academicJournals

Vol. 5(11), pp. 270-277, November, 2013
DOI: 10.5897/IJFA2013.0377
ISSN 1991-637X ©2013 Academic Journals
http://www.academicjournals.org/IJFA

International Journal of Fisheries and Aquaculture

Full Length Research Paper

Wealth based fisheries management of chambo (*Oreochromis* spp.) fish stock of Lake Malombe in Malawi

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Accepted 16 September, 2013

A study to establish bioeconomic options for economic exploitation of Chambo (Oreochromis spp.) 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 in the analysis. Primary qualitative and quantitative data from fishers and consumers were collected using a pretested semi structured questionnaire. Time series data from 1976 to 2011 was generated from the Traditional Fishery Data Base at Fisheries Research Station. The logistic regression analysis showed that the goodness of fit Hosmer and Lemeshow test yielded c2 (8) of 6.924 and was insignificant at 0.05 (P = 0.214). The -2 Log Likelihood showed that the model fitted the data at an acceptable level (P = 0.001). Six predictor variables (stratum, marital status, literacy, years in fishing and daily working hours) were significant. Autoregressive Integrated Moving Average model (0, 1, 1) was selected. From the selected model, at the current exploitation rate it was forecasted that Chambo catches would decline to -1,111.80 tons in 2021 from 4,118 tons in 1976. From the Gordon Schaefer dynamic model, it is estimated that the economic rent at maximum economic yield, is MK2.148 million as compared to MK1.533 million at maximum sustainable yield. The Gordon Schaefer bioeconomic model showed that high economic rents are associated with maximum economic yield than maximum sustainable yield. Based on the bioeconomic analysis, it is recommended that Chambo fisheries be managed at maximum economic yield, which implies reducing the current fishing effort.

Key words: Logistic model, Lake Malombe, forecasting, bioeconomics, economic rent.

INTRODUCTION

Malaŵi ranks among the world's most densely populated and least developed countries. The fishing sector is important to both Malaŵi's economy and its overall food security, providing 300,000 to 450,000 jobs and 4% of GDP (FAO, 2008). However, most natural fish stocks in Malawi are either fully or over exploited. Coupled with the highest population growth rate in Southern Africa of 2.8% annually (NSO, 2008), this has reduced per capita consumption of fish in Malaŵi from 14 kg per person per year in the 1970s, to less than 4 kg by 2008 (Jamu and Chimatiro, 2005; FAO, 2008). These declining trends in fish catches and per capita availability of fish are reflected across Africa (Brummett et al., 2008). Additionally, Malaŵian 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 tons in 1984 to 7,000 tons in 2001 (NASP, 2004).

Prior to 1993, the Fisheries Management approach in Malawi has mainly been influenced by the principles of the conservation paradigm, that is, a biologically

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centralized led approach (Matiya and Wakabayashi, 2005). As a result one of its sectoral policy objectives is to maximize the sustainable yield from fish stocks that can economically be exploited from natural waters. The conceptual approach is 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 others on both theoretical and practical reasons. Estimation problems arise due to poor assumptions in some models and lack of reliability of the data (Bousquet et al., 2008). As a management goal, the static interpretation of MSY is generally not appropriate because it ignores the fact that fish populations undergo natural fluctuations 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 Lake Malombe case where Chambo catches have decline from 4118 tonnes in 1976 to 240 tonnes in 2012.

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 (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.

Faced with the widespread failure of the conventional fishery management systems either to deliver sustainable economic benefits or conserve the resource base, alternative approaches are urgently needed for Lake Malombe fishery (Cunningham et al., 2009). There is much to be said for the approach that argues that successful management requires the incentives of fishers to be aligned with those of managers (Hilborn and Walters 2005). From a practical perspective, the study suggests that bioeconomic management could be the best way to approach the problems currently facing the Lake Malombe fisheries. Economy is one of the conditioning factors of fishing activity. Thus the research was conducted to establish bioeconomic options for economic exploitation of Chambo (*Oreochromis* spp.) fish stocks of Lake Malombe.

METHODOLOGY

Study area

The study was conducted in Lake Malombe which is about 450 km^2 and located on the floor of the rift valley just to the south of the much larger Lake Malaŵi. The lake lies between latitude 14°21' to 14°45' south and longitude 35°10; to 35°20' east in the southern district of Mangochi (DoF, 2004).

