BIOECONOMIC ANALYSIS OF CHAMBO (*Oreochromis spp*.) AND KAMBUZI (small *Haplochromine* spp.) FISH STOCKS OF LAKE MALOMBE

PhD (AQUACULTURE AND FISHERIES SCIENCE) THESIS

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UNIVERSITY OF MALAŴI

BUNDA COLLEGE OF AGRICULTURE

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MSc (AFS), BSc (Agric)

A THESIS SUBMITTED TO THE FACULTY OF NATURAL RESOURCES IN PARTIAL FULFILMENT OF THE REQUIREMENT FOR THE AWARD OF THE DEGREE OF DOCTOR OF PHILOSOPHY (Ph.D) IN AQUACULTURE AND FISHERIES SCIENCE

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DECLARATION

I, Wales, Singini declare that this thesis is a result of my own original effort and work, and that to the best of my knowledge, the findings have never been previously presented to the University of Malawi or elsewhere for the award of any academic qualification. Where assistance was sought, it has been accordingly acknowledged. Parts of the materials presented in this thesis have been published and they appear as:. Wealth based fisheries management of *Orechromis* species (Chambo) of Lake Malombe in Malawi (2013), International Journal of Fisheries and Aquaculture: Logit analysis of socio-economic factors influencing intertemporal preference of fisheries resource users of Lake Malombe in Malawi (2013), Journal of Applied Social Sciences: Modelling and forecasting *Oreochromis* species (Chambo) production in Malaŵi – A stochastic model approach (2013), Recent Research in Science and Technology: Bioeconomic approach to rebuilding *Oreochromis* species of Lake Malombe, Malaŵi (2012), Journal of Engineering Science and Technology: Bioeconomic approach to rebuilding Small *Haplochromine* species of Lake Malombe, Malawi (2012) Journal of Scientific and Technology: Modelling and forecasting small *Haplochromine* species (Kambuzi) production in Malaŵi – A Stochastic Model Approach (2012), Journal of Scientific and Technology Research.

Wales Singini

Signature: ______________________________

Date: ______________________________

CERTIFICATE OF APPROVAL

We, the undersigned, certify that this thesis is a result of the author's own work, and that to the best of our knowledge, it has not been submitted for any other academic qualification within the University of Malawi or elsewhere. The thesis is acceptable in form and content, and that satisfactory knowledge of the field covered by the thesis was demonstrated by the candidate through an oral examination held on [11, 11, 2013].

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DEDICATION

To my wife Smeda Matundu, you have been patient and committed to my study. I left you alone at home but you encouraged me. Our parents, brothers and sisters for being there for me. Professor Emmanuel Kaunda , you have taken me throughout my education at Bunda (BSc, MSc and PhD).

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ABSTRACT

A study to establish bioeconomic options for economic exploitation of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) fisheries of Lake Malombe was conducted between 2010 to 2012. Three models, logistic regression, Univariate Autoregressive Integrated Moving Average and Gordon Schaefer bioeconomic models were used to test the research hypotheses. Primary data from resource users were collected using a pretested semi structured questionnaire. Time series data on catch, effort, fish price and costs from 1976 to 2011 were generated from the Traditional Fishery Data Base at Fisheries Research Station in Monkeybay. The logistic regression analysis showed that from thirteen predictor variables, six predictor variables were significant. Autoregressive Integrated Moving Average models for forecasting showed that catches for Chambo will decline to -1,111.80 tons in 2021 from 4,118 tons valued at MK1.318 million in 1976, but Kambuzi catches will increase to 4,224 tons in 2021 from 93 tons valued at MK175 thousand in 1976. Gordon Schaefer dynamic models estimated a maximum economic yield of MK2.148 million as compared to MK1.533 million for maximum sustainable yield for Chambo and MK2.172 million maximum economic yield as compared to MK0.715 million maximum sustainable yield for Kambuzi. The study concludes that there are high economic rents associated with maximum economic yield than maximum sustainable yield. It is recommended that Chambo and Kambuzi fisheries be managed at maximum economic yield, which implies reducing fishing effort. One way of achieving this is to introduce a rights based fisheries regime, which should be based on the intertemporal preferences.

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LIST OF ABBREVIATIONS AND ACRONYMS

ACF	Autocorrelation Function
AFMA	Australian Fisheries Management Authority
AR	Auto Regressive
ARFIMA	Auto Regressive Fractionally Integrated Moving
ARIMA	Autoregressive Integrated Moving Average
ARMA	Auto Regressive Moving Average
ARV	Average Relative Variance
BVAR	Bayesian Vector Auto Regressive
BVC	Beach Village Committee
CAS	Catch Assessment System
CPR	Common Pool Resource
CSY	Competitive Sustainable yield
DoF	Department of Fisheries
EA	Ecosystem approach
EAF	Ecosystem Approach to Fisheries
EFF	European Fisheries Fund
FAO	Food and Agricultural Organization
GDP	Gross Domestic Product
GoM	Government of Malawi
IFMP	Integrated Fisheries Management Plans
IQ	Individual Quota

ITQ	Individual Transferable Quota
kg/yr	Kilogram per year
MA	Moving Average
MAE	Mean Absolute Error
MAE	Mean Absolute Error
MAPE	Mean Absolute Percentage Error
MAPE	Mean Absolute Percentage Error
MaxAE	Maximum Absolute Error
MaxAPE	Maximum Absolute Percentage Error
MEY	Maximum Economic Yield
MK	Malawi Kwacha
MLE	Maximum likelihood estimation
MSY	Maximum Sustainable Yield
MTF	Malawi Traditional Fisheries
MTPR	Marginal Time Preference Rate
MVE	Marginal Value of fishing Effort
NBIC	Normalized Bayesian Information Criterion
NORMAC	Northern Prawn Fishery Management Advisory Committee
NPF	Northern Prawns fishery
NPV	Net present value
NSO	National Statistics Office
NSSH	Norwegian spring spawning herring

OAY	Open Access Yield
OSY	Optimal Sustainable Yield
PACF	Partial Autocorrelation Function
pers obs.	Personal Observation
PV	Present Value
RMSE	Root Mean Square Error
RMSE	Root Mean Square Error
SAP	Structural Adjustment Program
SAR	Simple Auto Regressive
SARIMA	Seasonal Auto Regressive Integrated Moving Average
SEA	South East Arm
SVAR	Structural Vector Auto Regressive
TAC	Total Allowable Catch
TC	Total Cost
TFDB	Traditional Fishery Data Base
TR	Total Revenue
TSR	Total Sustainable Revenue
UNCLOS	United Nations Convention for the Law of the Sea
UNDP	United Nations Development Programme
VAR	Vector Auto Regressive
WB	World Bank
WHO	World Health Organisation

CHAPTER ONE

INTRODUCTION

1.1. Overview of global fisheries

Capture fisheries and aquaculture supplied the world with about 148 million tonnes of fish in 2010 (with a total value of US$217.5 billion), of which about 128 million tonnes was utilized as food for people (Food and Agricultural Organization of the United Nations [FAO], 2011). Overall global capture fisheries production is at about 90 million tonnes although there have been some marked changes in catch trends by country, fishing area and species. The data for 2011 indicate increased production of 154 million tonnes, of which 131 million tonnes was destined as food (FAO, 2012). World per capita food fish supply increased from an average of 9.9 kg (live weight equivalent) in the 1960s to 18.4 kg in 2009, and estimates for 2010 point to a further increase in fish consumption to 18.6 kg. Of the 126 million tonnes available for human consumption in 2009, fish consumption was lowest in Africa (9.1 million tonnes, with 9.1 kg per capita), while Asia accounted for two-thirds of total consumption, with 85.4 million tonnes (20.7 kg per capita). (FAO, 2012).

The contribution of aquaculture to global supplies of fish, crustaceans, molluscs and other aquatic animals has grown dramatically, from 3.9 % of total production by weight in 1970 to 36% in 2006, accounting for 47 % of the world’s fish food supply. With an average annual growth rate of 8.7% since the 1970s, aquaculture is the fastest-growing animal-based food sector. However, there are concerns about the sustainability of the growth of the aquaculture sector (FAO, 2012).

The global proportion of non-fully exploited stocks has decreased gradually since 1974 when the first FAO assessment was completed. In contrast, the percentage of overexploited stocks increased, especially in the late 1970s to 2010 from 10 percent in 1974 to 26 percent in 2010. The increased percentage of overexploited fish stocks and the decreased proportion of non-fully exploited species around the world convey the strong message that the state of world fisheries is worsening and has a negative impact on fishery production. Overexploitation not only causes negative ecological consequences, but it also reduces fish production, which further leads to negative social and economic consequences.

To increase the contribution of fisheries to the food security, economies and well-being of the coastal communities, effective management plans must be put in place to rebuild overexploited stocks. Many of African fisheries resources are considered overexploited or collapse with a few being fully exploited. This is mainly due to accessibility of the resource by a wide range of user groups. Illegal harvesting which targets many of the same resources appears to be on the rise and will have dramatic impacts on the economic wellbeing of traditional, commercial and recreational fishers, and on the environment (Traffic, 2010).

1.2. Overview of Malawi fisheries

Malawi's inland fishery takes place in different lakes, including Lake Malawi which covers an area of 30,800 km², Lake Chilwa, Lake Chiuta and Lake Malombe. National catch statistics from all water bodies for Malawi show that total catches for 2010 were at 95,724 tons and about 84.22 per cent of the catch originated from Lake Malawi, followed by 8.38 per cent from Lake Chilwa whilst Lake Malombe and Lake Chiuta contributed 3.49 per cent and 2.66 per cent respectively (Government of Malawi [GoM], 2011). The fishing sector is important to both Malawi's economy and its overall food security, providing 4% of GDP (FAO, 2008). The sector directly employs nearly 59,873 fishers and indirectly over 500,000 people who are involved in fish processing, fish marketing, boat building and engine repair. Furthermore, nearly 1.6 million people in lakeshore communities derive their livelihood from the fishing industry (GoM, 2011). Fish provides over 70 per cent of the dietary animal protein intake of Malawians and 40 per cent of the total protein supply. It also provides vital vitamins, minerals and micronutrients. Much of the fish is consumed in rural areas thereby contributing significantly to daily nutritional requirements to some of the vulnerable groups such as HIV and AIDS victims, orphans and the poor (GoM, 2011). Fish landings in 2010 had a beach or landed value of MK19.9 billion (approx USD 121.3 million) (GoM, 2011).

However, most natural fish stocks in Malawi are either fully or over exploited. Coupled with the highest population growth rate in Southern Africa (2.8 % annually) (National Statistical Office [NSO], 2008), this has reduced per capita consumption of fish in Malawi (Jamu and Chimatiro, 2005; FAO, 2008). The supply of fish per person has been steadily decreasing. In 1976 per capita annual supply was 12.9 kg, this fell to 9.4 kg in 1990 and then decreased further to 7.3 kg in 2010 (GoM, 2011). The current average per capita consumption of 7.3 kg/yr is by far less than the recommended 13-15 kg of the World Health Organisation (WHO). Despite this shortfall, the supply of fish continues to contribute significantly to food security and nutrition within the country. These declining trends in fish catches and per capita availability of fish are reflected across Africa (Brummett *et al*., 2008). Additionally, Malawian fish catches are increasingly dominated by commercially-less valuable fish such as usipa (*Engraulicypris sardella*) and Utaka (*Copadichromis* spp), while harvests of the commercially important Chambo (*Oreochromis* spp.) have declined from 23,000 tonnes in 1984 to 7,000 tonnes in 2004 (NASP, 2004) and to 109.07 tonnes in 2010 (GoM, 2010).

1.3. Overview of Lake Malombe fisheries

Around 1980's Lake Malombe produced over 12,000 tonnes of fish, representing approximately 17% of Malawi's total production. However, the fishery has experienced a rapid decline in annual catches from about 12,000 tonnes in 1988 to nearly 3,700 tonnes in 1999. In 2002, the lake contributed 2-5% of the total fish production (Department of Fisheries [DoF], 2002). This represents a considerable loss in income levels of the fishers and nutrition to the communities. The economic value of the lake that was at MK42 million (US $0.396 million) in 1988 dropped to about MK4 million (US$37,735) in 1996 (DoF, 1999). The high valued Chambo (*Oreochromis* spp.) declined while the low valued Kambuzi (small *Haplochromine* spp.) increased although of late its production has also been decreasing. The lake provided a living example that fishery resources are finite and therefore can become extinct if not properly managed.

The collapse of the Chambo fishery in Lake Malombe was initially documented by the FAO Chambo Fisheries Research Project in the early 1990s (Van Zalinge *et al*., 1991). The total Chambo catch in this water body fell from a record high of over 8 400 tons in 1982 to a low level of less than 200 tons by 1999. In 1980, the Chambo contributed 87% of the total catch for Lake Malombe, but by 1999 it only contributed about 2%. In the period 1976-1990, contribution of the Chambo to the total catch was 49% whereas in the period 1991-1999 it was 4%. The *Oreochromis* fishery was almost completely replaced by a fishery comprising a complex of *haplochromine* cichlids locally known as Kambuzi. The catch fluctuated heavily, reached levels of around 9500 tons in 1987 and 1990 and dropped to a level of around 2 800 tons four years later. FAO (1993) presented evidence that high fishing effort was the major cause of the decline in *Oreochromis* catches since 1981 and the report further warned of a possible collapse of the small *haplochromine* fishery as well. In addition, the Gulland and Holt plot and the Von Bertalanffy non-linear regression, Jones length cohort analysis, Thompson and Bell analysis and Fox model suggested that small *Haplochromine cichlids* (Kambuzi) stocks were overexploited by the Nkacha fishery. Nevertheless, the Kambuzi fishery remained profitable. Therefore, a complete collapse of the Malombe fishery was not outside the realm of the possible.

The decline of the Lake Malombe fish stocks is attributed to several factors mainly overfishing, use of illegal gears, habitat degradation and non-compliance to regulations.

Overfishing of fish stocks in Lake Malombe is directly linked to increased fishing effort that has been observed over the last decade. The numbers of fishers, fishing gears and fishing crafts have increased over time. The common use of illegal gears with small meshes further increased effort. Small-meshed gears catch juveniles and immature fish. Consequently, increased effort resulted in both growth and recruitment overfishing. This ultimately led to the collapse of the fishery in Lake Malombe because all stages of life history became vulnerable (Seisay *et al*., 1992).

Attempts were made to restore fish habitats, protect juveniles and breeding fish and reduce fishing effort. While these had sound biological basis, it was soon realized that in the past, this approach alone was inadequate to ensure successful implementation as regulations or restrictive controls were simply ignored. The fisheries of Lake Malombe have been subjected to management measures such as closed seasons, minimum size and takeable size. These management techniques, however, do not address problems of open access and fishers do not follow these management methods. This has resulted in increased fishing effort that has contributed to overfishing.

However, when the serious decline of the Chambo in Lake Malombe was exposed in the early 1990s (Hara *et al*., 2002) a management plan was formulated by the FAO supported Chambo Fisheries Project to help save this collapsing fishery. The management plan was formulated based on conventional technical measures but was to be implemented through a more consultative and participatory approach called Participatory Fisheries Management (PFM) (Hara *et al*., 2002). This approach was envisaged to provide an alternative management arrangement as opposed to the top-down approach common with central government agencies. The PFM initiative started on the lake in 1994 but, unfortunately, even with this set up a decade down the line, the status of the Chambo stocks in Lake Malombe was in no better shape (Banda *et al*., 2002).

Most scientific studies that have contributed to fisheries management in Malawi have been based on stock assessment and biological models. However, there has been very weak link between the stock assessment and bioeconomic approaches in designing models for fisheries management. Furthermore, intertemporal preference of a common pool resource user has not been considered in designing management strategies. Where centralized or conventional fisheries management regime based on stock assessment has failed there is need to search for fisheries management systems that encompasse socio-economic, technological and political domains (Jentoft, 2001).

This study focused on the use of bioeconomic modelling for the development of rebuilding strategies. Bioeconomic approaches are particularly useful where fisheries laws allow consideration of economic, social, and cultural considerations in developing optimal rebuilding plans. Bioeconomic models can also be used to help managers balance the risk of protecting fishery stocks against the economic and social risks to fishermen, processors, and the communities that depend on their activities. Bioeconomic models, if properly used, can help managers develop objective analysis in order to select rebuilding strategies that have the best chance to maximize social welfare. Most importantly, if rebuilding is the objective then a dynamic model that examines the path to the objective (either biomass level for stock rebuilding or profit level for fisheries rebuilding) is necessary.

1.4. Objectives of the study

The main objective of the research was to establish bioeconomic options for economic exploitation of Chambo (*Oreochromis* spp.) and Kambuzi (small *haplochromine* spp) fish stocks of Lake Malombe.

1.4.1. Specific objectives

i. To assess intertemporal preferences of fisheries resource users in the exploitation of fish stocks of Lake Malombe.
ii. To forecast patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine* spp.) catches in Lake Malombe, so as to help in formulating strategies for economic management and conservation of the stocks.
iii. To estimate resource economic rents associated with maximum economic yield (MEY) and maximum sustainable yield (MSY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine* spp.) fishery of Lake Malombe.

1.4.2. Hypothesis

i. There are no intertemporal preferences among fisheries resource users in the exploitation of fish stocks in Lake Malombe.

ii. There are no differences between current catch patterns and forecasted catch patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine* spp.) in Lake Malombe.

iii. There are no differences in resource economic rents associated with maximum sustainable yield (MSY) and maximum economic yield (MEY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine* spp.) fishery of Lake Malombe.

1.5. Significance of the study

1.5.1. The choice of Lake Malombe

Lake Malombe supports a highly productive fishery based on medium sized, (Chambo) and small (Kambuzi) cichlids. Lake Malombe is polymictic (fully mixed); nutrients are well recycled and the productive zone extends to the bottom. It is believed that rainfall runoff contributes significantly to the productivity of the lake. The limnology of Lake Malombe from the chlorophyll a and Secchi disk (indicators of productivity) show evidence that it is much richer than Lake Malawi. Fishing is the major socio-economic occupation for the communities around Lake Malombe. The population of the area in 2000 was estimated at about 69,000 fishing families residing in at least 45 villages (Matiya and Wakabayashi, 2005). Despite the highly productive fishery that the lake supports, the lake has experienced rapid declining catches over the years.

This study used data for Chambo (*Oreochromis* spp.) (Figure 1.1) caught by gill net and Kambuzi (small *haplochromine* spp.) (Figure 1.2) caught by nkacha net from Lake Malombe. The species were selected based on the contribution to the overall economic output of Lake Malombe. The GOM/FAO/UNDP Chambo Fisheries Research Project (1993) reported that in terms of economic contribution, Kambuzi contributed MK3, 250,000, Chambo contributed MK950, 000, Mbaba (large *Haplochromine* spp) contributed MK940, 000 and Mlamba (*Clarias* spp) contributed MK330, 000 to the overall economic output of Lake Malombe.

Cichlids dominate the fishery in Lake Malombe. In terms of species composition, small *Haplochromine* spp., locally known as Kambuzi, is the most abundant fish in the lake. Kambuzi species, with an average length of 8 cm, constitutes over 70% of the fish catches. In the 1980's Chamb*o* used to constitute over 66% of the fish catch. Now the Chambo, with an average length of 27 cm and high valued, constitute only 3% of the catch. Other species in the lake include Mcheni (*Rhamphochromis* spp.) catfish (7%), Mbaba (*Buccochromis* spp.) (11%) and others including Kampango (*Bagrus meridionalis*) (DoF, 2004).

Figure 1.1 Chambo fish from Lake Malombe (2012)

Figure 1.2 Kambuzi fish from Lake Malombe (2012)

In socio-economic terms, the decline of the fish catches has resulted in economic losses to the fisheries sector and the national economy. The annual average economic value of the total landings during the periods 1976-90 and 1991-2003, translates to MK4.8 billion and MK2.2 billion, respectively. This is an economic loss estimated at MK2.6 billion per annum and is mainly attributed to the decline of the Chambo catches. Species other than the Chambo fetch lower prices at the market and, therefore, even their increased landings could not offset this economic loss attributed to the Chambo decline. The restoration of the Chambo stocks must, therefore, be regarded as a task of major economic importance to the Malawi rural economy (Banda *et al*., 2005).

Fish imports have generally increased for the past years due to declining fish catches in Malawi with 2010 registering total fish imports of 2,481,269kg valued at MK96,219,166 (USD506,416) (GoM, 2011). Most of the fish imports came from Zimbabwe, South Africa, Tanzania, Mozambique, Namibia, Lebanon, India and China.

1.5.2. Importance of bioeconomic approach in fisheries management

The importance of resource rent in fisheries has long been acknowledged. By generating such rents, economically efficient management systems increase value addition and the sectors contribution to the gross domestic product (GDP) and growth (Arthur *et al*., 2005). However, despite the successful adoption of such systems in some countries around the world, economics continues to have relatively little influence on fisheries policy. This lack of influence is particularly noticeable in developing countries, precisely where the contribution that effectively managed fish resources might make to the GDP is most urgently needed. The key requirement to increase the adoption of economically rational fisheries management is to convince policymakers to focus explicitly on the wealth-generating potential of fish resources.

Bioeconomic modelling has long been advocated as an important tool in managing fisheries for determining the sustainable levels of catch and effort and the exploitation path to achieve those equilibrium levels, particularly for rebuilding fish stocks (Clark, 1985, 1990; Hannesson, 1993; Seijo *et al*., 1998; Anderson and Seijo, 2009). The bioeconomic model of a fishery combines the underlying stock dynamics with the harvest functions and the costs of harvest and economic value of the extracted resources (whether retained or discarded). Such a model can address, for example, how quickly a fishery can be rebuilt so that stocks are increasing while ensuring a level of harvest to maintain employment and markets. Bioeconomic models accomplish this by specifying a policy objective (e.g. maximize landed value, landings, employment, or any combination) to determine prescribed catch and/or effort levels that consider the salient characteristics of both the stock and the fishery. Bioeconomic models allow us to incorporate the interaction between fishing behaviour and the biology of the stock through effort and catch, whose optimal values (i.e. those that maximize the objective) are mutually dependent. The simplest bioeconomic models are used to provide an estimate of the sustainable catch and corresponding effort level that results from a value-based objective function; this theoretically maximizes the economic yield (MEY).

Since bioeconomic modelling can incorporate some elements of human decision making (Larkin. *et al.*, 2011), it is a tool that is most effective for modelling fisheries instead of simply the resource stocks in a fishery. If fishery managers have concluded that the level of stock is too low and, therefore, want to manage the fishery to operate at a higher stock level; that is most aptly referred to as stock rebuilding. This scenario is contrasted to the desire of fishery managers to improve the fishing industry without increasing stock size. This latter scenario is more aptly referred to as fisheries rebuilding since it inherently involves the human dimension. When considering a stock that is undergoing overfishing or one that is overfished it is an important case to consider fisheries that are in need of rebuilding; fisheries may need rebuilding for purely social or economic reasons.

The fact that the MEY considers the economic characteristics of the fishery is a statement about the methods used to derive a management solution and not a justification for using it in management. All too often, especially for overfished stocks, economics is blamed for causing the need for rebuilding. But the MEY solution is best characterized as one that considers the economic efficiency associated with the sustainable yield curve, and there are a number of salient benefits for pursuing such a goal or at least evaluating it for any given fishery (Dichmont *et al.*, 2010). Since the solution is characterized by the fact that the differences between benefits and costs are the greatest, profits will always be maximized. This is important because it means that the approach is responsive to changes in economic conditions such as the price of the product and harvesting costs. The implication of efficiency (i.e. strictly using the resources that are needed in the fishery and no more) is that excess resources (i.e. capital) can be used alternatively in the economy. Lastly, the MEY solution is one that minimizes harvesting costs, which can help improve the competitiveness of a product. Minimizing costs can also provide an industry with resiliency to exogenous negative shocks.

By contrast, the MSY solution has no direct relationship with economic characteristics of the fishery and can generate zero or even negative profits (Kompas *et al*., 2009). Thus, the fourth reason why MEY might be considered preferable to the MSY as a management goal is that the MSY solution compromises the ability of a fishery to remain viable. Lastly, under reasonable bioeconomic assumptions, MEY may be associated with a larger equilibrium stock size than MSY (Grafton *et al*., 2007). One of the most compelling reasons to consider the bioeconomic (MEY) solution as a means of evaluating a fishery is that it models the efficient use of resources. The fact that the MEY solution is responsive to changes in the economic conditions of the fishery means that it is useful to explore how the single species model reacts to such realities.

The MEY explicitly considers the interests of the harvesters in addition to the necessary biological dynamics by including a harvest (i.e. production) function that translates fishing effort into catch. This function, and the resulting measure of net economic value of the resource, is considered crucial at the policy level since fishing is inherently an anthropocentric activity. In contrast, the MSY does not account for the costs of harvest, which are often stock dependent. This is why most economists advocate for consideration of the MEY by policy makers (Kompas *et al*., 2009).

The bioeconomic approach to fisheries management considers benefits to society in several ways (e.g., economic return, maximum economic yield) rather than just in terms of the traditional biological objective of maximizing the yield. In addition, consideration needs to be given to conserving the fish stocks targeted, and the ecosystems on which they depend. This implies that there are multiple objectives that fisheries management needs to consider explicitly (Kompas *et al.*, 2009).

1.5.3. Importance of time series in fisheries management

Forecasting biomass available for a fishery is an extremely relevant topic, because it plays a central role in management of stocks, preceding decision making (Makridakis *et al.,* 1983). In fisheries management policy, the main goal is to establish the maximum fishing effort applicable in a defined area during a known period to keep the stock replacement rate stable. To achieve this aim, it is necessary to predict the effect of uncontrollable events on abundance. Changes in abundance can be forecasted if quantitative data is available on the past catch, and if the assumption of continuity is accepted: That is to say, if we assume that some features of the past pattern will continue into the future (Makridakis *et al*., 1983; Stergiou *et al*., 1997).

Apart from methods based on biological principles, a variety of statistical techniques have also been used in fisheries forecasting. These methods are directed towards: (a) modelling on the basis of deterministic, regression techniques that explain changes in fishery variables in terms of changes in various biotic and/or abiotic variables; (b) modelling on the basis of univariate time series techniques that treat the system as a black-box, i.e. viewed as an unknown generating process and (c) methods that synthesise the two above mentioned general approaches (Stergiou *et al*., 1997).

Time-series analysis of fishery data has been an important tool for fisheries management and decision-making as it reveals hidden trends and seasonality patterns (CIESM, 2003). Several statistical models (Autoregressive integrated moving average model (ARIMA), transfer function models, intervention analysis, decomposition and regression models, and MAFA techniques) have been widely used for fishery time-series and forecasting, as summarized by CIESM (2003).

The term time series analysis is used to distinguish a problem, firstly from more ordinary data analysis problems (where there is no natural ordering of the context of individual observations). Secondly, from spatial data analysis there is a context that observations relate to geographical locations. There are additional possibilities in the form of space-time models (often called spatial-temporal analysis). A time series model will generally reflect the fact that observations close together in time will be more closely related than observations further apart. In addition, this method often makes use of the natural one-way ordering of time, so that values in a series for a given time will be expressed as derived from past values, rather than from future values

ARIMA modelling for optimal forecasting techniques and decision support system was used to forecast the general trend of fish catch time-series data in Lake Malombe because of increased reliability and accuracy. ARIMA models are linear techniques, meaning that predictions of future values are constrained to be linear functions of past observations, under the assumption that the data series is stationary. Due to their relative simplicity, linear models have been the main research focus and application tools. This methodology has been used to model and forecast the landings and catch per unit effort of many fish and invertebrate species (Lloret *et al*., 2000; Pierce and Boyle, 2003).

The ARIMA model is a widely-used model for univariate time series. It incorporates three terms, namely, the Auto Regressive (AR) term, the integrated term, and the Moving Average (MA) term. The AR term is simply a linear regression of the current value of the series against one or more prior values of the series. It captures the dependency of current value and its nearest prior values. Since usually a time series may receive random shocks in a noisy environment and may memorize the previously received random shocks for a while, the MA term is introduced to capture the random shocks to the future. The combination of the AR term and the MA term is called the ARIMA model. The ARIMA model assumes that the data are stationary, that is, the statistical properties of data do not change over time. However, this assumption does not hold in most real data series. Thus, the integrated term is introduced to remove the impact of non-stationary data by differencing (Gujarati, 2004).

