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The status and future of the Lake Naivasha fishery, Kenya

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Abstract

Lake Naivasha is a freshwater lake situated in the eastern rift valley of Kenya. Only five species of fish are present, all of which have been introduced. They are *Oreochromis leucostictus*, *Tilapia zillii*, *Micropterus salmoides* (largemouth bass), *Barbus amphigramma* and *Poecilia reticulata* (guppy). The first three of these form the basis of an important gill net fishery and bass are also taken by rod and line for sport. *Barbus* are occasionally caught by dip net. Actual and potential yields for the Lake Naivasha fishery are discussed and the fishery is shown to be under-performing. The feeding regimes of the commercially exploited fish were examined in the context of available food supply, in particular the benthic fauna. Small bass depend heavily on *Micronecta* and large bass mostly take crayfish. Detritus predominates in the diet of *Oreochromis leucostictus* and *Tilapia zillii* but the former also eats algae and the latter, *Micronecta* and macrophyte. Various food resources, especially the benthos, appear to be under-utilized and so it is possible that further species could be introduced to enhance the commercial fishery.

Introduction

Lake Naivasha is a shallow (3–6 m) freshwater lake, approximately 160 km^2 in area, situated in the eastern rift valley of Kenya about 100 km north of Nairobi. It lies in a closed basin at an altitude of 1890 m above sea level, receives 90% of its water from the perennial River Malewa, and is subject to considerable fluctuations in water level. Dominant vegetation types are belts of papyrus (*Cyperus papyrus* L.) around the margins, stands of submerged macrophytes, of which the principal species is *Najas pectinata* (Parl.), and mats of floating plants comprising *Salvinia molesta* Mitch. and *Eichhornia crassipes* (Mart.). An overview of the lake and its changing ecology can be found in Harper et al. (1990).

Resulting from a probable history of occasional drying out, Lake Naivasha when first studied (c.1900) had only one species of fish present, the endemic *Aplocheilichthys antinorii* (Vinc.) which was last recorded in 1962 (Elder et al., 1971). Since 1925, various fish introductions have been made, some successful and some not (Litterick et al., 1979; Muchiri & Hickley, 1991). Present today are *Oreochromis leucostictus* (Trewewas), *Tilapia zillii* (Gervais), *Micropterus salmoides* Lacépède (largemouth bass), *Barbus amphigramma* Blgr. and *Poecilia reticulata* Peters (guppy). Since 1959, the two tilapias and the bass have formed an important fishery (Muchiri & Hickley, 1991) with all three species being commercially exploited using gill nets and the bass also being taken by rod and line for sport.

The purpose of this paper is to relate the current status of the commercial fishery to information on fish feeding regimes and potential yields so as to identify whether or not there is scope for better management and utilisation of the resource.

Methods

Commercial catch data were obtained from the Fisheries Department of the Kenya Government. Fishermen use multifilament gill nets with a minimum stretched mesh size of 100 mm and are limited to a maximum of 10 nets of not more than 100 m in length. All catches must be landed at a single station near Naivasha town where fisheries personnel record the weight of the catch from each canoe. Data collection commenced in 1963. In addition, some *B. amphigramma* were taken downstream of a weir on the River Malewa.

Gill net catch statistics were fitted to a version of the Schaefer model (Ricker, 1975; Pauly, 1983): $C = \mathrm{a} + \mathrm{b}E$ where C = catch per unit effort, E = effort (with effort being the number of canoes licensed to fish in a given year), a and b are constants. Maximum sustainable yield (MSY), optimum effort and equilibrium yields were then calculated: $\mathrm{MSY} = \mathrm{a}^2/4\mathrm{b}$; optimum effort = a/2b; equilibrium yield = $\mathrm{a}E - \mathrm{b}E^2$.

