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Ecohydrology and physical fish habitat modifications in lakes

Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya

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Abstract

Lakes Naivasha and Baringo in the eastern Rift Valley of Kenya are shallow, freshwater lakes that are subject to major fluctuations in water level and suffer from habitat degradation as a consequence of riparian activity. Lake Naivasha is approximately 160 km^2, is bordered by *Cyperus papyrus* and its aquatic macrophytes are in a state of flux. The most significant riparian activity is the large scale production of flowers for the European market. Lake Baringo is approximately 140 km^2 and lies in a semi-arid region. Its most noticeable feature is its extreme turbidity which is mainly due to excessive soil erosion resulting from deforestation and overgrazing. This turbidity has led to near extinction of submerged macrophytes and a lake bed virtually devoid of benthic fauna. Fishing pressure has added to the environmental stresses being endured by the fish populations and commercial catches have been detrimentally affected. Accordingly, periods of fishery closure are now imposed upon both lakes. Limited remedial action is feasible and some local stakeholders are attempting to introduce mitigation measures. For Lake Naivasha there is an agreed riparian owners' management plan which tackles issues such as water usage and protection of the *C. papyrus* margin. For Lake Baringo there is a Rehabilitation of Arid Environments initiative which promotes such activities as restoration of riparian vegetation and appropriate stock management.

Key words: Rift Valley lakes, ecohydrology, fish, macrophytes, turbidity, soil erosion.

1. Introduction

Ecohydrology is the scientific concept that promotes the integration of hydrology and ecology and the control of these processes to enhance the absorption and assimilation capacity of ecosystems (Zalewski *et al.* 1997). Methodologies include using hydrological processes to control biota and as such can provide an effective and efficient mechanism for the restoration of degraded environments and associated sustainability of society. Freshwater ecosystems accumulate the impacts of human activities and consequently the quality of fish habitat depends to a large extent upon the density of the human population and its activities within the basin (Zalewski, Welcomme 2001). This paper describes the detrimental impact of degraded environments on two important Kenyan fisheries and how starting to control the key catchment and riparian processes could lead to fishery restoration and sustainability.

Site descriptions

Lakes Naivasha and Baringo are shallow, freshwater lakes in the eastern Rift Valley of Kenya. Other lakes in the Kenyan Rift Valley are brackish or saline. Bathymetric maps and associated information are given in Figs 1 and 2.

Lake Naivasha is approximately 160 km^2, is 190 km south of the equator at an elevation of 1890 m a.s.l. and is semi-arid (Agro Climatic Zone 5). It is bordered by *Cyperus papyrus* swamp. Rainfall is around 680 mm with two rainy seasons. Soils are silt loam to clay with a humic topsoil in many places and well drained (although in places, poorly drained). Particles from eroded topsoil are intercepted the fringing papyrus. Riparian ownership of lake Naivasha is private.

Lake Baringo is approximately 140 km^2, is 60 km north of the equator, lies in the Rift Valley floor at 900 m a.s.l., and has a semi-arid climate. The littoral community is poorly developed around much of the lake. Being in the Intertropical Convergence Zone (ITCZ) the lake has two rainy seasons with annual rainfall around 600 mm. Soils are clay and clay loams and the risk of soil erosion is high because of the soil properties (clay fills pores or seals the surface giving low infiltration capacity). Forty-six percent of the land in the district is too steep or too dry for agriculture and pastoralism is the main source of family income. Riparian use and ownership is variously private and communal.

