EFFECTS OF LAKE NAIVASHA (KENYA) CLOSURE TO FISHING ON *TILAPIA ZILLII* (GERVAIS 1848) POPULATION CHARACTERISTICS

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ABSTRACT

Fishing activities on Lake Naivasha were banned for a year in 2001 following a rapid decline in fish catches attributed to overexploitation and environmental degradation. Studies were done to estimate growth, mortality, and exploitation rate of *Tilapia zillii* from length frequency data collected in January to December in 1995, 2002 and January to May 2003 from commercial catches in Lake Naivasha to evaluate the effect of the fishing ban. Experimental gillnetting studies were done during 2001 closure period. Data analysis was done using FISAT (FAO-ICLRAM Stock Assessment Tool) software.

The asymptotic length (L_∞) was estimated at 28.93, 29.00, 37.08 and 28.90 cm TL, growth curvature (*K)* of 0.56, 0.83, 0.36 and 0.60 yr^{-1}, total mortality (*Z)* of 3.50, 5.14, 1.22 and 4.56 yr^{-1} and exploitation rate (*E*) of 66, 71, 33 and 72 % in 1995, 2001, 2002 and 2003 respectively. The study showed remarkable changes in population characteristics immediately after the lifting of the ban in 2002. The annual catches also rose from 0.9 t in 2000 before fishing ban to 21 t in 2002 after lifting of the ban.

The increase in L_∞, catches and a reduction of *K*, *F* and *E* immediately after lifting of the ban revealed that the closure of the fishery had a positive impact on the *T. zillii* fishery. However, the same parameters and catches in 2003 two years after lifting of the ban were at a level indicative of intense exploited again.

Remedial measures to sustain the fishery are recommended. These include: limiting entry to the fishery, eradication of illegal fishing methods, reduced environmental degradagation, encouraging alternative livelihood and involvement of the community in the fisheries management.

Keywords*:* environment degradation, co-management, population characteristics

INTRODUCTION

Lake Naivasha originally contained only endemic fish *Apocheilichthys antinorii* (Vinc.) which was last recorded in 1962 but since 1925, various fish introductions have been made, some successful and some not (Muchiri and Hickley 1995; Hickley *et al.* 2004).

The overall fish species composition in catches has been variable over the years from 21-1150 t yr^{-1}(Hickley *et al.* 2002; 2004), and three phases of development have been identified: an initial boom (1959-1973), a period of stability (1974-1988) and recently, a poor performing fishery (Hickley *et al.* 2004). A total of 1150 t yr^{-1} and 280 t yr^{-1} were recorded during the boom and the stability phases respectively. The poor performing phase averaged 150 t yr^{-1}, including 21 t yr^{-1}, the lowest, in 1997 (Hickley *et al.* 2004).

The mean annual commercial species composition of the fin-fish landed for the period 1987-2000 was dominated by *Oreochromis leucostictus* (Trewavas), 71.1%, *Micropterus salmoides* (Lacépède), 19.5% and *Tilapia zillii* (Gervais) 8.8% (Hickley *et al.*, 2004). There was a shift in composition with dominance of *Cyprinus carpio* (L) 45.7%, *O. leucostictus* 27.2%, *M. salmoides* 16.2% *T. zillii 10.9*% in the 2002-2005 commercial catches. The other important fishery in the lake is of the introduced Louisiana crayfish, *Procambarus clarkii* (Girard) which is consumed locally and some is exported.

Mugo and Ojuok (2002) state that the most numerous species in terms of numbers is *T. zillii*, accounting for 42.6% followed by *O. leucosticus* (38.0%) and *M. salmoides* (19.3%).

