association with this dimension was also evident. We refer to this dimension as “expensive vs less expensive foods”. For the rural sample, this dimension was grouped on the frequency of consumption of foods, such as tilapia versus rarely consumed foods such as tinned fish and catfish, which we refer to as “available vs. less available foods”.

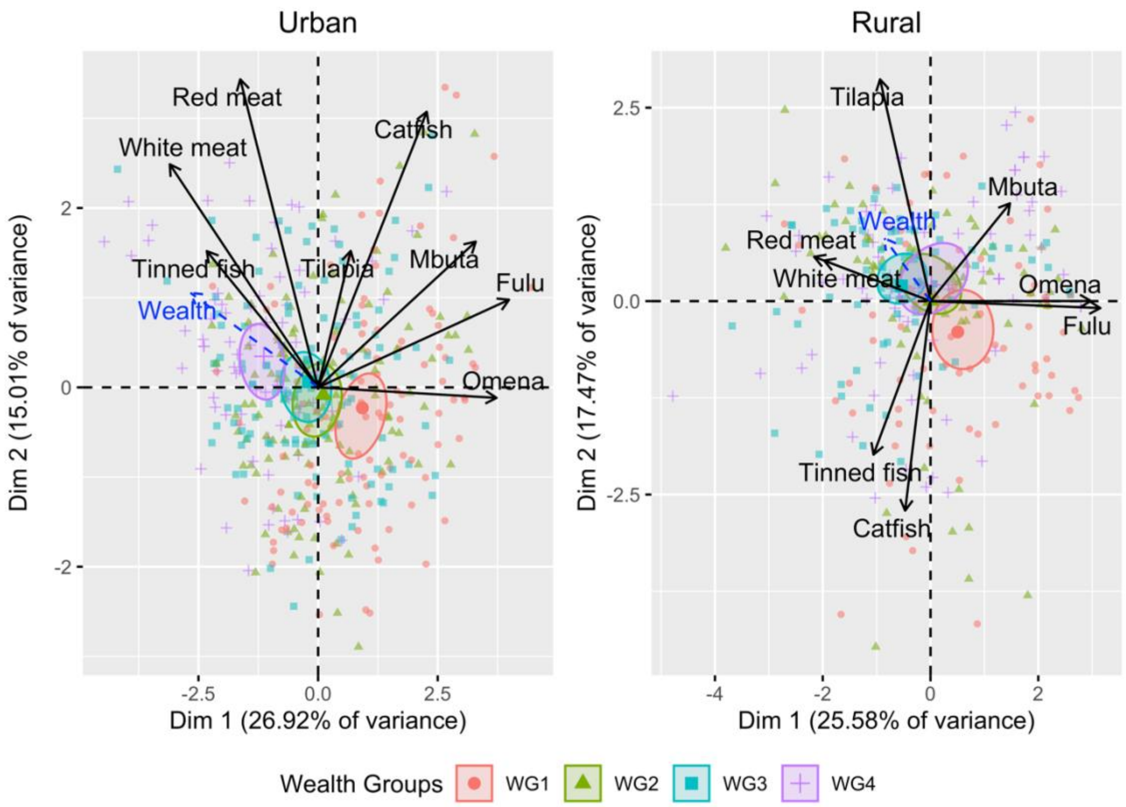


Figure 4.6. *Principal component analysis of food frequencies shown with black arrows representing the magnitude and direction of the coefficient. A blue line labelled "wealth" indicates association of increasing wealth percentile (not computed as a variable in the PCA). Wealth status is alternatively shown as quartiles with Wealth Group 1 (WG1) the least wealthy group and WG4 the wealthiest group, for both rural (n= 305) and urban (n = 424) sub-samples.*

We aimed to assess how tilapia ranked overall compared to other animal-source foods based on each attribute, and how these rankings were associated with each other. In Figure 4.7, we see that, indeed, the utilitarian attributes (price and portioning) and the hedonic attributes (quality and taste) were clustered together. The main difference along dimension 1 was how high tilapia ranked overall compared to the other animal-source foods, while the main difference on dimension 2 was the "utilitarian vs. hedonic attributes". Wealth had a minor association in this analysis and the wealth groups were not included in Figure 4.7 to reduce clutter in the graphic.

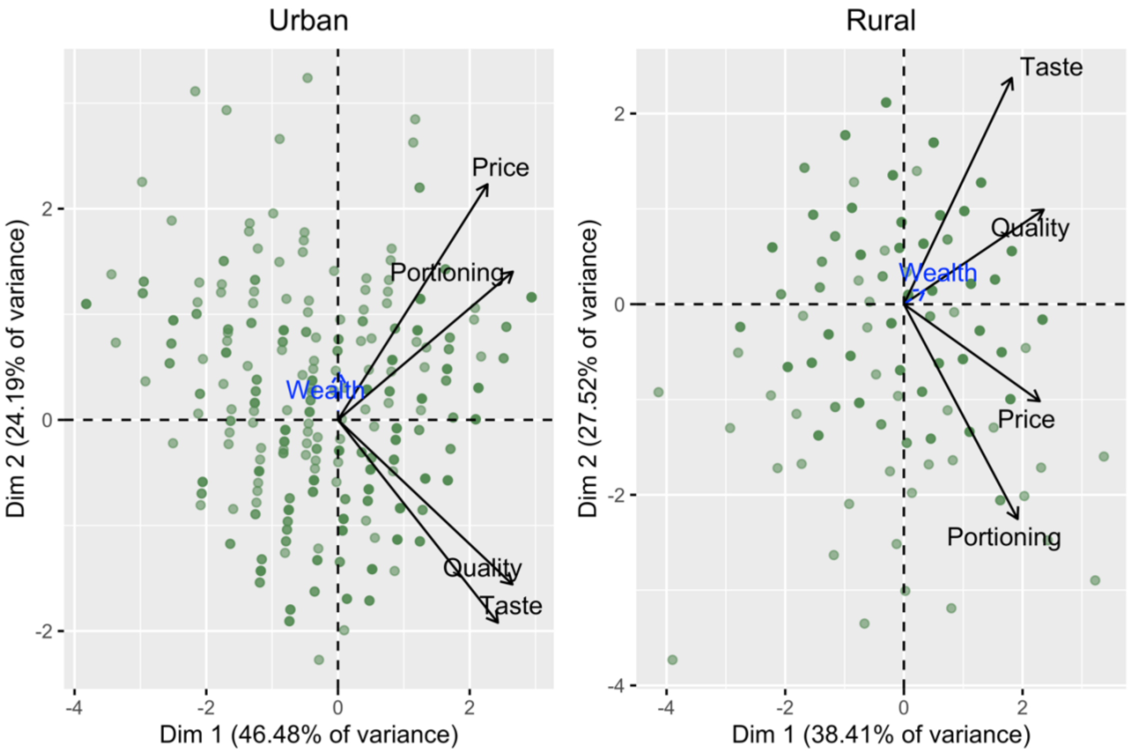


Figure 4.7. *Principal component analysis with total rank of tilapia out of four other animal source foods for each attribute, shown with black arrows representing the magnitude and direction of the coefficient. A blue line labelled "wealth" indicates association of increasing wealth percentile (not computed as a variable in the PCA) for rural (n= 305) and urban (n = 424) sub-samples. Wealth groups not included to reduce clutter in the graphic.*

4.4.4 Choice experiment with tilapia size

When we presented the frozen tilapia samples in the choice experiment, participants generally took the time to observe each size category and decided which size they individually preferred to consume (Table 4.4). Over 80% of respondents in the urban and rural samples chose the larger categories (medium and large). Almost 30% in both samples changed their mind once price information was provided.

Table 4.4. *Choice of tilapia size before and after price information was given as a proportion of urban and rural population samples (%)*

Tilapia choice preference	Urban (n = 424)	Rural (n = 305)
	(%)	(%)
Size of tilapia preferred to eat? (no price information)		
Large	58%	48%
Medium	25%	41%
Small	13%	11%
Very small	4%	0%
After price information was given, was there a change in preference?		
No change	72%	73%
Yes, changed to smaller category	25%	7%
Yes, changed to bigger category	4%	20%

Since respondents noted how many units of fish they would purchase, we roughly calculated the fish supply (grams) consumed per capita in a household by taking the number of fish selected in each size category multiplied by the median price point in the weight range, divided by the number of people in the household. The average weight of fish chosen by respondents as a meal for that day in rural households was 925 ± 526 g, compared to 742 ± 410 g in urban households, which resulted in 223 g ± 108 per person per household in rural areas and 199 ± 94 g in urban areas.

4.4.5 Drivers of small tilapia preferences

We aimed to assess specifically how the wealth index and the results of the PCA's influenced the choice for tilapia size. We found that wealth was a key predictor and that people in the lower wealth percentiles had a higher probability of selecting small tilapia over large tilapia (Figure 4.8). The probability was more than three times higher for people in the lowest wealth percentiles in the urban sample compared to the rural sample. The probability of choosing smaller categories is further broken down in each category in Appendix 4.5.

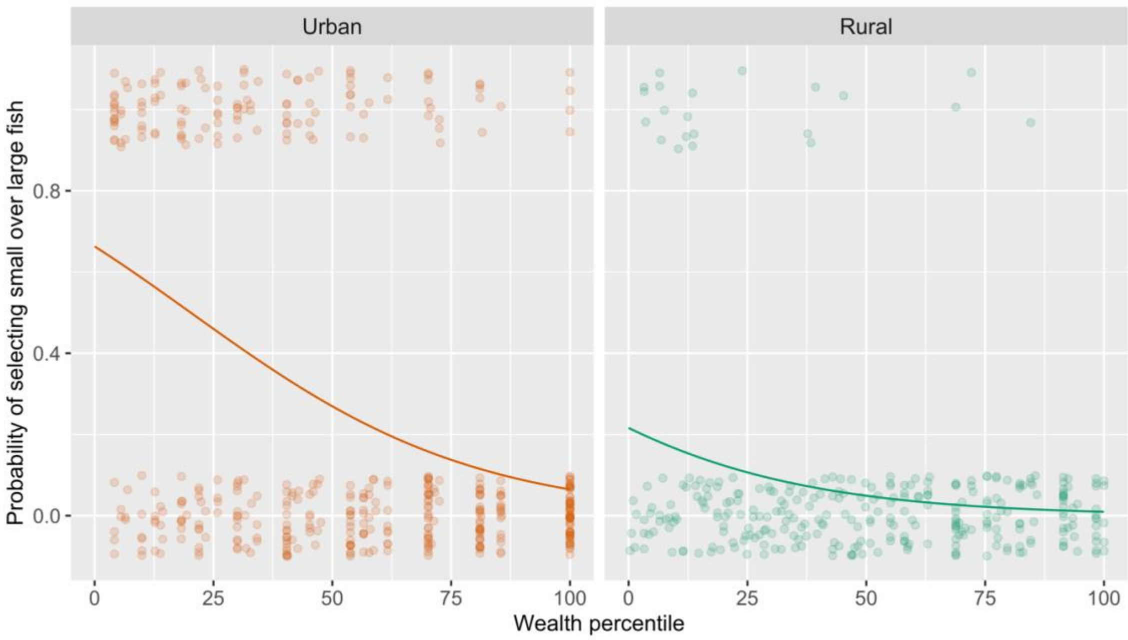


Figure 4.8. *Probability of selecting small tilapia over large tilapia based on wealth percentile for rural (n= 305) and urban (n = 424) sub-samples. Large and medium categories have been combined into category "large"; while small and very small categories have been combined into category "small".*

When computing the decision-tree analyses with all the demographic factors, wealth index factors, PCA factors from the FFQ, and PCA factors from the attribute rankings, we found that wealth was a primary predictor in tilapia size preference for both sub-samples (Figure 4.9). People in higher wealth percentiles generally chose larger tilapia and had a lower probability of choosing small tilapia. This was further segmented by people who were more associated with the "meat eaters" along the first dimension of the PCA with the FFQ. This was true for both the urban and rural samples. The urban sample had slightly more nuanced segmentation, with people who consumed more expensive foods generally decreasing their probability of choosing small tilapia. Less wealthy people who ranked taste and quality of tilapia as more important also decreased their probability of choosing small tilapia. People who ranked tilapia highly overall (as an average of all attributes) also lowered their probability of choosing small tilapia. Demographic factors such as age, household size, gender or tribal/ethnic identity were not identified as important predictors in the decision-tree analyses. The prediction success of the model in both decision trees was relatively high with an accuracy of 77% and 94% for the urban and rural samples, respectively.

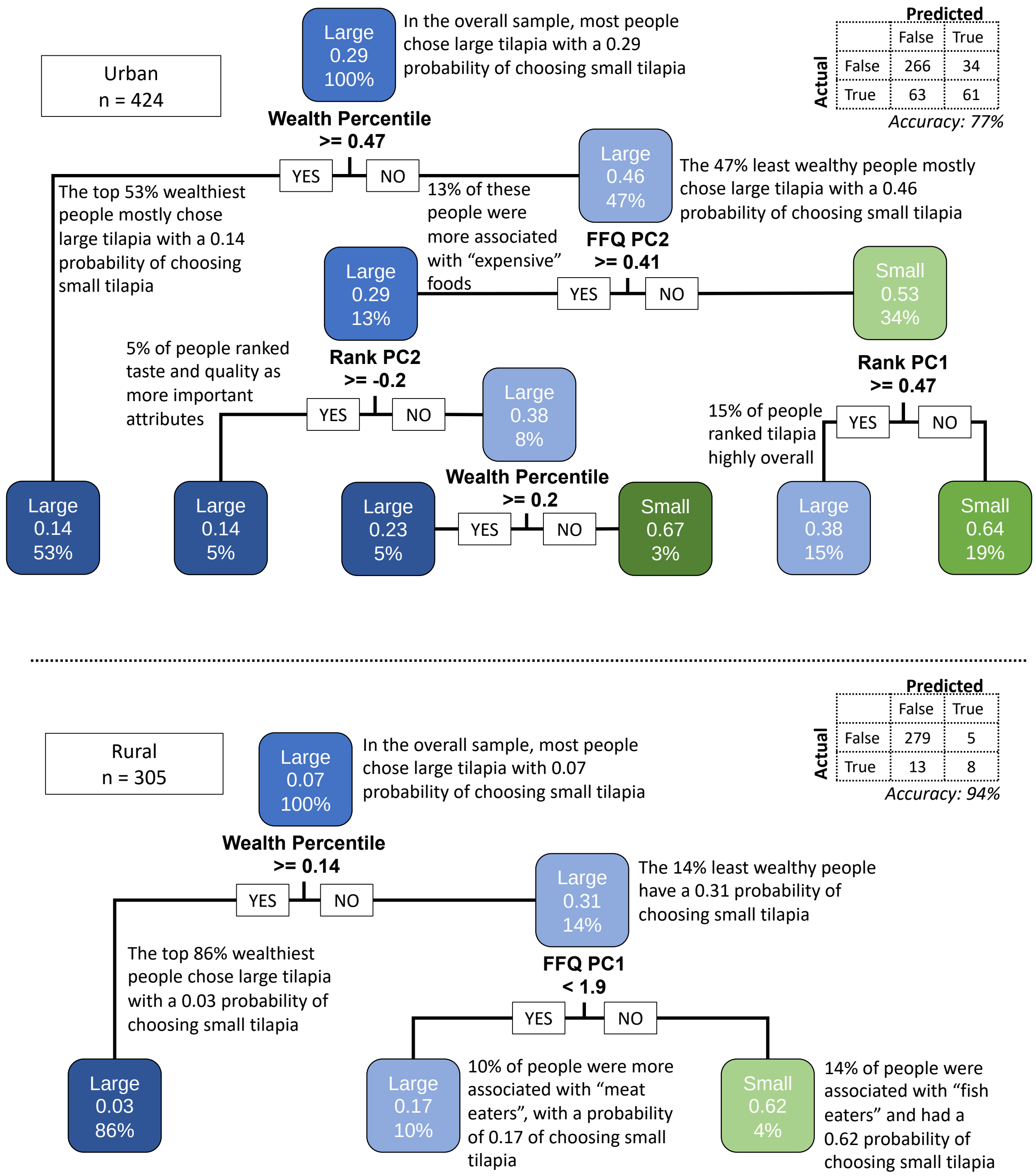


Figure 4.9. *Decision-tree analyses of choosing small tilapia with urban [top panel] and rural samples [bottom panel]. Each box represents a node in the decision tree starting with 100% of the sample at the top of the tree, and is coloured by tilapia size choice, i.e., blue (large tilapia) and green (small tilapia) with darker shading indicating higher fraction of sample making that choice. The first line in each node ("Large" or "Small") indicates the majority choice for that node. The second value in each box is the probability of choosing small tilapia for that node. The third value is the proportion of the sample used in the regression analysis at that node. Under each box the most significant predictor of the model further segments the sample based on a value in bold font under each box (Yes or No as higher or lower) and restarts the linear regression with two new branches. A confusion matrix of actual and predicted values is provided in the top right corner of both plots, showing the accuracy of the model.*

4.5 Discussion

4.5.1 Market context for fish preferences

Although there were similar demographic characteristics across the sample, the rural and urban population groups differed in their purchasing and consumption preferences. The value chains and markets were specific to each geography, informing the availability of fish and other animal source foods. People from rural areas consumed fish more regularly, especially omena and fulu, as well as consuming a higher average weight of tilapia per capita in the household compared to urban consumers (based on the sizes of fish they chose in the choice experiment). Previous studies have shown that a preference for small, dried fish, such as omena and fulu, was driven strongly by economic value due to their cheaper price points (Belton et al., 2022). The proximity to Lake Victoria means that people living in this area have some of the highest fish supply rates per capita in the country (Hansen et al., 2011).

Most people living in rural areas in our study were ethnically Luo, known to have a strong cultural preference for fish (Onyango & Ochiewo, 2023). When interviewing Luo respondents in the study, we had to clarify that we included omena and fulu as “fish”, since some people considered large fish (tilapia, perch, catfish) in this category, while small fish were seen as a different food category. It was not clear from our study whether the smallest tilapia (50-99g) for example, was prepared and consumed like fulu, while large tilapia was consumed differently. Ethnic identity had little impact on our decision-tree models though we did not include cultural meanings ascribed to fish species and size, including the subsequent recipes and dishes made from these fish or how they were consumed. It is probable that “fish-eating” cultures in riparian communities prefer and consume a wide range of fish species and sizes in different ways, whereas urban consumers are more limited to products found in shops and restaurants (Cornelsen et al., 2016).

In the urban samples (particularly in Nairobi), there were many people that needed clarification on the fish species we included in this study. Many people had never heard of fulu for example, and other people made statements such as “*but fish is fish*” when asked what their favourite fish was to consume. The implication was that some, mostly urban Kenyans from Nairobi, thought of large fish and fillets as a complete food product, giving less consideration to size and species differentiation. Regardless, urban Kenyans in our survey still consumed fish more frequently than meat showing a high preference for a range of different fish species. Based on the PCA results with the FFQ, tilapia fell somewhere between the “fish eaters” cluster and the “meat eaters” cluster. It is likely that in places such as Nairobi, where there is an eclectic mix of ethnicities, people have moved beyond their native communities and experimented with different foods (Chevalier, 2015). The results suggest that fresh, farmed tilapia is becoming an “urban” fish and a favourite Kenyan dish that is transcending ethnic backgrounds.

Few people in both the urban and rural samples chose omena or fulu as their favourite fish, yet omena was the most frequently consumed fish in both samples. Omena and other small, dried fish are a vital source of protein, fatty acids, and micronutrients for poorer, food insecure communities (Adesogan et al., 2020). Tilapia was indicated as the favourite fish to eat of most people in the survey showing the high demand and status of the commodity even across wealth divides.

More than two thirds of people living in urban centres bought tilapia in fried form from female street vendors ("M*ama Samaki*). Most urban people stated that proximity and convenience were the main reasons for buying fried tilapia. This "fast-food" nature of tilapia value chains in urban Kenya differed to rural areas where more people bought tilapia in fresh form from open-air markets and cooked it themselves. People in these latter areas stated that availability and price was the main reason for buying tilapia this way. In rural areas, it was evident from our survey that price was an important attribute, whereas taste and quality were more important attributes in urban areas. This differs somewhat to studies in Western societies that show that "fish-eating" cultures favour hedonic attributes when making choices around fish consumption (Juhl & Poulsen, 2000). In riparian, fish-eating cultures around Lake Victoria where fish makes up most of the animal-source protein and where poverty levels are still high, utilitarian attributes seem to be key drivers of food choice.

In both samples, price was a primary driver of food choices of poorer segments of the population. Overall, people in both study samples had a similar rate of tilapia consumption, though rural people had much higher frequencies of consumption of other fish species, while the former had higher frequencies of consumption of meats. Thus, tilapia seemed to be an important fish in both geographies, providing a "middle-of-the-road" option compared to other animal-source foods, but also in terms of its price point and availability. Tilapia was highly favoured from a quality and taste perspective compared to other animal-source foods and is highly likely to remain an important food source for many Kenyans in the future.

4.5.2 Drivers of small tilapia choice

The study specifically set out to assess the drivers of preferences for small tilapia. Just under 20% of people in both samples preferred to consume small tilapia with the rest choosing larger categories. In the urban sample, the preference for small tilapia increased to almost 30% of the sample when price was introduced as a factor. Much of the preference for small tilapia was driven by wealth status and its cheaper price point with a higher probability of choosing small tilapia the lower a person's asset endowment. After introducing price as a factor, around a quarter of people chose a smaller size grade in the urban sample while around the same in the rural sample chose a larger size grade. This discrepancy can be partially explained by the fact that we were using wholesale prices of farmed tilapia as our size categories. In rural areas, where there is competition from wild-caught tilapia our wholesale prices were likely reasoned to be better by consumers. Here, people were more aware of the existence of tilapia cages and the differences between farmed and wild tilapia than the urban sub-sample. Prices for wild-caught tilapia is highly variable, depending on the day's catch and the seasons, while farmed tilapia prices are more constant. Since smaller fish species are found in abundance, including wild juvenile tilapia, people in rural areas may have perceived farmed tilapia as a typically larger product, and thus worth the price in weight.

In urban areas, women traders buy fresh, farmed (and sometimes wild) tilapia from retail outlets for frying as part of a value addition strategy to accommodate the "fast-food" needs of the urban population. The value-addition of fried tilapia makes it more expensive per kilogram than the wholesale prices we used in our choice experiment. Since most people in urban areas purchased fried fish, which were often sold in larger size grades, people in our choice experiment were offered tilapia categories that they were less frequently accustomed to. Given that much of the tilapia fried in the streets of Nairobi and Kisumu are from commercial cage farmers, only a small portion of total yields from these cages are of smaller size grades, therefore there is likely to be more larger tilapia than small tilapia in urban markets. Over 70% of people stated that lower price was the main reason for changing from larger to smaller categories. Still, most people did not alter their choice, and the main preference was, overwhelmingly, for large tilapia.

Preferences for small tilapia were driven by people's consumption behaviours of animal source foods and their rankings of these foods based on various attributes. Tilapia was frequently consumed in our study sample, and it was rated as having higher quality and taste than other food products. Tilapia was a more desirable product than omena, fulu, mbuta, and broiler chicken. Although not broached by this study, people's perception of tilapia as a farmed or wild product was somewhat blurred in urban areas. During the survey process many people tried to differentiate imported Asian tilapia from Kenyan tilapia, with the former negatively perceived by most people. Kenyan tilapia was often called “lake tilapia” by respondents regardless of whether it was farmed or not. There were some people however, who stated that they did not consume farmed tilapia because they did not trust farming methods.