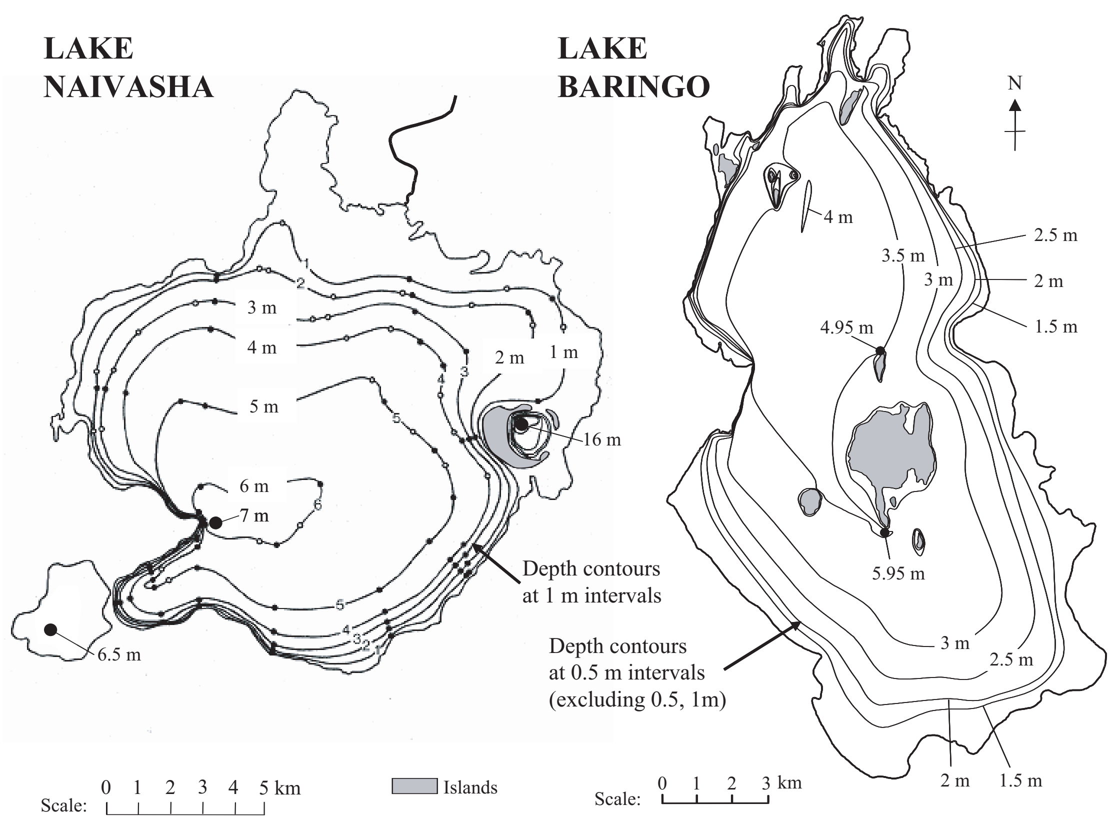

Fig.1. Bathymetric maps for Lake Naivasha (August 1991; after Hickley *et al.* 2002) and Lake Baringo (August 2003). Contour lines are 1 m and 0.5 m (commencing at 1.5 m) intervals respectively. Spot depths for deepest points shown; contour lines <3m around Baringo islands not shown.

