Bioeconomic Approach To Rebuilding Small Haplochromine Cichlids of Lake Malombe, Malawi

Wales Singini, Emmanuel Kaunda, Victor Kasulo, Wilson Jere, Orton Msiska

Abstract: The paper deals with the surplus production models of Verhulst Schaefer that were applied to the small *haplochromine cichlids* fishery to investigate the sustainability properties of the stock and management of the fishery. The basic objective of this paper is to illustrate the way in which bioeconomic analysis can achieve long run sustainable exploitation of the fishery. For this purpose, conventional economic model was used along with biological population growth model to develop a bioeconomic model. The parameters of the bioeconomic model were estimated using data of catch, effort, price and cost of small *haplochromine cichlids* fishery from 1976 to 2011. Standard reference points were analyzed and profit function was introduced to analyse the fishery economic rents. In order to achieve maximum level of economic rent from the fishery maximum economic yield solution was determined and recommended for adoption in the management of small *haplochromine cichlids* in Lake Malombe.

Keywords:- Bioeconomics, cichlids, economic rent, fisheries management, haplochromine Lake Malombe, rebuilding.

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1 INTRODUCTION

This study was based on the understanding that conventional fisheries management in Lake Malombe has contributed to rapid fish decline in Lake Malombe. This therefore, calls for an alternative approach to fisheries management that would contribute to significant rebuilding of the resources. The study was developed based on the notion that Maximum Economic Yield (MEY) solution is best characterized as one that considers the economic efficiency associated with the sustainable yield curve, and there are a number of salient benefits for pursuing such a goal or at least evaluating it for any given fishery (Dichmont *et al*, 2010). Since the solution is characterized by one where the difference between benefits and costs are the greatest, profits will always be maximized. This is important because it means that the approach is responsive to changes in economic conditions such as the price of the product and harvesting costs. The implication of efficiency is that excess resources can be used alternatively in the economy. The MEY solution is one that minimizes harvesting costs, which can help improve the competitiveness of a product. Minimizing costs can also provide an industry with resiliency to exogenous negative shocks. 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 (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 *et al*., 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. It is not necessary for the resource to exist biologically, but there is an obvious economic interest in exploiting it. Bioeconomic modelling has long been advocated as an important tool in managing fisheries for determining the sustainable levels of catch and effort and the exploitation path to achieve those equilibrium levels, particularly for rebuilding (Anderson and Seijo, 2009). This is because a bioeconomic model of a fishery combines the underlying stock dynamics with the harvest function and the costs of harvest and economic value of the extracted resources (whether retained or discarded). Such a model can address, for example, how quickly a fishery can be rebuilt in terms of being sufficiently confident that stocks are increasing while ensuring a level of harvest to maintain employment and markets. Under reasonable bioeconomic assumptions, MEY may be associated with a larger equilibrium stock size than MSY (Grafton *et al*., 2007). Certainly one of the most compelling reasons to consider the bioeconomic (MEY) solution as a means of evaluating a fishery is that it models the efficient use of resources. The MEY explicitly considers the interests of the harvesters in addition to the necessary biological dynamics by including a harvest (i.e. production) function that translates fishing effort into catch. This function, and the resulting measure of net economic value of the resource, is considered crucial at the policy level since fishing is inherently an anthropocentric activity. In contrast, the MSY does not account for the costs of harvest, which are often stock dependent. This is why most economists advocate for consideration of the MEY by policy makers (Kompas *et al*., 2009). There is a perceived risk of extinction that is associated with allowing a fishery to remain open during periods of low stock levels that is so great as to justify a closure, despite the negative economic consequences associated with closures. This argument is supported with historical evidence of overfished stocks that have been unable to recover (e.g. Safina *et al*., 2005; Rosenberg *et al*., 2006, Worm *et al*., 2009). However, as Larkin *et al*. (2006) has shown, rebuilding stocks as fast as biologically possible has real social costs. Balancing these costs with the risk of lower than expected stock growth or possible risk of extinction can be evaluated within bioeconomic models that explicitly evaluate biological and economic risks. In contrast to several high profile studies

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showing that benefits are maximized by rebuilding as fast as possible (e.g. Sumaila and Suatoni, 2005; Gates, 2009), it has been observed that delayed rebuilding can considerably increase average harvest levels and benefits. Gates (2009) reported that using 4% discount rate and slowing the rebuilding target by a decade, would increase average harvest levels by 93% on average since the model allows for fishing through the rebuilding period. The associated benefits of this slower rebuild are that the net present value increases 58%, due in part to the higher product price from low stock levels in the early years. Thus, mandating rebuilding only on biological criteria may produce significant economic losses, particularly for slow-growing stocks in fisheries with high discount rates. In this paper the objective was to develop a simple bioeconomic model which will be used to investigate the comparative study of resource stock and harvesting of small *haplochromine cichlids* by using surplus production model of Verhulst Schaefer.