When it came to price as an attribute, tilapia was clearly more expensive than other animal-source products in our survey and, thus, the reason why some people transitioned to smaller sizes of tilapia. The ability to portion tilapia in general was not a high priority for Kenyans in our attribute ranking, though small tilapia may have been easier to portion, which drove some people to choose smaller size grades. When enumerators in our study reflected on some of their discussions with respondents, it occurred that some people preferred to portion larger tilapia into halves or quarters, especially as thicker fillets could be deboned for better edibility for younger children. On the other hand, people who chose small tilapia preferred to consume whole fish and found it easier to give each person in the family their own whole piece, depending on the age of children. Our survey did not manage to capture the age and number of children effectively, and any future studies should consider this in assessing the preferences for fish and size (Kümpel Nørgaard et al., 2007).

Once accounting for wealth, the probability of choosing small fish increased for people that were more associated with the “fish eaters” cluster in our assessment of people’s dietary patterns. People who eat fish frequently are generally able to make more informed decisions based on a mixture of hedonic and utilitarian attributes (Verbeke et al., 2007). People in our sample, further increased the probability of choosing small tilapia if they did not rank tilapia highly, meaning that a lower overall rank was associated with small tilapia. The probability of choosing small tilapia was increased by people who ranked portioning and price (utilitarian attributes) higher, as well as by people who were more associated with less-expensive foods, both of which were driven by wealth status. Since more urban consumers than rural consumers chose small tilapia and then further changed to smaller categories when price was introduced, the stronger market for small tilapia may be in lower-income urban area where people eat fish either because of cultural dispositions or because fish is generally cheaper to eat than meat. People in rural areas on the other hand, were already well accustomed to a range of small fish they consumed at much higher frequencies than the urban market and perhaps small tilapia was not as highly demanded. The demand for tilapia was thus strongly linked to the status of the Lake Victoria fishery and available aquatic resources. This may not be the case in inland rural areas in Kenya where fish is scarcer. Poorer market segments in both our study, however, made choices around price and the ability to portion fish, suggesting that small tilapia is likely filling a protein-supply gap when people cannot afford meat and want an alternative to small, dried fish in both rural and urban areas.

4.5.3 Implications for aquaculture development in Kenya

The study was designed against a backdrop of the growing aquaculture industry in Kenya. The growing value chain has resulted in an increasing supply of fresh, farmed, mostly larger, tilapia to markets. This value chain transformation has challenged local capture fishery value chains but also allowed women vendors in especially urban areas to accommodate the “fast-paced” lifestyles of urban Kenyans in their desire to purchase already prepared (fried) fish for home consumption. Small tilapia is often seen as a by-product of the larger commercial cage industry because of the methods used in tilapia farming. Other small tilapia is sourced from freshwater lakes and rivers while small-scale pond and cage farmers struggle to grow fish to large sizes due to financial constraints. Invariably, small tilapia is part of the aquaculture value chain and will be for some time, though size of tilapia has rarely been considered in consumption studies in the region.

Almost a quarter of people in our sample chose small tilapia, driven by wealth status or their ability to source other animal-source foods. The implication is that there is a market in urban Kenya for the direct production and sale of small tilapia. In rural areas, further away from capture fisheries and fish trade routes, the demand for a cheaper animal-source food may be high, though tilapia may be less-known. There are regions in Kenya where fish is rarely consumed, and as a result, people have poorer nutritional outcomes (Hansen et al., 2011). Earthen pond and cage farmers from the small-scale sector could look to access new markets through the purposive cultivation of small fish. There is less risk in growing small fish as they demand less feed and time to be harvested at half their maximum weight or less, resulting in improved cash flows (El-Sayed, 2002). This provides opportunities for the small-scale aquaculture sector, which to date has struggled to secure markets and compete with larger companies in the value chain (Obiero et al., 2019b; Kaminski et al., 2018). The commercial cage culture industry could look to market small tilapia to poorer communities in Kenya, or purposively grow small fish as part of their production and marketing strategy.

There is an aquaculture-fisheries continuum in Kenya, where the line between farmed and wild fish becomes blurred at the market level and where the source of origin is the same aquatic system (e.g., aquaculture and fisheries in Lake Victoria). In many cases it is difficult to assess which fish is cultivated or not, and Kenyan consumers are rarely made aware of where tilapia comes from or how it is produced. The danger of promoting small tilapia is that it promotes the capture of juvenile fish from capture fisheries and could challenge current fisheries management restrictions in the country. The production and sale of small tilapia should thus be promoted as a pro-poor food source that has potential to supplement protein needs for certain populations, but which should be sourced sustainably.

4.6 Conclusion

The study aimed to assess the drivers of tilapia preferences, particularly for different sizes of fish. The study used various measures of constructs of people's dietary patterns of animal-source foods and the utilitarian and hedonic attributes they ascribe in making food choices. Two sub-samples of urban and rural populations were targeted to try capture a wide array of Kenyan consumers. The results show that tilapia was frequently consumed and important in people's diets. Tilapia ranked highly in people's preferences and was a widely desired product compared to other animal-source foods. A minority segment of the population preferred or were limited to buying small tilapia because of their wealth status, but also their ability to source other foods; or because they ranked utilitarian attributes such as price and portioning higher than other attributes. Since small tilapia is invariably part of the capture fishery and growing aquaculture value chain in Kenya, assessing who eats this fish and why is critical. This study suggests that small tilapia is likely filling a protein-supply gap when people cannot afford meat and want an alternative to small, dried fish in both rural and urban areas. The production and consumption of small tilapia can be promoted in aquaculture value chains, especially if it increases fish consumption in poorer markets. This enables poorer people to benefit from the growing aquaculture value chain in Kenya, but also provides opportunities for small-scale fish farmers who may otherwise struggle to produce large fish.

4.7 Appendices for Chapter 4

Appendix 4.1. *Sample stratified by socio-economic status and suburbs/markets*

	Urban (Nairobi)	***N***	**Urban (Kisumu)**	***N***	**Rural**	***N***
Low-income	Kibera	39	Obunga	30	Mbita	53
	Dandora / Kayole	68	Nyalenda	35	Sindo	50
Middle-income	Donholm	36	Kondele	35	Oyugis	50
	N. West	33	Nyamasaria	35	Awendo	53
High-income	Westlands	36	United Mall	29	Rongo	50
	Lavington	18	West End	30	Homa Bay	49
Total		230		194		305

Appendix 4.2. *Factor loading from principal component analysis of wealth assets*

Asset	**Urban n = 424**		**Rural n = 305**	
	Factor 1 (44.3% of variance)	**Factor 2** (13.4% of variance)	**Factor 1** (36.4% of variance)	**Factor 2** (13.4% of variance)
Electricity	0.50	0.63	0.76	-0.00
Piped water	0.75	-0.03	0.14	0.67
TV	0.63	0.43	0.67	0.13
Fridge	0.77	-0.22	0.55	-0.18
Gas	0.66	0.25	0.73	-0.17
Smartphone	0.65	0.03	0.70	-0.02
WIFI	0.69	-0.40	-	-
Car	0.64	-0.47	-	-
Walls	-	-	0.74	-0.01
Motorcycle	-	-	0.09	0.74

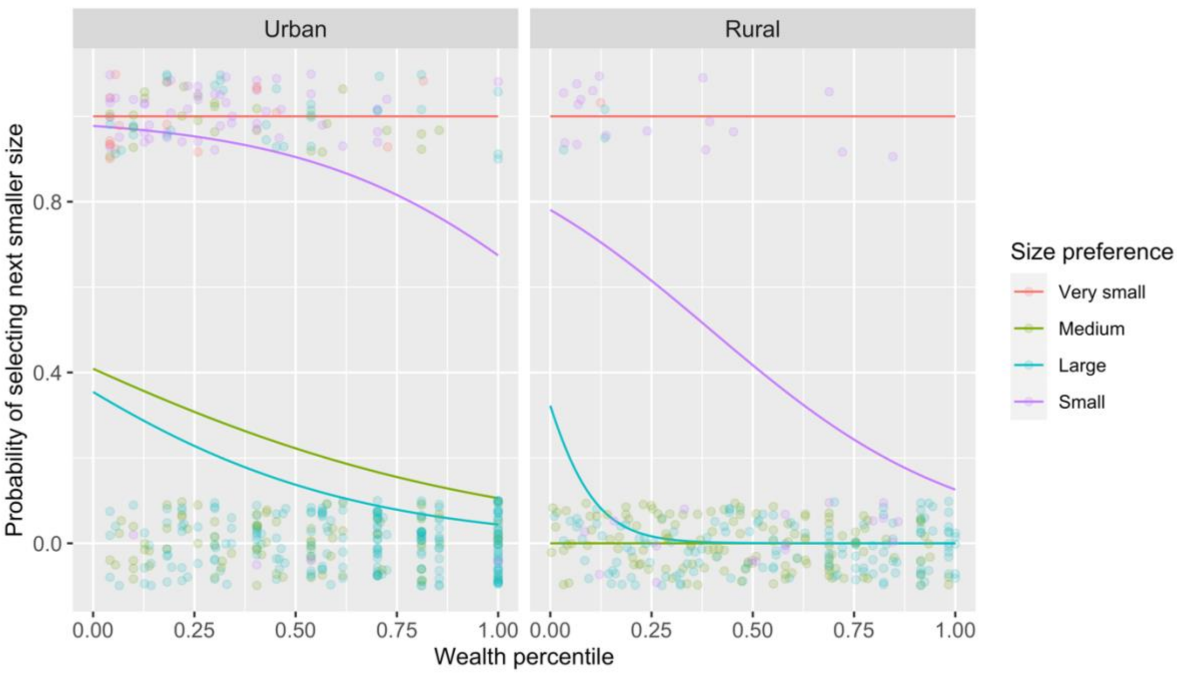
Appendix 4.3. *Factor loading from principal component analysis of food frequency questionnaire (FFQ)*

Food Frequency	**Urban n = 424**		**Rural n = 305**	
	Factor 1 **Fish eating** (26.9% of variance)	**Factor 2** **Expense** (15% of variance)	**Factor 1** **Fish eating** (25.6% of variance)	**Factor 2** **Expense** (17.5% of variance)
Fulu	0.73	0.18	0.80	-0.02
Omena	0.68	-0.02	0.76	0.00
Mbuta	0.60	0.30	0.37	0.32
Catfish	0.41	0.56	-0.12	-0.69
Tilapia	0.13	0.28	-0.24	0.73
Red meat	-0.30	0.63	-0.55	0.15
Tinned fish	-0.43	0.28	-0.27	-0.50
White meat	-0.57	0.45	-0.50	0.133

Appendix 4.4. *Factor loading from principal component analysis on food attribute ranking*

Attribute	**Urban n = 424**		**Rural n = 305**	
	Factor 1 Overall tilapia ranking (46.5% of variance)	**Factor 2 hedonic vs utilitarian attribute** (24.2% of variance)	**Factor 1 Overall tilapia ranking** (38.4% of variance)	**Factor 2 hedonic vs utilitarian attribute** (27.5% of variance)
Portioning	0.72	-0.52	0.56	-0.66
Quality	0.72	-0.42	0.69	0.29
Taste	0.66	0.38	0.53	0.70
Price	0.62	0.60	0.67	-0.30

Appendix 4.5*. Probability of selecting small tilapia over large tilapia based on wealth percentile using all categories of tilapia.*



CHAPTER 5

Growing smaller fish for inclusive markets? Increasing stocking density and shortening the production cycle of Nile tilapia in cages on Lake Victoria

*Published in **Aquaculture** 2024, 581: 740319;*
https://doi.org/10.1016/j.aquaculture.2023.740319

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Abstract

Fish farmers aim to maximise fish weight relative to the feed inputs needed to turn a profit. Yet, many farmers in Africa lack the cash flow to grow large fish and many consumers prefer, or are limited to purchasing, small fish. This study aimed to intentionally produce small tilapia in cages by assessing the effects of higher stocking densities and shorter growth cycles on production and financial efficiency. An experiment with 3 treatments and 6 replicates took place on Lake Victoria. The first treatment (T1) used a stocking density of 2.9 ± 0.3 kg per m^{-3} and aimed to produce fish to an average body weight (ABW) of 400 g (final ABW = 500.33 $\pm$ 31.01 g after 138 days). Treatment two (T2) did the same but with double the stocking density (5.9 ± 0.3 kg per m^{-3}), resulting in a final ABW of 439.22 $\pm$ 22.22 g over 138 days. The third treatment (T3) partially harvested 50% of the cage (after 76 days) once reaching an ABW of 230.92 ± 22.55 g. The remaining fish in T3 were on-grown for a total of 138 days (final ABW = 499.86 ± 15.95 g). A fourth production scenario (M1) based on data from T3, modelled a

100% harvest after 76 days of culture. There were no significant differences in mortality between treatments. There were no statistical differences in the feed conversion ratio (FCR) between T1 (1.51 ± 0.03) and T2 (1.49 ± 0.02), though T3 was statistically lower (1.46 ± 0.02; $p = 0.03$). Cages in T1 had a higher proportion of fish between 400 and 599g while fish in T2 were mostly between 300 and 499g. T3 had a bimodal distribution with most fish either in 200-299 g or 400-499 g. There was little effect on average price per kg for T1 (3.0 ± 0.01 USD) and T2 (2.98 ± 0.01 USD), though T3 (2.89 ± 0.04 USD) was significantly lower ($p = 0.001$). Overall, T2 had significantly higher gross margins (17% ± 2.08) than T1 (13% ± 2.3, $p = 0.021$) and T3 (7.2% ± 2.43, $p = 0.001$), while M1 had the lowest gross margins (-11.8% ± 5.5). The results suggest that farmers can increase stocking densities. Some farmers can use partial harvesting strategies or shorter cycles to produce small tilapia and achieve faster cash flows, though the economic margins are lower. Such approaches can provide opportunities for poor farmers and consumers.

Key words: “small fish”; “tilapia”; “nutrition-sensitive”; “Kenya”; “Lake Victoria”

5.1 Introduction

Aquaculture in sub-Saharan Africa is becoming an increasingly important source of food and nutrition (Mapfumo, 2020). While the contribution to fish supply from aquaculture remains low in comparison to that of fisheries, it has grown exponentially in the last decade (FAO, 2020). This increase in supply is due to the rapidly expanding tilapia farming industry specifically, with countries such Kenya leading the cage culture revolution on some of Africa’s largest lakes (Kaminski et al., 2018; Njiru et al., 2018). Most commercial tilapia farmers manage their production to maximise body weight of fish, which are then sold in fresh form, almost exclusively to regional urban centres and capital cities (Adeleke et al., 2020). Farmed tilapia can generally fetch premium prices in the region, challenging traditional, wild-caught tilapia value chains that often produce dried/smoked products (Asiedu et al., 2015). While the contribution of aquaculture to overall per capita fish supply has grown over the years, there is some criticism that commercial tilapia cage operators produce predominantly large fish for wealthier segments of society (Genschick et al., 2018; Marinda et al., 2018). There is a wealth differentiation in tilapia consumption in Zambia for example, where poorer segments of society purchase smaller tilapia supplied mostly through frozen imports from Asia, while larger, domestically produced tilapia are purchased from supermarkets by wealthier consumers (Genschick et al., 2017). Similar scenarios are evident in Kenya and there are few domestic producers looking to fill this market niche (Soma et al., 2021; Munguti et al., 2022)

There seems to be an opportunity for commercial farmers and especially the small-to-medium-sized (SME) sector to actively produce and supply small tilapia. Many farmers struggle to produce large tilapia, due to the lack of cash flow to grow fish for the four to six months required to reach "optimal" market size (Ofori et al., 2010). Consumers in many African countries consume and sometimes prefer smaller-sized fish, including smaller or juvenile cichlids such as tilapia (Obiero et al., 2014; Murphy et al., 2020). The preference for small fish is driven by its lower price point, local culinary habits, preparing and portioning fish for the family, or the perceived health benefits of eating small fish (Darko et al., 2016; Ayuya et al., 2021). Such distinct preferences of various social groups are not always considered in the commercial breeding and cultivation of fish (Omasaki et al., 2016; Mehar et al., 2021).

The idea that farmers can grow tilapia to a small yet profitable market size is not necessarily new (Smith & Torres, 1985). For many practitioners and academics, maximising the biomass from a cage by increasing the weight of individual fish is a fundamental goal of aquaculture production, and is especially important for companies that grow fish for filleting. This is not the case in Kenya, where consumers prefer whole fish to fillets. Maximising the average body weight (ABW) of individual fish may not be the main objective for farmers looking to satisfy rural and/or low-income consumers who purchase small, whole fish (Chikowi et al., 2021; Soma et al., 2021). Growing small fish results in the use of less feed inputs, and lower feed conversion ratios (FCR), resulting in quicker cash flows, and potentially important implications for sustainability (El-Sayed, 2002; Besson et al., 2016; Rodde et al., 2020; Genschick et al., 2021). There are potential human nutrition benefits too, as small fish are sometimes consumed whole, including the bones and viscera, resulting in greater micronutrient intake (Kabahenda et al., 2011; Fiorella et al., 2018). Having smaller and less valuable fish may also reduce incidences of theft or reduce exposure to economic fallout from natural disasters such as floods and droughts

Growing individually small tilapia requires shortening the production cycle, which in turn, suggests that stocking density can be increased to maximise biomass output. Assessing the effects of stocking densities, stocking rates or stocking size of fish are common research objectives in academia and the private sector (Shoko et al., 2016; Shamsuddin, et al., 2022). Studies suggest that higher stocking densities generally slow growth and in some cases reduce fish survival (Ridha, 2005; Azaza et al., 2013; Liu et al., 2018). There is constant debate on which stocking densities are best suited for specific cages and ponds in different aquatic systems around the world, though most approaches aim to increase stocking densities to optimise carrying capacity for maximum financial returns (Conte et al, 2008).

Some farmers ensure a variety of fish sizes by conducting partial harvests of smaller fish earlier in the production cycle, allowing the remaining fish to grow to a larger size (Knud-Hansen & Kwei Lin, 1996). Partial harvests allow commercial farmers to harvest sooner and improve their cash flow, as well as to meet market demand for different sizes of fish (Saiti, et al., 2007). Studies have shown that partial harvesting can decrease competition for feed, improve growth rates and yields, and increase profitability (Yu & Leung, 2006). Partial harvesting is common in many small-scale farming systems in Africa, especially in extensive earthen pond systems (Kaminski et al., 2022). This form of harvesting is useful because farming households can consume fish from their ponds/cages or have access to an immediate influx of cash through the quick sale of some fish (Kaminski et al., 2018).

The study aimed to assess the biological and financial potential of purposively growing small fish by shortening the production cycle, partially harvesting smaller fish midway through a cycle, and increasing stocking density.

The experiment took place with Nile tilapia (*Oreochromis niloticus*) in the Kenyan part of Lake Victoria. Nile tilapia, although not endemic to Lake Victoria, is an important capture fishery, along with the non-native Nile Perch (*Lates* *niloticus*) and small, pelagic fish such as omena (*Rastrineobola argentea*) (Munguti et al., 2022). Nile tilapia remains one of the most frequently consumed fish in Kenya and its culture has become an increasingly important source of supply in recent years (Esilaba et al., 2017). Although most aquaculture production in Kenya is dominated by a few large commercial companies, there are over 40 small-scale cage farming establishments around Lake Victoria raising fish for local markets (Njiru et al., 2018).

Many Kenyans still live in extreme poverty and fish makes up most of the animal-source protein for most households and is especially critical for poorer households (Cornelsen et al., 2016; Fiorella et al., 2014; Obiero et al., 2019). The results of this trial are intended for the commercial cage sector to assess whether a reorientation of production towards additionally supplying small, cheaper fish can be feasible and profitable. The approach, generally, aims to move the aquaculture sector into a more inclusive, nutrition-sensitive direction that includes the food and nutrition security needs of the most vulnerable in society (Rosenberg et al., 2018). The approach depicted in this study aims to produce tilapia that is more affordable for poorer people. By so doing, aquaculture becomes more accessible for producers and consumers aiming to benefit from tilapia value chain developments (Kaminski et al., 2020).

5.2 Materials and methods

5.2.1 Experiment design

The trial was conducted at Victory Farms Ltd., located in Homa Bay County in Kenya. The farm is the largest cage operator on Lake Victoria supplying around 7,500 metric tonnes (MT) of Nile tilapia (*Oreochromis niloticus*) per annum. Fish were grown in metal cages sized at 27 cubic metres (3m x 3m x 3m) and enclosed with polyethylene nets. Little fouling of nets occurred during the trial and no net changes or washes were necessary. The cages floated in deep water just over one kilometre from the landing site and placed side by side in two rows of nine (total 18 cages) with 0.5 metre gap between cages (see Figure 5.1).

Fingerlings were obtained from two nursery cages situated in the lake operated by Victory Farms Ltd. Fingerlings were transferred to the trial site when they reached an average of 39.5 ± 1.77 g (based on 5 samples of 20 fish per nursery cage). The biomass (kg) of fish was weighed in bulk upon transfer from nursery cages and fingerlings were not individually counted. The number of fish stocked in each cage was back calculated by summing all mortalities with the final number of fish harvested at the end of the trial, and this figure is used throughout our calculations.

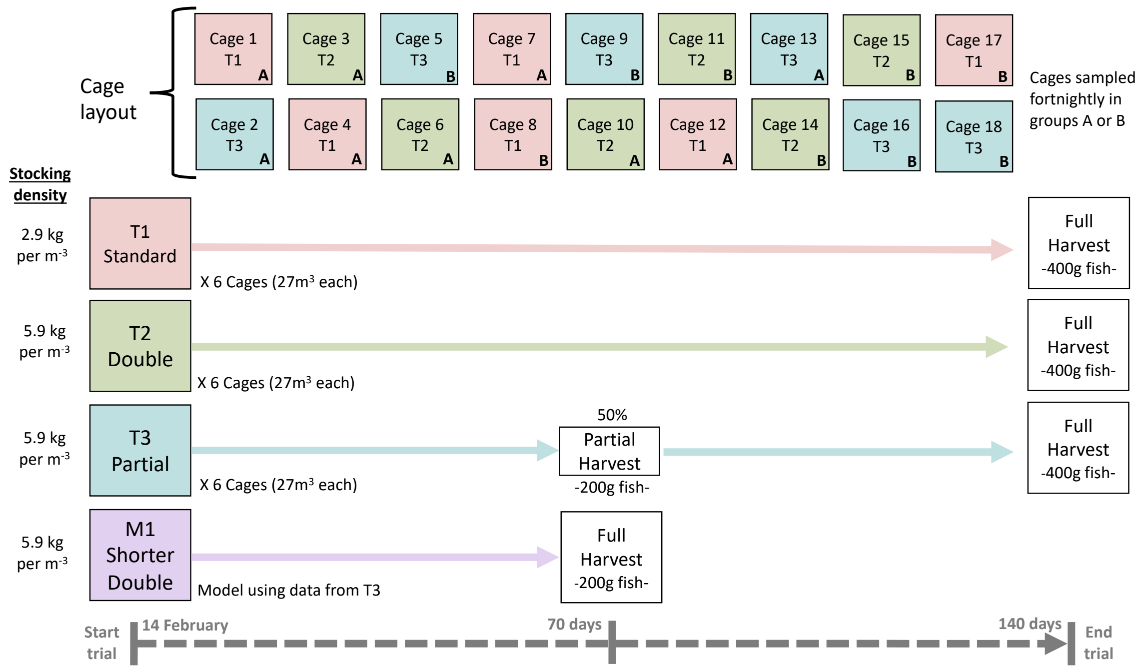


Figure 5.1. *Experimental design and cage layout*

The experiment consisted of three treatments and six replicate cages per treatment (see Figure 5.1). The standard target stocking density for cages of this size was determined to be 80 kg of fish per cage (2.96 kg per m^{-3}). The nominal operating parameters for the trial are seen in Figure 5.1. Since this is a trial using actual grow-out cages as part of a commercial farm operation, the final stocking parameters differed slightly (see Table 5.1). Treatment 1 (T1-Standard) cages were stocked with the standard average stocking density while Treatment 2 (T2-Double) doubled the stocking density. A third treatment (T3-Partial) also doubled the stocking density except a 50% partial harvest was introduced midway through the cycle, and the remaining fish were cultured to full size. Finally, a fourth production scenario (M1) was modelled based on data from T3, where the entire biomass was harvested instead of a partial harvest (i.e., shorter production cycle labelled 'M1-Shorter-Double').