T. zillii which was introduced in Lake Naivasha in 1956 is widely distributed in Africa and Eurasia (Muchiri *et al.,* 1995; Froese and). *T. zillii* is common in shallow marginal waters, avoids deoxygenated waters at all stages of growth. The species feeds mainly on detritus and insects in Lake Naivasha (Muchiri *et al.*, 1995). Several countries report adverse ecological impact after introduction (Muchiri *et al.* 1995; Froese and Pauly 2002). *T. zillii* is important ecologically and commercially and it plays a salient role in determining the dynamics and structure of Lake Naivasha, and is valued as food by man (Abiya 1996; Muchiri *et al.* 1995).

Following dramatic decline in fin-fish species in the late 1990s in Lake Naivasha, a year long ban on fishing activities was imposed in 2001 (Mugo and Ojuok 2002). Population characteristics of *T. zillii* in Lake Naivasha which have not been previously published were estimated to evaluate the effect of fishing activities ban and recommend a sustainable fishery.

The major commercial fishery of Lake Naivasha is based on introduced species of *Oreochromis leucostictus* (Trewavas), Black bass, *Micropterus salmoides* (Lacépède), *Tilapia zillii* (Gervais) and crayfish (*Procambarus clarkii* (Girard) and recently the common carp, *Cyprinus carpio* (L) (Muchiri *et al.* 1995; Abiya 1996; Mugo and Ojouk 2002; Hickley and Harper 2002; Hickley *et al.* 2002; 2004).

MATERIALS AND METHODS

Study area

Lake Naivasha is shallow, endorheic, freshwater lake, approximately 150 km^2 in area, located in the Eastern rift valley of Kenya (Figure 1). It lies in a closed basin at an altitude of 1890m above sea level and receives 90% of its water from perennial rivers Malewa and Gilgil while the remaining input comes from empheral streams, rainfall and ground seepage. The lake is 4-6 m deep, and is subject to considerable fluctuations in water levels. Although a closed basin, it has remained a freshwater lake and this is attributed to water and salt loss by seepage (Beadle 1932; Jenkins 1936; Siddiqui 1977) and the burial and deflation of salts, their removal by seepage and possibly by fringing swamps (Richardson and Richardson 1972). Water temperature is generally in the range of 18-22^{0}C. The area is semi arid, receiving approximately 600 mm of rainfall year^{-1} and has transpiration of 1700 mm year^{-1}. Rainfall is bimodal, with peak in April and minor one in October and November. The area hosts 3 National Parks and a RAMSAR site. Around the lake, there is a vibrant horticultural economy which is fully dependent on the available water resources. A detailed description of Lake Naivasha is given by Muchiri *et al.* (1995) and Abiya (1996).

Sampling

Length frequency data on *T. zillii* fished by gill nets was collected five days a week from commercial fishery in January to December in 1995, January to July in 2001, August to December in 2002, and January to May in 2003. All commercial fish caught in Lake Naivasha are landed at one site. Additional fish samples were obtained from experimental gillnetting from August 2001 to July 2002. For experimental gill netting, fleets of multifilaments nets with stretch meshes from 50 mm to 125 mm were used to collect fish samples from eight sites representing various habitats in the lake (Figure 1).

