BIO-ECONOMICS OF COMMON RESOURCE OVER EXPLOITATION: CASE OF LAKE MALOMBE *CHAMBO* (*Oreochromis Sp*. CICHLIDAE) FISHERY IN MALAWI.

BY

FRANCIS MAGUZA-TEMBO

MSc. Thesis

Submitted in partial fulfilment of the requirement for the Master of Science Degree in International Fisheries Management

Economics Department
Norwegian College of Fisheries Science
University of Tromsø, Norway

TROMSØ MAY, 2002

DEDICATION

Dedicated to my dear Maureen and daughter Talandira.

To My Sisters and all relatives, " Things will never be the same again, but life has to go on".

To My Fallen Heroes! Mum, Dad and Brothers. "You all initiated My Education but never so Its fruits:"

ACKNOWLEDGEMENTS

First and Foremost thanks to God "You are always great to me, continue doing so". I express my gratitude to Dr Arne Aide for his valuable supervision and guidance in carrying out this work.

I am indebted to NORAD for granting me the scholarship to attain higher education in Norway; it is with hope that the knowledge I have acquired will be shared with people who never had this chance. SEMUT your contribution enabled me to have ease in my fieldwork thanks. Thanks to the International Fisheries Management programme Co-ordinators (Anne Marie Hekton, George Santos (Elvar Haffredson)) and all lectures (Sumaila Rasheed (UBC), John Pope (GB), Conner Bailey (Auburn), Bjørn Hersoug (NFH) to mention a few, 'You took a big task of expanding my knowledge on fish and fishery'.

Acknowledgements to G. Matiya and Dr. E. Kaunda (Bunda College), Dr. M. Banda, Dr S. Donda, F. Njaya and M. Makuwira all from GoM (Fisheries Dept.). I appreciate for sharing some of your ideas and materials with me during data collection (fieldwork).

Special thanks are extended to my classmates (International Friends) 'I know it was not an easy ride but we have made it'. Mbachi, Isaac and Sheila you took your time reading manuscripts of this paper that is worthy mentioning. And lastly to all people, who have been part to my stay in Tromsø, I say thank you.

ABSTRACT

Increased attention has been paid over recent years to the Over exploitation of small-scale fishery resources. This paper offers a simple bio-economic model of fishery exploitation orientated towards both Lake Malombe *Chambo (Oreochromis sp.)* and the Whole Lake Malombe Fishery. The catching of *Chambo* in Lake Malombe has historically been important to Malawi Fisheries, and the changes that have taken place in the Fishery have had major social and economic consequences on communities around the Lake. Bi-oeconomic exploration of this fishery has been based on the catch, effort and price data from 1976 to 1999. It has been demonstrated here that, *Chambo.* Fishery provides a unique illustration of the economic and biological effects of technological (gear type) change in situations where access to the natural resource remains virtually unrestricted (open access). The components of the model are explained with reference to their guiding economic (Maximum Economic Yield) and biological (Maximum Sustainable Yield) reference points. And it is estimated in the study that if yield of *Chambo* falls below 6900 tons and 14 621 tons for the Whole fishery, then the rate at which the population regenerates itself falls below the rate of extraction. The paper also draws the problem of effort over capacity as the current capacity exceeds, by a wide margin, the capacity that would be required to harvest a sustained yield. In addition to the over capacity is the problem of selectivity in the gear types. Such over capacity and non-selectivity in fishing gear makes control of catch and efforts difficult and threatens the fishery.

TABLE OF CONTENTS

List of Figures

Tables

CHAPTER ONE

1 INTRODUCTION

Fish resource utilisation is first and foremost an economic activity. Its purpose is to provide a sustainable flow of benefits to human society. As indicated by Conrad and Clark (1987), in recent years, the relative economic efficiency of the fishing industry has significantly declined in many countries. This is partly due to overexploitation, and the consequent reduced yield from many fish stocks. The currently widespread low economic performance of fishing in Lake Malombe mainly on *Chambo* Fishery is not only harmful to the fishing communities. It is detrimental to society as a whole since it devalues the social importance of communities around the lake and weakens the willingness of national authorities to maintain strong scientific research in the field of fisheries biology and economics.

The major cause of over exploitation and waste in fisheries is the condition of free and open access to the resource. With a minimum number of assumptions, it is possible to derive some useful hypotheses regarding to several important aspects of resource overexploitation behaviour. The reason, of course, is that no one in open access fishery is able to exercise entrepreneurial control over the application of variable resources to the fixed resource. Entry of efforts will proceed until all potential rents to the fish stock have been exhausted. The fishery and species are then left in a sub-optimal “bio-economic” equilibrium in which a harvest may be taken, but with fish stock that is too low and amounts of capital and efforts that are too high in terms of efficiency. Since an open access resource is normally misused from an efficiency standpoint, the research will gather a comparison on how much more rent (profits) would have been earned if a sole profit maximiser controlled the harvest. The estimates will shed light on the issue of losses due to common property exploitation and give a rough measure of losses due to the open access nature of property rights.

1.1 Malawi Fisheries

Despite being a landlocked country, Malawi has developed a remarkable fishing industry. The maximum catch was 88,000 tonnes in 1987 but dropped to 67,000 tonnes in 1993. It is estimated that the number of fishermen is approximately 40,000 people. The secondary sectors like fish trade and boat building employ approximately 20,000 people. Considering the average household size in Malawi, about 250,000 to 300,000 people are dependent on the success and failure of the industry (Anon, 1991). The status of the fishing industry is on account of about 30 % of the total area of the country (119,000 $Km^{2)}$, which is covered by water. Lake Malawi with 27,000 Km^2. Its fish fauna comprises more than 1000 fish species, which is a unique character among the fresh water lakes. Other fisheries of very strong local importance are on Lakes Malombe (390 Km^2), Chilwa (590 Km^2), and Chiuta (113 Km^2) and in the Shire River system. The products of the fishing industry play a significant role in the nutrition of the population, which is currently estimated at 10 million. Fish constitutes about 70 % of the protein intake in the country. However the high population growth rate of approximately 3 % p.a. will in future increase pressure on the sector. The national per capita supply of fish currently stands around 7.7 Kg/year, a drastic drop from the 12-18 kg/year levels that were registered in the 1970s (Hara, 1993).

1.1.1 Economic Contribution of Fishery Industry

At least 90 percent of the total catch in the country comes from artisanal fishing activities (Anon, 1991). The fishery provides a direct and an indirect source of income, food, and employment. Today commercial fishing on Lake Malawi also contributes significantly to employment opportunities and foreign exchange earnings (Njaya, 1998). The contribution of fisheries to the countries' GDP is relatively small compared to that of agriculture. However, it represents an important source of employment, particularly in rural areas and it provides about 70-75% of the total animal protein for both urban and rural low-income families. Annual fish consumption in recent years fluctuates between 6 and 7 kg/person/year. However, owing to lower production from the northern sector of Lake Malawi, the annual per capita consumption of fish in the central and northern regions (3.8 kg/person/year, and 5.2 kg/person/year respectively) is much lower than in the southern region (15.7 kg/person/year). Also, the price of fish in the central and northern regions is about twice as high as that in the south (Anon, 1996).

1.1.2 Problems Associated with Fisheries in Malawi

Over fishing and increased economic activity are depleting the fish stock in Lakes of Malawi. Fish production in Malawi has shown a positive growth trend during the 1960s and 1970s (Weyl et. al., 1999). Currently, there has been a tremendous decline in production, to some extent due to the climatic fluctuations but also due to some heavy exploitation (Nyambose 1997) of near shore and demersal stocks in the south of Lake Malawi an Lake Malombe.

1.1.2.1 Social and Cultural Attributes

Nyambose (1997) described high population growth rate as one contributing factor to over fishing, species loss, and pollution of the lake. Since fish from the lakes and aquaculture provides about 70 % of animal protein consumption in the country as the population grows, so does the consumption of fish, there by creating pressure on the fish from the lakes. The high population growth has increased land cultivation in the catchment’s areas of the lakes and contributed to the pollution in the lakes through the use of fertilisers and the chemicals and disruption of natural ecosystems through the clearing of the catchment’s areas. The fishing communities still hold on to their traditional practices and they continue to resist outside conservation efforts as long as their needs are not taken into consideration. The traditional way of thinking has resulted in the fishermen harvesting large quantities of fish which has altered the ecological balance in the lake, reducing the numbers and species of fish and affecting other wildlife such as birds which feed on fish.

1.1.2.2 Economic

Widespread poverty within the population plays a significant role in the environmental degradation of the lakes. It is particularly difficult for poor and hungry people to make the critical trade-offs necessary for long-term sustainability of natural resources because of their pressing immediate needs. The people living in the lakeshores have always relied on the lakes for fish as food, transport, water for domestic purpose, recreation, and other daily needs (Kureya, 1998). The lakes are their life. Now with the introduction of large-scale commercial fishing in Lake Malawi and the government's attempts to address the problem of over fishing in Lake Malombe by banning fishing and use of other gear types, it is likely mistaken to put additional and undue restrictions on subsistence fishermen to earn their much needed form of living.

1.1.2.3 Environmental and Climatic

Problems mostly related to the use of agro-chemicals such as DDT have had serious results on the aquatic environment as death of fish due to pollution has been reported in most of the lakes like Malawi, Malombe to mention a few. The water Hyacinth has also affected most of the lakes in the country. The country is associated with tropical climates. Summers are hot, rainy, and associated with growing crops for indigenous subsistence farmers, while winters are generally dry, cold and not very excellent for fish production. Events such as El Ninõ and La Ninã are common, and have had an impact through floods and undesirable changes of climate and temperature (Kureya, 1998).

