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Full Length Research Paper

Econometric analysis of the effects of water hyacinth on the fish catches in Lake Victoria, East Africa

Ngeno Vincent*, E. K. Ngeno, B. K. Langat and M. J. Kipsat

Department of Agricultural Economics and Resource Management, Moi University, Kenya.

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Lake Victoria is Africa's most important source of inland fishery production. The lake serves as a source of human food and raw material for the fishmeal industry. Several challenges face the lake fishery, including the invasion of water hyacinth. This paper analyses the effects of the invasion of water hyacinth on fishing in Lake Victoria. A static catch per unit of effort functions were estimated using Schaefer models for Lake Victoria fisheries. The investigation on the trend in the lake's stock during the period 1985 - 2005 focused particularly on the effect of the water hyacinth on fish stocks and fish catches coefficients. The results shows that the fish catch declined due to the growing abundance of water hyacinths. The impact of the hyacinth on the fish catch was greatest in the Kenya section of Lake Victoria.

Key words: Water hyacinth, fish catch, Schaefer model, Lake Victoria, East Africa.

INTRODUCTION

By early 1990s, the adverse effects arising from water hyacinth mats were alarming (LVEMP, 1997). Water hyacinth mats invaded fishing grounds and blocked waterways. For individual fishermen, the hyacinth mats reduced their catch by covering fishing grounds, delaying access to markets due to loss of output, increasing fishing costs due to the time and effort spent clearing waterways, forcing translocation and causing loss of nets. Twongo (1998) noted that the weed mats sealed off breeding, nursery, feeding and fishing grounds for various inshore fish species, like tilapia and young Nile perch. The mats also had detrimental effects by blocking light, severely reducing oxygen levels and allowing poisonous gases, such as ammonia and hydrogen sulfide to accumulate.

At the same time, the water hyacinth is believed to have promoted fish diversity, particularly smaller species and the young. Mechanisms for this include providing shelter from predators as well as reducing fishing pressure. It enhanced the abundance of lungfish and *Haplochromines* and depressed the number of tilapias and *Synodontis,* a member of the catfish genus (Twongo, 1998). Thus, structural changes in the species composition of Lake Victoria's fish stocks may have been induced by the water hyacinth infestation of the lake. The purpose of this study was to explore the effects that water hyacinths have on fishing.

*Corresponding author. E-mail: ngenota@yahoo.com.

METHODOLOGY

The study area

Lake Victoria, with a surface area of 68,800 km^2 and an adjoining catchment of 184,000 km^2, is the world's second largest body of fresh water, second only to Lake Superior. Its maximum depth is about 80 m and the average is about 40 m. The lake's shoreline is long (about 3500 km) and convoluted, enclosing innumerable small, shallow bays and inlets, many of which include swamps and wetlands which differ a great deal from one another and from the off-shore environment of the lake. Kenya, Tanzania and Uganda control 6, 49, 45% respectively, of the lake surface. The gross annual economic product from the lake catchment is in the order of US $3 - 4 billion and it supports an estimated population of 25 million at per capital annual incomes in the range US $90 - 270. The lake catchment thus, provides the livelihood of about one third of the combined gross domestic product. The lake catchment economy is principally an agricultural one, with a number of crops and a high level of subsistence fishing. The quality of the physical environment is therefore a fundamental factor in maintaining and increasing the living standards of the growing populations in Kenya, Uganda, Tanzania, Rwanda and Burundi (Labrada, 1996).

Type of data

To study the impacts of water hyacinth on the fish harvest coefficients, time-series data on aggregate catches, the number of vessels engaged in fishing on the lake, and the abundance of the water hyacinth over the period 1975 - 2005 were used. These data were collected from the fisheries departments of Kenya, Uganda and Tanzania. Due to lack of comprehensive data on components of fishing effort, a proxy for effort was calculated using the number of boats engaged in the fisheries each year. Also, the available data on boats provided no information on boat characteristics, that is, it was not possible to disaggregate boats according to type, size or other features. The boats, therefore, were considered homogenous units of effort. The technology for the majority of these vessels, however, was known to be fairly simple and similar.