***Table 5.1**. Stocking operating parameters of the trial*

Operating parameter	Standard (T1)	Double (T2)	Partial (T3)	Shorter Double (M1)
	Mean ± SD	**Mean ± SD**	**Mean ± SD**	**-**
Total fingerlings (no.)	2227.2 ± 184.3	4560 ± 373.3	4414 ± 250.4	Same as T3
Stocking rate (no. m^{-3})	82.5 ± 6.8	168.9 ± 13.8	163.5 ± 9.3	Same as T3
Stocking biomass (kg)	79.7 ± 4.3	159.1 ± 7.2	158.1 ± 8.2	Same as T3
Stocking density (kg.m^{-3})	2.9 ± 0.2	5.9 ± 0.3	5.9 ± 0.3	Same as T3
Size of fingerling (g)	35.9 ± 2.5	35.0 ± 2.8	35.8 ± 1.1	Same as T3

Fish were stocked on 14th of February 2022 and were fed to satiation with purchased formulated pellets five times daily with 2 mm feed (34% CP), reduced to four times daily with 3 mm feed (32% CP), and finally three times daily with 4 mm feed (32% CP). The amount of feed in T3 cages was corrected after approximately 50% of the fish population was removed during the partial harvest.

5.2.2 Data collection and sampling

Water quality measurements were recorded using an optic sensor (Oxy Guard Handy Polaris) daily between 14h00-15h00. Temperature and dissolved oxygen (DO) were found to be in optimal range, typical for the region (25.1–27.6 °C; 2–7.9 mg/L) (Mengistu, et al., 2019). Turbidity was measured using a secchi disk and found to be in optimal range (2–4 m).

The amount of feed consumed (kg) per cage and the number of observed fish mortalities were recorded daily. Sample fish weights were collected a total of 8 times from each cage: fortnightly until the partial harvest point (5 samples); and thereafter monthly until the end of the trial (3 more samples). Cages were organised and sampled in groups (A & B) of nine cages each with equal representation from all treatments (see Figure 5.1). Fish were randomly selected from different areas of the cage (n = 30/cage, n = 6 cages/treatment) and weighed individually with a scale (0.01 g); thereafter, all fish were returned to the cage.

During the partial harvest of T3 cages, after 76 days of culture, approximately 50% of the biomass of fish were harvested. After 138 days of culture, all remaining fish were harvested from all treatments. Harvested fish were scaled and gutted at the Victory Farms Ltd. processing site and graded into ten different sizes from Grade 0 (<100 g) to Grade 10 (> 1000 g) (see Table 5.2). The post-processing biomass (kg) of fish for each grade was recorded to account for the loss in weight after processing.

The costs of feed, labour, and fingerlings, and the selling price of fish in different grades, were recorded and collected via key informant interviews with farm staff. The average cost of fingerlings was 30 Kenyan Shillings (KES) per piece. The cost of labour per cage was based on the daily wage for one person (600 KES per day) to feed one cage with an additional 25% wage increase for cages that were double stocked to compensate for the marginal increase in feeding labour. All units in Kenyan Shillings (KES) were exchanged into United States Dollar (USD) (120.65 KES = 1 USD). It must be noted that the costs for fingerlings and labour are context specific to Victory Farms Ltd. No other variable costs were included as they differ widely across farming operations in Kenya.

Table 5.2. *Size grade (weight range) and price as United States Dollar (USD)*

Grade size	Weight range	Equivalent USD/kg*
Size 0	< 100 g	1.82
Size 1	100 – 199 g	2.25
Size 2	200 – 299 g	2.85
Size 3	300 -399 g	2.97
Size 4	400 – 499 g	3.03
Size 5	500 – 599 g	3.01
Size 6	600 – 699 g	3.13
Size 7	700 – 799 g	3.22
Size 8	800 – 899 g	3.36
Size 9	900 – 999g	3.36
Size 10	> 1000 g	3.36

* Exchange rate: USD 1 = KES 120.65

5.2.3 Calculations and data analysis

5.2.3.1 Biometric parameters

The mean weight of fish was averaged from the sample of 30 fish at each sampling event and the interquartile range was calculated to reflect the range of individual fish weights over time. Mortality was calculated as a percentage of the original number of fish stocked. The feed conversion ratio (FCR) was calculated as the amount of feed (g) divided by the biomass gained after stocking. The FCR was also calculated as a time series using each sampling event. The FCR of the M1-Shorter-Double scenario was calculated using the partial harvest data from T3 by taking the number of fish left after the partial harvest divided by the number of fish that were removed from the cage, giving the true fraction that was partially harvested in T3 (target was 50% harvest), which was then used to calculate the biomass gain up to that point. The same FCR calculation used the feed input and mortalities up until the day of the partial harvest.

Standard growth rates or other methods of estimating growth were deemed unuseful since half of the fish were removed from T3-Partial but also because the design of the sampling intervals and groups meant that too much variation was introduced as different cages were sampled at different times.

Since fish from the partial harvest were not sorted into different size grades in the same as way they were for the final harvest, the mean weight of the sample of fish (n = 30) collected on the day of the partial harvest was used to estimate the proportion of fish that would have been graded into different sizes. This proportion for each size grade is then multiplied by the actual biomass of fish that were partially harvested.

5.2.3.2 Financial parameters

Financial parameters are all presented in USD. The total revenue is calculated as the post-processing weight of fish (kg) multiplied by the average price of fish (USD) per kg. Using the proportion and price of fish in each grade from Table 5.2 we calculated an average price of fish per cage, as well as the total value of each cage, assuming all fish were sold.

The direct production costs (DPC) included the sum of the total value of feed (USD/kg) and labour (USD/day multiplied by the number of feeding days) and total cost of fingerlings (USD/fish). A gross margin was calculated as the total revenue minus the DPC. The gross margin was also calculated as a percentage of the total revenue. To make the results generalizable across different production systems in Kenya, we present both the gross margins of total revenue with and without fingerling and labour costs, as these costs vary greatly between farming operations.

The same procedure to model FCR in M1 above was used to model the financial parameters for M1: we took the biomass (kg) at partial harvest multiplied by the number of fish left after the partial harvest of T3 divided by the number of fish partially harvested.

5.2.3.3 Statistical analysis

All calculations and analysis were performed in R Studio, version 1.3.1056 (R Core Team, 2020). ANOVA was used to test for significant differences between treatments and a Tukey post-hoc test was applied to identify which treatments were different from each other. Significance was considered at or below the 5% probability level. We specifically tested for differences in production indicators: FCR, final harvest ABW, mortality, and proportion of biomass in each size grade. We also tested for differences in financial indicators: average price of fish, total value of cages, and total gross margins as the net USD amount after subtracting the DPC, and as a percentage of total revenue. The statistical analyses were performed only for comparisons between T1, T2, and T3 and not for M1.

5.3 Results

The trial was successfully completed on 1st of July 2022 after 138 days of culture when fish averaged over 400 g. The partial harvest of T3 cages occurred on the 30th of April after 76 days of culture when fish averaged over 200 g. The results for production indicators are presented first showing only minor differences between mortality, FCR and individual sizes attained. The financial indicators are presented after this, also showing only minor differences in price per kg, total value, and gross margins, suggesting the trial was successful in showcasing the feasibility of purposively growing small tilapia.

5.3.1 Mortality

The cumulative mortality for each cage over time is illustrated in Figure 5.2. The highest rate of mortalities occurred soon after stocking, with one cage (no. 18) suffering particularly higher mortalities for unknown reasons (possibly due to its location on the corner of the cage layout – see Figure 5.1). An increase in mortalities occurred across all cages in the last week of June due to a seasonal algal bloom on Lake Victoria, which coincided with a drop in temperature and DO, and a sharp rise in turbidity (see Annex 5.1).

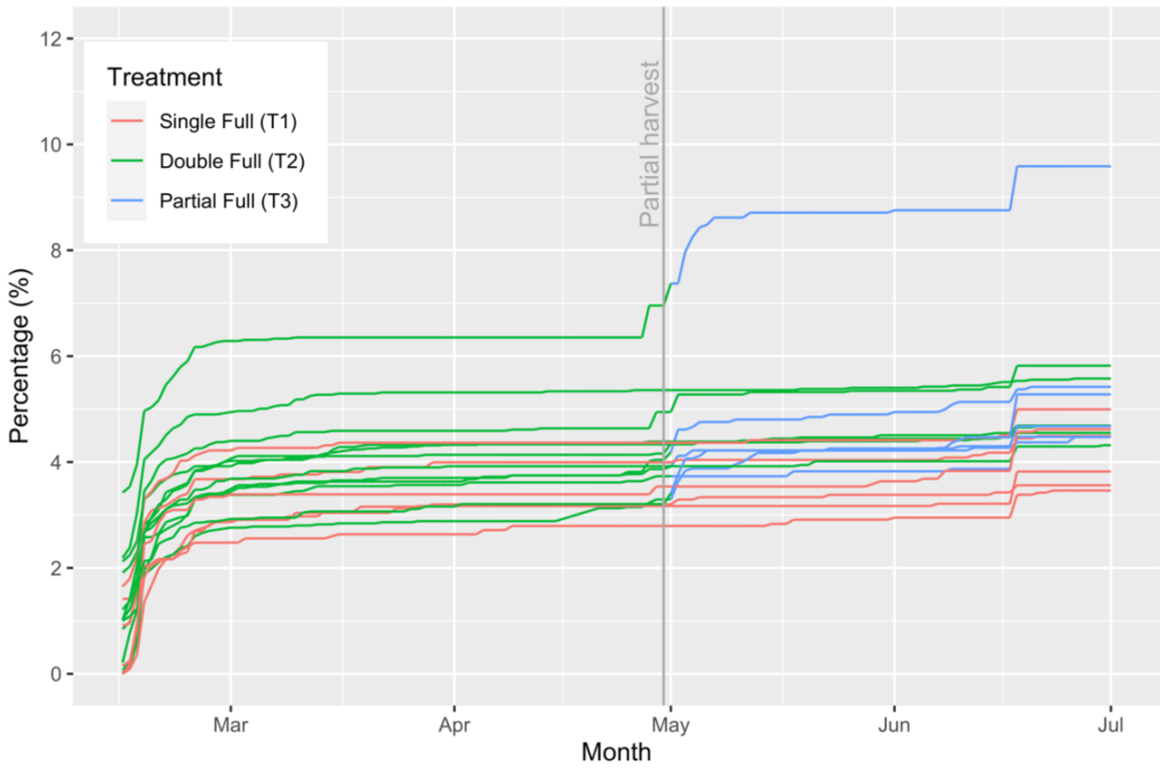


Figure 5.2. *Time series of observed mortality rate (%) as a proportion of original number of fish stocked for each cage in all three treatments. The grey vertical line reflects the partial harvest event after 76 days of culture.*

. Treatment 1 experienced an average of 4.2 ± 0.01 % cumulative mortality compared to 4.9 ± 0.01% for T2 and 5.3 ± 0.02% for T3. The cumulative mortality of T3-Partial until the day of the partial harvest was 4.4 ± 0.01 %, which is also the modelled mortality value for M1-Shorter-Double. To see whether increased stocking density or partial harvesting affected mortality of fish we used ANOVA and a post-hoc Tukey test and found no statistical differences in the final mortality between treatments

5.3.2 Feed conversion ratio (FCR)

ANOVA and a post-hoc Tukey test was used to determine the effects of increased stocking density and partial harvesting on FCR. The T1-Standard cages had an average FCR of 1.51 ± 0.03, with no significant difference to T2-Double (1.49 ± 0.02) (see Figure 5.3). However, T3-Partial with a mean FCR of

1.46 ± 0.02 was significantly lower than T1 ($p = 0.0044$) and T2 ($p = 0.0287$). The modelled mean FCR for M1-Shorter-Double (1.33 ± 0.04), after 76 days of culture, should be read attentively as it relies on data from the partial harvest and is thus not included in the ANOVA. The model (M1) does, however, show a lower FCR at the partial harvest point.

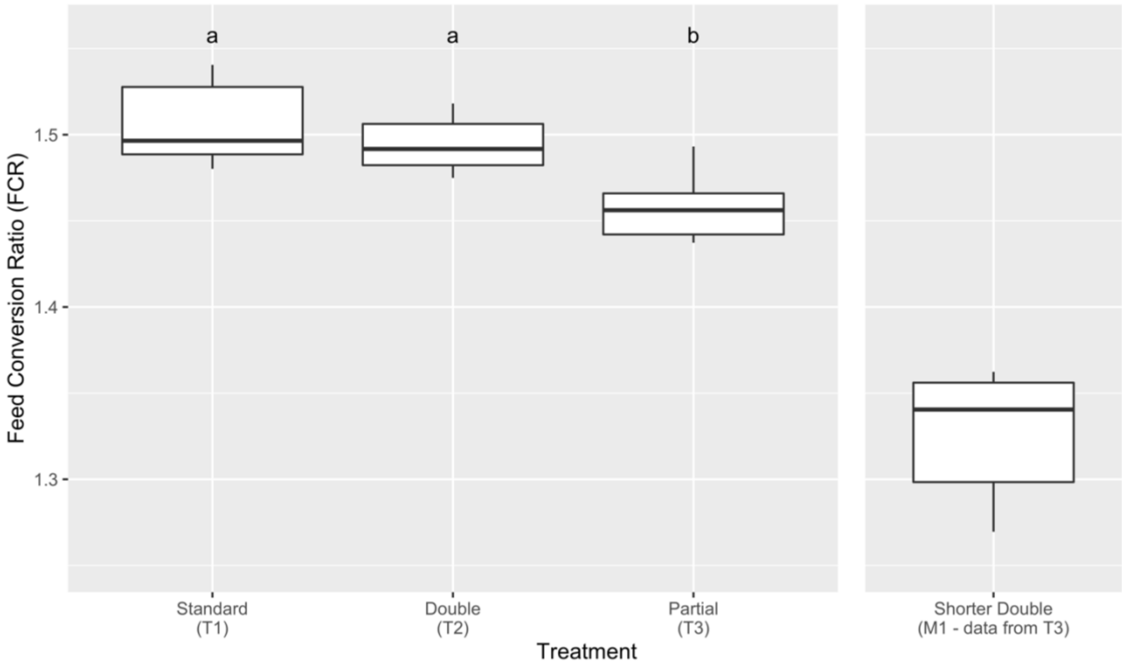


Figure 5.3. *Boxplot of variation in FCR by treatment. Each box created from 6 replicate cages, showing median (solid line), interquartile range (box) and full range (whiskers). Left panel shows FCR by the end of the trial while the right panel shows FCR of M1 at final harvest after 76 days. Differences calculated with ANOVA and Tukey test and statistical significance ($p < 0.05$) denoted with different letters (a, b, or c). ANOVA did not include the M1-Shorter-Double scenario.*

We showcase FCR as a time series using each sample of fish (n=30) by treatment, as shown in Figure 5.4. The FCR before the partial harvest was notably lower, showcasing the potential production benefits of producing small tilapia.

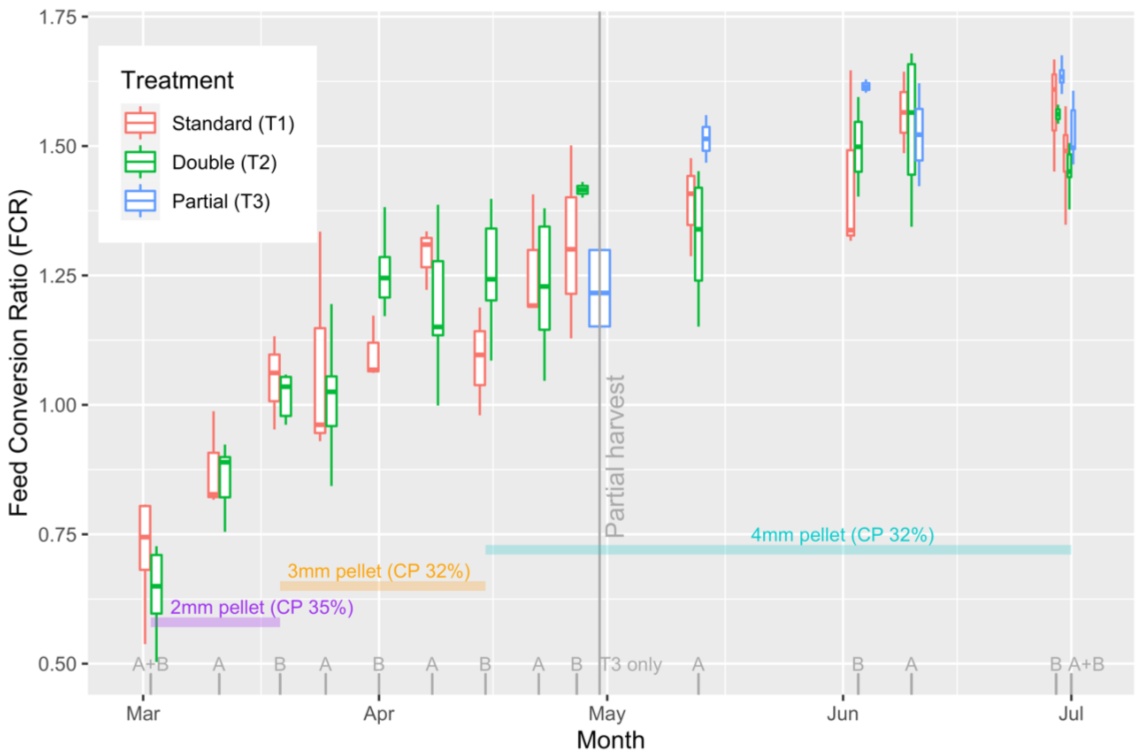


Figure 5.4. *Time series of FCR with boxplot of variation from fish weight samples (n = 30) from three cages in each treatment per sampling event (shown with grey ticks, group A or B, on x-axis). Each box shows median FCR (solid line), interquartile range (box) and full range (whiskers). The grey vertical line reflects the partial harvest after 76 days of culture. A time series of the feed pellet size including crude protein (CP) used in the trial are presented with labels.*

To see how much feed was used in each cage we present a time series for the whole trial (see Figure 5.5). Before the partial harvest, T2 and T3 were treated as double stocked cages. However, T3 received slightly lower feed on average (990 ± 70. kg) compared to T2 (1043 ± 95 kg), though the differences were not statistically significant when using an ANOVA and post-hoc Tukey test (not shown in figure). Notably, after the partial harvest, when T1 and T3 were treated as standard stocking density cages, fish in T3 again consumed slightly less feed in total (863 ± 55 kg) than T1 (898 ± 69 kg). There were no statistically significant differences, but these small differences could be the reason why the FCR for T3 was significantly lower than T1 and T2.

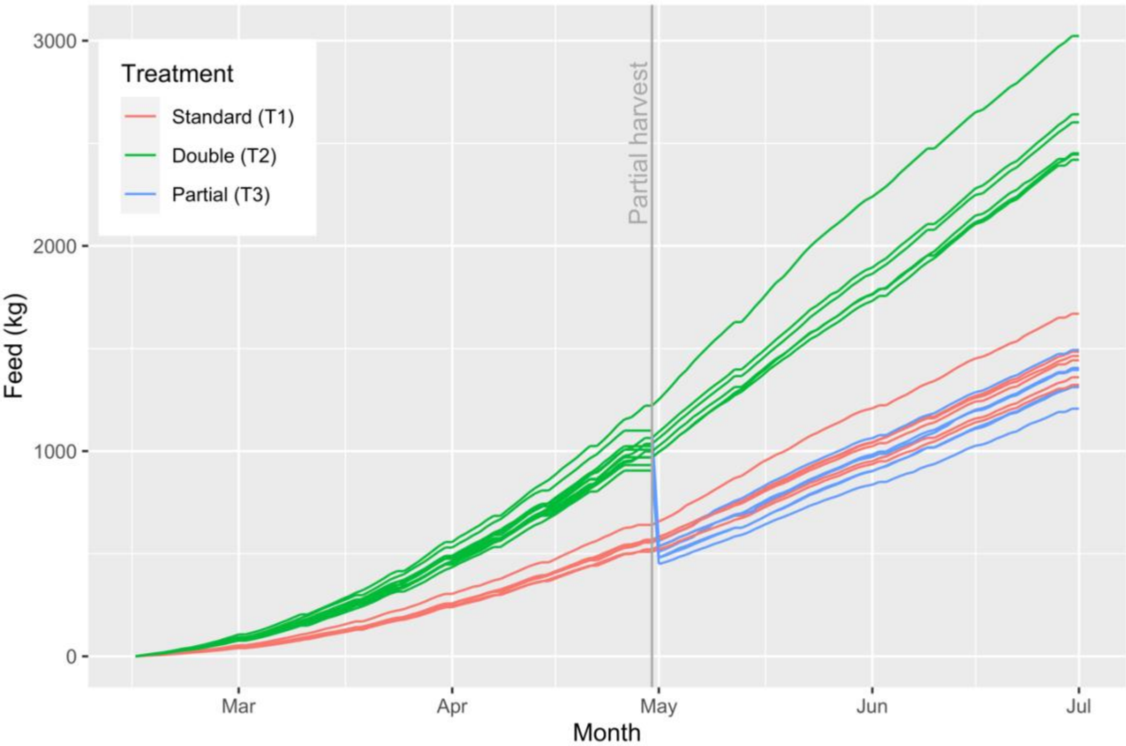


***Figure 5.5**. Time series of amount of feed (kg) for each cage in all three treatments. The grey vertical line reflects the partial harvest event after 76 days of culture.*

5.3.3 Average body weight (ABW) and size distribution

Figure 5.6 shows the average body weight and interquartile range of fish over time from each of the fish weight samples (n = 30) by treatment to see how fish grew at each stage of the trial.

