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EXPLORING THE BIOLOGICAL AND SOCIO-ECONOMIC POTENTIALS OF *RHAMPHOCHROMIS* SPECIES FOR THE EXPANSION OF MALAWIAN AQUACULTURE

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ABSTRACT

The biological & socioeconomic potentials were explored to determine if *Rhamphochromis* species (cichlids) are suitable for cage aquaculture in Malawi. Structured questionnaires were used to explore socio-economic parameters and literature was reviewed to explore biological parameters. All variables from questionnaires were collapsed into principal component analysis (PCA) to create response variables PC1 and PC2 which were then used with a generalized linear mixed-effect model (GLMM). The results showed a highly significant effect among fish species with *R. brevis* selected with the highest mean score from the model. All stakeholders agreed on selecting *R. brevis* as a species with high preference and good taste, with a big size and highly valued and marketable, but they differed on their opinions of other fish species. Despite a lack of biological information about *Rhamphochromis sp.*, they are known to be deep-water piscivores which are maternal mouthbrooders and substrate spawners with no defined spawning period. This report, therefore, concluded that *Rhamphochromis sp.* and especially *R. brevis*, might have the socioeconomic and biological potential to be suitable for cage aquaculture development, but further research is needed to confirm this.

Keywords: bioeconomic, socio-economic, cage aquaculture, *Rhamphochromis* species, Malawi

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1 INTRODUCTION

Fish is crucial to a nutritious diet in many areas across the world. Fish and fish products are recognized not only as some of the healthiest foods on the planet but also as some of the least impactful on the natural environment. For these reasons, they are vital for national, regional, and global food security and nutrition strategies, and have a big part to play in transforming food systems and eliminating hunger and malnutrition (De Silva, Nguyen, Turchini, Amarasinghe, & Abery, 2009). Aquaculture has expanded fish availability to regions and countries with otherwise limited or no access to the cultured species, often at cheaper prices, leading to improved nutrition and food security. Globally, aquaculture has been the main source of fish available for human consumption, contributing a share of 52%, and is expected to continue increasing in the long term (FAO, 2020). Global aquaculture production is 82.1 million tons of aquatic animals of which Asia alone accounts for 89 percent share in the last two decades (FAO, 2020). The share of aquaculture by individual countries to the total global fish supply differs country by country with China, India, Indonesia, Viet Nam, Bangladesh, Egypt, Norway, and Chile being the major producing countries over the past two decades (Teletchea F. , 2021).

Despite the large proportion aquaculture makes up of the global fish supply, Malawi's local fish supply is still largely dependent on capture fisheries production. Malawi's total fish production is 82.1 million tons, of which capture fisheries alone account for 95 percent in the last five years (FAO, 2020). The poor aquaculture development in Malawi is challenged by the slow growth of farmed Malawian species, which fail to reach the production threshold level of Nile Tilapia, *O. niloticus*. Historically, the poor uptake of private sector aquaculture has resulted in a perception among many lower-income stakeholders that the risks of starting up small-scale pond aquaculture are too great to achieve financial viability (Imani Enterprise Ltd, 2016). The development of commercial aquaculture in countries such as Nigeria, Ghana, Zimbabwe, and Zambia have largely been based on a more private sector, entrepreneur-led model (Imani Enterprise Ltd, 2016), supported by the governments to introduce more viable and profitable species such as *O. niloticus* into aquaculture systems. This is not the case in Malawi where the introduction of exotic fish species into Malawi's ecosystems is restricted by the Fisheries Conservation and Management Act of 1997, which gives Malawi no option other than to farm the local fish species in aquaculture ventures.

1.1 Malawian Aquaculture and Fish Diversity

Lake Malawi supports over 1000 fish species, which belong to 65 genera and 11 families (Weyl, Ribbink, & Tweddle, 2010). There are five main indigenous fish species being utilized under aquaculture development which include: the tilapias *Oreochromis shiranus, Oreochromis karongae, Oreochromis mossambicus, Copndoton rendalli,* and the catfish *Clarias gariepinus* (Figure 3) (Chirwa, Kassam, Jere, & Mtethiwa, 2017). *O. shiranus* seems to be preferred by most of Malawi's fish farmers and it is widely distributed among aquatic ecosystems of Malawi. However, the species is not doing well in aquaculture development due to early maturity and precocious breeding (Blow & Leonard, 2007) resulting in smaller table sizes of about 50g (Chirwa, Kassam, Jere, & Mtethiwa, 2017), which is not viable for private investment. This has resulted in low aquaculture production, hence the low contribution to the total fish supply, triggering the importation of fish from other countries to support the growing population of Malawi. However, there is high existing potential for aquaculture development in Malawi: the vast lake Malawi and other water reservoirs, the diversity of fish species endemic to Malawi, and the good land for both cage development and pond-based aquaculture.

1.2 Problem Statement

The goal of this study was to explore the biological and socioeconomic potential of *Rhamphochromis* species for aquaculture development in Malawi. Despite the potential opportunities in fish farming and the government's increased efforts to boost productivity and growth in the aquaculture industry, there still exist a significant gap in per capita fish consumption, with Malawi's government reporting 10kg of fish per person per year in 2020 (GoM, 2020) and the FAO reporting 20kg of fish per person per year for the world in the same year (FAO, 2020). Stakeholders in the aquaculture subsector are more demanding in terms of fish species selection, and issues related to farmed fish species should be highly prioritized regarding fish farmers' concerns and government policies. A good fish species is an important idea to grasp to better comprehend many elements of stakeholders' behavior in order to engage in aquaculture growth. Fish growers in Malawi allege that there is a lack of variety of farmed fish species accessible, low output potential, and many challenges to making a profit from fish farming, making aquaculture unattractive to potential investors. Despite these challenges, Malawians are becoming more interested in eating fish (GoM, 2020). This study uses biological and socioeconomic surveys aid in the identification of elements that influence decision-making and the proposal of adjustments to suit the expectations of end users (KOTLER, 2000). As a result, understanding these elements is critical not only for profit, but also for aquaculture technologies that promote fish output and consumption (Trondsen, Scholderer, Lund, & Eggen, 2004). The viability of fish species in aquaculture is determined not only by how well they withstand local conditions, but also by how well they contribute to the nation's economy. For example, in many regions of the world, *O. niloticus* has proven to be adaptable to local conditions as well as commercially profitable. However, because to restrictions imposed by the Fisheries Management and Conservation Act of 1997 to safeguard endemic biodiversity, *O. niloticus* cannot be introduced into Malawi's aquatic ecosystems. Malawi has little choice but to concentrate on the development of its endemic fish species because of this restriction. Therefore, the goal of this research is to investigate the biological and socioeconomic factors that could help identify species with potential for expansion in aquaculture in Malawi.

1.3 Justification

An important method for increasing aquaculture production is the introduction of novel fish species (especially endemic species) and aquaculture technologies (particularly cage aquaculture) (FAO, 2020). However, further research is required to explore how to increase benefits while limiting risks associated with expanding aquaculture. As a result, the purpose of this research is to investigate the ecological and socioeconomic potentials of *Rhamphochromis* species native to Lake Malawi, as well as to identify good candidates for long-term aquaculture in Malawi. This paper summarizes the present knowledge of *Rhamphochromis* species and how it might be applied to aquaculture advancements and innovations. It identifies knowledge gaps, allowing researchers to propose important research paths to achieve the goal of developing *Rhamphochromis* species for aquaculture. This study backs up the 2016 National Fisheries and Aquaculture Policy, which promotes the use of local species and improved strains of indigenous species to protect biodiversity (NFAP, 2016). This scientific information is the foundation for the development of *Rhamphochromis* species in aquaculture, and it will also inform and guide management measures to allow for long-term growth.

1.4 Objectives

The goal of this project is to explore the biological and socioeconomic potentials of *Rhamphochromis* species to determine whether they are suitable for aquaculture and identify suitable candidates for sustainable aquaculture development in Malawi. To achieve this goal, this project has three primary objectives as follows:

i. Determining if biological parameters of *Rhamphochromis* species are suitable for the sustainable development of aquaculture in Malawi.

ii. Evaluating socioeconomic factors to consider for the development of *Rhamphochromis*. species for cage aquaculture in Malawi.

iii. Identifying suitable candidates among the species of genus *Rhamphochromis* for sustainable development of aquaculture in Malawi.

2 THEORETICAL FRAMEWORK AND LITERATURE REVIEW

2.1 Biological Considerations for Developing New Fish Species

New fish species are developed for aquaculture by a continual and dynamic process that begins when wild fish are transferred to captivity (Teletchea F. , 2021). This process considers both biological and cultural components of development, as well as the implications for humans and other evolved species. Aquaculture fish species should be constantly adapted to both captive environments and people, with the ultimate goal of changing selected characteristics in successive generations to produce more productive and efficient individuals (Bilio, 2008). Fish species can, on the other hand, be accepted fully developed for aquaculture in a variety of ways. For Balon, fish are fully developed for aquaculture when they change form, function, color, and behaviour, often only partially resembling their wild ancestors, and survive poorly as feral forms if returned to the wild without human protection (Balon, 2004). For Bilio, fish species are considered domesticated when they show the first results of selective breeding or when no such evidence is found, after at least three successive cycles of reproduction (generations) under controlled conditions (Bilio, 2008). Duarte considered that fish are fully developed when breeding, caring, and feeding of organisms are controlled by humans (Duarte, Marba, & Holmer, 2007). For Gjedrem, developed fish strains are the result of several generations of selection (Gjedrem & Rye, 2018).