2. Methodology

The study used quantitative data for small *haplochromine cichlids* locally known as Kambuzi on catch and effort, beach price and cost of fishing from 1976 to 2011. The data was generated from a computer based programme called Traditional Fishery Data Base (TFDB) which is used by the Department of Fisheries for storing fisheries data. Field data is collected by the Department of Fisheries through the annual longitudinal survey in Lake Malombe. Lake Malombe is divided into three statistical strata for purposes of data collection.

2.1. Parameter estimation

There are three main approaches used in estimating the parameters of the biomass dynamic model (surplus production model), when the only data available is on fish catch and effort. These are equilibrium methods, regression methods and time-series fitting methods (Hilborn and Walters, 1992). Equilibrium methods, as the name suggests, assumes that fish stock is at equilibrium, and that the relationship between catch per unit effort (U_t) and effort is linear. In general, these regressions perform poorly because the equilibrium assumption underlying their derivation is usually far from satisfied (Conrad and Clark, 1994). Regression methods involve transforming the equations into a linear form and then fitting by linear regression. These approaches are computationally easy and in some cases they recognize the dynamics of the fisheries. However, they often make strong assumptions about the error structure. The basic idea of a time-series fitting is to take an initial estimate of the stock size at the beginning of the data series, then use the time-series fitting model to predict the whole time-series. The parameter values are then adjusted to provide the best fit of the predicted-to-observed time-series of the relative abundance of catch data. In this paper the regression method for estimating the parameters r, q, K and e was adopted. Although this method makes strong assumptions about the error structure, it is recommended for illustrative analysis (Hilborn and Walters, 1992). Different regression methods can be identified from the literature (for example Conrad and Adu-Asamoah, 1986; and Uhler, 1980). Three models are particularly distinct and most widely used in the estimation of parameters of the production function: the Schaefer (1957) model, the Fox (1970) model, and the Schnute (1977) model. This paper adopts Schnute's (1977) method of estimating the parameters r, q, and K. The first step in this method is to define an equation that uses catch and effort data to predict catch per unit effort (U). The population growth function where fish biomass equals its natural logistic growth rate minus the catch rate can therefore be expressed in terms of U. Thus,

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

Becomes

$$\dot{U} = rU(1 - U/qK) - qEU \tag{2}$$

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

$$\frac{\dot{U}}{U} = r - qE - \frac{r}{qK}U \tag{3}$$

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

$$\ln\left(\frac{U_{st+1}}{U_{st}}\right) = r - qE_t - \frac{r}{qK}U_t \tag{4}$$

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

Since integrating over some time period involves time averaging over that period the definition for E_t is the usual total effort per year. The same applies to Y, the catch rate, so that U_t is the annual catch per unit effort. Equation (4) suggests that a linear regression of one variable, ln (U_{st+1}/U_{st}) on two variables E_t and U_t, can be used to estimate the three parameters r, K, and q. U_{st} might be approximated by;

$$U_{st} \cong ½(U_t + U_{t-1}). \tag{5}$$

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

By substitution, the equation becomes,

$$\ln\left(\frac{U_{t+1} + U_t}{U_t + U_{t-1}}\right) = r - qE_t - \frac{r}{qK}U_t \tag{6}$$

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

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

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

$$\ln\left(\frac{U_{t+1}}{U_t}\right) = r - q\left(\frac{E_t + E_{t+1}}{2}\right) - \frac{r}{qK}\left(\frac{U_t + U_{t+1}}{2}\right) \quad (7)$$

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 gives the corresponding catch per unit effort. Though derived from a slightly complicated procedure, this equation suggests that next year's catch per unit effort can be predicted by specifying next year's anticipated effort. A stochastic version of this equation is obtained by replacing t by t-1 and by adding the error term, ε.