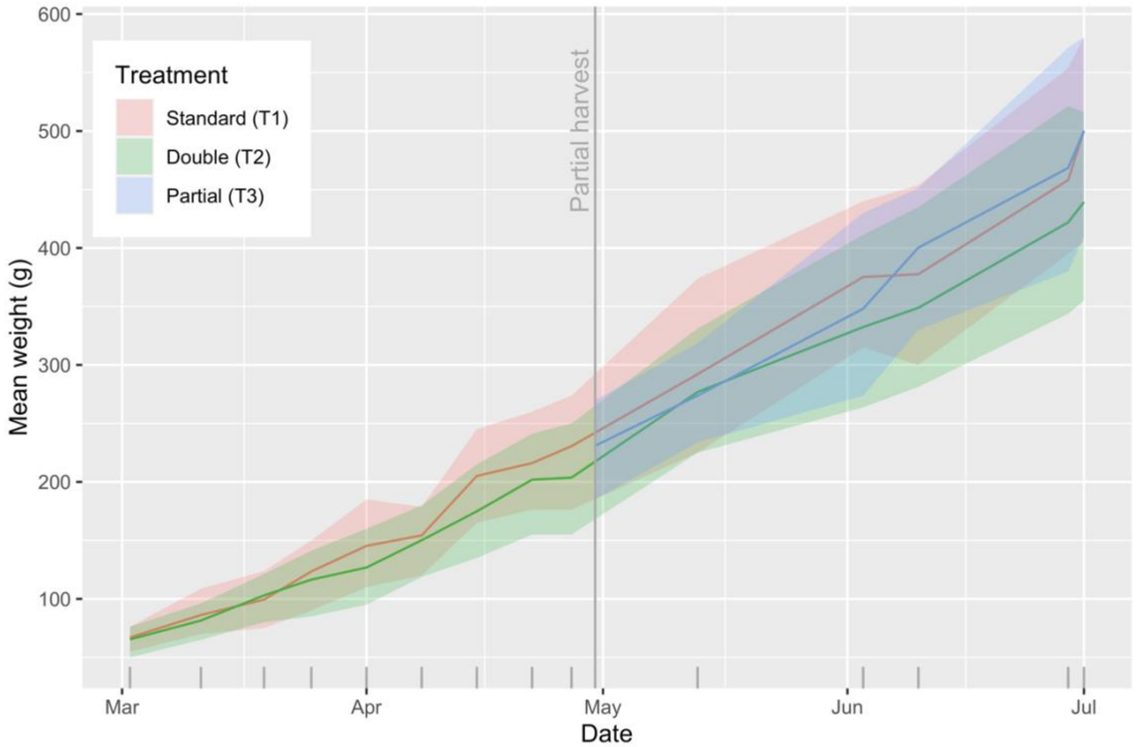


Figure 5.6*. The mean weight of fish (n = 30) fish per cage averaged for three cages from each treatment in sampling groups A or B (shown as grey ticks on the x-axis). The shaded area reflects the interquartile range of the fish weight samples. The grey vertical line reflects the partial harvest event after 76 days of culture.*

Despite different amounts of feed, we found that the final ABW of T1-Standard (500.33 ± 31.01 g) and T3-Partial (499.86 ± 15.95 g) were almost the same when tested with ANOVA and a post-hoc Tukey test (Figure 5.7). Increased stocking density when combined with a partial harvest did not seem to affect the growth of fish. The ABW for T2-Double (439.22 ± 22.22 g) was, however, statistically different to both T1 ($p = 0.0044$) and T3 ($p = 0.0287$) showing the effect of increased stocking density on growth. The mean weight of M1-Shorter-Double was 230.92 ± 22.55 g.

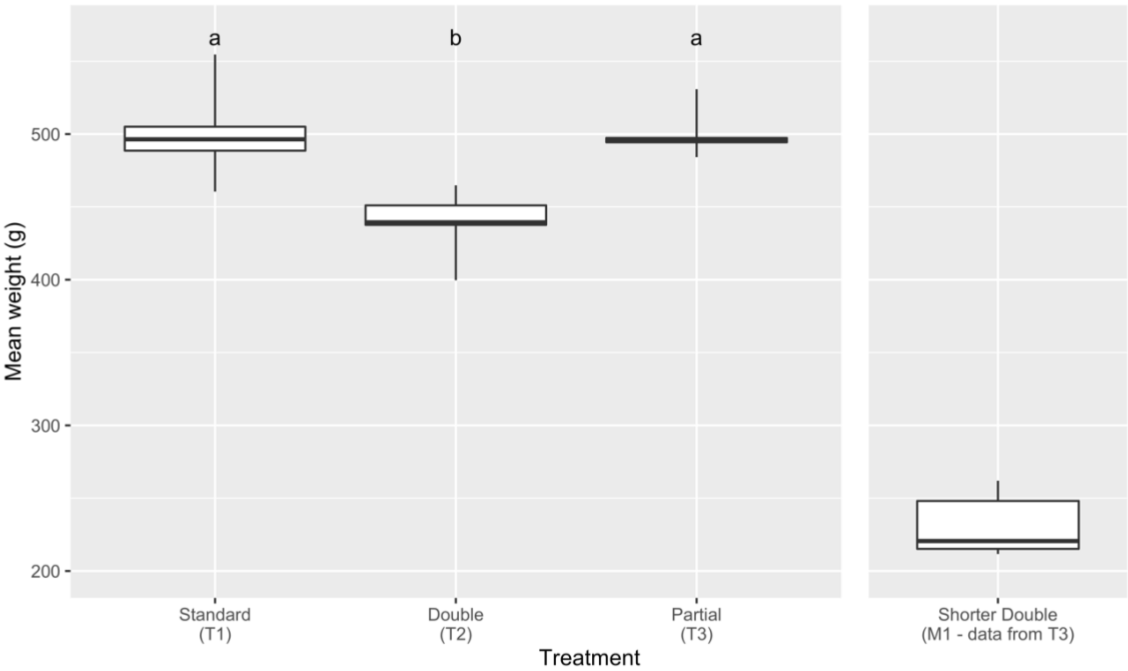


Figure 5.7. *Boxplot of variation of average body weight (ABW). Each box created from 6 replicate cages, showing median (solid line), interquartile range (box) and full range (whiskers). Left panel shows ABW by the end of the trial while the right panel shows ABW of M1 at final harvest after 76 days. Differences calculated with ANOVA and Tukey test and statistical significance ($p < 0.05$) denoted with different letters (a, b, or c). ANOVA did not include the M1-Shorter-Double scenario.*

The results of an ANOVA to see if increased stocking density and a partial harvest affected size distribution of fish (% of total yield) was significant ($p = 0.0018$). Figure 5.8 shows the final size distribution and standard deviation as a proportion (%) of the biomass harvested in each size grade. Most of the biomass of fish in T1-Standard was between 400 g and 600 g, while most of the biomass of fish in T2-Double was between 300 g and 400 g. The partial harvest meanwhile had a bimodal effect on size distribution for T3-Partial with roughly a quarter of the biomass of fish between 200 and 300 g and another quarter in the 400 and 499 g size category. Most of the fish in M1-Shorter-Double were in Grade 2: 200 g – 299 g.

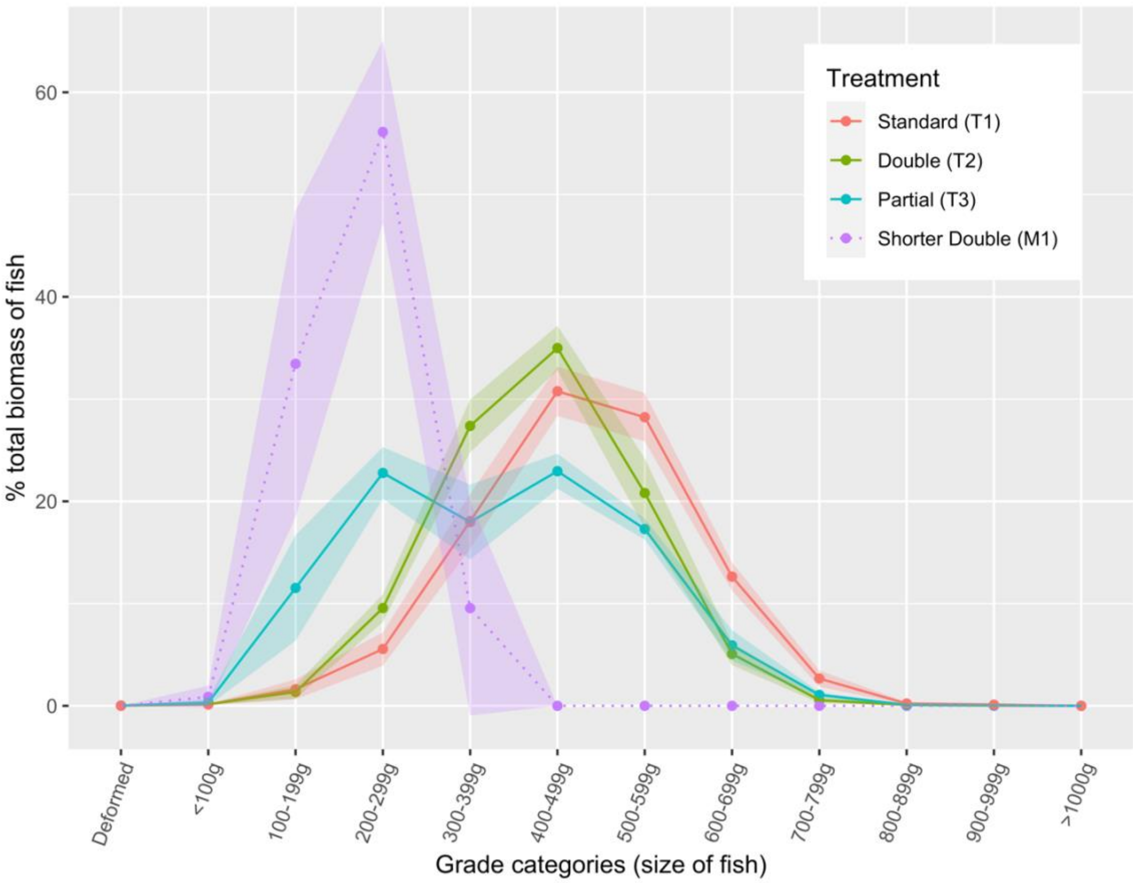


Figure 5.8. *Size grades of fish from the different treatments. The average proportion (%) of the final biomass of fish (after processing) in each size grade and averaged by treatment. The shaded area reflects the standard deviation from the mean. The results for Partial (T3) includes biomass of both partial harvest and final harvest.*

5.3.4 Financial model

The final production and financial results are summarised in Table 5.3. The treatments had little effect on the average price of fish when using an ANOVA with post-hoc Tukey test. T1-Standard (3.0 ± 0.01 USD) and T2-Double (2.98 ± 0.01 USD) had similar overall average prices. T3-Partial (2.89 ± 0.04 USD), however, had statistically lower average price of fish compared to the other two treatments ($p = 0.001$), showing the effects of a partial harvest (Figure 5.9). Since

M1-Shorter-Double had <10% of the biomass of fish over 300 g, the average price was lower at 2.65 ± 0.1 USD.

Table 5.3. *Final summary of production and financial results*

Variable	Single (T1)	Double (T2)	Partial (T3)	Shorter Double (M1)
	n=6	n=6	n=6	-
Production parameters				
Mean survival rate	95.8%	95.1%	94.7%	95.6%
Mean size of fish (g) at partial harvest	-	-	230.1	-
Mean size of fish (g) at final harvest	500	440	500	230.1
Mean FCR‡	1.51	1.49	1.46	1.33
Input				
Mean biomass of fish stocked (kg)	79.7	159.1	158.1	158.1
Mean amount of feed until partial harvest (kg)	-	-	990	-
Total feed (kg), incl. partial harvest	1457	2597	1853	990
Operating costs				
Fingerlings (USD)	554	1134	1098	1098
Fish Feed (USD)	1236	2205	1592	881
Labour (USD)	686	858	781	472
Output				
Biomass of fish (gutted and scaled) at partial harvest (kg)	-	-	412	-
Total biomass of fish (gutted and scaled) at final harvest (kg)	949	1699	1297	830
Revenue				
Average sale price per USD/kg of fish)†	3.00	2.98	2.89	2.65
Total value of fish in cage (USD)	2851	5067	3745	2199
Gross Margin (USD) – incl. all costs	376	871	275	-251
Gross Margin (%) – incl. all costs	**13%**	**17%**	**7%**	**-12%**
Gross Margin (%) – without fingerlings & labour costs	57%	57%	57%	60%

‡ FCR based on biomass of fish before processing (gutting and scaling)

† Average price calculated as biomass of fish for each grade multiplied by price for each grade

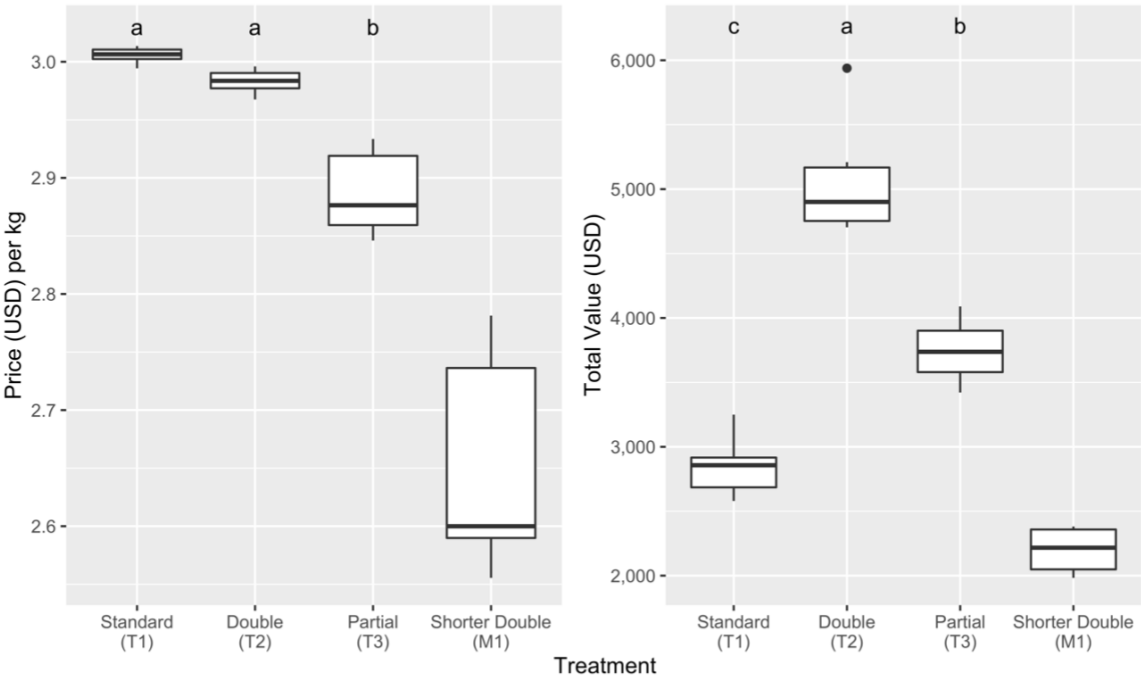


Figure 5.9. *Boxplot of variation of USD price per kg price (left panel) and total USD value (right panel). Each box created from 6 replicate cages, showing median (solid line), interquartile range (box) and full range (whiskers). Differences calculated with ANOVA and Tukey test and statistical significance (p < 0.05) denoted with different letters (a, b, or c). ANOVA did not include the M1-Shorter-Double scenario.*

ANOVA and post-hoc Tukey tests were used to assess whether treatments had any effect on gross margins. When factoring all the costs, including feed, labour and fingerlings, the overall gross margins were highest for T2-Double (870.66 ± 196.12 USD), more than double the other two treatments. The T3-Partial (274.61 ± 104.98 USD) and T1-Standard (375.61 ± 96.22 USD) cages had no significant difference in gross margins despite the former treatment stocking double the number of fish and removing half the population midway through the cycle (Figure 5.10). The labour and fingerling costs for double stocked treatments were higher and this lowered the gross margin to below the break-even point for M1-Shorter-Double (-11.8% ± 5.52). The T2-Double cages meanwhile had the best overall gross margin as a proportion of revenue (17% ± 2.1), significantly higher to T1-Standard (13.0% ± 2.3, p = 0.0214). T3-Partial had the lowest gross margin of the three treatments (7.2% ± 2.4), which was significantly lower than T2-Double ($p = 0.001$), and significantly lower than T1-Standard ($p = 0.001$). The costs of feed, labour, and fingerlings will vary between different operations, which is why we present the gross margins with and without fingerling and labour costs (Figure 5.10). When these costs were not included, the latter M1-Shorter-Double model had the best overall gross margin with 59.9% ± 1.6, while the other three treatments were similar, with around 56.7% ± 0.5 for T1, 56.5% ± 0.5 for T2 and 57.5% ± 0.5 for T3.

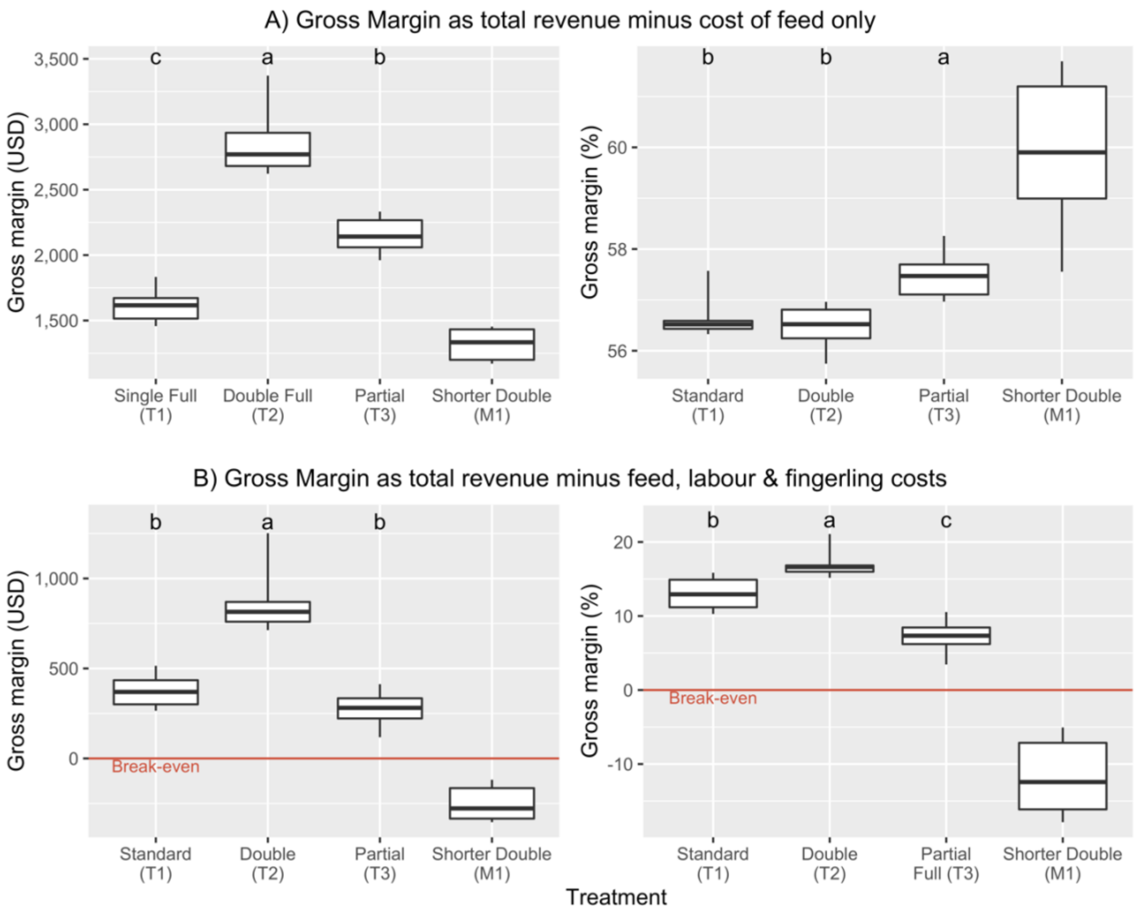


Figure 5.10. *Boxplot of variation of gross margin as total USD value and percentage of total revenue. Each box created from 6 replicate cages, showing median (solid line), interquartile range (box) and full range (whiskers). The top two panels (A) include calculation with feed costs only, while the bottom two panels (B) include sum of feed costs, labour, and fingerlings. Differences calculated with ANOVA and Tukey test and*

statistical significance (p < 0.05) denoted with different letters (a, b, or c). ANOVA did not include the M1-Shorter-Double scenario.

5.4 Discussion

Increasing stocking density and shortening the production cycle had few effects on biological indicators. The effects on financial indicators are more complex and require contextualisation to the Kenyan aquaculture sector. In general, the results of the trial suggest that purposively growing small tilapia over a shorter growing cycle is technically and financially feasible albeit at lower gross margins compared to growing larger fish. The costs used in the assessment, however, are highly variable and context-dependent, as are the situations of a vast array of different SME farmers. The overall efficiency and profitability will depend greatly on a cage operator's target market and ability to source fingerlings at a reasonable price. The objectives of each famer vary (e.g., higher margins or faster cash flows), and some manoeuvrability in production systems is needed.

5.4.1 Production potential of growing small tilapia

Increasing stocking density and introducing a partial harvest had no effect on fish survival. The tilapia in this study were stocked at a relatively large average size (30-40 g) compared to the norm for Kenyan farms, which likely supported higher survival (Gibtan et al., 2008). Cage operators that stock smaller fish, around 10-20 g, may experience higher mortalities (Ofori et al., 2009). The stocking rate in terms of number of fish per cage used in this study were specific to small-scale cages used in Kenya (Orina et al., 2018). The growth differences between stocking densities in the first phase of the trial (i.e., before the partial harvest) were marginal. The low stocking density cages resulted in roughly 7% higher ABW around midway through the cycle compared to high stocking density cages, and this increased to a 14% difference by the end of the trial. The mean FCR after 76 days in a double stocked cage was lower than after 138 days, meaning that growing small fish was more economical in terms of feed efficiency in the first weeks of production. Depending on stocking densities and total number of fingerlings, however, the costs of production rose quickly, making the enterprise less economical. Shortening the production cycle suggests that farmers could produce fish to an average weight of between 200 and 230 g in half the time it would take to produce fish to an average of around 500 g.

Higher stocking density made no statistical difference to the FCR at full growth, suggesting that increasing the biomass of fish in small cages is more efficient and should be encouraged. The effect that higher stocking densities may have on water quality, potential disease outbreaks and discharge, however, should be carefully monitored (Aura et al., 2017; Njiru et al., 2018). This study did not assess the effects of increasing stocking density on environmental parameters. The negative effects of cage culture on water quality in Lake Victoria has been previously documented (Musa et al., 2022; Kashindye et al., 2015).

Our study suggests that introducing partial harvests can be an effective strategy for farmers looking to maximise the output of two distinct size grades of fish for the market, namely between 200 and 300 g as well as between 400 and 500 g. This gives the producer advantages in cash flow as well as producing and selling fish twice, rather than once in a cycle.

Interestingly, the fish that remained in the cages after the partial harvest reached a final ABW almost equal to cages with initial lower stocking densities. Once half the population was removed from the high stocking density cages, fish fed more efficiently, which translated into better growth performance. The effect of the partial harvest on feeding behaviour cannot be verified by this study. The partial harvest may have disrupted the dominance hierarchy of the cage, therefore improving access to feed, and providing a growth rebound for subordinates (Azaza et al., 2010). This may explain why the FCR of the partially harvested cages were better than both the standard and double stocked cages at final harvest. Studies suggest that partial harvesting can increase productivity of tilapia systems as they decrease competition and increase individual growth rates and total yields (Brummett, 2002). Partial harvesting can be more beneficial than single-batch harvesting or gradual thinning strategies, though there is a limit to the frequency of discrete harvests in a grow-out cycle, as they can disrupt feeding, increase stress, and thus reduce efficiency (Yu & Leung, 2006). Partial harvesting is common in small-scale aquaculture in sub-Saharan Africa and should be promoted if it helps with cash flow, income generation or increasing food and nutrition security (Kaminski et al., 2022).