Development of a new fish species is a risky journey that may take years or even decades (Teletchea F. , 2021). Once the full life cycle is controlled in captivity, there are no longer exchanges between farmed individuals and their wild congeners, and development can proceed toward the production of improved individuals. For some developed species, several generations under selection have allowed improving specific traits very rapidly (Fontaine & Teletchea, 2019). Therefore, the time lag between the onset of domestication and selective breeding can be considerably shorter in aquaculture (less than a decade), with both occurring in tandem in many cases (Teletchea F. , 2021). However, it was found that without proper management, numerous breeding programs resulted in a quick loss of genetic diversity due to inbreeding, possibly leading to a decline of productivity, a reduced population fitness, and an increased susceptibility to stress and disease (Duarte, Marba, & Holmer, 2007). Therefore, caution should be taken not to go too quickly when implementing breeding programs and adequately balance market values (e.g., growth rate, fillet quality) and non-market values, such as ethics and welfare (Saraiva, Castanheira, Arechavala-Lop, Volstorf, & Heinzpter Studer, 2019). Research has pushed the physiological limits of many fish species in growth, fertility, and size, as a consequence of (or resulting in) highly artificial conditions, possibly altering their welfare, which is one of the key issues of aquaculture today (Saraiva et al., 2019). It is also crucial to maintain sufficient genetic variation (e.g., establish a base population with ample genetic variation, keep a large effective population size, and introduce genetic variation from outside the breeding stock) of domesticated and selected fish to ensure that they are more robust and able to cope with various environmental changes (Olesen, Bentsen, Phillips, & Ponzoni, 2015). Supported by continuous advances in sequencing and bioinformatics, genomic tools can now be hugely valuable to inform sustainable genetic improvement and their improved affordability and accessibility mean that they can now be applied across the broad range of aquaculture species and at all stages of the domestication process to optimize selective breeding (Teletchea F. , 2021).

2.2 Examples of Domestication

Among the domesticated fish species, common carp and Nile tilapia are probably the most selected for the longest period of time globally (Bilio, 2008). In Europe, the most domesticated and selected species are common carp, rainbow trout (*Oncorynchus mykiss*), Atlantic salmon, gilthead sea bream (*Sparus aurata*), European seabass (*Dicentrarchus labrax*), and turbot (*Psetta maxima*) (Janssen et al., 2017). Selective breeding programs in fish have historically focused on improving growth (Gjedrem & Rye, 2018). Genetic gain averages about 10% to 20% per generation for growth rate when this is the main, or only, selected trait (Gjedrem & Rye, 2018). In addition to growth, feed conversion efficiency, age at sexual maturity, improved resistance to bacterial and viral diseases, and a number of traits related to product quality (e.g., muscle lipid content, flesh color, tenderness, flavor) have been gradually included in various breeding programs, particularly for Atlantic salmon (Teletchea F. , 2021). In a recent survey conducted among breeding companies of five species farmed in Europe, Janssen et al. (2017) found that growth performance was universally selected upon. Among the 27 breeding programmes, both morphology and disease resistance were included in 15, product quality in 13, processing yield in 12, and reproduction and feed efficiency in 7 (Gjedrem & Rye, 2018). In conclusion, the future seed market will most likely continue to request genetic material that is selected for growth rates as well as other traits (Olesen, Bentsen, Phillips, & Ponzoni, 2015).

Even while most fish species failed to reach a substantial volume, the global output is now highly skewed toward the farming of a few species, the boom in fish aquaculture was based in part on the discovery of commercially viable fish species (Sicuro, 2021). The most commonly farmed species have been widely introduced around the world (De Silva, Nguyen, Turchini, Amarasinghe, & Abery, 2009). Seven of the eight most widely farmed fish species are recorded more frequently in non-native nations than in native ones (FAO, 2020). Common carp, for example, is farmed in 48 countries, including 37 where it was introduced (FAO, 2020). Similarly, Nile tilapia (33 introduced) and rainbow trout (40 introduced) are farmed in 45 nations (FAO, 2019). Non-native species can have a direct or indirect impact on biodiversity, and these effects can be immediate or long-term (De Silva, Nguyen, Turchini, Amarasinghe, & Abery, 2009). As a result, lowering reliance on non-native species, and thus minimizing potential negative impacts on biodiversity, is increasingly seen as a necessity for aquaculture's long-term viability (De Silva, Nguyen, Turchini, Amarasinghe, & Abery, 2009). In this setting, there are competing demands for further diversification vs the need to concentrate on and enhance the efficiency of existing farmed species' output (FAO, 2020). According to Bilio (2008), it is no longer desirable to seek further diversification by exposing more species to experimentation, but rather to focus our efforts on a few species and exploit intra-specific diversity potential, or the largely unknown genetic diversity resources within truly domesticated species. On the other hand, there is still a lot of room for domesticating new fish species, especially native ones, to create a more varied aquaculture sector that will be more adaptable to environmental change (Valladão, Gallani, & Pilarski, 2018). This method could also help to remove, or at least reduce, the negative ecological and genetic effects of non-native species introduced either directly or indirectly (De Silva, Nguyen, Turchini, Amarasinghe, & Abery, 2009). The desire to promote native species for aquaculture has resulted in substantial developments in a number of nations in recent years (Valladão, Gallani, & Pilarski, 2018). Native species' contribution to global aquaculture may rise, leading to a more diversified and even production than currently exists (Teletchea F. , 2021). As a result, it is expected that, at least in the next decade, both intraspecific and interspecific diversification will be pursued, i.e., improving previously domesticated and selected species while also farming new fish species (FAO, 2019).

As a result, the process of developing new fish species is a lengthy and never-ending process that permits fish to adapt to both captivity and human environments (Teletchea F. , 2021). For most farmed animals, this process began only a few decades (or even years) ago, and so only around one-third might be deemed domesticated. Several features, including growth, were altered as a result of domestication. New breeding programs will need to strike a balance between market and non-market values while maintaining enough genetic diversity to ensure that fish are both productive and resilient to environmental changes (Sicuro, 2021). Aquaculture's long-term viability will be dependent on two factors: first, the continued improvement of already domesticated fish species, and second, our willingness and capacity to diversify the number of farmed, preferably native, species to promote a more diversified and sustainable aquaculture industry (Teletchea F. , 2021).

2.3 Biological Parameters for Development

Diamond (1997) proposed that the wild ancestors must possess six characteristics before they could be considered for domestication. *1)* Efficient diet – Animals that can efficiently process what they eat and live off plants are less expensive to keep in captivity. Carnivores feed on flesh, which would require the domesticators to raise additional animals to feed the carnivores and therefore increase the consumption of plants further. *2)* Quick growth rate – Fast maturity rate compared to the human life span allows breeding intervention and makes the animal useful within an acceptable duration of caretaking. Some large animals require many years before they reach a useful size. *3)* Ability to breed in captivity – Animals that will not breed in captivity are limited to acquisition through capture in the wild. *4)* Pleasant disposition – Animals with nasty dispositions are dangerous to keep around humans. *5)* Tendency not to panic – Some species are nervous, fast, and prone to flight when they perceive a threat. *6)* Social structure – All species of domesticated large mammals had wild ancestors that lived in herds with a dominance hierarchy amongst the herd members, and the herds had overlapping home territories rather than mutually exclusive home territories. This arrangement allows humans to take control of the dominance hierarchy. The aim for developing new fish species should be to explore the biological potentials of new candidates, including growth rates, asymptotic length, mortality, consumption by biomass, biological yield, and biomass, for the fish species under study. The analysis of these biological parameters helps to identify fish species with high growth rates and early sexual maturation. The predominance of species with short life cycles and a reduced number of age classes, determines high rates of stock turnover, which indicates high productivity for fisheries, and a low risk of overfishing. Therefore, it must be very clinical to identify new candidates with important advantages over others to diversify aquaculture production for sustainable development.

2.4 Genus Rhamphochromis

According to IUCN and the Catalog of Fishes (IUCN, 2021), there are five species recognized as legitimate within the genus *Rhamphochromis*. Researchers such as Weyl, Ribbink, and Tweddle recorded the same number and names of species which include, *R. brevis*, *R. esox*, *R. ferox*, *R. longiceps* and *R. woodi* (Weyl, Ribbink, & Tweddle, 2010). All *Rhamphochromis* species are elongate, streamlined predators of fish and arthropods. They are maternal mouthbrooders: females spawn with territorial males, take eggs away in their buccal cavity and brood clutches for periods of three to four weeks before releasing free-swimming offspring (Genner et al, 2007).

3 MATERIALS AND METHODS

3.1 Project Design

This project was designed and prepared as an integral aspect of Malawi's sustainable aquaculture development, and it falls within the framework of the National Fisheries and Aquaculture Policy 2016, which aims to achieve the goals of Malawi's Development Vision 2063 and the Millennium Development Goals (MDGs III). The project design considered the data-gathering processes and methods, as well as data shipping conditions from Malawi. The project also aligns with the UNESCO-GRO FTP goal of strengthening GRO-FTP Fellows' professional capacity to actively contribute to work in their organizations and perceive development potential in their home countries.

3.2 Study Sites

We studied three districts of artisanal fishing communities in Malawi: Karonga district in the North, Nkhotakota district in the central, and Mangochi district in south (Fig. 1). Karonga District is located at the northern end of Lake Malawi, 50 km south of the Tanzanian border, 226km North of Mzuzu City, and it covers an area of 3,416 square kilometers making up 3.5% of the total land area of Malawi (94,276 sq. km). Karonga is situated at latitude 9.9333’S, longitude 33.9333’E and its economy is dependent on agriculture, fishing, forestry, mining, local commerce and industry, and tourism. The Northern region forms the deepest part of Lake Malawi, about 720 meters deep and rocky, hence fewer fishing activities take place. Nkhotakota district is positioned at latitude of 12055’54.07”S and longitude of 34016’51.79”E in the central region of Malawi. The district is on the west coast of Lake Malawi. It borders Nkhata Bay to the North, Mzimba to the Northwest, Kasungu to the West, Ntchisi to the Southwest and Salima to the South and shares an international boundary with the Republic of Mozambique to the East. The district is 200 km Northwest of Lilongwe, the capital city of Malawi and it is the third largest in the central region having an approximate area of 7500 square kilometers. The district covers 6.3 percent of the country’s land. Mangochi District covers an area of 6,273 km² and has a population of 610,239 and borders with Mozambique to the east. It is fiercely hot in summer and ambient in winter. It is on the flood-plain for Lake Malawi. These study sites and fishing communities were selected according to logistic and opportunistic advantages: these sites have been the focus of other research projects and there is availability of fisheries staff to carry out the survey.