Thus,

$$\ln\left(\frac{U_t}{U_{t-1}}\right) = r - q\left(\frac{E_{t-1} + E_t}{2}\right) - \frac{r}{qK}\left(\frac{U_{t-1} + U_t}{2}\right) + \varepsilon \quad (8)$$

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

2.2. Reference points

The analytical expressions of maximum economic yield (MEY), open-access (OAE) and the maximum sustainable yield (MSY) in terms of biological parameters along with economic variables were derived. These reference points were analyzed for the future management policies of a fishery and sustainable development of ecosystem. Maximum Sustainable Yield (MSY) effort, catch and stock were obtained by:

First derivative of yield function:

$$F_{msy} = \frac{r}{2q} \quad (9)$$

Substituting Fmsy into sustainable yield function:

$$Y_{msy} = \frac{rK}{4} \quad (10)$$

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

Replacing B in the revenue function:

$$F_{be} = \frac{r}{q}\left(1 - \frac{C}{pqK}\right) \quad (11)$$

$$Y_{be} = \frac{CF_{be}}{P} \quad (12)$$

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

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

$$\text{MVE} = pqk\left(1 - \frac{2qf}{r}\right) \quad (13)$$

Therefore:

$$f_{MEY} = \frac{r}{2q}\left(1 - \frac{c}{pqk}\right) \quad (14)$$

$$Y_{MEY} = \frac{r}{4}\left(k - \frac{C^2}{p^2q^2k}\right) \quad (15)$$

2.3. Economic model

To attain efficiency in the economic sense, there is need to take into account the costs of fishing and revenues that are generated from selling the harvested fish. It is necessary to use catch-effort relationship to define revenues and costs as a function of fishing effort. Given price, p, per unit of fish harvested for each year, the total revenue, TR, was obtained by: TR(E) = pH(E); where TR is the total revenue, p is the average beach price of fish per year and H is the harvest/catch per year. Given cost, *c*, per unit of effort per year, the total costs, *TC*, of fishing was obtained by: TC (E) = cE Where TC is the total cost of fishing, c is the unit cost of fishing per year and E is the effort level of fishing per year. Thus sustainable economic rent was defined as:

$$\pi = \text{TR} - \text{TC} \quad (16)$$

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:

$$\text{PV}_\pi = \frac{\text{TR(t)} - \text{TC(t)}}{(1 + i)^t} = \frac{\pi(t)}{(1 + i)^t} \quad (17)$$

Where PV is the present value profit and i is the social rate of discount. Net present value (NPV) of a flow of benefits and costs through time was estimated in order to ascertain the viability of fishing in Lake Malombe through time. The NPV was obtained according to Sumaila and Suatoni (2005) as:

$$\text{PV}_\pi = \frac{P_1}{(1 + i)^1} + \frac{P_2}{(1 + i)^2} + \frac{P_3}{(1 + i)^3} \ldots + \frac{P_{10}}{(1 + i)^{10}} \quad (18)$$

3. Results of parameter estimation

The parameters of the Verhulst Schaefer model were estimated using Equation 8. Regression results of the equation are reported in Table 1.

Table 1. Parameter estimate from the Schnute (1977) model.

r	q	r/qk	R^2	F-statistics	Durbin Watson test
0.22 (0.453)	-0.000000795 (-0.371)	-0.069 (1.047)	0.32	0.548	2.454

The figures in brackets are t- statistics.

The regression results show that the intrinsic growth rate (r) has the expected positive sign. The model had low R^2 which might have been influenced by unstable year to year catch and effort. There are huge up and down fluctuations in catch and effort during the period without following similar pattern. A similar argument was made for the findings in Lake Malombe (Tweddle *et al*., 1991b). The other influence of low R^2 could be that the model explains year to year changes in relative growth of catch per unit effort and not one way trend on catch per unit effort (Schnute, 1977).

3.1. Results of bioeconomic model

Variables catch (Y) in tones, effort (F) in number of pulls and stock (B) in tones were estimated using MSY, MEY and OAY. The estimates of the variables are reported in Table 2. The parameter estimates from the regression of equation 8 reported in Table 1 were used to calculate the reference points.

Table 2. Estimates of MSY, MEY, OAY, costs, revenues and economic rents

Variable	MSY	MEY	OAY
Catch (tons)	2326.92	1464.08	1217
Effort (pulls)	38364	37490	276730
Cost (million MK)	62.112	13.493	
Revenue (million MK)	62.827	15.666	
Rent (million MK)	0.715	2.172	