Conceptual framework

A static Schaefer model

This model was build on three premises: (1) that catch per unit of effort is directly proportional to the density of fish, (2) that the density of fish is directly proportional to the abundance of fish at the time *t*, (3) that the harvest coefficient depends on the abundance of water hyacinth in the lake in period *t*.

$$\frac{\partial B}{\partial t} = B = rB(t)\left(1 - \frac{B(t)}{K}\right) - h(t) \quad (1)$$

Where, r the intrinsic growth rate of fish stock and K is the carrying capacity of the environment. Fish growth takes a logistic function form. Water hyacinth mats were observed to have both positive and deleterious effects on fish growth, although the net effects are still unknown. For this reason the hyacinth effect in the fish growth function were omitted.

In the equation shown, $h(t)$ is the fish harvest function for the period *t*. The harvest of fish is a function of effort water hyacinth abundance and the fish stocks. The fisheries production function is assumed to be linear in effort and fish stocks, and is presented as;

$$h(t) = q(w(t))w_t B(t), \quad (2)$$

Where, it is assumed

$$\frac{\partial h}{\partial w} = \frac{\partial h}{\partial q} \cdot \frac{\partial q}{\partial w} \leq 0, \quad \frac{\partial h}{\partial E} > 0, \quad \frac{\partial h}{\partial B} > 0 \quad (3)$$

Where, $w(t)$ the water hyacinth abundance is in period *t* and measured in hectares of hyacinth mats, w_t is the level of effort in period *t*, $q(w(t))$ is the water hyacinth-induced harvest coefficient, which is assumed to be a function of water hyacinth abundance and other factors. The water hyacinth coverage of the fishing grounds reduces the ease with which fish is harvested. Therefore, its effect on the coefficient and on harvest is expected to be negative. The relation between q and w was defined as;

$$q(w(t)) = \alpha\left(1 - \frac{w(t)}{Z}\right), \quad (4)$$

Where, Z is defined as the area of the lake that is relevant for fishing operations and is measured in hectares. $\left(1 - \frac{w(t)}{z}\right)$ is the proportion of the fishing area which is free of the water hyacinth mats. The effect of the water hyacinth on the fish catches is given by;

$$\frac{\partial q}{\partial w}\begin{cases} = -\frac{\alpha}{z} \; if \; \underline{w} \leq w(t) \leq \overline{w} \\ = 0 \; \leq w(t) \leq \underline{w} \end{cases} \quad (5)$$

Where, $w \in (0, \overline{w})$ and $\alpha \in (0,1)$. $\underline{w}$ is the minimum amount of hyacinth coverage necessary for inducing inconveniences in the fishable zone z. $\overline{w}$ is the maximum coverage by the water hyacinth mats that may be realized without weed control interventions in zone z. α corresponds to the exogenous component of the harvest coefficient.

Ricker (1975) defined the fish catches coefficient as the fraction of a fish stock that is caught by a defined unit of fishing effort. This implies that, $0 \leq q \leq 1$ periods characterized by the absence of water hyacinth –related interruptions in fishing are assumed to be those with either very low level of hyacinth matting or those periods before the lake was infested with the weed. In those instances, the value of $w(t)$ is less than $\underline{w}$. The water hyacinth-induced fish catch coefficient then reduces to the constant in the Schafer model, that is, $q = \alpha$ The net effect of hyacinths on stocks, is not yet known using (4) to substitute for q in (2), the harvest function 6, be rewritten as;

$$h(t) = \alpha\left(1 - \frac{w(t)}{z}\right)E(t)B(t), \quad (6)$$

And

$$\frac{\partial q}{\partial w}\begin{cases} = -\frac{\alpha}{z}E(t)B(t) \; if \; \underline{w} \leq w(t) \leq \overline{w} \\ = 0 \; if \; 0 \leq w(t) \leq \underline{w} \end{cases} \quad (7)$$

When the fishery is in equilibrium, fish harvest is always equal to the sustainable yield for some defined level of stock (Hanneson, 1993). Making use of this condition, (1) and (6) imply that the catch-effort (or the sustainable yield) functions is given by;

$$h(t) = A\left(1 - \frac{w(t)}{z}\right)E(t) - 1)\left(1 - \frac{w(t)}{z}\right)^2 E(t)^2 \quad (8)$$