Among the methods based on univariate techniques, the ARIMA models by Box and Jenkins (1976) stand out because of their wide range of application. These statistical models assume linear dependence between the time series data. Thus, each observation can be explained as a linear function of its past values, but with some errors. The variability found in the results from applying ARIMA models is due mostly to the fact that they are linear univariate models (the linear relationship between variables is assumed). ARIMA models have the same properties as the most simple time series models like moving average (MA) and autoregressive (AR) models. They can include cyclic/seasonal components and their mathematics is not excessively complex. These properties have favoured the application of this kind of model to predict different variables in numerous fields of engineering and the sciences, including fishery science (Phillips, 1983; Stocker and Noakes, 1988; Stergiou, 1989, 1990, 1991; Stergiou *et al*., 1997; Lloret *et al*., 2000; Becerra-Mu˜noz *et al*., 2003; H¨anninen *et al*., 2003; Punz´on *et al*., 2004; Guti´errez-Estrada *et al*., 2004).

CHAPTER TWO

LITERATURE REVIEW

2.1. History of fisheries management in Malawi.

Prior to 1993, the Fisheries Management approach in Malawi was mainly influenced by the principles of the conservation paradigm, i.e. a biologically centralized led approach (Matiya and Wakabayashi, 2005). As such one of its sectoral policy objectives was to maximize the sustainable yield from fish stocks that could economically be exploited from natural waters. The conceptual approach was based on the theories of Maximum Sustainable Yield (MSY) (FAO, 2005).

Although it is widely practiced by state and federal government agencies regulating wildlife, forests, and fishing, MSY has come under heavy criticism by ecologists and economists for both theoretical and practical reasons. The concept of MSY is not always easy to apply. Estimation problems arise due to poor assumptions in some models and lack of reliability of the data (Bousquet *et. al*., 2008). Biologists, for example, do not always have enough data to make a clear determination of the population's size and growth rate. Calculating the point at which a population begins to slow due to competition is also very difficult. The concept of MSY also tends to treat all individuals in the population as identical, thereby ignoring other aspects of population structure such as size or age classes and their differential rates of growth, survival, and reproduction (Bousquet *et. al*., 2008). Starting to harvest a previously unharvested population will always lead to a decrease in the population size. Thus, it is impossible for a harvested population to remain at its original carrying capacity. Instead, the population will either stabilize at a new but lower equilibrium size or, if the harvesting rate is too high, decline towards zero (Mace, 2001).

As a management goal, the static interpretation of MSY (i.e. MSY as a fixed catch that can be taken year after year) is generally not appropriate because it ignores the fact that fish populations undergo natural fluctuations (i.e., MSY treats the environment as unvarying) in abundance and will usually ultimately become severely depleted under a constant-catch strategy (Townsend *et.al*., 2008). The MSY approach to fisheries management in Malawi is generally considered a failure due to declining national catch figures and examples of overfishing like the case of Lake Malombe.

2.2. Research contribution to fisheries management of Lake Malombe

Fisheries science has continued a strong emphasis on studying factors that affect the growth, mortality, and reproduction of fish stocks in an ecosystem context, but opportunities to directly incorporate growing body of knowledge on intertemporal preference is lagging (Maunder and Watters, 2003; Schirripa and Colbert, 2006). Fisheries experts now recognize that resource conflicts can be diminished and resources better managed when fishers and other resource stakeholders are more involved in management, and access rights are distributed more effectively and equitably.

FAO (1993) jointly with United Nations Development Programme (UNDP) and the Malawian Fisheries Department undertook a project whose main immediate objective was to formulate a suitable management plan for the Chambo (*Oreochromis spp.)* fisheries in the south-east arm of Lake Malawi, the Upper Shire River and Lake Malombe. The emphasis of the research was the biological stock assessment on Chambo. For management purposes the biological stock assessment was complemented by socio-economic investigations (baseline, cost and earning, fish marketing surveys). The biological, stock assessment and socio-economic findings were used to evaluate predictive scenarios developed for different management options. The FAO (1993) research used Gulland and Holt plot and the Von Bertalanffy non-linear regression method to estimate growth parameters from the dissected mean lengths. Jones's (1984) length cohort analysis was used to estimate stock size and fishing mortalities (F). Yield (catch as weight) and stock biomass were predicted for various levels of fishing effort, using the length-based Thompson and Bell analysis.

Jones length cohort analysis assumes that fishing effort remain constant, recruitment remain constant and affect all age classes in the same way and finally it assumes that length composition data represents an average situation. Thompson and Bell analysis assumes constant recruitment and predicts long term catches. Considering the dynamic state of fishery in Lake Malombe that is characterized by increased entry into fishing business as the only form of livelihood for people around the lake, sharp decline in catches, fish maturing early due to excess fishing pressure (Kapute *et.al*., 2008), the models used would have underestimated or overestimated the status of standing stock in the lake. Furthermore, the research was based purely on biological studies which informed the greater part of management strategies developed by the project. All the management options recommended by the project were based on centralized management approach which had not worked for Malawi fisheries management. Even when the management options were based on apparently sound science, they failed to prevent severe overfishing. The reason for these failures were due to lack of consideration of the economic incentives and time preference affecting fishermen (Clark, 2006).

In the bioeconomic analysis the FAO project used Fox model. Despite the better fit of the Fox models, it is believed that at high effort levels they give unrealistically optimistic predictions for African Cichlid stocks (FAO, 1993). This is because the fish have low fecundities, and thus recruitment is likely to be strongly related to the adult stock size, leading to rapid collapse at a high fishing effort.

A study by Maguza-Tembo (2002) on bioeconomics of common resource overexploitation of Lake Malombe Chambo (*Oreochromis* spp. Cichlidae) fishery in Malawi applied Gordon-Schaefer and Gompertz/Fox models to analyze biological maximum sustainable yield (MSY) and economic maximum economic yield (MEY). The study showed evidence of Chambo and whole fishery overexploitation. The study showed that there was under fishing before 1987 and overfishing after 1987. To attain efficient levels the study suggested reduction of effort in Chambo fishery to attain MSY and MEY.

The study developed management advice which has also proved difficult to implement. The study was based on theoretical approach to fisheries management as such it has not fully contributed to the management of fisheries of Lake Malombe. The study did not consider time preference of common pool resource user in developing management options. Fish populations are better managed by regulating the actions of people (Duzgunes, 2008). If fisheries management is to be successful, then associated human factors, such as the reactions of fishermen, are of key importance, and need to be understood (Duzgunes, 2008).

Furthermore, the study applied Fox Model for comparison with Gordon-Schaefer model. Fox model is a surplus production model for the calculation of the MSY of a fishery based on a regression of the logarithm of catch per unit effort (cpue) on effort. The approach is not appropriate for fish stocks which collapse suddenly at high levels of exploitation as the case of Lake Malombe fishery (Van Zalinge *et.al*., 1992). Although the equilibrium estimators MSY and MEY are useful benchmarks in the bioeconomic analysis of fisheries, their static nature diminish their reliability as appropriate management tools. Considering it extremely unlikely that the fishery system reflects equilibrium states, the dynamic fitting of the Schaefer-Gordon model should be preferred to its static counterpart, as it takes into account the intertemporal flow of costs and benefits from different fishing effort levels and dynamic biomass fluctuations (Seijo, 1998).

A study by Kapute *et.al*. (2008) in Lakes Malawi and Malombe estimated maturity, age and growth of *Oreochromis karongae*. The growth parameters were estimated using von Bertalanffy growth model (Sparre and Venema, 1998). Even though the study managed to establish growth parameters for management of Chambo in Lakes Malawi and Malombe, its contribution was limited to stock assessment and biological management of fisheries. The parameters estimated did not consider the fishers preference in the management of common pool resources. The finding could only contribute to the conventional fishery management systems. Furthermore, the study did not estimate some parameters which are inputs into stock size/biomass estimation models such as Jones Length cohort analysis, Thompson and Bell analysis and the age structured dynamic models.

A study by Weyl *et.al*. (2005) assessed *Copadichromis chrysonotus* resource in Lake Malombe using per-recruit analysis. Age-based growth, mortality and sexual maturity parameters necessary for the pre-recruit models were estimated. Length–frequency analysis described length-at-age (l_t) with the von Bertalanffy model. The study showed that the *C. chrysonotus* resource is over-utilised. Effort reductions were recommended such that fishing mortality should be reduced to rebuild spawner biomass to acceptable levels. The contribution of the study was limited to stock assessment and biological management of fisheries resource. The parameters estimated did not consider the fishers preference in the management of common pool resources. The finding could contributed to the conventional fishery management systems. It is therefore important to explicitly take account of intertemporal preferences in the decision-making process if a governance system for a given fishery is to succeed (Sumaila and Domínguez-Torreiro, 2010).

2.3. Bioeconomic approach to rebuilding fisheries

There is a perceived risk of extinction that is associated with allowing a fishery to remain open during periods of low stock levels that is so great as to justify a closure, despite the negative economic consequences associated with closures. This argument is supported with historical evidence of overfished stocks that have been unable to recover (e.g. Safina *et al*., 2005; Rosenberg *et al*., 2006, Worm *et al*., 2009). However, as Larkin *et al*. (2006) has shown, rebuilding stocks as fast as biologically possible has real social costs. Balancing these costs with the risk of lower than expected stock growth or possible risk of extinction can be evaluated within bioeconomic models that explicitly evaluate biological and economic risks.

In contrast to several studies showing that benefits are maximized by rebuilding as fast as possible (e.g. Sumaila and Suatoni, 2005; Gates, 2009), it has been observed that delayed rebuilding can considerably increase average harvest levels and benefits. Gates (2009) reported that using 4% discount rate and slowing the rebuilding target by a decade, would increase average harvest levels by 93% on average since the model allows for fishing through the rebuilding period. The associated benefits of this slower rebuild are that the net present value increases 58%, due in part to the higher product price from low stock levels in the early years. Thus, mandating rebuilding only on biological criteria may produce significant economic losses, particularly for slow-growing stocks in fisheries with high discount rates.

Agar and Sutinen (2004) considered the impacts of different rebuilding strategies in a multi-species fishery. More specifically, they considered alternative gear restrictions and non-selective technologies by changing the catchability of the over- and under-exploited species. These rebuilding strategies were then analyzed within the context of biological predator-prey interactions between the species and economic cost interdependencies in the fishing of the two species. Rebuilding outcomes varied considerably with the type of technology employed (changing the catchability coefficient) and the presence of cost and biological interactions. In particular, consideration of biological interactions drastically increased the ambiguity of the outcome, and different combinations of interactions and technologies further depleted the stock rather than rebuilding it. They concluded that the failure to consider such interdependencies may negatively affect rebuilding efforts.

Larkin *et al*. (2006) considered the effects of different rebuilding timeframes under different discount rates on the annual sustainable catch and the net present value of benefits of harvesting fish from two different populations: a moderate-lived species and a long-lived species. An age-structured dynamic bioeconomic model was developed to account for the different cohorts. Net benefits were calculated using price and variable cost functions that were inversely proportional to landings and spawning biomass, respectively. Tradeoffs between rebuilding timeframes, average harvest levels and the value of the fishery were examined. The results highlighted the importance of bioeconomic models when a fishery faces rigid rebuilding guidelines.

The most recognizable bioeconomic model is where a single stock is harvested by a single homogeneous fishing gear. Such a model determines a combination of a harvest level and effort level that maximizes the net present value of harvests under identical conditions in perpetuity. This "equilibrium" solution is considered the sustainable economic solution that produces maximum economic yield (MEY) and is an alternative to a biological solution of maximizing the harvest level over time or maximizing the sustainable yield (MSY). The divergence of these two solutions provides policy advice from a bioeconomic perspective. Such an approach can be used for rebuilding but it lacks information on the optimal time horizon or time path. Because static models exclude information on the transition, and the reasons behind the need for rebuilding, they are inadequate for addressing the rebuilding of fisheries (Clark, 2006a).

Bioeconomic analysis for rebuilding requires an examination of how key parameters affect the optimal time horizon and time path as stock levels increase. How parameters affect the static equilibrium can be quite different from how they impact the dynamics of a time path. And, while constant parameters may be acceptable for determining an initial equilibrium target (e.g. MEY), the dynamic specification may need to consider endogenous effects such as how costs vary with stock size or effort or how fish prices may change with harvest levels or fish size. For long lived stocks, bioeconomic models may need to include the age structure of the population. This would be especially critical if there was concern over the abundance of older females that could disproportionately affect successful rebuilding as opposed to modelling the overall size of the biomass. Cohort-based bioeconomic models would also be important where the unit value of an individual can vary by age which in turn can affect the optimal allocation of stock among heterogeneous harvest groups that use different gear, fish in different areas, or produce different products (e.g. Armstrong and Sumaila, 2000; Larkin and Sylvia, 2004). Recent advances in the theory of bioeconomic models for age-structured populations (e.g. Tahvonen, 2009) are likely to inspire more empirical research of such populations.

There is worldwide concern for the sustainability of fisheries and commercial fisheries in particular (e.g. Hilborn *et al*., 2005; Worm *et al*., 2009). Some international organizations and countries have revised management plans and established specific protocols for addressing the need to rebuild fisheries (Khwaja and Cox, 2009). One tool used to manage and rebuild fish stocks is calculation of reference points which associate specific harvest management rules with different levels of the stock. While these technical rules are intuitively appealing they ignore fishers' behaviour and economic conditions of the fisheries (Hilborn, 2002; Clark, 2006b). Management based on standardized reference points and global rules may also ignore the biological realities of local contexts. Reference points often discourage innovation and the development of better management alternatives (Hilborn, 2002). While reference point-based management might result in stock recovery, the process is often characterized by an inability to assess success or failure in achieving fishery goals beyond those established for the stock. A focus on predetermined biological-based rules limits creative options within a broader economic and social context.

There is a larger question behind the choice of management strategies and tools regarding the ultimate purpose of fisheries and the parameters to be used for rebuilding. Hilborn (2002) points out that emphasizing the precautionary principle has caused neglect of the true purpose of a fishery, which is to produce social and economic benefits to society. Stock conservation (i.e. sustainable harvest levels) and maximization of social benefits over time from a fishery are not mutually exclusive goals; they are, by necessity, compatible and complementary. Full social benefits from a fishery are not realized when the fish stock is over-exploited since by definition population is below the level that produces MEY. Conversely, recovery of an over-exploited fish stock cannot take place if economic and social realities are ignored.

Once a stock is declared overfished, it is tempting to consider the most direct, enforceable, and effective solution to rebuild the stock: close fisheries (Clark, 2006a). In fact, many studies advocate closure as a solution to what is considered to be an urgent problem (Safina *et al*., 2005; Sumaila and Suatoni, 2005; Rosenberg *et al*., 2006; Gates, 2009). Many studies claim that expedient rebuilding is the benefit-maximizing rebuilding strategy in the long run (Hilborn *et al*., 2005): the sooner we close, the sooner we open, so benefits are realized sooner. Rosenberg *et al*. (2006) reiterate the relevance of this approach by claiming that the overall (negative) economic impact (from keeping fisheries open) is likely to be much greater as a result of a long continued decline and delay in rebuilding than from a short-term reduction in catch in order to rebuild populations quickly. In addition to the appeal of a simple approach, a common justification for rebuilding as soon as possible is solely because it is biologically possible within a reasonable time frame. Referring to stocks in the United States, Rosenberg *et al*. (2006) states that most stocks have the potential to be rebuilt within 10 years (Safina *et al*., 2005), so this lack of demonstrable progress is disappointing.

According to Caddy and Agnew (2004), leaving fisheries open during rebuilding is impractical and will not generate sufficient financial returns. The authors, in reviewing rebuilding attempts worldwide, do, however, acknowledge that the collapse of Canadian ground fish stocks made closure inevitable, but revealed that this measure is not inevitably successful. The study by Caddy and Agnew advocated for closure, but did not examine rebuilding within a broader bioeconomic context. Over 60 considerations are listed in developing a rebuilding plan but these are primarily based on seven case studies. None of these cases acknowledge economic behaviour or whether economic, social, community and cultural concerns are relevant.

While the literature advocating closures contains intuitive appeal, intuition is often the only reason (other than a supportive legal environment) provided to justify a closure. The quantitative analyses that have been used to support the quickest possible rebuilding horizon (e.g. Sumaila and Suatoni, 2005, or Gates, 2009) utilize simplistic financial analysis with flawed assumptions. The review process noted that there are few studies that conducted an economic analysis that explicitly considered or supported a closure (i.e. considered both the benefits and costs). That said, there are some studies that have supported the continuation of fishing using a model that accounts for the salient social and economic factors for any given fishery (Gates, 2009). Delaying the rebuilding horizon in order to allow for some level of harvesting can provide the following benefits (Gates, 2009): Continued data collection, especially on the stock that can be used to monitor the recovery; support for the sustainability of coastal communities; retain malleable capital, including labour, in the harvesting and or processing sectors; maintain markets at the local level versus a loss of the market to imports; provide higher product prices initially for distinct products and higher yields later on as the average size of individual increases; and reduce harvesting costs as the stock size grows and positive discount rates increase the relative value of harvests early in the rebuilding horizon.

The notion that generalizations regarding effective rebuilding strategies (e.g. automatic closures) may not be optimal to rebuild fisheries are also supported by recent evidence regarding the success of rights-based management systems (Costello *et al*., 2008). The overall results claim that individual transferable quota (ITQ) fisheries are significantly less prone to collapse than non-ITQ fisheries. Thus, the role of the institutions in rebuilding and sustaining a viable fishery is paramount. Any rebuilding strategy must assure that the same mistakes are not repeated, which often involves capacity reduction programs or a change in institutional structure (Whitmarsh *et al*., 2000). Arguments for the development of institutional systems that account for the incentives of fishermen were, for example, summarized by Hilborn *et al*., (2005) and were noted by Rosenberg *et al*. (2006).

Many rebuilding efforts focus on first estimating a pre-determined biological rebuilding target, and then examining how to achieve it. This approach is often mandatory (e.g. in the United States this approach is based on the current interpretation of national standards) but is inconsistent with the premise of managing and sustaining a fishery over time. This is because the MSY may not be economically sustainable and, therefore, will not stabilize a fishery or a community. The determination of a target stock level based on the sustainable yield curve only considers historic effort, which is not absent of economics. If economics are of concern, then the benefits and costs should be considered appropriately. However, the assumption that economics is a tool to be used only after a rebuilding target has been determined, or after any imbalances between stock size and fishing capacity have been resolved, is pervasive (e.g. Penas, 2007; Khwaja and Cox, 2009).

Identifying a target MSY level for rebuilding is challenging, even when economic conditions are stable. The MSY is a long-run concept, but it is one that will change with deviation in any number of factors including biological parameters (such as caused by changes in the ecosystem), the level of effort devoted to fishing, or the relationship between the stock and the harvest level. For example, if general economic conditions change, or technology changes, then effort devoted to fishing might change (Whitmarsh *et al*., 2000). There are countless other examples of exogenous factors that can affect fishing mortality and, thus, the estimation of MSY, or change the MSY during the rebuilding process. These changes are realistic but are not considered under a protocol that requires the establishment of a target to be used for at least a decade. Successful recovery depends more on management infrastructure and socio-economic context than on stock calculations alone, whose accuracy has often been overestimated (Caddy and

Agnew, 2004). Given the imprecise nature of the MSY (and by extension the reference points used to examine the underlying stock level) and that it has, at best, played a supporting role in previous successful recoveries, it is curious that its use as an absolute target continues.

The establishment of an MSY target that is higher than current stock levels provides an indication of the future productivity of the resource, which is an effective way to communicate that management can improve a fishery. According to Munro (2009), however, although the future productivity of a resource is the necessary incentive for sustainable fisheries and rebuilding, what is often overlooked is that the timing of harvest is crucial and could be more important than the size of the stock. More specifically, Wiedenmann and Mangel (2006) found that a suboptimal age distribution may occur even if MSY level is achieved. Larkin and Sylvia (1999) provided an early example of how changing the timing of harvest during the season had a long run positive impact on yield and stock size for a mid-water hake species managed with an annual quota. By allowing harvest later in the season, after fish had a chance to recover from spawning and migration, the fleet could harvest fewer but larger individuals.

In addition to the stock effect from harvesting fewer fish and changing the age structure to have more and larger (older) fish, there was also a positive effect on the value of the resource since fish could be used to produce different, higher-valued products with higher recovery rates. Homans and Wilen (2005) modelled the potential market effects from altering harvest schedules and their effect on optimal management without compromising the stock. These examples are intended to highlight the foregone potential of a fishery when target stock size is determined initially and in isolation when, in fact, it could be considered an endogenous policy variable.

The finding that the MSY can be a solution where profits are zero or negative means that an MSY target may not be sustainable from a community (i.e. fishery) perspective (Kompas *et al*., 2009). While this finding should be sufficient to question the potential effectiveness of using MSY as a management target, it remains in use for rebuilding stocks. For example, the traditional assumption of Alaskan fisheries management has been that if the resource was managed to produce maximum sustainable yield (MSY), the economics would take care of itself (Bue *et al*., 2008). Using a detailed bioeconomic model of the Pacific salmon fishery, with multiple fleets and markets and stochastic dynamics, the authors show that benefits are maximized by harvesting at a stock level that is below that used to generate the MSY. While Grafton *et al*. (2007) have shown that the size of the biomass associated with MSY compared to MEY depends, in part, on the growth rate of the species and not traditional economic factors such as prices, costs, or discount rates.

Ward and Kelly (2009) provided additional insights to emphasize the risk in assuming the MSY will sustain a fishery. According to Ward and Kelly (2009) simple biologically based stock assessments, even if accurate, are not a good metric of success or failure because managers have so many objectives that have to be balanced in the management process. Stock size can be increased to improve economic efficiency, or the economic viability of the fishing industry. Alternatively, stock size can be improved by increasing the harvest cost until some arbitrary, precautionary MSY is achieved which is detrimental to the fishing industry and the communities dependent on it. While both points are acceptable from a biological perspective, only the MEY stock size is consistent with economic and social objectives.

Aside from the issue of a target stock size, the importance of a viable recovery path that explicitly recognizes the financial sustainability of the commercial fleet has been recognized as a critical factor to a successful rebuild (e.g. Martinet *et al*., 2007; Martell and Walters, 2008). This is an important realization since, as Caddy and Agnew (2004) identified, it is usually supposed that a return to a normal exploitation strategy will follow once the recovery target has been achieved, but experience shows that growing disputes over stock status between stakeholders occur as some recovery becomes evident. So, while it is true that the net benefits defined strictly as socioeconomic objectives may not be the only factor important to rebuilding, it is rare that the costs or benefits associated with managing for an MSY target do not matter at all. The converse is also true; fisheries managers and society as a whole should not consider biological or ecological factors as the sole determinants in evaluating the effectiveness of a rebuilt fishery.

Bioeconomic models can require substantial amounts of data and sophisticated solution techniques, especially when considering stochastic information on biological and economic parameters (Smith, 2008). While applied bioeconomic models increase the scope of data needs, the type of bioeconomic model will dictate the level of data needed.

Simple surplus production models can be used with the price of fish and the costs of fishing to determine the maximum economic yield (MEY) (Milon *et al*., 1999). Fisheries that are characterized by distinct cohorts may, on the other hand, need price and yield information by age or size and seasonal data if costs or demand varies by week or month (e.g. Larkin and Sylvia, 1999). Incorporating the behaviour of harvesters adds additional complexity and data requirements. Data needs vary directly with the complexity and realism of the bioeconomic models. With respect to rebuilding, bioeconomic models it is important to use biological and economic information to evaluate alternative rebuilding targets and approach paths. However, this use of economics as a tool is often confused with financial analysis; namely, short-run policy that is justified by socio-economic concerns that run counter to biological recommendations regarding the stock (Aps *et al*., 2007). But the strength in bioeconomic modelling is that it captures the behaviour of fishermen with respect to their response to profits, which allows for a suite of policy-relevant analysis (Whitmarsh *et al*. 2000; CEMARE, 2009).

Bioeconomic analysis or economic analysis is not synonymous with generating values associated with pre-defined harvest plans. It is perhaps the possibility that policy recommendations may differ between biological and bioeconomic analysis, or that the bioeconomic analysis will identify winners, losers, or the role of special interest groups, that can cause bioeconomic analysis to be considered contentious and, therefore, too costly or time consuming. Bioeconomic models are descriptive representations of a fishery that identify a course of action that is consistent with the goal(s) of managers. Bioeconomic models can, therefore, be used to examine proposed alternative objectives and actions (Frost and Andersen, 2006). Bioeconomic studies have proven successful at changing the management debate from determining the target stock level to what type of management tools account for the incentives of fishers in a way that maximizes the net benefits to society. Therefore, the use of bioeconomics has likely proved great in changing the institutions that govern fisheries worldwide (Hannesson and. Arnason, 2009), but whether such systems are universally beneficial (despite the bioeconomic evidence) remains a subject of debate.

Deterministic bioeconomic models can produce point estimates of sustainable harvest levels or the exploitation path that will maximize the economic benefits derived from the stocks. In the case of overfished stocks, these optima may differ significantly from the status quo. While significant changes to a fishery may appear daunting, they serve to highlight potential resource rents and the importance of having explicit management objectives. Bioeconomic models can also incorporate stochasticity into the determination of the optimal rebuilding plan. The biological and economic relationships in stochastic specifications are usually non-linear and dynamic and have the features of any dynamic system, including phase shifts and threshold effects. As a result, the benefits and costs are not proportional to biological management or harvests such that a change in any one variable is not likely to have a linear effect on the optimal solution; that is, the results are not scalable. As such, several bioeconomic studies caution that adjusting the harvest or effort levels predicted by the models can compromise the ability of the fishery to reach the desired solution (Milon *et al.*, 1999; Kompas and Che, 2004). The implementation of a policy that is not supported directly by the models can lead to an unfounded discrediting of the bioeconomic approach as the industry fails to improve. Conversely, with uncertainty taken into account, it is not reasonable to approach an estimated target in a slow way, with adaptive management responses to changes in prices, costs and the underlying biology of the fishery (Kompas *et al*., 2009).

2.4. The role of intertemporal preference in fisheries management

Most fisheries science relies in some way on the biological data for fisheries management, but recently there is a growing interest in the importance of engaging with fishers' knowledge (Haggan *et al*., 2007), which has led to substantial improvements in the relationships between scientists, fishers and managers. Fishers' knowledge is increasingly valued in fisheries management as the fishers' experience and knowledge of the ecosystem can strengthen science and management and improve the legitimacy of fisheries governance. The human side of adjustment is often treated as a secondary issue in fisheries management processes (OECD, 2007) reflecting a general lack of engagement with social issues in fisheries management (Symes and Phillipson, 2009). However, the importance of social factors in helping or hindering the process of fisheries management is increasingly being recognized. The common short-term focus for fishermen needs to be replaced by a more long-term approach which considers fisheries policy within wider economic planning (Swan and Gréboval, 2005). This will increase the capacity for long-term adaptability and resilience of fisheries communities (OECD, 2007).

The participation of fishermen in research and data collection increases trust between fishermen and scientists and improves the credibility of scientific advice and resulting management. Engagement with fishers' knowledge in collaborative research projects appeared to be largely participative (Stanley and Rice, 2007). Long-term exclusive rights of access generally provide incentives for the industry as a whole to conduct sustainable fisheries for the benefit of their future business (Hilborn *et al*., 2005, Branch *et al*., 2006b, Beddington *et al*., 2007, and Costello *et al*., 2008). However short-term economic pressures, high discount rates and uncertainty about future benefits can still provide incentives to overexploit (Acheson, 2006).

Though intertemporal preferences play a critical role in most important economic decisions, economists have not identified a reliable method for measuring them (Frederick *et al*., 2002). The vast majority of research on time preferences has used laboratory studies in which the experimenter controls the choices that subjects face. Laboratory experiments often ask subjects to weigh immediate rewards against delayed rewards. A typical study asks subjects if they would prefer $X now or $Y at a specified future date (e.g., a month from now). People's widely documented tendency to prefer smaller rewards now over larger rewards later has been characterized as revealing short sightedness or impatience (Read, 2004).

The fundamental question raised by the literature on intertemporal choice is; why do people's choices often seem so short sighted or impatient, and why do people differ in their degree of impatience, as inferred from the choices they make? Much of the work on intertemporal choice has centered on the specific issue of temporal discounting: how people choose between smaller amounts of money or other goods in the immediate future and larger amounts of money or goods to be received at a later date (Frederick *et al*., 2002). In this context, the discount rate, the degree to which an outcome loses value by being delayed for a given period of time, can be interpreted as a measure of impatience.