The theoretical annual yield (Y) of fish was estimated using a range of models suitable for use with non-temperate data. These were based on various measures including lake surface area (A), morphoedaphic index (MEI; the ratio of total dissolved salts (TDS) to mean lake depth (Z)), primary productivity ($P = \mathrm{gO_2\ m^{-2}\ d^{-1}}$, $X = \mathrm{gC\ m^{-2}\ yr^{-1}}$), air temperature ($T$) and effort ($E$) as listed below by author:

(a) Crul (1992): $Y = 8.32\ A^{0.92}$ ($Y = \mathrm{t\ yr^{-1}}$);
(b) Henderson & Welcomme (1974): $Y = 8.7489\ \mathrm{MEI}^{0.3813}$ ($Y = \mathrm{kg\ ha^{-1}}$)
(c) Melack (1976): $\log Y = 0.113\ P + 0.91$ ($Y = \mathrm{kg\ ha^{-1}}$);
(d) Oglesby (1977): $Y = 0.00038\ X^{2.21}$ (Y = mg dry wt $\mathrm{m^{-2}\ yr^{-1}}$);
(e) Schleisinger & Regier (1982):
(i) $\log_{10} \mathrm{MSY} = 0.061\ T + 0.043$ ($Y = \mathrm{kg\ ha^{-1}}$);
(ii) $\log_{10} \mathrm{MSY} = 0.044\ T + 0.482 \log_{10} \mathrm{MEI} + 0.021$ ($Y = \mathrm{kg\ ha^{-1}}$);
(iii) $\log_{10} Y = 0.051\ T + 0.358\ E_{\mathrm{Low}} + 0.161 \log_{10} \mathrm{MEI} - 0.383$ ($Y = \mathrm{kg\ ha^{-1}}$);
(iv) $\log_{10} Y = 0.050\ T + 0.349\ E_{\mathrm{High}} + 0.146 \log_{10} \mathrm{MEI} - 0.367$ ($Y = \mathrm{kg\ ha^{-1}}$).

In the foregoing equations the following values were used: $A = 163\ \mathrm{km^2}$; $Z = 3.35$ m; TDS = 231; MEI = 68.95; $P = 8.98\ \mathrm{gO_2\ m^{-2}\ d^{-1}}$; $X = 99.16\ \mathrm{gC\ m^{-2}\ yr^{-1}}$; $T = 21\ °\mathrm{C}$; $E_{\mathrm{Low}} = 1$; $E_{\mathrm{High}} = 2$. Sources of data for mean values of TDS and primary production were Melack (1979), Harper (1987), Harper (1991) and original (this study) and, for temperature, Litterick et al. (1979) and Muchiri (1990). Area is for 1991, the year in which the average depth was measured (see below).

In order to determine the above figure for average depth the lake was surveyed during August 1991 using a Lowrance X-15 chart recording echo-sounder with a 20° transducer beam. The soundings were carried out from a small boat driven at constant speed between two defined positions and, using known travel times and distances, the chart recordings were transcribed into depth profiles. Åse et al. (1986) had used a similar echo-sounder in 1983 but had concentrated on the north of the lake. After confirmation of the 1983 findings, the 1991 survey concentrated on previously unmeasured areas.

From 1987, annual collections of bass and tilapia specimens for gut analysis were obtained by gillnetting (11–50 mm bar mesh) in the major habitat types of open water, submerged macrophyte beds, rocky shoreline and the marginal vegetation fringe. Stomachs were removed from representative samples across the size range captured, for each habitat type from each sampling year, and analysed as described by Muchiri (1990) and Hickley et al. (1994).

Results

Lake depth

A depth contour map based on both actual readings from the 1991 echo-sounder traces and interpolation from the map published by Åse et al. (1986) is given in Figure 1. Note that the lake level was approximately 1.75 m lower in 1991 than in 1983. Two examples of depth profiles, from west to east and south to north, are given in Figure 2.

Commercial fish catches

The annual catches for the gillnet fishery are shown in Figure 3. Over the years there have been great fluctuations in both the amount of fish landed (21–1150 t $\mathrm{yr^{-1}}$) and the number of fishing canoes (6–104). Catch per canoe ranged from 0.73 to 92.8 t $\mathrm{yr^{-1}}$. The average species composition of the catch (1987–1998) was *O. leucostictus* 67.6%, *T. zillii* 10.2% and *M. salmoides* 22.2%. The mean sizes (fork length) of fish landed were *O. leucostictus*, 192 mm (S.D. = 23 mm), *T. zillii*, 168 mm (S.D. = 17 mm), and bass, 262 mm (S.D. = 18 mm).