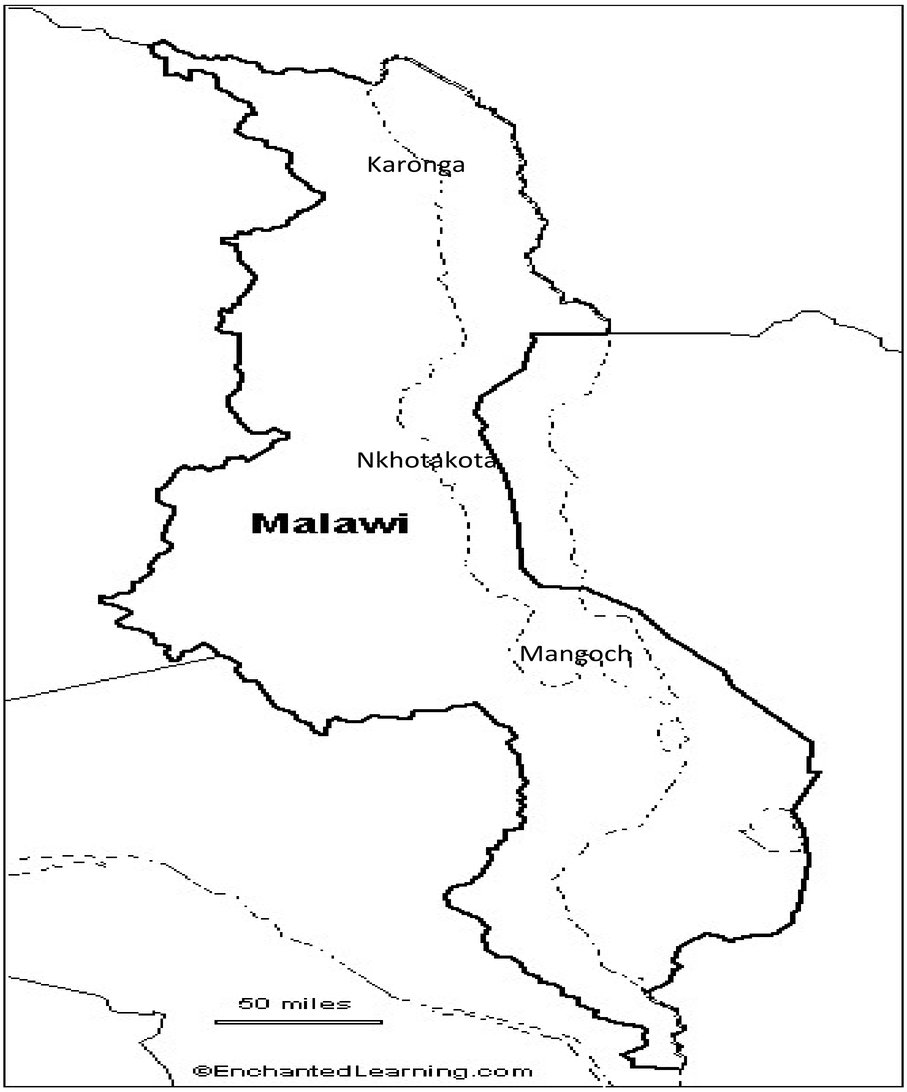

Figure 1. Map of Malawi, showing Karonga, Nkhotakota and Mangochi where survey was conducted (study area).

3.3 Data Collection

Structured questionnaires were administered through a standardized, undisguised google form both online and offline (Appendix 3). The survey was tested before use to validate the bids used in the survey questionnaire and identify possible shortfalls in the study. Sizes of fish, taste, marketability, price, and preferences regarding *Rhamphochromis* species were elicited. The final questionnaire had two sections. The first section contained warm-up questions to get the respondents thinking about the current fish species under aquaculture, challenges encountered in fish farming, current fish species, whether it is a good idea to introduce new fish species into aquaculture, and willingness to farm new fish species. The respondents were provided with a list of fish species containing photos for easy identification. The second section focused on biological and socioeconomic parameters around the introduction of new fish species into aquaculture with an emphasis on *Rhamphochromis* species. In this section, six variables were the focus: Taste, Size, Marketability, Price, Affordibility, and Preference. The price of the fish was used as a standard measure of change in preference for the species and was defined as either high or low price. The taste of the fish was categorized as good or not good and are recorded as dummy variable yes or no in the PCA. The variables were abbreviated to shorten them for easy use in PCA. The abbreviations, definitions and descriptions of the variables used in this study are shown in table 1

Table 1. Description of the abbreviations used as PCA variables.

Variable	Definition of variable	Description of Variable
ToF	Taste of Fish	Dummy variable where Yes=1 and No=0
SoF	Size of Fish	Dummy variable where Yes=1 and No=0
PoF	Price of Fish	Dummy variable where Yes=1 and No=0
Marketable	Marketability of Fish	Dummy variable where Yes=1 and No=0
MP	Most Preferred	Dummy variable where Yes=1 and No=0
WoF	Willingness of Farmer for new species	Dummy variable where Yes=1 and No=0
SCFA	Suitable Candidate for Aquaculture	Dummy variable where Yes=1 and No=0
GIFNS	Good Idea for New Species	Dummy variable where Yes=1 and No=0
AoF	Affordability of Fish	Dummy variable where Yes=1 and No=0
GIFRS	Good Idea for *Rhamphochromis* Species	Dummy variable where Yes=1 and No=0
Species	Treatments or factor under investigation	Dummy variable where Yes=1 and No=0
Stakeholders	Groups of respondents	Dummy variable where Yes=1 and No=0
Occupation	Source of Income	Dummy variable where 0 = Fishing, 1 =Farming, 2 = Traders, 3 = Formal employment, 4 = no occupation
Experience	Number of years of working	Dummy variable where Yes=1 and No=0

3.4 Data Analysis

To examine socioeconomic characteristics, we first used a principal component analysis (PCA) to reduce variables into main component axes. The values were then extracted, and the hypothesis was tested using a generalized linear mixed effects model (GLMM) performed on PC1 and PC2. All statistical analyses were performed in R version 4.1.2 (R Core Team, 2021). All tests were two–tailed with a significance level set to α =0.05.

3.4.1 Principal Component Analysis (PCA)

Six variables were used in this analysis and were collapsed into first principal component scores using a Principal Components Analysis (PCA): Fish taste (ToF), Fish size (SoF), Price of Fish (PoF), Marketability (Marketable), Affordability of fish (AoF) and most preferred species (MP). Each individual fish in both PC1 and PC2 categories was then assigned a score from the component that explained most of the variation in the data. To identify the most suitable candidates, we used these socioeconomic scores obtained in PCA as a response variable in a GLMM model.

3.4.2 Generalized Linear Mixed-Effects Models (GLMM).

PC1 and PC2 were analysed using generalized linear mixed-effects models (GLMM). For each analysis, the full model included: Species (*R. brevis, R. esox, R. ferox, R. longiceps* and *R. woodi*) as a fixed factor, Region (North, Central and South), Stakeholders (Fishers, Fish farmers, Consumers and Fisheries experts), Gender and age were set as random factors. The full model was reduced by backward selection based on the Akaike Information Criterion (AIC) (Zuur et al., 2009). Diagnostics based on residuals of the model were performed to assess the adequacy of the reduced model and compliance with the underlying assumptions. Dependent variables were transformed whenever necessary to ensure that the residuals followed the assumed error distribution. Finally, the effects of the independent variables were estimated from the reduced models and their significance was tested by likelihood ratio tests (LRT) between models respecting marginality of the effects that are supposed to follow a $\chi 2$ distribution under the null hypothesis (type II tests; (Fox et al., 2011)). This analysis was followed by a post-hoc multiple comparison test (Hothorn et al., 2008) to assess pairwise differences.

4 RESULTS

4.1 General characteristics of the respondents

Table 1 shows a summary of the descriptive statistics of the respondents interviewed. The age of the respondents ranged from 18 to 72 years with the age group of 36-54 years contributing the majority of responses (57.7%). The survey was dominated by male respondents accounting for 65.9% while females accounted for 34.1%, suggesting that men dominate fishing and fisheries activities more than women in Malawi (Makwinja, 2020). There were four categories of stakeholders who participated in the survey: consumers (people who eat fish and were selected from random markets within three regions, 25.5%), fisheries experts (people who were trained in the fisheries field, 23.4%), fish farmers (people who are directly involved in fish farming and own a fish pond, 25.5%), and fishers (people who are directly involved in catching fish from the aquatic reservoirs and at least own fishing equipment, 25.5%). For occupation, about 25.5% of respondents were fish farmers, 25.5% fishers, 20.8% government employees, 12.3% businessmen, 6.8% NGO workers, and 9.1% had no occupation. About 36.2% of the respondents were from the central region, 33.2% and 30.6% were from northern and southern regions respectively. The number of years of experience ranged between 0 to over 21 years with the 6-10 years' experience group contributing about 36.6% of the total response variables.

4.2 Results from the Principal Components Analysis

The first component (PC1) was responsible for 43.6 percent of the data variation. A high PC1 score implies that the fish is of good size, taste, and price, and that the fish is marketable, most preferred, and highly affordable (loadings: MP = 0.61, SoF = 0.55, PoF = 0.56, Marketability = 0.59, ToF = 0.60 and AoF =- 0.20). Socioeconomic variables with the highest vector loadings in PC1 are MP, ToF, Marketability, PoF, and SoF. A high score in PC2 implies high affordability. Although species distributions along the axes thus show considerable overlap, the frequency of the observations within each socioeconomic variable differs for each species. The highest vector loadings in PC1 are MP, SoF, and PoF. *R. brevis* is associated with all these vectors.