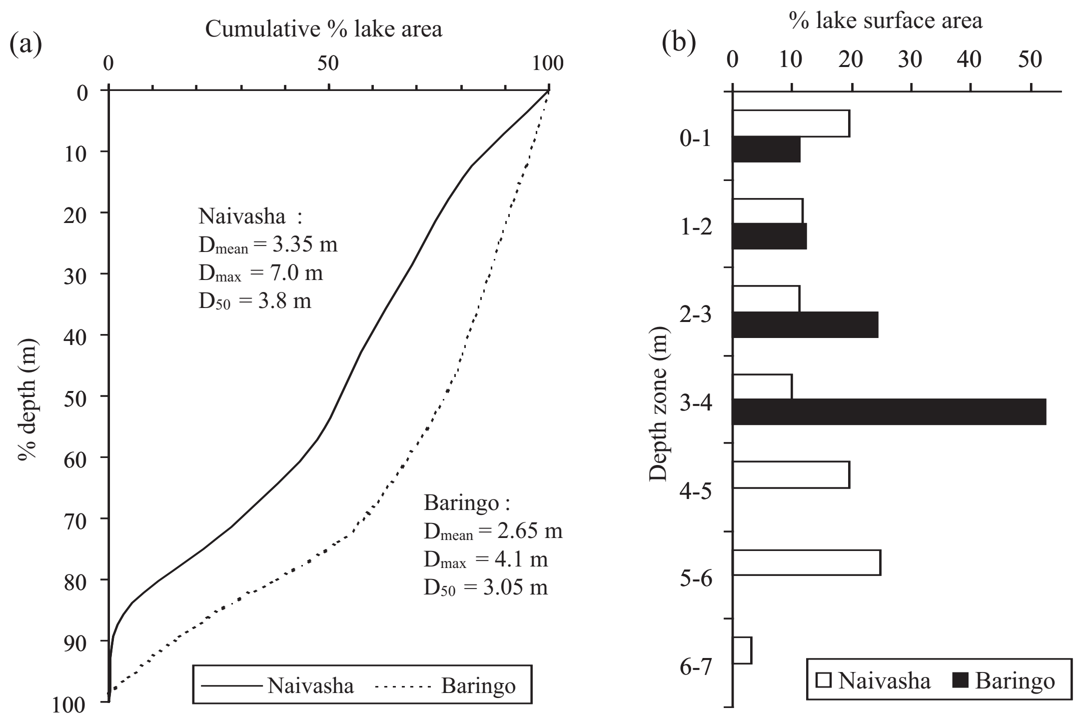

Fig. 2. (a) Percentage hypsographic curves for Lakes Naivasha (August 1991, solid line) and Baringo (August 2003, dotted line) with values for mean depth (D_{mean}), maximum depth (D_{max}) and 50 percentile depth (D_{50}); (b) Percentage of lake area underlain by each depth zone for Lakes Naivasha (plain bars) and Baringo (black bars).

Pressures on the lakes

The Rift Valley lakes of Kenya are of importance to national economy as natural assets, particularly in the context of tourism. In addition, those such as Naivasha and Baringo, which are fresh enough to support fish populations, provide support to the local economy by enabling a fishing industry. Local opinion on the importance of Lake Naivasha is represented by Fig. 3. Lake Naivasha became a Ramsar site in April 1995 (Wetlands International 2001) and Baringo in January 2002 (Ramsar 2001) but the pressures on the lakes' ecosystems and thus on the sustainability of their fisheries are considerable. Both lakes are subject to major fluctuations in water level and habitats are degraded as a consequence of riparian activity.

The most significant riparian activity on Lake Naivasha is the large scale production of flowers for the European market and at least 50% of the perimeter of the lake is under agriculture of some description. Former stock-rearing, ranching and cultivation of sisal gave way in recent years to the present irrigated horticulture. Horticultural technology, with its attendant use of pesticides has grown dramatically over the past two decades and this has been accompanied by cultivation

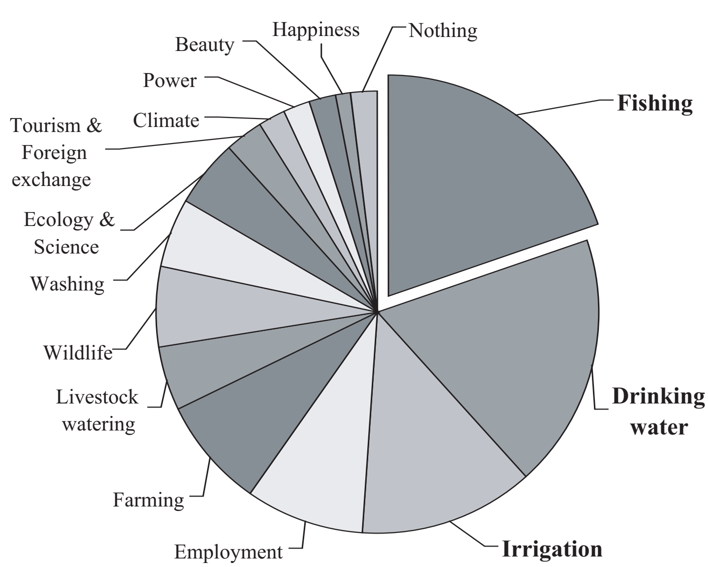

Fig. 3. Principal reasons for Lake Naivasha being considered by the local community to be important. Pie chart is a breakdown of 119 answers given by 62 people (see methods).

