



International Journal of Fisheries and Aquatic Studies

ISSN: 2347-5129
IJFAS 2015; 2(3): 207-210
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www.fisheriesjournal.com
Received: 11-10-2014
Accepted: 29-12-2014

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Prediction of yield and optimum fishing effort for the Tilapia (*Oreochromis niloticus*, Linnaeus, 1758) stock of lake Hawassa, Ethiopia.

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Abstract

Oreochromis niloticus (Tilapia) is the major commercially exploited species in Lake Hawassa that contributes more than 85% of the total annual landings from Lake Hawassa. On the other hand its potential is not rigorously studied so far in Lake Hawassa and in the other lakes as well. In the present study the Schaefer and Fox models were used to predict the Maximum Sustainable yield (MSY) and optimum fishing effort (f_{MSY}) of tilapia in Lake Hawassa using catch effort data collected over a period of 9 years (2005-2013). Accordingly The MSY of tilapia in Lake Hawassa is around a 500 tones / year and the optimum level of fishing effort to be expanded on the stock should be below 1000 nets per day. The current yield estimate is by half less than that of the yield predicted during the early 1990's, which is 900 tones/year (LFDP, 1993). This shows that the tilapia stock of Lake Hawassa is overfished. Accordingly, seasonal closure and enforcement of minimum mesh-size regulations as well as a limitation of the number of gillnets should be implemented on the lake in order to protect the stock from depletion.

Keywords: *O. niloticus*, Lake Hawassa, Stock assessment, Schaefer-Fox models, MSY, f_{MSY}.

1. Introduction

Ethiopia has about 7,444 km² of inland waters (Abebe and Geheb, 2003)^[1] from which about 51,481 tones of fish can be sustainably harvested per annum. Although the current level of fish production, which is around 10,000 tones/year (LFDP, 1997), is below 1/5th of the potential, most of the potentials are to be expected from the main rivers as the riverine fishery is still untapped. On the other hand, the commercial fishery of most Ethiopian lakes has tremendously increased to the extent that some commercially important fish species have already become victims of overexploitation. In this regard Lake Hawassa is one of the most abused lakes in the country. In this lake, fishing efforts have increased by five folds and landings by nearly ten folds since the last three decades. For example, during the early 1980's, the fishing efforts were below 200 nets per day. Whereas in the 1990's, it had increased to about 400 to 700 nets per day (LFDP, 1993) and currently more than 1000 nets are set per day majorly to exploit the tilapia stock.

The impact of this alarming rate of fishing pressure is further worsened by the progressively decreasing trend of the mesh width of the nets. Also the exploitation of fish species of Lake Hawassa is highly biased towards Tilapia (*Oreochromis niloticus*) that accounts to more than 85% of the catch. The other two commercially exploited fish, Catfish (*Clarias gariepinus*) and large barbs (*Labeobarbus niloticus*) account only 10 and < 1% of the annual landings, respectively. As a result the tilapia stock of Lake Hawassa is showing serious signs of overexploitations. For instance the catch per unit effort, which used to be 20 to 25 tilapia /net in the early 1980's is now not more than 5 fish/net.

In view of this alarming rate of fishing pressure, there is an urgent need to set up sound management practices and this requires knowledge about the exploitation potentials of the stocks, mainly tilapia. The present work is therefore an attempt to estimate the maximum Sustainable Yield (MSY) of tilapia in Lake Hawassa as well as the optimum level of fishing efforts to be expanded on the tilapia stock of the lake. Accordingly catch and effort data collected over a period of 9 years (2005–2013) have been used to predict the exploitable potentials of the stock.