Three separate phases in the development of the fishery were identified:

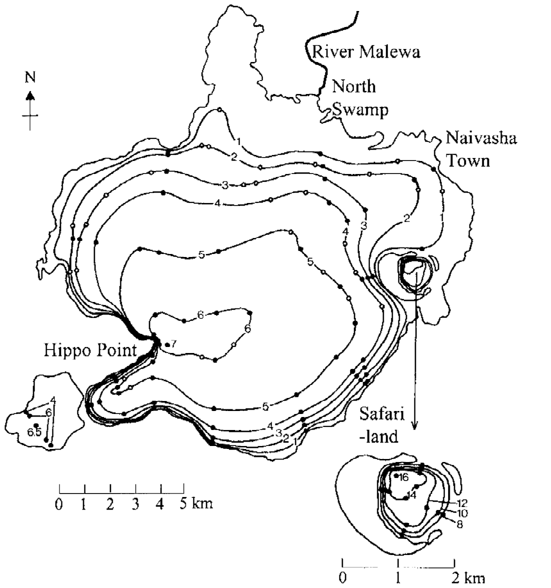

Figure 1. Bathymetric map (m) of Lake Naivasha based on 1991 transects (solid circles) and Åse et al. (1986, open circles).

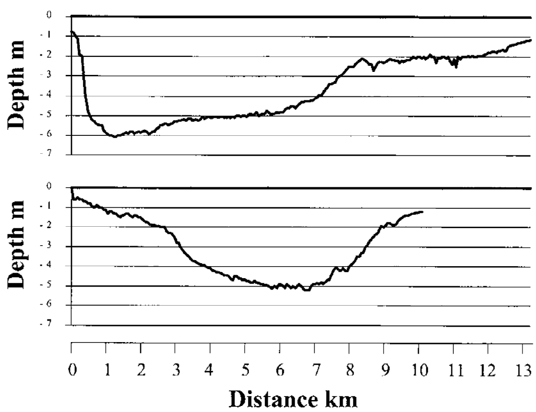

Figure 2. Depth profiles of Lake Naivasha. The upper graph shows approximately West to East, from Hippo Point to Naivasha Town, and the lower graph approximately South to North, from Safariland to North Swamp. Locations are shown in Figure 1.

(1) The period of development of the new fishery from 1959 to the time when the fishery collapsed in the early 1970s. During this 'boom and bust' phase the maximum recorded catch of 1150 t yr^{-1} was attained.

(2) The middle phase from 1974 to 1988 during which the fishery recovered and was then typified by fish catches which fluctuated but were still relatively high.

(3) The recent period of a poorly performing fishery with low reported catches.

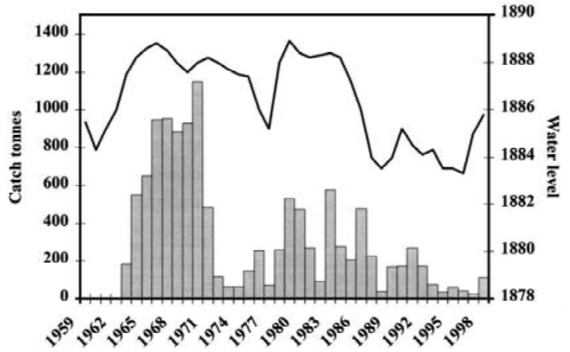

Figure 3. Total catches (bars) from the gill net fishery and water level changes (solid line) for Lake Naivasha during the period 1959–1998 inclusive. Commercial fishing started in 1959 and records kept from 1963.

Muchiri & Hickley (1991) attributed some of the fluctuations observed during the first two phases to fishing pressure, changing lake levels and the loss of submerged macrophytes. Although there were restrictions imposed on the maximum number of gill nets allowed under each fishing licence, the number of licensed canoes was at times very large. There is a considerable demand for fish in the neighbouring urban centres and horticultural estates whose populations recognise the importance of including fish protein in their diet. Fish catches appeared to be related to trends in water level changes with a rise in lake level generally followed by increased catches and a fall in level followed by a corresponding decline in fish catch. Submerged macrophytes almost disappeared during the early 1980s and this appeared to severely affect recruitment of new individuals to sustain the fishery.