close to the lake. Also, as the labour intensive flower industry developed, so did the need for housing, water and latrines (Enniskillen 2002). The local population is approximately 250 000. The lake resources are also of critical importance to geothermal electricity generation, tourism, wildlife and conservation (Harper *et al.* 1990).

Lake Baringo's most noticeable feature is its extreme turbidity which is mainly due to soil erosion. This results from low vegetation cover, caused by deforestation and overgrazing, exacerbated by high intensity, sporadic rainfall on steep slopes. In recent years two thirds of the total catchment (8655 km^2) has been grazing and the rest of the land under agriculture, apart from <1% forest. All the grazing area and two thirds of the agricultural land is environmentally degraded; almost 90% of the catchment. The Baringo District population is at least 360 000 and growing (2.65% p.a.). Associated livestock numbers are correspondingly large; approximately 900 000 goats, 200 000 sheep and 300 000 cattle. At the end of the annual dry season it is usual to receive reports of livestock deaths due to starvation. An additional problem is the installation of dams on the inflow rivers and the impounding or diversion of water otherwise destined for the lake.

2. Methods

Commercial fish catch statistics were obtained from the Fisheries Department of the Kenya Government. In Lake Naivasha, additional annual sampling of juvenile fish was carried out using mono-filament survey gill nets set during the daytime. The survey net catches were converted to a catch per unit effort (CPUE) where the measure was total catch converted to numbers of fish per standard gill net per hour. A standard gill net comprised five 30 m long x 1.5 m deep sections, being one each of 11, 15, 20, 24 and 35 mm bar mesh.

The theoretical annual yield (Y) of fish was estimated using a range of models suitable for use with non-temperate data as described by Hickley *et al.* (2002). In the equations the following values were used for Lakes Naivasha and Baringo respectively: Area (A) = 163, 141 km^2; Mean depth (Z) = 3.35, 2.65 m; Total dissolved solids (TDS) = 231, 280; Air temperature (T) = 21, 26°C.

The bathymetry of Lake Naivasha was determined in August 1991 as described by Hickley *et al.* (2002). Lake Baringo was surveyed during the period 14th - 20th August 2003 using a Lowrance X-15A chart recording echo-sounder with a 20° transducer beam as in the bathymetric survey of Lake Naivasha (Hickley *et al.* 2002). The soundings were made from a small boat driven at constant speed along 32 tracks of total distance 104 km, the positions of which were monitored with a Garmin 12 hand held GPS receiver. To optimise survey accuracy, a system of tracks crossing the main track was used (Håkanson 1981). For each paper echo-recording chart, the positions along the track line at which depths at 0.5 m intervals occurred were plotted on a plan outline of the lake and joined to form contour lines. The lake outline was derived from a 1:50 000 scale map (Kenya Government 1982) which was based on aerial photographs taken in August 1977 and January 1978. Depth profiles were transcribed directly from the echo-recording charts. Morphometrical values were determined according to Hakanson (1981).

The area of cover by aquatic macrophytes in Lake Naivasha was derived from source data in Hickley, Harper (2002) and that for papyrus from source data in Boar *et al.* (1999), Boar, Harper (2002) and Everard, Harper (2002).

Water transparency of Lake Baringo in most years was measured monthly using a Secchi disc in 10 locations chosen at random in each of the southern, central and northern sectors of the lake and the mean of means used for an annual value. On 16th August 2003, total light remaining at depths in the water column was measured with a LI-COR LI 190SA Quantum Sensor. Measurements in μmol photons m^{-2} s^{-1} were converted to the percentage of incident light received at the water surface. Readings were taken mostly at 1 cm intervals at the inflow of the Molo River and in the open water and at intervals of up to 5 cm at the lakeward edge of a Typha swamp in the southern part of the lake.