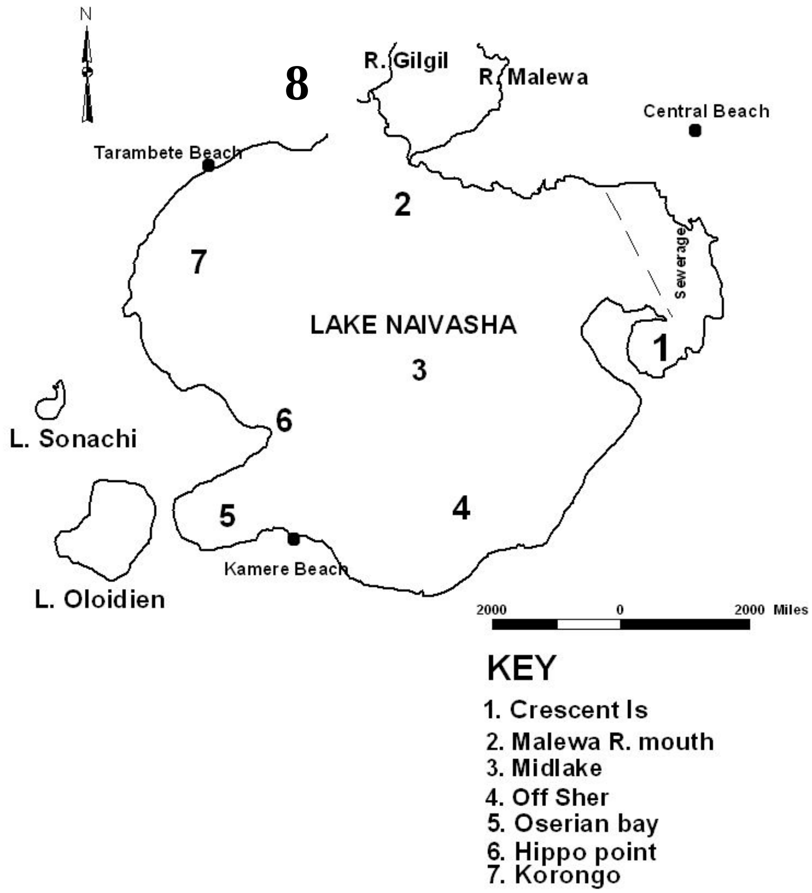

Figure 1. Map of Naivasha showing the sampling sites

Total length (TL) of the fish was measured to the nearest cm using a measuring board. Data analysis was based on length frequency distribution analysis (Pauly *et al.*, 1984; Sparre and Venema, 1998). The Electron Length Frequency Analysis (ELEFAN I and II) computer programmes incorporated in FAO-ICLRAM Stock Assessment Tool (FISAT) (Gayanilo *et al.*, 1996) was used to estimate population parameters. Data was merged into a single file thus constituting a single ''artificial year''. The estimate of growth parameters were based on the von Bertalanffy growth formula (VBGF) (Sparre and Venema, 1998) expressed by the formula:

$$L_t = L_\infty (1\text{-exp} (-K^{(t- to)})),$$

where, L_t is the predicted length at age t, L_∞ is the asymptotic length, K is a growth constant, t_o is the age the fish would have been at zero length. The growth performance index (ø') was computed according to Pauly and Munro (1984):

$$ø' = log_{10} K + 2\ log_{10} L_\infty,$$

where, is the growth constant (yr^{-1}) and L_∞ is the asymptotic length. (are similar, can't you use a different symbol?).

Total mortality coefficient (Z) was estimated using length-converted catch curve (Pauly *et al.*, 1984). This method consists of a plot of the natural logarithm of the number of fish in various age groups against their corresponding age. A regression analysis is done on the descending right hand arm of the catch curve, and Z estimated as the negative slope. The natural mortality coefficient (M) was estimated following Pauly's empirical formula (Pauly, 1980), linking natural mortality with the von Bertalanffy parameters, K (yr^{-1}), L_∞ (cm) and the mean annual temperature (T °C) of the water in which the fish stock lives (in this case 25°C):

$$\log_{10}(M) = -0.0152 - 0.279 * \log_{10} L_\infty + 0.6543 \log_{10} K + 0.463 \log_{10} T$$

Fishing mortality (F) was computed from the relationship $F = Z\text{-}M$, while the exploitation rate (E) was calculated from the relationship $E = F/Z = F/(F + M)$ where E= the fraction of deaths caused by fishing (exploitation rate), F = fishing mortality per year and Z and M have the same significance as before.

Gear selection was estimated by backward extrapolation of the catch curve, thus estimating the number of juveniles which ought to have been caught had it not been for incomplete selection and recruitment (Pauly *et al.*, 1984). Seasonal changes in recruitment were displayed in graphical form indicative of the recruitment pattern. Growth parameters estimates of L_∞, K and t_o were used as inputs in this analysis in applications of the FISAT program.