Sampling and data collection

To assess factors that influence fisheries resource users' intertemporal preferences, the survey was conducted in two major strata, namely; Lake Malombe West and Lake Malombe East. The sites were considered because of the wide use of Gill net and Nkacha net which are the main target gears of Chambo in Lake Malombe. The survey administered a pretested structured questionnaire to two hundred and fifteen (215) sampled fishers (gear owners and crew members) and consumers in the two major strata. For bioeconomic and time series analysis, the study collected quantitative secondary data for Chambo (*Oreochromis species*) on catch, effort, beach price and cost of fishing for Lake Malombe from 1976 to 2011. The data was collected from Government of Malawi, Department of Fisheries Research Unit at Monkey-Bay. The data were obtained from a computer based programme called Traditional Fishery Data Base (TFDB) which is used by the Department of Fisheries for storing fisheries data.

Data analysis

Logistic regression model

The binary logistic model was used to examine factors that influence people's intertemporal preference in fisheries resource utilization. Logistic regression 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, twelve predictor variables that were either numerical or categorical were used in the analysis according to Hilbe (2009). The model was simplified according to Matiya and Wakabayashi (2005) as in Equation 1;

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

Where Y = To have a negative intertemporal preference, β_0 is the intercept and β_1, β_2, β_3,…, β_{13}, 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

ARIMA modelling

The Box-Jenkins ARIMA approach was used to model and forecast Chambo stock catches from the period of 2011 to 2021. 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). 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 in Equation (2) was used.

$$Y_t = \sum_{i=1}^{p} \phi_i Y_{t-i} + \sum_{j=1}^{q} \theta_j e_{t-j} + \varepsilon_t \quad (2)$$

Where Y_t is the observation at time t, ϕ and θ are coefficients and ε is an error term.

Biomass dynamic model parameter estimation

Schnute (1977) model approach was used in estimating the parameters of the biomass dynamic model (Gordon Schaefer model). The parameters r, q, and K were estimated using a regression equation shown in Equation (3) without making the equilibrium assumption.

$$\ln\left(\frac{U_t}{U_{t-1}}\right) = r - q\left(\frac{E_{t-1}+E_t}{2}\right) - \frac{r}{qK}\left(\frac{U_{t-1}+U_t}{2}\right) + \varepsilon \quad (3)$$

Where 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 study adopted the Schnute (1977) 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). 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.

Estimation of reference points

The analytical expressions of maximum economic yield (MEY) and the maximum sustainable yield (MSY) in terms of biological parameters along with economic variables were derived. These reference points were estimated for the future management policies of a fishery and sustainable development of Lake Malombe.

Maximum Sustainable Yield (MSY) effort and catch were obtained by Equations (4) and (5) respectively.

$$F_{msy} = \frac{r}{2q} \quad (4)$$

$$Y_{msy} = \frac{rK}{4} \quad (5)$$

Where r is the intrinsic growth rate, K is the carrying capacity and q is the catchability coefficient.

The Maximum Economic Yield (MEY) effort and catch were obtained by Equations (6) and (7) respectively. 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.

$$f_{MEY} = \frac{r}{2q}\left(1 - \frac{c}{pqk}\right) \quad (6)$$

$$Y_{MEY} = \frac{r}{4}\left(k - \frac{C^2}{p^2q^2k}\right) \quad (7)$$

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. The present value of a flow of benefits and costs through time was expressed according to Seijo et al. (1998) as:

$$PV_{\pi} = \frac{TR(t)-TC(t)}{(1+i)^t} = \frac{\pi(t)}{(1+i)^t} \quad (8)$$

Where PV_{π} is the present value profit and i is the social rate of discount TR is the total revenue, TC is the total cost.

Estimation of net present value

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

$$PV_{\pi} = \frac{P_1}{(1+i)^1} + \frac{P_2}{(1+i)^2} + \frac{P_3}{(1+i)^3} \ldots + \frac{P_{10}}{(1+i)^{10}} \quad (9)$$

Where P is the present value for year 1 to year 10.

RESULTS

The intertemporal preference analysis

The logistic regression coefficients for the determinants of intertemporal preference of fishers and consumers are contained in Table 1. The goodness of fit Hosmer and Lemeshow (H-L) test yielded χ^2 (8) 6.924 and was insignificant (P = 0.214), suggesting that the model fitted to the data well. The -2 Log Likelihood shows that the model fitted the data at an acceptable level (P = 0.001). Accuracy of prediction, overall percent corrected was 74.9% indicating that more of the variation was explained by the model. Since the purpose of the model was to identify main factors that influence people's intertemporal preference, the model was appropriate for the purpose, considering its goodness of fit and high predictive ability.