Fish yields

Figures 4(a)–(d) show regression plots of computed catch per unit effort on effort, together with the resulting equilibrium yield curves, for the whole period from 1962 to 1998 alongside separate plots for the three identified phases of the fishery.

Estimates of actual fish yields are shown in Table 1(a). For the entire period 1962–1998, the computed maximum sustainable yield (MSY) was 641 t yr^{-1} with an optimum effort of 36 canoes. MSY for the development phase (1962–1973) was 731 t yr^{-1} and optimum effort was 20 canoes whereas in the 15 year long middle phase (1974-88) MSY was much lower at 341 t yr^{-1} and optimum effort higher at 51 canoes. These changes were reflected in a consequential decrease in CPUE from 47 t yr^{-1} to 9 t yr^{-1}. In

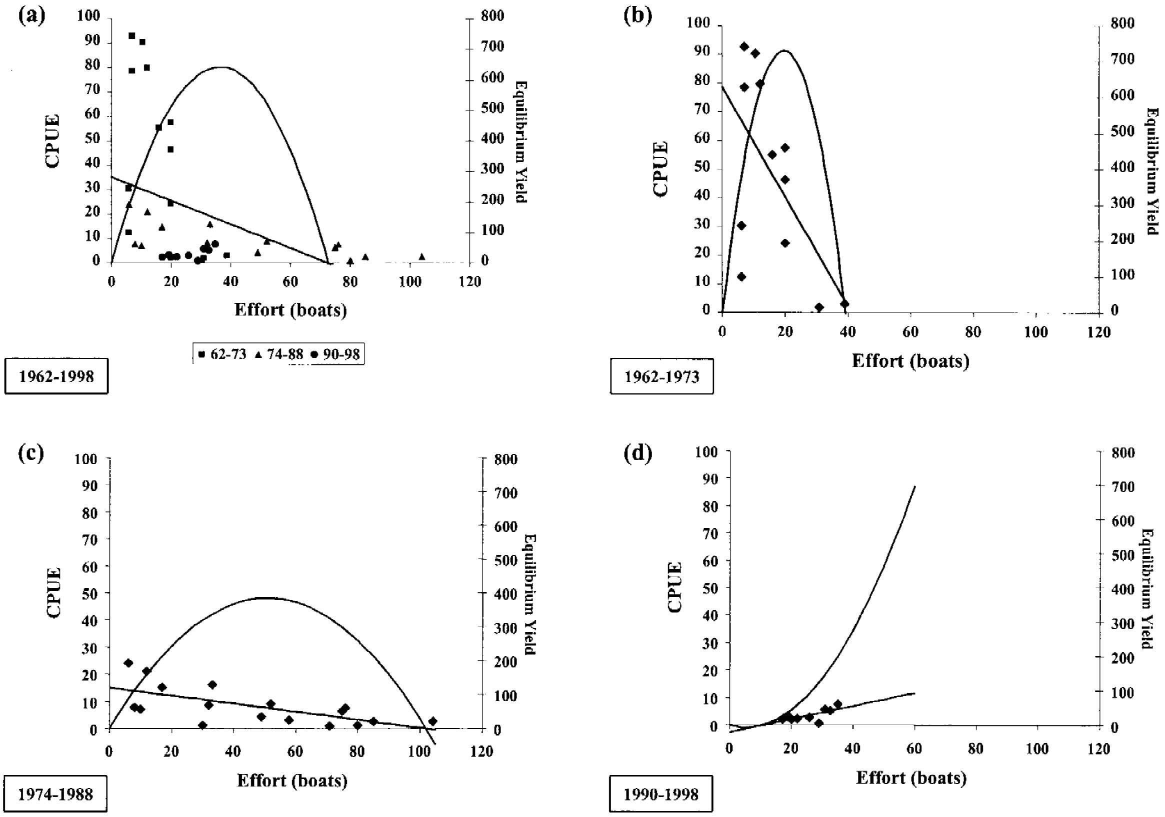

Figure 4. Regression plots of computed catch per unit effort (CPUE) on effort (E), together with the resulting equilibrium yield curves, for the whole study period alongside separate plots for the three development phases of the fishery. (a) 1962–1998; CPUE = 35.29 − 0.485E (r^2 = 0.196) (b) 1962–1973; CPUE = 78.48 − 1.897E (r^2 = 0.358) (c) 1974–1988; CPUE = 15.06 − 0.148E (r^2 = 0.435) (d) 1990–1998; CPUE = 2.59 − 0.237E (r^2 = 0.491).