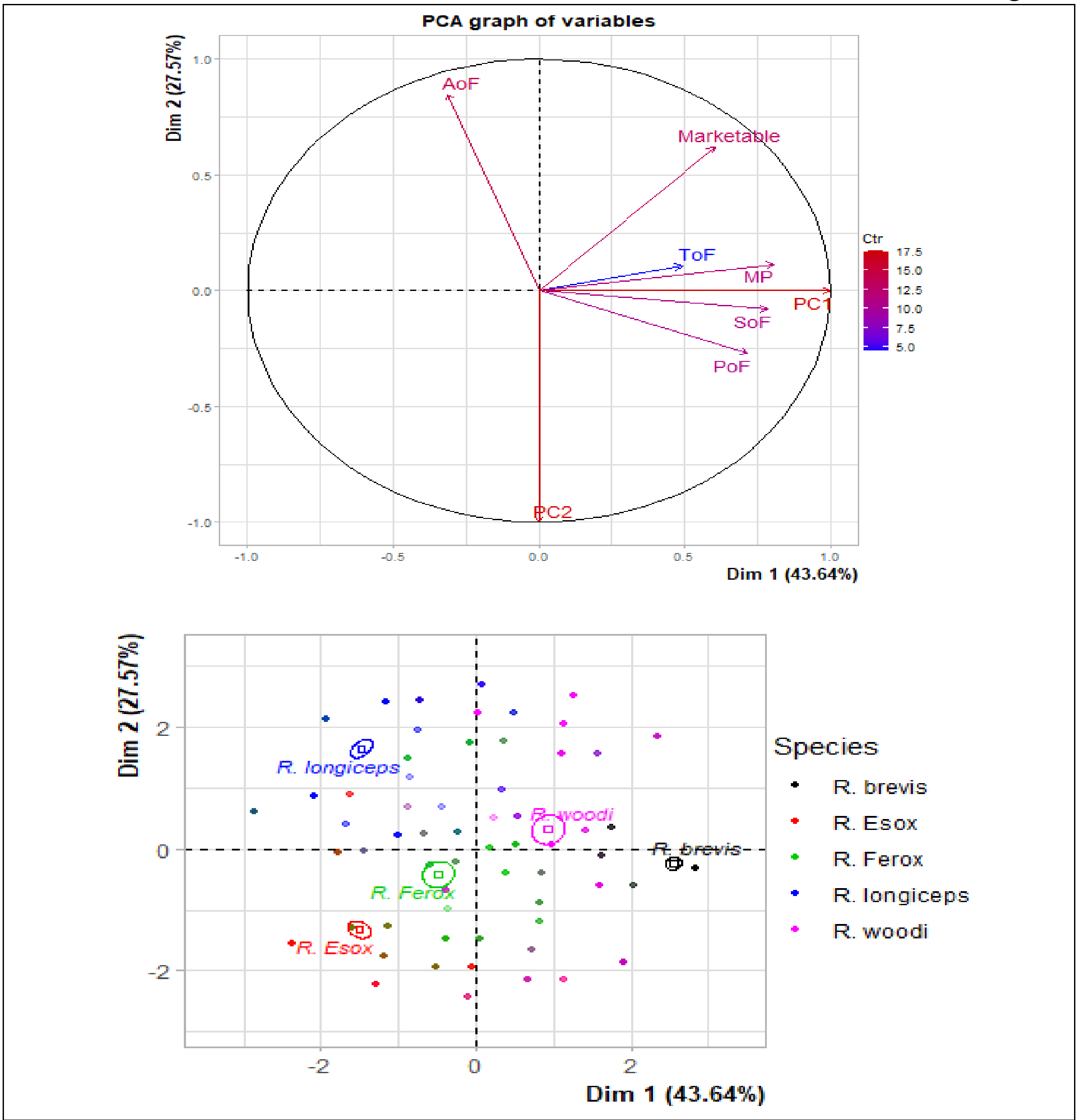

Figure 2. Individual factor map (PCA.) The labeled individuals and variables are those with the higher contribution and best shown on the plane construction. The individuals are colored by species.

4.3 Generalized Linear Mixed-Effects Models (GLMM)

Both PC1 and PC2 were significantly different between species (Table 2). The only remaining random factor after back selection was Stakeholders. Post hoc tests for PC1 showed that all the species differed from each other except for *R. longiceps* and *R. esox* (See table 6). *R. brevis* was significantly higher than the other four species. *R. wood* was significantly higher than *R. ferox* while *R. longiceps* and *R. esox* were significantly lower than *R. ferox*. Post hoc tests for PC2 show that all the species differed from each other except *R. brevis* and *R. esox* and *R. woodi* and *R. ferox*. *R. longiceps* was significantly lower than all other fish species (Figure 5 and Table 2).

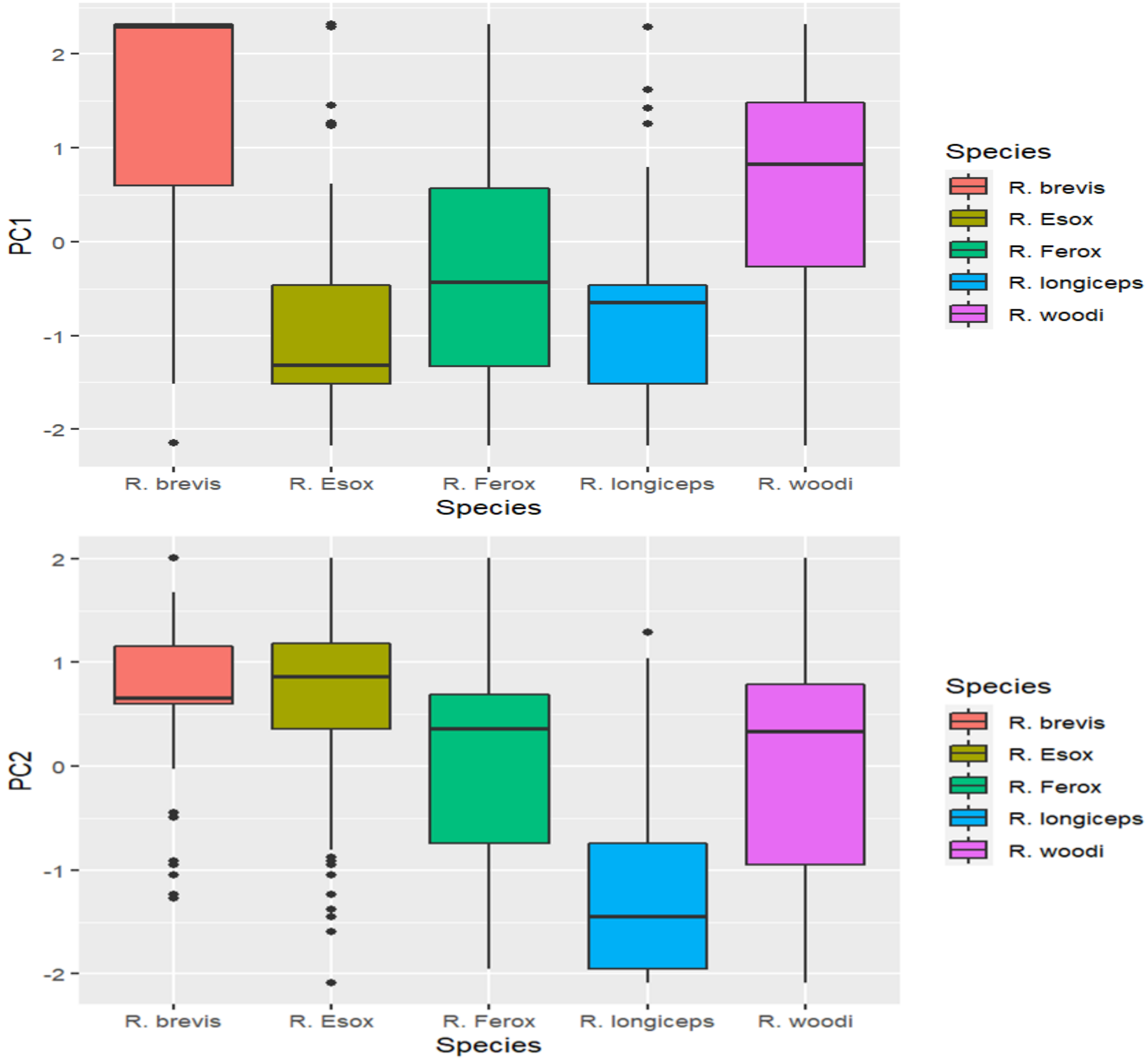

Figure 3. Boxplot for PC1 and PC2 scores showing the variations among species.

Table 2. Summary of ANOVA model testing the effect of species.

Response Variable	Effect	Estimates	std. Error	df	X^2	p-value
PC1	Intercept	2.57	0.10	4	603.63	< 0.001
	R esox	-2.25	0.11	4	603.63	< 0.001
	R ferox	-1.45	0.11	4	603.63	< 0.001
	R longiceps	-2.06	0.11	4	603.63	< 0.001
	R woodi	-0.60	0.11	4	603.63	< 0.001
PC2	Intercept	0.63	0.17	4	792.08	< 0.001
	R esox	0.00	0.08	4	792.08	< 0.001
	R ferox	-0.52	0.08	4	792.08	< 0.001
	R longiceps	-1.89	0.08	4	792.08	< 0.001
	R woodi	-0.68	0.08	4	792.08	< 0.001

The variable ‘Stakeholders’ was shown as a significant random factor in both PC1 (chi-2 = 95,8, P < 0,001) and PC2 (chi-2 = 95,8, P < 0,001). Post-hoc tests on the interaction between species and stakeholders were then performed for PC1 and PC2. Post hoc tests showed significant pairwise differences in PC1 for both *R. esox* and *R. ferox* (consumers were significantly higher than fishers), while for *R. woodi* fishers and farmers were significantly higher than consumers and for *R. longiceps* consumers were significantly higher than experts and in PC2 for *R. esox*, fishers and experts were significantly higher than farmers and consumers, for *R. ferox*, experts were significantly higher than consumers, and fishers, for *R. woodi*, consumers and experts were significantly higher than fishers and farmers, and for *R. longiceps* experts was significantly higher than fishers. There was no significant pairwise interaction for *R. brevis* in both PC1 and PC2 but farmers in PC1 were significantly lower than any other stakeholders (Fig. 6 & 7).