Fehr and Leibbrandt (2009) in the cooperativeness and impatience in the tragedy of the commons study argues that the exploitation of a common pool resource (CPR) involves a negative interpersonal and inter-temporal externality because individuals who exploit the CPR reduce the current and the future yield for both others and themselves. Accordingly, economic theory which assumes the existence of general across-situational traits predicts that fishermen who exhibit more cooperative and less impatient behaviour in the field should be less likely to exploit the CPR.

Economic theory hypothesizes that there is little cooperation in sustaining common pool resources (CPRs) where individual and collective interests are in conflict. The standard assumption of pure self-interest implies that natural resources like fishing grounds are overexploited, and that we are often trapped in an inevitable process that ends in the Tragedy of the Commons (Hardin, 1968). An additional aggravating factor for resource conservation is the propensity to discount future outcomes. The more impatient resource users are, the more they exploit natural resources. Considerable evidence shows that some individuals are cooperative and voluntarily sustain CPRs or public goods

(Cardenas, 2000; Casari and Plott, 2003; Croson, 2008; Dufwenberg and Kirchsteiger, 2004; Sobel, 2005; Falk and Fischbacher, 2006; Segal and Sobel, 2007).

Economic theories of preferences predict that individuals who exhibit a higher propensity to cooperate in the common pool resources (i.e. those who demonstrate cooperativeness), and those who show more patience in the time preference experiment exploit the CPR less for the following reasons: (i) a higher current exploitation reduces the current yield of other fishermen. Thus, ceteris paribus, other-regarding fishermen will impose fewer current negative externalities on others; and (ii) a higher current exploitation (in terms of fish that have not yet reached fertility) also reduces the future yield for both others and themselves. Therefore, more cooperative and less impatient individuals will impose fewer (current and future) negative externalities on others and themselves (Fehr and Leibbrandt, 2009).

Each society member has temporal preferences concerning the consumption of a good in different time periods. This is measured by the marginal time preference rate (MTPR). The term marginal is used because a MTPR measures the individual preference between small increments in consumption through time. This presupposes that the individual has dissimilar expectations about the amount of a good that will be consumed in different periods. Preference analysis in the use of a fishery resource could not be static, for two reasons: 1) its renewable nature implies variability in availability and uncertainty in its magnitude through time; 2) a different temporal marginal preference of resource use will exist according to the type of fishery considered. For example, open access fisheries are generally characterized by a high MTPR, because of the inherent characteristics of fish stocks (Seijo, 1998). Thus, there will be incentives to increase fishing effort levels (and thus yields and profits) in the short- run, having little or no concern for the future.

A decision maker who is uncertain about future taste prefers not to commit to a course of action today, and so has a preference for flexibility (Kreps; 1979; Dekel *et al*., 2009 and Dekel *at al*., (2007). Contemporary views of intertemporal choices often characterize people's behavior as shortsighted (Ainslie, 2001). In some models, an appropriate level of discounting is determined by economic considerations, such as how much interest could be earned in the intervening time.. Empirical research has found that actual behavior is generally more impatient than what would be predicted by economic factors (Laibson, 1997) and is characterized by disproportionate preference for smaller short-run outcomes, as compared either to one's own long term preferences.

While Parfit's views have been recognized as potentially having profound implications for how we think about intertemporal preferences (Baron, 2002; Frederick, 2006; Read, 2004), few empirical studies have directly investigated the role of connectedness in intertemporal choice. Frederick (2002) investigated the relationship between perceived connectedness to the future self and intertemporal choices and found no correlation between measure of connectedness and higher discount rates across people. In contrast, in a paper reporting a provocative correlational result, Ersner-Hershfield (2009) asked participants to make judgments about the current self, future self, and other people and found that those people for whom thinking about the current self most resembled thinking about the future self tended to show less devaluation of monetary rewards over time. Ersner-Hershfield *et al*., (2009) also present evidence that people who report having accrued greater total assets or more money invested in a home, in securities, in other material goods, and in the bank tended to rate themselves as more similar to who they would be in 10 years than people who had fewer assets.

In particular, a key driver of choice over time is that people have less information about the future than about the present. Thus, outcomes delayed to the further future can involve more uncertainty and risk, and intertemporal choice might be explained, in part, by differences in risk between immediate and delayed options (e.g., Mischel *et al*., 2003).

Caplin and Leahy (2000) challenge the traditional approach to discounting cardinal utility, focusing on the intrapersonal setting. They treat the current self and future self as analogous to two different persons with potentially different interests. In this approach, the correct intertemporal weighting depends on how much the current self cares about the future self, and vice versa.

In view of the key role that economic theory assigns to individuals' preferences in the exploitation of CPRs, the study examined implications of intertemporal preference on the utilization of fisheries resources of Lake Malombe. To achieve the goal the study relied on data sets that related individual behaviour in decisions pertaining to utilization of common pool resource. The results of the study have important implications in developing a management strategy that will consider people's choices. The approach will provide empirical evidence that when designing policy measures, taking people's choices into account is useful, as it is an obstacle in the implementation of resource preserving policies. Likewise, knowledge about the conditional nature of fishermen's behaviour may be useful, i.e., their conditional willingness to cooperate in concrete situations, even if cooperation goes against their immediate self-interest.

2.5. Theories of Box-Jenkins models

Numerous studies have investigated the relative accuracy of alternative forecasting models. Some of these models used in forecasting inflation among others are Vector Auto Regressive (VAR), Bayesian Vector Auto Regressive (BVAR), Structural Vector Auto Regressive (SVAR), Seasonal Auto Regressive Integrated Moving Average (SARIMA), Simple Auto Regressive (SAR), random walk and Auto Regressive Fractionally Integrated Moving Average (ARFIMA). Among these models is the Auto Regressive Integrated Moving Average (ARIMA) model, used in this study to model annual catch series of Chambo and Kambuzi from 1976 to 2011 and also forecast catches on short-term basis from 2012 to 2021.

In a more general context, there have been many instances in which ARIMA models (Ljung, 1987) have been applied to fishery time series with varying degrees of success (e.g. Fogarty, 1989; Stergiou, 1989, 1991; Pajuelo and Lorenzo, 1995; Stergiou and Christou, 1996; Stergiou *et al*., 1997; Park, 1998; Pierce and Boyle, 2003; Georgakarakos *et al*., 2002). However, ARIMA models require long stationary time series but most fisheries time series are short and non-stationary. To overcome the last problem, time series can be de-trended or integrated series can be analysed. Nevertheless, while traditional auto-regressive integrated moving average (ARIMA) models have been fitted to time series, reliable fishery forecasts remain out of reach (Pierce and Boyle, 2003).

While Mendelssohn (1981) used Box-Jenkins models to forecast fishery dynamics, Prajneshu and Venugopalan (1996) discussed various statistical modelling techniques such as, polynomial, ARIMA time series methodology and nonlinear mechanistic growth modelling approach for describing marine, inland as well as total fish production in India. Tsitsika *et al.* (2007) also used univariate and multivariate ARIMA models to forecast the monthly pelagic production of fish species in the Mediterranean Sea. Among the methods based on univariate techniques, the ARIMA models by Box and Jenkins (1976) stand out because of their wide range of application.

Czerwinski, *et.al.* (2007) tested two univariate forecasting techniques to evaluate the short-term CPUE capacity to forecast for Pacific halibut *Hippoglossus stenolepis* (Pleuronectidae). The first methodology, based on the Box–Jenkins approach (autoregressive integrated moving average models (ARIMA models), assumed a linear relationship in the time series data. The second methodology, using artificial neural network models (ANNs), enabled highly non-linear processes to be modelled. The best results from a seasonal ARIMA model indicated that non seasonal autoregressive term combined with a non-seasonal moving average term and a seasonal moving average term was suitable to explain variance in the validation phase, providing statistically acceptable estimations.

Meyer *et al*. (1998) considered the autoregressive integrated moving average (ARIMA) for forecasting and found that ARIMA models are surprisingly robust with respect to alternative (multivariate) models. Gudmundsson (1998) also used the Variable regression coefficient time lags as the source of randomness to find the relationships between time series. This was modelled by means of variable regression coefficients.

Jai Sankar (2011) used a stochastic model in the study of forecasting fish product export in Tamilnadu. The aim of the study was to forecast fish product export in Tamilnadu, based on data on inland and marine fish product export during the years 1969 to 2008. The study considered Autoregressive (AR), Moving Average (MA) and Autoregressive Integrated Moving Average (ARIMA) processes to select the appropriate stochastic model for forecasting fish product export in Tamilnadu. Based on ARIMA (p, d, q) and its components ACF, PACF, Normalized BIC, Box-Ljung Q statistics and residuals estimated the appropriate ARIMA model was selected for forecasting fish product export. For evaluating the adequacy of AR, MA and ARIMA processes, various reliability statistics like R^2, Stationary R^2, Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and Bayesian Information Criterion (BIC) were used for selection of a better fit model. Based on the chosen model, it was possible to predict fish product exports.

Jai Sankar and Prabakaran (2012) in the study to forecast milk production in Tamilnadu used the Box-Ljung Q statistics to transform the nonstationary data into stationarity data and to check the adequacy for the residuals. For evaluating the adequacy of AR, MA and

ARIMA processes, various reliability statistics like R^2, Stationary R^2, Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), and Bayesian Information Criterion (BIC) were used for selection of a better fit model. Based on the chosen model, it was possible to predict milk production. Jai Sankar *et al.* (2010) also used stochastic modelling for cattle production and forecasted the yearly production of cattle in the Tamilnadu state while Zuur *et al*. (2003a, b) used Akaike's information criterion (AIC). The AIC is defined as the difference between a measure of fit (maximum likelihood) and the number of parameters (number of trends, explanatory variables and structure of R).

There are many measures of forecasting accuracy that one may use to compare different models. Legates and McCabe, (1999); Abrahart and See (2000) used the correlation between observed and predicted CPUE expressed by means of the correlation coefficient R. The coefficient of determination (R^2) describes the proportion of the total variance in the observed data that can be explained by the model. Other measures of variances applied were the percent standard error of prediction (% SEP) (Ventura *et al*., 1995), the coefficient of efficiency (E^2) (Nash and Sutcliffe, 1970; Kitanidis and Bras, 1980) and the average relative variance (ARV) (Gri˜n´o, 1992). These four estimators are unbiased estimators that are employed to see how far the model is able to explain the total variance of the data. In addition, it is advisable to quantify the error in the same units as the variables. These measures, or absolute error measures, included the root of the mean square error (RMSE) and the mean absolute error (MAE).

CHAPTER THREE

MATERIALS AND METHODS

Chapter three provides description of methods that were applied in the implementation of the research. The chapter provides a detailed explanation on relevant methods that were used to test the hypotheses that there are no intertemporal preferences among fisheries resource users in the exploitation of fish stocks in Lake Malombe; there are no differences between current catch patterns and forecasted catch patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) in Lake Malombe and that there are no differences in resource economic rents associated with maximum sustainable yield (MSY) and maximum economic yield (MEY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) fishery of Lake Malombe. The chapter is divided into three sections covering section 3.1 study area which provides a detailed description of Lake Malombe: 3.2 Data collection which describes the procedures and processes that were used in data: 3.3 Data analysis which describes in detail how intertemporal preference, time series and bioeconomic data were analysed including mathematical models and computer programmes.

3.1. Study area

Lake Malombe is about 450 km^2, located on the floor of the rift valley just to the south of the much larger Lake Malawi (Bell, 1998). The lake lies between latitude 14^{0}21’ to 14^{0}45’ south and longitude 35^{0}10; to 35^{0}20’ east in the southern district of Mangochi (DoF, 2004). The lake is connected by the short channel of the Shire River to Lake

Malawi (Figure 3.1). As such it shares some of the unique characteristics of the larger lake’s aquatic ecology, including a high level of fish biodiversity, genetic plasticity and endemism. However, it differs in some important respects, in that Lake Malombe is shallow, turbid and nutrient-rich, with shelving vegetated shores without the many rock outcrops so characteristic of Lake Malawi. Fish diversity is lower in Lake Malombe but per unit biomasses and productivity are higher.

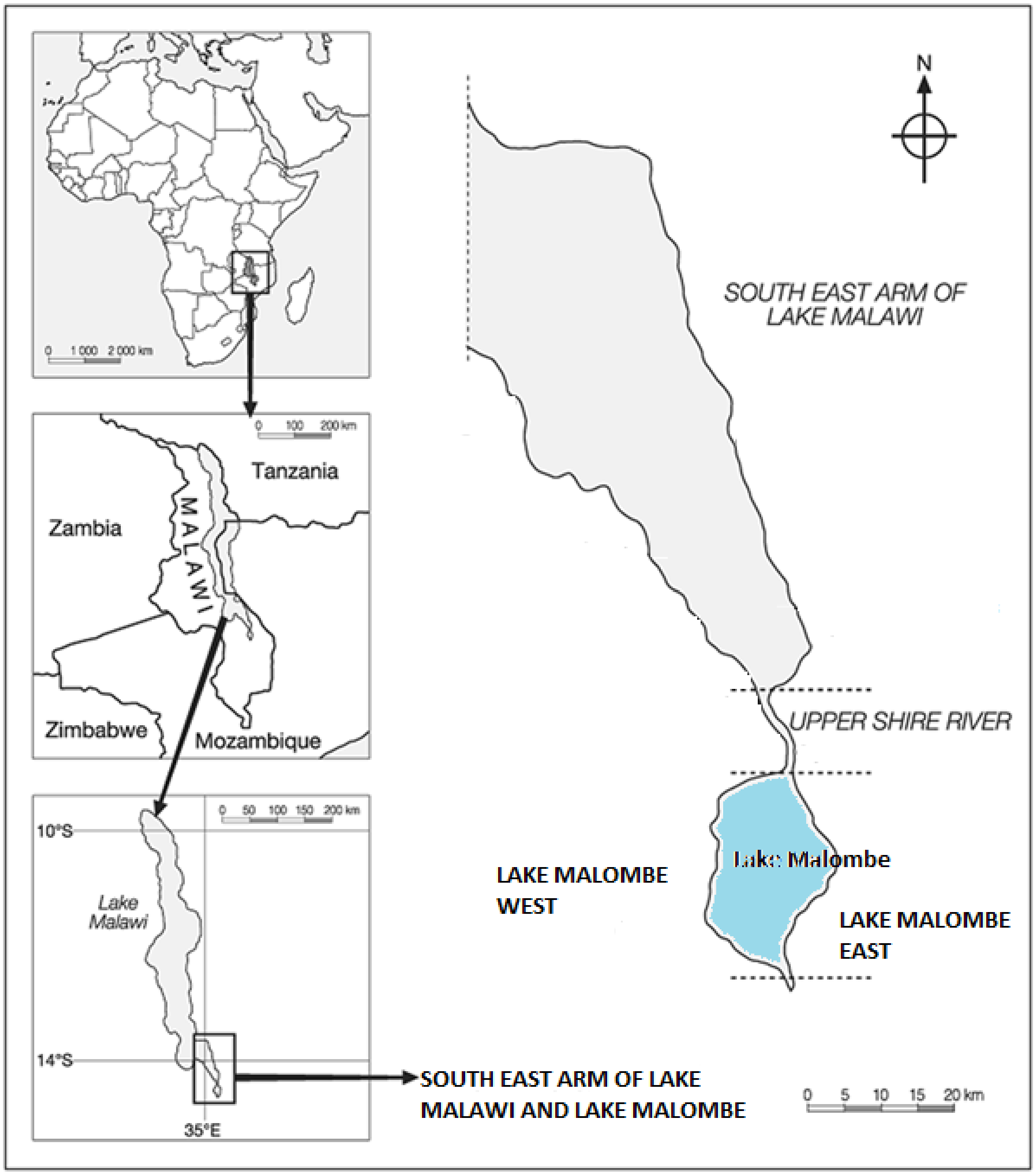


Figure 3.1 Map showing the position of Lake Malombe (2012)

3.2. Data collection

The study was based on three approaches that are; logistic analysis of intertemporal preference, time series analysis and bioeconomic analysis,

3.2.1. Intertemporal preference data

To assess factors that influence fisheries resource users' intertemporal preferences, a single visit multiple subject survey was conducted between November and December 2011 in two major strata namely; Lake Malombe West and Lake Malombe East. The selection of the strata was in line with the Department of Fisheries Research Unit sampling program. For purposes of statistical data collection, the Department of Fisheries Research Unit divided Lake Malombe into three major statistical strata, which include Lake Malombe East coded as 1.1, Lake Malombe West coded 1.2 and Upper Shire coded 1.3. Within each major stratum four minor strata are selected for sampling based on number and types of fishing gears. The study considered Lake Malombe West and Lake Malombe East because of the wide use of Gill net and Nkacha net which are the main target gears for Chambo and Kambuzi respectively in Lake Malombe.

In Lake Malombe West stratum, data was collected from four sampling sites while in Lake Malombe East data was collected from two sampling sites due to inaccessibility of the other sampling sites (Table 3.1). Simple random sampling technique based on frame survey census list was used in the selection of respondents. The survey administered a pretested structured questionnaire to a total of two hundred and fifteen (215) sampled fishers (gear owners and crew members) and consumers around Lake Malombe.

Table 3.1 Sample size of respondents from Lake Malombe

Stratum	Sampling site	# GO 2011 FS	# GO interviewed	# CM interviewed	# consumers interviewed	Total Survey
LM West	Mwalija	8	7	13	38	58
	Katapwito	13	11	17	6	34
	Chapola	9	9	16	10	35
	Mtambo	12	6	9	7	22
LM East	Matache	7	5	15	8	28
	Likulungwa	31	15	10	13	38
Total		80	53	80	82	215

Note: GO means gear owners, CM means crew members, FS means frame survey.

3.2.2. Bioeconomic and time series data

The quantitative secondary data for Chambo (*Oreochromis species*) and Kambuzi (small *haplochromine cichlids*) on catch, effort, beach price and cost of fishing for Lake Malombe from 1976 to 2011 was used. The data was collected from Government of Malawi, Department of Fisheries Research Unit at Monkeybay and Mangochi Fisheries District Office. The data was obtained from a computer based programme called Traditional Fishery Data Base (TFDB) which is used by the Department of Fisheries for storing fisheries data. From the Traditional Fishery Data Base (TFDB), the data was transferred into excel programme where it was arranged for the necessary analyses.

3.2.3. Field data collection

Field data on catch, effort, beach price and cost of fishing are collected by the Department of Fisheries through the normal annual longitudinal studies such as Catch Assessment System (CAS), Malawi Traditional Fisheries (MTF) and annual frame surveys. For purposes of data collection, Lake Malombe is divided into three statistical strata. These are Lake Malombe East coded as 1.1, Lake Malombe West coded 1.2 and Upper Shire coded 1.3. Within each major stratum four minor strata are selected for sampling based on number and types of fishing gears to satisfy the calculated sample sizes based on a 10% coefficient of variation. The systems of data collection utilise a stratified sampling procedure.

Catch and effort records are collected annually on four selected sampling sites in each major stratum and each site is visited 4 times in a month. At each sampling site, the recorder (Fish Scout) carry out a census of numbers and types of craft and fishing gear found on the selected site on day one. For the next three days, catch and effort data are collected from the sampled fishing units. The type of information collected include, catch in weight by type of fish, type, size and number of gears, the number of fishermen involved and type of canoes/boats. The system uses the sample data to estimate the total fish landings by applying raising factors. In cases where catches are reported in dozens, the amount is converted into kilograms before entering on the form. Total catch is expressed in weight of biomass in metric tons; while effort, which is the input, is expressed in terms of seine hauls or gillnets set. Beach prices of each fish species based on the gear are also recorded during the survey.

3.2.4. Cost structure data

Cost data on boat and gear for the past years was obtained from various Fisheries Annual Frame Survey reports and boat manufactures in Mangochi. Additional data on boat and gear census was obtained from the Fisheries Annual Frame Survey Report (2010). A separate survey was conducted in the major strata where statistical data collection was done by the Fisheries Department to obtain data for 2011 fixed costs and variable costs from gear owners. The study considered variable costs which included daily wage of crew members, daily food expenses and cost of batteries. Capital investment costs were considered as short to medium term costs of fishing and included boat and gear costs. Fixed costs were considered as short term costs incurred for annual license fee paid to Malaŵi Government, and annual boat and gear maintenance costs (costs required to maintain the vessel at its maximum performance level).

Variable costs for the past years were estimated by back calculation using annual inflation rates for each year. Data on inflation rate since 1976 was obtained from the Malawi Economic Report (2011). To estimate total annual variable costs for Chambo fishery, 300 days of fishing per year were multiplied by the daily average costs of fishing. The 300 days of fishing per year were based on 25 days of fishing per month. For Kambuzi fishery, three months of closed season (October, November and December) were excluded in estimating the total annual variable costs; as such 225 days were used to estimate total annual variable costs of fishing. Total boat and gear costs of fishing were estimated by multiplying the number of boats and gears by the cost of a single boat and gear. Total cost structure of Chambo and Kambuzi fishery were obtained by adding total variable costs and total capital costs which included boat coats, gear costs, annual license fee and annual maintenance costs.

3.3. Data analysis

3.3.1. Intertemporal preference data analysis

3.3.1.1. Descriptive analysis

Descriptive statistics including frequencies and percentage for various variables were calculated. Cross tabulations were done for variables included in the logit regression model. Chi-square test was used to determine if the respondents from different categories were significantly different in the intertemporal preference.

3.3.1.2. Logit regression analysis

The binary logistic model was used to examine factors that influence people's intertemporal preference in fisheries resource utilization. Logistic regression sometimes called the logistic model or logit model) was used for prediction of the probability of occurrence of an event by fitting data to a logistic function. Like other forms of regression analysis, more predictor variables that were either numerical or categorical were used in the analysis according to Hilbe (2009).

Logistic regression model was considered because it is well suited for describing and testing hypotheses about relationships between a categorical outcome variable and one or more categorical predictor variables (Peng *et al.*, 2001). Logistic regression solves the problems by applying the logit transformation to the dependent variable. In essence, the logistic model predicts the logit of *Y* from *X*. Logistic regression is a useful way of describing the relationship between one or more independent variables (e.g., age, sex, tribe.) and a binary response variable, expressed as a probability that has only two values (Agresti, 2007).

The dependent variable (Y) was dichotomized with a value of (0) if respondents have positive intertemporal preference (prefer to consume fisheries resources immediately (t_1), rather than in subsequent periods t_2) and (1) if respondents have negative intertemporal preference (willing to transfer part of the consumption in the current period t_1 to the subsequent period t_2). Thirteen predictor independent variables were regressed against the binary dependent variable of intertemporal preference. The binary logistic regression model as specified in equations, 3.1 and 3.2, according to Kidane *et al.* (2005) and Matiya *et al.* (2005), was used to determine factors influencing respondents' intertemporal preference in fisheries resource use. The logistic regression analysis was carried out by the Logistic procedure in SPSS version 16.0 in Microsoft Windows 7.

The probability function of respondents is given according to Kidane *et al.* (2005) in simple logistic form in equation 1. The odds ratio $P_i/1-P_i$ are in favour of having negative intertemporal preference to the probability of having positive intertemporal preference.

$$Logit\,(y) = ln\left(\frac{P_i}{1-P_i}\right) = \alpha + \beta X + \varepsilon_i \tag{3.1}$$

where P_i is the probability of having negative intertemporal preference, α is the *Y* intercept, β is the regression coefficient, X is the predictor and ε_i is the error term.

Therefore the model with multiple predictors can be specified according to Matiya *et al*. (2005) as follows;

$$Logit\ (Y) = Ln\left(\frac{P_i}{1-P_i}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \cdots + \beta_{12} X_{12} \tag{3.2}$$

Where Y = To have intertemporal preference, β_0 is the intercept and β_1, β_2, β_3,…, β_{12}, are the regression coefficients of X_1, X_2, X_3,…, X_{12} respectively. X_1 is stratum, X_2 is category of respondent, X_3 is age of respondent, X_4 is sex, X_5 is marital status, X_6 is household size, X_7 is religion of respondent, X_8 is tribe/ethic group of respondent, X_9 literacy, X_{10} is period stayed in the area, X_{11} is years in fishing and X_{12} is working hours per day

In terms of the adequacy of sample sizes for logit regression analysis, the literature has not offered specific rules applicable to logistic regression (Peng *et al*., 2002). However, several authors on multivariate statistics (Marascuilo & Levin, 1983; Tabachnick & Fidell, 1996, 2001) have recommended a minimum ratio of 10 to 1, with a minimum sample size of 100 or 50, plus a variable number that is a function of the number of predictors. On the basis of the general rule of a minimum ratio of 10 to 1, with a minimum sample size of 100, the study met the recommendation.

3.3.1.3. Description of variables specified in the model

This section focuses on description of the variables specified in the logistic regression model. Using conclusions inferred from other studies and empirical findings from the study area, the influence of various household characteristics was estimated.

Dependent variable (Y)

Dependent variable (Y) was the response variable and it was dichotomous in nature. It was incorporated into the model as dummy variable with the value of 0 showing positive intertemporal preference and 1 showing negative intertemporal preference.

Stratum (X_1)

Stratum was considered as area where the fisheries resource user stays based on the areas designated by Fisheries Department for statistical purposes. The two areas considered are Lake Malombe West (1.1) and Lake Malombe East (1.2). Lake Malombe West was expected to generate positive intertemporal preference because of the location of the stratum. The area is along the main road and close to Mangochi town where the market for fish is readily available. The demand for fish is expected to influence fishers to be impatient in fisheries resource use. Lake Malombe East (1.2) is far from the fish market and the place is inaccessible during the rainy season. The area is expected to have negative intertemporal preference because the current demand for fish is low. FAO (1993) noted that Chambo, the most valuable fish caught in the area, was mainly sold to customers in town centres such as Blantyre, Limbe, Thyolo, Lilongwe and even Mzuzu, whereas the processed small fish was sold to people all over the country.The variable was incorporated into the model as dummy variable with the value of 0 showing Lake Malombe West and 1 showing Lake Malombe East.

Category of respondent (X_2)

The category of respondent was specified in the logistic regression model as fish consumers and fishers. Consumers were those that are not involved in fishing but access fish from fishers while fishers were considered as gear owners and crew members. Fish consumers were expected to have negative time preference because they depend on fishers to have fish. Fishers were expected to have positive time preference because fishing may be the only form of livelihood they have and thereby influencing consumers demand for fish. Matiya and Wakabayashi (2005) noted that fishing was the main cash income source for 80% of people around Lake Malombe. The variable was therefore incorporated into the model as dummy variable with the value of 0 showing fishers and 1 fish consumers.

Age of respondent (X_3)

Age was an explanatory variable that can influence intertemporal preference. It was included in the model to assess if it had time preference. Age as measured by the actual number of years of the household head plays a vital role in terms of fisheries resource utilization, where older household heads are expected to have better access to fishing gears than younger heads because younger men either have to wait to accumulate resources for fishing equipments (Kidane *et al.*,2005). The variable was incorporated into the model as dummy variable with the value of 0 adults and 1 showing youth.

Sex (X_4)

The variable was included in the model to examine if gender had any effect on time preference. Men and women engage in different activities at household level as defined by the African historical cultural domain. Household head gender is conjectured to influence type of activities likely to be carried out by female or male headed families. The households headed by males were therefore expected to participate in fisheries more than female headed households, implying a positive intertemporal preference. Matiya *et al*. (2005) noted that fishing is a male dominated occupation. Over 98% of the boat owners were male while 86.2% of those who did not own a boat but engaged in other activities like agriculture were female. The variable was incorporated into the model as dummy variable with the value of 0 showing male and 1 showing female.

Marital status (X_5)

The variable was entered in the model as single headed households and married headed households. The variable was included in the model to assess if it influences intertemporal preference. It was expected that single headed households would be more willing to forgo current consumption for the future. FAO (1993) noted that fish processing and trading is the only fishing or fishing-related activity, in which single women participate. Even so, the proportion of female traders is rather low. Factors, which prevent women from taking up fish trading include the traditional patterns of labour division, the lack of start-up money and limited access to the resource. The entry of married Yao women into fish trading is often hampered by male attitude towards business women. The variable was incorporated into the model as dummy variable with the value of 0 showing married and 1 single.

Household size (X_6)

Household size may positively influencing people to venture into fishing. The more children one has, the higher the probability that the number of fishermen will increase. Because of poverty, the family may not be able to support all the children and some might venture into fishing as a way of making a living. It has been observed that in developing countries which are subjected to high unemployment rate; fishing is one of the last few remaining job opportunities for a labour force lacking training and capital (land) (Matiya *et al*., 2005). The households with large family sizes are likely to be involved in fishing to support the family, implying that they would have positive time preference Matiya *et al*. 2005 noted that the average number of children per family was 6 which were higher than the national figure of 5 children per household. Holden and Lunduka (2013) also noted in farm input subsidy programme that households with more children and with a higher consumer/worker ratio were more likely to have received fertilizer coupons. These differences were highly significant. The variable was incorporated into the model as actual number of family members.