recent times, the average CPUE (3.5 t yr^{-1}) has been at an all time low and MSY could not be calculated.

Theoretical annual fish yields are presented in Table 1(b). The average estimate shows the potential fishery yield to be 889 t yr^{-1}, more than previously recorded MSY values and considerably higher than the 384 t yr^{-1} for the relatively stable 1974–1988 period. The lowest estimates of theoretical yield equate to the 1974–1988 MSY value whereas estimates based on primary production are twice the value of the MSY for the development phase of the fishery (1962–1973).

The River Malewa fishery

The exploitation of the *B. amphigramma* spawning migration up the River Malewa by fishermen using dip-nets was short-lived. Fishing commenced in 1983, catches peaked at 62.9 t yr^{-1} in 1986, decreased to 26.1 t yr^{-1} in 1987 and thereafter only a small number of fish have been caught.

Feeding habits of fish

Micropterus salmoides

Hickley et al. (1994) reported that, until fish reach a size of 260 mm fork length, bass in Lake Naivasha were almost totally dependent upon free-living invertebrate food organisms. Thereafter, additions to the diet included crayfish, fish and frogs. The most important invertebrate prey species for the smaller bass were the water boatman, *Micronecta scutellaris* (Stal.) and dipteran pupae. For bass in the larger length category, the crayfish, *Procambarus clarkii* (Girard), was the preferred food. *Micropterus salmoides* in Lake Naivasha can, therefore, be classed as a generalized macro-predator, principally feeding on free living animals of a kind most likely to be found in the littoral zones.

Table 1. Estimates of actual and theoretical fish yields calculated for Lake Naivasha: (a) Summary statistics for catch per unit effort (CPUE) on effort (E) and the resultant maximum sustainable yield (MSY) (b) Theoretical yields based on various predictive models. For formulae and data sources see Methods

(a)

Year	E No. canoes (range)	Average CPUE t canoe^{-1}	Optimum E No. canoes	MSY t yr^{-1}
1962–1998	30 (6–104)	20.52	36.34	641
1962–1973	16 (6–39)	46.88	19.63	731
1974–1988	45 (6–104)	8.94	50.96	384
1990–1998	26 (17–35)	3.52	(5.46)	(−7)

(b)

Model	Parameters used	Theoretical annual yield t yr^{-1}
Crul (1992)	Surface area	902
Henderson & Welcomme (1974)	Morpho-edaphic index (MEI)	716
Melack (1976)	Gross primary production (g O_2m^{-2} d^{-1})	1371
Oglesby (1977)	Gross primary production (g Cm^{-2} yr^{-1})	1599
Schlesinger & Regier (1982)	Air temperature	344
Schlesinger & Regier (1982)	Air temperature & MEI (for depth <25 m)	1105
Schlesinger & Regier (1982)	Air temperature, MEI & effort (low)	358
Schlesinger & Regier (1982)	Air temperature, MEI & effort (high)	727
Mean of estimates		889

Oreochromis leucostictus

Detritus was found to be the principal component of *O. leucostictus* diet (Muchiri, 1990; Muchiri et al., 1994). It is the most abundant food material available to fish in Lake Naivasha and its importance has been previously noted by Malvestuto (1974) and Siddiqui (1977). Of the other dietary constituents, various algae, especially planktonic forms, were predominant although some chironomid larvae and oligochaete worms were also taken. In terms of feeding category classification, *O. leucostictus*, whilst in the main a detritus feeder, can also be described as a micro-herbivore.