1.2 Study Area

Fig 1.1. Map of Malawi showing the position of the study Area Lake Malombe

1.2.1 Lake Malombe and Upper Shire

Lake Malombe and the Upper Shire River lie between latitude 14°21' to 14°45' south and longitudes 35°10' to 35°20' East. They are part of the Great Rift Valley system. Lake Malombe is shallow, with an average depth of 4m, about 30 km in length and has a maximum width of 15 km. The Upper Shire River, about 13 km long, flows from the southern tip of Lake Malawi before widening to form Lake Malombe. The lake has a surface area of approximately 390 – 450 km^2 and is fed by water from Lake Malawi through the Upper Shire River and is further enriched by inflowing streams from highly populated catchment areas and by recycling of nutrients in sediments as a result of the shallowness of the lake. Lake Malombe is therefore, much more productive than Lake Malawi (Njaya, 1998). In 1988, when the fishery was near its peak, the lake produced about 15,000 tonnes of fish, approximately 17% of Malawi's total production. However, the fishery has shown rapidly declining total annual catches (from about 15,000 tonnes in

1982 to nearly 2,000 in 1994), representing a considerable loss in income levels of the fishers (Donda, 1995).

The short channel of the Shire to Lake Malawi connects Lake Malombe. 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 (Hara, 1999). Fish diversity is lower in Lake Malombe but biomasses and productivity are higher.

1.2.2 Inhabitants

Fishing is the major socio-economic occupation for the communities around Lake Malombe and Upper Shire River. Chirwa (1997) reported that fishing and fish trading activities support some 400-gear owners, 2,700 fishers, 2,300 crew, approximately 1,220 traders and unspecified number of fish processors. A frame survey conducted in 1999 indicated that 410 gear owners, 1,651 ancillary workers operated on Lake Malombe (Weyl *et a*l., 1999). A population who is primarily Moslem Yao who immigrated into the area in the 19th century densely settles the areas around Lake Malombe. However, some Christian Chewa villages remain representing the previously dominant ethnic group in the area. The land surrounding Lake Malombe falls into the areas of two Yao Traditional Authorities or Chiefs, Chief Mponda and Chief Chowe. The population of the area in 1996 was estimated at about 69,000 fishing families residing in the east. There are 45 villages (33 of them along Lake Malombe and 12 along the Upper Shire River). The villages have no fewer than 82 fishing beaches about 65 on Lake Malombe and 17 on the Upper Shire River.

Njaya (1998) indicated that populations around the Lake are primarily farmers. However, a majority is involved in the fishing industry, either as gear-owning entrepreneurs, as crewmembers operating fishing gear or as fish processors and traders. Many of those involved in fishing are also farmers; fishing fulfils an important role in that it provides income at the start of the farming season to purchase inputs and fertiliser. Many families already combine fishing with part or full-time agriculture, growing mainly maize and groundnuts. Some of the owners who supply boats and equipment, reaping 50 percent and upwards of the value of the catch have substantial farms. But the poorer people who do crew the boats and split the remaining share of the catch earn less than US$ 10 a month. Sufficient land to make a living is even beyond their reach.

1.2.3 The Fishery

Lake Malombe Fishery has undergone dramatic changes both in gear utilisation and catch composition (Weyl, et.al 1999). *Chambo* was the main species in the 1970s, increasing to a level of more than 6000 tons of reported catches in the early 1980s and decreasing to very low levels of as low as 100 tons in the late 1980s and early 1990s. Following the partial collapse of the fishery in the late 1980s and early 1990s, the Department of Fisheries of the Malawi Government recognised that remedial action was required (Njaya, 1998). As a result of research and monitoring co-ordinated by the Fisheries Research Station at Monkey Bay, a number of draft regulations were developed in 1992 by the government intended to rehabilitate the fishery on the Lake. These included restricting the mesh size to 25 mm, (1 inch), for seine nets; tightening the enforcement of a closed season on the Lake and banning the use of beach seines. The 1992 decision to promulgate these regulations corresponded with a period of political transition in Malawi, culminating in the change of government in 1993. But partly because of a lack of funds the regulations have been widely flouted and the government has been unable simply to enforce the proposed regulations. According to a fisheries bulletin No. 45 of 1999 produced by the Department of Fisheries the *Chambo* fishery in the Lake is currently considered to have collapsed.

The species composition of the total catches does comprise the cichlid *(Oreochromis* spp.) locally known as *Chambo* including three species. All are mouth brooders, maturing at about 30 cm. The taxonomic status of most *kambuzi* species is not yet clear. They are quite small (maximum 12 cm) maturing at about 5 to 6 cm and have low fecundity. Recruitment is strongly related to the size of the adult stock, thus being capable to high fishing pressure (Tweddle *et a*l, 1994). Other species appearing in commercial catches are mainly catfish like *Clarias gariepinu*s, *Bagrus meridionalis* (locally called *kampang*o) and certain cyprinids like *Engraulicypris sardella* (locally known as *usip*a). The species composition of the catch has also changed overtime, Chambo was the main catch until the late 1980s then *Kambuzi* became increasingly important and is currently the most important fishery in the lake.

1.2.4 Chambo

There are three *Chambo* species endemic to Malawi, which are *Oreochromis lidole, Oreochromis karongae and Oreochromis squamipinnis*. At present, it is still not possible to distinguish the three species with accuracy, except for mature males using breeding colour (Pålson et. al. 1999). *Chambo* is a mouth brooder and most females and fry spend a long period together in shallow water nursery areas. All species of *Chambo* do swim from shallow to deep water during their life history and their breeding season does stretch from July to April. Most important biological parameters of *Chambo* have been shown in table 1.1. The table shows the growth and life history parameters, L_{max} is the asymptotic length, or the theoretical maximum length *Chambo* can reach, K is considered as a growth function or the rate at which the fish grows to reach L_{max}. The length and weight relationship factors ($W= a L^{b}$), natural mortality (m), length and age at first maturity (Lm and tm) are also shown in table 3.5.

1.2.5 Gear Used

The most common gears used include *nkacha* seines, *kambuzi* seines and gill nets (Donda, 1995 and Njaya, 1998). The number of C*hambo* seines has been reducing from 11 in 1988 to almost nothing in 1997 indicating that either C*hambo* stocks are still dwindling or that there is a shift in investment from more expensive C*hambo* seines to cheaper gill nets, which have steadily been increasing from 1988 to 1997. The *kambuzi* seines that were 101 in 1989 have been reducing to around 30 in late 1990s while *nkacha* seines have been more than 200 since 1991 (Donda et. al., 1999). The implication is that without complying with changing of mesh size from fine meshed *nkacha* to about 19 mm or 25 mm mesh sized seines; the habitat and catching of juvenile fish will continue threatening recovery of the declined *Chambo* stocks. The number of operators has, however, been between 2,000 and 3,200 from 1988 to 1997.

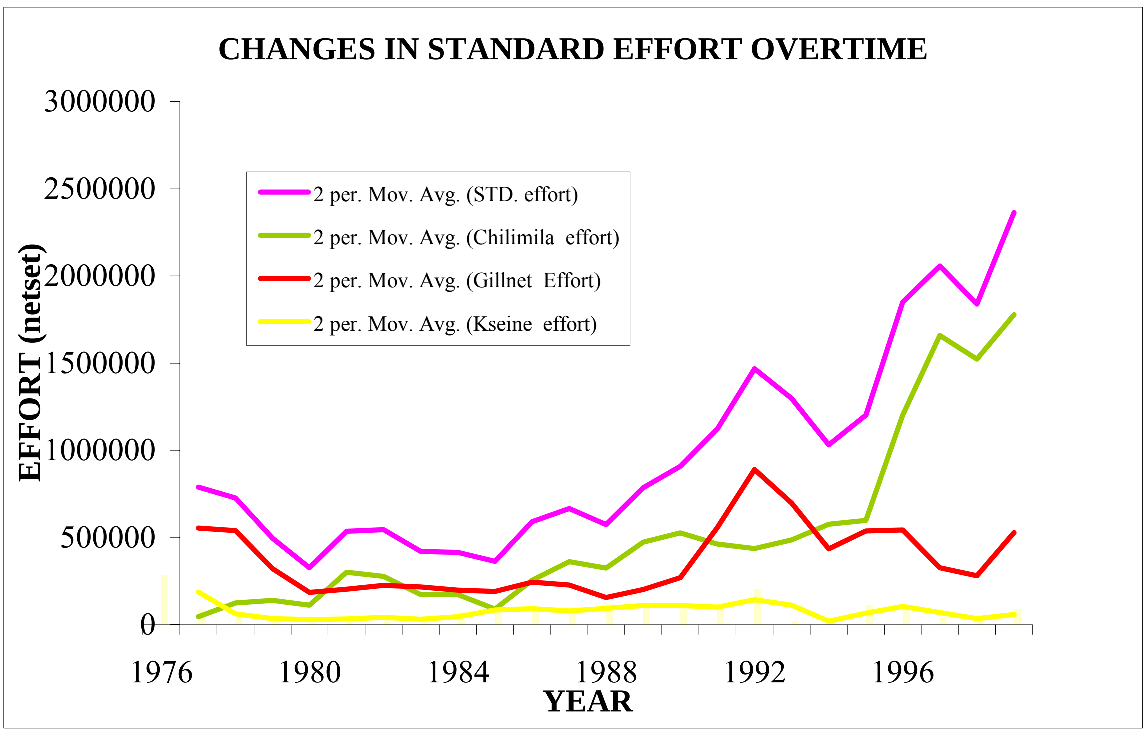

Fig.1.2. Trends in Fishing Effort (2 year Period).

1.3 Rationale of the Study

If fishing is to remain economically sound and be run on the basis of sustainable exploitation, the industry and the operators must be motivated to support and strengthen measures to exploit the resource in a sustainable way (Henderson and Tugwell, 1979). The fishing sector, however, has a low economic profile in most countries and is not supposed to strengthen society by generating profit. This low profile has direct influences on the whole industry and on the scientific foundation for the exploitation: the fishing sector, operators and industry, tend to contribute little to the scientific effort, which in turn weakens the co-operating ground between operators, the scientific community and the relevant authorities.

Fishermen like any other economic agents are driven by the profit maximisation objective at least in the short run (Cunningham et.al., 1985). With this there are all reasons to believe that fishermen and fishing efforts will increase as fish catch commands high prices in the market. Their fishing efforts will increase because of the high demand that exists for both fish and fish products. The high demand is reflected in high relative prices. Thus without proper management the danger that the resource can reach extinction levels is high. Thus where there are economic incentives to fish more, regulatory mechanisms are needed to ensure sustainability of the resource. The underlying idea is that the prevailing fishing regime should be economically efficient and ecologically sustainable.