Religion of respondent (X_7)

The religion of respondent was included in the model to assess if it influences intertemporal preference of people. Different religions have different beliefs and cultural backgrounds which may influence ones decision in fisheries resource utilization. Some religions prohibit consumption of certain fish and this may have influence on the consumption of such species. Some religions believe that everything God has given should be consumed because more will be provided for now and in future. Such beliefs were expected to influence current consumption. The variable was dichotomized into Christian and Islam. The variable was incorporated into the model as dummy variable with the value of 0 showing Islam and 1 showing Christian.

Tribe/ethic group of respondent (X_8)

The tribe of the respondent was included in the model to assess if it influences intertemporal preference of people. Different tribes have different beliefs and cultural backgrounds which may influence ones decision in fisheries resource utilization. The area surrounding Lake Malombe is densely settled by a population who are primarily of *Yao* tribe and therefore most fishers (77.5%) belong to this tribe (Matiya and Wakabayashi, 2005).This means most of the people have the same cultural background and this might be of importance when implementing a community based management system. A few fishers of *Chewa*, *Lomwe* and *Nyanja* tribe are also found operating in the lake. The variable was incorporated into the model as dummy variable with the value of 0 showing Yao and 1 showing other tribes.

Literacy (X_9)

Fisheries management is a complex system whose direct and indirect contribution to humanity is not obvious. Education in that respect helps people to appreciate fisheries management. In essence, as noted by Muchapondwa (2003), education would make it easier for households to comprehend negative externalities and passive user values of natural resources. Ideally, decisions pertaining to fisheries use are expected to be influenced by education level of households. It was expected that those with education would understand the importance of conservation and this would preserve fisheries resources in Lake Malombe. Education in that respect helps people to appreciate more values of resource conservation. Similar effects were also earlier on observed by Zidana *et al.* (2007) reporting a negative relationship between river bank cultivation and education. The variable was incorporated into the model as dummy variable with the value of 0 showing illiterate and 1 showing literate.

Period stayed in the area (X_{10})

The variable was included in the model to show how the length of time one stays in the fishing area influences time preference. It was expected that the longer the time, the greater the experience. Individuals with short experience of the area may be frustrated with low fish catches as such they may be willing to cooperate in the management of resources. The variable was incorporated into the model as dummy variable with the value of 0 period more than 16 years and 1 showing period between 1 to 15 years.

Years in fishing (X_{11})

The variable was included in the model to show how the years in fishing influence time preference. It was expected that one with greater experience of fisheries trend may be willing to contribute to new management approaches based on the experiences. Individuals with few years of fishing aim at maximizing the current utility from the resources without caring about the trend. The variable was incorporated into the model as dummy variable with the value of 0 showing period between 1 to 15 years and 1 showing more than 16 years.

Working hours per day (X_{12})

The variable was included in the model to show how working hours per day influence intertemporal preference. It was expected that if one was fishing for long hours per day, then one would not be willing to contribute to new approaches to fisheries conservation implying that they have positive time preference. Individuals with few fishing hours per day are willing to forgo current consumption for the future. The variable was incorporated into the model as dummy variable with the value of 0 showing more than 16 hours of fishing and 1 showing 1 to 15 hours of fishing.

Table 3.2 Description of variables specified in the model

Coefficient	Characteristic	Code used
Y	Preference	0= positive, 1= negative
X_1	Stratum	0= L. Malombe W, 1= L. Malombe E
X_2	Category of responded	0= fish, 1= fishers consumer
X_3	Age of respondent	0= adults, 1= youth
X_4	Sex of respondent	0= male, 1= female
X_5	Marital status	0= married, 1= single
X_6	Household size	Actual number of family members
X_7	Religion	0= Christian, 1= Islam
X_8	Tribe/ethnic group	0= Yao, 1= Other tribes
X_9	Literacy	0= Illiterate, 1= literate
X_{10}	Period in the area	0= more than 16, 1= 1-15years
X_{11}	Years in fishing	0= 1-15years, 1= more than 16
X_{12}	Daily working time	0= more than 16, 1= 1-15hours

3.3.1.4. Evaluation of the logit regression model

A bivariate (Chi-squared) analysis was carried out to assess how each explanatory variables influences the dependent variable. The regression was first run with all the variables. This was done because some variables on their own may not be significant. However, their interaction may show that they contribute to influence different intertemporal preference. The model was evaluated by examining the goodness of fit, Chi-square and -2 log likelihood.

3.3.2. Time series analysis

3.3.2.1. Box-Jenkins ARIMA modelling theoretical framework

The Box-Jenkins forecasting models are based on statistical concepts and principles that are able to model a wide spectrum of time series behaviour. There is a large class of models to choose from and a systematic approach for identifying the correct model form. Furthermore, there are statistical tests for verifying model validity and statistical measures of forecasting uncertainty. These consist of four iterative procedures such as: Model Identification, Model Fitting, Model Diagnostics and Forecasting. The four iterative steps are not straight forward but are embodied in a continuous flow chart depending on the set of data one is dealing with or handling. See figure 3.2 for the chart of the Box-Jenkins ARIMA modelling approach that was followed.

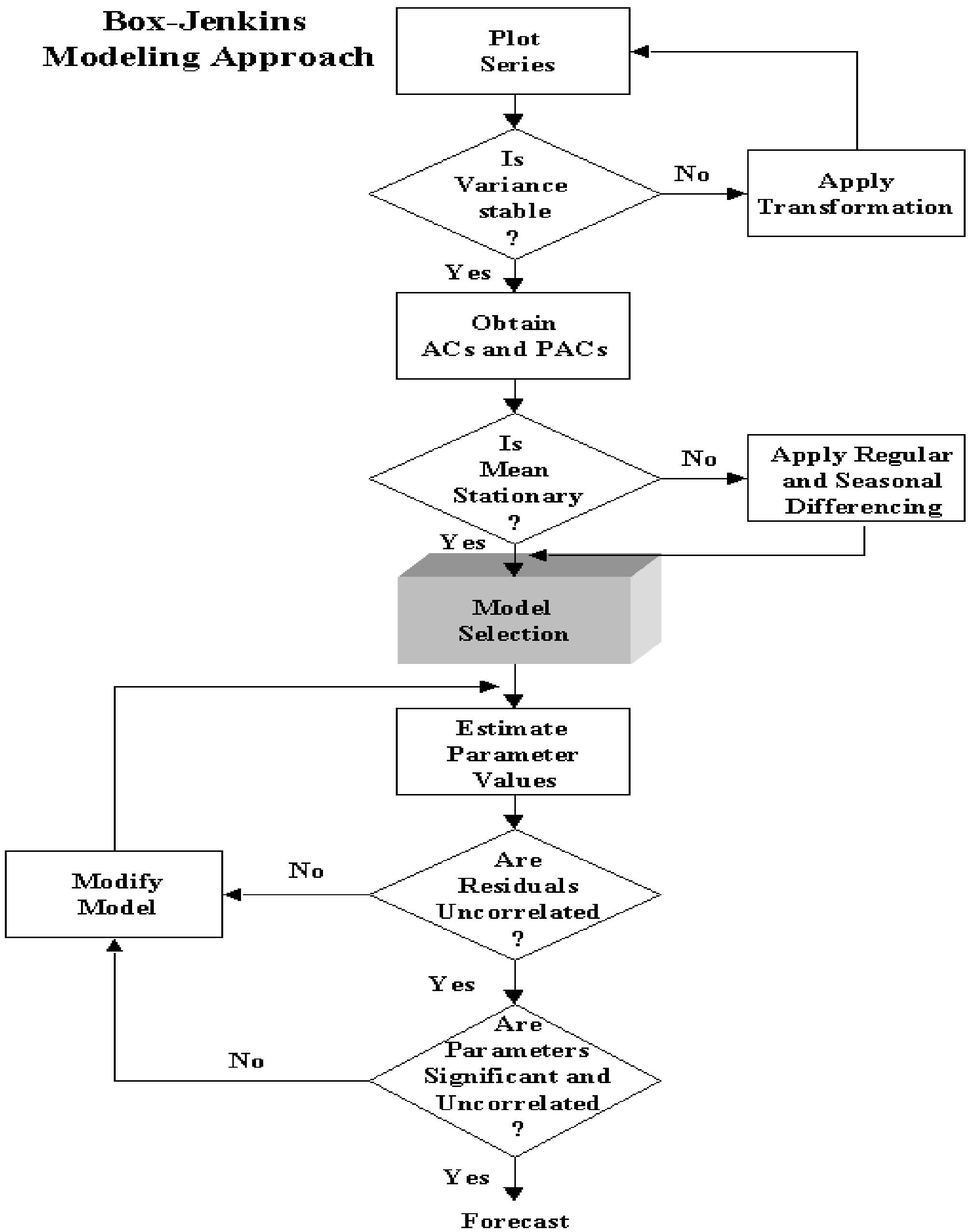


Figure 3.2 Flow chart for Box Jenkins ARIMA modeling (adopted from Box Jenkins)

3.3.2.2. ARIMA model

The Box-Jenkins ARIMA approach was used to model stock catches from 1976 to 2011. ARIMA model (autoregressive integrated moving average) was used to estimate model coefficients and forecast future fisheries catch patterns. One of the reasons for the popularity of the ARIMA modelling is its success in forecasting. In many cases, the forecasts obtained by this method are more reliable than those obtained from the traditional econometric modelling (Gujarati, 2004).

The model used in this study was an auto-regressive, integrated, moving average, called an ARIMA (p, d, q) model. The auto-regressive element (p) represents the lingering effects of preceding scores. The integrated element (d) represents trends in the data, and the moving average element (q), represents the lingering effects of preceding random shocks. ARIMA (p,d,q) models (Box and Jenkins, 1976) assume that time series is a linear combination of its own past values and current and past values of an error term. The ARIMA model was selected for analysis because it is flexible and can be used for various applications with different features. The ARIMA model can be used to model time series with a wide variety of features such as trend and seasonality by incorporating the AR term, the integrated term, and the MA term together and by adjusting the parameters of each term (Lloret *et al*., 2000; Becerra-Mu˜noz *et al*., 2003; H¨anninen *et al*., 2003; Punz´on *et al*., 2004; Guti´errez-Estrada *et al*., 2004). The mathematical model can then be written as follows:

Autoregressive model: AR (*p*) model

Autoregressive model AR (p) is a type of random process which is often used to model and predict various types of natural phenomena. The idea behind the autoregressive models is to explain the present value of the series X_t, by a function of (p) past values such as X_{t-1}, X_{t-2}, $X_{t-3}\ldots$, X_{t-p}. Therefore an Autoregressive process of order p is written as:

$$Y_t = \varphi_1\gamma_{t-1} + \varphi_2\gamma_{t-2} + \cdots, +\varphi_p\gamma_{t-p} + \varepsilon_t \qquad (3.3)$$

where Y_t is the observation at time t, $\varphi_2\ldots\ \varphi_p$ are constants and $t = 0 \pm 1, \pm 2$ and ε_t is white noise.

Moving average: MA (q) model

Moving average is a term consisting of a model parameter times a model forecast error. This is used to specify stationary time series and is defined as:

$$Y_t = \theta_1\varepsilon_{t-1} + \theta_2\varepsilon_{t-2} + \cdots, +\theta_p\varepsilon_{t-p} + \varepsilon_t \qquad (3.4)$$

Where Y_t is the observation at time t, $\theta_2\ldots\theta q$ are constants and $t = 0 \pm 1, \pm 2\ldots$and ε_t is white noise.

Autoregressive moving average: ARMA (*p, q*) model

ARMA model is a combination of the simple AR and MA model of order (*p, q*) called autoregressive moving average (ARMA). It is defined mathematically as:

$$Y_t = \varphi_1\gamma_{t-1} + \varphi_2\gamma_{t-2} + \cdots, +\varphi_p\gamma_{t-p} + \theta_1\varepsilon_{t-1} + \theta_2\varepsilon_{t-2} + \cdots, +\theta_p\varepsilon_{t-p} + \varepsilon_t$$
(3.5)

where Y_t is the observation at time t, φ and θ are coefficients and ε_t is a purely random process with mean zero and variance σ^2.

ARIMA model

ARIMA model (autoregressive integrated moving average) is a generalization of the simple AR model that uses three tools for modelling the serial correlation in the disturbance. It is called an integrated model because the stationary ARMA model that is fitted to the differenced data has to be summed or "integrated" to provide a model for the nonstationary data. For a stationary time-series, Y_t, Box and Jenkins (1976) proposed an ARIMA (*p, d, q*) model which considers the last p-known values of the series as well as q of the past modelling errors as follows:

$$Y_t = \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j e_{t-j} + \varepsilon_t \tag{3.6}$$

where Y_t is the observation at time t, ϕ and θ are coefficients and ε_t is an error term

3.3.3.3. Testing for stationarity of data

Most of the time series data are nonstationary. Any series that is not stationary is said to be nonstationary and hence must pass through the due process of the Box- Jenkins approach to make it stationary. To check for stationarity of the catch data, graphical analysis method was used.

3.3.3.4. Model identification

The purpose of model identification was to determine the right order of the autoregressive (AR) component, the integrated component (I), and the moving average (MA) component, respectively. In the study data were differenced once to obtain stationarity. Differencing is a trend removing operation by using special kind of linear filter with weights (-1, 1). The first lag (lag 1) differencing operator was denoted by ∇, thus:

$$\nabla \times = \times_t - \times_{t-1} \tag{3.7}$$

The backward shift operator denoted by B was then used to obtain:

$$B \times_t = \times_{t-1} \tag{3.8}$$

Having determined the correct order of differencing required for the series to be stationary, the appropriate ARMA form to model the stationary series were suggested.

The Box-Jenkins methodology essentially involved examining plots of the sample autocorrelograms and partial autocorrelograms and inferring from patterns observed in these functions the correct form of ARIMA model to select.

Gujarati (2004) pointed out that when the PACF has a cut off at p while the ACF tails off; it gives an autoregressive of order p (AR (p)). If the ACF has a cut off at q while the PACF tapers off, it gives a moving-average of order q (MA (q)). However, when both ACF and PACF tail off, it suggests the use of the autoregressive moving-average of order p and q (ARIMA (p, q)). Sometimes the ACF does not die out quickly, which may suggest that the stochastic process is nonstationary. This situation suggests the use of the ARIMA (p, d, q) to difference the data (d) times, once or twice, until stationarity is obtained.

3.3.3.5. Model fitting

Model fitting consisted of finding the best possible estimates for the parameters of the tentatively identified models. In this stage, maximum likelihood estimation (MLE) method was considered to estimate the parameters. MLE method for estimation of ARIMA was applied in SPSS version 16.0. MLE runs an algorithm several times, using as the starting point the solution obtained in the previous iteration/run. Basically SPSS maximizes the value of a function by choosing the set of coefficient estimates that would maximize the function. Each time, it uses the estimates obtained in the previous iteration/run. The level of significance of the parameters was tested at ($P = 0.05$).

3.3.3.6. Model diagnostics

In model diagnostics, various diagnostics such as the method of autocorrelation of the residuals and the Ljung-Box-Pierce statistic were used to check the adequacy of the identified models. If the model was found to be inappropriate, the process was returned back to model identification and cycle through the steps until, ideally, an acceptable model was found. In order to achieve an acceptable model tests on whether the estimated model conformed to the specifications of a stationary univariate process was carried out. In particular, plots of autocorrelation and partial autocorrelation of the residuals were used to identify misspecification.

The following tests were used in selecting the best or candid model: Correlogram of the residuals; Normalized Bayesian Information Criterion (BIC), R-square, Stationary R-square, Root Mean Square Error (RMSE), Mean Absolute Percentage Error (MAPE), Maximum Absolute Percentage Error (MaxAPE), Mean Absolute Error (MAE) and Maximum Absolute Error (MaxAE). The correlogram of the residuals were considered by plotting the ACF of residual fitted to the model and if most of the sample autocorrelation coefficients of the residuals are within the limit $\pm 1.96/\sqrt{N}$ where N is the number of observations upon which the model is based then residuals are white noise indicating that the model is good fit. The lower values of the test were used in selecting the best model for the other tests.

3.3.3.7. Forecasting

The Box-Jenkins methodology requires that the model to be used in describing and forecasting a time series be both stationary and invertible. Thus, in order to tentatively identify a Box-Jenkins model, we must first determine whether the time series we wish to forecast is stationary. Forecasting was done within the sample with the aim of testing for the predictability power of the models. Catch data series for Chambo and Kambuzi were forecasted from 2012 to 2021 (10 years period) in order to show the patterns of catches within the period.

3.3.3. Bioeconomic parameter estimation

There are three main approaches used in estimating the parameters of the biomass dynamic model (surplus production model), when the only data available is on fish catch and effort. These are equilibrium methods, regression methods and time-series fitting methods (Hilborn and Walters, 1992). Equilibrium methods, as the name suggests, assumes that fish stock is at equilibrium, and that the relationship between catch per unit effort (U_t) and effort is linear. The linear relationship is derived from the sustainable yield function by lumping together some parameters. The sustainable yield function is given by;

$$Y = qEX = qKE(1 - q\,{}^{E}/_{r}) \tag{3.9}$$

where Y is the yield, q is the catchability coefficient, X is the biomass, K is the carrying capacity, E is the fishing effort and r is the intrinsic growth rate

This can be expressed in the form:

$$\frac{Y}{E} = qK - \frac{q^2K}{r}E = a - bE \qquad (3.10)$$

where a = qK and b = $\frac{q^2K}{r}$. Thus, the coefficients a and b can be estimated by means of a linear regression of Y/E against E (Conrad and Clark, 1994).

In general, these regressions perform poorly because the equilibrium assumption underlying their derivation is usually not satisfied (Conrad and Clark, 1994). For instance, whenever they are applied to data gathered during a stock decline, they usually overstate the surplus production and sustainable fishing effort. Thus, the equilibrium assumption which implies that every catch observed is in fact sustainable cannot be true, if the fish stock is declining (Hilborn and Walters, 1992). Furthermore, only two parameters are estimated and this may be of little use in an analysis where more than two parameters are required (Conrad and Clark, 1994).

Regression methods involve transforming the equations into a linear form and then fitting by linear regression. These approaches are computationally easy and in some cases they recognize the dynamics of the fisheries. However, they often make strong assumptions about the error structure.

The basic idea of time-series fitting is to take an initial estimate of the stock size at the beginning of the data series, then use the time-series fitting model to predict the whole time-series. The parameter values are then adjusted to provide the best fit of the predicted-to-observed time-series with respect to relative abundance of catch data. In general this involves estimating the normal parameters r, q and K plus one additional parameter X_0, which represents the initial biomass. Nonlinear parameter estimation techniques are normally used to find the best fit of the predicted biomass, given the observed catches (Hilborn and Walters, 1992).

This study adopts the regression method for estimating the parameters r, q, K and e. Although this method makes strong assumptions about the error structure, it is recommended for illustrative analysis (Hilborn and Walters, 1992). The major weakness with the equilibrium method, as already mentioned, is that it fails to take into account the dynamics of the fishery, due to the assumption of equilibrium stock. Time-series fitting, on the other hand, can simply be considered as an extension of the regression methods since it uses the initial estimates of r, q, and K to estimate X_0, the initial stock.

3.3.3.1. Schnute's (1977) estimation method

Different regression methods can be identified from the literature (see for example Conrad and Adu-Asamoah, 1986; Ludwig and Walters, 1989 and Uhler, 1980). Three models are particularly distinct and most widely used in the estimation of parameters of the production function: the Schaefer (1957) model, the Fox (1970) model, and the Schnute (1977) model. This study adopts Schnute's (1977) method of estimating the parameters r, q, and K. The first step in this method is to define an equation that uses catch and effort data to predict catch per unit effort (U).

since $Y = qEX$

then $Y/E = qX = U$

and $X = U/q$ (3.11)

where Y is the yield, q is the catchability coefficient, X is the biomass, E is the fishing effort.

The population growth function where fish biomass equals its natural logistic growth rate minus the catch rate can therefore be expressed in terms of U. Thus,

$$\dot{X} = rX(1 - X/K) - qEX$$

Becomes $\dot{U} = rU(1 - U/qK) - qEU$ (3.12)

By dividing both sides by U, this can be expressed as

$$\frac{\dot{U}}{U} = r - qE - \frac{r}{qK}U \tag{3.13}$$

When this equation is integrated from t to (t+1), it becomes,

$$\ln\left(\frac{U_{st+1}}{U_{st}}\right) = r - qE_t - \frac{r}{qK}U_t \qquad (3.14)$$

Where E is the rate of fishing and U is the catch per unit effort.

Since integrating over some time period involves time averaging over that period the definition for E_t is the usual total effort per year. The same applies to Y, the catch rate, so that U_t is the annual catch per unit effort. Equation (3.14) suggests that a linear regression of one variable, ln (U_{st+1}/U_{st}) on two variables E_t and U_t, can be used to estimate the three parameters r, K, and q. However, U_{st} is the catch per unit effort at the beginning of year t. This creates a problem in that while typical fisheries data include E_t and U_t, it does not include U_{st} and U_{st+1} since the two involve instantaneous values at the start of each year. Schnute (1977) proceeded by assuming that U_{st} might be approximated by,

$$U_{st} \cong ½(U_t + U_{t-1}). \qquad (3.15)$$

That is, the catch per unit effort at the start of each year t is approximately equal to the average of the two annual averages for U in years just following and just preceding the first day of the year t. By substitution, the key equation becomes,

$$\ln\left(\frac{U_{t+1} + U_t}{U_t + U_{t-1}}\right) = r - qE_t - \frac{r}{qK}U_t \qquad (3.16)$$

This equation is dropped on the basis that it suggests that U_{t+1} could be predicted without knowing E_{t+1} which is impossible and contradictory to the basic assumption of the fisheries model. Schnute's (1977) parameter estimation equation is obtained by adding the key equation for year t to the same equation for year (t+1), dividing the result by 2 and assuming that,

$$U_t \cong \sqrt{U_{st} U_{st+1}} \ .$$

The assumption for U_t implies that the average catch per unit effort is roughly the geometric mean of its value at the beginning and end of each year. In exact form the estimation equation becomes;

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = r - q\left(\frac{E_t + E_{t+1}}{2}\right) - \frac{r}{qK}\left(\frac{U_t + U_{t+1}}{2}\right) \qquad (3.17)$$

The expression $(E_t + E_{t+1})/2$ gives the effective level of effort exerted between years t and t+1, and $(U_t + U_{t+1})/2$ is the corresponding catch per unit effort. This equation suggests that next year's catch per unit effort can be predicted by specifying next year's anticipated effort. A stochastic version of this equation is obtained by replacing t by t-1 and by adding the error term, ε.

Thus,

$$\ln\left(\frac{U_t}{U_{t-1}}\right) = r - q\left(\frac{E_{t-1} + E_t}{2}\right) - \frac{r}{qK}\left(\frac{U_{t-1} + U_t}{2}\right) + \varepsilon \tag{3.18}$$

A regression of this equation was used to obtain estimates of the parameters r, q and K without making the equilibrium assumption.

Since Chambo fishery has shown to be declining rapidly over the years, two scenarios were created for the estimation of parameters. The scenarios included the period from 1976 to 1989 when Chambo fishery was under equilibrium and period from 1990 to 2011 when Chambo fishery was over exploited. The whole period from 1976 to 2011 was considered for Kambuzi fishery since it has shown to be increasing with time (DoF, 2010).

3.3.4. Estimation of reference points

The analytical expressions of maximum economic yield (MEY), open-access (OAY) and the maximum sustainable yield (MSY) in terms of biological parameters along with economic variables were derived. These reference points were analyzed for the future management policies of a fishery and sustainable development of an ecosystem.

3.3.4.1. Gordon Schaefer logistic model

Maximum sustainable yield (MSY) level of effort was derived from the sustainable yield function by differentiating it with respect to effort. The Gordon Schaefer logistic model describes population growth based on the following mathematical expression:

$$\frac{dB}{dt} = rB(t)\left(1 - \frac{B(t)}{K}\right) \tag{3.19}$$

where r is the intrinsic population growth rate, B(t) is population biomass in time t and K is the carrying capacity of the environment.

Under exploitation, Schaefer (1954) introduced the catch rate Y(t) as:

$$Y(t) = qf(t)B(t) \tag{3.20}$$

where f(t) is the fishing effort and q is the catchability coefficient, defined as the fraction of the population fished by an effort unit (Gulland, 1983).

Therefore, biomass change through time is expressed as:

$$\frac{dB}{dt} = rB(t)\left(1 - \frac{B(t)}{K}\right) - qf(t)B(t) \tag{3.21}$$

Under sustainable level:

$$rB(t)\left(1 - \frac{B(t)}{K}\right) = qf(t)B(t) \tag{3.22}$$

Divide both sides by rB:

$$1 - \frac{B}{K} = \frac{qf}{r}$$

Then:

$$B = K\left(1 - qf/r\right)$$

Substituting (B) in yield function to obtain the sustainable yield function (SYF):

$$Y = qfK\left(1 - qf/r\right) \tag{3.23}$$

3.3.4.2. Maximum Sustainable Yield (MSY)

Maximum Sustainable Yield (MSY) effort, catch and stock were obtained according to Seijo *et al. (*1998) as follows:

First derivative of yield function:

$$F_{msy} = \frac{r}{2q} \tag{3.24}$$

Substituting Fmsy into sustainable yield function:

$$Y_{msy} = \frac{rK}{4} \quad (3.25)$$

First derivative of logistic growth function:

$$B_{msy} = \frac{K}{2} \quad (3.26)$$

3.3.4.3. The Open Access Yield (OAY)

The Open Access Yield (OAY) effort, catch and stock were obtained by:

$$\pi = PY - CF, \text{or } \ TSR - TC \quad (3.27)$$

where π is the net revenue derived from fishing, P is the average beach price of fish, Y is the total yield, C is the cost of fishing, F is the fishing effort, TSR is the total sustainable revenue and TC is the total cost of fishing.

Replacing B in the revenue function:

$$F_{be} = \frac{r}{q}\left(1 - \frac{C}{pqK}\right) \quad (3.28)$$

$$Y_{be} = \frac{CF_{be}}{p} \tag{3.29}$$

$$B = \frac{c}{pq} \tag{3.30}$$

3.3.4.4. The Maximum Economic Yield (MEY).

The level of harvesting which maximize the profits to the fishery is determined by maximum economic yield (MEY). Maximum economic yield can be obtained from the fishery when the difference between total revenue earned by the fishery and total cost used to harvest is at a maximum.

The Maximum Economic Yield (MEY) effort and catch were obtained by:

The fishing effort at maximum economic yield (MEY) was obtained by equating the marginal value of fishing effort (MVE) to the unit cost of fishing effort and solving for f.

$$MVE = pqk\left(1 - \frac{2qf}{r}\right) \tag{3.31}$$

Therefore:

$$f_{MEY} = \frac{r}{2q}\left(1 - \frac{c}{pqk}\right) \tag{3.32}$$

$$Y_{MEY} = \frac{r}{4}\left(k - \frac{c^2}{p^2q^2k}\right) \quad (3.33)$$

3.3.5. Trend analysis of annual economic rent

To attain efficiency in the economic sense, there is need to take into account the costs of fishing and revenues that are generated from selling the harvested fish. It is necessary to use catch-effort relationship to define revenues and costs as a function of fishing effort. The annual economic rent was defined according to Seijo *et al*. (1998) as: Given price, p, per unit of fish harvested for each year, the total revenue, TR, was obtained by:

$$TR = pH \quad (3.34)$$

where TR is the total revenue, p is the average beach price of fish per year and H is the harvest/catch per year.

Given cost, *c*, per unit of effort per year, the total costs, *TC* (including TVC and TFC), of fishing was obtained by:

$$TC = cE \quad (3.35)$$

where TC is the total cost of fishing, c is the unit cost of fishing per year and E is the effort level of fishing per year.

The difference between the total revenue of the fishery and the total fishing costs is known as the sustainable economic rent provided by the fishery resource at any given level of fishing effort.

$$\pi = \text{TR} - \text{TC} \qquad (3.36)$$

The total revenue function for estimating annual fishery profits was based on the actual catch and price data per year. The total cost function was based on annual total variable costs and fixed costs that included daily labour and meals, annual license fee, annual maintenance, gear and boat costs. Fishing in Lake Malombe is done up to 25 days per month as such, 300 days per year and 225 days per year were used in estimating annual variable cost for Chambo and Kambuzi fishery, respectively.