5.4.2 Economic potential of growing small tilapia

Increasing stocking density, according to our results, provided the best financial returns for farmers, if fish were cultivated to a full growth cycle. The financial returns diminished significantly when the partial harvest was introduced or if a production cycle was cut short. The reason for this is mainly because of the cost of fingerlings. The maximum stocking density (kg m^{-3}) for all cages by the end of the trial remained relatively unchanged given the low mortalities. Any future cage operators looking to adopt such techniques would need to assess the cost and availability of fingerlings as well as their target market. In the wider Kenyan sector, the marketing objectives and associated costs vary widely across cage operators (Musa et al., 2021).

Kenyan fish producers are driven by local consumer preferences for whole fish rather than fillets, and thus lack the incentive to maximise fillet yield through large fish production. In certain contexts, consumers in Kenya also prefer or are limited to small, more affordable tilapia, since prices are dictated on a per kilogram basis and smaller fish are cheaper than larger fish (per kilogram). Should this market exist in rural areas and peri-urban centres away from the capital and closer to producers, a significant opportunity emerges to save on transport and cold storage costs too (Musa et al., 2021). Opportunities for marketing small tilapia to urban centres are feasible, as poorer people in urban areas gradually start purchasing more foods from supermarkets (Neven et al., 2006). A majority of the urban population reside in informal settlements and can only afford small-sized fish (Soma et al., 2021). These conditions present opportunities for SME Kenyan producers.

The ability for producers to make quicker albeit lower returns in shorter time periods when growing smaller fish means that cash flow is more manageable, especially if farmers are buying feed and seed on credit. Cash flow is most challenging towards the end of the cycle when large fish exponentially increase operational feed cost – coupled with poor access to investment, the economic feasibility of cage farming for SME famers may be limited by the long production period until sales produce a cash influx. A mid-cycle cash influx would support the higher costs of feeding larger fish. While profit may be maximised with the production of larger fish, this may not be feasible for farmers with cash flow challenges. This is important when considering that some producers may be operating in economic conditions characterised by volatile exchange and interest rates and where environmental conditions may provide additional uncertainties and challenges. Despite the slightly lower gross margins on smaller fish in our trial, the ability to harvest sooner may be more beneficial for lower-income farmers or new entrants into the sector. Farmers may need to find trade-offs in faster cash flows versus higher margins, with the costs of fingerlings being the biggest factor in this trial.

This study did not attempt to include other costs such as fuel, energy, transport, depreciation, etc. Only the costs of feed, seed and labour were introduced in the financial model, since they generally make up the bulk of costs for farming operations in Kenya (Omasaki et al., 2016; Obiero et al., 2022). The main factors affecting the differences in gross margins in our study was the cost of fingerlings. The fingerling costs need to be contextualised as they vastly vary in the region, and they should not be seen as a definitive reason why growing smaller fish resulted in lower gross margins in our model. Naturally, doubling the stocking density required doubling the number and cost of fingerlings. Introducing two shorter cycles in the time it took to grow larger, table-sized fish further doubled the fingerling cost. Since breeding and nursing of fingerlings is still a challenge in Kenya, which affects total seed supply in the region, and since SME farmers do not usually operate their own hatcheries, this presents a major challenge for the adoption of the approaches tested in this study, and for the development of the SME sector, in general (Nyonje et al., 2018). We present both the results with and without fingerling costs for this reason, as famers will have to experiment with stocking density, size of fingerlings, and days of culture that suit their needs best. Other ways of reducing fingerling costs could include forgoing costly sex reversal hormones and stocking mixed-sex fingerlings (Bostock et al., 2022). Should farmers establish economies of scale where seed and feed inputs are spread over more units of production, the returns may increase significantly.

Market analyses may reveal that smaller fish are consumed in rural areas closer to site of production and thus may not incur the high costs needed to transport larger fish to urban markets.

5.4.3 Opportunities for cage-culture operators in Kenya and beyond

The approach presented in this study may be limited to the Kenyan part of Lake Victoria, though similar approaches could be trialled in other water bodies in Africa. Studies show that most SME cage farmers in the Lake Victoria region operated 2m × 2m × 2m cages (Orina et al., 2018). Stocking densities of these cages ranged from around 150 – 500 fish per m^3. Small-scale cages experienced mortality upwards of 20% signifying that these farmers likely stocked smaller-sized fish (Ibid.). The Kenya aquaculture industry may benefit from a more robust nursing value-chain node, as shown in Ghana where the development of nursing cage operations resulted in decreased mortality of tilapia in grow-out cages (Asase et al., 2016).

The trial in this study took place at a large, commercial cage farm, albeit in cages that would be classified as small-scale. The production interventions explored in this study are not limited to the small-scale sector and larger cage farmers can attempt to grow small fish in addition to large fish. Some farmers could opt to only grow small fish in shorter cycles although stocking densities and costs would need to be reconfigured to extract the best economic returns. Victory Farms Ltd. sell their fish to traders and retail outlets all over Kenya but predominately in the capital city, Nairobi. While the company manages to sell fish to different market segments, the smaller-sized tilapia makes up a significantly lower proportion of total yield. This could mean that the poorest segments of the market rarely purchase farmed tilapia and are still relying on wild-caught fish. A significant market niche thus emerges and should be explored further.

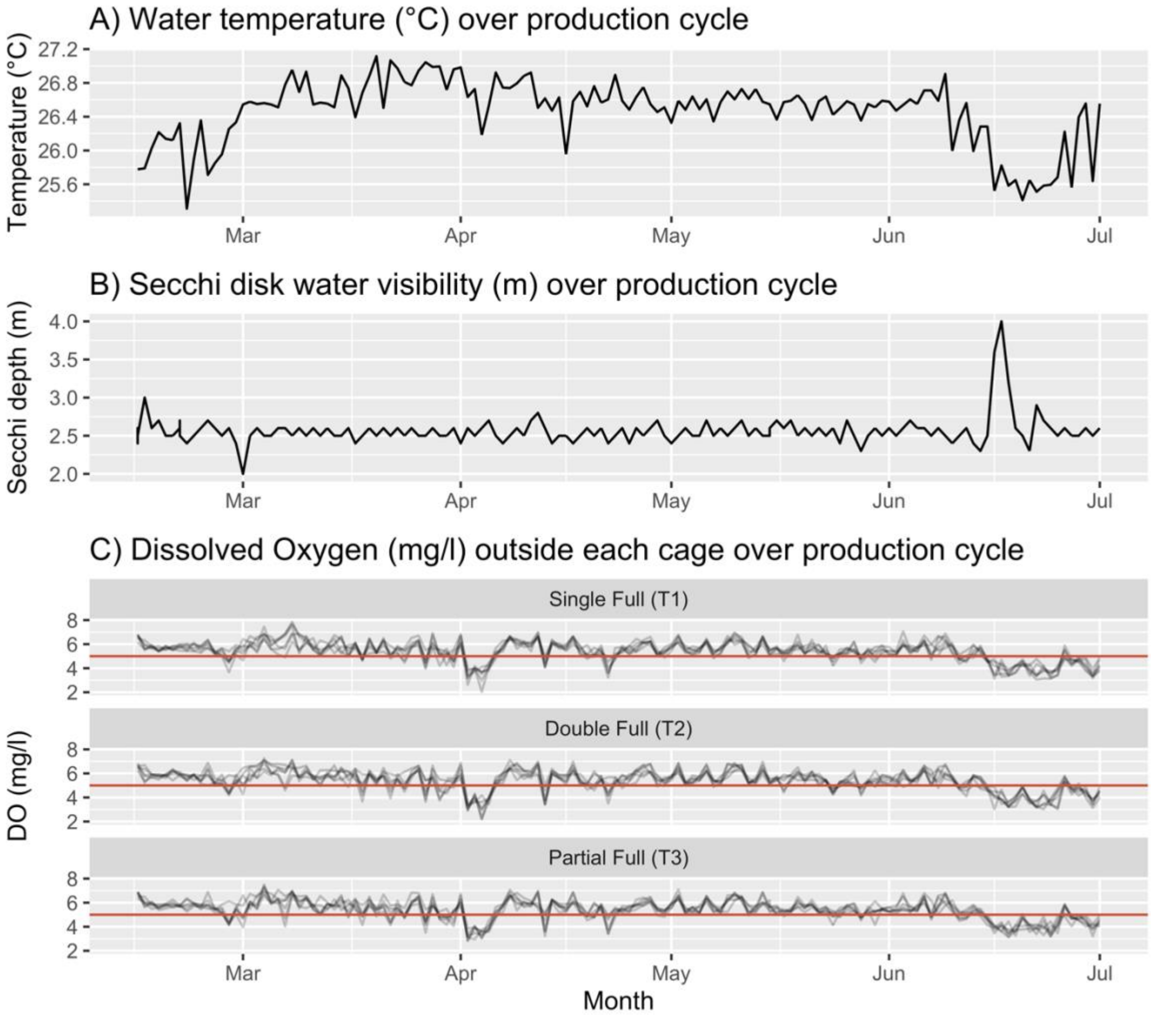
Targeting lower-income consumers with small fish would mark a significant shift for aquaculture in the region by accommodating the bottom-of-the-economic-pyramid (Kaminski et al., 2020). Furthermore, when eating smaller fish, generally more of the fish is consumed compared to fillets consumed on larger fish, which may result in better health and nutrition outcomes as people consume parts that are richer in micronutrients. Globally, small fish plays a crucial role in impoverished people's diets (Kawarazuka & Béné, 2011). The production methods presented in this study can be described as a nutrition-sensitive approach to aquaculture as it actively seeks to accommodate and maximise the nutrient requirements of the most vulnerable people in society. It allows those who were previously disadvantaged more opportunities to access the value chain and increase their intake of a valuable animal-source protein (Hotz et al., 2015).

5.5 Conclusion

The study tested the technical and financial feasibility of purposively growing small tilapia. The production strategy included increasing stocking density and shortening the growth cycle. The results show that there were no significant effects on fish survival, while increasing stocking density resulted in slower individual growth. Using partial harvesting as a production strategy together with higher stocking densities significantly improved FCR and had no effect on growth. Increasing stocking density had no effect on average price of fish at final harvest while partial harvesting provided an opportunity to grow and sell small and large fish at notably different price points. The gross margins were relatively similar among treatments, though once the cost of seed was introduced, increasing stocking density and shortening the production cycle lowered gross margins, significantly. Farmers could experiment with different stocking densities and harvesting strategies to try and increase their margins. The economic outcomes will depend on the market demand for small fish as well as the accessibility of seed. The approaches introduced in this study offer alternative methods to grow and sell tilapia. By adopting such approaches, aquaculture value chains can become more inclusive of lower-income enterprises and consumers. Adopting approaches that move away from maximising the growth of single species opens the doors for innovation in aquaculture, which is perhaps more adaptable to aquaculture in the African context.

Appendices for Chapter 5

***Appendix 5.1**. Water parameters including A) water temperature (°C); B) Secchi disk water visibility (m); and C) Dissolved Oxygen (DO) (mg/l), as an average of each cage over the whole production cycle. Red line depicts optimal DO level of 5 mg/l.*



Discussion & Conclusion

CHAPTER 6

Moving on from the productivist paradigm: A food sovereignty and nutrition-sensitive approach to tilapia farming in sub-Saharan Africa

This thesis set out to accomplish four objectives. The first objective was to move assessments of aquaculture in Africa beyond the productivist paradigm and highlight the value of fish farming to smallholder rural communities - beyond just estimating fish yields and incomes. To achieve this, the thesis assessed the role of ponds in farming systems and how they might affect diets and food security, using rural Zambia as a case study. The second objective sought to redesign subsistence-oriented aquaculture systems and optimise nutrient potential by introducing pond-based polyculture and intermittent harvesting as nutrition-sensitive solutions. The third objective aimed to include consumer preferences for animal-source foods, with a specific focus on fish size preferences, into aquaculture value chain developments. While the focus here was on consumers rather than processers, traders and retailers, the idea was to see how consumer preferences are reflected in the context of a rapidly commercialising cage culture sector, using Kenya as a case study. The fourth objective sought to use these insights from Kenya and redesign commercial production systems to better fit the needs of especially poorer consumers, and thus, prioritise their food provisioning needs, and ultimately their nutrition and health outcomes. To achieve this, a nutrition-sensitive solution for commercial cage culture was tested. Increasing stocking densities and shortening the production cycle or introducing partial harvests for greater product size differentiation, allows for more informed targeting of products to different market segments. Below, an analysis of each chapter is provided, examining synergies across different results within a nutrition-sensitive framework. This chapter concludes the thesis with an argument for greater food sovereignty in food systems as a vehicle to attain the goals of nutrition-sensitive aquaculture.

6.1 Nutrition-sensitive livelihoods in smallholder systems

The thesis argues that farmers, and other poor actors, are generally marginalised from tilapia value chains in Africa, i.e., producers from participating in high-value supply chains and markets, and consumers from affording high-value products. The thesis confirmed that smallholder farmers in Zambia rarely used commercial inputs or sold fish to established markets, whilst poorer consumers in Kenya consumed more wild fish and/or smaller tilapia rather than larger farmed tilapia. Both poorer farmers and poorer consumers were thus predominantly locked out of the commercialising aquaculture value chain.

It must be noted that aquaculture value chains in Africa are still nascent, and the emergence of commercial strands have had little direct impact on or input from extensive smallholder systems, which have existed for some decades on the continent. The sudden transformation of the value chain, however, has created a growing impetus for greater commercialisation, advocated by governments and practitioners, with a renewed hope that smallholders can benefit from these developments. The danger, as in other fast-commercialising agricultural commodities on the continent, is that the establishment of large commercial mega-farms and high technological, capital-intensive value chains can marginalise poorer people (Akram-Lodhi, 2015). While there is room for poorer, smallholder farmers to benefit from commercialisation and improve their productivity; farming household who struggle to make ends meet will strain to extract optimal benefits from commercial value chains. This thesis tries to provide practical solutions for those still locked out of commercial trends occurring in Zambia and Kenya.

The sudden influx of fresh tilapia challenges the existing dried/smoked value chains. For the time being, the few, new mega-farms existing in both countries can target their produce to the top-end of the economic pyramid. How aquaculture responds to consumer needs of those further down the pyramid remains to be seen, though this thesis provides some practical insights and solutions.

Poverty and “poor people” are defined here as those who are marginalized to a certain degree from accessing the natural, human, and financial resources, skills, and technologies to actively participate in value chains by either producing or buying commodities and inputs relative to the value chain (Kaminski et al., 2020). While not all smallholder farmers and consumers are poor, and there is heterogeneity in the realities faced by poor people in different contexts, the thesis aimed to identify actors who were constrained by their resource endowments and technical capabilities relative to larger firms operating in the same chain or their ability to purchase certain foods and/or maintain a healthy diet (Dixon et al., 2003; Murphy, 2010).

The first chapter of Part 1 presented the case of smallholder farmers in northern Zambia, some of whom adopted aquaculture and some who did not. Since aquaculture is not widely adopted in rural agricultural households in Zambia (less than 4% of agricultural households in northern Zambia), it was better to compare the adoption of aquaculture by farming households with those that have similar livelihoods and asset endowments. In general, all farming households in the sample were found to be similar and aquaculture was not the mainstay of most people’s livelihoods.

In moving away from the productivist paradigm, this chapter did not look at productivity, profitability, or yield outputs from ponds. While these metrics have their place, attempting to assess actual yields or productivity of small-scale tilapia farms (both cages and ponds) is, in many cases, a futile exercise. The systems differ so vastly: ponds come in all shapes, sizes, and depths, and they change from season to season. Estimating quantities of inputs and total harvests is further complicated by the arbitrary nature of tilapia farm management in much of the region, where different amounts of feed are added into the system (if available); or because farmers intermittently harvest fish throughout the season; or because they use mixed-sex fingerlings that breed and recruit in the pond (Kaminski et al., 2019).

Unless researchers and practitioners physically observe an entire production cycle, it is almost impossible to know how productive these systems truly are based simply on recall interviews with farmers (Garaway & Arthur, 2019). Most studies in Africa rely solely on these recall methods. Using productivity as a measure of success becomes obsolete if we struggle to obtain accurate data in the first place. Therein, lies the challenge to better understand the role of aquaculture in improving livelihoods, economic development, or food and nutrition security. Moreover, we keep looking for approaches that try to improve productivity metrics, yet few projects do so successfully, or at least in a way that can be scaled out (Lundeba et al., 2022). Often, we look to “feed and seed” as the solution to inadequacies in smallholder systems, and since these supply chains and infrastructure are limited in much of Africa, we tend to cast aside smallholder aquaculture as inefficient.

Instead, the results from Chapter 2 paint a detailed picture of farming households’ livelihoods, diets, and daily struggles with food security. The overwhelming majority of these households were moderately to severely food insecure, highlighting the urgent need to understand how and why people choose to cultivate fish or not. There is evidence to suggest that, for the time being, tilapia farming in Africa does not elevate smallholders out of poverty via income generation (Kassam & Dorward, 2017). However, this paper did show that aquaculture may be preventing households from slipping further into food insecurity.

Aquaculture offers households multiple pathways to food and nutrition security, such as providing more fish for consumption, selling fish for a quick influx of cash, and improving irrigation capabilities to diversify and intensify crop production. The latter is important because crop diversification improves dietary diversity, which impacts positively on food security (Jones et al., 2014). The importance of aquaculture in seasonal food supply fluctuations is even more important when considering the results of the polyculture trial study (Chapter 3). In this study, households were able to harvest fish from their ponds especially in times when food, or fish specifically, was scarce. It is important therefore, to not only assess how households can escape poverty and increase food security, but even just arrest decline into further impoverishment and food insecurity (Krishna, 2004). Stocking multiple species into ponds on low-protein diets goes against standard tilapia farming handbooks, though it is exactly what subsistence-oriented households, that struggle to commercialise, fall back on to produce food.

For this reason, understanding the farming and livelihood characteristics of households is crucial.

Certain characteristics of fish farming households are rarely considered in studies in Africa. Since farmers are pluriactive and operate multiple different livelihoods at the same time, this should be a key consideration when devising rural aquaculture systems (Short et al., 2022). Household food security status and the pressures that come with subsistence-oriented farming, as well as provisioning and consuming foods, need to be strongly considered in any attempt to improve aquaculture on the farm. Nutrition-sensitive frameworks aim to find evidence of how interventions can lead to food security, which leads to better nutritional and health outcomes (Allen & de Brauw, 2018). One of the main ways to achieve such outcomes is by increasing dietary diversity (Ruel et al., 2018).

In many ways, aquaculture as a livelihood strategy already constitutes a nutrition-sensitive system. Since aquaculture is not a traditional farming activity for most rural households in Zambia, adopting it, in whatever form, may provide at the very least, an increase in fish supply and protein (Aiga et al., 2009). In Bangladesh however, where aquaculture is more established, fish consumption increased by 30% in two decades, partly because of productivity gains made in tilapia farming, however, the consumption of non-farmed species fell by 33%, resulting in lower micronutrient intake for human populations over time (Bogard et al., 2017). The decrease in nutrient intake was partly due to the overall nutritional quality of available fish as more people shifted their consumption from small indigenous species to fillets of farmed tilapias and carps. This points to a need for monitoring what fish is grown and how they are consumed.

In Zambia, these sort of major production shifts have not yet occurred, but it does suggest that the nutrient quality of what is produced may be more important than total yields, especially since farmers struggle to maximise these yields in the first place.

This leads to the introduction of the second chapter in Part 1 of the thesis (i.e., Chapter 3). Since most tilapia farmers in the region do not operate highly “productive” ponds and since most fish are consumed in the household, the introduction of a pond system that is low-input and high nutritional output was seen as a win-win solution. Polyculture ponds as part of artisanal farming systems have an established history in much of Asia. The polyculture study in this thesis aimed to extend the lessons from these systems to Zambia. In keeping to nutrition-sensitive goals, the polyculture trials implemented in northern Zambia aimed to assess the nutrient intake of fish consumed from ponds compared to other sources of fish. The ponds were never designed to be the main source of fish, but rather a supplementary source to wild fisheries and dried fish markets. It is important to note that the latter sources of fish will play a much larger role in supplying a diversity of species and nutrients to vulnerable populations.

The ponds were successful in providing key nutrients, especially fatty acids, during certain periods. Households consumed more fish from polyculture ponds during times when fish was scarcer, most notably during the national fishing ban when capture fisheries were closed. Not only does this show the interconnection between aquaculture and fisheries but it highlights the importance of having a local food system in proximity to the household, and which can be managed directly by farmers. This points to the need for recognising larger aquatic food systems and the continuum between aquaculture and fisheries in how people harvest and cultivate fish but also in people's food choices, especially given seasonal food and hunger fluctuations. Recognising that aquaculture and fisheries in places such as northern Zambia are inseparable in their supply of fish is vital in finding ways to strengthen the resilience of vulnerable communities and the food systems they depend on.

Nutrition-sensitive systems are those that allow for better food access, especially if this can come from farmers' own production (Ruel et al., 2013). Nutrition-sensitive production systems should be tailored to the needs of farming systems and household livelihoods. There are two important characteristics of farming households often missing from assessments of smallholder aquaculture in Africa. First, farmers, including monoculture farmers, intermittently harvest fish throughout their pond cycles, as evidenced from the polyculture trial in Chapter 3. This suggests that unless partial harvests or thinning strategies with carnivorous fish are used, tilapia farms will never be as productive as farming manuals claim they can be. Since households use their ponds for food or to raise immediate cash, intermittent harvesting should be prioritised, not discouraged by extension officers. Intermittent harvesting ties in with partial harvesting strategies explored in Kenya in Chapter 5 of this thesis. These types of harvesting systems should be looked at seriously in the African context, for both small-scale and commercial systems, as they expedite food and nutrition security by allowing for more frequency of fish consumption but also faster cash flows and greater access to fish products for poor communities.

The second characteristic often missing from assessments of smallholder systems is that farmers, including most self-confessed “monoculture farmers”, are almost all operating polyculture ponds by default. This means that there are few purely monoculture farmers in these areas. This is another major characteristic of fish farming often ignored on the continent because of a belief that single-species cultivation is the answer to better productivity and production potential. The findings in this thesis suggest that promoting the monoculture of tilapia strains purchased from government hatcheries is misguided when most ponds are already either stocked with different tilapia species from multiple different sources or self-recruiting fish enter ponds from rivers and streams. In an age where biodiversity is a key indicator of sustainable food systems, polyculture methods should be celebrated and conserved.

Time and time again studies ignore that most of these ponds are, in fact, polyculture systems. Mamun et al. (2021) found that ponds often characterised as “shrimp” systems in Bangladesh were negatively viewed for their environmental performance whereas they were, in fact, polycultures with tilapia and other species; but also integrated with agriculture, and were thus critical to food and nutrition security of farming households. The lesson from this study, and this thesis, is that accurately describing systems and their impacts on human wellbeing and sustainability is critical.

Yet, pond farmers in much of Africa are encouraged by extension officers to remove unwanted fish species. This denies farmers the ability to grow both “commercial” fish in their ponds and small indigenous species that have higher micronutrient content. Since these communities fall into severely food insecure categories, as found in this thesis, it seems especially ill-advised to ask farmers to kill unwanted fish species and refrain from intermittent harvesting. Studies have shown that the aquatic habitats at the interface between fisheries and aquaculture can be a high source of micronutrients and diverse foods (Amilhat et al., 2009a).