1.4 Research Gap

The importance of Fisheries resources to the economy of Malawi cannot be understated. These resources make a significant contribution to the Gross Domestic Product (GDP), provide both direct and indirect employment and supply relatively cheap protein to the population. The *Chambo* stocks in Lake Malombe declined rapidly in the late 1980s and collapsed in the early 1990s (Pålson et. al. 1999). The collapse was probably brought about by too high catches and excessive fishing of juvenile *Chambo* (ages 0-1). The collapse of the *Chambo* fishery is regarded as an economic disaster to Malawian nation as it was estimated that some 5000 tonnes of *Chambo* are worth millions of US$ annually. Fisheries research has been a relevant part of research activity in Malawian waters during the last sixty years (Pålson et. al 1999). This activity has accumulated most of the biology knowledge of Malawian fishes presently available for management purposes. However continuous monitoring and collection of time series data on fish stocks, catches, effort, cost and prices has generally been lacking. The aspect of fisheries research and the economic studies in the Malawian waters needs more attention, as it is indicated by Pålson (1999), that the translation of scientific knowledge into fisheries policy and management measures is developing to a limited degree.

1.5 Profession Contribution of the Study

This paper examines a number of theoretical economic concepts that are central to the management of the exploitation of the fisheries resources in a manner that ensures sustainability in economic terms. It specifically focuses on the applicability of these concepts to the Lake Malombe fisheries. The findings of this study will fill the existing gap of empirical studies that focus on the economic analysis of the sustainable use of fishery resources in Malawi. The information is also expected to assist policy-makers and interested parties to make informed decisions about the economic management of fisheries. The experience can be extended to similar situations of overexploitation with regards to other fishery resources and other renewable resources in general. The knowledge will further facilitate the designing of appropriate measures.

1.6 Study Objectives.

The main objective of this study is to examine the number of theoretical economic concepts that are central to up-bringing of resource overexploitation and elucidate an optimal or sustainable exploitation of fishery resources, predicting the steady state equilibrium of the fishery, focusing especially on their applicability to Lake Malombe Fisheries. The study intends to base on empirical investigations that will provide insight into identifying existence of steady state equilibrium involving both positive *Chambo* stocks and positive fishing effort; establishing the main causes influencing overexploitation; providing a contrast of the inefficient open access equilibrium, sustainable and economic equilibrium and also coming up with recommended regulatory reference points.

CHAPTER TWO

2 MODELS

2.1 Economics of Fishery Exploitation

There are four general types of models, which can be applied in the analysis of overfishing. These are the single species and constant price models, single species and variable price models, multiple species and constant price models and lastly multiple species and variable price models (Israel and Banzon, 1996). The single species and constant price model were chosen for this study. There are two single species and constant price models that are employed popularly in empirical research, the Gordon-Schaefer (GS) model and the Gompertz/Fox model. The GS model originated from Gordon (1953) and Schaefer (1954, 1957) While the Gompertz and/Fox model has its beginnings in Fox (1970).

The questions addressed in these models do concern the characteristics of a resource and resource management systems that rendered them incompatible, so that resources are incapable of sustaining the systematic pressures placed upon it by humans. The models assume that annual growth of fish is related to the level of stock, by an inverted bell-shaped curve (Fig.2.1). Given the constraint of the carrying capacity of the environment, the model postulates that growth is large when stocks are small, and as the stock increases growth increases at a decreasing rate until it reaches a maximum and eventually falls (Tinteberg, 1996). Growth therefore reaches a maximum at intermediate stock sizes. Annual catches can be sustained indefinitely as long as the catch equals annual growth. This is referred to as Maximum Sustainable Yield. In this case Maximum Sustainable Yield refers to the catch level, which if maintained perpetually would produce the largest annual net benefits. The limitations of the model are that it includes only a single species and it ignores the age structure of the fish population. The model therefore is limited in its usefulness as an operational tool in managing tropical fisheries that reach commercial size at varying ages. Despite these shortfalls, the model provides a useful framework for understanding the basic economic principles involved in fisheries management.

2.2 Model's Choice, Description and Specification of Variables

The model used was that of renewable resource, its choice being motivated by its relevance to the topic of the study. The model tried to clarify the roles of harvesting, population growth, and the increased effort in the depletion of fish stocks. The model includes a biological production function (bio economic model) and profit function. The variable catch was expressed in weight of biomass while the effort that is a composite input is expressed in terms of net sets. The model will focus on assessing the level of exploitation of *Chambo* fishery in Lake Malombe with a view of establishing the extent of over exploitation over the years 1976-99: - and establishing levels on which fish would have been undertaken efficiently (economically) and sustainability (biologically) to avoid the present catastrophe. To be able to assess this the following was considered: - Non-formal interviews with fishermen and Fisheries Officers to learn their perception on the level of exploitation of the fishery, reviewing past case studies conducted in the area and looking at the trend of the catch in both *Chambo* and the whole fishery, which also do indicate the extent of over fishing. The decline in total catches with corresponding increase in effort shows a likelihood of biological, if not in this case recruitment over fishing existence and this implies that economic over fishing had already occurred in the fishery.

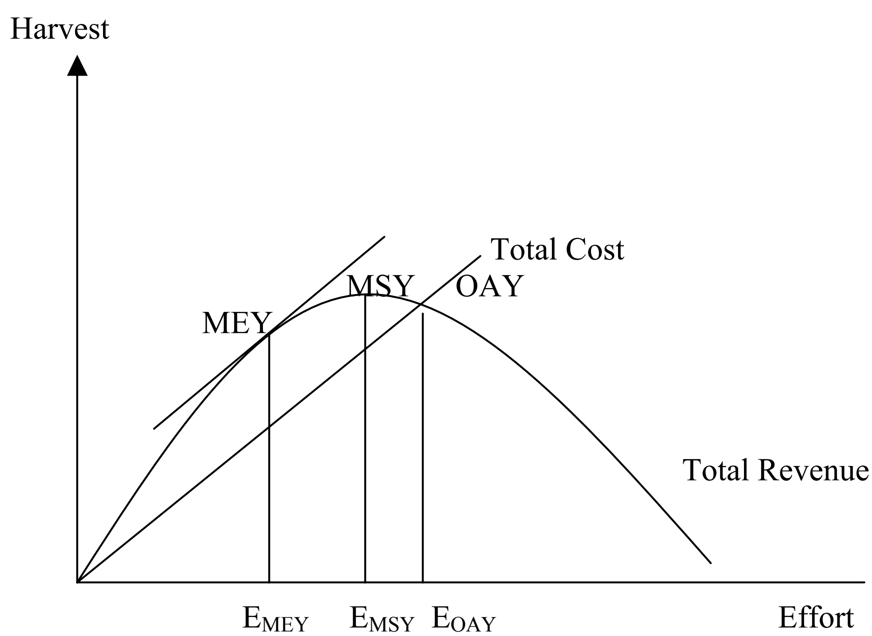

Fig. 2.1. A Catch-Effort curve

2.3 Bio-Economic Model

It is impossible to formulate any useful economic model of fishery without specifying the underlining biological dynamics of the fishery. More sophisticated models that account for the age structure of the fish population can be estimated if sufficient detailed data are available and this was not the case with this study. A biological model of multi-species fishery is generally complex but a single species model can in most cases capture its essentials. We have therefore built our model assuming a single species fishery. In this study two biological models have been used, The Fox/Gompertz and the Verhulst/Pearl surplus production models. In order to explain the model set up the latter has been used. The Verhulst/Pearl surplus production model is defined as

(1) $$F(x_t) = \alpha X_t \left(1 - \frac{X_t}{K}\right)$$

Where *Xt* = the stock of fish at time *t, K* is the environmental carrying capacity, *α* equals the intrinsic growth rate, *t* is the index of time. This implies a parabolic growth curve, which is depicted in Fig. 2.1. The natural equilibrium is reached when the stock of fish is equal to the environmental carrying capacity, $X = K$. That is why *K* is termed as the maximum value that *X* can reach. To obtain the maximum natural growth in equilibrium and the corresponding stock size, the first order derivative of equation (1) should equal to zero: -

(2) $$\frac{dF(X)}{dX} = \alpha\left(\frac{1-2X}{K}\right) = 0$$

From this we see that the stock size of maximum sustainable yield is $\frac{K}{2}$. This model can also be transformed in a very simple way to an equilibrium catch- effort model. Given the bi-linear harvest function;

(3) $$H(E, X) = qEX = qEK$$

Where *H* = catch or harvest, *q* = catchability coefficient, *E* is effort. Setting *H = F (X)* the long-term harvest function is obtained by $H = F(X) = \alpha X_t \left(1 - \frac{X_t}{K}\right)$, which is

(4) $$H = \alpha X_t \left(1 - \frac{X_t}{K}\right)$$

Structure of the fish population can be estimated if sufficient detailed data are available. This was not the case with Lake Malombe Fishery. Therefore $H = \alpha X - \left(\frac{\alpha X^2}{K}\right)$, But we know that $H = qEX$ from (3). Implying that $qEX = \alpha X - \frac{\alpha X^2}{K}$, Multiplying by $\frac{K}{X}$ throughout gives, $KqE = \alpha K - \alpha X$ and solving for X we obtain

(5) $$X = \frac{K(\alpha - qE)}{\alpha}$$

Using equation (5) in (3) it gives us

(6) $$H = EqK\left(1 - \frac{qE}{\alpha}\right)$$

Since q, K and α are all constant parameters, we can express the following as:

(6^1) $$H = \beta_1 E - \beta_2 E^2$$

Where $\beta_1 = qK$; $\beta_2 = \left(\frac{q2K}{\alpha}\right)$, and dividing through by E we get the catch per unit efforts as a linear function of effort. Since data on effort and catch are available on Lake Malombe, this allowed us to estimate the parameters β_1 and β_2 by linear regression of the catch per unit of effort on effort: That is

(7) $$\frac{H}{E} = \beta_1 - \beta_2 E$$

The study was conducted using the model presented in equation (7) above known as the Gordon-Schaefer model. The Corresponding long term harvest production equation based on the Gompertz/Fox surplus production model is given by

(8) $$H = E * e^{\beta_3 \beta_4 E}$$

2.3.1 Estimation of MSY and Effort at MSY

In order to come up with Maximum Economic Yield and Open Access Yield the Maximum Sustainable Yield was the first to estimate, and this was done using the following calculations from the models. Since the Schaefer model, is a parabola then its maximum level of yield can be obtained at an effort level of: -

(9) $$E_{MSY} = \left(\frac{-\beta_1}{2\beta_2} \right)$$

And the corresponding yield is:

(10) $$MSY = \left(\frac{-\beta_1^{\,2}}{4\beta_2} \right)$$

And for the Gompertz/Fox model with its asymmetric curve and having a fairly steep slope on the left side and much more gradual decline on the right of the Maximum Yield level. The E_{MSY} and Maximum Sustainable Yield for the Fox Model can be calculated by differentiating Yield with respect to effort from equation (8).