Where, $A = \alpha K$ and D = $\frac{\alpha^2 K}{r}$. (1- $\frac{\alpha^2 K}{r}$. is referred to as the effective effort that declines as the water hyacinth level increases. When $0 \leq w(t) < \underline{w}$, the effective effort is equal to E_t. Estimation of (8) enables to find the values of the parameters A and D. There are three unknowns; α, r and K. Any information on r and K will enable to estimate the values of the parameter α. The estimated $\hat{\alpha}$ is then used to estimate the catch of fish for the different levels of water hyacinth over years. Estimated values of r and K may be used in the equations containing A and D to find $\hat{\alpha}$.

Estimation

Non-stationary time-series data implies the estimate of unit roots in the data. Unit root tests-for example, the augmented Dickey-Fuller (ADF) tests and Philip-Perron tests-were used to establish the order of integration of the series. The distribution theory supporting the ADF tests assumes that the errors are statistically independent and have a constant variance. The Philip-Perron tests are ageneral-ization of the Dickey-Fuller procedure that allows for fairly mild assumptions concerning the distributions of errors (Enders, 1995). Perron (1987) argued that most macroeconomic variables are not characterized by unit root processes. Instead, the variables appear to be trend stationary processes couple with structural breaks. Perron's test for a unit root in the presence of structural breaks considered a regression equation of the form;

$$\Delta y_t = a_0 + u_1 D_l + u_2 D_p + a_2 t + a_1 y_{t-i} + E_{t_1} \quad (9)$$

Where, D_p is a pulse dummy that is equal to 1 in the year of the jump or break, and zero otherwise. D_l is a level dummy that is equal to 1 for all *t* beginning with the year within which the structural break occurred. Under the presumption of a one-time change in the mean of a unit root process, $a_1 = 1, a_2 = 0, u_2 = 0$. The alternative hypothesis is that there is a permanent stationary process. In this case, $a_1 < 1$ and $u_1 = 0$

Tests for unit roots in the series that took into account the possibilities of structural breaks were therefore used. The parameters for the pulse and level dummies were both zero in all estimations. The Phillip-Perron tests thus failed to detect the structural breaks in the data. This could be a result of the narrowness of the time series used. Instead unit root tests of the augmented Dickey-Fuller (ADF) format were conducted on the data for the sub-samples 1975 - 1985 and 1986 - 2005. The ADF tests indicated that for the sub-sample 1986 - 2005 data were stationary. Tests on data from the 1975 - 1985 sub-sample indicated non-stationary data. The data was divided into two sub-samples, 1975 - 1785 and 1986 - 2005, and separate functions estimated for each sample. The F-statistics from 1986 Chow breakpoint were all significant at the 1% level. Thus, the hypothesis of the stability of the parameters in the two sub-samples was rejected. Since the data for the earlier period was non-stationary, analysis was based on data for 1986 - 2005.

RESULTS

The catch-effort functions

Coefficients in the lake-wide, Tanzania, and Uganda estimation had the expected signs and were all significant at the 1% level. The estimated coefficients for the Kenya section had the expected signs. However, the coefficient on the effort-squared variable was not significant. The DW statistics were less than 1 for all sections indicating first order autocorrelation. Autocorrelation has been a common problem in fisheries model estimations (Hannesson, 1983). It reflects the fact that catches in any period depend on catches in earlier periods. The results for the static analysis are reported in Table 1.

The calculations for the solutions of the values for $\hat{\alpha}, r$ and K requires to have some prior information on one of the three unknowns. As noted above, no estimates of K for aggregate stocks were available for Lake Victoria. However, Pitcher and Bundy (1995) conducted an assessment of the lake-wide Nile Perch between 1.06 and 1.61. This estimated range for the intrinsic growth rates seemed to be rather high, but their justification was that it was quite reasonable for the perch species. The carrying capacity for these species was estimated to be between 1,000 and 1,870 kilotons. From these estimates, implied range for the maximum sustainable yield for Nile perch was between 279 and 489 kilotons per year.