Tilapia zillii

As for *O. leucostictus*, the diet of *Tilapia zillii* was reported as being principally detritus (Muchiri, 1990; Muchiri et al., 1994) but this species consumes a significant amount of macrophyte (mostly *Najas* and *Potamogeton*), rather than algae, and relatively large quantities of insect material. *T. zillii* is, therefore, a detritus feeder like *O. leucostictus* but with a secondary classification of omnivorous browser.

Barbus amphigramma

Muchiri (1990) indicated that *B. amphigramma* is primarily an insectivore, although zooplankton was an important dietary component.

Poecilia reticulata

As the guppy was introduced in an attempt to control mosquito larvae (Litterick et al., 1979), and has been used elsewhere in the tropics for this purpose (Costa, 1985), it is likely that the fish will take any similarly sized aquatic invertebrates to be found in the littoral zone.

Invertebrate fauna

The benthic fauna of Lake Naivasha comprises principally oligochaetes and chironomid larvae (Clark et al., 1989; Muchiri, 1990; Muchiri et al., 1994) a typical biota of many tropical lakes (e.g. Burgis et al., 1973; Green, 1979; Marshall,1982). The worms most commonly found in samples were the tubificids *Limnodrilus hoffmeisteri* (Clarepede) and *Branchiura sowerbyi* (Beddard). The predominant chironomid was *Chironomus formosipennis* Keiffer. Recent work (Raburu, 2002) estimated biomass and production of these benthic organisms to be 4.07 g dry wt m^{-2} yr^{-1} and 8.08 g dry wt m^{-2} yr^{-1}, respectively.

The littoral macro-invertebrate fauna shows greater species richness with approximately 50 species being present at any one time (Clark et al., 1989; Muchiri, 1990). By far, the most abundant organism recorded in all habitats, ranging from flooded farmland to open water, was the hemipteran *Micronecta scuttellaris* (Stal.) at approximately 400 m^{-3} Clark (1992).

Food web

From the information that they obtained on fish diets, Muchiri et al. (1994) constructed a basic food web. In order to facilitate recognition of any under-utilised resource, they restricted the pathways to only the most important of the feeding relationships. Possible under-utilisation was identified in relation to zooplankton, phytoplankton, fish and, in particular, the benthos.

Discussion

Since commercial fishing started, fish have been taken with gill nets which, in theory, makes regulating the fishery easier than if gears such as seine nets and trawls are used. As gill nets are selective, desired mesh sizes can be imposed and effort controlled by limiting numbers and lengths of nets in addition to regulating the numbers of fishing vessels. Unfortunately, the task of enforcing such regulations is often the difficult part for the fisheries manager. The most serious problems to be addressed are those of ensuring conformity with the gill net specifications and size limits by licensed operators and of curbing illegal fishing by unlicensed fishermen who have no regard for regulations. The latter issue is, however, as much a social concern as a fisheries one and requires a combined effort by the Fisheries Department, riparian interests and other stakeholders in the Naivasha region in order to educate and rehabilitate those people involved. A code of conduct has been drawn up by the Lake Naivasha Fisheries Department (1998) in an attempt to foster responsible fishing practices and to promote compliance with the legislation (Kenya Fisheries Act – Cap 378).

Although fish caught by unlicensed fishermen are unrecorded there was no loss of information on catches brought to the official landing station. Therefore, in spite of difficulties in obtaining accurate data, it could be considered that the reported commercial catches provide a good representation of the pattern of exploitation. Unfortunately, however, in recent years it has been observed that there has been an increasing tendency for more fish to be traded other than at the official location. It is possible, therefore, that the presumed poor performance of the fishery in the 1990–98 period could in part be due to under-reporting rather than reduced catches. Nonetheless, the fact that the lake level and catch show a very recent upturn (Fig. 3), and that in Figure 4(d) CPUE increases with effort, could indicate that the fishery is about to enter a recovery phase.

Calculations of MSY, although based on a simple version of the Shaefer model (Ricker, 1975; Pauly, 1983), are likely to be reliable. Muchiri et al. (1995) also worked on the fish catches for the 15 year period 1974–1988 inclusive. Using sophisticated catch and effort data analysis software (MRAG, 1992) to fit the data to various models of population growth, MSY estimates of 365–446 t yr^{-1} were obtained, as compared with 384 t yr^{-1} given in Table 1.