The results in Table 1 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) were significant ($p < 0.05$), implying that they are important factors that influence people's intertemporal preference in fisheries resource use. Out of the five significant predictor variables three had positive significant coefficient (stratum (X_1), Literacy (X_9), and years in fishing (X_{11}). 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:

$$\text{Logit}(Y) = 0.038 + 1.924X_1 + (-1.409\,X_5) + 1.055X_9 + 0.054X_{11} + (-.159X_{12}). \quad (10)$$

Estimates of ARIMA model

The preliminary analysis for examining stationarity of the data was conducted by considering the time series plots

Table 1. Logistic regression coefficients of the socio-economic factors.

Predictor variable	X_i	Coefficient	S.E. of coefficient	Wald statistics	P Value
Constant		0.038	1.043	0.001	0.971
Stratum	X_1	1.924	0.399	23.216	0.000*
Category of respondent	X_2	-0.162	0.421	0.148	0.700
Age	X_3	0.431	0.382	1.274	0.259
Sex	X_4	-1.061	0.822	1.667	0.197
Marital status	X_5	-1.409	0.422	11.166	0.001*
Household size	X_6	0.062	0.069	0.807	0.369
Religion	X_7	0.518	1.357	0.146	0.703
Tribe	X_8	0.394	1.239	0.101	0.751
Literacy	X_9	1.055	0.420	6.308	0.012*
Period stayed in area	X_{10}	-0.154	0.406	0.144	0.704
Years of fishing	X_{11}	0.054	0.027	4.077	0.043*
Daily working time	X_{12}	-0.159	0.058	7.540	0.006*

*Significance at 0.05 probability level; Goodness of fit Hosmer and Lemeshow (H-L) χ^2 = 10.789; df = 8; P = 0.214
-2 Log Likelihood = 236.105; Prediction of success = 74.9%; Cox and Snell R^2 = 0.248; Nagelkerke R^2 = 0.331.