Lower harvesting efforts and alternative management strategies of these aquatic systems can increase incomes, nutrition, agro-ecosystem services, and biodiversity conservation (Amilhat et al., 2009b).

Naturally, understanding the biological parameters of polyculture systems is important. Productivity metrics help tweak the system and assess which fish are more compatible together, which trophic niches they occupy, and how production efficiency can be improved, etc. Understanding the productivity, and hence, economic value of these ponds is useful too. In this sense, productivity metrics are needed, however, a productivist discourse that aims to improve quantity and productivity above all else is not. Nutrition-sensitive agriculture should be implemented within the ecological boundaries of local food systems (Keding et al., 2013). In terms of aquaculture, this means promoting agroecological principles and ecosystem services frameworks that promote integration with agriculture, better nutrient cycling, taking advantage of the trophic web (especially phytoplankton and periphyton), and better water quality management (Aubin et al., 2019). The polyculture ponds introduced in this thesis may have additional environmental benefits since there are fewer inputs, resulting in generally fewer diseases and less need for chemicals and products, such as antibiotics and disinfectants (Ali et al., 2016).

Advocates for nutrition-sensitive systems stress the importance of food justice, which in many ways includes the role of women's social status and empowerment (Ruel et al., 2018). By increasing women's access to and control of resources and encouraging participation in agriculture, the health and nutrition of women and therefore, of children can be improved (Sharma et al., 2020). A study in Bangladesh, for example found that higher female autonomy in food access and choice had better impact on whole blood omega-3 index and associated health outcomes (Grieve et al., 2023). Future studies that look to improve on or scale-out pond polyculture as a nutrition-sensitive intervention need to consider social issues and environmental sustainability.

6.2 Commercial systems can be nutrition-sensitive too

It is important to note that nutrition-sensitive systems should not be the sole prerogative of poorer farming households. In fact, there is probably more justification for larger commercial systems to think about how their production systems respond to the nutrient requirements of human populations, but especially for those who still suffer from malnutrition or hidden hunger. Some scholars have alluded to such value chains as poverty alleviation mechanisms that target the bottom of the pyramid and provide greater opportunities, either by empowering and employing smaller enterprises or by allowing poorer people to be consumers of products and services (Humphrey & Navas-Aleman, 2010).

The term inclusive value chain is often used to describe approaches that attempt to enhance farmers, traders and consumers access to markets, and improve productivity and efficiency in ways that have positive effects on livelihoods, food security, climate resilience and gender equality (Ros-Tonen et al., 2019). Bush et al., (2019) note that “development pathways are forged in the context of pre-existing relations of class, power and gender that structure access to productive resources (land, capital, technology), but have also contributed to the reworking of these relations, sometimes deepening existing inequalities, sometimes attenuating them”. Here, Bush and colleagues are talking about the possibility of further marginalization as commercialization and the emergence of new forms of resources and capital are harnessed at the expense of the poorest of the poor. Rooted in Prahalad’s (2004) theory of the commercial and development potential of ‘serving the poor’ at the base of the economic pyramid, it is argued that market interventions can help businesses make profits and alleviate poverty. Moving one step further, nutrition-sensitive approaches aim to do so with evidence-based interventions that service the nutritional needs of people and increase food and nutrition security (Ruel et al., 2018).

Key to this, is to first understand where the nutrition and food security gaps are, as was shown in the case of smallholder systems in rural Zambia. Another step, is to understand the food provisioning and consumption preferences of consumers, and how this affects the availability and accessibility of foods (Mehar et al., 2019). Food provisioning refers to the organisation of social and economic practices involved in the delivery of food, and refers to how information on foods is communicated, how they are sourced, stored and packaged, etc. (Tezzo et al., 2020). Consumption is defined as the selection, purchasing and eating of foods, determined by preferences for different traits such as quality and taste, and informed by economic status or social and cultural traditions, among other factors (Spaargaren et al., 2012). This is especially pertinent in the context of increasing urbanization rates, as more and more Africans move to larger urban towns and purchase foods from retailer and supermarkets.

Remaining within the nutrition-sensitive agriculture framework, it is critical to not only look at rural, smallholder and subsistence-oriented systems, but also those that are rapidly commercialising and feeding urban populations. While a typical value chain approach should look at all downstream activities from processing, trading and retail, this thesis looked at production and consumption only. The main reason for this is that in Africa, aquaculture value chains are relatively short. Most small-scale farms sell directly to retailers and consumers while most larger commercial farms vertically integrate all downstream activities.

The first chapter of Part 2 introduced the case of consumer preferences for tilapia in Kenya to see if such preferences could inform production methods further upstream in the value chain. It was evident from this study that some consumers preferred small tilapia. The preference for small tilapia was driven mostly by economic factors but also local culinary habits, as well as different needs for preparing and portioning of fish for family meals. Unlike Western value chains, the preferences for tilapia were strongly influenced by utilitarian attributes such as price. Fish made up the primary and cheapest form of animal-source protein for most people, however, poorer people preferred or were limited to purchasing smaller fish species, and specifically, smaller tilapia products.

The chapter argued that such distinct preferences of various social groups are not always considered in the commercial breeding and cultivation of fish and more effort should be made to service those at the bottom of the pyramid. Nutrition-sensitive agriculture advocates for introducing value chain interventions downstream of farming, such as improving market access by providing better sources of information on nutrient-rich foods and healthy diets, as well as introducing behavioural change campaigns to teach people about the nutritional benefits of eating smaller fish.

The thesis did not look at these types of interventions but rather at how producers could redesign their systems to target consumers at the bottom of the economic pyramid. In some ways this post-productivist approach loops back to productivism in arguing that changes need to be made in production efficiencies. Since aquaculture in Africa is still at a nascent stage, there is an opportunity to define production systems to fit the characteristics of the value chain and incorporate the views and preferences of consumers.

While the dominant paradigm and historical trends in aquaculture development in Asia centres on intensification (productivity enhancement), a redesign of food systems away from this as a priority is seen as critical, given the ecological, economic, social, and political transitions changing the food system landscape in Africa at a rapid rate (Pretty et al., 2018). Redesign in this sense is a social, institutional, and agricultural challenge that aims to make productive use of human, social and natural capital in ways that promote ecological sustainability and health outcomes alongside productivity (Ibid.).

The approach introduced in the second chapter of Part 2 of the thesis (i.e., Chapter 5) aimed to do exactly this. By increasing stocking densities and shortening production cycles, commercial producers could target small tilapia to poorer markets. Commercial tilapia farming in Africa often results in variation of different sizes of fish (Huang & Chiu, 2008). If sex-reversal hormones are not used, tilapia will breed in ponds meaning that fish of different sizes will be harvested. A lack of proper grading technologies and limitations in seed production mean that most cage farmers produce a small portion of undersized fish. Imported fish from Asia come in different sizes and many are sold lower than 200g average body weight, often targeting lower-income consumers (Genschick et al., 2017). Small tilapia will invariably be part of the aquaculture story in Africa for many years to come.

The trial in Chapter 5 showed how commercial farmers can look to purposively grow small tilapia or at least maintain a portion of their harvest as smaller-size grades. Some may argue that technically this is not a nutrition-sensitive approach, in that we were unable to track the nutrient benefits that small tilapia provided to different communities (Ruel et al., 2013). We also did not track exactly which parts of tilapia were consumed and by whom. A follow up study should look at edible portions and collect nutrient analyses of different tilapia sizes, including of the different parts of the fish that are consumed, and how cooking methods impact on nutrient content. This chapter also did not look at the environmental cost of increasing stocking densities and the impact this can have on local ecosystems. Regardless, we argue that the tilapia cage trial, in combination with the preceding chapter on consumer preferences, was a first step towards thinking about nutrition-sensitive production that aims to service the bottom of the pyramid.

Importantly, although the trial took place at a large-scale commercial farm, it was run in small-scale cages so that the results were applicable to the small-scale cage industry emerging in Kenya. While this thesis has stressed the marginalization of small-scale famers from commercial developments on the continent, this remains truer for pond farmers than it does for small-scale cage farmers. The establishment of large commercial cage farms and the expanding input industry has enabled smaller enterprises to grow. Many of these SME cage farmers still struggle to access high quality seed and feed, and there are a range of problems from licencing to zoning to adequate business and technical skills, etc. However, for now, the emergence of small-scale cage farming has the potential to commercialize along the rapid growth of some of the mega-farms.

The results of the trial, therefore, are especially pertinent to these small-scale cage farmers. The results suggest pond farmers might be able to do the same though this would need to be verified by independent studies with pond farmers. For now, the evidence in this trial suggests that alternative production methods such as shortening cycles and partial harvesting can allow for increased stocking densities and better cash flow management. Such solutions can be a good option for small-scale cage farmers in the region but also allow poorer consumers to access farmed fish.

Further value chain developments can, for example, look at improvements in transportation infrastructure and processing to increase the supply of small tilapia. Nutritional information in markets and shops but also subsidies for nutritious foods can further make value chains more nutrition-sensitive (Sharma et al., 2021). Other ways of scaling such production systems and making them more inclusive can be done through contract farming models or out-grower schemes where larger farms or hatcheries provide inputs and a guarantee on the sale of smaller fish (Kassam et al., 2011). Producer organisations can also form together and consolidate their produce to reduce costs for transport and marketing (Kaminski et al., 2020). Redesigning production systems need value chains to go through a process of adaptation, driven by a wide range of actors cooperating in new ways of value chain governance and building agricultural knowledge economies that promote sustainable, nutrition-sensitive approaches. Such transformations require greater food sovereignty in the value chain.

6.3 Food sovereignty as a vehicle to nutrition-sensitive aquaculture

Until now, this thesis has assessed the gaps between producing and consuming farmed fish and provided some solutions for small-scale and commercial systems in both cage and pond cultivation. While these solutions can be adopted by individual farmers there is a need to first convince farmers that growing bigger fish in monoculture systems may not always be beneficial. In some ways this requires a paradigm shift, and hence the need for agricultural transformation. Some of the solutions presented in the thesis will not be adopted by all farmers. For the solutions to be able to make some differences to smallholders and consumers, a concerted effort at transforming the value chain will be needed.

Agricultural transformations that aim to deliver adequate, healthy food for all people, requires the integration of production redesign, system-wide transitions in value chains and agricultural externalities into food prices or through consumer demand (Pretty et al., 2018). Such food system transformations require cooperation and the ability to adapt agroecosystems as well as grow the confidence of value chain actors to innovate (Ibid.). There is an opportunity in bourgeoning aquaculture value chains in Africa to create new knowledge and skills that promote these transformations through greater cooperation, as compared to more mainstream food commodity value chains where there are greater dependencies, exploitation, and control by large agri-food regimes

(Agarwal, 2014). The capacities of farmers and communities to drive these transitions can be supported by developing new forms of collective social learning and knowledge economies around food production (Pretty et al., 2018).

This thesis aimed to introduce interventions that are adaptable to local contexts, and which respond to the needs and nutritional requirements of poorer people. However, for these technologies (i.e., polyculture systems and targeted small fish growth) to be more established, the institutions and social structure within food systems need to adapt too. New knowledge economies suggest that extension systems, development agencies, farmers and consumers co-create information loops that emphasise the need for technological advancement and behavioural change (Ibid.). This means, in the context of the thesis for example, that government extension agents promote intermittent harvesting and polycultures, while small-scale cage famers see the opportunity to grow and sell smaller fish in lower-income markets. Indeed, even large-scale farms such as Victory Farms Ltd in Kenya see the opportunity for growing and selling small fish to different market segments, hence their interest in running the trial in Chapter 5 on their farm.

This thesis argues that knowledge economies need to move beyond productivism and adopt sustainable intensification of food systems including technologies and practices that are nutrition sensitive. The goal here, is for smallholders and consumers to have greater control and less dependency on capital-intensive inputs, and where greater attention is paid to the social and environmental context of food production and consumption (Cadieux & Slocum, 2015).

There are examples of such cooperation in agriculture food systems. In Cuba, the Campesino-a-Campesino movement integrated agroecology into the redesign of production systems, making use of cooperatives and steadily moving away from pesticides whilst increasing agricultural yields (Rosset et al., 2011). In Western Africa, innovation platforms with farmers and scientists increased yields in maize and cassava and resulted in greater returns for women (Jatoe et al., 2015). In Bangladesh, farmer field schools developed early maturing rice varieties through research trials (Malabayabas et al., 2014). Many of these approaches are rooted in the concept of food sovereignty.

At its heart, food sovereignty is about "food justice", which aims to transform food systems by eliminating disparities and inequalities (Gottlieb & Joshi, 2010). Food sovereignty is both a political movement that aims to overcome dominant agri-food regimes, as well as a rhetorical device used to describe systems where the rights of people to healthy and culturally appropriate foods are produced through ecologically sound and sustainable methods, and where people have the right to define their own food system (Alonso-Fradejas et al., 2015).

There are calls for food sovereignty to be more widely adopted in aquaculture and fisheries (Gephart et al. 2020; Allegretti & Hicks, 2022). In the case of smallholder tilapia systems in sub-Saharan Africa, the case for food sovereignty could not be stronger. Most aspiring smallholder fish farmers have little choice but to try grow tilapia fingerlings supplied by government hatcheries or NGOs. Most farmers' introduction to tilapia farming is through extension officers using production manuals drawn up in Asia. Few farmers have access to private hatcheries, and even if they did, fingerling prices are too high (Moyo & Rapatsa, 2021). Feed suppliers are often out of reach, many require bulk orders, or farmers simply do not have the cash flow to feed and grow tilapia to marketable size (Mwema et al., 2021). Very few small-scale farmers use formulated feeds as they haphazardly feed fish with surplus produce or biowaste from their farms. In most cases fish receive little to no feed, relying simply on the natural foods produced in the pond. Small-scale cage famers search for alternative feeds as they struggle to remain profitable. Even when well-intentioned development programs subsidize inputs such as seed, fish still do not grow, owing partly to the poor genetic quality of seed stocks in under-funded public hatcheries, or poorly designed ponds that are too shallow, overstocked/understocked with fish, or vulnerable to predators and thieves. The haphazard subsidisation of inputs further leads to problematic dependencies on development agencies, which holds the small-scale sector back (Harrison, 1996).

The rate of pond abandonment among smallholders is high, as farmers attempt to grow tilapia, generally under the auspices of donor-led interventions, and then either give up for the above reasons, or operate ponds that are more akin to backyard vegetable gardens. The latter strategy can be quite effective, though the efficiency and level of integration of these systems in Africa are far from optimal. Most farmers are taught to establish monoculture tilapia farms whereby additional fish species in the system are to be eliminated. Farmers are taught that tilapia should be stocked at specific stocking densities and grown unabatedly for six or more months. Intermittent or partial harvesting of fish throughout the growth cycle is frowned upon. Most development agencies and government officials implement gender-blind programmes that tend to work with male household-heads while ignoring the important role women play in fish farming (Kruijssen et al., 2018). Much of the land, or lake concessions, designated for fish farming is decided upon by traditional authorities and older men, leaving few choices for young, aspiring farmers (Kakwasha et al., 2020). In many places such as Malawi or Zambia, species-use restrictions mean that farmers are limited to using indigenous species while farmers in other parts of the country are using exotic, fast-growing species. In many ways, pursuing tilapia farming as a livelihood and/or business activity in the region is restrictive, exclusive, and difficult to implement in a way that extracts maximum benefits (profit or direct nutrients).

It is precisely why food sovereignty should appeal to many smallholder farmers because they already produce tilapia, and other fish, mostly the way they want to and in a way that fits their local livelihood context. The concept should appeal to larger commercial farms too, as it promotes domestic production, localised markets, health policies, and improved input supply as well as targeting the bottom-of-the-economic-pyramid, which often makes up the largest profit pool in African societies.

Food sovereignty is mainly about improving choices, including on how foods are produced and consumed rather than these choices being made by large corporations, market institutions, development agencies, and governments (Levkoe et al., 2019). Food sovereignty segues with concepts such as nutrition-sensitive agriculture, both which seek to develop food systems that maximise the contribution of food production to human nutrition and health outcomes, especially those derived from equitable access to diverse, nutrient-rich foods (Uccello et al. 2017). In places such as Zambia and Kenya, where food insecurity and malnutrition are rife, pursuing such outcomes are critical. Food sovereignty thus values the social significance of food production and its importance to people's livelihoods and their right to food and nutrition security, and which encourages people to decide how to produce and procure culturally acceptable, safe foods that meet their preferences and capabilities, without compromising their ecosystems or livelihoods (Levkoe et al. 2019). There is an ecological aspect to food sovereignty in that developing food systems should be done with low external input and agroecological methods that maximise ecosystem services and improves resilience (Ibid.). Food sovereignty rejects methods that harm ecosystem functions, and which depend on energy-intensive monocultures. How cage culture vs pond culture fit into these constraints remains to be determined, and not the focus of this thesis, however, the ecological argument under such auspices is stronger for pond rather than cage farming.

Food sovereignty promotes localised food systems where providers and consumers are at the centre of decision-making and where knowledge and skills are developed to fit local socio-economic contexts (Akram-Lodhi, 2015). For this reason, the integrated agriculture-aquaculture systems, polyculture systems, and targeted small fish growth approaches promoted in this thesis give rise to opportunities for small and large producers as well as for consumers across the wealth and urban/rural divide.

Food sovereignty and nutrition-sensitive approaches to farming systems merge in some ways with sustainable intensification, though, food sovereignty focuses more on the political framework under how intensification can be implemented. In some cases, extensification qualifies as sustainable intensification, as there are incentives to maintain low-intensity, ecological production systems that provide communities with highly nutritious fish, instead of trying to compete with large companies for urban markets (Belton & Little, 2011). Harvesting smaller fish rather than maximising fish weight may also be seen as a reductive approach to farming. However, agroecological practices should harness, maintain, and enhance biological and ecological processes in agricultural production, to reduce the use of purchased inputs and agrochemicals and to create more diverse, resilient, nutritious, and productive agroecosystems (HLPE, 2019). Lowering FCRs and fish size or growing multiple different fish in a system at the same time achieves, at least, some of these objectives. Other tools advocated by food sovereignty approaches are diversification; mixed cultivation; intercropping (e.g. rice field fisheries); cultivar mixtures; habitat management techniques for crop-associated biodiversity; biological pest control; improvement of soil structure and health; biological nitrogen fixation; and recycling of nutrients, energy and waste (Ibid.). The solutions implemented in this thesis touch on some of these approaches with the added goal of maximising nutrient potential for human societies.

This thesis has provided a window into the world of smallholder farmers and a broad range of fish consumers in Zambia and Kenya, respectively. The findings in the thesis, although not directly comparable to other countries in Southern or Eastern Africa, are indicative of challenges and opportunities faced by smallholder aquaculture farmers and consumers in the region. The thesis was able to show how important aquaculture can be to smallholder homesteads in rural areas, especially when farmers operate ponds that are integrated with other horticulture activities. The freedom of choice beyond the stocking of single-species was beneficial for farmers as they were able to grow and consume various fish that were dense in micronutrients and fatty acids. The thesis showed how poorer consumers in urban and rural areas prefer smaller tilapia on the market, though this demand is not being met because of a focus on producing larger, table-size fish. Redesigning systems away from strict protocols that dictate stocking densities, growing periods and size of fish may be beneficial for small-scale operators and/or even larger commercial players in actively targeting small fish to lower-income areas.

Though not the main focus of this thesis, there are a myriad of different approaches that could move smallholders and consumers towards food sovereignty. Although this thesis focused primarily on production techniques and technologies, other approaches could be introduced such as farmer field schools, innovation platforms or other value chain interventions that promote cooperation, collective action and new knowledge economies. This thesis ends with a useful table that reveals the alternative production approaches that complement the ones introduced in this thesis. Such approaches to small-scale tilapia production are not necessarily new, yet they are rarely evident in smallholder systems in Africa. Many of these alternative production approaches can be mixed or matched and do not need to occur in isolation, but it certainly points to the need for more research on how to sustainably intensify (or extensify) local production systems.

Table 6.1. *Summary of alternative production systems that are more applicable to small-scale farming characteristics and help achieve food sovereignty*

Alternative production system	Description	How the system complements smallholder farming characteristics and leads to greater food sovereignty
Natural Feed-based Regimes	Using natural, locally produced foods and fertilisers that promote phytoplankton-based growth) and/or using natural waste from the farm	• Uses the availability of on-farm resources or closely available natural products that already exist in the area • More adaptable to local livelihood context • No necessity for formulated feeds and feed mills • More ecosystem friendly • Lower input costs
Integrated aquaculture and agriculture	Establishing systems that promote the integration of aquatic and terrestrial farming activities (e.g., growing tomatoes on pond dykes) and allowing farmers to better manage their time and labour for producing many different foods	• Mixing different livelihoods already managed by farmers (or introducing new diverse, nutrient-rich foods). • More beneficial for division of labour in household • More efficient water-use and farm management • More adaptable to local livelihood context • Managing labour and time better • Increased production and dietary diversity for food and nutrition security
Polyculture systems and multi-trophic aquaculture	Mixed fish systems to improve yields and sustainability, producing self-recruiting, nutrient-rich fish - includes carnivorous species that control recruitment of fast breeding species, or the use of different aquatic organisms to reduce waste, provide ecosystem services, and improve efficiency	• Producing more diverse fish that people prefer • Overcomes restrictiveness of monoculture systems by relying on different fish species • Promotes intermittent harvesting of non-commercial species • Overcomes lack of seed issue if species are self-recruiting (though more commercial polyculture systems can exacerbate seed issues) • Gives farmer a diversity of products and choices • Promotes better health outcomes as smaller, nutrient-rich fish can be stocked and consumed

Mixed-sex tilapia systems	Stocking mixed-sex fingerlings and allowing them to breed. Whilst this is already largely practiced, better management of such systems is needed	• Can intermittently harvest throughout cycle • Can use already existing, localized seed networks • No need for sex-reversible hormones • Producing larger biomass of fish of different market sizes • Support autonomy of juvenile supply - no requirement for constant re-stocking of seed
Targeted small tilapia production	Purposively growing tilapia to a smaller size that fits current market and consumer demand. Fish are grown for shorter periods under increased stocking densities	• Applicable for ponds and cage farming • Targeting fish products that are generally affordable by low-to-middle-income consumers • Growing fish for shorter more manageable cycles (can be adopted by larger commercial farms too) • More cash flow and lower FCR • Tapping into local, rural markets • Lower risk in terms of natural catastrophe such as floods and drought
Household and gender transformative approaches to farming systems	Establishing equitable and complementary roles for household members involved in fish farming, especially those that aim to challenge the inequalities faced by women	• Adapting already existing gendered division of labour to establish better aquaculture management regimes • Better use of time and labour • Makes participation in aquaculture more equitable and inclusive • Improves household-decision making, responsibility-sharing and overall productivity
Decentralised hatchery operators	Rural farmers actively breed fish to produce fingerlings for sale in simple hapa-based or pond-based systems, for direct sale in localised communities, i.e., farmers produce their own seed	• Farmers already engage in complex seed networks in rural areas • Allows farmers to order and purchase seed when their season begins • Gives farmers another income source • Overcomes issue of seed supply and reliance on government hatcheries • Can ensure better quality fingerlings that are less stressed • Localised production systems that service rural communities
Client-responsive breeding programmes	Traits and preferences differentiated by clients of breeding programs, including especially women and poor communities	• Breeding programs that have been gender-blind have proved costly failures • Breeding programs that explicitly address preferences of women (and men) may be more effective in meeting client needs and overcoming the gender gap in adoption

6.4 Conclusion

The thesis does not attempt to paint the current productivist paradigm as inefficient. On the contrary, in places such as Egypt, or around some of Africa's Great Lakes, the status quo production paradigm has been remarkably successful in growing yields and creating jobs. In Egypt, the growth of tilapia in ponds has had positive effects, improving the accessibility and consumption of fish across the country. Increasing the production and yields of fish can have positive aspects for many households and consumers. In Bangladesh, export-driven shrimp and prawn farming in coastal communities generated broad social benefits by allowing worse-off households to achieve higher productivity of farmed aquatic animals, increasing vegetable production, increasing fish consumption, and improving recommended nutrient intake (Mamun et al., 2021).