The theoretical fish yields given in Table 1 were calculated from limnological and primary production data. Hanson & Legget (1982), using a data set of 26 temperate lakes, suggested that total phosphorus and macrobenthos biomass were superior to MEI as predictors of fish yields but reported that for two tropical lakes, George and Naivasha, predictions from total phosphorus fell below observed values. Reasons suggested for this were that for tropical lakes, as against temperate ones, fish production is higher and most commercially important species are herbivores. The same situation of underestimation appears to be true for the use of macrobenthos biomass because when the current estimate of 4.07 g m^{-2} (Raburu, 2002) is used in the various formulae proposed by Hanson & Legget (1982) fish yield estimates of only 70–225 t yr^{-1} are obtained. Recently, Welcomme (1999) considered methods for estimating the potential output from fisheries and concluded that there is no system as yet to predict the symptotic level at which Y_{max} will occur other than the generalised predictors such as MEI. Accordingly, the theoretical fish yields for Lake Naivasha were calculated in such a way.

The potential fish yields, with a mean of 889 t yr^{-1}, suggest that the overall MSY for the Naivasha fishery could be higher. In particular, the estimates based on primary production models (Melack, 1976; Oglesby, 1977) and on the Schlesinger & Regier (1982) model for shallow lakes produced yield estimates (1105–1599 t yr^{-1}) around double the overall MSY of 641 t yr^{-1}. These results suggest that Lake Naivasha may have a potential for a larger fisheries output than is realised at the present time.

Tropical lakes typically support many species of fish, the number being broadly correlated with basin area (Welcomme, 1999). Albeit considerable variance according to altitude and degree of isolation, from figures derived from Vanden Bosch & Bernacsek (1990) for 160 tropical lakes (Number of species = 5.9 lake area (km^2) $^{0.2684}$), a lake such as Naivasha could be expected to contain in the order of 23 species. Such species would be then be likely to undertake a wide range of feeding strategies (Lowe-McConnell, 1987).

By modifying the classification scheme proposed by Matthes (1964), Hickley & Bailey (1987) identified five major feeding categories for common species of fish found in the large, shallow, papyrus-fringed lagoons which form the perennial waters of the Sudd swamps (R.Nile). Whilst not necessarily fully applicable to a lake like Naivasha, such a classification serves to indicate the types of fish that could be expected in a shallow water tropical system. The categories are mud-feeders, microherbivores, macroherbivores, omnivores and carnivores. Carnivores can be further subdivided into zooplanktivores, bottom-feeders, browsers in vegetation, generalised macropredators and piscivores. In Lake Naivasha the tilapias, *Oreochromis leucostictus* and *Tilapia zillii*, with their large uptake of detritus, represent mud-feeders. *O. leucostictus* also partly fulfils the role of microherbivore by taking green algae and diatoms, although this species alone is unlikely to fully exploit phytoplankton production. Of the larger plant material, some is eaten by *T. zillii* but *Procambarus clarkii*, which forms the basis of a commercial crayfish fishery (Lowery & Mendes, 1977), is capable of cropping the macrophytes to a major extent (Harper et al., 1990). Omnivores are represented by *T. zillii*, *B. amphigramma* and the guppy. Although zooplankton featured in the diet of both *B. amphigramma* and juvenile bass, neither species fulfils the role of zooplanktivore to a degree compatible with reports that offshore secondary production is high (Mavuti & Litterick, 1981; Harper, 1984, 1987). The largemouth bass is a generalized macropredator.

It appears, therefore, that in terms of the above classification the Naivasha fish fauna is not sufficiently species rich. Indeed, it would be difficult for any fish population comprising only five species to fully exploit all potential food resources. This view is supported by Moreau (1997) who, taking account of modeling by Mavuti et al. (1996) using ECOPATH (Christensen & Pauly, 1992), concluded that Lake Naivasha is a good example of trophic under-exploitation. As early as the mid 1970s it was suggested (Siddiqui, 1977) that new species should be introduced to exploit the remaining niches. Such a proposal has now been carried forward into the Lake Naivasha Management Plan (LNRA, 1999) with a view to increasing commercial catches and providing local employment opportunities.