3.3.6. Estimation of present value

The present value of a flow of future revenues was estimated in order to allow comparisons of money during different time periods. The future values were discounted to reflect the earnings lost by not being able to immediately invest the future sum. The discount rate (i) of 17.5% based on 2011 bank lending interest rate was used for this purpose. Discounting does not mean that future earnings are actually lost; but that they are not worth the same in the present as in the future because of risk and uncertainty regarding future catches. A 10 years projection from 2011 to 2021 was used for the estimation of present value of a flow of future revenues. The present value of a flow of benefits and costs through time was expressed according to Seijo *et al*. (1998) as:

$$PV_{\pi} = \frac{TR(t) - TC(t)}{(1+i)^{t}} = \frac{\pi(t)}{(1+i)^{t}} \qquad (3.37)$$

where PV is the present value profit and i is the social rate of discount.

Net present value (NPV) of a flow of benefits and costs through time was estimated in order to ascertain the viability of fishing Chambo and Kambuzi in Lake Malombe through time. The NPV was obtained according to Sumaila and Suatoni (2005):

$$PV_{\pi} = \frac{P_1}{(1+i)^{1}} + \frac{P_2}{(1+i)^{2}} + \frac{P_3}{(1+i)^{3}} \ldots + \frac{P_{10}}{(1+i)^{10}} \qquad (3.38)$$

where P is the present value from 1 to 10 years

CHAPTER FOUR

RESULTS

Chapter five presents results of the study which focused on assessing the intertemporal preferences of fisheries resource users in the exploitation of fish stocks forecasting patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) catches and estimating resource economic rents associated with maximum economic yield (MEY) and maximum sustainable yield (MSY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) fishery of Lake Malombe. The chapter has been divided into four sections covering results from the intertemporal preference analyses, time series analyses and bioeconomic analyses.

4.1. Intertemporal preference

4.1.1. Frequency of respondents' intertemporal preference

The frequency of respondents' intertemporal preference in fisheries resource use of Lake Malombe is presented in Table 4.1.

Table 4.1 Intertemporal preference of respondents

Variables	Characteristic	Category	% Positive preference	% Negative preference	Chi Square
X_1	Stratum	Lake Malombe West	62	38	0.004*
		Lake Malombe East	33	67	
X_2	Respondent	Fish consumer	41	59	0.008*
		Fisher	60	40	
X_3	Age	Adult	48	52	0.302
		Youth	56	44	
X_4	Sex	Male	52	48	0.469
		Female	36	64	
X_5	Marital status	Married	56	44	0.049*
		Single	40	60	
X_6	Household size	Family members	53	47	0.655
X_7	Religion	Christian	45	55	0.606
		Islam	53	47	
X_8	Tribe	Others	54	46	0.951
		Yao	53	47	
X_9	Literacy	Illiterate	58	42	0.004*
		Literate	35	65	
X_{10}	Period in area	1-15years	48	52	0.412
		More than 16	55	45	
X_{11}	Years fishing	1-15years	55	45	0.047*
		More than 16	33	67	
X_{12}	Working time	More than 16,	93	7	0.002*
		1-15hours	50	50	

Note: * indicates significance at 0.05 probability level.

Others under tribe (X_8) represents all other tribes other than Yao.

Table 4.1, shows that stratum, category of respondents, marital status, literacy level, years in fishing and daily working hours have significant variations in positive or negative intertemporal preference ($p < 0.05$, χ^2). In Lake Malombe East, fish consumers, single marital status, literacy, and fishers who have been fishing for more than 16 years have negative intertemporal preference. Age of respondent, sex, household size, religion, tribe and period of stay in an area, have insignificant variations in positive or negative intertemporal preference ($p > 0.05$, χ^2).

4.1.2. Logit model evaluation

Accuracy of prediction of 74.4% was obtained and is presented in Table 4. Since the purpose of the model is to identify main factors that influence people's intertemporal preference, the model is appropriate for the purpose, considering its goodness of fit and high predictive ability. The logistic regression coefficients for the determinants of intertemporal preference of fishers and consumers are contained in Table 4.2. The goodness of fit Hosmer and Lemeshow (H-L) test yielded χ^2 (8) of 6.924 and was insignificant ($p = 0.214$), suggesting that the model fitted to the data well. The -2 Log Likelihood showed that the model fits the data at an acceptable level ($p = 0.001$).

Table 4.2 Observed and the predicted frequencies for intertemporal preference

	Predicted		
Observed	Positive	Negative	% correct
Positive	91	23	79.8
Negative	32	69	68.3
Overall % correct			74.4

Logistic Regression with the cut off of 0.50

4.1.3 Statistical tests of individual predictor variables

The results in Table 4.3 show that from the twelve predictor variables fitted in the logistic regression model, five variables (stratum, marital status, literacy, years in fishing and daily working hours) have a significant impact ($p < 0.05$) on intertemporal preference in fisheries resource use. Seven variables (category of respondent, age of respondent, sex, household size, religion of respondent, tribe/ethnic group of respondent and period stayed in an area) do not have significant impact ($p > 0.05$) on intertemporal preference in fisheries resource use. Out of the five significant predictor variables three have positive significant coefficient (stratum (X_1), Literacy (X_9), and years in fishing (X_{11}). The test of the intercept (the constant) is insignificant ($p = 0.971$).

Variables that were insignificant were dropped from the model thus the final model contains the following independent variables: stratum (X_1), marital status (X_5), literacy (X_9), years in fishing (X_{11}) and daily working hours (X_{12}).

Therefore, the model can be estimated as;

$$\text{Logit (Y)} = 0.038 + 1.924X_1 + (-1.409\ X_5) + 1.055X_9 + 0.054X_{11} + (-.159X_{12}). \quad (4.1)$$

Table 4.3 Logistic Regression Coefficients of the Socio-economic Factors

Predictor variable	X_i	β	S.E.	Wald	P Value	Exp(β)	95.0% C.I.for EXP(B)	
							Lower	Upper
Constant		.038	1.043	.001	.971	1.039		
Stratum	X_1	1.924	.399	23.216	.000*	6.847	3.131	14.974
Category	X_2	-.162	.421	.148	.700	.850	.372	1.942
Age	X_3	.431	.382	1.274	.259	1.539	.728	3.254
Sex	X_4	-1.061	.822	1.667	.197	.346	.069	1.732
Marital status	X_5	-1.409	.422	11.166	.001*	.244	.107	.558
Household size	X_6	.062	.069	.807	.369	1.064	.930	1.217
Religion	X_7	.518	1.357	.146	.703	1.679	.117	24.002
Tribe	X_8	.394	1.239	.101	.751	1.482	.131	16.809
Literacy	X_9	1.055	.420	6.308	.012*	2.871	1.261	6.539
Period in area	X_{10}	-.154	.406	.144	.704	.857	.387	1.898
Years of fishing	X_{11}	.054	.027	4.077	.043*	1.056	1.002	1.112
Working time	X_{12}	-.159	.058	7.540	.006*	.853	.762	.956

* indicates significance at 0.05 probability level

Goodness of fit Hosmer and Lemeshow (H-L) $\chi^2 = 10.789$, df = 8, $P = 0.214$

-2 Log Likelihood = 236.105 ($p = 0.001$)

Prediction of success = 74.9%

4.2. Time series

4.2.1. Stationarity of time series data

The preliminary analysis for examining stationarity of the data was conducted by considering the time series plots of catch data of Chambo and Kambuzi caught in gill net and nkacha net respectively from 1976 to 2011 as shown in Figures 4.1 and 4.2. The plots give an initial clue about the likely nature of the time series. It is shown in Figures 4.1 and 4.2 that catch data for the period of 1976 to 2011 was nonstationary for the two common fish species of Lake Malombe due to an unstable means which increase and decrease at certain points. The means are not constant throughout the series as they assume downward and upward trends by changing from the highest peak to the lowest peak and vice versa. There are sudden swings throughout the 1976 to 2011 period showing that the means and variances are non stationary.

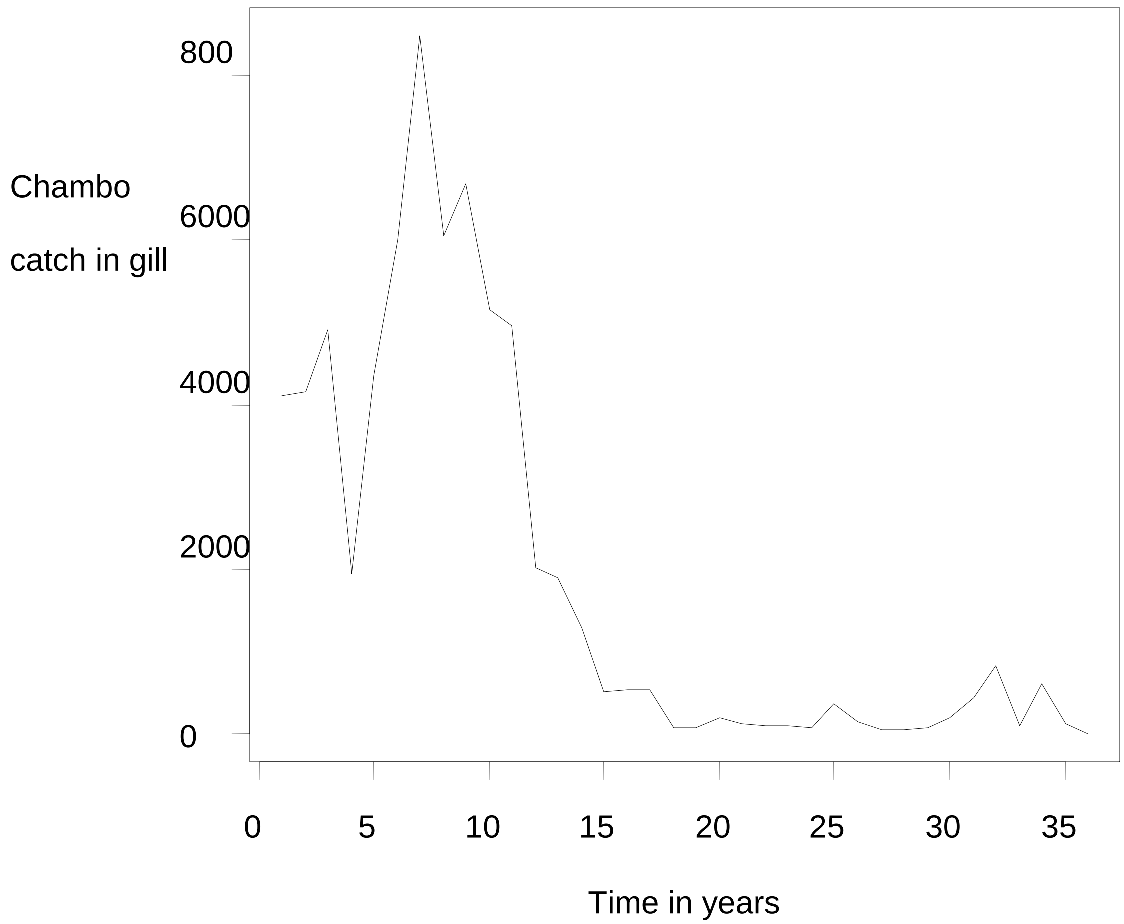


Figure 4.1 Time series plots of Chambo catch (tones) in Gill nets: 1976 to 2011

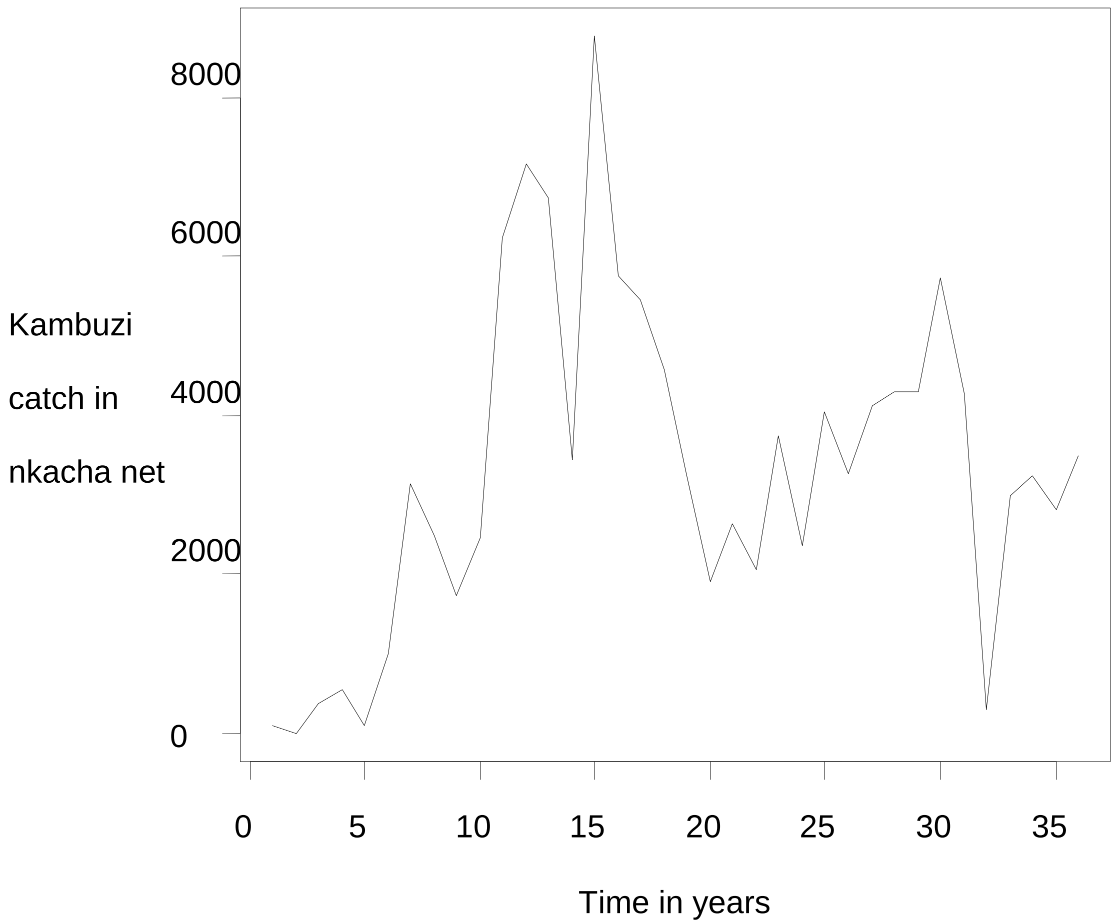


Figure 4.2 Time series plots of Kambuzi catch (tones) in Nkacha nets: 1976 to 2011

The test of stationarity of the catch data using plots of autocorrelation function (ACF) and partial autocorrelation function (PACF) charts are shown in Figures 4.3 and 4.4. The correlograms suggest that the data for Chambo and Kambuzi caught in gill net and nkacha net respectively are nonstationary as evident from the correlograms (Figures 4.3 and 4.4). The ACF and PACF of the residuals were examined by observing any individual coefficients that were outside some specified confidence interval around zero. The ACF and PACF for Chambo catch in gill net and Kambuzi catch in nkacha net were above the critical limit indicating the absence of stationarity. ACF for Chambo catch at lags 1 to 6 and PACF at lag 1 and 5 were individually statistically significant, for they were outside the 95% confidence bounds. ACF for Kambuzi catch at lags 1, 2, 3, 4, 9, 10 and PACF at lag 1 were individually statistically significant, for they were outside the 95% confidence bounds.

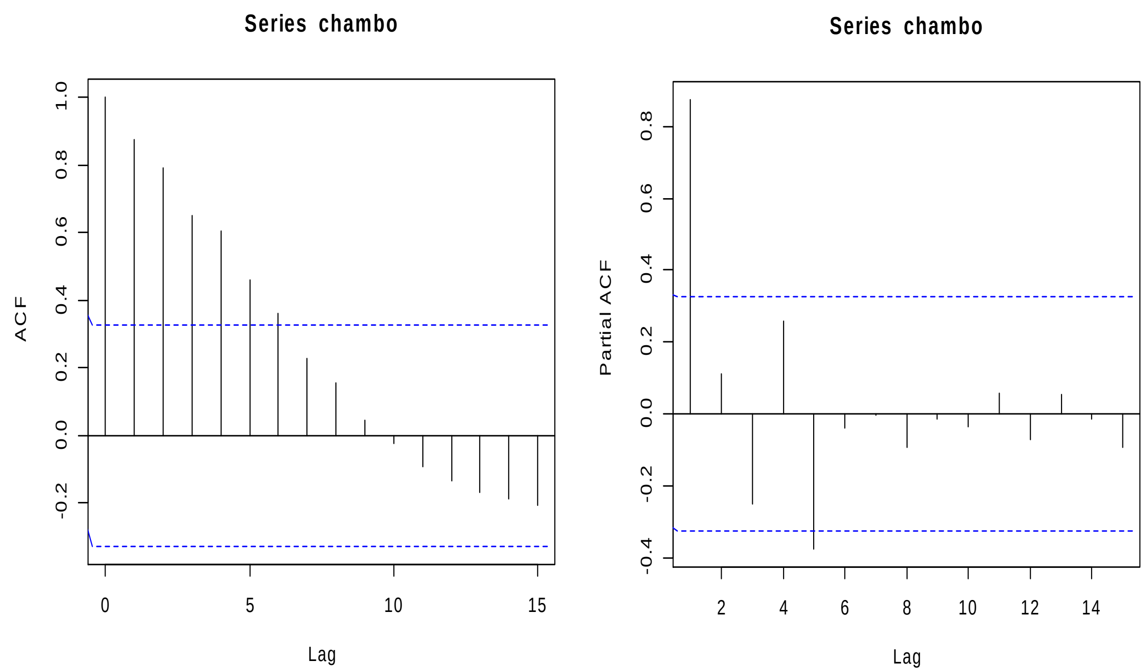


Figure 4.3 Autocorrelograms and partial autocorrelograms of catch data for Chambo catch

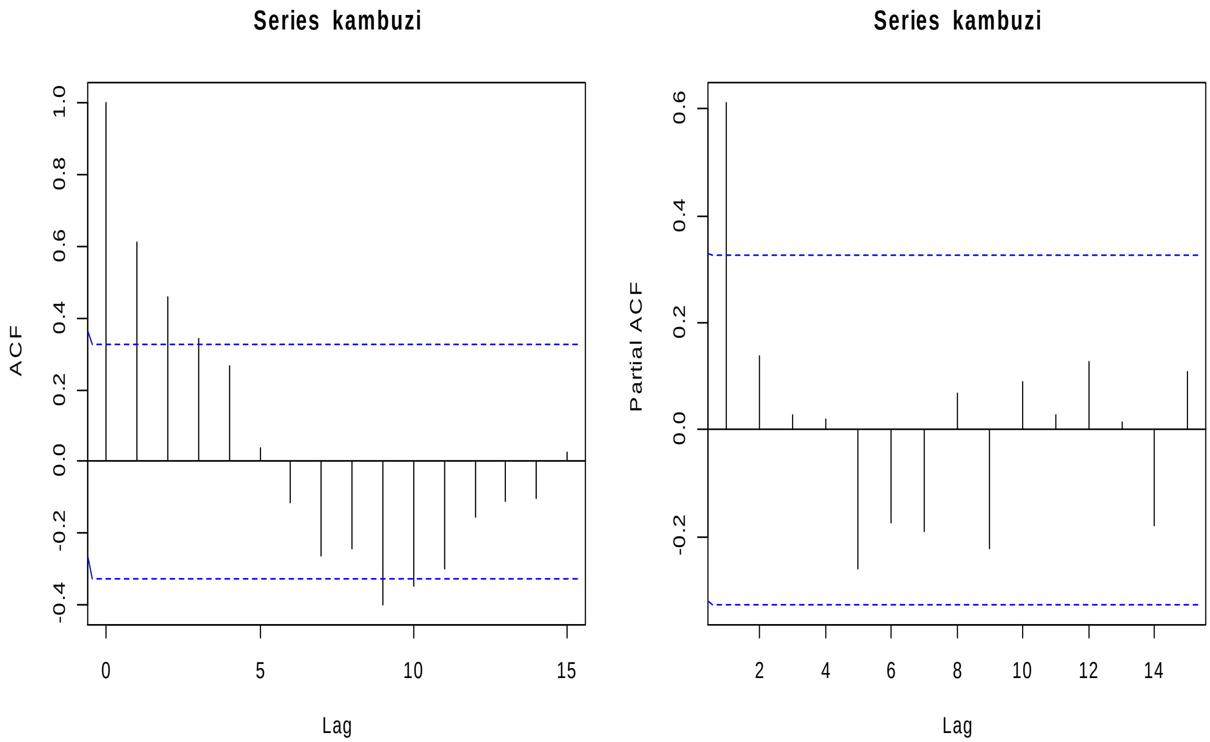


Figure 4.4 Autocorrelograms and partial autocorrelograms of catch data for Kambuzi catch

Table 4.4 ACF and PACF for scores of Chambo catch in Gill nets before differencing

Lag	Autocorrelation	Std. Error	Box-Ljung Statistic			PAC
			Value	df	Significance	
1	.874	.160	29.838	1	.000	.874
2	.790	.158	54.933	2	.000	.111
3	.652	.155	72.567	3	.000	-.249
4	.604	.153	88.186	4	.000	.260
5	.461	.151	97.570	5	.000	-.374
6	.363	.148	103.573	6	.000	-.039
7	.229	.146	106.037	7	.000	-.003
8	.154	.143	107.196	8	.000	-.094
9	.046	.140	107.305	9	.000	-.015
10	-.024	.138	107.334	10	.000	-.035
11	-.093	.135	107.805	11	.000	.058
12	-.133	.132	108.814	12	.000	-.070

Table 4.5 ACF and PACF for scores of Kambuzi catch in Nkacha nets before differencing

			Box-Ljung Statistic			
Lag	Autocorrelation	Std. Error	Value	Df	Significance	PAC
1	.611	.160	14.582	1	.000	.611
2	.459	.158	23.074	2	.000	.138
3	.343	.155	27.954	3	.000	.028
4	.265	.153	30.955	4	.000	.020
5	.039	.151	31.023	5	.000	-.261
6	-.117	.148	31.647	6	.000	-.175
7	-.264	.146	34.924	7	.000	-.190
8	-.244	.143	37.841	8	.000	.068
9	-.398	.140	45.884	9	.000	-.221
10	-.347	.138	52.229	10	.000	.089
11	-.302	.135	57.205	11	.000	.029
12	-.154	.132	58.561	12	.000	.128

4.2.2. First differencing of Chambo and Kambuzi catch data

Catch data for Chambo and Kambuzi were differenced once to make the data stationary. Figures 4.5 and 4.6 show time series plots of first differenced catch data for Chambo and Kambuzi caught in Gill nets and Nkacha nets, respectively, from 1976 to 2011. Figures 4.5 and 4.6 show that catch data for the period of 1976 to 2011 are stationary for Chambo and Kambuzi species due to stable means around certain points. There are no sudden swings throughout the 1976 to 2011 period showing that the means and variances are stationary.

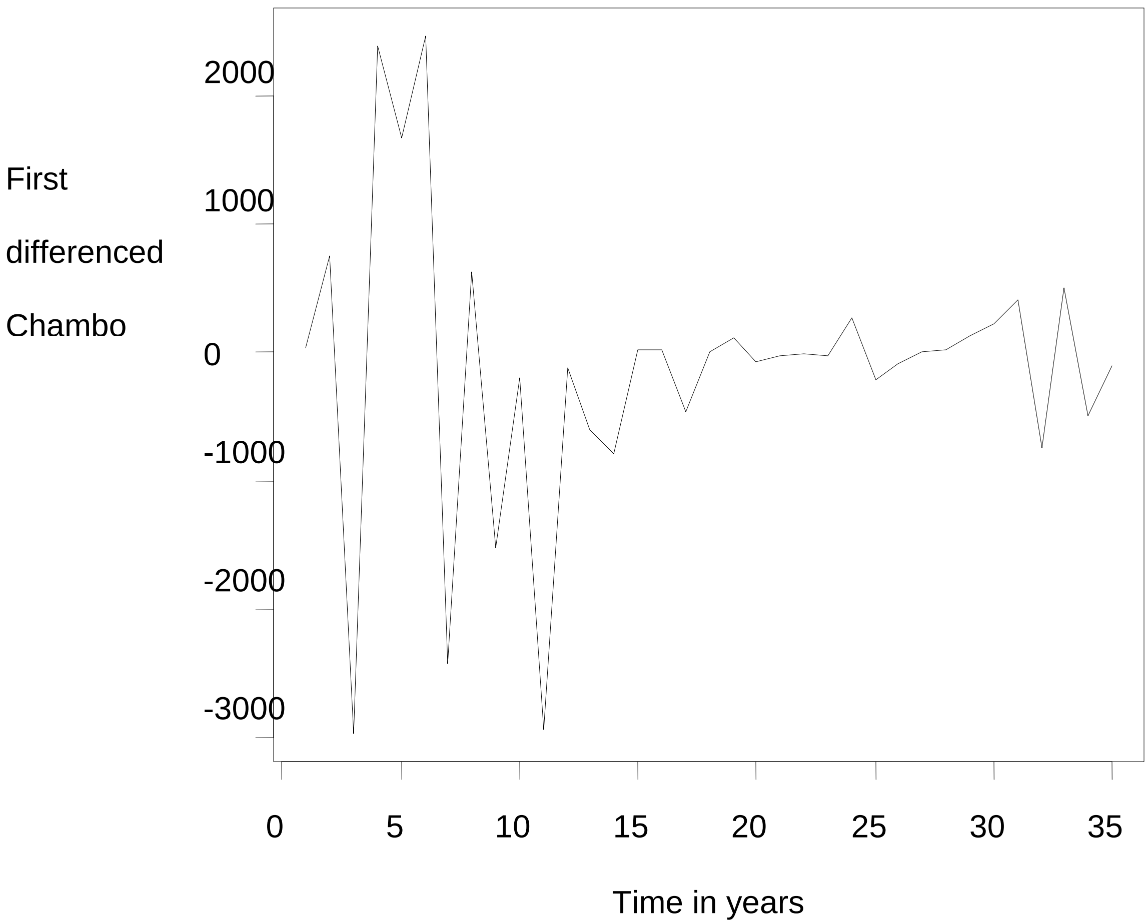


Figure 4.5 Time series plots of Chambo first differenced catch data

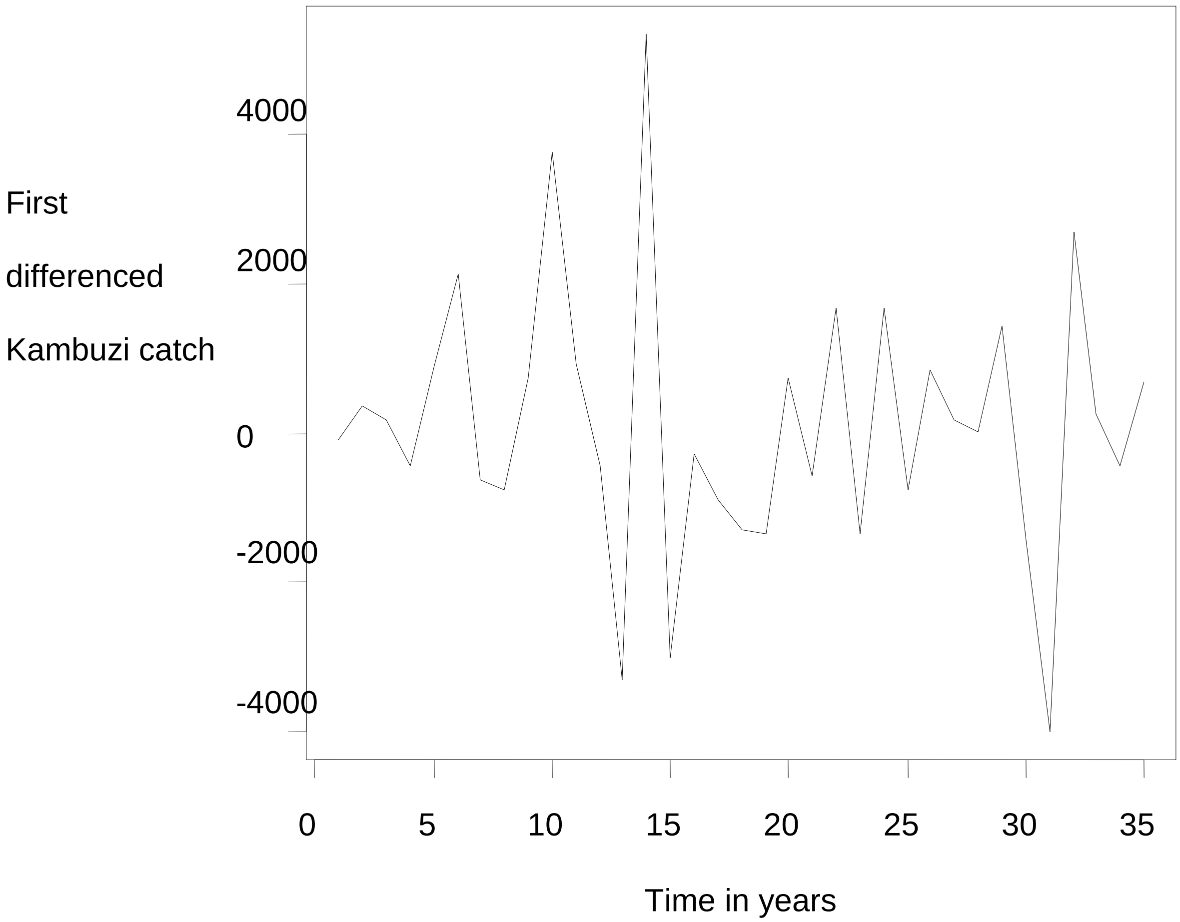


Figure 4.6 Time series plots of Kambuzi first differenced catch data

The outputs of the first difference of ACF and PACF for Chambo and Kambuzi catch data are shown in Figures 4.7 and 4.8. The first differenced ACF and PACF for Chambo catch showed that thirteen lags for ACF and 15 lags for PACF were individually statistically insignificantly different from zero, for they were within the 95% confidence bounds indicating the presence of stationarity. Lag 4 for ACF was individually statistically significantly different from zero. The ACF correlogram for Chambo catch showed that observation at lag 1 was correlated to itself and was equal to 1 (Figure 4.7).