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2. Materials and methods

2.1 Description of the study area

Lake Hawassa is located at the south and southwest parts of Hawassa city, which is 273 km far from Addis Ababa. Geographically, the lake lies between $6^{\circ}33' - 7^{\circ}33'$ N and $38^{\circ}22' - 38^{\circ}29'$ E at an altitude of 1680 masl (Figure 1). The area of the lake is 91 km² and it has an average depth of 11m, a maximum length of 17 km and a maximum width of 11km. The main effluent of the lake comes from the east and drains from the swampy lake called Lake Shallo (Cheleleka) through Tikur Wuha River which is a perennial river. The lake is a closed catchment lake with no surface water out flow.

In Lake Hawassa, there are six fish species, namely, Nile tilapia (*Oreochromis niloticus*), The African catfish (*Clarias gariepinus*), Large Barbus (*Labeobarbus niloticus*), small barbus (*Barbus paludinosus*), *Apocheilichthys antinori* and *Garra quadrimaculata* (LFDP, 1997). Tilapia is the most fished species from the lake accounting to more than 85 % by weight of the total annual catch followed by catfish and large barbus that account to 14 % and < 1 % by weight of the annual landings, respectively. The three minnow fish, *Barbus paludinosus*, *Apocheilichthys antinori* and *Garra quadrimaculata* are not fished because of their small size.

The fishery on Lake Hawassa is almost exclusively conducted with surface gillnet although long-lines are also used to some extent to catch catfish. The nets are prepared locally by fishermen themselves or by some other people involved in fishing gear making. The mesh size between nets and within single net is very much variable but average 90 mm. The number of vertical meshes is always 34. The color of the twine is commonly white. The twine thickness is typically 0.3 mm. The nets are, on average 80 m long and 2 ½ m wide.

The nets are set in the late afternoon and collected early next morning. For the transport to and from the fishing grounds, simple plank rowing boats are used. Starting from 1991 the number of fishermen as well as the fishing gears have dramatically increased. This affected the fish stock in the lake, particularly the tilapia stock. Because of that the yield of tilapia has declined in the past years.

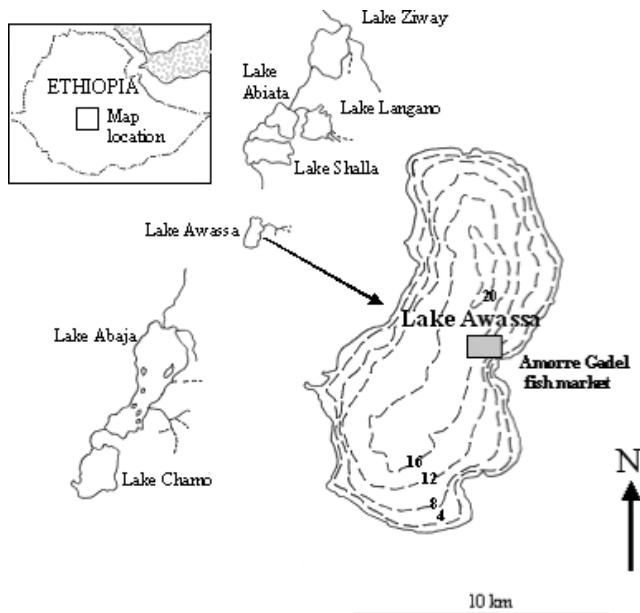


Fig 1: Location of Lake Hawassa in the Ethiopian part of the Eastern Great Rift of Africa. Inset: map of Ethiopia showing the northeastern section of the Great Rift

2.2 Methods of data collection and analysis

Tilapia catch and effort (no of nets) data were collected from ten randomly sampled boats for five days every month at the major fish landing site locally known as fish market or Amoragedel. Spring balance was used to take the total weight of the catch of each sampled boat. The gillnets of each sample boat were counted during every sampling occasion. Similarly, a gillnet inventory of all boats was done every month. Catch per Unit Effort (CPUE) was obtained by dividing sample catch by sample effort. Total catch was obtained by multiplying the average CPUE of the month by the total effort (no of nets set) and number of working days per month. Accordingly the total annual catch and effort of the respective year was obtained by summing up the monthly total catch and effort data.