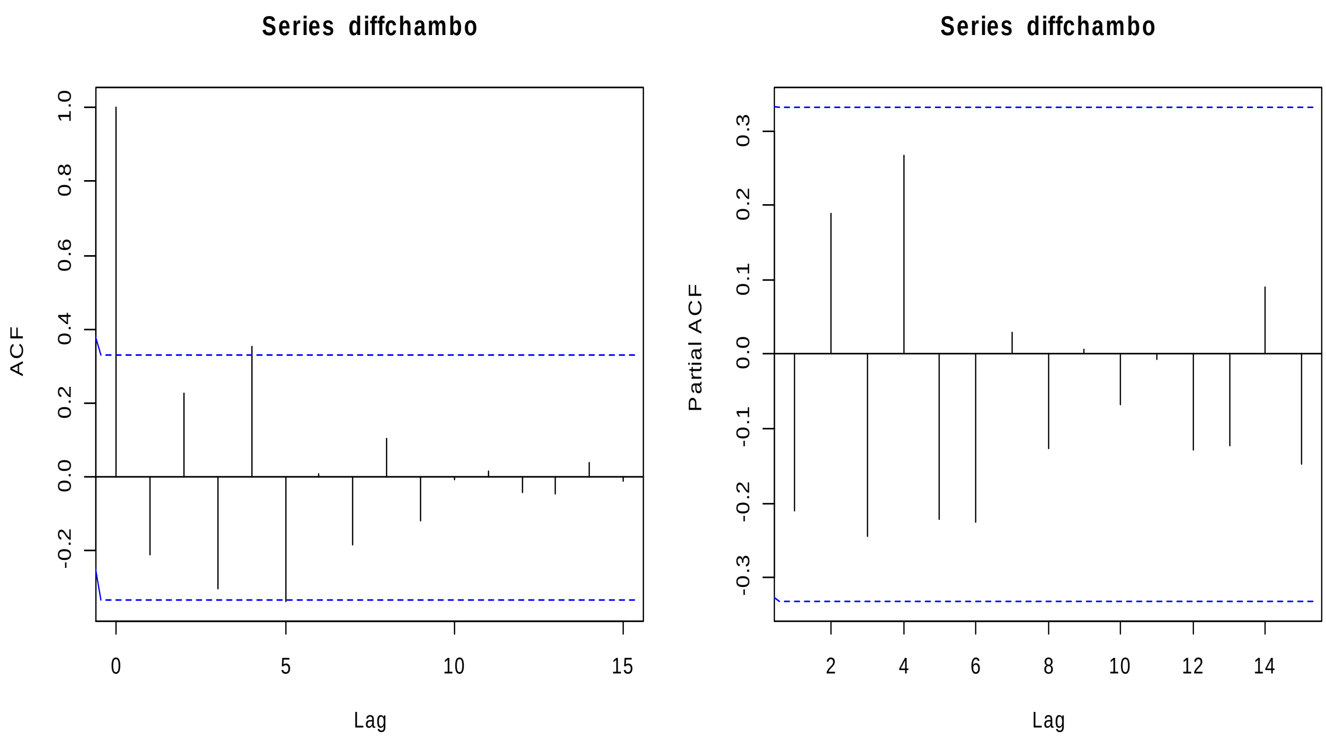

Figure 1. Autocorrelograms and partial autocorrelograms of first differenced catch data for Chambo catch in gill nets: 1976 to 2011.

of catch data of Chambo caught in gill net from 1976 to 2011. It was shown that catch data for the period of 1976 to 2011 was non stationary due to an unstable means which increased and decreased at certain points. The first differenced ACF and PACF showed that thirteen lags for Autocorrelation Function (ACF) and 15 lags for Partial Autocorrelation Function (PACF) were individually statistically insignificantly different from zero, for they all were within the 95% confidence bounds indicating the presence of stationarity as shown in Figure 1.

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 were suggested for model selection.

The model selection criteria which consisted of the

Table 2. 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

Table 3. 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)

Normalized Bayesian Information Criterion (NBIC), stationary R-square, 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) shown in Table 2 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) has the least Normalized BIC of 14.26 compared to other ARIMA models.

Table 3 shows 10 years catch forecast for Chambo catches based on ARIMA (0, 1, 1) up to 2021. It is noted that the magnitude of the difference between the forecasted and actual values were low for the selected model. The noise residuals are combinations of both positive and negative errors which show that, the model is not forecasting too low or too high on the average. Hence, from the ongoing assessment per the actual and the forecasted catches of Chambo in Table 3, it could be suggested that the model had good forecasting power.

Estimates of biomass dynamic parameters

Table 4 shows the regression of Schnute (1977) model. 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.

Estimates of bioeconomic reference points

Variables catch (Y) in tones and effort (F) in number of pulls were estimated using MSY and MEY. The estimates of the variables are reported in Table 5. The costs, revenue and economic rents associated with MSY and MEY are reported in Table 5. The values were calculated based on estimated MSY and MEY catch in kilograms and effort in pulls.

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.

Estimates of present value

The estimates of present values are reported in Figure 2. The results show that the present values of 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.

Estimates of net present value

The NPV was estimated to ascertain the economic viability of Chambo fishery in Lake Malombe using Gill net. The results of estimated NPV are reported in Figure 3. Figure 3 shows that under the current fishery status it would not be economically viable to harvest Chambo in Lake Malombe using Gill net. Compared to the estimated MEY NPV the results show that Chambo fishery would be economically viable to harvest at MEY.

DISCUSSION

Although Lake Malombe is known to have an open access

Table 4. Parameter estimate from the Schnute (1977) model.

Model	r	q	r/qk	R^2	F- statistics	Durbin Watson test
Chambo(1976-1989)	0.361(1.034)	-0.00000011(-1.426)	0.274(4.445)	0.70	10.341	1.809
Chambo(1990-2011)	-0.249(-0.295)	0.00000175(0.107)	58.597 (0.162)	0.38	0.014	2.078

Figures in brackets are t- statistics.

Table 5. Estimates of MSY, MEY, cost, revenue and economic rents.

Period	Variable	MSY	MEY
	Catch (tons)	1086.80	1008
	Effort (pulls)	164090	100939
Chambo (1989)	Cost (million MK)	1.505	0.148
	Revenue (million MK)	3.925	3.641
	Rent (million MK)	2.420	3.492
	Catch (tons)	14.71	10.51
	Effort (pulls)	69166	36380
Chambo (2011)	Cost (million MK)	2.222	0.535
	Revenue (million MK)	3.756	2.683
	Rent (million MK)	1.533	2.148

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 shown in the study provides an opportunity for introducing rights based approach to fisheries management. Historically, community rights fisheries management has been practiced in many parts of Africa, Asia and other 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.

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. 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.

Regarding economics, economic efficiency occurs when the sustainable catch and effort level for the fishery maximizes profits. The study showed that at the MEY level, the harvest and cost of harvest are lower than those associated with MSY 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 effort level 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).