The first differenced ACF for Kambuzi catch showed that thirteen lags for ACF and fourteen lags for PACF were individually statistically insignificantly different from zero, for they were all within the 95% confidence bounds. The ACF correlogram for Kambuzi catch showed that lag 1 was correlated to itself and was equal to 1 while lag 2 was statistically significantly different from zero. The PACF correlogram for Kambuzi catch showed that lag 1 was statistically significantly different from zero (Figure 4.8)

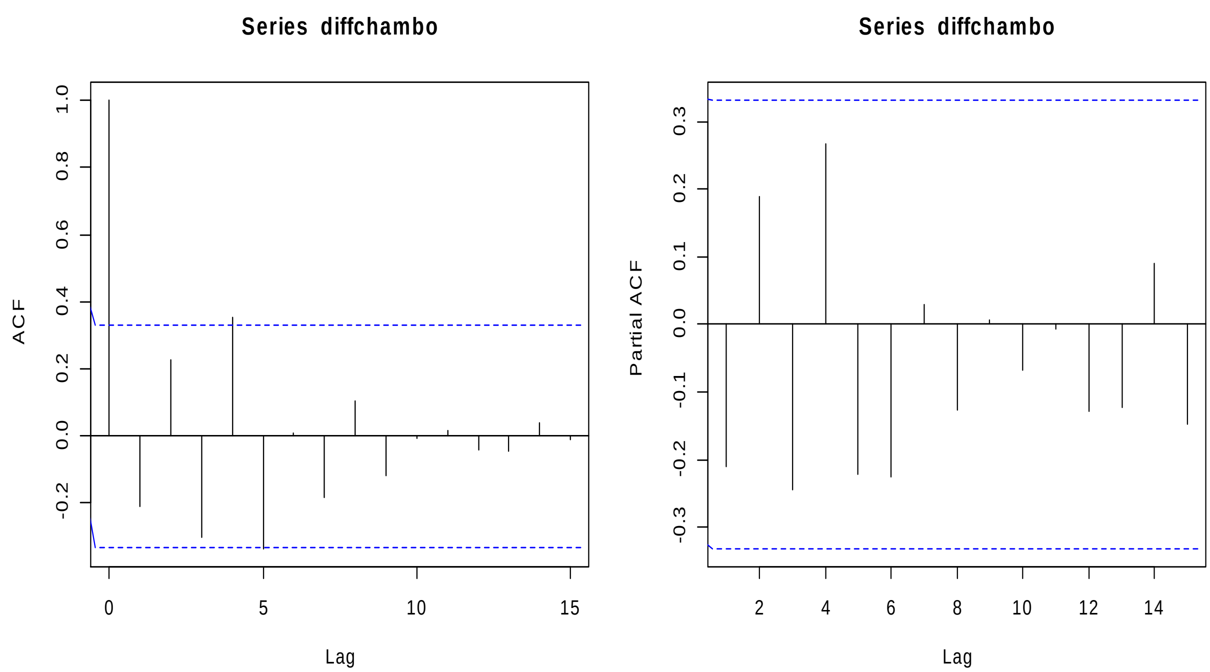


Figure 4.7 Autocorrelograms and partial autocorrelograms of first differenced Chambo catch data

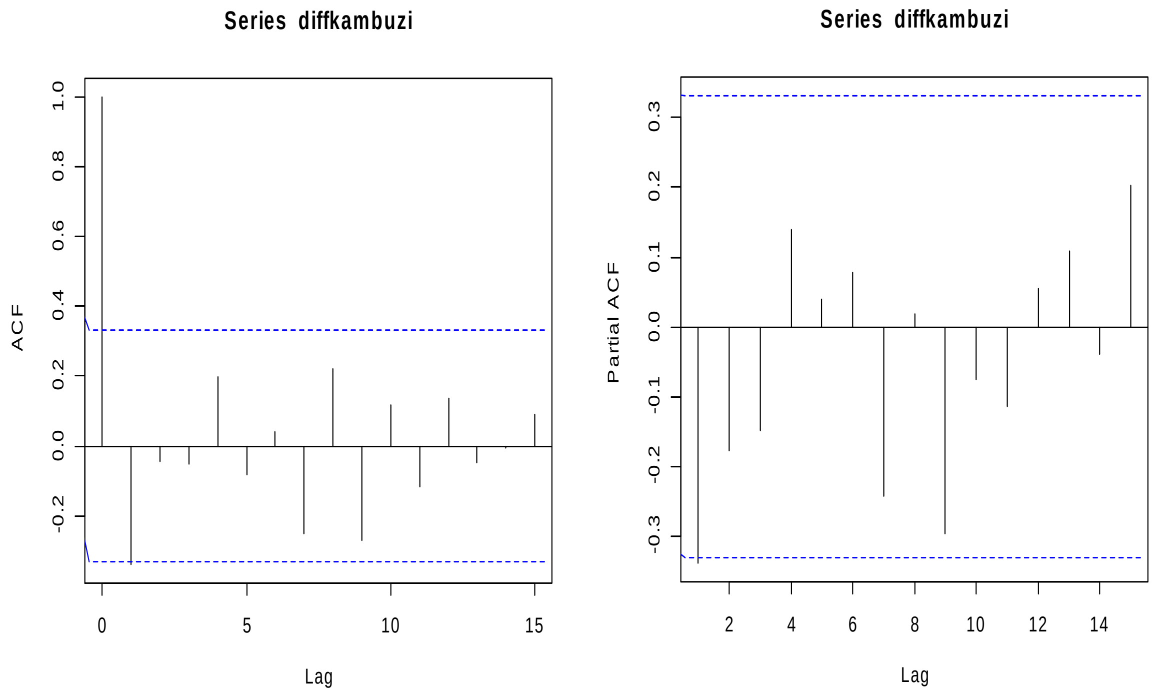


Figure 4.8 Autocorrelograms and partial autocorrelograms of first differenced Kambuzi catch data

Box-Ljung statistics showed that the ACF of Chambo data at any of the 10 lags were insignificant while lags 4 and 5 were significant (p = .013 and p = .004 respectively). ACF for Kambuzi data was significant at lag 1 (p = .037)(Tables 8 and 9)

Table 4.6 ACF and PACF for first order differenced scores of Chambo catch

			Box-Ljung Statistic			
Lag	ACF	Std. Error	Value	Df	Significance.	PACF
1	-.185	.162	1.297	1	.255	-.211
2	-.124	.160	1.899	2	.387	.189
3	.105	.157	2.347	3	.504	-.244
4	-.048	.155	2.445	4	.013	.267
5	-.005	.152	2.446	5	.004	-.221
6	-.104	.150	2.929	6	.818	-.226
7	-.240	.147	5.596	7	.588	.029
8	.157	.144	6.771	8	.562	-.127
9	.033	.142	6.824	9	.655	.006
10	-.038	.139	6.900	10	.735	-.068
11	.075	.136	7.206	11	.782	-.008
12	-.033	.133	7.267	12	.839	-.128

Table 4.7 ACF and PACF for first differenced scores of Kambuzi catch in nkacha net

			Box-Ljung Statistic			
Lag	ACF	Std. Error	Value	Df	Significance	PACF
1	-.338	.162	4.357	1	.037	-.338
2	-.042	.160	4.427	2	.109	-.177
3	-.051	.157	4.531	3	.210	-.148
4	.198	.155	6.173	4	.187	.139
5	-.081	.152	6.457	5	.264	.039
6	.042	.150	6.534	6	.366	.078
7	-.251	.147	9.453	7	.222	-.243
8	.219	.144	11.764	8	.162	.018
9	-.270	.142	15.385	9	.081	-.297
10	.118	.139	16.102	10	.097	-.075
11	-.116	.136	16.827	11	.113	-.115
12	.138	.133	17.900	12	.119	.054

On this account it was confirmed that the data were stationary and several models such as ARIMA (0, 1, 5), ARIMA (0, 1, 4), ARIMA (0, 1, 3), ARIMA (0, 1, 2) and ARIMA (0, 1, 1) for Chambo catch in Gill net and ARIMA (0, 1, 1) and ARIMA (1, 1, 1) models for Kambuzi catch in Nkacha net were suggested for model selection.

4.2.3 Model estimation

Having obtained some suggested models the best possible estimates for the parameters were found by considering the final estimates of parameters and the model selection criteria. Table 4.8 reports the final estimates of parameter for the suggested ARIMA models.

Table 4.8 Final estimates of Chambo and Kambuzi catch ARIMA models

Model	Model type	Coefficient	SE Coefficient	T Value	P Value
Chambo (0,1,5)	Constant	-108.65	64.33	-2.808	0.009
	MA 1	0.200	6.47	0.031	0.976
	MA 2	0.109	4.39	0.025	0.980
	MA 3	0.067	4.53	0.015	0.988
	MA 4	-0.263	6.86	-0.038	0.970
	MA 5	0.880	7.44	0.118	0.907
Chambo (0,1,4)	Constant	-110.82	231.19	-0.479	0.635
	MA 1	-0.087	0.178	-0.489	0.628
	MA 2	-0.143	0.171	-0.835	0.410
	MA 3	0.251	0.177	1.417	0.167
	MA 4	-0.360	0.180	-1.999	0.055
Chambo (0,1,3)	Constant	-137.87	102.09	-1.350	0.187
	MA 1	-0.090	0.165	-0.545	0.590
	MA 2	0.001	0.164	0.006	0.996
	MA 3	0.581	0.180	3.23	0.003
Chambo (0,1,2)	Constant	-118.10	183.64	-0.643	0.525
	MA 1	0.149	0.176	0.847	0.404
	MA 2	-0.107	0.176	-0.610	0.546
Chambo (0,1,1)	Constant	-118.41	161.17	-0.735	0.468
	MA 1	0.159	0.172	0.927	0.031
Kambuzi(0,1,1)	Constant	92.215	174.06	0.53	0.600
	MA 1	0.409	0.16	2.56	0.015
Kambuzi(1,1,1)	Constant	92.107	174.59	0.526	0.602
	AR 1	0.031	0.43	0.944	0.004
	MA 1	0.434	0.393	0.278	0.002

4.2.3 Model selection

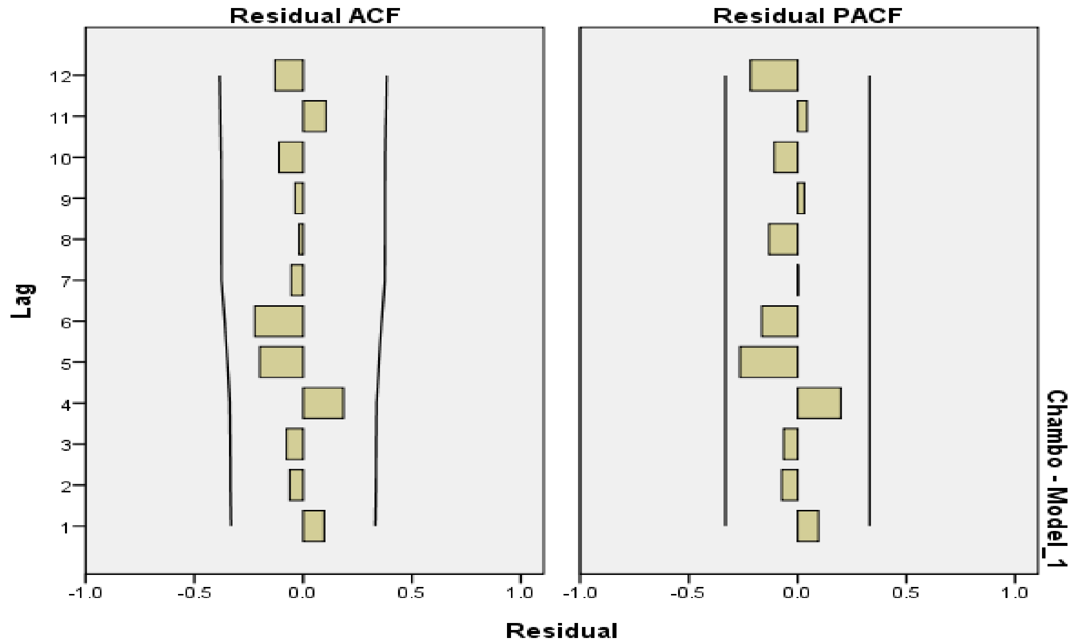
The model selection criteria which consisted of the Normalize BIC, stationary R-squared, R-squared, RMSE, MAPE, MaxAPE, MAE and MaxAE shown in Table 4.9 were used in selecting the candid model from the suggested models as well as evaluating the accuracy of the forecast. The Normalized BIC test indicates that the model with the least Normalized BIC is better in terms of forecasting performance than the one with a large Normalized BIC. Therefore, ARIMA (0, 1, 1) for Chambo fishery has the least Normalized BIC of 14.26 compared to other ARIMA Chambo models. ARIMA (0, 1, 1) for Kambuzi catch has the least Normalized BIC of 15.09 compared to other ARIMA models for Kambuzi catch as shown in Table 4.9. The R-Squared, RMSE, MAPE, MAE, MaxAPE, and MaxAE were further taken into consideration as they measure the accuracy of the fitted time series model. RMSE and MAE served as measures for comparing forecast of the same series across different models and hence the smaller the error, the better the forecasting ability of the model.

Table 4.9 Model selection criteria

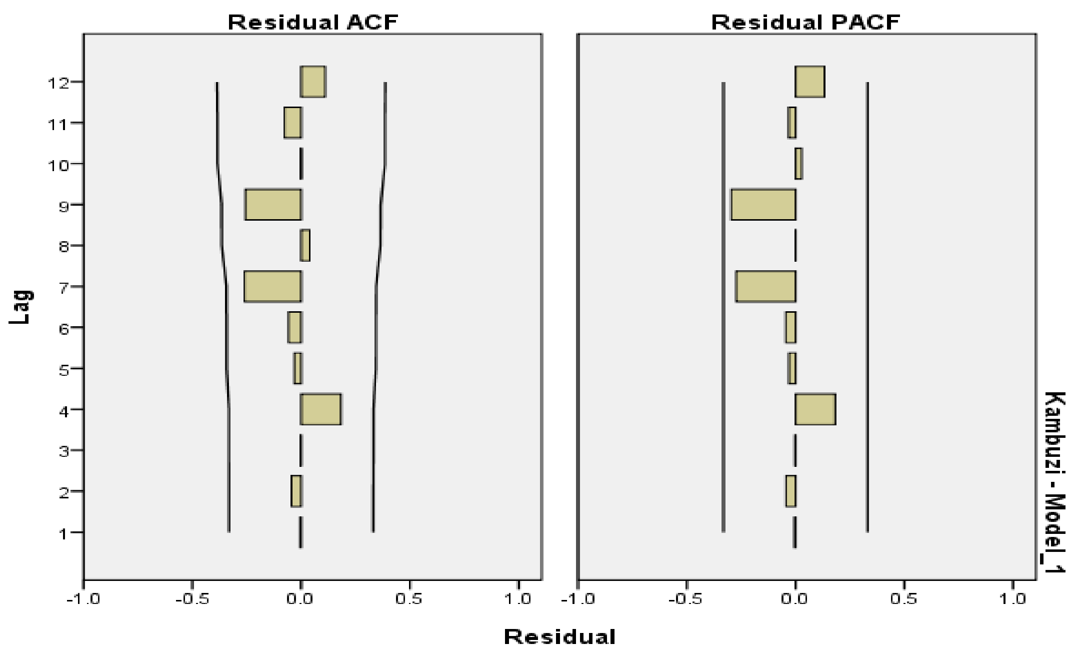
Model	SR^2	R^2	RMSE	MAPE	MaxAPE	MAE	MaxAE	NBIC
Chambo (0,1,5)	0.210	0.830	1088.25	255.99	4455.68	672.11	3008.29	14.59
Chambo (0,1,4)	0.185	0.829	1088.38	304.88	3975.34	729.47	2860.01	14.49
Chambo (0,1,3)	0.109	0.810	1117.60	308.66	3903.49	757.34	2882.49	14.40
Chambo (0,1,2)	0.05	0.801	1135.72	132.54	1105.09	664.27	2741.95	14.37
Chambo (0,1,1)	0.03	0.797	1128.17	117.76	529.24	687.70	2923.65	14.26
Kambuzi (0,1,1)	0.146	0.849	1708.19	160.32	2488.31	1194.92	4487.98	15.09
Kambuzi (1,1,1)	0.146	0.853	1734. 53	160.14	2486.80	1196.94	4467.05	15.20

Figure 4.9 shows plots of ACF and PACF residuals for Chambo and Kambuzi models. The sample autocorrelation coefficients of the residuals are extremely low and lie within the limit of ±0.327 (1.96/square root 36) showing that the residuals are white noise indicating the models are good fit.

(a)



(b)



Figures 4.9 Plots of ACF and PACF residuals for Chambo (a) and Kambuzi (b) catch forecasting models

The RMSE, MAPE, MaxAPE, MAE and MaxAE in Table 4.7 gave an indication of a smaller error and a better forecasting ability for ARIMA (0, 1, 1) for Chambo catch and ARIMA (0, 1, 1) for Kambuzi catch than the other suggested models. Based on the supporting model selection criteria and the forecasting evaluation criteria, it is proposed that the best models among the four suggested models as stated above are ARIMA (0,1,1) for Chambo catch and ARIMA (0,1,1) for Kambuzi catch written as:

Chambo ARIMA (0, 1, 1) model

$$Y_t = \theta_1 \varepsilon_{t-1} + \varepsilon_t \tag{4.2}$$

Substituting the values of θ_1 into equation;

$$Y_{(t)} = -118.41 + 0.159_{\varepsilon_{t-1}} + \varepsilon_t \tag{4.3}$$

Kambuzi ARIMA (0, 1, 1) model

$$Y_t = \theta_1 \varepsilon_{t-1} + \varepsilon_t \tag{4.4}$$

Substituting the value of θ_1 into equation;

$$Y_t = 92.215 + 0.409\varepsilon_{t-1} + \varepsilon_t \tag{4.5}$$

4.14. Forecasted catches of Chambo and Kambuzi

Table 4.10 shows 10 years catch forecast for Chambo catches based on ARIMA (0, 1, 1) up to 2021. It was noted that the magnitude of the difference between the forecasted and actual values were low for the selected models. The noise residuals are combinations of both positive and negative errors which shows that, the model is not forecasting too low on the average or too high on the average. Hence, from the ongoing assessment per the actual and the forecasted catches of Chambo in Table 4.10, it could be suggested that the model had good forecasting power.

Table 4.10 Forecast of Chambo catch (in tons): ARIMA (0, 1, 1).

Year	Forecasted catch	95% confidence bounds
2011	206.80	(-1947.83,2361.43)
2012	-268.67	(-2423.30,1885.96)
2013	-218.45	(-3047.29,2610.40)
2014	-478.29	(-4025.05,3068.48)
2015	-442.71	(-4441.81,3556.38)
2016	-688.60	(-5217.52,3840.32)
2017	-666.32	(-5562.55,4229.90)
2018	-899.54	(-6232.30,4433.22)
2019	-889.33	(-6541.31,4762.64)
2020	-1111.05	(-7141.16,4919.05)
2021	-1111.80	(-7429.18,5205.58)

Table 4.11 shows 10 years catch forecast for Kambuzi catches based on ARIMA (0, 1, 1) up to 2021. It was noted that the magnitude of the difference between the forecasted and actual values were low for the selected models. The noise residuals are combinations of both positive and negative errors which shows that, the model is not forecasting too low on the average or too high on the average. Hence, from the ongoing assessment per the actual and the forecasted catches in Table 4.11, it could be suggested that the model had good forecasting power.

Table 4.11 Forecast of Kambuzi catch (in tons): ARIMA (0, 1, 1)

Year	Forecasted catch	95% confidence bounds
2011	3038.92	(-436.32,6514.16)
2012	3394.08	(-81.16,6869.31)
2013	3486.29	(-550.11,7522.70)
2014	3578.51	(-950.06,8107.07)
2015	3670.72	(-1301.52,8642.96)
2016	3762.94	(-1616.51,9142.39)
2017	3855.15	(-1902.78,9613.08)
2018	3947.37	(-2165.66,10060.39)
2019	4039.58	(-2409.01,10488.18)
2020	4131.80	(-2635.75,10899.34)
2021	4224.01	(-2848.12,11296.14)

Tables 4.10 and 4.11 showed that the forecasted catch trend for Chambo has a downward trend with time for the next 10 years (2012 to 2021) while the forecasted catch trend for Kambuzi has an upward trend with time for the next 10 years (2012 to 2021) as shown in Figure 4.10. The forecasted trends also show that the difference between upper and lower confidence limits increase from the year 2012 to the year 2021 for both Chambo and Kambuzi. It can also be noted that the trends for both species may range from decreasing to increasing from the year 2012 to 2021.

(a)

(b)

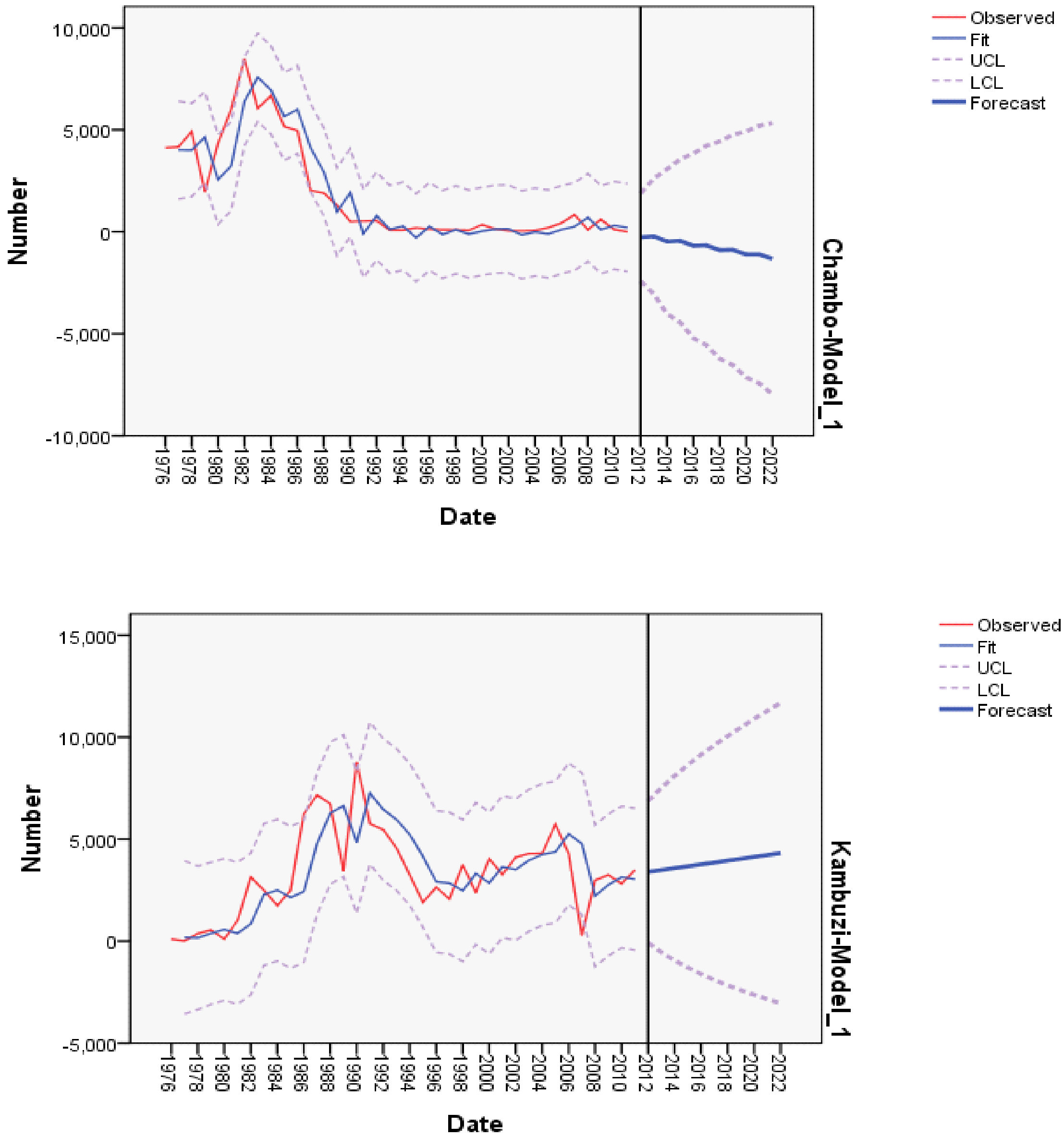


Figure 4.10 Forecasted trends for Chambo (a) and Kambuzi (b) models

4.3. Bioeconomic analysis

4.3.1 Estimates of bioeconomic parameters

Estimates from the regression of Schnute (1977) model that were estimated using Equation 3.22 are presented in Table 4.12.

Table 4.12 Parameter estimate from the Schnute (1977) model.

Model	r	q	r/qk	R^2	F-statistics
Chambo	0.361	-0.00000011	0.274	0.70	10.341
1976 - 1989	(1.034)	(-1.426)	(4.445)		
Chambo	-0.249	0.00000175	58.597	0.38	0.014
1990 - 2011	(-0.295)	(0.107)	(0.162)		
Kambuzi	0.22	-0.000000795	-0.069	0.32	0.548
1976 - 2011	(0.453)	(-0.371)	(-1.047)		

The figures in brackets are t- statistics.

The regression results showed that the parameters for Chambo fishery model from 1976 to 1989 were statistically significant (p = 0.003) as well as the corresponding F- statistics. The parameters for Chambo fishery model from 1990 to 2011 and Kambuzi fishery model were statistically insignificant and the corresponding F- statistics were statistically insignificant. The intrinsic growth rates (r) have the expected positive signs except for (r) value of Chambo fishery model from 1990 to 2011 which had a negative sign, showing the declining trend of the stock. The measure of goodness of fit (R^2) showed that only 38% and 32% of the variability in the response was explained by the explanatory variable for Chambo fishery model of 1990 to 2011 and Kambuzi fishery model respectively. Chambo fishery model of 1976 to 1989 had R^2 of 0.70 indicating that 70% of the variability in the response is explained by the explanatory variable.

4.3.2. Estimates of MSY, MEY and OAY

Variables catch (Y) in tones, effort (F) in number of pulls and stock (B) in tones were estimated using MSY, MEY and OAY. The estimates of the variables are reported in Table 4.13.