(11) $$E_{MSY} = \left(\frac{-1}{\beta_4} \right)$$

And its corresponding yield will be

(12) $$MSY = \left(-\frac{1}{\beta_4} \right) e^{\beta_3 - 1}$$

2.4 Economic Model

From an economic point of view, Maximum Sustainable Yield does not imply the efficient harvesting of resources. Efficiency is concerned with maximising the net benefits from the use of economic resources, i.e., maximising the resource rent. To attain efficiency in the economic sense, we need to take into account the costs of fishing and revenues from selling the fish catch. The difference between the revenues generated and the cost of fishing is the profit earned by the fishery. The concept of Maximum Sustainable Yield implies that catches (population), effort level and net benefits remain constant overtime. With this the catch-effort curve can be converted to define revenues and costs as a function of fishing effort measured in the net sets per year.

In this model the relationship between cost and effort is assumed to be linear, then total cost of fishing effort will be defined as;

(13) $$TC(E) = aE$$

Where a denote the unit cost of fishing which includes opportunity cost of labour and capital and E the unit of effort. In order to calculate the value of the fishery, the total revenue function was calculated using the following formula;

(14) $$TR(E) = pH(E)$$

Where p denote the average price. Given the average price of fish and the long-term assumed unit cost per unit of effort the profits or economic rent of the fishery was calculated using;

(15) $$\pi(E) = TR(E) - TC(E)$$

Further at the open access point, total fishing costs do equal to the total revenue from the fishery ($TC(E) = TR(E)$), therefore using the Gordon-Schaefer model the effort at open access yield can be obtained by equating $MC = AR$ or $a = \frac{pH(E)}{E}$ and

(16) $$aE = pH(E) \equiv E_{OAY} = \left(\frac{\frac{a}{p} - \beta_1}{\beta_2} \right)$$

And for the yield level at open access situation can be found by substituting the effort of Open Access Yield in the equation (6^1)

2.5 Maximising Resource Rent

The long-term economic optimum is where the marginal sustainable yield is equal in value to the cost of an additional unit of effort. The marginal sustainable yield is obtained by calculating the first order condition of equation (6^1); that's $\frac{dH}{dE} = \beta_1 - 2\beta_2 E$. At the maximum $\frac{dH}{dE} = 0$; Therefore $\beta_1 - 2\beta_2 E = 0$ and $\beta_1 = 2\beta_2 E$ which then gives us

(17) $$E = \frac{\beta_1}{2\beta_2}$$

The value of which is given as $P\left(\frac{dH}{dE}\right) = P(\beta_1 - 2\beta_2 E) = MR$ Therefore we set

(18) $$MC(E) = P(\beta_1 - 2\beta_2 E)$$

At a point where $MR = MC(E)$ is the Maximum Economic Yield.

CHAPTER THREE

3 DATA

To be able to undertake the analysis on the Bio-economics of resource over exploitation of *Chambo* fishery on Lake Malombe, data was gathered on the following variables catch, effort, price of *Chambo* and due to unavailability of the data on cost of fish harvesting some assumptions were made. The Secondary time-series data covering the period 1976-99 were used.

Table 3.1. Real Effort[1] (1976-1999) and Converting Factors .

	Gillnet Effort	Chilimila seine Effort (hauls)	Chilimila Converting Factor	Kambuzi seine Effort (hauls)	K.seine Converting Factor
1976	485016	14220	2.92	35092.5	8.18*
1977	624230	11425.5	4.50	21659	4.03
1978	454078	62459.5	3.16	7686	4.89
1979	189092	28261	2.82	9786	3.29
1980	183084	39722	3.63	5094	4.88
1981	223114	45153	10.10*	7525	5.52*
1982	228093	23930	4.05	9779	4.35
1983	203330	60063.5	4.15	30047.5	0.66
1984	191371	36109.5	2.61	19132	3.73
1985	189707	46077	1.84	34484	2.81
1986	297010	103029	4.13	15824	5.52*
1987	158670	187232	1.58	21217	3.24
1988	154553	236396	1.50	51183	2.30
1989	247973	406434	1.46	36610	2.79
1990	291183	236466	1.95	28351	4.21
1991	826032	183923	2.52	19978	4.19
1992	952609	447921	8.95*	13425	15.05*
1993	443677	192810	2.92	4035	5.57
1994	426520	307122	1.92	15021	1.12
1995	649463	189393	3.2	14061	8.07*
1996	436335	467980	3.84	7209	13.5
1997	218445	472431	3.22	15537	2.79
1998	341739	452732	3.37	5190	4.90
1999	716077	326171	6.22*	13271	6.83*

[1] Real effort from Weyl et.al., 2001 and converting factors from math 4 programming using gillnet std. And factors with (*) are considered outliers.

3.1 Fish Catch and Fishing Effort Data

The available time-series catch data from the sources were inconsistent. In particular, the total catch and even *Chambo* catches were underestimated. Due to the variability of the fishing gears in the fishery the study focused on three Fishing gears; Gillnet, Chilimila and Kambuzi seine. The Gillnet effort is measured in net sets and Chilimila and Kambuzi seine effort measurements are in hauls. This study used a modified measure for fishing effort, which is the standardised effort in gillnet units.

All the effort values have been converted into standard gillnet units. Converting factors were found by running a mathematical program and these were multiplied with the real effort to get the standardised effort. A year-by-year procedure was used to obtain the standard CPUE values, E.g. std. CPUE Chilimila 1980 = CPUE (Chilimila, 1980)/ CPUE (gillnet, 1980). The fishing effort data used in the study are also provided in Tables 3.1 and 3.2.

3.1.1 Trends in *Chambo* catch

Trends in the *Chambo* catches in Lake Malombe have been characterised by fluctuations since 1970. According to Pålson et.al (1999) the annual catch was close to 4000 tons during 1976-1980 and increased to 8484 tons in 1982 which has been the largest recorded annual catch in Lake Malombe. In the late 1980s there has been a drastic decline in catches and from 1993 annual landing records have been less than 200 tons. Between 1976 and 1982, there was an increase of 48 % in *Chambo* landings from 4118 tons to 8485 tons an average increase of 14.3 % per annum. In the period from 1983 to 1986 the catches were more or less static. 1987 registered the first decline in the catches, which has persisted to late. Based on the catch per unit effort (CPUE), statistics suggest that there has been a decline in the total catch over the years with a lot of fluctuations. In 1983, for example, the *Chambo* catch was 6 055 tons from all the lake and the catch in 1995 went as low as 193 tons. This suggests a fall by 98.5 % in 12 years. At the same time the number of net sets increased from 472 425 to 1 368 993. However, there were trend fluctuations in both catch and effort within the period with decline in CPUE (Table 3.2).

Table 3.2. Catch[2] and CPUE (1976-1999).

	CPUE CHAMBO	*CHAMBO CATCH*	*TOTAL CATCH*	*CPUE TOTAL CATCH*
1976	0.0051	4118	4769	0.006
1977	0.0055	4161	4867	0.006
1978	0.0071	4921	6834	0.010
1979	0.0065	1956	2911	0.010
1980	0.0123	4344	4969	0.014
1981	0.0083	6017	7559	0.010
1982	0.0231	8485	12936	0.035
1983	0.0128	6055	9677	0.020
1984	0.0187	6678	10375	0.029
1985	0.0139	5159	8314	0.022
1986	0.0061	4969	12618	0.016
1987	0.0039	2023	12330	0.024
1988	0.0030	1900	10535	0.017
1989	0.0014	1295	6607	0.007
1990	0.0006	504	12084	0.014
1991	0.0004	522	9625	0.007
1992	0.0001	545	7600	0.001
1993	0.0001	83	5811	0.006
1994	0.0001	82	4134	0.004
1995	0.0001	193	2653	0.002
1996	0.0001	127	3573	0.002
1997	0.0001	104	2789	0.002
1998	0.0001	98	4793	0.003
1999	0.0000	73	2593	0.001

[2] Source: Pålson, O.K., Buliran, A. and Banda M (1999) and the CPUE are from estimations (section 3.1). CPUE figures are rounded to their nearest.

3.1.2 Trends in the total catches

Between 1990 and 1999, artisan fish landings decreased by 78 % from 12 084 tons to only 2593 tons; an average annual fall of 10.1 %. Similarly, catch per unit effort also decreased from 0.007 unit per net set in 1991 to 0.001 unit per net set in 1999 and the decline in catches and catch rates indicates over fishing. The CPUE trends in the table suggest that the efforts were not changing in a uniform pattern over time, which can be explained by four major factors; the employment of increasingly higher effort levels; the increased use of fishing gears with reduced mesh size, which are indiscriminate in their catch; Increase in un-reported catches; and increased use of illegal catching methods like poisonous plants which affects the environmental carrying capacity. All these factors are the conditions of open access in the resource utilisation. From Figure 3.1 and Table 3.2, the relationship between the Efforts to yield shows that effort level have surpassed the maximum level. This relationship indicates that the optimal level of *Chambo* production was about 6,000 tons, with 1.09 million net sets and 14,000 tons of total catch using 1.5 million net sets.