Following Taylor (1958), it is calculated as the age at 95 % of $L\infty$, using the parameters of von Bertalanffy growth function as estimated above, $t_{max} = t_0 + 3/K$. Age at time zero or the birthday of the fish was computed using Pauly's (1979) empirical formula:

$$t_o = -0.3922 - 0.2752 \log L_\infty - 1.038 \log K$$

The relative-yield per recruit (Y'/R) was predicted using the Beverton and Holt model as modified by Pauly and Soriano (1986).

$$(Y'/R) = EU^{M/K} * \{1-((3U)/1+m)) + (3U^2/(1+2m)) - (U^3/(1+3m))\},$$

where (Y'/R) = relative yield (g) per recruit, $m = (1\text{-}E)/(M/K)$ and E=F/Z , E, F, Z and M have same significance as before, the rate at which length tends towards the asymptote of dimension $1/t$, $U = 1\text{-}L_c/ L_\infty$ = length (mm) of fish at first capture, L_∞= the mean length fish would reach if they were to grow indefinitely, L_c is the length at first capture. Plot of (Y/R) was done selection ogive which assumes an increasing probability of capture with length (Sparre and Venema, 1998). Information on annual catches were obtained from the Department of Fisheries.

RESULTS

Population structure showed that majority of fish caught in 1995, 2001, 2002 and 2003 ranged between 14 to19 cm TL, 11 to 20 cm TL, 18 to 23 cm TL, and 16 to 21 cm TL respectively (Figure 2). The largest fish measuring 36 cm TL was collected in 2002 immediately after the ban was lifted.

Asymptotic length (L_∞) ranged from 28.90 cm TL in 2003 to 37.08 cm TL in 2002 (Table 1). The steepest growth rate curvature (K) of 0.83 yr^{-1} was recorded in 2001 and the lowest of 0.36 yr^{-1} in 2002. The highest total mortality of 5.14 yr^{-1} and the lowest of 1.22 yr^{-1} were recorded in 2001 and 2002 respectively. Exploitation rate was highest (73%) in 2003 and lowest (33%) in 2002. The phi prime ranged between 2.67 to 2.84 with fish caught in 1995 and 2001 recording the highest and the lowest respectively (Table 1).

Probability of capture (resultant curve) derived from the length-converted catch curve showed that 50 % of *T. zillii* entry to the fishery had the highest length of 15.1 cm TL and the lowest of 9.86 cm TL in 2003 and 2001 respectively (Table 1).

Table 1 : Major population parameters of *Tilapia zillii* from Lake Naivasha , Kenya

Parameter	Year			
	1995	2001	2002	2003
L∞ (TL, cm)	28.93	29.00	37.08	28.90
K($year^{-1}$)	0.56	0.83	0.36	0.60
to (years)	-0.53	-0.17	-0.36	-0.56
t_{max} (years)	4.82	2.90	7.97	4.44
’	2.67	2.84	2.69	2.70
Z ($year^{-1}$)	3.40	5.14	1.22	4.56
F ($year^{-1}$)	2.23	3.63	0.40	3.34
M ($year^{-1}$)	1.17	1.51	0.82	1.23
LC50(cm)	13.67	9.86	14.70	15.16
E	0.66	0.71	0.33	0.73
E_{50}	0.34	0.24	0.32	0.36
Emax	0.64	0.51	0.61	0.70

The maximum and the lowest age attainable were 7.97 and 2.90 years in 2002 and 2001 respectively. The relative yield-per-recruit using the selection ogive had $E_{0.5}$ with a range of 0.24 in 2001 to 0.36 in 2003 and E_{max} of 0.51 in 2001 to 0.67 in 2003. Trends in catches since 1994 showed that the lowest catches were in recorded in 1999 (0.3 mt) and the highest in 2002 (21 mt) which was followed thereafter by a drastic drop (Figure 2).