The lower value of the estimated growth rate for Nile perch from the Pitcher and Bundy study was used to solve for the values of r and k from the estimated parameters in the static functions. A common population growth rate for the Nile perch lake-wide was assumed. The growth rates for the other species was not known for the other species but since tilapia and dagaa only, constitute small proportions of catch from the lake, these figures were used for the total stock. The estimated fish catches coefficient, $\hat{\alpha}$ and the carrying capacity k and maximum sustainable yield for Lake Victoria, and for the three sections of the lake are reported in Table 1. The estimated carrying capacity for the lake was 1,752 kilotons, yielding a maximum sustainable yield of 464 kilotons. From the results, the harvest of fish was highest in the Kenyan section.

Water hyacinth induced harvest coefficients

The estimated values of $\hat{\alpha}$ and the hectares covered by water hyacinth were incorporated in harvest coefficient in (4) in order to calculate the water hyacinth – induced harvest coefficients. These were calculated for the years 1995 - 2008. Both the results from the static analysis revealed that on average harvest of fish was reduced by 45, 2 and 6% in the Kenya, Tanzania and Uganda sections of Lake Victoria, respectively. The larger reduction in the harvest of fish in Kenya's section can be explained by the high abundance of water hyacinth mats in this area compared to the example of Tanzania. These results revealed that the presence of water hyacinth in

Table 1. Estimated carrying capacity: Static analysis.

Variable	Lake section			
	Lake-wide	Kenya	Tanzania	Uganda
	Coefficients	Coefficient	Coefficients	Coefficients
Effort	33.3***(10.2)	46.7**(3.4)	35.1***(9.92)	26.6*** (6.1)
$Effort^2$	-0.0006***(-5.11)	-0.003(-1.19)	-0.002***(-4.92)	-0.0014***(-5.32)
Adjusted R^2	0.41	0.90	0.93	0.38
Sigma	87.500	57.300	42.300	27.400
RSS	1.22E+11	5.26E+10	2.86E+10	1.20E+10
DW	0.46	0.90	0.93	0.38
Log likelihood	-229.3	-221.7	-216.2	-203.4
Observations	50	50	50	50
α	0.000019	0.000063	0.00054	0.000054
k (Metric tons)	1,752,000	741,000	649,000	492,000
$MSY^{\pm}$ (Metric tons)	464,000	196,000	172,000	130,000

***, **,* indicate significance at 1, 5, and 10%, respectively. The figures in parentheses are t-statistics; ± MSY is maximum sustainable yield.

the lake drastically reduced the harvest of fish in the Kenyan section of Lake Victoria. The effects on the Tanzania and Uganda sections were milder.

According to the Uganda statistical Abstract 2006, catches of Nile Perch continued to increase until 2004 but declined severely (by 20%) in 2005. Newspaper reports in 2007 suggested that the decline is becoming even more serious (New Vision, 2007). This fits well with the analysis here that the hyacinth somewhat delayed over fishing and now that they are gone, over fishing has accelerated again.

Conclusion

The effects of the water hyacinth on the fish catches in Kenya Tanzania and Uganda fisheries of lake Victoria was explored by incorporating the water hyacinth biomass as a negative factor in the fish catch coefficient. The results indicate that the fish catch in the Lake Victoria fisheries was reduced by a factor of 2 - 45% during the period when the lake was highly infested by the water hyacinth. The decline was greatest in the Kenya section. The weed also caused numerous problems to the shipping hydro- power and other activities besides fishing. It is therefore understandable that strong measures were pursued to control its growth. But what caused the excess supply of nutrients and sparked the flourishing growth of the water hyacinth is still unknown. It should also be recognized that although the water hyacinth were a serious problem, they ironically also had the benefit of (temporarily) reducing fishing pressure.

At present, there appears to be a drastic decline in fish stock in Lake Victoria. The need to substantially reduce efforts on the Lake and take other measures to salvage the stocks from the path of extinction is raised by this study. It will become even more crucial when the hyacinth is cleared and this obstacle to fishing is removed. This may well be the explanation for the current crisis. Better estimates of the fisheries parameters may be calculated in the future with longer time series. Another area for future research will be to disaggregate the data by species and to model not only the effects on harvest but also the biological effect of hyacinth on the fish stock function.

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