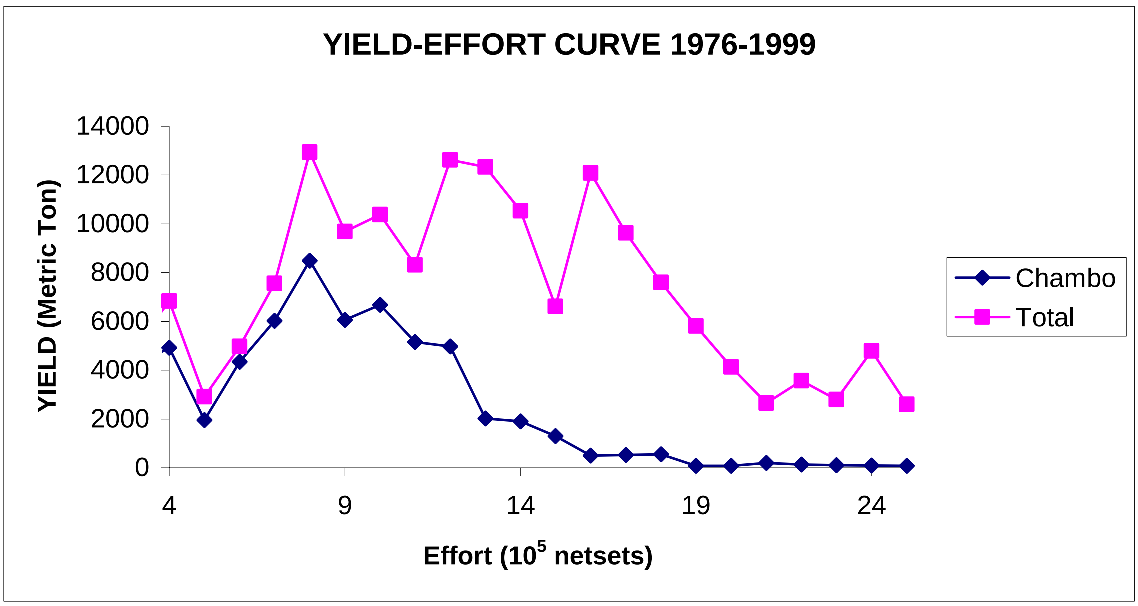

Fig. 3.1. Yield-Effort Curves in the Fishery 1976-1999

Table 3.3. Effort[3] in Gillnet units (1976-1999).

	Gillnet Effort	*Chilimila Effort*	*Kambuzi Seine Effort*	*Total Standard Effort*
1976	485016	41522	287057	813595
1977	624230	51415	87286	762931
1978	454078	197372	37585	689035
1979	189092	79696	32235	301023
1980	183084	144191	24859	352134
1981	223114	456045	41538	720697
1982	228093	96917	42539	367548
1983	203330	249264	19831	472425
1984	191371	94246	71362	356979
1985	189707	84782	96900	371389
1986	297010	425510	87348	809868
1987	158670	295827	68743	523240
1988	154553	354594	117721	626868
1989	247973	593394	102142	943509
1990	291183	461109	119358	871649
1991	826032	463486	83708	1373226
1992	952609	408893	202046	1563548
1993	443677	563005	22475	1029157
1994	426520	589674	16824	1033018
1995	649463	606058	113472	1368993
1996	436335	1797043	97322	2330700
1997	218445	1521228	43348	1783021
1998	341739	1525707	25431	1892877
1999	716077	2028784	90641	2835502

[3] Effort is measured in net set

3.2 Parameter Estimation

Parameters estimated by regressing the catch per unit effort data on the corresponding effort data (Table 3.2 and 3.3) for both Chambo and Whole fishery. As expected, the coefficients of effort were negative in all regressions on the Gordon Schaefer model. For the Fox model parameters were estimated by regressing the natural logarithms of catch per unit effort data (Table 3.2) on the corresponding effort data (Table 3.3) for both *Chambo* and Whole fishery. The estimation of the biological specifications of the GS and Fox models is provided in Table 3.4.

Table 3.4. Estimated parameters[4].

Model	Fishery	β_1 and β_3	β_2 and β_4	R^2
Gordon-Schaefer	Chambo	0.0091 (5.298)	$-3*10^{-9}$ (-2.920)	0.247
	Total Catch	0.0171 (7.265)	$-5*10^{-9}$ (-3.444)	0.321
Gompertz-Fox	Chambo	-4.916 (-9.465)	$-1*10^{6}$ (-4.450)	0.450
	Total Catch	-4.0578 (-19.547)	$-8*10^{7}$ (-5.706)	0.578

- t-values are in parenthesis and one percent level of significance was used.
- β_1 and β_2 are for G-S model and for β_3 and β_4 Gomperttz/Fox model.

[4] DATA TREATMENT

- Type of multi-species fishery is Technical with no predator prey relationships.
- Assuming all catches were from only three gears Gillnet, *Chilimila* and *Kambuzi* seine.
- *Chambo* fishery is treated independent of the whole fishery but same effort.
- Whole fishery includes *Chambo* catches using same effort.

3.3 Prices of Fish and cost of Effort

The study used MK20.15 per Kg (1998 price) as an average constant price of fish over the years. The cost of effort was found by assuming the catch and effort levels of 1998 to be Open access condition where by the Total cost (*aE*) has to be equal to Total revenue (*pH*) with zero economic rent[*] and by back calculating the unit cost of effort (1998) was found to be (a = 0.05). $P_{1998}H_{1998} = a\ E_{1998}$

$$a = P_{1998}H_{1998} / E_{1998}$$

This unit cost of effort was used constantly over the years.

Table 3.5. Growth parameters of *Chambo*

Biological Parameter	Mean (From three species)
Maximum Length (L_{max})	37 cm
K	0.345/year
a	0.018
b	2.99
Natural Mortality (m)	0.7025
Age at first maturity (tm)	2.68 years
Length at maturity (Lm)	21.58m
Life span	8.05 years

Source: Banda, M.C., (1992).

[*] Anderson (1986), defined a rent in fisheries as the difference between the total revenues obtained from the fishery and the total costs (estimated at their opportunity costs) of employing the various factors of production. Total costs include charges for replacement of assets. Therefore a rent is often considered as a "surplus" profit over and above what is considered normal. However, it would be extremely complex to design a system for the extraction of economic rent from fisheries, not least because, for most fisheries, effort must be significantly reduced before a rent is created.

CHAPTER FOUR

4 FINDINGS

Due to differences in the results obtained from the two models Gordon-Schaefer and the Gompertz/Fox Models, This chapter presents results of one-model. In this case the Gordon-Schaefer model results are the one presented. However a comparison will be made between the models on the yield levels of Maximum sustainable point and the amount of effort that takes this yield.

4.1 MSY, MEY, OAY Levels and Economic rent in *Chambo* fishery

Using the estimated parameters of the Gordon-Schaefer model in Table (3.4) and the values for the price of fish and cost of effort for *Chambo* fishery, the Maximum economic yield, Effort to attain Maximum Economic Yield, Maximum sustainable Yield, Effort to attain Maximum Sustainable Yield, Open Access Yield and Effort to attain OAY levels were computed (Table 4.1). As indicated, Maximum Sustainable Yield was at 6900 metric tons valued at MK139.035 Million and produced at the effort level of 1 516 667 net sets. When these estimated values were compared with catch and effort values in Table (3.2) and (3.3), the nearest Maximum Sustainable Yield level occurred back in the early 1980s. The Maximum Economic Yield, on the other hand, was at 6367 metric tons valued at MK 128.3 Million and produced at the effort level of 1 094 681 net sets. Comparing this with the figures in Table (3.2) and (3.3), this level was also attained back in the late 1980s. The Open Access Yield was at 5474 metric tons valued at MK110.31 Million and produced at effort level of 2 189 361 net sets. Figures in Table (3.2) indicate that this level had already occurred. The computed total revenues, total costs and economic rents using the results of the GS model provided in Table (4.1). The Maximum Economic Rent that will be generated when the *Chambo* fishery is operated at Maximum Economic Yield level is MK73.56 Million. On the other hand, if operated at Maximum Sustainable Yield, the Economic Rent is MK63.20 Million.

Table 4.1. Key indicators[5] using the Gordon-Schaefer model

Variable	*Chambo* Fishery			Whole Fishery		
	MSY	MEY	OAY	MSY	MEY	OAY
Catch (ton)	6900	6367	5474	14621	14229	7255
Effort (Mill. net set)	1.52	1.09	2.19	1.71	1.46	2.91
Revenue (Mill. MK)	139.04	128.30	110.31	294.61	286.71	146.18
Cost (Mill. MK)	75.83	54.73	110.31	85.50	72.84	146.18
Profit (Rent) (Mill. MK)	63.20	73.56	0	209.11	213.87	0

4.2 MSY, MEY, OAY Levels and Economic rent in Whole fishery

For consistency, the Gordon-Schaefer model was again used to estimate the Maximum Sustainable Yield, Maximum Economic Yield and Open Access Yield for the whole fisheries (Table 4.1). The Maximum Sustainable Yield was at 14 621 metric tons valued at MK294.61 Million and attained at effort level of 1 710 000 net sets. Compared with the catch and effort levels in Table (3.2) and (3.3), the Maximum Sustainable Yield in the whole fishery was never reached before the catches stated declining. In contrast, the Maximum Economic Yield was at 14 229 metric tons valued at MK286.71 Million and attained at the effort level of 1 456 808 net sets. Comparing with figures in Table (3.2), this level was also never reached again. The Open Access Yield was at 7254 metric tons valued at MK146.18 Million and achieved at the effort level of 2 913 617 net sets.

[5] A constant price of MK 20.15 per Kilogram Yield and a unit cost of effort 0.05 was used for Revenue , Cost and Rent calculations Refer calculations using equations in section 2.3, 2.4 and 2.5.

Compared to figures in Table (3.2) and (3.3), it appeared that the whole fishery never reached the Maximum Sustainable Yield before but it went straight into Open Access Yield. This can be because of recruitment over fishing. Table (4.1) is containing the computed total revenues, total costs and economic rents using the results of the Gordon-Schaefer model. If operated at Maximum Economic Yield, the Maximum Economic Rent that can be derived from the whole fisheries is about MK213.88 Million per year. If operation is at Maximum sustainable Yield, the Economic Rent is MK209.11 Million.