DISCUSSION

FISAT was successfully used on length frequency data for *T. zillii* in order to estimate the population parameters. The asymptotic length (L_∞) in this study of *T. zillii* before ban (28.9 cm TL), during the ban (29.0 cm TL) and two years after the lifting of the ban (28.9 cm TL) are low compared to one year after the lifting of the ban (37 cm). The L_∞ recorded after lifting of ban is high compared to the same species in other parts of the world (Froese and Pauly 2002) (Table 2). Apart from 2002 when the growth curvature (*K*) was 0.36 yr^{-1}, in the other years, *K* (0.56-0.83 yr^{-1}) was high compared to the same species in other parts of the world (Froese and Pauly 2002; Table 2). Length at 50% capture was lowest during the 2001 closure (Lc_{50}=14.70 cm) and a further increase was recorded after the lift of the ban (Lc_{50}=15.16 cm) in 2003. The optimal maximum yield (E_{max} =0.51) was obtained during the closure period when fishing was at its minimal, while the projected maximum years the fish could live was highest in 2002 (t_{max}=7.97 years). Selection ogive which gives a more realistic estimation of fishing pressure than knife edge selection (Pauly and Sarioano 1986; Sparre and Venema 1989) indicated that there is excess fishing pressure in the lake in all the years except in 2002 (*E* = 0.33) the period immediately after the lifting of the ban.. Heavy fishing pressure in Lake Naivasha is supported by high fishing mortality rate coefficient (*F*) (2.23-3.63 yr^{-1}) and exploitation rate (0.66-0.73) before the ban and two years after lifting of the ban (Table 2).

Table 2 : Growth parameter estimates for T. zillii.(Adaptated from: Froese and Pauly 2002)

L_∞(cm)	Length	K)yr-1)	*φ’*	Country
28.1	TL	0.50	2.60	Egypt
21.1	TL	0.66	2.47	Egypt
26.3	TL	0.23	2.21	Israel
34.0	TL	0.20	2.74	Burkina Faso
15.5	SL	0.51	2.09	Egypt
17.0	SL	0.66	2.14	Egypt
18.9	SL	0.38	2.14	Syria
21.9	SL	0.63	2.46	Niger
24.8	SL	0.54	2.52	Niger
25.5	SL	0.72	2.67	Nigeria
28.6	SL	1.19	2.99	Uganga