The Maximum Sustainable Yield (MSY) of Tilapia was estimated using Schaefer and Fox models as follows (Schaefer, 1954, 1957; Fox 1970).

$$\text{Schaefer parabola yield model: } Y_i = af_i + bf_i^2$$

$$\text{Fox parabola yield model: } Y_i = f_i * e^{a+bf_i}$$

Where,

Y_i = The total annual yield of tilapia during year i (tons/year)

f_i = The total annual effort expanded by the fishery during year i (no of gill nets/year)

a and b are constants of the relationship

The above parabola yield equations were transformed into linear form as follows

$$\text{Schaefer Linearized equation: } Y_i/f_i = a + bf_i$$

$$\text{Fox linearized equation: } \ln(Y_i/f_i) = a + bf_i$$

Where,

Y_i/f_i = Catch per unit effort (tons/net) of the respective year

f_i = The total annual effort expanded by the fishery during year i (no of gill nets/year)

a and b are constants of the relationship

Accordingly a linear regression was established between Y_i/f_i and f_i (Schaefer model) and between $\ln(Y_i/f_i)$ and f_i (Fox model) and the corresponding intercept (a) and slope (b) values were estimated. Hence, from the above relationship The Maximum Sustainable yield (MSY) and optimum fishing effort level that gives the maximum sustainable yield (f_{MSY}) were estimated as follows (Schaefer, 1954, 1957; Fox 1970; Ricker, 1975; Caddy, 1980; Pauly, 1984; Schnute, 1985).

Schaefer model

$$MSY = a^2/4b$$

$$f_{MSY} = a/2b$$

Fox model

$$MSY = -(1/b) * e^{(a-1)}$$

$$f_{MSY} = -1/b$$

Where,

MSY is the maximum sustainable yield of tilapia (tones/year) and f_{MSY} is the fishing effort that should be expanded on the tilapia stock per year to get the maximum sustainable yield (gill nets/ year).

3. Results and discussion

Annual tilapia yield and effort level expanded by the fishery Total annual yield of tilapia (tones/year) and annual effort (no. of gill nets per year) expanded on the tilapia fishery of Lake Hawassa between the years 2005 upto 2013 are shown in Table 1. Accordingly, on average an estimated number of

492587 gill nets were expanded by the fishery annually during the mentioned nine years and this gave an average of about 480 tones of tilapia per year. This means an average of about 1350 nets were set per day during the said period. As seen from the table, effort levels have been declining from close to 80,000 nets per year in 2007 to about less than half in 2013.

Table 1: Total annual effort (gillnets/year) and annual yield (tones/year) of tilapia caught from Lake Hawassa between 2005 and 2013. Columns 4 and 5 are CPUE and Ln (CPUE) values prepared for Schaefer and Fox yield model, respectively.

Year	Total annual effort (nets/year)	Total annual yield (tones/year)	CPUE (tones/net)	Ln (CPUE)
2005	502842	550	0.001093783	-6.81811
2006	607620	573.7	0.000944176	-6.9652
2007	799080	366.7	0.000458903	-7.68667
2008	563880	500	0.000886713	-7.02799
2009	485880	480	0.000987898	-6.91993
2010	368160	450	0.001222295	-6.70703
2011	368040	470	0.001277035	-6.66321
2012	360780	490	0.001358168	-6.60162
2013	377000	440	0.001167109	-6.75323
Average	492587	480.04		

3.1 Yield estimation

Based on the Schaefer model, the equation that expresses the CPUE (Y_i/f_i) of tilapia in Lake Hawassa as a function of fishing effort is given as follows (Figure 2a).

$$Y_i/f_i = 0.002 - 0.000000002f_i$$

From this, the corresponding parabola yield equation for the tilapia of the Lake Hawassa fishery is expressed as follows (Figure 3a)

$$Y_i = 0.002f_i - 0.000000002f_i^2$$

Accordingly, values of the intercept (a) and the slope (b) are 0.002 and -0.00000002, respectively.