CHAPTER FIVE

5 DISCUSSION

5.1 Comparing G-S and Gompertz/Fox Maximum Sustainable point

In the estimation of Maximum sustainable yield and its effort levels equation (9) and (10) were used respectively for the Gordon and Schaefer (G-S) model and equations (11) and (12) respectively for Gompertz/Fox model. The Maximum Sustainable Yield and Effort at Maximum Sustainable Yield from the two models are different. For *Chambo* Fishery the Gompertz/Fox model estimated the Maximum Sustainable Yield level of 2696 tons, at an effort level of 1 000 020 net sets. And the Gordon-Schaefer's Maximum Sustainable Yield level is much higher 6900 tons at an effort level of 1 516 667 net sets (Fig. 5.1).

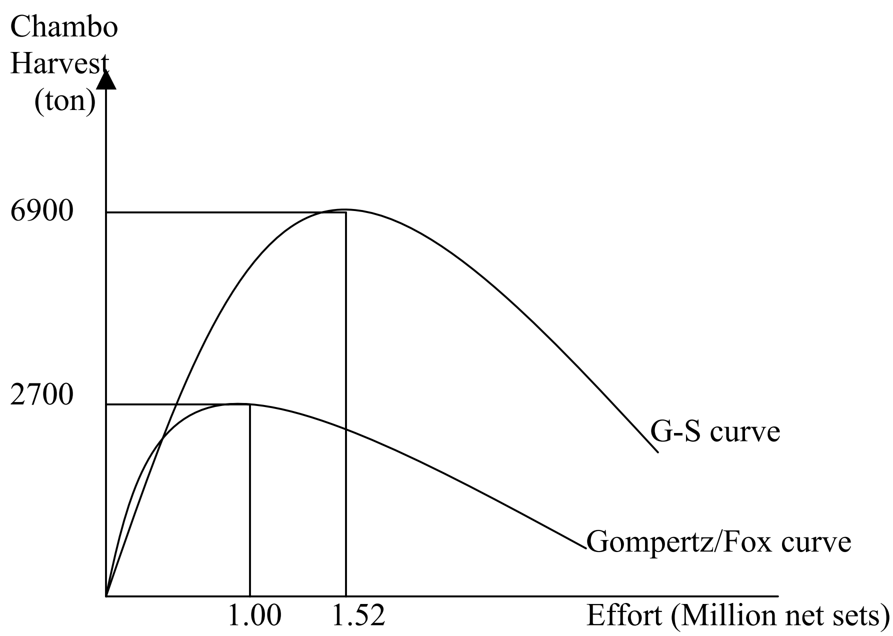

Fig. 5.1. Yield Effort Curves of G-S and Gompertz/Fox Models on *Chambo* Fishery.

For the whole fishery, the Gompertz/Fox model estimated a Maximum sustainable Yield of 7950 tons at an effort level of 1 250 000 net sets and the Gordon-Schaefer's estimate was 14 621 (almost double that of Gompertz/Fox yield), to be taken at an effort level of 1 710 000 net sets (Fig. 5.2).

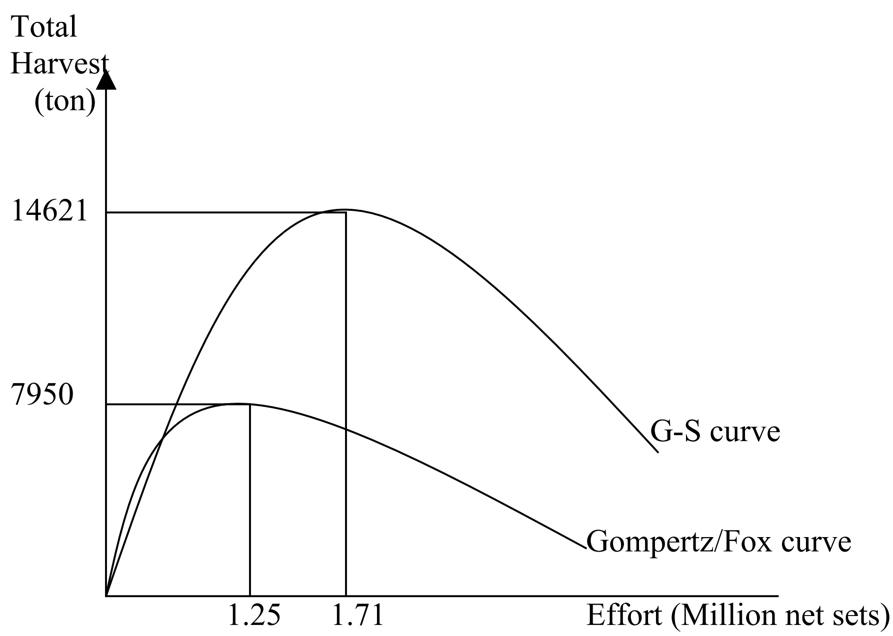

Fig. 5.2. Yield Effort Curves of G-S and Gompertz/Fox Models on Whole Fishery.

On the two models it is rather difficult to suggest one that has closer or reliable estimates to obtain a sustained yield. However according to the work of Eide (1995) using the parameters of individual growth and mortality models as those shown in figure 3.5. (*chambo* growth parameters) and a long term equilibrium model based on the Pella and Tomlinson model (Eide,1995). It can be estimated that the natural mortality (m) of *Chambo* is equal to 0.89732, and since the Gordon-Schaefer model assumes a natural mortality (m=2) of 2, which is about twice that of *Chambo* it can be regarded to overestimate a sustained yield. On the other hand the Gompertz/Fox model assumes the natural mortality (m=1) of 1, and this is closer to that of *Chambo* hence it can be argued that the Gompertz/fox model is offering closer estimates of sustained yield in the fishery.

5.2 Is There *Chambo* over-exploitation?

Overexploitation of fish stock can be estimated from detailed scientific data on stock levels, regeneration and catch. However, this sort of information is not always available and less costly methods such as observing certain indicators like catch size over time, changes in the relative share of juveniles over-time, catch per unit effort, price changes, or changes in market supplies, changes in the percentage composition of species over time in total catch etc is used. For example if there is a tendency to catch more juvenile fish this is an indication that there is over fishing. A declining CPUE also indicates over fishing. A rise in the price of catch or declining market supplies suggests that the resource is becoming scarce. However, no single indicator can suffice to provide the needed information as each of the indicators has its own shortcomings. For example where we have market imperfections or controlled prices, an increase in price does not necessarily imply that resources are getting scarce. Therefore combinations of all or at least some of these are important to reach at a reasonable conclusion.

According to the above-mentioned indicators, it is evident that there is overexploitation of *Chambo*. The findings of this study shows that economically the fishery has been exploited but this has come not as a result of economic factors i.e. increase in the fish prices on the market or the decrease in cost of effort, rather it is due to the excessive fishing of juvenile *Chambo* (ages 0 and 1). The study was conducted using three types of gear; Gillnet that targets *Chambo* and the other two gears *Chilimila* and *Kambuzi* seine, which do target smaller cichlids but at the same time do have a by-catch of *Chambo*, which is profitable than target species. *Chilimila* and *Kambuzi* seine has a small mesh size and are capable of catching 10cm-sized *Chambo*, which is almost half the length at maturity (Lm = 22cm) (Table 3.5). In addition to *Chilimila* and *Kambuzi* seine there are other fishing gears like *Nkacha* nets that do sweep everything on their way, these gears have resulted in the recruitment failure in the *Chambo* fishery. Pålson et.al (1999) described the exploitation case of fish in Lake Malombe and the fate of the *Chambo* as a Malthusian over fishing because there is an increase in socio-economic pressure, due to rapid increase in poverty and population, along side decrease in the natural resources.

This can be referred as Malthusian trap, which has resulted in the situation difficult to reverse

5.3 Sustainability and Efficient Issues

To establish the ecological sustainability of current fish harvesting practices, an estimate of the maximum sustainable yield was made and compared with the actual catches. Basing on this the decision criterion was that if the level of effort (net sets or hauls) and the total catch exceeded the Maximum Sustainable Yield level then the fishing activities would be regarded as unsustainable. Basing on equation (10), we found that the maximum sustainable level of net sets in the *Chambo* fishery was 1.52 million net sets and 1.71 million net sets for the whole fishery. This level when compared with the recorded number of net sets suggests that the *Chambo* fishery sustained excess capacity of net sets from 1976 to 1980 with rather a corresponding decrease in reported catches, there after the effort declined with fluctuating trends, where as for the whole fishery the trend shows that the fishery was able to sustain this level of net sets up to 1993 (Fig 3.1). Substituting this figure, into the models, we observed that the corresponding maximum sustainable yield was 6 900 tones of *Chambo* and 14 621 tones of fish for the whole fishery (Table 4.1). When compared with the actual catch of *Chambo* only one year out of 24 years recorded catches over Maximum Sustainable Yield . This is rather the opposite of what the other signs of over fishing are showing in the fishery, this can be as a result of having a lot of unreported catches and also the increased catch of fish that is small in size, and weight as the measurement of biomass does not making sense. The catch trend started to have a drastic decline below a thousand ton from 1990 suggesting the depletion of the species.

On the model results of the whole fishery the corresponding catch of effort at Maximum Sustainable Yield is 14 229 tons. According to the effort recorded we found that the whole fishery sustained excess capacity of net sets for about 11 years out of 24 years, that's almost half of the period. On the basis of the criterion stated earlier that the current fishing is not sustainable. Thus there is a need to institute appropriate measures. As shown in the yield-effort curve (Fig 3.1) if we can assume the curves to be normally distributed, then for the yield to be zero, meaning for the resource to be drawn into extinction, effort has to be increased twice of its maximum level.