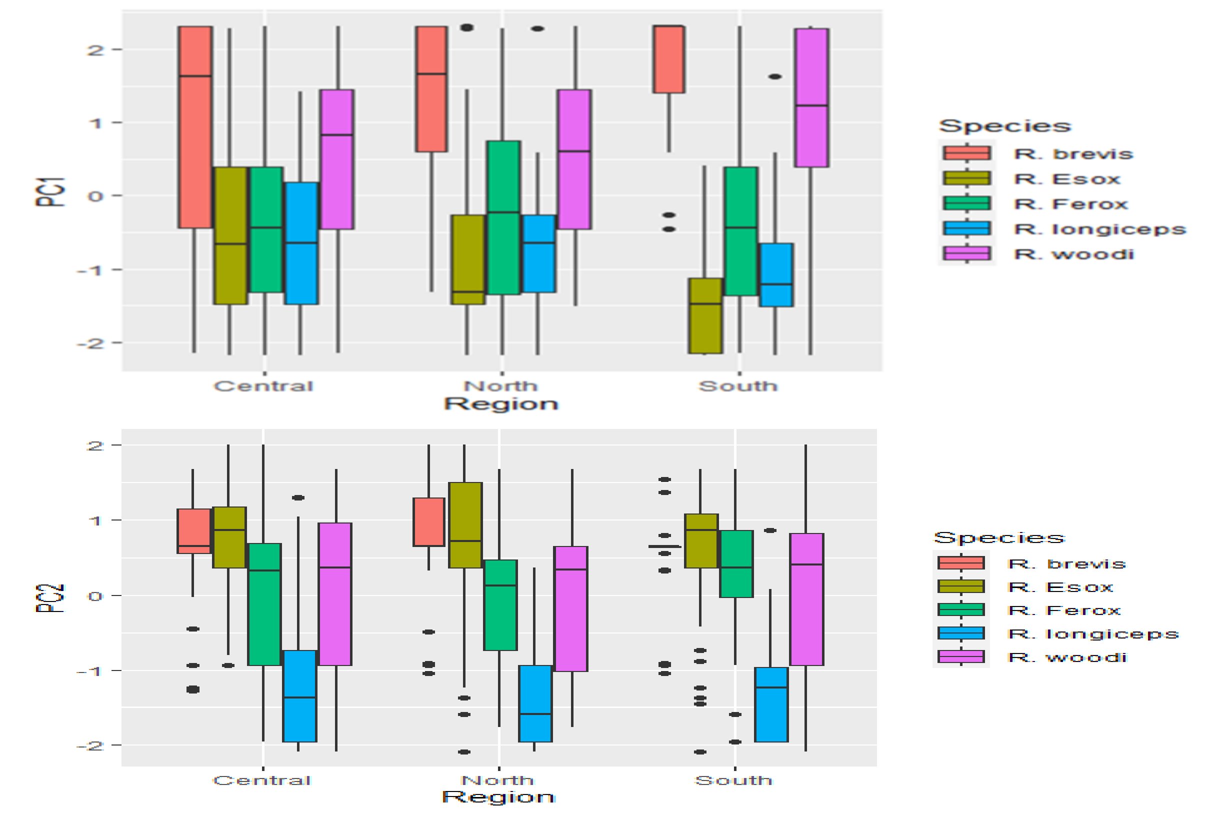

Figure 4. Boxplot for species loadings in PCA among the stakeholders.

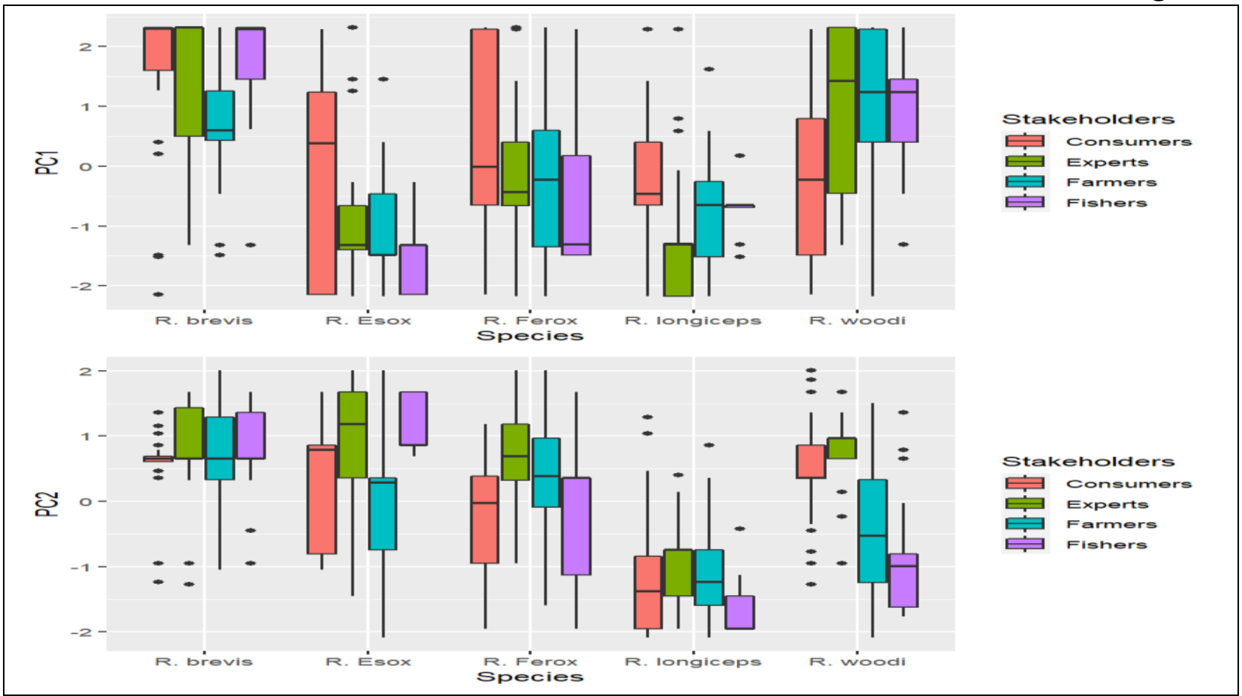

Figure 5. Boxplot for species loadings in PCA among the stakeholders.

4.4 Review of biological parameters of *Rhamphochromis sp.*

4.4.1 Nutrient composition of Rhamphochromis sp.

The nutrient composition of fresh Rhamphochromis sp. (mean moisture content, crude protein, crude fat, ash and energy) was reported by Msusa N. (2016) and is presented in Table 3.

Table 3. Nutrient composition of fresh *Rhamphochromis sp.*, compared to that of *Oreochromis shiranus*. (Msusa N., 2016).

Nutrients	***O. shiranus***	***Rhamphochromis* species**
Moisture	93.31±0.16	57.2±4.57
Crude protein	63.41±0.14	49.5±0.18
Crude fat	21.75±0.47	35.8±0.02
Ash	13.52±0.72	11.9±0.04
Energy		25.6±0.41

4.4.2 Ecology and Distribution

Rhamphochromis species are cichlids endemic to the Lake Malawi basin, also including Lake Malombe, Lake Chilingali, Chia Lagoon and upper Shire River (Genner, et al., 2007). They mainly occur in offshore open waters down to depths of 200m, but a few species are also found near the coast (Konings A. , 1990). On the other hand, *Oreochromis shiranus* is an inshore fish species, favoring shallow swampy areas and temporary pools and streams, but it is also found throughout the lake, including offshore.

4.4.3 Reproduction

This study has discovered similarities in breeding behavior between *Rhamphochromis* species and *O. shiranus*. They are both maternal mouthbrooders: female *Rhamphochromis* spawn with territorial males, take eggs away in their buccal cavity and brood clutches for periods of three to four weeks before releasing free-swimming offspring, while *O. shiranus* females build basin-shaped nests in shallow water from 0.15 m to 1.5 m deep, in sand overlaid with mud, in the vicinity of rooted aquatic vegetation; females brood eggs and young in the mouth until the young reach a length of about 10 mm.

The size at 50% maturity is taken as the size at which the percentage of ripe fish is half of the maximum for the species (leaving out size-classes with small sample sizes). It was found that there were no consistent differences in sizes of ripe males and females. Table 4 shows the size at maturity for several *Rhamphochromis* species, compared to *O. shiranus.*

Table 4. Size at maturity ($L_{m,}$ in cm) for *O. shiranus* and *Rhamphochromis* species. NF means Not Found in the literature.

	O. shiranus	***R. brevis***	***R. esox***	***R. ferox***	***R. longiceps***	***R. woodi***
Female (L_m)	17	NF	18.7	NF	13.8	16.4
Male (L_m)	22	NF	20.4	NF	14.3	19.8
Total Length	39	42	42	45	28	42

4.4.4 Diet

The pelagic cichlids of genus *Rhamphochromis* are the main piscivores of Lake Malawi. They mostly feed during daytime with peaks in feeding activity at dawn and dusk, following the vertical migration patterns of their prey (Alison et al 1996). This same study reported a food consumption:biomass ratio (QIB yrl) calculated from diel stomach content data for *R. longiceps* (4.20-24.7), which was obtained from an empirical model relating food consumption to fish morphology. *Rhamphochromis* species can be acclimatized to survive under aquarium environments where they can feed on flake and pellet food. Compared to the feeding behavior of *Oreochromis* species, the diet of *O. shiranus* is somewhat less complicated as they feed mainly on algae, detritus and zooplankton (Turner et al., 2004).

4.4.5 Fecundity

Comparisons of egg production between *Rhamphochromis* species and *O. shiranus* (Table 6) reveal that *R. esox* and *R. woodi* have higher fecundity than *O. shiranus* while *R. longiceps* has lower fecundity. There was no information to explain whether the number of eggs are related to the body sizes of the fish species. Information for *R. brevis* and *R. ferox* were not available to make comparison. Some report that *R. brevis* is synonymous with *R. woodi,* however the IUCN and Catalog of Fishes have accepted it as a legitimate separate species (IUCN, 2021). Still, it may be appropriate to assume that many aspects of their biology and ecology are similar to that of *R. woodi*.

Table 5. *Rhamphochromis* species and *Oreochromis shiranus* fecundity comparisons (Turner et al., 2004).

Species	**Fecundity**
O. shiranus	100-400 eggs
R. esox	117-680 eggs
R. longiceps	52-76 eggs
R. woodi	Over 546

5 DISCUSSION

Getting accurate information was complicated by our difficulty in distinguishing fish species from each other and limitations on accessing biological data. The reported information was gathered by interviewing stakeholders from different areas and reviewing primary literature. Considering these limitations, the information reported in this study should be treated with caution.