Table 4.13 Estimates of MSY, MEY and OAY solution for Chambo and Kambuzi fishery

Period	Variable	FS status	MSY	MEY	OAY
Chambo	Catch (tons)	1295	1086.80	1008	236.95
(1989)	Effort (pulls)	508385	164090	100939	328182
	Stock (tons)		6016.66		2141
Chambo	Catch (tons)	240	14.71	10.51	6.89
(2011)	Effort (pulls)	100375	69166	36380	226364
	Stock (tons)		1181.21		378
Kambuzi	Catch (tons)	3484	2326.92	1464.08	1217
(2011)	Effort (pulls)	41794	38364	37490	276730
	Stock (tons)		21153.85		9988

Note: FS is frame survey, MSY is maximum sustainable yield, MEY is maximum economic yield and OAY is open access yield

The results are typical of Gordon Schaefer fisheries model. As expected the open access solution produced the lowest catch level associated with the highest level of effort for all the three models. The MSY solution gave the highest level of catch and the MEY gives the lowest level of effort. The OAY solution gave the lowest level of stock size for the three periods. The effort levels in pulls for MSY, MEY and OAY were calculated in Gill nets and Nkacha nets by dividing the effort level in pulls by the average number of pulls per net. Table 4.14 shows the estimated MSY, MEY and OAY effort levels in nets compared to actual data.

Chambo fishery exceeded the yield of MSY by 16% and effort at MSY by 67% in 1989 while in 2011 the yield at MSY was exceeded by 93% and effort at MSY was exceeded by 31%. Kambuzi fishery in 2011 exceeded the yield at MSY by 33% while the effort at MSY was exceeded by 8%.

Table 4.14 Estimated MSY, MEY and OAY effort levels in nets

Period	FS data	MSY nets	MEY nets	OAY nets
Chambo gill net (1989)	113	100	98	201
Chambo gillnet (2011)	247	89	36	291
Kambuzi nkacha net (2011)	140	51	49	365

Note: FS is frame survey, MSY is maximum sustainable yield, MEY is maximum economic yield and OAY is open access yield

4.3.3 Estimates of MSY and MEY costs, revenues and economic rents

The costs, revenue and profits associated with MSY and MEY are reported in Table 4.15. The values were calculated based on estimated MSY and MEY catch in kilograms and effort in pulls and number of nets.

Table 4.15 Estimates of MSY and MEY costs, revenues and economic rents

Period	Variable	MSY	MEY
Chambo fishery1989	Cost (million MK)	1.505	0.148
	Revenue (million MK)	3.925	3.641
	Rent (million MK)	2.420	3.492
Chambo fishery 2011	Cost (million MK)	2.222	0.535
	Revenue (million MK)	3.756	2.683
	Rent (million MK)	1.533	2.148
Kambuzi fishery 2011	Cost (million MK)	62.112	13.493
	Revenue (million MK)	62.827	15.666
	Rent (million MK)	0.715	2.172

It is estimated that the maximum economic rent for Chambo fishery in 1989 was reached at an effort level of 100939 pulls corresponding to 98 gillnets. Maximum economic rent for Chambo fishery in 2011 was reached at an effort level of 36380 pulls corresponding to 36 gill nets. The maximum economic rent for Kambuzi fishery in 2011 was reached at an effort level of 37490 pulls corresponding to 49 nkacha nets.

4.3.4. Trend of annual fishery economic rents

The trend analysis of annual fishery economic rents of Chambo and Kambuzi fishery are shown in Figures 4.11 and 4.12.

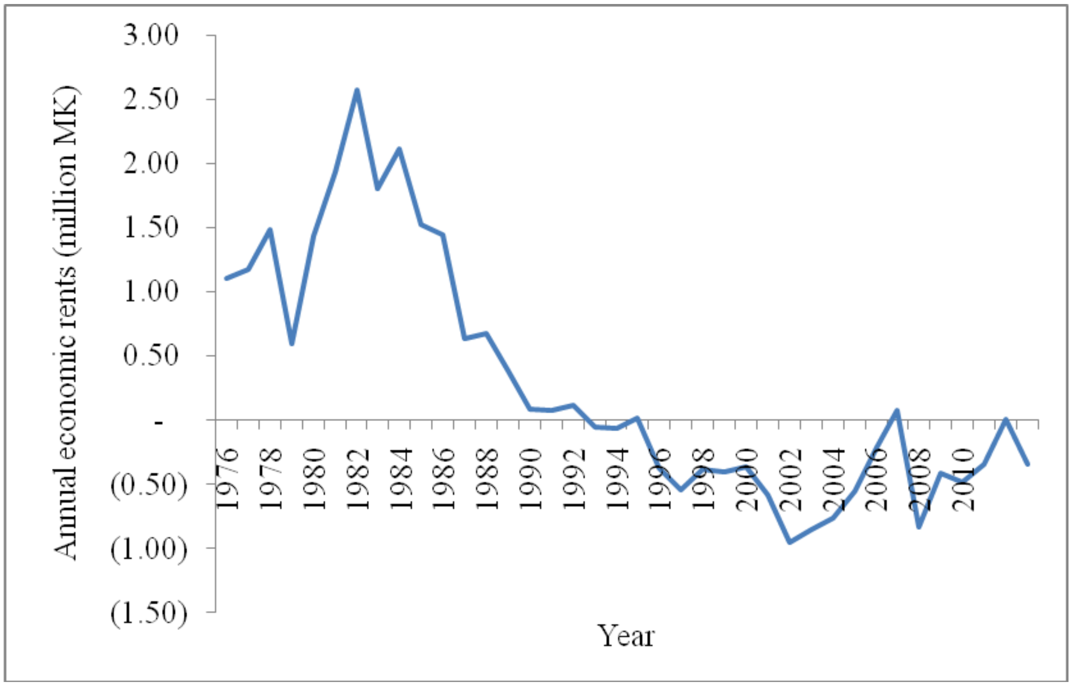


Figure 4.11 Trend of annual economic rents for Chambo fishery

Figure 4.11 shows that the annual profits of Chambo fishery in gill net have been declining over time. Positive economic rents were observed from 1976 to 1992 with maximum benefits in 1982. This coincided with the period when the fishery was in equilibrium. Since 1992, the fishery has experienced negative economic rents and this coincided with the period of overexploitation.

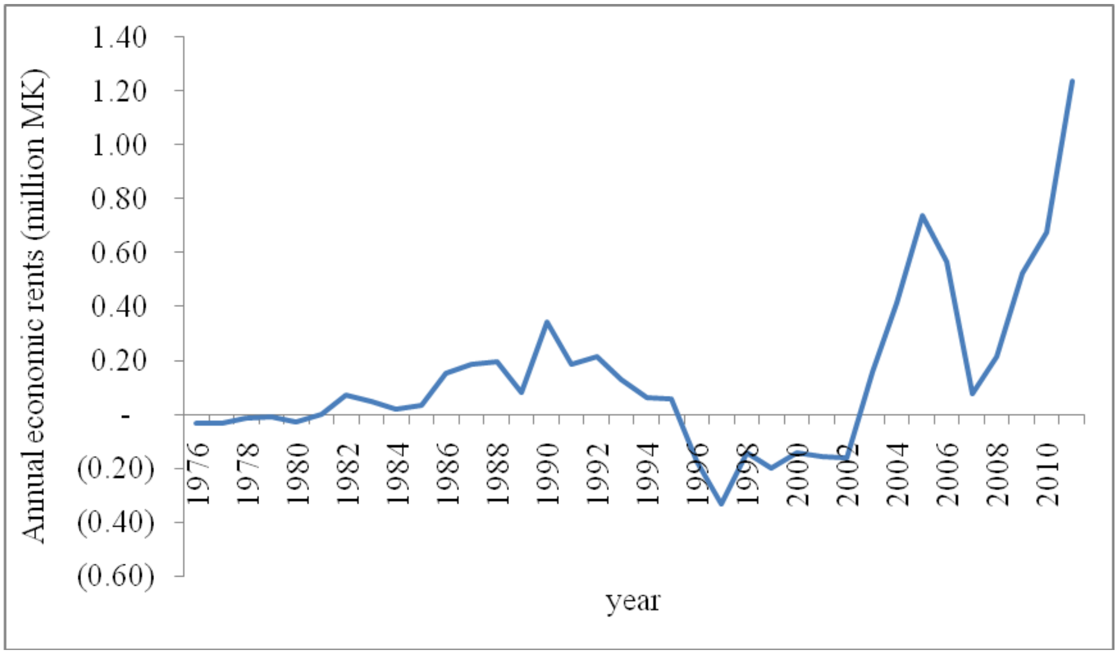


Figure 4.12 Trend of annual economic rents for Kambuzi fishery

Figure 4.12 shows that the annual economic rents of Kambuzi fishery in nkacha net have been fluctuating up and down over the years. Negative economic rents were observed during the period from 1976 to 1981 as well as period from 1995 to 2001. Positive economic rents were observed during the period from 1982 to 1995 and the period from 2002 to 2011.

Table 4.16 shows the annual profit, MEY economic rents and MSY economic rents for Chambo and Kambuzi fishery in Lake Malombe. The results show that it is more profitable to operate at MEY for both Chambo and Kambuzi fishery in Lake Malombe than at current status quo and at MSY.

Table 4.16 Estimates of annual economic rents, MEY rents and MSY rents for Chambo and Kambuzi fishery

Period	Annual economic rents (MK)	MEY rent (MK)	MSY rent (MK)
Chambo fishery1989	381,133.03	3,492,704.39	2,420,540.74
Chambo fishery 2011	(347,452.82)	2,148,821.78	1,533,953.24
Kambuzi fishery 2011	1,238,413.25	2,172,225.52	715,078.50

4.3.5. Estimates of present value of fishery

The estimates for present value of Chambo and Kambuzi fishery were projected for the next 10 years covering the period from 2011 to 2021. The current Chambo and Kambuzi fishery economic rents were discounted to estimate the present values and were compared with the MEY and MSY present values. The results of present value for fishery rents for Chambo and Kambuzi fishery are reported in Figures 4.13 and 4.14.

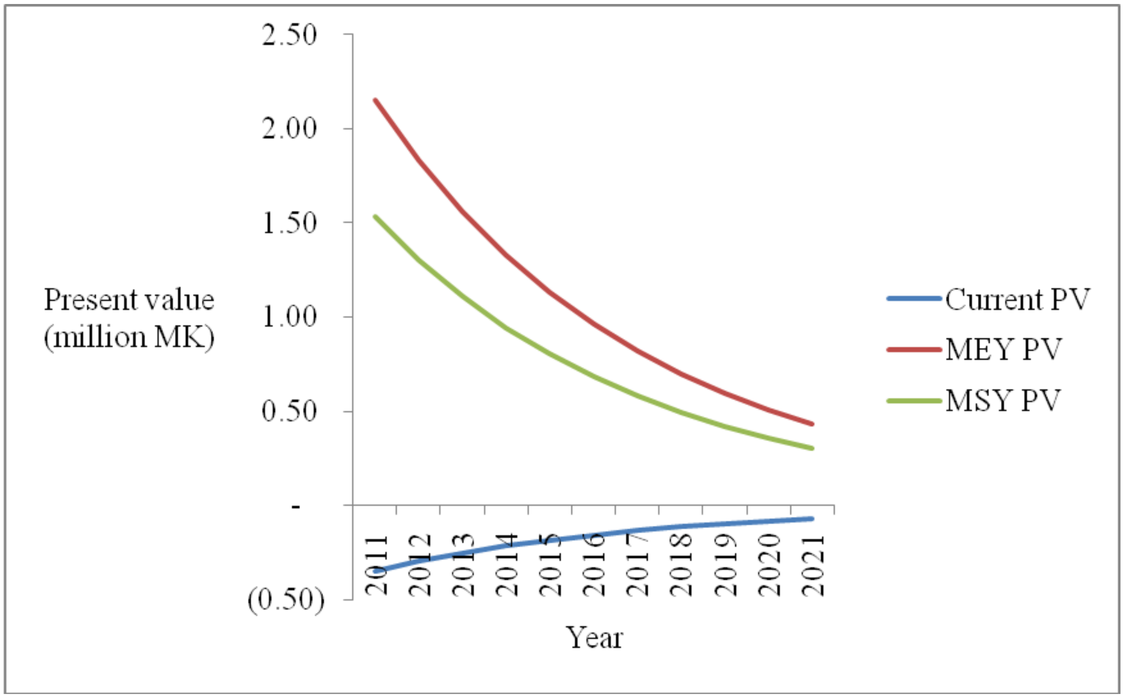


Figure 4.13 The estimates of Chambo fishery present value

The results show that the present values for the Chambo fishery economic rents from 2011 to 2021 are negative while present value for MEY are positive and are declining with time. Overall, the present values of MEY solution are higher than the present values of the current fishery status and MSY.

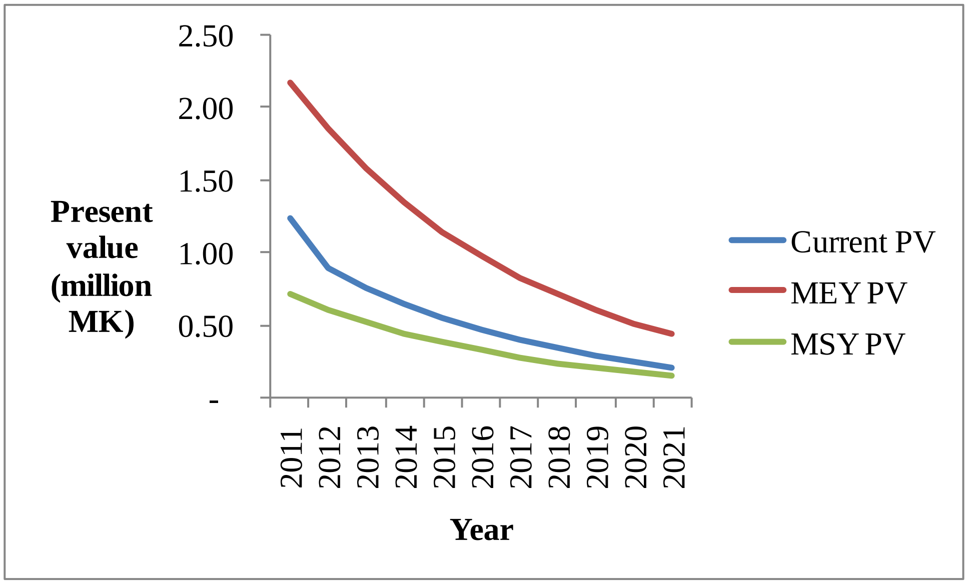


Figure 4.14 The estimates of Kambuzi fishery present value

These results show that the present values for the Kambuzi fishery economic rents, MEY and MSY from 2011 to 2021 are positive and are declining with time. Overall, the present values of MEY are higher than the present values of the current fishery status and MSY.

4.3.6. Estimates of Net Present Value (NPV)

The NPV was estimated to ascertain the economic viability of Chambo and Kambuzi fishery in Lake Malombe using Gill net and Nkacha net respectively. The results of estimated NPV are reported in Figures 4.15 and 4.16.

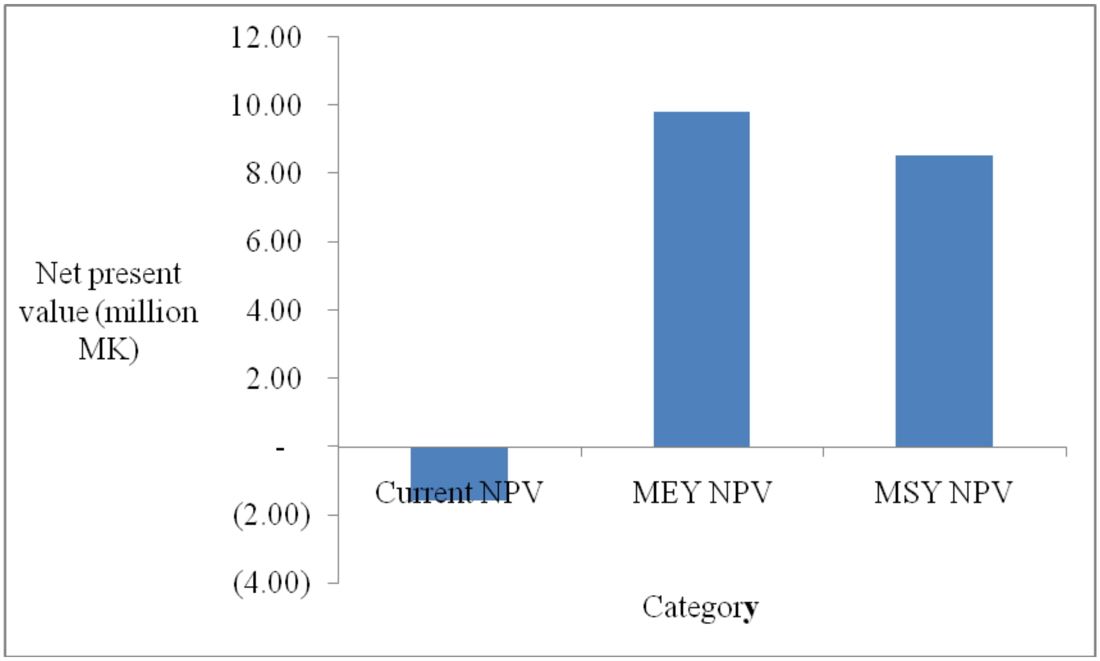


Figure 4.15 Estimated Net Present Value for Chambo fishery from Lake Malombe

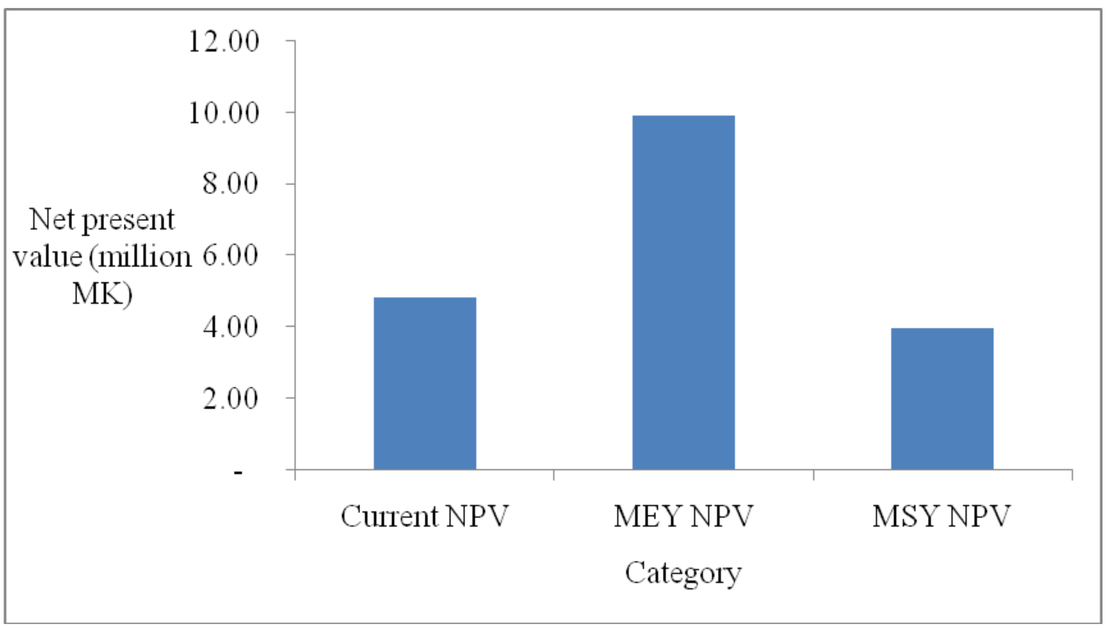


Figure 4.16 Estimated Net Present Value for Kambuzi fishery from Lake Malombe

Figures 4.15 and 4.16 show that under the current fishery status it would not be economically viable to harvest Chambo in Lake Malombe using Gill net. On the other hand, Kambuzi fishery in Nkacha net will be economically viable.

CHAPTER FIVE

GENERAL DISCUSSION

5.1 Intertemporal preference and fisheries management

Although Lake Malombe is known to have an open access nature in fisheries exploitation, the study has shown that society members have intertemporal preferences concerning the exploitation of fisheries resources of Lake Malombe. The intertemporal preferences provide an opportunity for introducing a rights based approach to fisheries management.

Historically, community rights fisheries management has been practiced in many parts of the world (Willmann, 2000). This applies in particular, where fishers live in small fishing communities that are socially and economically organized through traditional values. This traditional community organization creates a social group that often stands together and takes on the responsibility to defend and manage resources in its areas. However, it is not a rule of thumb that when people come together they will act rationally, sometimes the opposite is true. When rights over resources are vested in people who benefit from good management and bear the burden of mismanagement of those resources, incentives to use the resources fairly and wisely are generated. Despite challenges, community rights fisheries management remains the most effective means of managing resources in circumstances where other property rights management regime cannot be implemented due to social and political reasons (Willmann, 2000).

The social group with positive intertemporal preference are those that are viewed to be impatient in resource exploitation while a social group with negative intertemporal preference are those that are patient and cooperative. The social group with positive intertemporal preference usually views the future of fishing as bleak and as such they prefer to maximize current exploitation. Holdsworth (2003) pointed out that their behaviour might be influenced by some barriers to change such as willingness to act, lack of awareness and information, habits and routines, convenience and psychological effects. Some proportion of people state that they simply do not want to change their behaviour or they do not have time to do it. Thus, such people do not care about the future (Holdsworth, 2003).

A lot of fishery significant behaviours are a matter of habit and daily routine, thus they are not even considered. Many resource users are simply not aware of what they could do to consume sustainably or the impact their actions have on sustainability (Holdsworth, 2003). Habits are very strong barriers to changing one’s behaviour. Agyeman and Kollmuss (2002) found it to be the biggest obstacle to sustainable consumption. General routine often prevents consumers from implementing changes in their consumption patterns. Their habits and routine are closely related with their priorities, thus, often time, friends and financial resources are valued higher than sustainable consumption.

Some people commonly see environmental problems as too distinct from their daily lives and do not see a necessity to change their behaviour (Burningham and Thrush, 2001). They have a perception that global problems do not affect them and the consequences will only be seen in a long-term. A similar idea is also perceived about the positive effects of changed behaviours, suggesting that they will only be seen in several years.

The thinking of the impatient members agrees with the economic theory which hypothesizes that there is little cooperation in sustaining common pool resources (CPRs) where individual and collective interests are in conflict. The standard assumption of pure self-interest implies that natural resources like fishing grounds are overexploited, and that we are often trapped in an inevitable process that ends in the Tragedy of the Commons (Hardin, 1968).

However, considerable evidence shows that some individuals are cooperative and voluntarily willing to sustain fisheries resources of Lake Malombe. Other studies also have evidence which shows that some individuals are cooperative and voluntarily willing to sustain common pool resources (CPR) or public goods (Cardenas, 2000; Casari and Plott, 2003; Croson, 2008; Dufwenberg and Kirchsteiger, 2004; Sobel, 2005; Falk and Fischbacher, 2006; Segal and Sobel, 2007). The members who were cooperative and willing to forgo current consumption were on the view that fisheries resources should be conserved for future generation by reducing the current fishing activities. The study shows that individuals who exhibit a higher propensity to cooperate in the common pool resources (i.e. those with negative time preference), and those who show more patience are willing to conserve the declining fisheries resources of Lake Malombe for the following reasons: (i) a higher current exploitation reduces the current yield (ii) a higher current exploitation (in terms of fish that have not yet reached fertility) also reduces the future yield for both others and themselves. Those who showed more patience in the study, are willing to use fishing gears which exploit the fisheries resources less such as gill net and abandon use of nkacha net, which is more destructive.

The results agree with the economic theory that preference analysis in the use of a fishery resource could not be static, for two reasons: 1) its renewable nature implies variability in availability and uncertainty in its magnitude through time; and 2) a different temporal marginal preference of resource use will exist according to the type of fishery considered. For example, open access fisheries like Lake Malombe are generally characterized by a high Marginal Time Preference Rate (MTPR) (Seijo *et al.*, 1998), because of the inherent characteristics of fish stocks. Thus, there will be incentives to increase fishing effort levels (and thus yields and profits) in the short- run, having little or no concern for the future (Seijo *et al*., 1998). The exploitation in open access fisheries involves a negative interpersonal and inter-temporal externality because individuals who exploit the common pool resource (CPR) reduce the current and the future yield for both others and themselves (Fehr and Leibbrandt, 2009).

Variable stratum was considered in the model to assess the effect of geographical difference between Lake Malombe West and East on intertemporal preference of fisheries resource users. It is shown that Lake Malombe East has a negative intertemporal preference. This might be attributed to geographical distribution and social economic activities surrounding Lake Malombe West and Lake Malombe East strata. Lake Malombe West is along the main road from Mangochi to Liwonde and has several economic activities along the road where demand for fish and prices of fish are high. The demand and prices of fish might have influence on choice of exploitation of fish stocks. The results confirm what was observed in the field during data collection. The data collection period coincided with closed season of Lake Malombe which runs from October to December, but during the period, it was observed that fishers of Lake Malombe West were still catching fish using restricted gears such as Nkacha of ¾ inch, Kandwindwi of ¼ inch and mosquito net. This confirms that fisheries resource users of Lake Malombe West are impatient in the utilization of fish stocks. Lake Malombe East is far from major economic centres. The stratum is located in one of the most remote parts of Mangochi District bordering Liwonde National Park where accessibility especially during rainy season is a problem even for regular fisheries monitoring by the Department of Fisheries..

The marital status of respondents was included in the model to assess if it has an effect in determining intertemporal preference. Married group of respondents was impatient in resource use (positive intertemporal preference) implying that they prefer to exploit fish stocks immediately, rather than in subsequent periods. The single category of respondents was cooperative in resource use (negative time preference) implying that they are willing to conserve the declining fisheries resources of Lake Malombe. The choices of intertemporal preference might be attributed to the current challenging household economic needs against household size. Perhaps the inherent pressure to support the large families compel them to undertake the immediate exploitation. The average household size was 6 which is higher than the national figure of 4.4 per household (NSO, 2008).

Due to poverty the families may not be able to support all the household members. A study by Matiya *et al*. (2005) on Lake Malombe found that household size is positively influencing people to venture into fishing. Married group usually has large household size which might influence such households to have positive intertemporal preference as a way of making up for immediate living.

The variable literacy has shown that the more educated one is the higher the probability of having a negative intertemporal preference. The literate group is cooperative in resource use (negative intertemporal preference) while the illiterate group is impatient in resource use (positive intertemporal preference). Education in that respect helps people to appreciate more values of conserving fisheries resources. In essence, education would make it easier for households to comprehend negative externalities and passive user values of natural resources as noted by Muchapondwa (2003). Ideally, decisions pertaining to fisheries resource utilization are expected to be influenced by education level of households.

The variable years of fishing has shown that the group that has been fishing for more than sixteen years is willing to act in the conservation of fisheries resources implying that they care about the future. Some proportion of people stated that they simply want to change their behaviour. The group that has been fishing for more than sixteen (16) years which represents the older group is willing to manage fisheries resources than the younger group. The findings differ with Holdsworth, (2003) who reported that older people might feel that they have done their share for the society and now they want to enjoy the rest of their lives without any inconvenience that sustainable development might demand. Another argument is that they cannot consume any less (Collins et al., 2003).

5.2. Time series and fisheries management

How much data is needed for forecasting models is probably the most common question asked today. Hyndman and Kostenko (2007) indicated that it depends on the type of statistical model being used and on the amount of random variation in the data. The usual answer is as much as possible because the more data is available, the better the structure and patterns that are used for forecasting. Some authors report universal minimum data requirements for different forecasting techniques, including those designed for seasonal time series (Hanke *et al.*, 1998). Such reports are misleading, because they ignore the underlying variability of the data, and that data requirements depend critically on the variability of the data (Hyndman and Kostenko, 2007).

The preliminary Box-Jenkins analysis of the Chambo and Kambuzi catch data using time series plots showed that the data was non stationary. This implies that the underlying generating processes are not based on constant means and constant variance with the autocorrelation functions essentially not constant through time. The observations made by Pierce and Boyle (2003) and Georgakarakos *et al*. (2002) that use of ARIMA models require stationary time series but most fisheries time series are non-stationary support the preliminary analysis of this study.

Czerwinski *et.al*., (2007) argued that the Normalized BIC test reveals that the model with the least Normalized BIC is better in terms of forecasting performance than the one with a large Normalized BIC. The study therefore, observed that ARIMA (0, 1, 1) for Chambo catch has the least Normalized BIC and ARIMA (0, 1, 1) for Kambuzi catch has the least Normalized BIC. The R-Squared, stationary R-square, RMSE, MAPE, MAE, MaxAPE, and MaxAE were further taken into consideration as they measure the accuracy of the fitted time series model. RMSE and MAE serve as measures for comparing forecast of the same series across different models and hence the smaller the error, the better the forecasting ability of the model. Empirically ARIMA (0, 1, 1) for Chambo catch and ARIMA (0, 1, 1) for Kambuzi indicate smaller forecasting errors than the other suggested models.