This thesis aims to highlight the dangers of rapidly commercialising value chains and the effects this may have on smallholders and consumers if they are not included in value chain developments. The commercialisation of aquaculture in sub-Saharan Africa should be supported and smallholders that can manage to operate commercial, monoculture tilapia systems should be encouraged to do so. However, the touting of aquaculture as a poverty alleviation and food security tool by governments, researchers, and development agencies alike, needs to be tempered, as the current productivist paradigm is setting up smallholders for failure, the fault of which lies beyond just the lack of feed and seed. With few choices and limited participation, smallholders are simply unable to produce tilapia at textbook standards that result in attractive returns on invested resources (i.e., cash, labour, etc.). Instead, using a food sovereignty approach that advocates for localised community and farmer needs, as well as low-income consumer demands, we can challenge the current productivist paradigm by widening the scope and objectives of aquaculture to include more nuanced food and livelihood systems that aim to be nutrition sensitive. Social and nutrition outcomes become as important as production outcomes. By so doing we can devise different approaches to aquaculture production that are more adoptable for smallholder farmers and accessible for poorer consumers. Approaches such as the ones introduced in this thesis, can be used beyond tilapia aquaculture and applied to coastal aquaculture or catfish farming, for example. Broadening the vision of aquaculture in society beyond just the scope of production will allow for more equitable, sustainable, and inclusive aquaculture on the continent.

Future studies of aquaculture in sub-Saharan Africa should look to use control groups of farmers who do not adopt aquaculture, since aquaculture is rarely the mainstay of rural agricultural households in the region. This allows for more accurate measurements of the benefits of adopting aquaculture. Studies should refrain from looking at the aquaculture system in isolation without looking at other agricultural and livelihood activities conducted by farming or fishing households. More research should be done to investigate ways in which aquaculture can integrate with other agricultural activities. Researchers and practitioners should look to improve methods of measuring productivity in ponds by moving away from recall methods and, for example, using food consumption and dietary instruments as indicators of pond production and/or the rewards extracted from aquaculture. The preferences and views of consumers at the end of the value chain are vital to the development of aquaculture on the continent. Dietary and nutritional outcomes are critical objectives in Africa, and aquaculture will play a major role in realising these outcomes.

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Annexes

Annex 1: Survey instruments used in Chapter 2

This draft baseline has been developed after review of the project proposal and log frame. The questionnaire should be 60-70 min long, and requires only 1 enumerator to administer. An attempt has been made to develop a questionnaire that will allow us to assess the stated impacts:

- Increased availability of small-fish production through the integration of small-indigenous fish species (SIS) in small-scale aquaculture
- Increased household access (direct and indirect) to small-fish species through SIS in aquaculture for home consumption and retail
- Improved consumption of micronutrient-rich small fish at household level, and identification of barriers towards the consumption of small-fish among young children.
- Increased production of vegetables, in particular vitamin A-rich orange sweet potatoes (OSP)
- Increased consumption of OSP among households.

To address and improve gender equity and women's empowerment, especially regarding intra-household food intake, agricultural practices and work load, the survey will collect sex-disaggregated data where possible to identify access points for future interventions.

Participant selection: The survey is to be administered in households engaged in aquaculture and / or agriculture production (see sampling) and to (a) household member(s), who is considered to be 1) the main food preparer in the household and 2) a household member who is considered being chiefly responsible for agriculture, fisheries, and aquaculture activities. It is possible that one or more household members need to be interviewed. The household members to be interviewed shall be of a minimum age of 15 years and older. In the case of more than one eligible respondent for food preparation or agriculture, fisheries, and aquaculture chose randomly one person out of all eligible person.

Begin with introducing yourself and giving the participant a copy of the survey information sheet. DO NOT BEGIN THE QUESTIONNAIRE UNTIL THE PERSON(s) HAS / HAVE GIVEN HER / HIS CONSENT TO PARTICIPATE IN THE SURVEY. IF ONE OF THE PERSONS DOES NOT WANT TO PARTICIPATE THANK HER / HIM FOR HER / HIS TIME AND MOVE TO THE NEXT ELIGIBLE HOUSEHOLD.

Has the consent form been signed?	1= Yes, proceed to survey 2= No, do not proceed with survey	☐ No ☐ Yes

A. Identification of key respondents / participants

Q No	Household member	Name	Sex	Age (yy)	Relation to household head (select one)
A1	Household head:		☐ F ☐ M		
A2	Main food preparer:		☐ F ☐ M		☐ Household head ☐ Wife / husband ☐ Daughter / son ☐ Mother / father ☐ Grandchild ☐ Cousin ☐ Other (please specify) ________
A3	Responsible person for agriculture / fisheries / aquaculture:		☐ F ☐ M		☐ Household head ☐ Wife / husband ☐ Daughter / son ☐ Mother / father ☐ Grandchild ☐ Cousin ☐ Other (please specify) ________

>> If main food preparer & responsible person for agriculture / fishery / aquaculture are available and give consent to participate in the study, please proceed with the interview.

B. Interview ID

Q No	Question	Response / code
B1	Name of enumerator:	
B2	Farm ID:	
B3	Date of survey *(dd.mm.yyyy)*	

B. Household / farm location

Q No	Question	Response / code
C1	District:	
C2	Ward	
C3	Village	
C4	Phone number of household head:	

C5	GPS coordinates:	Lat: Long:

D. Household characteristics

Q No	Question	Response / code
D1	Household size: *(no. of people)* *"Household" refers to those who live under the same roof and share meals together"*	
D2	Highest education obtained by HH head: *(select one)*	☐ Declined to answer ☐ No formal education ☐ Some primary ☐ Primary completed ☐ Some secondary ☐ Secondary completed ☐ Post-secondary
D3a	Are there any children (*aged <= 18 years*) who live with you in your house?	☐ No >>*D4* ☐ Yes
D3b	What are the ages and gender of the children (aged <=18 years) who live with you in the household?	
	Child 1	☐ female ☐ male Age: _____
	Child 2	☐ female ☐ male Age: _____
	Child 3	☐ female ☐ male

		Age: _____	
	Child 4	☐ female ☐ male Age: _____	
	Child 5	☐ female ☐ male Age: _____	
	[“Add Field” to list more children]		
D4	Size of farm / land in total *(includes residential land and the land you and your household members cultivated)*	**Number**:	**Unit**: ☐ ha ☐ lima ☐ acre ☐ meter squared
D5	In what income generating activities were you and your household involved during the last 12 months? *(select multiple if applies)*	☐ Crop production (maize, cassava, etc.) ☐ Vegetable production ☐ Bean and legume production ☐ Groundnut production ☐ Fisheries ☐ Aquaculture ☐ Small business ☐ Teaching (teacher) ☐ GOV worker ☐ Hired labor – permanent ☐ Hired labor – seasonal ☐ Mechanic ☐ Other (please specify) ____________	
D6	Total disposable money available (or income generated) within the household during the last 12 months: (*in ZMW*)		
D7	Main income source of the household	☐ Crop production (maize, cassava, etc.) ☐ Vegetable production ☐ Bean and legume production	

	during the last 12 months: *(select one)*	☐ Groundnut production ☐ Fisheries ☐ Aquaculture ☐ Small business / Self-employed ☐ Teaching (teacher) ☐ GOV worker ☐ Hired labor – permanent ☐ Hired labor – seasonal ☐ Mechanic ☐ Other (please specify) ______
D8	Total income generated during the last 12 months from your household's **main** income source: *(in ZMW)*	
Q No	**Question**	**Response / code**
E1	Highest education obtained by the person responsible for agriculture production(s) *(select one)*	☐ Declined to answer ☐ No formal education ☐ Some primary ☐ Primary completed ☐ Some secondary ☐ Secondary completed ☐ Post-secondary
E2a	Was your household involved in agriculture (crops, vegetables, etc.) production during the last 12 months?	☐ No >> *QF1* ☐ Yes
E2b	What crops and vegetables did you or any of your household members grow during the last 12 months?	☐ Maize ☐ Cassava ☐ Beans ☐ Groundnuts ☐ Potatoes ☐ Sweet potatoes (yellow & white) ☐ Orange sweet potatoes (OSP) >> *QE1b1* ☐ Rice

	(select all that apply)	☐ Rape ☐ Spinach ☐ Cabbage ☐ Chinese cabbage ☐ Okra ☐ Tomatoes ☐ Onions ☐ Pumpkin or squash ☐ Other (please specify)	
E2b1	How much orange sweet potato did you grow (produce) during the last production cycle in total:	**Number**:	**Unit:** ☐ Pieces ☐ Kg ☐ Bag(s) (50kg) ☐ Bucket(s) ☐ Other (please specify)
E2b2	Where did you grow orange sweet potatoes during the last production cycle? *(select all that apply)*	☐ Homestead garden ☐ Field ☐ Pond dyke ☐ Other (please specify)	
E2b3	During which months do you grow OSP? *(Please indicate the month from planting seeds/ vines until harvest)*	☐ January ☐ February ☐ March ☐ April ☐ May ☐ June ☐ July ☐ August ☐ September ☐ October ☐ November ☐ December	
E2b4	From where did you source your orange sweet potato seeds / vines for the last or ongoing agricultural season?	☐ Supplied through NGO ☐ Obtained from fellow farmers ☐ Self-produced ☐ Government's / ministry's input support program ☐ Other (please specify)	

E2b5	How do you and your household members utilize the OSP that you produce? *(select all that apply and indicate the percentage of OSP used for each purpose)*	☐ Retail (if yes >> QE2b5a) %: ________________ ☐ Home consumption %:________________ ☐ Barter %:________________ ☐ Other (please specify) ________________________ %:________________	
E2b5a	Average price (in ZMW) when selling orange sweet potatoes:	**ZMW**:	**Unit:** ☐ Per piece ☐ Per kg ☐ Per bag(s) (50kg) ☐ Per bucket(s) ☐ Other (please specify) ________________
E3	Are other household members involved in the production of OSP? If so, who is involved in the following activities other than you?	☐ No >> *QF* ☐ Yes	
E3a	Obtaining OSP seeds / vines:	☐ No one ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)	
E3b	Preparation of field / garden / etc.:	☐ No ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)	
E3c	Field care / maintenance (weeding, etc.):	☐ Nobody than me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)	

E3d	Harvest for household consumption:	☐ Nobody than me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
E3e	Harvest for barter:	☐ Nobody than me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
E3f	Harvest for retail:	☐ Nobody than me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
E3g	Food preparation:	☐ Nobody than me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)

E. Agricultural production

>> This tool needs to be administered to the person identified in section A as primary responsible person within the household for agriculture production<<

F. Fisheries

Q No	Question	Response / code
F1	Is your household / are any of your household members involved in capture fisheries?	☐ No >> *QG1* ☐ Yes
F2	How often do you or / and your household members go fishing per week? *(select the no of days)*	☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7
F3	What are the top 5 most frequently caught species during the past year: *(select top 5)*	☐ Bomba ☐ Bream ☐ Bwelele ☐ Cifinsa ☐ Cingongongo/Cinyimba ☐ Imbilya ☐ Imintesa / Mintesa ☐ Imanda or Tiger Fish

		☐ Imfindu ☐ Inyenda ☐ Itala ☐ Inkundu / Cikundu ☐ Matuku / Amatuku ☐ Mbubu ☐ Milonge ☐ Misenga, Matemba ☐ Mishipa / Mushipa / Umumbulwe ☐ Mpende ☐ Mulembetesa ☐ Muliba ☐ Nembwe ☐ Nkamba ☐ Nsuku ☐ Polwe ☐ Sampa, Vundu ☐ Uluya ☐ Other (please specify) ________________________
F4	How did you utilize the fish you and your household members caught during the past year? *(select all that apply and indicate the percentage of fish used for each purpose)*	☐ Retail %: ________________ ☐ Home consumption %:________________ ☐ Barter %:________________ ☐ Other (please specify) ________________________ %:________________
F5	Who in your household is the primary decision maker regarding the utilization (sale, home consumption, barter, etc.) of fish you catch?	☐ Household head (m) ☐ Household head (w) ☐ Both, household head and partner ☐ Son of household head ☐ Daughter of household head ☐ Other (please specify) ________________________
F6	Are other household members involved in fisheries and fish processing at household level? If so, who is involved in the following activities other than you?	☐ No >> *QG1* ☐ Yes

F6a	Collection of bait, preparation and setting of fishing gear:	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
F6b	Checking nets and fishing:	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
F6c	Fish cleaning:	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
F6d	Fish processing (sun-drying, smoking, etc.):	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
F6e	Retail of fresh and processed fish:	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)

G. Aquaculture

>> This tool needs to be administered to the person identified in section A as primary responsible person within the household for aquaculture production<<

Q No	**Question**	**Response / code**
G1	Was your household involved in aquaculture production during the last 12 months until today?	☐ No *>>QH1a* ☐ Yes
G2	Highest education obtained by the person responsible for aquaculture production(s) *(select one)*	☐ Declined to answer ☐ No formal education ☐ Some primary ☐ Primary completed ☐ Some secondary ☐ Secondary completed ☐ Post-secondary
G3	When did your household start practicing aquaculture? *(yyyy)*	

G4	Total number of aquaculture ponds 'operated' by the household: *(No of ponds)*		
G5a	Do you have to pay lease for any of the ponds you use for aquaculture?	☐ No >> *QG6a* ☐ Yes	
G5b	How many ponds are under lease? *(No of ponds)*		
G5c	Lease rate per pond per month: *(in ZMW)*	**ZMW:**	**Unit:** ☐ per month ☐ per season ☐ per year ☐ Other (please specify) ________
G6a	Are currently any ponds not stocked?	☐ No >> QG7 ☐ Yes	
G6b	How many of your ponds are not stocked? *(give no of ponds not stocked)*		
G6c	What is / are the reason(s) for not-stocking: *(select multiple if applies)*	☐ No cash to purchase fingerlings ☐ Lack of transportation to collect fingerlings from hatchery or fellow farmers ☐ Waiting for fingerlings to be available at government hatchery ☐ Waiting for fingerlings from fellow farmers ☐ Waiting for fingerlings from breeder farmers, order is placed ☐ I source fingerlings from the wild, but during this time of the year, availability is low ☐ Pond(s) need(s) reparation work ☐ High seepage in pond(s) ☐ No / not enough water available ☐ Lack of feed and / or fertilizer ☐ Don't know where to source fingerlings from ☐ Other (please specify) ________	

G7	Are other household members involved in your household's aquaculture production besides you? If so, who is involved in the following activities other than you?	☐ No >> *QG* ☐ Yes
G7a	Fingerling recruitment and acquisition:	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
G7b	Pond maintenance	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
G7c	Collection / obtaining of feed and fertilizer	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
G7d	Feeding and fertilizing	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
G7e	Intermittent harvest	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
G7f	Final harvest	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)
G7g	Retail of fish	☐ Nobody but me ☐ Son ☐ Daughter ☐ Wife / husband ☐ Other (please specify)

G8. For the ponds that are currently stocked:

Pond No	**Water surface area** (length / width in meters)	**Water level (depth)** (cm)	**Species stocked** (1) Tilapia rendalli (Mpende) (2) Oreochromis macrochir (Nkamba) (3) Oreochromis niloticus (Nile tilapia) (4) Tilapia sparrmanii (Matuku) (5) Other (specify)	**No of fingerlings stocked per species** (total amount by species)	**Source of fingerling by species** (1) from the wild (2) Misamfu (3) Fellow farmers (4) Breeder Farmer (WorldFish) (5) other (specify)	**Price per fingerling** (ZMW)	**Stocking date** (month)	**Expected harvest date** (month)	**Primary water source (select one)** (1) river / stream (2) spring / well (3) underground water (4) damboo (5) other (specify)	**Water availability (in respect to primary water source) (select one)** (1) seasonal (2) permanent (all year round)	**Feed type (select all that apply)** (1) organic fertilizer (2)chemical fertilizer (3) commercial feed (pellets) (4) self-made feeds (5) insects (6) household waste (6) Other	**If commercial feeds are used, what brand is used?** (1) Tiger Feeds (2) Savanna Feeds (3) Novatek Feeds (4) National Millings Feeds (5) Other (specify)
1	Length: Width:		1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:					
2	Length: Width:		1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:					
3	Length: Width:		1: 2:	1: 2:	1: 2:	1: 2:	1: 2:					

G9. Regarding your previous harvest(s) (*recall the information by pond*)

Pond No	**Species purposely stocked** (1) Tilapia rendalli (Mpende) (2) Oreochromis macrochir (Nkamba) (3) Oreochromis niloticus (Nile tilapia) (4) Other (specify)	**No of fingerlings stocked per species** (total amount by species)	**Source of fingerling by species** (1) from the wild (2) Misamfu (3) Fellow farmers (4) Breeder Farmer (World Fish) (5) other	**Price per fingerling per species** (ZMW; '0' if sourced from the wild)	**Stocking date per species** (month)	**Date of final harvest** (month)	**Feed type (select what applies)** (1) organic fertilizer (2) chemical fertilizer (3) commercial feed (pellets) (4) self-made feeds (5) insects (6) household waste (6) Other	**Total amount of feed / fertilizer used by product type** (in kg) (if not applicable: indicate with "NA")	**Total costs for selected feeds / fertilizer per kg by product type used** (ZMW) (if not applicable: indicate with "NA")	**Number of fish (per species) harvested at the end of the rearing period?**	**Average size fish at harvest by species** (1) < 10 cm (2) >10 cm (3) >15 cm (4) > 20 cm	**No of fish sold at final harvest (by species)** Units: Piece (1) Bundle (2) Bag (3) Bucket (4) Other (5) (specify)	**Average price of fish sold at final harvest** (ZMW) Units: Piece (1) Bundle (2) Bag (3) Bucket (4) Other (5) (specify)	**No of fish used / consumed within the household by species at final harvest** Units: Piece (1) Bundle (2) Bag (3) Bucket (4) Other (5) (specify)	**No of fish used for barter by species at final harvest** Units: Piece (1) Bundle (2) Bag (3) Bucket (4) Other (5) (specify)
1	1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:			1: 2: 3: Etc.:		1: 2: 3:		1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:
2	1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:			1: 2: 3:		1: 2: 3:		1: 2: 3:	1: 2: 3:	1: 2: 3:	1: 2: 3:

Q No	Question	Response / code
G10	Besides the fish you've purposely stocked in your ponds, what other fish species did you find in your pond at harvest? *(select all that apply)*	☐ Bomba ☐ Bwelele ☐ Cifinsa ☐ Cingongongo/Cinyimba ☐ Imbilya ☐ Imintesa / Mintesa ☐ Imfindu ☐ Inyenda ☐ Itala ☐ Inkundu / Cikundu ☐ Matuku / Amatuku ☐ Mbubu ☐ Milonge ☐ Misenga, Matemba ☐ Mishipa / Mushipa / Umumbulwe ☐ Mpende ☐ Mulembetesa ☐ Muliba ☐ Nembwe ☐ Nkamba ☐ Nsuku ☐ Polwe ☐ Other (please specify) ______________
G11	What do you do with the 'by-catch' in your pond? *(select all that apply and indicate the percentage of intermittently harvested fish used for each purpose)*	☐ Sale %: ______________ ☐ Home consumption %: ______________ ☐ Barter %: ______________ ☐ Remove from the pond and discard %: ______________ ☐ Remove from pond and release into open water %: ______________ ☐ Other (please specify) ______________________ %: ______________
G12	Did you intermittently harvest during the rearing period from any of your ponds during the last 12 months?	☐ No >> End survey ☐ Yes

G12a	For what purpose did you intermittently harvest fish? *(select all that apply and indicate the percentage of intermittently harvested fish used for each purpose)*	☐ Retail %: _______________ ☐ Home consumption %:_______________ ☐ Barter %:_______________ ☐ Other (please specify) _______________________ %:_______________

Thank the participant(s) for his / her / their time. Ask if they have any questions before leaving the house.

Household Food Consumption and Sourcing Survey

Respondent must be the main food preparer of the household

Section A: Household Identification

Question No.	Household Identification Question	Response/Code
A1	Name of respondent	_______
A2	Gender	☐ Male ☐ Female
A3	Age	_______
A4	Are you responsible for most of the food preparation in this home?	☐ No >>*end survey* ☐ Yes

Section B: 24-Hr Household Dietary Recall to provide information about household food consumption in the previous 24 hours and to calculate HDDS

Interviewer: I would like to ask you about the types of foods that you or anyone else in your household ate yesterday. "Household" refers to those who live under the same roof and share meals together.		
Question No.	**Dietary Recall Question**	**Response/Code**
B1	Was yesterday a celebration or occasion where your household ate special foods or ate more/less than usual?	☐ Yes *(conduct recall another day or survey another household)* ☐ No

B2: Please describe all foods and drinks that were consumed by any member of your household yesterday. Include foods prepared in the home *and* consumed in the home and food prepared in the home for consumption outside of the home. Do *not* include foods that were both prepared *and* consumed outside the home.
Start with the first food/drink consumed yesterday morning and list everything that was eaten or drank during the day or night.

Notes: When composite dishes are mentioned, ask for a list of ingredients.
When fish is mentioned, ask about which fish species.
After the respondent finishes, probe about meals not mentioned or snacks between meals.
Ask "Was anything added to this?" (e.g. sugar in coffee or tea).