$E_{extinction} = 2 * E_{MSY}$. Therefore *Chambo* Fishery Extinction = 2 * E_{MSY}= 2 * 1 516 667 = 3 033 334 net sets and Whole Fishery Extinction = 2 * E_{MSY} = 2 * 1 710 000 = 3 420 000 net sets. This implies that if the number of effort is left to grow to as high as 3.03 million net sets, *Chambo* specie would be drawn to extinction and the whole fishery will not be in existence with the effort level of 3.42 million net sets. These levels of extinction are in line with the Gordon-Schaefer model because for the Gompertz/Fox model it does not consider complete extinction of the resource, what it believes in is that the curve will move asymptotically (Fox, 1970).

5.4 Maximum Economic Yield (MEY)

From an economic perspective, effort relative to the Maximum Sustainable Yield point is not the relevant issue. We are interested in the resource rent. As long as the cost per unit of fishing effort is positive, a fishery harvested at the Maximum Sustainable Yield level is economically over fished. Resources rent is maximised at lower level of effort, the Maximum Economic Yield level. The Maximum Economic Yield point however, depends on prices and costs and therefore is not constant overtime. It will vary as the price of catch and inputs change and high price of effort will reduce the amount of efforts.

The Maximum Economic Yield level of *Chambo* catch and its corresponding effort calculated is 6 367 tons and 1.09 million net sets respectively and for the whole fishery, the catch and corresponding effort level was 14 229 tons and 1.46 million net sets respectively. Table 3.1 shows slight under fishing before 1987 and over fishing after that as the level of effort is increasing the yield in weight is drastically declining. This can be explained due to the effort pressure that is exerted in small fish, which does not contribute a lot in terms of total weight in yield, but individual or number of fish catches

5.5 Required Reduction of Fishing Effort

Based on the results, fishing effort needs to be reduced from the 1999 level of 2.84 million net sets (Table 4.1). In percentage terms, effort in the *Chambo* fishery will have to be reduced by about 159 percent to arrive at Maximum Economic Yield on the other hand to attain the Maximum Sustainable Yield, it has to be lowered by approximately 87 percent. To attain efficient levels, the fishing effort in the whole fishery has to be lowered from this level by 95 % Percent to attain the Maximum Economic Yield, and by 66 percent to attain Maximum Sustainable Yield.

5.6 Profit Maximisation under Controlled Access

If we reveal the nature of the profit-maximising solution, which might be achieved under a regime, which is capable of determining at will the exact rate of harvesting, it is often imagined that this must coincide with the maximum sustainable yield. However, there are economic arguments, which suggest that a quite different rate might materialise (Wilen, 1985). For a start, the costs of fishing have to be considered. These are liable to rise as the fish stock fall for the reason that, when their density is reduced, the fish are liable to be harder to locate and catch. This suggests that a lowering of catches might be desirable in order to increase the density of the fish and to lower the costs of fishing, even at the expense of foregoing some revenue from sales. On the other hand, a strong preference for immediate profits at the expense of future ones might encourage an unsustainable rate of extraction leading to the extinction of the stocks.

Fishing has, for centuries been conducted within the organisational framework of common property, free enterprise and competition (Swanson, 1983). This framework ignores the biological and economic laws of the fishing activity and leads to biologically excessive exploitation and economically inferior results. This situation has to fundamentally be changed, the fishing industry, as a whole has to adapt to new circumstances and adopt exploitation practices based on rational analysis and the long-term view. Governments, in shaping exploitation strategies, have to give priority to solutions that facilitate the transformation of the industry mentality from the short-term catches to long-term sustainable harvest levels. For this to be feasible, it is crucial to form a link between the vested interests of the fishing industry or communities and the socially most beneficial sustainable exploitation of the resources. One obvious way to do this is to allocate property rights of sufficiently high quality (e.g. security of title, duration, exclusivity and transferability) to individual fishermen or fishing communities. As indicated by Clark and Conrad (1987), the overriding goal of fisheries and the exploitation of resources in general must be the generation of net economic long-term benefits. Any deviation from this objective makes society as a whole worse off and is therefore difficult to justify. An increased emphasis should be placed on research in the area of the economics of fisheries, and in particular on the design of management systems conducive to the maximisation of net economic long-term benefits from the fishing activity.

5.7 Conclusion

There are a number of underlying factors resulting in overexploitation on the fishery of Lake Malombe. They can be broadly classified as being results of high rates of population growth; poverty exacerbated by dwindling resources from unsustainable exploitation of fisheries, agricultural land and forests, often as a result of the common property, open access nature of the resource; poverty exacerbated as a result of resource degradation from unsustainable development and pollution; lack of employment opportunities and/or socio-economic opportunities to avoid resource overexploitation; lack of awareness about sustainable resource management amongst stakeholders and policy-makers; lack of a cohesive, inter-departmental government approach to management and development of resources within the zones.

Economic models and the models of population growth may be used in the management of renewable resources such as in the regulation of fisheries. Here the objective is to achieve an optimal rate of extraction, which allows the fish populations to regenerate themselves rapidly in spite of their losses. This is not simply a matter of ensuring that fishing does not lead to the extinction of fish populations. Even when it does not threaten the survival of the fish, over fishing will certainly cause wasted effort. Unfortunately, it is true that, in practice, we do have to guard against the danger of extinction through over-intensive fishing in which the effort devoted to the pursuit goes far beyond optimal levels and is, therefore, largely self- frustrating. The problem, which is widely acknowledged, arises when there is open access to the fish stocks. Whilst it may be in the common interest of all the exploiters to reduce the intensity of fishing, it will not be in the interest of any individual to do so if the only consequence is to allow a competitor to take a greater share of the meagre supplies.

To fish invariably at the maximum sustainable rate would, of course, be very perilous. If ever the population should fail to regenerate itself fully, or if the maximum rate of extraction were exceeded momentarily, then the population would be driven to extinction. However, disaster might be averted if an ever-increasing effort were required in order to sustain the maximum rate of extraction in the face of a declining fish stock. For the effort might become uneconomic before the fish were imperilled by extinction. In effect, the maximum sustainable rate of extraction represents an unstable equilibrium. The same problem of instability arises in the case of over fishing where a harvest is being extracted from a population. It can be seen from the results that, if the yield falls below 6 900 ton for *Chambo* stocks and 14 621 for the whole fishery, then the rate at which the population regenerates itself will fall below the rate of extraction, and therefore the stocks will head for extinction. The conclusion is that a stable equilibrium can only be reached if the rate of extraction is less than the maximum rate.

According to the current rate of extraction in Lake Malombe, there is an obvious indication that the fish species in the lake cannot regenerate itself because it is far away below the Maximum sustainable yield. Mainly some fishing gear used in the Lake poses a threat to the fish resource, by catching juvenile fish and destroying the habitat due to the dragging force (Hara, 1996). The sustainable harvesting of resources in general requires that the catch rate should not exceed the growth rate of fish. This is known as Maximum Sustainable Yield (MSY), which is the biological optimum. Beyond such a point harvesting is unsustainable, because then over fishing occurs (Dasgupta and Heal, 1979). Another aspect is that of maximising the economic rent by attaining the economic equilibrium, referred to as the Maximum Economic Yield (MEY). According to the findings of this study, it is a requirement that this fishery should be on an intensive Management from the interested stakeholders with strong emphasis in enforcement of the existing regulations.

5.8 Summary and Policy Implications

The objective of this study was to empirically analyse the over-exploitation of Lake Malombe fishery. It was deemed important to undertake this study for the purpose of investigating the applicability of some fishing models in a small-scale fishery. Based on the findings some policy implications and recommendations are made. The study observed some of the environmental problems, these are for example; the use of crude gears such as small mesh size nets which catch mostly juveniles and hence reduce the future stocks, lack of enforcement on existing legislation i.e. banning the use of small meshed size nets, due to lack of alternative sources of subsistence, marginal population particularly among the youths have been pushed into the fisheries sector as last resort resulting into the over-capitalisation of the fishing sector and hence over-exploitation of the resources, pollution of fishery resources from land based activities; also there is an increasing destruction of spawning areas, which serves as feeding, and nursery areas for *Chambo*, and other fish species leading to reduction of the stock (Njaya, 1998).

According to the Fisheries Officers and some fishermen interviewed agreed that the increase in the number of fishermen was a problem as far as fish availability was concerned. Since it has been found that exploitation has already reached and surpassed the maximum sustainable level. In view of this, there is need to undertake regulatory measures to preserve the species, a need to reallocate resources from the existing open access situation to a controlled system designed to maximise the net value of production. Policies that recognise and incorporate indigenous communities will most likely be successful if sufficient authority and power are delegated to the local level. Empowering the communities to instil them with direct responsibility in managing and protecting the resources.

A policy to simply lower effort will likely be more politically difficult to implement in this fishery, because fishing is largely subsistence in nature and a matter of survival and livelihood for fishermen. Therefore forcing them out of their livelihood without an acceptable alternative form of employment is not a health thing to be done by policy makers. It is only through the explicit provision of alternative livelihood opportunities that fishermen can be made to leave the fishery. To affect this, small-scale livelihood programs must be promoted around the Lake areas by government agencies in cooperation with non-government organizations to help effect reduction of excessive fishing effort. The promotion of resource and environmental education in fishing communities is the main means of reducing fishing effort. As fishermen become aware of the dangers that over fishing poses to their welfare, the more likely they will practice sustainable fishing activities. The growing number of education and awareness projects in fisheries is a big step in the right direction and must be continuously supported by the government.

Finally, it should be remembered that fishermen bring about over fishing not only by increased fishing effort but also by the employment of destructive gears and techniques. Hence, to help conserve fisheries resources, the effective enforcement of the fishery laws, rules and regulations related to destructive gears must be pursued. Equally important is the need to educate local communities on the effects of resource destruction and the benefit from well managed aquatic resources. Once aware of such benefits, communities will move to adopt conservation methods and to ensure that other communities and groups adopt regulations as well. In this regard the idea of community based conservation, for example, the co-management arrangements that have been established around the lake since 1990 (Donda, 1995) and the formation of Beach Village Committees (BVCs) are cases of promising approach. A great emphasis should be placed on involving local communities in research, education, and training programs. Local people and their indigenous knowledge of fish resources should be integrated into the management system and be utilised in designing management plan. With this therefore, regulations for conservation measures need to be imposed mainly for two reasons; to preserve the fish stock from destruction and depletion and to protect the economic position of the fishing community.