The MAE, MAPE, MaxAPE, MaxAE in Table (4.14), give an indication of smaller error and a better forecasting ability for ARIMA (0, 1, 1) for Chambo catch and ARIMA (0, 1, 1) for Kambuzi catch than the other suggested models. The coefficient of determination (R^2) described the proportion of the total variance in the observed data that was explained by the model. The values show that the models accurately explain the observed variation in the series. Stationary R-squared was considered as a measure that compares the stationary part of the model to a simple mean model. This measure is preferable to ordinary R-squared when there is a trend or seasonal pattern. Stationary R-squared can be negative with a range of negative infinity to 1. Negative values mean that the model under consideration is worse than the baseline model.

Abrahart and See, (2000) argued that in order to achieve an acceptable model there is need to test whether the estimated model conforms to the specifications of a stationary univariate process. In particular, the residuals should be independent from each other and constant in mean and variance over time. The study used plots of autocorrelation and partial autocorrelation of the residuals which showed that individual coefficients were within some specified confidence interval around zero indicating that the models were acceptable.

Forecasting is an interesting subject, partly because it plays a central role in management: it precedes planning which, in turn, precedes decision making (Makridakis *et al.*, 1983). Policy makers establish goals and objectives, seek to forecast uncontrollable events, then select appropriate actions which, hopefully, will result in the realisation of the goals and objectives.

Quantitative forecasting can be applied under the following conditions: (a) past quantitative information is available and (b) some aspects of the past pattern will continue into the future. In general, historical fishery time series satisfy condition (a) and have been extensively used for the provision of a variety of information on fishery resources e.g. description of fishery units: Murawski *et al.*, (1983) and state of fisheries resources and management (Fox, 1970; Pauly, 1989; Sparre et al., 1989).

The Box-Jenkins methodology requires that the model to be used in describing and forecasting a time series should be both stationary and invertible (Box and Jenkins, 1976). Therefore the study used the Box- Jenkins approach to make data series stationary. There are many measures of forecasting accuracy that one may use to compare different models (Legates and McCabe, 1999; Abrahart and See, 2000). The study selected models on the basis of overall forecasting performance and meeting the entire prerequisites which are well in line and support the model regarding robustness, forecasting evaluation and the forecasting accuracy. The supporting statistics like NBIC, R-square, stationary R-square, RMSE, MAPE, MaxAPE, MAE and MaxAE have outperformed other models. The estimators used in the study are unbiased estimators that were employed to see how far the models were able to explain the total variance of the data.

Czerwinski *et.al*. (2007) argued that a good model has a low forecasting error, therefore when the magnitude of the difference between the forecasted and actual values are low then the model has a good forecasting power and if the difference is high, then the model has a low forecasting power. Having this positive behaviour of the models, the models have outperformed as far as their forecasting power is concerned. The forecasted values from 1976 to 2011 follow closely with the actual values from 1976 to 2011. The noise residuals are combinations of both positive and negative errors which shows that, the model is not forecasting too low on the average or too high on the average. Hence, from the ongoing assessment per the actual and the forecasted catches of Chambo it could be suggested that the models had good forecasting power. This predictive power of the model indicates that actual and predicted values have high level of close match.

Hence, from the ongoing assessment per the actual and the forecasted catch it could be suggested that Chambo catch is expected to decrease steadily with time and Kambuzi catch is expected to gradually increase. It must however be acknowledged that they are likely to face uncertainties like Uncertainties in the state and dynamics of the fishery including the effects of other species with which they interact, the improved management systems, climate change which might influence changes in catches either in a positive or negative way. Caution should be used in utilization of the forecasts presented in this study. From a strictly forecasting perspective, ARIMA models have often been criticized for the excessive reliance on past time series behaviour and their difficulty in predicting future structural changes. Whenever possible, they should be seen as statistical tools to support expert judgment, funding allocation, and management decisions in the most data-limited and assessment-limited settings (Prista *et al*., 2011). ARIMA models do not take into account events like biological, chemical and physical incidences. It assumes that the current trend will continue into the future. Nevertheless, catch forecasts are extremely useful in formulation of policies regarding stock management.

5.3. Bioeconomics and fisheries management

Lomax (2007) proposed that for the multiple regression analysis, it is necessary to first consider the statistical significance of the full model before going on to interpret the significance of the individual predictor variables. The regression results from the study showed that the parameters for Chambo fishery model of 1976 to 1989 were statistically significant and the corresponding F- statistics was statistically significant. The parameters for Chambo fishery model from 1990 to 2011 and Kambuzi fishery model were statistically insignificant and the corresponding F- statistics were statistically insignificant.

It was noted that Chambo fishery model of 1976 to 1989 was based on data collected when the fishery was in equilibrium. During this period, there were minimal fluctuations in the year to year catch and effort. Catch was fluctuating in a similar pattern as effort. The direct relationship between catch and effort influences the value of R^2. However, Chambo fishery model of 1990 to 2011 had declining and unstable year to year catch and effort due to unstable and limited fish stock in the lake. The high fluctuations in the year to year catch and effort data are likely to have influenced the relationship between the dependent and independent variables in the model resulting into low R^2.

The Kambuzi fishery model had low R^2 which might have been influenced by unstable year to year catch and effort. There have been high fluctuations in catch and effort during the period without following a pattern. At times catch has been high with low effort and vice versa implying that the relationship was changing over time. It was noted that in certain years catch per unit effort was not influenced by changes in effort as catches were high with low effort. A similar argument was made for the findings in Lake Malombe (Tweddle *et al*., 1991b). The other influence of low R^2 could be that the model explains year to year changes in relative growth of catch per unit effort and not the one way trend on catch per unit effort (Schnute, 1977; Hilborn and Waters, 1992).

Although it was not possible to find evidence for a statistically significant relationship between the response variable and all the predictor variables in the Chambo fishery model of 1990 to 2011 and Kambuzi fishery model of 2011, some variations of up to 38% and 32%, respectively, were explained by the models. As such the independent variables are not completely poor predictors of the dependent variable and the parameters estimated might be used for other analysis.

The intrinsic rate of population increase was taken as the rate of growth of a population when that population is growing under ideal conditions and without limits, i.e., as fast as it possibly can. This rate of growth implies that the difference between the birth rate and death rate experienced by a population is maximized. The study has shown that the intrinsic growth rate of Chambo fishery model of 1976 to 1989 and Kambuzi fishery model of 2011 as expected were positive. The intrinsic growth rate of Chambo fishery model of 1990 to 2011 was negative suggesting that the equation captured a depletion function. This is possible considering that the fishery was experiencing over exploitation in the period from 1990. Kasulo (2000) made similar observations in the estimation of the bioeconomic model of species diversity for Malawian fisheries.

The value of intrinsic rate of growth for a population is influenced by life history features, such as age at the beginning of reproduction, the number of young produced, and how well the young survive. A population with a higher intrinsic rate of growth will grow faster than one with a lower rate of growth. Kambuzi fishery has relatively low intrinsic rate of growth compared to Chambo (*ceteris paribus*). However, Chambo fishery shows that during 1976 to 1989 period the fishery was growing faster than the period from 1990 to 2011 even though it was the same species. The difference is likely to be due to fishing exploitation rate exerted on the fishery. During the 1976 to 1989 period Chambo fishery was in equilibrium implying that growth was equal to harvest as such fish were given space to grow before harvest. But during the 1990 to 2011 period the fishery was in a state of over exploitation implying that harvest was greater than fish growth due to excessive exploitation of the already declining stock. Similar observations were made by Kapute *et al.* (2008) in Lake Malombe for *Oreochromis karongae*. The study observed that *O. karongae* in Lake Malombe mature at a smaller size and younger age than those in Lake Malawi. Although early maturity in fish could be a response to environmental conditions (Bruton and Allanson, 1974; Khallaf *et al*., 2003), in Lake Malombe their early maturity could be a direct result of the high fishing pressure that has caused the collapse of the Chambo fishery in the lake (FAO, 1993 and Weyl *et al*., 2004b), as there were no major environmental changes.

Catchability is a concept in fishery biology which reflects the efficiency of a particular fishing gear. Its quantitative magnitude is expressed by the catchability coefficient, which relates the biomass abundance to the capture or fishing mortality. Catchability is also called gear efficiency (Hilborn and Walters, 1992) or sometimes fishing power, and is strongly related to gear selectivity because it is species and size dependent. The study has shown that Chambo fishery from 1990 to 2011, and from 1976 to 1989; and Kambuzi fishery have different catchability coefficients. The variations might be due to a number of factors that have been observed in Lake Malombe which may have impacts on exploitation of Lake Malombe. One factor that might have also resulted to such variation is the precision to which fishing effort data was recorded overtime.

It is likely obvious that improvements in fishing technology result in improvements in the ability of fishers to catch more fish. Fishers have reduced the gillnet mesh size from the recommended 3½ inches (DoF, 2003) to 3 inches. Even for Kambuzi fishery, fishers have modified the nkacha mesh size from the recommended ¾ to ¼ and introduction of two boats per gear. This is done to allow new fish aggregations to be exploited (Hannesson, 1983; Robins et al., 1996; Skjold *et al*., 1996). The economic changes might also cause changes in the dynamics of the exploited fish population (Salthaug and Aanes, 2003, Hilborn *et al*., 2003). Decreases in abundance will often cause a less-than proportional change in CPUE-derived indices (MacCall, 1990). Mechanisms that elicit this response include fisher search behaviour, which allows targeting of aggregations or relatively healthy fishing grounds despite stock-wide decreases. Fishers in Lake Malombe have changed their fishing practice by fishing more than 10 hours. These changes in fishing practice have allowed competitive or cooperative fisher behaviours to affect fishing success and catch rates (Ricker, 1975, Hutchings and Myers, 1994).

Theoretically, if the actual catch, effort level and stocking rate exceed the values of the MSY level, it indicates that the current fisheries exploitation is unsustainable. The findings of the study show that Chambo and Kambuzi fishery are not sustainable in Lake Malombe. This implies that the fisheries have moved into a phase of biological overexploitation. These findings show that people around Lake Malombe depend on the lake for their livelihood. The situation is worsened by the fact that there are few income generating activities in the area (Matiya and Wakabayashi, 2005). Matiya and Wakabayashi (2005) observed that the fishery of Lake Malombe is small scale and traditional in nature and that over 80% of the people get their income from fisheries. Fisheries are very important to local communities around Lake Malombe. It has been observed (FAO, 1993) that in developing countries, fishing is one of the last remaining job opportunities for a labour force that is lacking training and capital.

The failure of conventional fisheries management and co management has contributed to the overexploitation of fisheries resources in Lake Malombe. The problem has mainly been caused by overemphasis on theories of Maximum Sustainable Yield (MSY) based on biological data; and failure to enforce and implement fisheries regulations by the Fisheries Department due to resource limitations. The result has been overexploitation of fish stocks by fishers due to increase in effort levels chasing the same stocks and use of illegal gears that have contributed to recruitment overfishing. Indicators include the declining national catches and local examples of overfishing as the case of Lake Malombe. This calls for alternative approaches to modelling fisheries management such as bioeconomic to supplement or complement the conventional approaches.

Economic efficiency occurs when the sustainable catch and effort level for the fishery maximizes profits. This point is referred to as MEY that is the largest difference between total revenue and total cost of fishing (Clark, 1985). The study showed that at the MEY level, the harvest and cost of harvest are lower than those associated with MSY and OAY levels but the economic rents are higher. This indicates that economic objective of MEY is better than that of MSY in protecting the fishery from negative environmental and fishing shocks. The reduction of effort compared with the MSY and OAY effort levels saves costs and/or enlarges fishery revenues. Kompas (2005) indicated that the effort level at MEY is the most socially desirable level of effort because it is generating the highest net returns possible and provides an efficient use of resources devoted to fishing. Catch and effort levels at MEY will vary due to a change in the price of harvested fish and the cost of fishing. As long as the cost of fishing increases, the MEY as a target will always be preferred to MSY, the harvested fish at the MSY level becomes economic overfishing (Kompas, 2005).

Furthermore, under MEY management, the resource has a positive opportunity cost due to the spawning and growth capacity of fish that can be used for harvesting and to maintain a larger stock than what the open access provides. A larger stock gives lower unit cost of harvest than a small stock. This cost saving effect of increased stock level, called stock effect, is utilised to generate resource rent under the MEY regime. By reducing effort from MSY to MEY, the society saves on some factors of production that can be used in other sectors of the economy. This criterion is rather strict, requiring that the improvement should take place without making anyone else worse off (Kompas, 2005). However, economic development often takes place with net gains for someone, but losses for others.

To change from MSY and OAY to MEY fishing necessitates reduced effort and increased stock level Munro (2009). However, rebuilding fish stocks of Lake Malombe may take time since Chambo and Kambuzi have limited reproductive and growth capacity. For instance Chambo, like other Oreochromis species are maternal mouth brooders. That is, females carry the eggs and fry in their mouths until the young have developed to a stage where exogenous feeding is possible. As with many other tropical species with long breeding seasons, the proportion of ripe Chambo caught is generally small, even at the largest size-classes during the height of the breeding season.

Open access fishery inevitably leads to over-exploitation. According to Pauly (1980) there are four types of overfishing; growth over-fishing, recruitment over-fishing, ecosystem over-fishing and economic over-fishing. Growth over-fishing occurs when fish are caught before they are mature enough. Recruitment over-fishing occurs when reproduction is affected due to catching of adult fish in large quantities. Ecosystem over-fishing takes place when a particular fish stock level is not compensated due to increased fishing effort which causes other stocks to increase. Economic over-fishing occurs due to economic inefficiency of resource allocation to the fisheries sector as a result of increased fishing effort leading to low profit levels, well below the maximum sustainable level. The results show that Lake Malombe is an example of a lake where all the four types of overfishing have occurred.

The notion of economic rent in fisheries is embedded in the traditional bioeconomic fishery models. The fish stock as a natural resource is productive and thus earns a return.

This return or resource rent is most commonly realised in well-managed fisheries (Neher, 1990). The rent accruing directly from the fishery may be accounted for as the difference between revenues from, and costs due to fishing (Charles, 2001).The economic performance of capture fisheries is determined by the quantity of fish caught, the price of fish, the harvesting costs, and the productivity of the fisheries. The fishery of Lake Malombe show that the productivity of the fishery has declined while the harvesting costs are increasing due to increase in effort and inflation. Although, the beach price of fish has been increasing over time due to inflation and scarcity of the resource, the revenues have been adversely affected by low quantities of catch. FAO (1993) reported that Chambo catch in Lake Malombe declined since 1981 and this has affected the profits generated by the fishery.

The economic rent for Kambuzi fishery has responded directly to fish catches. Where fish catches have increased the profits have increased and where fish catches have declined profits have declined. Since 1981 when catches of Kambuzi started to dominate over Chambo catches, profits started to increase until 1990. Even FAO (1993) reported that the Kambuzi fishery in Lake Malombe was one of the most economically successful fisheries. Thereafter, the profits directly responded to the declining catches until 2002. Since 2002, the profits have been fluctuating in a positive manner until 2011. High catches over the years plus increase in beach prices have contributed positively towards generation of positive rents.

However, the study has shown that operating at MEY would generate more rents as compared to the OAY and the MSY. An open-access or unmanaged fishery does not generate resource (or fishery) rent, although some of its participants may earn other kinds of rents. This is because the advantages of the fishery in terms of its natural productivity are offset by competitive forces resulting in overexploitation, which in turn lowers the return to fishing effort (Tom *et al*., 2010). Open access to fisheries has been criticized for a number of reasons. Under open access, biological yield from the resource will be less than the maximum potential. The resource is vulnerable to changes in price and technology which tend to increase fishing effort over time, reducing yield and biomass and threatening the stock with collapse. A great deal of fishing effort, and therefore cost, is wasted. A larger catch could be obtained with less effort and less cost.

In contrast to the low or zero rent, the point of maximum profit occurs at the maximum economic yield. The maximum profit from a fishery is actually obtained when the fishery is kept at relatively low levels of effort compared to the open access. Biomass is kept relatively high, catch per unit of effort is high, and profits are high. A fishery that is managed to obtain the maximum economic yield is therefore also managed in a very conservative biological way. MEY thus occurs at a stock size that is larger than that at which maximum sustainable yield is achieved, leading to a win-win situation for both the fishers (added profitability) and the environment (larger fish stocks and lower impacts on the rest of the ecosystem) (Tom *et al*., 2010).

A new and compelling argument for reducing fish harvests (the profit motive) could persuade fishers to endure the short-term pain of lower catches for the long-term gain of higher returns for their labour. When stocks are allowed to recover, profits take a sharp turn upward. Profits are made when fish numbers are allowed to rise beyond levels traditionally considered optimal. In other words, bigger stocks mean bigger bucks (Quentin *et al.,* 2007). The simple reason is the stock effect; when fish are more plentiful and thus easier to catch, fishers don't have to spend as much on costs to fill their nets.

Rebuilding a fish stock means investing the foregone harvest, thus, revenue is reduced in the short run with the aim of getting more in return at a later stage. In this case a part of the potential net revenue is invested in the fish stock, the natural resource capital, to save for future purposes (Agar and Sutinen, 2004). For the society, the question at any point in time is whether to consume or invest. For an investment in the stock to be profitable, the return on this investment should be better than for other investment projects. A sum of money to be received in the future is not of the same value as the same sum of money received today, since money could be deposited in the bank at a positive interest rate. Thus the interest rate plays an important role in comparison of the value of money at different points in time. The analysis in this text is based on the assumption that effort, which combines inputs like crafts, gear and labour, has an alternative value in the society's production. This is a reasonable assumption for the long-term adaptation analysed within a bioeconomic framework. It takes time for stocks to adjust to changes in effort and other exogenous factors. Factors of production used to produce crafts and gear could alternatively have been used for the production of other goods and services for consumption and investment.

The potential economic benefits from rebuilding Chambo and Kambuzi at MEY in Lake Malombe are estimated to increase by 116% and 51% respectively in 2021. Other studies have also reported that rebuilding fisheries has high economic potential. For example, the potential economic benefits from rebuilding 17 overfished stocks in the United States is estimated at $567 million, or approximately three times the estimated net present value of the fisheries without rebuilding (Sumaila and Suatoni, 2006).

The net present value (NPV) for the current Chambo fishery solution indicates that the fishery is experiencing economic collapse and is advisable not to continue exploitation. Exploitation would only be viable if fishers are advised to operate at MEY. Unlike Chambo fishery, Kambuzi fishery at the current state has positive NPV but lower than the MEY NPV. This shows that it is economic to fish Kambuzi in short term, but it would be more economical and sustainable to operate at MEY. However, fishers operate in a world which is markedly different from most enterprises and that affects their behaviour. Risk and uncertainty are at the centre of their lives but the negative consequences can, to an extent, be offset in a well managed fishery where high levels of profitability can be achieved (Charles, 2001).

But even still, entering the fishery is a costly business and many fishers risk loss of home, income and even life. Such financial pressures affect their willingness and ability to comply with the management regulation and that willingness is further challenged by the lack of trust between fishers, researchers and managers. This encourages them to circumvent the policy obstacles placed in their way. Even when they are not aiming to circumvent the restrictions the fishers still become more efficient through technological creep and skill development. For many people in the fishery, dependency and vulnerability are key features that keep them in operation. They often have few alternative employment opportunities and there are strong cultural bonds which tie them into fishing.

CHAPTER SIX

CONCLUSION AND RECOMMENDATIONS

6.1. Conclusion

The main objective of the research was to establish bioeconomic options for economic exploitation of Chambo (*Oreochromis* spp.) and Kambuzi (small *haplochromine cichlids*) fish stocks of Lake Malombe. The study was conducted based on three specific objectives that included: Assess intertemporal preferences of fisheries resource users in the exploitation of fish stocks; forecast patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) catches and estimate resource economic rents associated with maximum economic yield (MEY) and maximum sustainable yield (MSY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) fishery of Lake Malombe.

The study hypotheses were: There are no intertemporal preferences among fisheries resource users in the exploitation of fish stocks in Lake Malombe; there are no differences between current catch patterns and forecasted catch patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) in Lake Malombe and there are no differences in resource economic rents associated with maximum sustainable yield (MSY) and maximum economic yield (MEY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) fishery of Lake Malombe.

Based on the objectives and hypothesis, the study concludes that there are intertemporal preferences among fisheries resource users in the exploitation of fish stocks in Lake Malombe. In this thesis intertemporal preference was categorised into positive intertemporal preference if one prefers to exploit fisheries resources immediately (t_1), rather than in subsequent periods (t_2) and negative intertemporal preference if one is willing to transfer part of the exploitation in the current period (t_1) to the subsequent period (t_2).

Although, Lake Malombe has an open access nature in terms of resource exploitation, the study has shown that some resource users are cooperative and impatient in the exploitation of resources. Resource users with negative intertemporal preference can contribute to the rebuilding of fisheries resources because they are willing to forgo current exploitation for future. Such group can be used to change the behavior of others in the exploitation of fisheries resources. The group can be used as local extension or change agents in advocating for rebuilding of Lake Malombe. The study has shown that intertemporal preference of fishers and consumers of Lake Malombe is influenced by factors such as stratum marital status, literacy level, years in fishing, and daily working hours.

Furthermore, the study has shown that there are differences between current catch patterns and forecasted catch patterns of Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) in Lake Malombe. Time series analysis of Chambo (*Oreochromis species*) and Kambuzi (small *haplochromine cichlids)* catches in Lake

Malombe, showed that Chambo catch in gill net has a down ward trend (from 4,118 tons in 1976 to -1,111.80 tons in 2022) while Kambuzi catch in nkacha net has an upward trend (93 tons in 1976 to 4,224 tons in 2022) implying that if the management of fisheries in the current state continues without rebuilding, the Chambo catch will be decreasing with time while Kambuzi catch will be increasing at a low rate (*cetelis paribus*). This is likely to have negative socioeconomic impacts on the future generation of resource users.

Finally, it can be concluded based on the bioeconomic analysis that there are differences in resource economic rents associated with maximum sustainable yield (MSY) and maximum economic yield (MEY) for Chambo (*Oreochromis* spp.) and Kambuzi (small *Haplochromine cichlids*) fishery of Lake Malombe. From the Gordon Schaefer fisheries model, MSY solution gave the highest level of effort and the MEY gave the lowest level of effort. The study has shown that Chambo fishery has MK2.148 million rent at MEY as compared to MK1.533 million at MSY. Kambuzi fishery has MK2.172 million rent at MEY as compared to MK0.715 at MSY. The results show that it is more profitable to operate at MEY for both Chambo and Kambuzi fishery in Lake Malombe than at current status quo and at MSY. It is estimated that the maximum economic rent for Chambo fishery is reached at an effort level of 36380 pulls corresponding to 36 gill nets. The maximum economic rent for Kambuzi fishery is reached at an effort level of 37490 pulls corresponding to 49 nkacha nets.

Chambo fishery shows that present value for MEY are positive and are declining with time. Overall, the present values of MEY solution are higher than the present values of the MSY. Using the discounted rents from MEY for Chambo fishery, the net present value of MK9.831 million would be achieved. Under Kambuzi fishery a net present value of MK9.938 million would be achieved in 2021 if the fishery is exploited at MEY. Based on the net present values it can be concluded that exploitation of Chambo and Kambuzi stocks will be economically viable in 2021 if the fisheries are exploited at MEY.

6.2. Recommendations.

For Lake Malombe, if the objective of ensuring sustainable resource use in order to contribute to economic growth is to be achieved, then the approach of operating at MEY by reducing fishing effort for Chambo and Kambuzi fishery respectively is the best. This approach will ensure both good biomass growth and maximize economic benefits in the long run. Based on the findings of the study and review of various global fisheries management it can be recommended that Lake Malombe fisheries management adopts economic fisheries management systems to complement the conventional management systems.

This research has provided estimates of bioeconomic options such as the MEY that can be used for managing the fish stocks of Lake Malombe. The reference points can be used as the management target for Chambo and Kambuzi fish stocks. Based on the bioeconomic options that have been established, direct economic restrictions is recommended for introduction in Lake Malombe by restricting effort i.e. restriction on number of fishing hauls and number of gears. The results of the study have shown that for Chambo fishery, the number of hauls should be reduced from 100375 to 36380 translating into reduction of gillnets from 247 to 36. This reduction in level of effort yields a maximum economic rent. For Kambuzi fishery, the number of hauls should be reduced from 41794 to 37490 translating into reduction of nkacha nets from 140 to 49 in order to achieve maximum economic rent. Based on the restriction on number of gears the study also recommends that each gill net should have an average of 1020.9 hauls per year and nkacha net should have an average of 757.41 hauls per year. The recommended fishing effort levels for Chambo and Kambuzi fishery are more profitable and can contribute to attainment of long term maximum net present values of MK9.831 million and MK9.938 million, respectively. Thus the use of MEY on rebuilding future stocks of Chambo and Kambuzi leads to two distinct ways to utilize the bioeconomic modelling framework: (1) minimize the loss in resource rents of rebuilding to the MSY; (2) maximize resource rents or any other management goal(s) by rebuilding to the MEY.

However, the reduction of fishing effort is in most cases not attainable due to inherent behaviour of fishers to invest more and more in illegal technology development to elude regulations to reduce effort. This approach must therefore be supported by other measures to ensure that effort reduction is achieved. One way of achieving this is to introduce a rights based fisheries regime. The study has shown that fisheries resource users of Lake Malombe have intertemporal preference. Since two categories of resource users exists in Lake Malombe, this provides an opportunity for introducing a rights based approach to fisheries management. The negative intertemporal preference group can be used to bring social cohesion with the positive intertemporal preference group to take on the responsibility of defending and managing resources in the area. This can be achieved if the social groups are protected from within and government interference is minimized. If the approach is internally built, it is likely that it will be socially acceptable because it will still keep fishers in operation throughout the rebuilding period while at the same time more economic rents are generated.

Rights-based management (RBM) provides a set of policy choices that involve a combination of use rights (fishing rights relating to access, effort and/or catch) and management rights (relating to co-management and rights over involvement in decision making). In general, use rights arrangements alone do not solve fishery problems. While not a panacea, rights-based management can have positive results if implemented carefully, in a context-specific manner. For this to occur, the many choices in RBM must be clearly understood. For example, rights can be held by individuals, or by groups, communities or regions. Rights can be transferable, or nontransferable (with intermediate and regulated options as well). Rights can be based on catch, on fishing effort, or on fishing territory.

One such option is that of community fishery rights held directly by communities and groups, with limited transferability. Community fishery rights place emphasis on local institutions within which fishermen make fishing and management decisions, combining social sustainability (local buy-in) with economic sustainability (including regional economic efficiency), while creating incentives for ecologically appropriate fishing.

This approach is well tested in various countries, with experiences indicating that such an option may suitably balance ecological, economic and social sustainability by effectively combining economic incentives, strong institutions, and long-term stability. For example, in eastern Canada, the rights are allocated to small geographical regions, ones in which the fishers are relatively cohesive. Annual decisions on fishing practices and management plans are made locally, while permanent transferability of quota between regions can be made only with the agreement of each region. This balances economic efficiency and social stability. Furthermore, hard decisions on the future are made locally, by fishermen in that area, in a manner that again balances economic and social sustainability, within suitable ecosystem bounds. This ensures local people are more in control of their future

Another alternative to reducing effort would be to deliberately finance the definitive withdrawal from fishing. This is paying the fishers to abandon extra gears and turn to community social groups and other activities. This evidently involves a cost for the fishing authority but if it is regulated correctly it can reduce the effort. It often not only implies purchasing the boats and gears that have been decommissioned, but it should also ensure a planning or orientation towards new investments. If new alternative investment opportunities are not offered, then it is possible that those who receive the financing to abandon gears may try to reinvest in this activity even though it is strictly prohibited. If income is oriented effectively towards other activities the foreseeable effects are to change the effort cost curve. Thus, it must be ensured that others do not enter to substitute those who have been removed, or that the reduction of effort produced by the reduction of gears is not compensated for by the increase in number of fishing hauls.

Further studies should be done on impact of climate change on fisheries of Lake Malombe. The recommendation is in line with the general observation of degradation and siltation in Lake Malombe which might also contribute to the collapse of fishery apart from increased effort levels.

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