This is the first study to explore the biological and socioeconomic potential of *Rhamphochromis* species for success in cage aquaculture development in Malawi. The study aimed to determine whether the biological and socioeconomic parameters of *R*. species were suitable for sustainable cage aquaculture and then to create a strategic framework for the development of the identified species with the most potential for success.

R. brevis was identified as the most preferred fish species, by size and price. Malawians rank *R.* species as their first choice for taste and preference (Kaunda et al. 2003). The adoption of *O. shiranus* as a common aquaculture species by fish growers in Malawi stems mostly from a lack of alternative commercial fish species throughout Malawi, specifically for commercial purposes. Sustainable aquaculture development is dependent largely on commercial investments. Aquaculture in Malawi is being promoted as a business and therefore, high valued species with economic potentials must also be promoted. *R.* species are among the more highly economically valued fish species in Malawi, ranked third from *O. karongae* (locally known as chambo) and *Labeo mesops* (locally known as ntchira) in terms of price (GoM, 2020). Therefore, we consider that *R. brevis* should be introduced and developed for commercial aquaculture purposes.

This study reveals that *R.* species seem to play an important role in the Malawian diet as are favored as much as *O. karongae*. The fact that *O. karongae* has high protein requirements is depicted on the growth performance by slow growth as well as small sizes at harvest. This implies that the feed formulation for *O. karongae* might be more expensive than that of *R. brevis*. *O. karongae* is the most popular species in aquaculture among all species available for fish growers. However, this study has indicated that *R. brevis* is the most preferred among the stakeholders who call for the introduction of new fish species in aquaculture. One of the key factors associated with fish consumption is the affordability of the fish (Kaunda, 2003). In this study, *R. longiceps* was reported as less preferred but highly affordable and marketable.

This survey of socioeconomic parameters has helped to identify factors that influence consumers' purchasing decisions and fish farmers' choice of fish raised. These results allow us to propose changes to meet both farmers' and consumers' expectations with new aquaculture development (Trondsen, Scholderer, Lund, & Eggen, 2004). Understanding the factors related to fish consumption and demand is important not only for the market, but also for the implementation of public policies that encourage fish consumption and consequent improvement of lifestyle, given the relationship between fish production and fish consumption (Trondsen, Scholderer, Lund, & Eggen, 2004).

Fish preferences by individuals may depend on the size and the price of the fish. In this study, the socioeconomic analysis confirmed that the most preferred fish species have good sizes and prices (Table 3). Consequently, the current most farmed fish species in Malawi do not reflect the consumers' preferences. *O. shiranus* is always argued to be a slow grower and can only grow up to 150 grams in six months. This is not economically viable for commercial investors.

This study confirmed that *R. brevis* can reach more than 1 kilogram in size. However, it is not yet established what length growth period this would require under aquaculture conditions.

Fish preferences by fish growers may depend on the biological behavior of the fish such as growth rate, reproduction cycles, feeding behavior, and nutritional requirements. The introduction of fast-growing fish species to aquaculture is important in order to engage investors in aquaculture development. This study looked at the reported biological parameters of *R. brevis* and found out that much of the desired information was not available. The ecological information would help for aquaculture innovations such as the design of fish cages.

The major challenge identified is the carnivorous behavior of feeding on the zooplanktonic pelagic *Engraulicypris sardella*. However, this study does not see piscivorous behavior as limiting factor for development. In Europe, Seabass and Atlantic Salmon are aggressive carnivores but have been developed for aquaculture purposes due to their economic values. Some literature indicates the presence of *Chaoborus edulis* in the stomach of *Rhamphochromis* species. With the growing feed production industry, it stands to reason that a substitute to natural prey can be found. However, we strongly recommend for further studies to investigate nutritional requirements and other aspects of reproduction cycle. We noted from the literature that *R. brevis* can be acclimated to aquarium conditions and will feed on processed food.

In this study, the breeding pattern of *Rhamphochromis* species has shown a non-seasonality pattern. (Turner, Robison, Shaw, & Carvalho, 2004) reported that spawning for *R. brevis* occurs in July but may be longer. Turner *et al* (2004) reported that *R. longiceps* were ripe in the months of February, March, July, August, September, and October, indicating that reproduction is probably nonseasonal throughout the lake. However, *O. shiranus* has a clear seasonal breeding patten which is usually in the hot season from September to April in Lake Malawi. This suggests that *Rhamphochromis* species may be less affected by seasonality in Malawi, which would make it a good candidate for aquaculture.

6 CONCLUSION

The relationship between socioeconomic and biological parameters are important to consider for development of new fish species for aquaculture. However, the assessment requires more investment in research to determine all required parameters and make information available for aquaculture innovations. Though there were some gaps in biological information available for *Rhamphochromis* species, this study identified *R. brevis* as the species with the most potential for aquaculture success, based on its good size, taste and price.

6.1 Recommendations

It is recommended that quantitative studies are performed on diet composition and food consumption rate as these are key requirements for understanding the suitability of the species for aquaculture development. Additionally, more information is needed on the reproduction and life cycle to allow the government to develop a research-based system for controlling life cycle aspects of *Rhamphochromis* species under aquaculture conditions.

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APPENDICES

Appendix 1: Results of the post-hoc pairwise analysis

Analysis of Deviance Table (Type II Wald chi square tests). Response: PC1

```
                              Chisq Df Pr(>Chisq)    
Species                    835.7098  4  < 2.2e-16 ***
Region                       1.3016  2   0.521640    
Stakeholders                21.0250  3   0.000104 ***
Species:Region              91.3526  8  2.470e-16 ***
Species:Stakeholders       196.8458 12  < 2.2e-16 ***
Region:Stakeholders         28.7372  6  6.821e-05 ***
Species:Region:Stakeholders 186.9455 24  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Summary for the interaction. Response: PC1

```
                       Df Sum Sq Mean Sq F value   Pr(>F)    
Species                 4  864.7  216.18 169.539  < 2e-16 ***
Stakeholders            3   21.7    7.23   5.671 0.000742 ***
Species:Stakeholders   12  199.0   16.59  13.007  < 2e-16 ***
Residuals            1155 1472.8    1.28                     
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Post-hoc pairwise comparison test, interaction between species and stakeholders. Response: PC1

```
                                                    diff          lwr          upr   p   adj
R.  brevis:Experts-R.  brevis:Consumers               0.0222  -0.7265    0.7710  1.000
R.  brevis:Farmers-R.  brevis:Consumers              -0.7460  -1.4783   -0.0137  0.040
R.  brevis:Fishers-R.  brevis:Consumers               0.0598  -0.6725    0.7922  1.000
R.  Esox:Experts-R.  Esox:Consumers                  -0.7608  -1.5096   -0.0120  0.041
R.  Esox:Farmers-R.  Esox:Consumers                  -0.8495  -1.5818   -0.1172  0.006
R.  Esox:Fishers-R.  Esox:Consumers                  -1.3690  -2.1014   -0.6368  0.000
R.  Ferox:Experts-R.  Ferox:Consumers                -0.4903  -1.2391    0.2584  0.716
R.  Ferox:Farmers-R.  Ferox:Consumers                -0.6035  -1.3358    0.1288  0.275
R.  Ferox:Fishers-R.  Ferox:Consumers                -1.0819  -1.8142   -0.3496  0.000
R.   longiceps:Experts-R.   longiceps:Consumers   -1.1502   -1.8990   -0.4014   0.000
R.   longiceps:Farmers-R.   longiceps:Consumers   -0.5294   -1.2617    0.2029   0.531
R.   longiceps:Fishers-R.   longiceps:Consumers   -0.5775   -1.3098    0.1548   0.356
R.  woodi:Experts-R.  woodi:Consumers                 0.9801   0.2313    1.7288  0.001
R.  woodi:Farmers-R.  woodi:Consumers                 1.2143   0.4820    1.9467  0.000
R.  woodi:Fishers-R.  woodi:Consumers                 1.2747   0.5423    2.0070  0.000
R.  brevis:Farmers-R.  brevis:Experts                -0.7682  -1.5170   -0.0195  0.037
R.  brevis:Fishers-R.  brevis:Experts                 0.0375  -0.7112    0.7864  1.000
R.  Esox:Farmers-R.  Esox:Experts                    -0.0887  -0.8374    0.6601  1.000
R.  Esox:Fishers-R.  Esox:Experts                    -0.6082  -1.3570    0.1405  0.300
R.  Ferox:Farmers-R.  Ferox:Experts                  -0.1131  -0.8619    0.6356  1.000
R.  Ferox:Fishers-R.  Ferox:Experts                  -0.5915  -1.3403    0.1572  0.353
R.   longiceps:Farmers-R.   longiceps:Experts      0.6207   -0.1280    1.3695   0.264
R.   longiceps:Fishers-R.   longiceps:Experts      0.5726   -0.1761    1.3214   0.417
R.  woodi:Farmers-R.  woodi:Experts                   0.2343  -0.5144    0.9831  1.000
R.  woodi:Fishers-R.  woodi:Experts                   0.2946  -0.4541    1.0434  0.998
R.  brevis:Fishers-R.  brevis:Farmers                 0.8058   0.0735    1.5382  0.014
R.  Esox:Fishers-R.  Esox:Farmers                    -0.5195  -1.2518    0.2128  0.568
R.  Ferox:Fishers-R.  Ferox:Farmers                  -0.4784  -1.2107    0.2539  0.720
```

```
R.   longiceps:Fishers-R.   longiceps:Farmers        -0.0481   -0.7804      0.6842   1.000
R. woodi:Fishers-R. woodi:Farmers           0.0603 -0.6719  0.7927 1.000
```

Analysis of Deviance Table (Type II Wald chisquare tests). Response: PC2

```
                              Chisq Df Pr(>Chisq)    
Species                    1152.783  4  < 2.2e-16 ***
Region                        2.748  2  0.2530874    
Stakeholders                167.658  3  < 2.2e-16 ***
Species:Region               26.436  8  0.0008844 ***
Species:Stakeholders        318.933 12  < 2.2e-16 ***
Region:Stakeholders          75.171  6   3.54e-14 ***
Species:Region:Stakeholders  156.300 24  < 2.2e-16 ***
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1
```