The results are typical of Verhulst Schaefer fisheries model. As expected the open access solution produced the lowest catch level associated with the highest level of effort. The MSY solution gives the highest level of catch and the MEY gives the lowest level of effort. The OAY solution gave the lowest level of catch. The maximum economic rent is reached at an effort level of 37490 pulls corresponding to 49 nkacha nets. This paper shows that operating at MEY would generate more rents as compared to the OAY and the MSY. An open-access or unmanaged fishery does not generate resource (or fishery) rent, although some of its participants may earn other kinds of rents. This is because the advantages of the fishery in terms of its natural productivity are offset by competitive forces resulting in overexploitation, which in turn lowers the return to fishing effort (Tom *et al*., 2010). Open access to fisheries has been criticized for a number of reasons. Under open access, biological yield from the resource will be less than the maximum potential. The resource is vulnerable to changes in price and technology which tend to increase fishing effort over time, reducing yield and biomass and threatening the stock with collapse. A great deal of fishing effort, and therefore cost, is wasted. A larger catch could be obtained with less effort and less cost. The standard of living of society could be higher if the excess inputs used to catch fish were used to produce other valuable goods and services. In contrast to the low or zero rent, the point of maximum profit occurs at the maximum economic yield. The maximum profit from a fishery is actually obtained when the fishery is kept at relatively low levels of effort compared to the open access. Biomass is kept relatively high, catch per unit of effort is high, and profits are high. A fishery that is managed to obtain the maximum economic yield is therefore also managed in a very conservative biological way. MEY thus occurs at a stock size that is larger than that at which maximum sustainable yield is achieved, leading to a win-win situation for both the fishers (added profitability) and the environment (larger fish stocks and lower impacts on the rest of the ecosystem) (Tom *et al*., 2010). The estimates of present value were projected for 10 years covering the period 2011 to 2021. Current economic rents were discounted to estimate the present values and were compared with the present values of MEY and MSY. The results of estimated Net Present Value are reported in Figure 1.

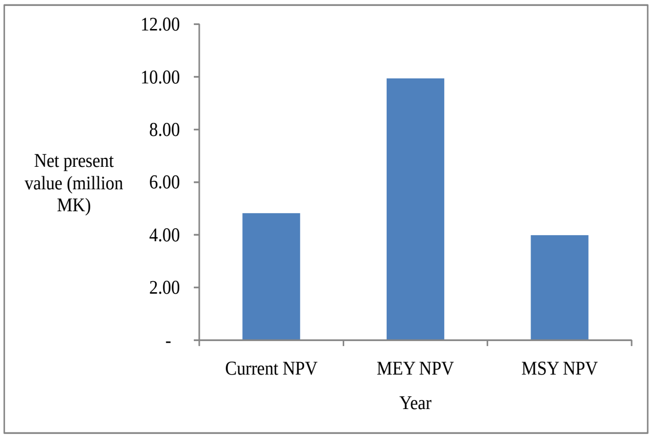

Fig 1. Estimated Net Present Value

This paper underscores the importance of adopting the MEY solution because it gives a better value of money in future as compared to MSY and open access. Rebuilding can only take place if harvesting is reduced or stopped for some time since harvest has to be less than natural growth to generate growth in the stock (Kompas *et al*., 2009). The current fishery has positive NPV but lower than the MEY NPV. This shows that it is economical to fish small *haplochromine cichlids* in short term, but it would more economical and sustainable to operate at MEY. However, fishers operate in a world which is markedly different from most of the enterprises and that affects their behaviour. Risk and uncertainty are at the centre of their lives but the negative consequences can, to an extent, be offset in a well managed fishery where high levels of profitability can be achieved (Charles, 2001).

4. Conclusion

The basic objective of this paper is to illustrate the way in which bioeconomic analysis can achieve long run sustainable exploitation of small *haplochromine cichlids* fishery that will maximize economic benefits while ensuring sustainable biomass growth. The approach that simultaneously meets both objectives, maximizing economic benefit while ensuring sustainable biomass, is to reduce fishing effort from the current level. To ensure that reduced fishing effort does not lead to inherent behaviour of fishers to invest more and more in illegal technology development to elude regulations to reduce effort, rights based fishing management approach has been recommended , as it limits competition for the resource. Under this regime the emphasis of the operators will be to reduce fishing costs to ensure maximum profit from their catch. It is believed that these results will help persuade fishers that it is in their interests to take the long-term view that by reducing their catch now they will more than make up any temporary financial losses with increased profits in the future. This is quite a different argument from the focus on sustainability. In this paper, it can be said that what is happening now is costing fishers' money but if they reduce the harvest now, it will pay off down the road. The findings will help overcome a key cause of over-fishing, fishery opposition to lower catches by demonstrating that when stocks are allowed to recover, profits take a sharp turn upward. But our results prove that the highest profits are made when fish numbers are allowed to rise beyond levels traditionally considered optimal. The simple reason is that when fish are more plentiful and thus easier to catch, fishers do not have to spend as much on costs to fill their nets i.e. profits are higher.

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