In the implementation of the regulatory measures there is a need to consider that policies and strategies should be flexible enough to allow proper reaction to changes in economic and biological conditions, a need to involve the participation and support of the local communities, which ensures minimum resistance by fishers. In addition to these, there is a need to monitor the data on catches, effort types and their target species, which are needed for a proper and viable management.

6 References:

Alverson D.L. and K. Dunlop., (1998). Status of world marine fish stocks. University of Washington School of Fisheries, United States.

Anderson, L.G., (1986). The Economics of Fisheries Mangement second Edition, John Hopkins University, Baltimore, USA

Arnason, R., (1990). Minimum Information Management in Fisheries. Canadian Journal of Economics 23, pp. 630-653.

Arnason, R., (1994). Theoretical and Practical Fishery Management. In E.A. Loyayza (ed.) Managing Fishery Resources, World Bank Discussion Papers 217.

Banda, M.C., (1992). Age and growth parameters of chambo (Oreochromis spp.) in the southeast arm of of Lake Malawi, as determined from opercular bones. FAO FI/DP/MLW/86/013 Field Doc. 20, 31 p.

Berkes, F., Mahon, R., McConney, P., Pollnac, R. and Pomeroy, R., (2001) Managing Small-scale Fisheries Alternative Directions and Methods, IDRC; Canada.

Bell F. W., (1970). Estimation of the economic benefits to fishermen, vessels, and society from Limited Entry to the Insure US. Lobster Fisheries. Working paper.

Bulirani A., Pålsson, O.K., Banda M.C., Weyl O.L.F., Kanyerere G.Z., Manase M.M., and Sipawe R.D., (1999). Fish Stocks and Fisheries of Malawian waters: resource Report. Government of Malawi, Fisheries Department, Fisheries Resource Unit. 54pp.

Clark, C. W., (1990). The Optimal Management of Renewable Resources. Second Edition. John Wiley & Sons, New York.

Clark, C., (1976). Mathematical Bioeconomics: The Optimal Management of Renewable Resources. John Wiley, New York, USA.

Clark, C., (1973). Profit Maximisation and the Extinction of Animal Species. Journal of Political Economy 81(4): 950-61.

Clark C.W., (1985). Bioeconomic Modelling and Fisheries Management. John Wiley and Sons: New York

Chirwa, W.C., (1997). The Lake Malombe and Upper Shire River Fisheries Co-management Programme: An assessment. In Norman, A.K., Nielsen, J.R., and

Sven-Jensen, S. Fisheries Co-management in Africa. Proceedings from a regional Workshop on Fisheries Co-management Research, 18-20 March 1997, Mangochi, Malawi.

Conrad, J. and Clark, C., (1987). Natural Resource Economics. Cambridge University Press, Cambridge, UK.

Cunningham, S., M.R. Dunn and D. Whitmarsh .,(1985). Fisheries Economics: An Introduction. Mansell Publishing Ltd., London.

Dalzell, P., P. Corpuz, R. Ganaden and D. Pauly., (1987). Estimation of Sustainable Yield and Maximum Economic Rent from the Philippine Small Pelagic Fisheries. ICLARM Technical Paper Series, Vol. 10, Number 3.

Dasgupta, P. and Heal, G. (1979)., Economic Theory and Exhaustible Resources. Cambridge University Press, Cambridge, UK.

Donda, S.J., (1995). Development of Fisheries co-management in Malawi. Fisheries co-management in Lake Malombe, Malawi, paper presented at the ICLARM, North Sea Centre, NARS Collaborative Research Project workshop, 29-31 May, 1995, Hirtshals, Denmark. Fisheries.

Donda, S.J., Njaya, F.J., and Hara, M., (1999). Comparative study of Fisheries co-management in Lakes Malombe and Chiuta, Malawi, paper presented during the international Conference on Fisheries Co-management Project 23-28 August, 1999, penang, Malaysia.

Eide, A., (1995). The Lobster Fisheries on the Continental Shelf of Cape Verde. An Introduction to a Bioeconomic study. Norwegian College of Fisheries Science, University of Tromsø, Tromsø, Norway.

FAO., (1997). Review of the state of world fishery resources: marine fisheries. FAO Fisheries Circular No. 920. Rome. 173 pp.

FAO., (1996). Chronicles of marine fishery landings (1950-1994). Trend analysis and fisheries potential, by R. Grainger and S.M. Garcia. FAO Fisheries Technical Paper No. 359. Rome. 51 pp.

FAO., (1999). Review of the State of World Fishery Resources: Marine Fisheries. Food and Agriculture Organization of the United Nations, Rome.

FAO., (1997). Fisheries Report on African countries.

Fox W.W., (1970). An exponetial Surplus-Yield for Optimising Exploited Fish Populations. Trans American Fishery Society. 99:80-88

Garcia, S.M and D. Staples., (2000). Sustainability reference systems and indicators for responsible marine capture fisheries: a review of concepts and elements for a set of guidelines. Marine and Freshwater Research.

Garcia, S.M. ,(1994). The precautionary principle: its implications in capture fisheries management. Ocean and Coastal Management, 22: 99-125.

GOPA, (1987)., Malawi fisheries development study. GOPA, Bad Homberg, Federal Republic of Germany.

Gordon, H.S., (1954). The economic theory of a common-property resource: the fishery. Journal of Political Economy 62:124-42.

Gordon, H., (1953). The Economic Theory of Common Property Resource: The Fishery. Journal of Political Economy. Vol. 62, pp. 124-142.

Gordon, H and Scott A., (1964) The economics theory of a Common Property Resources". The Fishery: JPE 62 April: 124- 42.

Henderson J.V and Tugwell M., (1979), Exploitation of the lobster fisheries: Some empirical results. In Tinterberg, T., Environmental and Natural Resources Economics Fourth Ed, (1996), Colby College. Harper Collins College Publishers.

Hanneson, R., (1983). Bioeconomic Production Function in Fisheries: Theoretical and Empirical Analysis. Journal of Fisheries and Aquatic Sciences, 40 968-982.

Hara, M., (1996). Problems of introducing community participation in fisheries management. Lesson from the Lake Malombe and Upper Shire (Malawi) participatory fisheries management programme. Pp 41

Hara, Mafaniso, (1999). southern African Perspectives No. 77. Fisheries comanagement : a review of the theoretical basis and assumptions. Pp 1-2.

Hardin, G., (1968). The Tragedy of the commons. Science, pp 1243-1248 ICLARM, 1991: The Context of Small-scale Intergrated Agriculture – Aquaculture Systems in Africa: A case study of Malawi.

ICES. (1995). ICES Code of Practice on the Introductions and Transfers of Marine Organisms - 1994. ICES Cooperative Research Report No. 204.

ICLARM and GTZ. (1991). The Context of Small-Scale Intergrated Agriculture-Aquaculture Systems in Africa: A case study of Malawi. ICLARM stud.Rev.18,302p, Manila phillipines.

Israel, D. C. and C. P. Banzon, (1996). Overfishing in the Philippine Marine Fisheries Sector: A Disaggregated Analysis. Economy and Environment Program for Southeast Asia. Final Report.

Kureya T., (1998). Report on Regional Economic Significance of Fishing in the Zambezi Basin.

Mkoko B.J. et. a.,l (1997). Report on Status of and Prospects for participatory fisheries management programmes in Malawi.

Njaya, F., (1998). The development of fisheries co-management programmes in Malawi: a comparative case study for Lakes Malombe, Chilwa and Chiuta. In Eide, A and T. Vassdal, (eds), IIFET 1998 proceedings, 1, 260.

Nyambose J., (1997), Report on Preserving the Future of Lake Malawi.

OECD., (1997). Towards Sustainable Fisheries: Economic Aspects of the Management of Living Marine Resources. Organization of Economic Co-operation and Development, Paris

OECD., (1997b). Towards Sustainable Fisheries: Economic Aspects of the Management of Living Marine Resources: Issue Papers. Organization of Economic Co-operation and Development, Paris.

Pålsson, O.K., Banda M.C., Bulirani A., (1999). A Review of Biology, Fisheries and Population Dynamics of Chambo (Oreochromis spp. Cichlidae) in Lake Malawi and Malombe. Government of Malawi, fisheries Bulletin No.38

Panayotou, T.F. and S. Jetanavanich .,(1987). The Economics and Management of Thai Marine Fisheries. ICLARM Studies and Reviews 14. Manila.

Razack, B.L., (Undated). An Economic Analysis to Sustainable Fisheries Management. Unit of Environmental Economics, Göteborgs Univeersitet, Sweden.

Schaefer, M.B (1954). Some aspects of the dynamics of the Dynamics of populations Important to the Management of Commercial marine fisheries. Bulletin of International American Tropical Tuna Commission 1:25-56

Scott, A.D. (1988). Development of Property in the Fishery. Marine Resource Economics 5, pp. 289-311.

Solow, R. (1974). The Economics of Resources or the Resources of Economics. American Economic Review 64.

Swanson, T. (1993). The Economics of Extinction Revisited and Revised. Oxford Economic Papers.

Swanson, T. (1993). The International Regulation of Extinction. MacMillan, London, UK.

Tinterberg, T., (1996). "Environmental and Natural Resource Economics" Fourth Edition, Colby College. Harper Collins College Publishers.

Tweddle, D., Alimoso, S.B., and Sodzapanja G. (1994). Analysis of Catch and Effort Data for the Fisheries of Lake Malombe, 1976-1989. Government of Malawi, Fisheries Bulletin No. 11.

Weyl O.L.F., Banda M.C., Manase M.M., Namoto W. and Mwenikombe L.H (2001). Analysis of Catch and Effort Data for the Fisheries of Souoth West arm of Lake Malawi 1976-1999. Government of Malawi, fisheries Bulletin No.46

Weyl, O.L.F., (1999a). Lake Malombe Artisanal Fishery Catch Assesment 1994-1998. NARMAP Technical Report No.1.23pp.

Wilen, J.E (1976). Common Property resources and the Dynamics of Overexploitation, PNRE paper no. 3. University of British Columbia'