	Foods	**Total Amount Consumed** (*only when* ***fish*** *or* ***orange sweet potato*** *are listed*)
Breakfast		
Snack		
Lunch		
Snack		
Dinner		
Snack *"Anything else to eat/drink after dinner and before bed?"*		

Review the previous day's consumption (each meal and snack) with the respondent and ask if any food or drinks are missing from the recall.
B3: *Based on the recall above, fill in the following table by selecting "0 (No)" or "1 (Yes)" for food groups consumed by the household in the previous day. Continue excluding foods that were prepared and eaten outside of the home.*

Yesterday, did you or anyone in your household eat…	**0 = No**	**1 = Yes**
A. Any nshima, bread, or other food made from millet/maize/rice/?	0	1
B. Any potatoes, yams, cassava, or any other foods made from roots or tubers?	0	1
C. Any vegetables? (different from those listed in Item B)	0	1
D. Any fruits?	0	1
E. Any beef, pork, poultry, bush meat, other flesh meats or organ meats?	0	1
F. Any eggs?	0	1
G. Any fresh fish, dried fish, or seafood?	0	1

H. Any beans, lentils, nuts, or products of these foods?	0 1
I. Any cheese, yogurt, milk, or other milk products?	0 1
J. Any foods made with oil, fat, or butter?	0 1
K. Any sugar or honey?	0 1
L. Any other foods (condiments, beverages)?	0 1
Data entry: Total Score (0-12)	

Question No.	Dietary Recall Question	Response/Code
B4a	Did you or any household member eat or drink anything yesterday that was both obtained *and* consumed outside of the home?	☐ No >> *QC1* ☐ Yes
B4b	The food/drink obtained and consumed outside of the home was:	____________

Section C: Food Sourcing and Variation in Household Consumption to assess production and availability of SIS and OSP for consumption

Interviewer: Now I will ask about household sourcing and consumption of a few specific foods.		
Question No.	**Food Sourcing & Variation Question**	**Response/Code**
C1	In the past 6 months, how frequently did your household obtain *large* fish species to eat from the following sources?	
C1a	Self-caught (e.g. rivers, lakes, streams)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C1b	Obtained from a vendor (includes mobile vendors, shops at market)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C1c	Own production (personal fish farming)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C1d	Other source	Source: ________ ☐ Never

		☐ Rarely ☐ Sometimes ☐ Often
C2	In the past 6 months, how frequently did your household obtain *small* fish species to eat from the following sources?	
C2a	Self-caught (e.g. rivers, lakes, streams)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C2b	Obtained from a vendor (includes mobile vendors, shops at market)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C2c	Own production (personal fish farming)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C2d	Other source	Source: ________ ☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C3a	Are there any household members who do not eat any small fish (species)?	☐ No >> *QC4* ☐ Yes
C3b	Who does not eat any small fish and why?	__________
C4	In the past year, which months did your household experience low or no availability of small fish species? *Select all that apply.*	☐ None, we never experience this ☐ Jan ☐ Feb ☐ Mar ☐ Apr ☐ May ☐ Jun ☐ Jul ☐ Aug ☐ Sep ☐ Oct ☐ Nov ☐ Dec
C5	In the past 6 months, did your household consume orange sweet potato?	☐ No >> *QC6* ☐ Yes >>*QC7*
C6	Where can you get orange sweet potato if you wanted to eat it?	☐ I don’t know ☐ Source: _____ >> *QD1*
C7	In the past 6 months, how frequently did you obtain orange sweet potato from the following sources?	

C7a	Purchase from a vendor (includes mobile vendors or shops at market)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C7b	Obtain from neighbors or nearby farmers	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C7c	Own production (grown on own land)	☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C7d	Other source	Source: _____ ☐ Never ☐ Rarely ☐ Sometimes ☐ Often
C8a	Are there any household members who do not eat any orange sweet potato?	☐ No >>*QD1* ☐ Yes
C8b	Who does not eat any orange sweet potato and why?	____________

Section D: Household Food Insecurity *in the past month to evaluate HFIAS*

Interviewer: The next set of questions are about experiences that you or any household member may have had in the past month due to a lack of resources. "Household" refers to those who live under the same roof and share meals together. "Lack of resources" refers to not having enough resources to obtain food—this includes cash and goods for bartering.

Question No.	**HFI Occurrence Question**	**Response/Code** **1**=Rarely (1-2x in past 4wks) **2**=Sometimes (3-10x) **3**=Often (>10x)
D1a	In the past 4 weeks, did you worry that your household would not have enough food?	☐ No >>*QD2* ☐ Yes
D1b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D2a	In the past 4 weeks, were you or any household member not able to eat the kinds of foods you preferred because of a lack of resources?	☐ No >>*QD3* ☐ Yes
D2b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D3a	In the past 4 weeks, did you or any household member have to eat a limited variety of foods due	☐ No >>*QD4* ☐ Yes

	to a lack of resources? (ex. eating just a few kinds of foods day after day)	
D3b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D4a	In the past 4 weeks, did you or any household member have to eat some food they did not want to eat because of a lack of resources to obtain other types of food? (Ex. Did you have to eat cassava instead of maize when you wanted to eat maize?)	☐ No >>*QD5* ☐ Yes
D4b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D5a	In the past 4 weeks, did you or any household member have to eat a smaller meal than you felt you needed because there was not enough food?	☐ No >>*QD6* ☐ Yes
D5b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D6a	In the past 4 weeks, did you or any household member eat fewer meals in a day (skip entire meals) because there was not enough food?	☐ No >>*QD7* ☐ Yes
D6b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D7a	In the past 4 weeks, was there ever no food at all in your household because there were no resources to get more?	☐ No >>*QD8* ☐ Yes
D7b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D8a	In the past 4 weeks, did you or any household member go to sleep at night hungry because there was not enough food?	☐ No >>*QD9* ☐ Yes
D8b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3
D9a	In the past 4 weeks, did you or any household member go a whole day and night without consuming any type of food because there was not enough food (this includes nshima, biscuits, or eating anything)?	☐ No >>*QD10* ☐ Yes
D9b	... How often did this happen in the past 4 weeks?	☐ 1 ☐ 2 ☐ 3

If the respondent answered "Yes" for Question D2, D3, D4, D5, or D6, proceed to ask the applicable follow-up question(s) about fish consumption.

Q No.	Referring to…	Follow-up Question	Response/Code
D10	QD2: You answered that during the past month, you	When this occurred, did the amount of fish	☐ Fish intake decreased

	or a household member were unable to eat the kinds of food that were preferred due to a lack of resources.	consumed decrease, increase, or remain the same compared to usual intake of fish?	☐ Fish intake increased ☐ Fish intake remained the same
D11	QD3: You answered that during the past month, you or a household member had to eat a limited variety of food day after day due to a lack of resources.	When this occurred, did you or that household member continue to eat fish?	☐ No, fish was not eaten ☐ Yes, fish was eaten
D12a	QD4: You answered that during the past month, you or a household member had to eat some food you/they did not want to eat due to a lack of resources.	Did the amount of fish consumed change?	☐ No ☐ Yes, fish consumption decreased ☐ Yes, fish consumption increased
D12b	QD4	Did the species of fish consumed change?	☐ No ☐ Yes. Explain: ______________
D12c	QD4	Did the form of fish consumed change? (dried/smoked/fresh)	☐ No ☐ Yes. Explain: _____________
D13a	QD5: You answered that in the past month, you or a household member had to eat a smaller meal than you/they felt was needed due to a lack of resources.	Was fish eaten as part of that meal?	☐ No >>*QD13b* ☐ Yes >>*Q13c*
D13b		Did you or the household member expect/plan to eat fish for that meal?	☐ No ☐ Yes, but fish had to be excluded from that meal >>*QD14 (if applicable)*
D13c		How much fish was consumed as part of that meal compared to a normal meal with fish?	☐ The portion of fish was the same size ☐ The portion of fish was smaller ☐ The portion of fish was bigger
D14	QD6: You answered that in the past month, you or a	When this occurred, did other household	☐ No, all household

	household member <u>had to eat fewer meals in a day (skip a meal)</u> due to a lack of resources.	members eat that meal?	members skipped the meal ☐ Yes, others ate—fish was part of the meal ☐ Yes, others ate—fish was not part of the meal

Q No.	HFI Follow-up Question	Response/Code
D15a	For components of Section D that you answered "Yes," is there any one household member that experienced them more often than others? *Ex. "When someone in the household <u>had to eat an undesired food</u>, <u>skip meals</u>, or <u>go to bed hungry</u> due to a lack of resources to obtain food, was it usually the same person?"*	☐ No >>*End* ☐ Yes
D15b	Who was affected the most?	☐ Father ☐ Mother ☐ Infant: ☐ M ☐ F ☐ Older child: ☐ M ☐ F ☐ Younger child: ☐ M ☐ F ☐ Other : ________

HH Level Food Frequency Questionnaire *covering the past 4 weeks to evaluate usual food intake at the <u>household</u> level. Assesses portion size for small fish species and orange sweet potato.*

The main food preparer of the household should respond to the following questions about <u>food consumed at home</u> in the past 4 weeks by anyone in the household. A "household" is considered all persons who live under the same roof and share meals together.

1. In the past 4 weeks, did anyone in the household consume beef?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume beef?
   - ☐ 1 time in past month
   - ☐ 2-3 times in past month
   - ☐ 1 time per week
   - ☐ 2 times per week
   - ☐ 3-4 times per week

- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

2. In the past 4 weeks, did anyone in the household consume pork?
   - ☐ No *(proceed to next question)*
   - ☐ Yes
   a. In the past 4 weeks, how often did the household consume pork?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day
3. In the past 4 weeks, did anyone in the household consume poultry (chicken or ducks)?
   - ☐ No *(proceed to next question)*
   - ☐ Yes
   a. In the past 4 weeks, how often did the household consume poultry?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day
4. In the past 4 weeks, did anyone in the household consume goat or lamb?
   - ☐ No *(proceed to next question)*
   - ☐ Yes
   a. In the past 4 weeks, how often did the household consume goat or lamb?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day
5. In the past 4 weeks, did anyone in the household consume organ meat?
   - ☐ No *(proceed to next question)*
   - ☐ Yes
   a. In the past 4 weeks, how often did the household consume organ meat?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day
6. In the past 4 weeks, did anyone in the household consume insects?
   - ☐ No *(proceed to next question)*
   - ☐ Yes
   a. In the past 4 weeks, how often did the household consume insects?

- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

7. In the past 4 weeks, did anyone in the household consume eggs?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume eggs?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day

8. In the past 4 weeks, did anyone in the household consume ***[fish species 1]***?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume ***[fish species 1]***?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day

   b. Each time ***[fish species 1]*** was consumed, how much was usually eaten by the household in total?

Insert grams (weighed on

   c. In what form was the fish usually obtained?
      - ☐ Dried (includes sun-dried or salted then dried)
      - ☐ Smoked
      - ☐ Fresh

9. In the past 4 weeks, did anyone in the household consume other meat? (Ex. rabbits, monkeys, turtles, field mice, moles, bush cats, bush birds)
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume other meat?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day

10. In the past 4 weeks, did anyone in the household consume beans or lentils (including cowpeas and soya beans)?

- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume beans or lentils?

- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

11. In the past 4 weeks, did anyone in the household consume groundnuts?

- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume groundnuts?

- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

12. In the past 4 weeks, did anyone in the household drink milk or have milk products (including infant formula, yogurt, and cheese)?

- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume milk or milk products?

- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

13. In the past 4 weeks, did anyone in the household consume wheat products (bread, cakes, pasta, etc.)?

- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume wheat products?

- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

14. In the past 4 weeks, did anyone in the household consume nshima?

- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume nshima?

- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

15. In the past 4 weeks, did anyone in the household consume maize?
    - ☐ No *(proceed to next question)*
    - ☐ Yes

    a. In the past 4 weeks, how often did the household consume maize?
    - ☐ 1 time in past month
    - ☐ 2-3 times in past month
    - ☐ 1 time per week
    - ☐ 2 times per week
    - ☐ 3-4 times per week
    - ☐ 5-6 times per week
    - ☐ 1 time per day
    - ☐ 2 or more times per day

16. In the past 4 weeks, did anyone in the household consume rice?
    - ☐ No *(proceed to next question)*
    - ☐ Yes

    a. In the past 4 weeks, how often did the household consume rice?
    - ☐ 1 time in past month
    - ☐ 2-3 times in past month
    - ☐ 1 time per week
    - ☐ 2 times per week
    - ☐ 3-4 times per week
    - ☐ 5-6 times per week
    - ☐ 1 time per day
    - ☐ 2 or more times per day

17. In the past 4 weeks, did anyone in the household consume finger millet (ragi)?
    - ☐ No *(proceed to next question)*
    - ☐ Yes

    a. In the past 4 weeks, how often did the household consume finger millet?
    - ☐ 1 time in past month
    - ☐ 2-3 times in past month
    - ☐ 1 time per week
    - ☐ 2 times per week
    - ☐ 3-4 times per week
    - ☐ 5-6 times per week
    - ☐ 1 time per day
    - ☐ 2 or more times per day

18. In the past 4 weeks, did anyone in the household consume cassava?
    - ☐ No *(proceed to next question)*
    - ☐ Yes

    b. In the past 4 weeks, how often did the household consume cassava?
    - ☐ 1 time in past month
    - ☐ 2-3 times in past month
    - ☐ 1 time per week
    - ☐ 2 times per week
    - ☐ 3-4 times per week
    - ☐ 5-6 times per week
    - ☐ 1 time per day
    - ☐ 2 or more times per day

19. In the past 4 weeks, did anyone in the household consume orange sweet potato?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume orange sweet potato?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day

   b. Each time orange sweet potato was consumed, how much was usually eaten by the household in total?

      Insert grams (weighed on

20. In the past 4 weeks, did anyone in the household consume white or yellow sweet potato?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume white or yellow sweet potato?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day

   b. Each time orange sweet potato was consumed, how much was usually eaten by the household in total?

      Insert grams (weighed on

21. In the past 4 weeks, did anyone in the household consume Irish potato?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

   a. In the past 4 weeks, how often did the household consume Irish potato?
      - ☐ 1 time in past month
      - ☐ 2-3 times in past month
      - ☐ 1 time per week
      - ☐ 2 times per week
      - ☐ 3-4 times per week
      - ☐ 5-6 times per week
      - ☐ 1 time per day
      - ☐ 2 or more times per day

22. In the past 4 weeks, did anyone in the household consume dark green leafy vegetables (rape, spinach, cassava leaves, bean leaves, pumpkin leaves, sweet potato leaves, etc)?
   - ☐ No *(proceed to next question)*
   - ☐ Yes

a. In the past 4 weeks, how often did the household consume dark green leafy vegetables?
- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

23. In the past 4 weeks, did anyone in the household consume carrots, pumpkin, or butternut squash?
- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume carrots, pumpkin, or butternut squash?
- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

24. In the past 4 weeks, did anyone in the household consume other vegetables (tomatoes, onions, okra, etc.)?
- ☐ No *(proceed to next question)*
- ☐ Yes

a. In the past 4 weeks, how often did the household consume other vegetables?
- ☐ 1 time in past month
- ☐ 2-3 times in past month
- ☐ 1 time per week
- ☐ 2 times per week
- ☐ 3-4 times per week
- ☐ 5-6 times per week
- ☐ 1 time per day
- ☐ 2 or more times per day

Annex 2: Survey instruments used in Chapter 3

Consent Form

Before beginning the interview, it is necessary to introduce the respondent to the experiment and survey and obtain their consent to participate.

Thank you for the opportunity to speak with you. This form is to get your consent to participate in this experiment conducted by WorldFish from July 2019 to March 2020. Your participation in this experiment is voluntary, and your responses and data will be anonymous. If you agree to participate in this experiment, you can choose to stop at any time. Your name will be on questionnaires and interviews but will not be included in the analysis or reports that are created from this experiment, all your answers are confidential. During this experiment your ponds will be stocked with multiple fish species and the WorldFish team will collect data on your pond production, household nutrition and food security and gender outcomes monthly.

Your participation is very important for our project objectives, thank you for your time.

If you have any questions about confidentiality and the survey please contact Lulu Middleton and Muleya Syapwaya (0970933649)

Name of participant: ………………………………………………………………………………………

Sign here: ……………………………………………………………………………………………….

Do you agree to participate in this experiment? ☐ **YES** (If YES, proceed with the survey) **No** ☐

WorldFish

Food Diary

Date (Ubushiku)	Gender of person responsible for sourcing (Mwaume nagula mwanakashi ufwaile isabi)	Species (Umutundu we sabi)	Form (dried, smoked, fresh) Lintu lya Kanikiwa ku kasuba, Kumulilo, ilibishi	Source (vendor, pond, wild) Ifumine kwisa isabi (mwashita fye, mucishiba chenu, Mwilungu ne mimana)	Quantity (weight, bp, gallon, pieces) Ubwingi bwe Sabi mulile (ama Kg, bp, gallon, impendwa ye sabi)

Annex 3: Survey instruments used in Chapter 4

Enumerator Name: __________________________________ Survey No.:……………………………….

1.1) Date: __________________________________ 1.2) Name of market/retail store…………………………….

Part 1: Socio-economic and cultural factors	
1.3) Gender of respondent	Male [ ] Female [ ]
1.4) What tribe are you?	∆ Kikuyu ∆ Luhya ∆ Kalenjin ∆ Luo ∆ Kamba ∆Somalis ∆ Kisii ∆ Mijikenda ∆ Maasai ∆ Turkana ∆ Asian/European/Arab ∆ Other
1.5) How old are you?	No. of years: ……….
1.6) Marital Status?	∆ Single ∆ Married ∆ Cohabiting ∆ Widowed/Divorced
1.7) Are you mainly responsible for grocery shopping in the household?	∆ Yes ∆ No ∆ We share this responsibility
1.8) Are you mainly responsible for cooking?	∆ Yes ∆ No ∆ We share this responsibility
1.9) How many people share the same pot of food?	No: #……….
1.10) What is the main source of income for the household?	∆ Formal employment ∆ Casual labour ∆ Self-employed / own business ∆ Fishing and/or farming ∆ Unemployed/remittance ∆ Other
Part 2: Economic status	
2.1) Do you have electricity in your house?	∆ Main-grid electricity (sometimes use generator, gas, solar) ∆ Not connected to main-grid (candles, paraffine/kerosene, wood fire, gas, solar)
2.2) Do you have tap water in your house?	∆ Piped water into dwelling, or own borehole, ∆ (no direct pipe) - communal well or pond, river, stream, lake, rain, water vendor
2.3) Do you have a TV?	∆ Yes ∆ No
2.4) Do you have a fridge?	∆ Yes ∆ No
2.5) Do you have WIFI in your house?	∆ Yes ∆ No
2.6) What do you use for cooking?	∆ Electric coil and/or gas LCG/jikokoko ∆ Stove/meko or charcoal jiko/ firewood
2.7) Do you have a smartphone?	∆ Yes ∆ No
2.8) Do you have a car?	∆ Yes ∆ No
Part 3.1: Fish purchasing and consumption habits	
3.1.1) Do you consume fish (including omena)?	∆ Yes ∆No
3.1.2) If "No", why? [Choose 1] ****** IF PERSON ANSWERS "NEVER" THEN END THE INTERVIEW ******	∆ Not affordable ∆ Not tasty ∆ Hard to find ∆ Unhealthy ∆ Difficult to portion ∆ Hard to eat ∆ Not traditional ∆ Smell ∆ Allergies ∆ Not sustainable ∆ Hard to or unsure of how to cook ∆ Other
3.1.3) Which fish is your favourite to eat?	………………………….
3.1.4) Why is this your favourite?	∆ Most affordable ∆ Tastiest ∆ Easiest to access ∆ Healthiest ∆ Easiest to cook ∆ Easiest to eat ∆ Most traditional fish in Kenya ∆ Most sustainable ∆ Easiest to portion for fam ∆ Other
3.1.5) How often do you consume tilapia/Ngege?	∆ Never ∆ A few times a year ∆ Once a month ∆ Once every 2 week ∆ Once a week ∆ Twice a week ∆ Three/four times a week ∆ Everyday
3.1.6) If "Never", why? [Choose 1] ****** IF PERSON ANSWERS "NEVER" THEN SKIP TO SECTION's 4 & 5 ******	∆ Not affordable ∆ Not tasty ∆ Hard to find ∆ Unhealthy ∆ Hard to eat ∆ Not traditional ∆ Not sustainable ∆ Difficult to portion ∆ Allergies ∆ Smell ∆ Hard to or unsure of how to cook ∆ Other
Part 3.2: Tilapia purchasing and consumption habits	

Take out the fresh fish from the cooler box and lay them out:	Very small (60-70g)	Small (120-130g)	Medium (220-240g)	Large (490-499g)
3.2.1) Which of these four fish would you prefer to eat?	[……….]	[……….]	[……….]	[……….]
3.2.2) If you were buying for your family today, how many of these fish would give a good meal for your family? [multiple choices]	No: #……….	No: #……….	No: #……….	No: #……….
3.2.3) Why do you make this choice? [if they mention children, note the ages of children]	……………………..			
3.2.4) If these are the prices today, which of these four products would you buy at these prices?	16 KES/pc 210 KES/kg 13 pcs/kg No: #……….	43 KES/pc 260 KES/kg 6 pcs/kg No: #……….	83 KES/pc 330 KES/kg 4 pcs/kg No: #……….	175 KES/pc 350 KES 2 pcs/kg No: #……….
3.2.5) If there was a change, why?	……………………..			

3.3. Preparing and cooking the fish	
Please answer the next questions thinking about the fish you just hypothetically purchased?	
3.3.1) Is this fish usually gutted and scaled?	∆ Yes ∆ No
3.3.2) In what form do you buy this tilapia?	∆ Fresh ∆ Frozen ∆ Fried ∆ Dried ∆ Smoked
3.3.3) Where would you usually buy this tilapia from?	∆ Supermarket ∆ Open market (gikomba) ∆ Retail outlet ∆ Butchery. ∆ Direct from farm-gate. ∆ Fish monger (mama Samaki) ∆ Direct from fisher/at the beach. ∆ Self-caught ∆ Only from restaurants (incl. online platform)
3.3.4) Why do you buy from here?	∆ It is the closest ∆ It is the cheapest ∆ It is the freshest ∆ There is always availability ∆ It is the only place I know ∆ Other
3.3.5) How would you usually cook this tilapia?	∆ stew the fish fresh ∆ stew the fried fish (wet fry) ∆ cook the fried fish (dry fry) ∆ grill/BBQ the fish ∆ oven bake the fish ∆ smoked the fish at home and eat later
3.3.6) Which parts of the tilapia do you eat?	∆ I throw the bones after eating the fillets and flesh ∆ I eat everything (including fillets, head and bones)
3.3.7) How do you usually portion tilapia in the household?	∆ Everybody gets one whole fish ∆ We split into portions (leave on the bone) ∆ We fillet the fish and throw the bones/head/tail
Part 4: Preference values	
4.1) When you buy fish, which of these are the most important to make your purchasing decision? Please rank them from most to least important (1-4).	Rank (1-4) Taste [……] Easiness to portion [……] Quality [……] Price (affordability) [……]

4.2) Do you agree with the following statements?	Yes	Same	No
	Price (affordability)		
4.2.1 tilapia is more affordable than chicken			
4.2.2 tilapia is more affordable than mbuta			
4.2.3 tilapia is more affordable than omena			
4.2.4 tilapia is more affordable than fulu			
	Taste		
4.2.5 tilapia is tastier than chicken			
4.2.6 tilapia is tastier than mbuta			
4.2.7 tilapia is tastier than omena			
4.2.8 tilapia is tastier than fulu			
	Easiness to portion		
4.2.9 tilapia is easier to portion than chicken			

4.2.10 tilapia is easier to portion than mbuta			
4.2.11 tilapia is easier to portion than omena			
4.2.12 tilapia is easier to portion than fulu			
	Quality (freshness, handling, condition, safety, …)		
4.2.13 tilapia is better quality than chicken			
4.2.14 tilapia is better quality than mbuta			
4.2.15 tilapia is better quality than omena			
4.2.16 tilapia is better quality than fulu			

Part 5: Food frequency of other animal proteins								
How often do you consume the following?	Never	A few times a year	Once a month	Once every 2 weeks	Once a week	Twice a week	Three/four times a week	Everyday
5.1) white meat (chicken or other poultry)?								
5.2) red meat (beef, pork, goat, mutton, or offal)?								
5.3) Nile perch (mbuta)?								
5.4) omena/dagaa?								
5.5) fulu?								
5.6) catfish/mudfish?								
5.7) imported canned fish (pilchards, mackerel, tuna)?								