Similarly, the linearized as well as the parabola yield equation for the tilapia of Lake Hawassa based on the Fox model are expressed as follows.

$$\begin{aligned} \ln(Y_i/f_i) &= -5.867 - 0.000002f_i && \text{Linear form (Fig 2b)} \\ Y_i &= f_i * e^{-5.867 - 0.000002f_i} && \text{Parabola form (Fig 3b)} \end{aligned}$$

From the above expression, values of the intercept (a) and the slope (b) are given as -5.867 and -0.000002, respectively.

Hence, based on the above, the MSY and f_{MSY} values are estimated as follows

$$\text{Schaefer model } MSY = 500 \text{ t/year}, \quad f_{MSY} = 500,000 \text{ gill nets/year}$$

$$\text{Fox model } MSY = 521 \text{ t/year}, \quad f_{MSY} = 500,000 \text{ gill nets/year}$$

As shown above, both models gave the same optimum fishing effort level (f_{MSY}) for the tilapia of Lake Hawassa which is

50,000 nets per year. Hence on a daily basis this is an effort level of about 1370 nets. Similarly the yield estimates obtained from both models is quite similar and this indicates that the estimates can be well trusted. Generally it can be said that a total of about 500 tones of tilapia can be harvested sustainably from Lake Hawassa but this figure is to be seen as a long term average.

As per the recommendation of Sparre and Venema (1992)^[13], safe level of exploitation (i.e., optimum fishing effort) is 20% less than the fishing effort that gives the maximum sustainable yield (f_{MSY}). Accordingly, taking 80% of the f_{MSY} obtained in this study (1370 nets /day), the optimum level of fishing to be expanded on the tilapia stock of Lake Hawassa should not exceed 1000 gill nets/year.

Yield estimates obtained in this study (500 tones /year) is close to the safe level of exploitation recommended by Reyntjens and Tesfaye Wudineh (1998)^[8], which is 528 tones/year.

Similarly Yosef (unpublished report) based on data collected in 2002, the estimated annual tilapia yield of about 550 tones/year. In addition, the present result is also close to the estimate by Yitayal Alemu *et al.* (in preparation) for the tilapia of Lake Hawassa, which is 466.28 tones/year estimated based on data collected in 2013.

The estimated optimum effort level in the present study for the Tilapia stock of Lake Hawassa i.e., close to 1000 nets/day) is slightly higher than the recommended safe level of fishing estimated by Reyntjens and Tesfaye Wudineh (1998)^[8] as 700 nets per day. Similarly, Yosef (unpublished data), based on data collected in 2002 recommended a fishing effort of less than 1000 nets for the Tilapia stock of Lake Hawassa. These differences could be due to usage different stock assessment models as the latter authors used analytical stock assessment models, which are different from the holistic models used in the present study.