Summary for the interaction. Response: PC2

```
                       Df Sum Sq Mean Sq F value Pr(>F)    
Species                 4  564.1  141.01  240.89 <2e-16 ***
Stakeholders            3   84.3   28.10   48.01 <2e-16 ***
Species:Stakeholders   12  154.9   12.91   22.05 <2e-16 ***
Residuals            1155  676.1    0.59                   
---
Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1
```

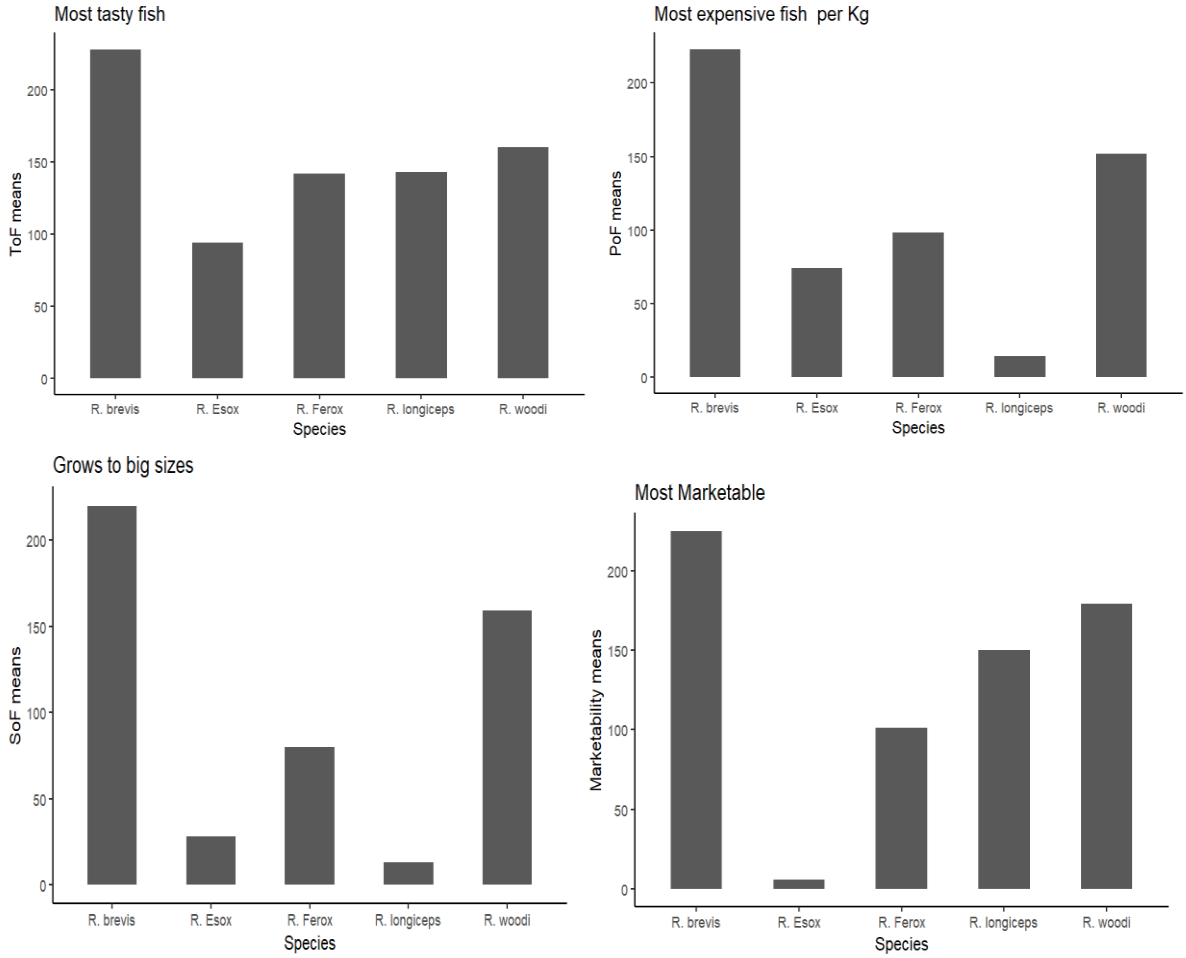
Post-hoc pairwise comparison test for PC2 interacting with species and stakeholders

```
                                              diff         lwr            upr   p   adj
R.   brevis:Experts-R.   brevis:Consumers            0.38324   -0.1241     0.890593  0.442
R.   brevis:Farmers-R.   brevis:Consumers            0.17021   -0.3260     0.666411  1.000
R.   brevis:Fishers-R.   brevis:Consumers            0.20220   -0.2940     0.698404  0.997
R.   Esox:Experts-R.   Esox:Consumers                0.70565    0.1983     1.213001  0.000
R.   Esox:Farmers-R.   Esox:Consumers               -0.38470   -0.8809     0.111497  0.390
R.   Esox:Fishers-R.   Esox:Consumers                0.79615    0.3000     1.292355  0.000
R.   Ferox:Experts-R.   Ferox:Consumers              0.90355    0.3962     1.410906  0.000
R.   Ferox:Farmers-R.   Ferox:Consumers              0.60906    0.1129     1.105257  0.002
R.   Ferox:Fishers-R.   Ferox:Consumers              0.11380   -0.3824     0.610004  1.000
R.    longicep:Experts-R.    longicep:Consumers      0.21858    -0.2888      0.725936   0.994
R.    longiceps:Farmer-R.    longiceps:Consumer      0.04675    -0.4495      0.542946   1.000
R.    longicep:Fishers-R.    longicep:Consumers    -0.48392    -0.9801      0.012280   0.066
R.   woodi:Experts-R.   woodi:Consumers              0.41135   -0.0960     0.918698  0.304
R.   woodi:Farmers-R.   woodi:Consumers             -0.96112   -1.4573    -0.464918  0.000
R.   woodi:Fishers-R.   woodi:Consumers             -1.47917   -1.9754    -0.982970  0.000
R.   brevis:Farmers-R.   brevis:Experts             -0.21303   -0.7204     0.294323  0.995
R.   brevis:Fishers-R.   brevis:Experts             -0.18104   -0.6884     0.326316  0.999
R.   Esox:Farmers-R.   Esox:Experts                 -1.09035   -1.5977    -0.583000  0.000
R.   Esox:Fishers-R.   Esox:Experts                  0.09051   -0.4168     0.597858  1.000
R.   Ferox:Farmers-R.   Ferox:Experts               -0.29450   -0.8018     0.212855  0.875
R.   Ferox:Fishers-R.   Ferox:Experts               -0.78975   -1.2971    -0.282398  0.000
R.    longiceps:Farmers-R.    longiceps:Experts    -0.17184    -0.6792      0.335514   1.000
R.    longiceps:Fishers-R.    longiceps:Experts    -0.70250    -1.2099     -0.195152   0.000
R.   woodi:Farmers-R.   woodi:Experts               -1.37246   -1.8798    -0.865112  0.000
R.   woodi:Fishers-R.   woodi:Experts               -1.89052   -2.3979    -1.383164  0.000
R.   brevis:Fishers-R.   brevis:Farmers              0.03199   -0.4642     0.528193  1.000
R.   Esox:Fishers-R.   Esox:Farmers                  1.18086    0.6847     1.677058  0.000
R.   Ferox:Fishers-R.   Ferox:Farmers               -0.49525   -0.9915     0.000947  0.051
R.    longiceps:Fishers-R.    longiceps:Farmers    -0.53067    -1.0269     -0.034466   0.022
R.   woodi:Fishers-R.   woodi:Farmers               -0.51805   -1.0143    -0.021852  0.030
```

PCA eigenvalue

	eigenvalue	variance.%	cum variance %
Dim.1	0.61	43.64	43.64
Dim.2	0.29	27.57	71.21
Dim.3	0.19	9.47	80.68
Dim.4	0.14	7.70	88.38
Dim.5	0.12	6.61	94.99
Dim.6	0.10	5.01	100.00

Appendix 2: Visualization of PCA variables for the five species analyzed.



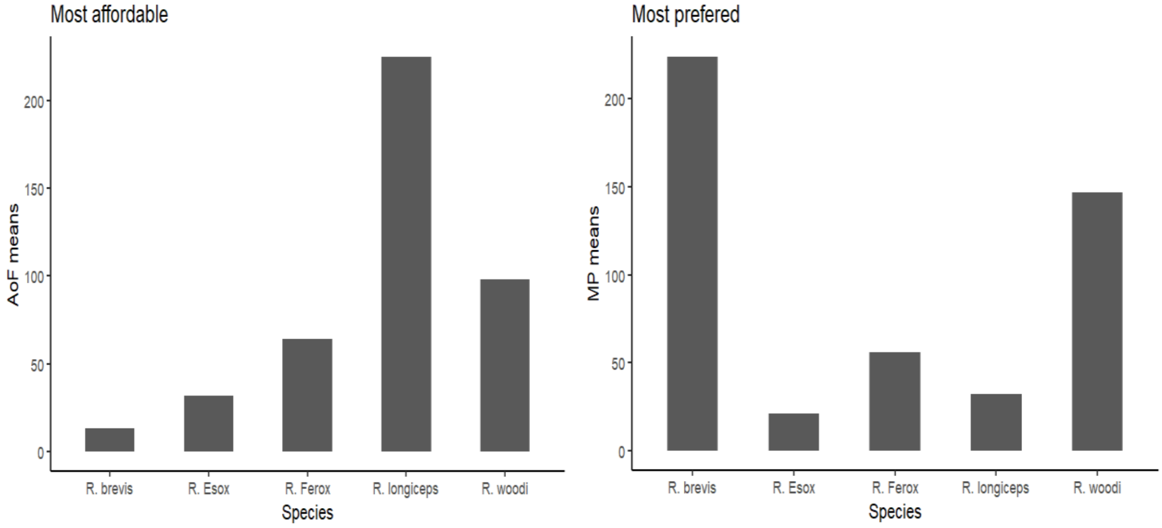


Figure A6. Percentage occurrence of the variables for the five species analyzed in PCA. Number of respondents analyzed was 235.