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

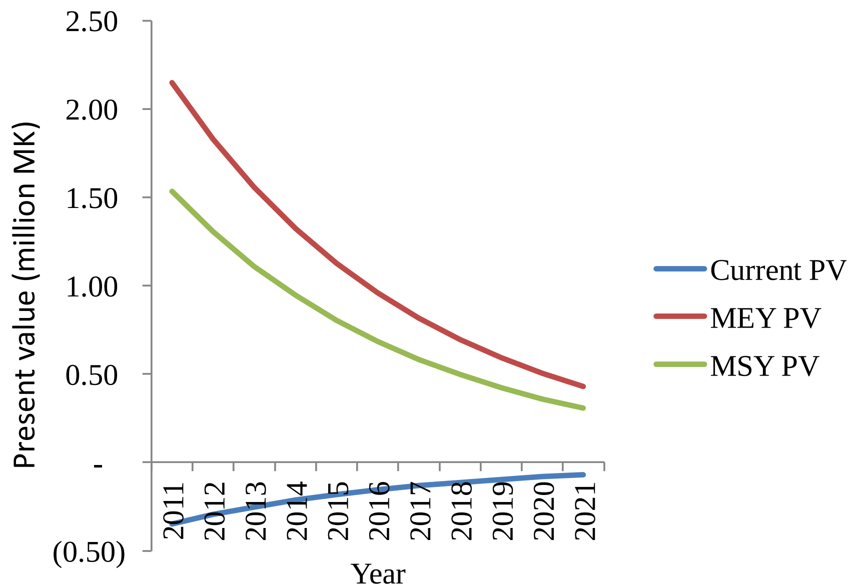

Figure 2. The estimates of Chambo fishery present value.

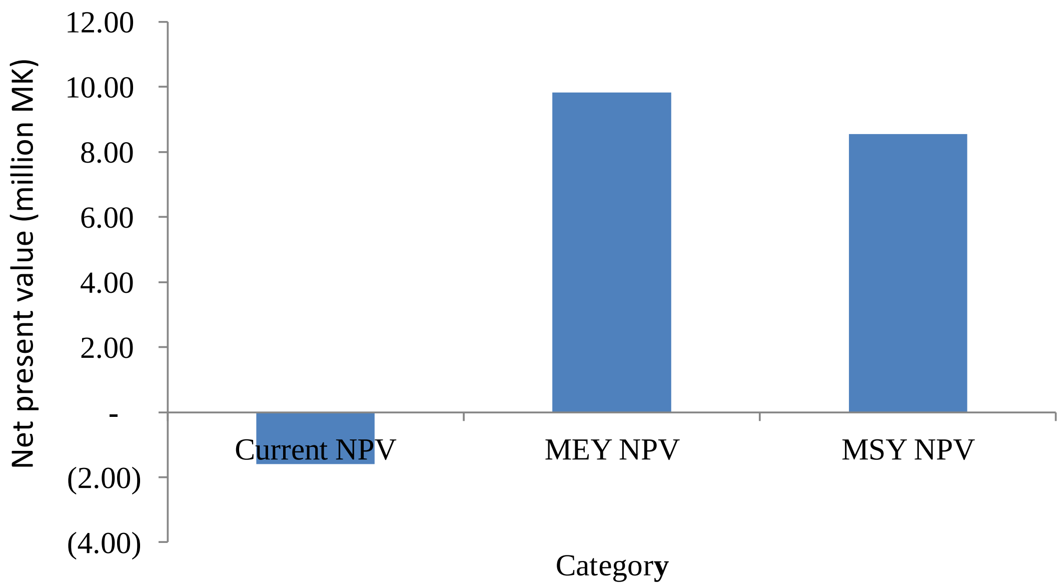

Figure 3. Estimated net present value for Chambo fishery from Lake Malombe.

are more plentiful and thus easier to catch, fishers do not have to spend as much on costs to fill their nets.

CONCLUSION AND RECOMMENDATIONS

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. The selected ARIMA model 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) implying that if the management of the stock in the current state continues without rebuilding, the Chambo catch will extinct. The results further showed that it is more profitable to operate at MEY for Chambo 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. 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 fishery is the best. This approach will ensure both good biomass growth and maximize economic benefits in the long run. 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.

ACKNOWLEDGEMENTS

The authors are highly indebted to The Regional Universities Forum (RUFORUM) for the financial support which made the study possible. Special mention to Professor Adipala Ekwamu, Dr. Moses Osiru and Dr Wellington Ekaya. The authors are also thankful to staff of Mangochi District Fisheries Office for the kindness and availability during data collection.

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