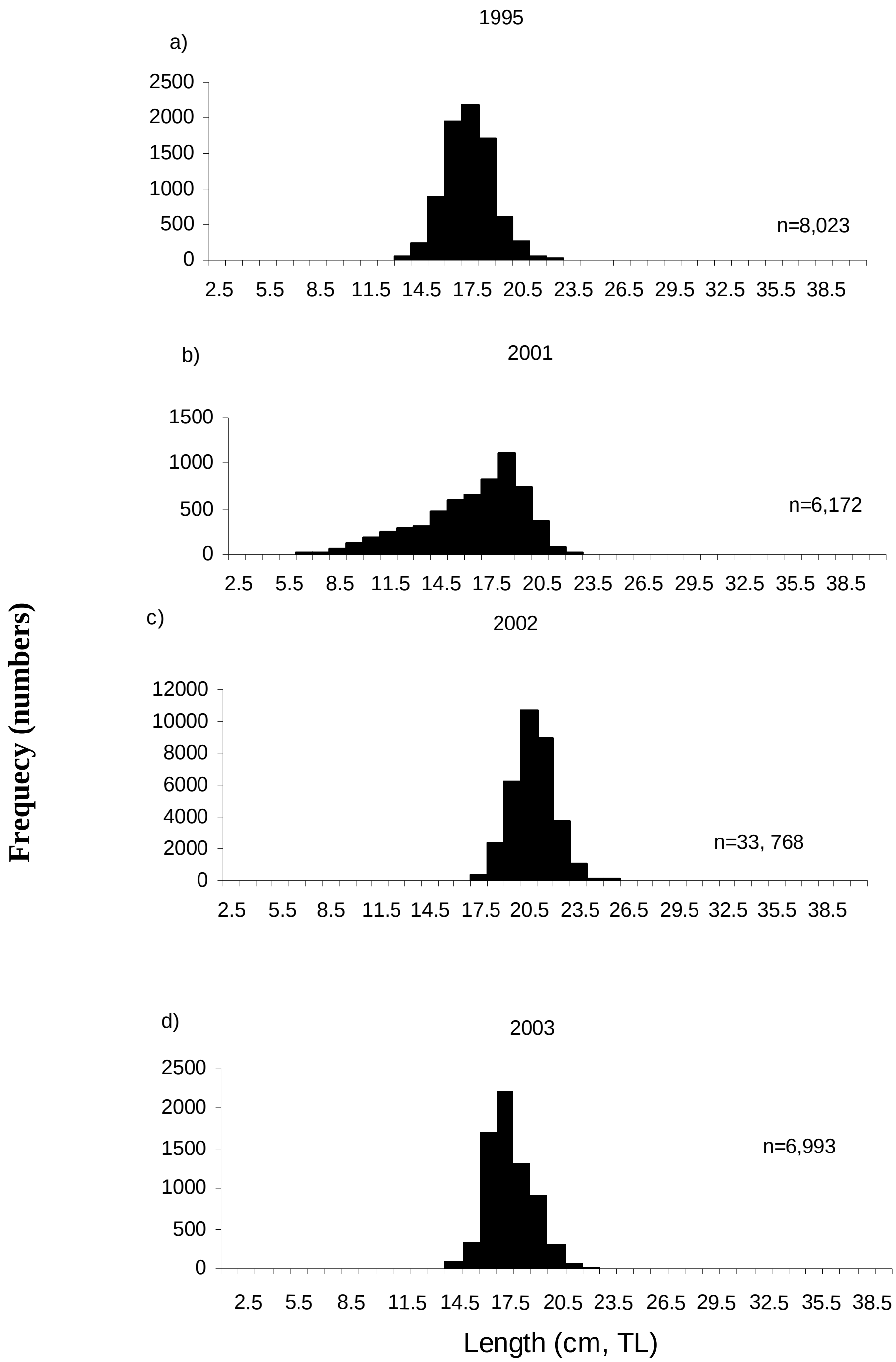

Figure 2 Length frequency distribution of *T. zillii* caught by gill nets from Lake Naivasha. a) 1995, b) 2001, c) 2002, d) 2003; n denotes the sample size.

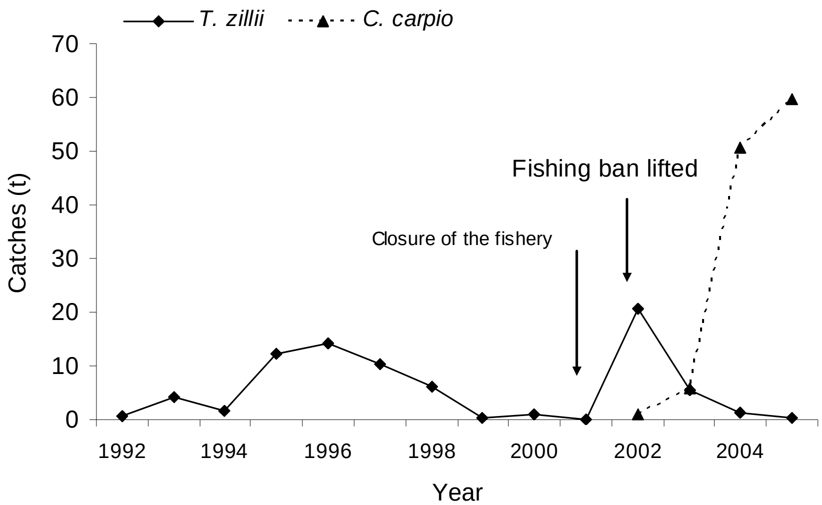

Figure 3. Annual catch trends in catches of *T. zillii* in Lake Naivasha and upsurge of *C. carpio* which is detrimetal to the suvival of *T. zillii.* Source: Kenya Fisheries Department,