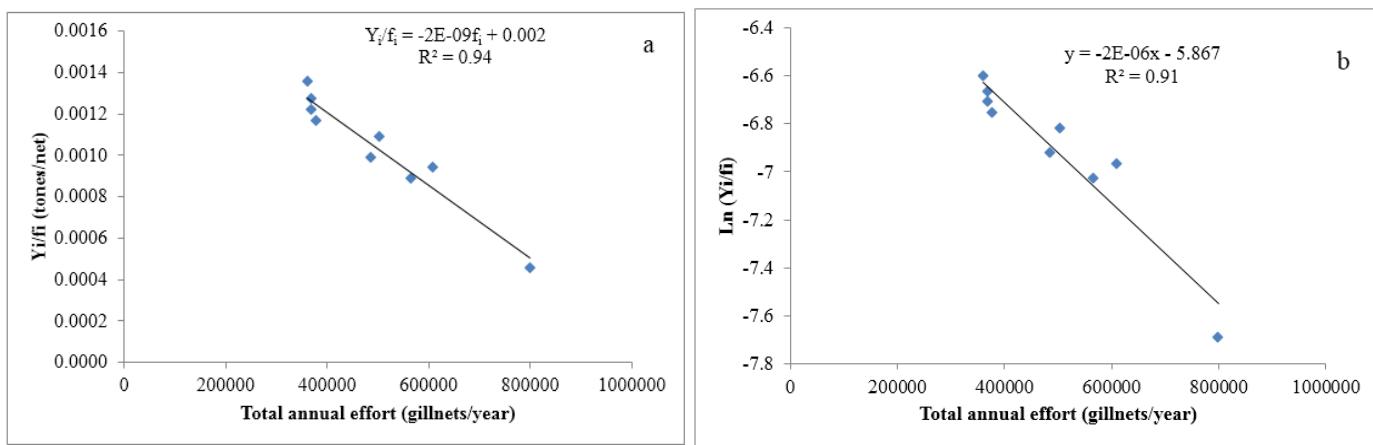


Fig 2: Yield per unit effort (tonnes/gillnet) of tilapia caught from Lake Hawassa between 2005 and 2013 (a) and Natural log values of Yield per unit effort (b) expressed as a function of total annual effort.

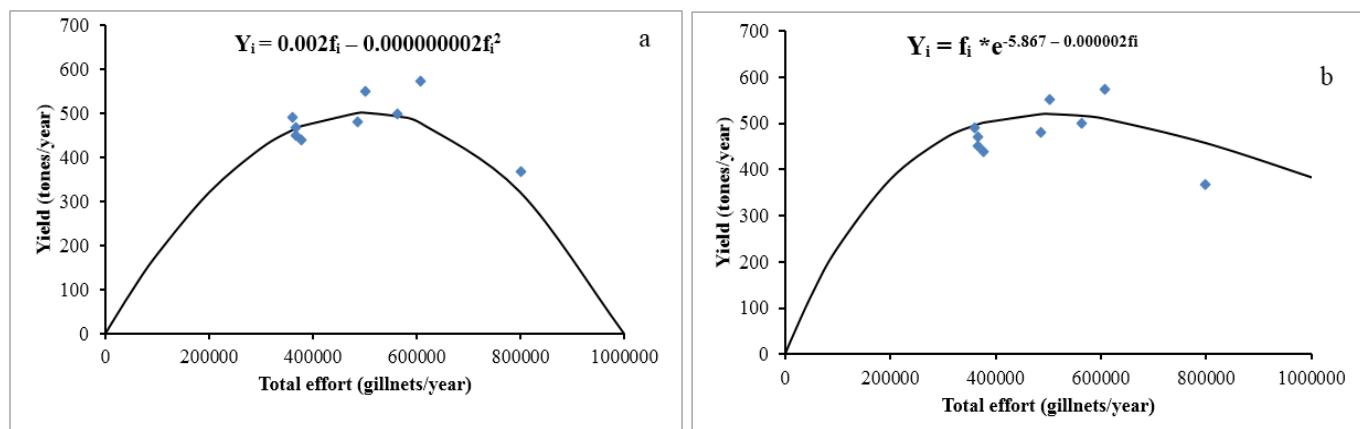


Fig 3: Total annual yield (tonnes/year) as a function of fishing effort for the tilapia stock of Lake Hawassa. Schaefer (a) and Fox (b) parabola yield curves are fitted to the data and shown with the respective equations.

4. Conclusion

Because of the huge increase in fishing effort and decrease in mesh size of the gillnets that happened since the last two decades, the yield estimate obtained in the present study is by half less than that of the yield estimate of 900 tonnes/year made based on data collected between 1992-1994 (LFDP, 1994). This shows that the tilapia of Lake Hawassa is being overfished. If this continues and enforcement measures are not taken promptly, the tilapia of the lake will be seriously depleted. To improve the current situation, it is therefore recommended to further reduce the number of the fishing gears (nets) as well as increase the mesh size of gillnets.

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