Based on prospective feeding guilds and the actual food web, Muchiri et al. (1994) identified four areas in terms of food and space with respect to the potential for stocking additional species of fish. The most convincing case, and that which would best be addressed in the first instance, is the bottom feeder. Given that it is the benthic oligochaetes and chironomid larvae which are under-utilized, one of the species of *Mormyrus* is likely to be a suitable candidate for introduction. With regard to introducing fish to consume more phytoplankton and zooplankton than is currently taken by the existing species, there is scope but the proposal is less robust. Species such as *Limnothrissa* or *Alestes* could be stocked to occupy the open water and take zooplankton but, as these species would not be susceptible to the existing gill net fishery, new fishing methods would have to be authorised. *Heterotis niloticus* (Cuvier) could be used to target the phytoplankton. *H. niloticus* has been introduced to a number of waterbodies and has established self-reproducing populations without seriously threatening the pre-existing fish fauna (Moreau, 1997) although, in Naivasha, the long term decline in *C. papyrus* (Boar et al., 1999) could impact upon the availablity of nest sites. With regard to the introduction of a dedicated piscivore, it might be best to leave all the cropping of fish to be carried out not by a top predator but by the activities of the commercial fishermen.

Clearly, the necessary feasibility appraisals of each potential species must address all aspects of suitability or otherwise. The EIFAC code of practice for species introductions (Turner, 1988) recommends taking into account feeding habits, growth rates, reproductive strategy, environmental conditions required, competition with resident species and the potential implications of the fishery for the new species. Nonetheless, when assessing the balance of risks associated with further introductions into Lake Naivasha, the overall species composition and present ecological nature of the lake is such that any unforeseen detrimental effects of stocking could be considered to be less serious in the long term than if they occurred elsewhere.

Due to the relatively unstable environmental conditions of Lake Naivasha (Harper et al., 1990), there is need for continuous appraisal of the fishery. Catch records need to be of high quality and so adequate enforcement of the fisheries regulations is essential (Lake Naivasha Fisheries Department, 1998). In particular, the key enforcement areas to be addressed are the non-compliance with the minimum (100 mm) mesh size, the trading of undersized fish, the setting of nets closer than 100 m from the shoreline, and the landing of fish other than at the official landing station. The establishment of more landing and recording stations (LNRA, 1999) would comprehensively improve the robustness of the catch statistics. Also, the number and length of gill nets fished would be a better measure of effort than the number of licensed canoes.

Fishery recommendations

It is concluded that, at the present time, the fish population of Lake Naivasha does not fully exploit the available food resources and the fishery is not as productive as it could be. It is recommended that there be acceptance of the proposal to enhance fish production by the introduction of additional species (LNRA, 1999). Potential species should be selected and full feasibility analysis as to their suitability be carried out as soon as is practicable. In addition, consideration should be given to the possibility of re-establishing the *B. amphigramma* of the 1980s. Building fish passes to facilitate spawning migrations might enable the population to recover sufficiently to be exploited once again.

It could be argued that there should be no introductions to a conserved wetland. Even if it were to be considered desirable, it is totally impractical, however, to attempt to reverse the inheritance of past stocking history. The lake cannot be returned to its former status of having only its single endemic fish species. Therefore, given that under certain circumstances social and economic benefits can be considered to be as important as conservation, the concept of further introductions becomes acceptable. Effort should be made, however, to draw from an African fish list when considering potential candidate species.

Any introductions must be part of an overall management package which should also include:

- Conservation measures based on sound ecology such as refuge areas, fish passes on the river weirs and close times;
- Appropriate legislation and the enforcement thereof, such as minimum mesh sizes and a ban on trading in undersized fish;
- Education to improve awareness of both user groups and those in authority;
- Addressing of associated social issues such as redeployment of the poachers.

If introductions are to be made, then this should be done sooner rather than later, with a phased approach to the associated measures such that any new restrictions are accompanied by increasing availability of fish.

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