Appendix 3. Questionnaires

Questionnaire for Consumer Survey

1. Name of respondent……………………………Date ……………………………
2. Phone Number: …………………………………………………………
3. Sex: Female Male
4. Age: below 18years, 19-36years, 37-54years, 55-72years, Above 72years
5. District ……………………….……..…… and Region………………………………
6. Occupation: None, Fisher, Fish farmer, Fish trader, businessman, Government employee, NGO, Others
7. What is your profession? ……………….…………………………
8. Please indicate your level of education.

Education	Tick (√)	Education	Tick (√)
No formal education		MSCE	
JCE		Certificate	
Diploma		First Degree	
MSc		PhD	
Others (please specify) ……………………………..			

9. What is your family's monthly income (Malawian Kwacha)?

< Mk50,000 Mk50000 – Mk150000 Mk150,000 – Mk200,000 MK200,000 – MK500,000 >Mk500,000

10. When did you last eat fish?

Today yesterday Within the week More than a week ago About a month More than a month ago Cannot remember

11. How often do you eat fish?

Daily, More than once a week, Weekly, More than once a month, Monthly, Once in a while

12. How often do you eat any of the following fish species?

Species	Daily	More than once a week	Weekly	More than once a month	Monthly	Once a while
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. woodi						

13. Among the following fish species, which one do you prefer most? (Please tick as many as are applicable against the reasons provided)?

Species	Taste is good	Affordable	Accessible	Available	Others (please specify)
R. Brevis					
R. Esox					
R. Ferox					
R. longiceps					
R. woodi					

14. Tick for each species provided against each indicator, whether the species is accessible, preferred, available and affordable?

Indicator	*R. Brevis*	*R. Esox*	*R. Ferox*	*R. longiceps*	*R. woodii*
Marketable					
Preferred					
Good sizes					
Affordable					

15. How many kilograms of fish do you buy or eat per month in your family?

0kg, <5kgs, 5-10kgs, 10-20kgs >20kgs

16. How much do you spend on fish *R. species* per month? ………………………(MK)

Species	0	Less than Mk850	Mk850-Mk5000	Mk5000-Mk10000	More than Mk10000
R. Brevis					
R. Esox					
R. Ferox					
R.longiceps					
R. woodi					

17. How do you evaluate the taste and price of the following fish species

Species	Taste		Price	
	Good	Not Good	Cheap	Expensive
R. Brevis				
R. Esox				
R. Ferox				
R. longiceps				
R. woodi				

18. Would you eat these fish species if raised in the following systems?

Species	**Fish ponds only**	**Fish Cages only**	**Both ponds and cages**	**Not eat any from neither**
R. Brevis				
R. Esox				
R. Ferox				
R. longiceps				
R. woodi				

19. Have you ever eaten farmed fish? Yes or No…If Yes, mention the name of species………………………………………………………………………………
20. If yes in question 19 above, are farmed fish better than captured fish species? Give a reason?
………………………………………..

Questionnaire for Fish Farmer's Knowledge

1. Scale of your farm: Commercial……artisanal……………………………
2. How long have you been a fish farmer? Just circle or tick

< 1 year, 1-5years, 5-15 years, 15-25 years > 25 years

3. How many fish species have you ever farmed? List them…………………………
4. Which one is most preferred? Give a reason ………………………………
5. What challenges do you face when growing *Oreochromis shiranus (Makumba)*?

Challenge	Tick (√)	Challenge	Tick (√)
Low quality of fingerlings		Difficulties to find feed	
Slow growers			
small table sizes			
Starts breed fast			
Others (please specify) …………..……..			

6. Is it a good idea to start growing a new fish species?
…………………………………..……………………..……………………………
7. What are your thoughts about growing new fish species?
…………..……………………………………...……………………………………
8. Have you ever eaten any of the following species? Tick all you have ever eaten.

Species	Tick (√) all you have eaten	Tick your most preferred
R. Brevis		
R. Esox		
R. Ferox		
R. longiceps		
R. wood		
None		

9. Evaluate the following species in terms of taste and price?

Species	**Taste**				**Price/Kg**			
	Not good	**Good**	**Very good**	**Excellent**	**Very low**	**Fair**	**Reasonable**	**Expensive**
R. Brevis								
R. Esox								
R. Ferox								
R. longiceps								
R. woodi								

10. Which one will you be willing to farm?

Species	Tick (√)
R. Brevis	
R. Esox	
R. Ferox	
R. longiceps	
R. wood	
None	

11. Which one do you think bears the following attributes for aquaculture? Tick all applicable.

Species	**Good tasty**	**Good size**	**Good price**	**Marketable**	**Most affordable**	**Most candidate**
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. wood						
None						

Questionnaire for Fishers' Knowledge

1. Type of fisher: Commercial………………………. artisanal………………
2. When did you last go fishing?

Today, yesterday, Within the week, More than a week ago, About a month, More than a month ago, Cannot remember

3. How often do you go fishing?

Daily; More than once a week; Weekly; More than once a month; Monthly; Once a while

4. How long have you been fishing?

< 1 year, 1-5years, 5-15 years, 15-25 years > 25 years

5. How often do you catch the following fish species?

Species	Everyday	Once a week	Once a month	Once a while	Don't catch any	Remarks
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. wood						

6. How many kilograms of the following fish do you catch per month?

Species	0Kg	<10Kgs	10-40Kgs	40-100Kgs	>100Kgs	Remarks
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. wood						

7. How do you compare the current catches of the following fish species to the previous years? Indicate increase or decrease or no change.

Species	5 years ago	10 years ago	20 years ago	>30 years ago	Remarks
R. Brevis					
R. Esox					
R. Ferox					
R. longiceps					
R. wood					

8. Which one do you think bears the following attributes for aquaculture? Tick all applicable.

Species	Good tasty	Good size	Good price	Marketable	Most affordable	Most candidate
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. wood						
None						

9. How big do these fish species grow (Maximum size) and their prices?

Species	Weight (kg) or number/kg					Price/kg
	<500g	500g-1Kg	1Kg-1.5Kg	1.5Kg-2Kg	>2Kg	
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. wood						

10. When do the following fish species spawn (Just tick). Refer to photos of each species provided.

Species Name	Summer			Spring			Winter			Autumn			All year round	Don't know when
	D	J	F	M	A	M	J	J	A	S	O	N		
R. Brevis														
R. Esox														
R. Ferox														
R. longiceps														
R. wood														

11. How do the following fish species spawn (Just tick and comment). Refer to the photos

Species Name	Method				
	Mouth brooders	Nest builders	Substrate spawners	Others (Describe)	Don’t know
R. Brevis					
R. Esox					
R. Ferox					
R. longiceps					
R. woodii					

12. Where do the following fish species spawn (Just tick and comment). Refer to the photos

Species Name	Spawning Area				
	Open waters/offshore	Inshore, coastal	Rivers	River mouths	Don’t know
R. Brevis					
R. Esox					
R. Ferox					
R. longiceps					
R. wood					

Questionnaire for Fisheries Experts

1. How long have you working?

< 1 year, 1-5years, 5-15 years, 15-25 years > 25 years

2. How often do you catch the following fish species?

Species	Everyday	Once a week	Once a month	Once a while	Don’t catch any	Remarks
Rhamphochromis Brevis						
Rhamphochromis Esox						
Rhamphochromis Ferox						
Rhamphochromis longiceps						
Rhamphochromis wood						

3. How many kilograms of the following fish do you catch per month?

Species	**0Kg**	**<10Kgs**	**10-40Kgs**	**40-100Kgs**	**>100Kgs**	**Remarks**
Rhamphochromis Brevis						
Rhamphochromis Esox						
Rhamphochromis Ferox						
Rhamphochromis longiceps						
Rhamphochromis wood						

4. How do you compare the current catches of the following fish species to the previous years? Indicate increase or decrease or stable.

Species	**5 years ago**	**10 years ago**	**20 years ago**	**>30 years ago**	**Remarks**
Rhamphochromis Brevis					
Rhamphochromis Esox					
Rhamphochromis Ferox					
Rhamphochromis longiceps					
Rhamphochromis wood					

5. Which one do you think bears the following attributes for aquaculture? Tick all applicable.

Species	**Good tasty**	**Good size**	**Good price**	**Marketable**	**Most affordable**	**Most candidate**
R. Brevis						
R. Esox						
R. Ferox						
R. longiceps						
R. wood						
None						

6. When do the following fish species spawn (Just tick). For reference, photos of each species are provided.

Species Name	**Summer**			**Spring**			**Winter**			**Autumn**			**All year round**	**Don't know when**
	D	**J**	**F**	**M**	**A**	**M**	**J**	**J**	**A**	**S**	**O**	**N**		
R. Brevis														
R. Esox														
R. Ferox														
R. longiceps														
R. wood														

7. How do the following fish species spawn (Just tick and comment). Refer to the photos

Species Name	**Method**				
	Mouth brooders	**Nest builders**	**Substrate spawners**	**Others (Describe)**	**Don't know**
R. Brevis					
R. Esox					
R. Ferox					
R. longiceps					
R. woodii					

8. Where do the following fish species spawn (Just tick and comment).

Species Name	**Spawning Area**				
	Open waters/offshore	**Inshore, coastal**	**Rivers**	**River mouths**	**Don't know**
R. Brevis					
R. Esox					
R. Ferox					
R. longiceps					
R. wood					

9. Have you ever worked on *R. species* for aquaculture? Yes or No…………

10. Is it a good idea to introduce *R. species* for cage aquaculture?
……………...

11. What is your perception about farming it?

…………………………………………………………………………………………………

12. In a program that involves the farming of *R. species*, would you take part?

…………………………………………………………………………………………………

Questionnaire for Policymakers/NGOs/Development partners

1. Would you be willing to avail resources for the culture of R. species?
………………………………………………………………………………………
2. Do we have any law that restrict the introduction of exotic fish species in Malawi?
………………………...
3. What does the law say about the introduction of new fish species in Malawi?
…………………………………………………………………………………
4. How flexible are our laws about aquaculture to change?
……………………………………………………..