The legal gear allowed in the lake is gillnets of 4''or more to allow fish to mature before being harvested. Only 43 boats are licenced by the fisheries Department, number of crew limited to 3 persons, no of gears per each boat restricted to 10 of the required sizes 4-10 inches ply 3. All the landings are supposed to be at two sites namely Kemere and central landing beach for easier control of fish sizes landed. However, none of these regulations are adhered to. Poaching using gears less than 4'' is rampant in the lake. Our survey enumerated more than 43 boats and rafts in the lake with more than 10 gears per boat. Even during the ban, unscrupulous fishers continued fishing at odd hours and Lake Naivasha fish has never missed in the market especially in Nairobi, the Capital of Kenya. The fishers normally land the legal sizes fishes at the recommended landing beaches while the undersize find their way to the market through other routes. The return of population characteristics in 2003 to the level before closure of the fishery is attributed to increased fishing pressure due to poaching and laxity in law enforcement.

Initial observations by Hickley *et al* (2004) indicted that after the reopening of Lake Naivasha for fishing, there was an upsurge of *C. carpio* which can have seriously disadvantage recovery of *T. zillii,* a substratum spawner. Our investigations revealed that *C. carpio* is now the major commercial species in Lake Naivasha. The carp is a benthivore and its detrimental effects are associated with its characteristic feeding behaviour which involves sucking in sediments with prey items and retaining food organisms whilst sediment particles are expelled. It is the habit of feeding on bottom sediment, which uproots aquatic plants, suspends the sediment and increases water turbidity. The behaviour of the carp will affect recruitment of *T. zillii* whose larvae develop in close association with the substrate (Froese and Pauly 2002). Uprooting of plants in already stressed Lake Naivasha macrophytes will drastically reduce the feeding base of *T. zillii,* a macrophytic feeder.

The fisheries department charged with the responsibility of managing the fisheries is ill equipped with personnel and transport to monitor the entire lake. Mugo and Ojuok (2002) recommended a maximum of 40 boats in the lake until the fishery recovered fully. Our findings revealed that this has not been observed. Further, the restriction on the maximum number of gill nets allowed per fishing license of 10 per boat and a minimum mesh size of 100 mm, (4'') are also not adhered to (Njiru and Ojuok 1997; Mugo and Ojuok 2002). Prior to the ban, poaching using illegal nets of 50 mm (2'') and excess of 80 nets per boat were common (Mugo and Ojuok 2002). There are indications that these illegal practices are creeping back again in the lake.

Continued increase of boats, fishers and use of mesh size smaller than recommended and subsequent capture of immature fish will lead to a further reduction of the size of *T. zillii* at first capture. The fishers will further reduce their mesh size and resort to unorthodox fishing to target the smaller fishes. To sustain the fishery, the recommended 40 boats and ten nets per boat and in addition the registration of boats and license of nets should be enforced. To succeed in enforcement, all stakeholders should be involved. Community based monitoring, control and surveillance should be given priority because the fisheries department lacks the personnel and is ill equipped. Co-management, if successful, would drastically reduce use of illegal gears and curb poaching on the lake. Fish landed should be sold through co-operatives societies to improve returns to the fishers. Alternative livelihood, such as aquaculture, ecotourism and farming, should be encouraged to reduce pressure on the lake fishery.

About 1/3 of the average inflow of the major river is abstracted by Olkaria Geothermal power station. Water abstraction leads to reduction in water levels affecting the wetlands- feeding /nursery grounds of T. zillii Exploitation of water has to be managed.

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