Public opinion of the importance of Lake Naivasha was gauged by interviewing sixty-two residents of the southern shore during August 2000. Interviews were semi structured using a variety of approaches to the question asking. Each interview lasted about 45 minutes. Category percentages were assigned to a total of 119 answers given.

3. Results

Habitat

Recent surface water levels for Lakes Naivasha and Baringo are shown in Fig. 4. The mean depth of Lake Naivasha, when the bathymetric survey was carried out in 1991, was 3.35 m but this was at a time when the lake level, although low, was not exceptionally so. Notwithstanding the temporary rise in level following El Niño rains, the overall trend remains downward and contemporary newspaper reports continue to express concern (e.g. Mwakugu

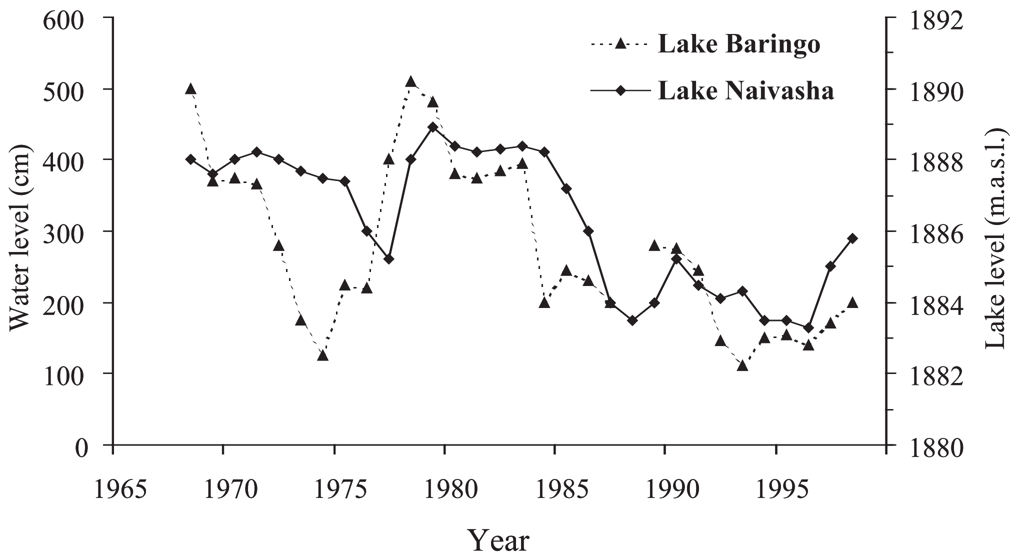

Fig. 4. Recent water surface level fluctuations for Lakes Naivasha (m a.s.l., solid line) and Baringo (cm, dotted line).

2003). The mean depth of Lake Baringo is reported to have been 5.6 m in the 1960s (Ssentongo 1995), over 8 m in the late 1970s (Meyerhoff unpubl.), decreasing to just below 3 m in 1994 but reaching 4.5 m again in 1998 following El Niño rains. At the time of the 2003 bathymetric survey (Fig. 1) the mean depth was 2.65 m. Satellite imagery (Johansson, Svensson 2002) confirms an allegation that the lake is silting up because whilst the lake outline in August 2003 was comparable with that in 1977/78 when the source data were collected for the 1:50 000 map (see methods), the mean depths are certainly not.

In Lake Naivasha there has been a considerable reduction in the total area of *C. papyrus* over the last 40 years as a consequence of both water level fluctuation and the reclamation of exposed stands to increase areas of cultivation. Fig. 5 shows the area of papyrus cover and, notwithstanding the short term increase in early 1988 in response to a temporary increase in water level, the trend is an overall and serious decline. Lake Naivasha also has experienced an almost extirpation of its submerged macrophytes which, at best, are in a state of flux. An episode of disappearance is plotted in Fig. 5. Similarly, Lake Baringo has

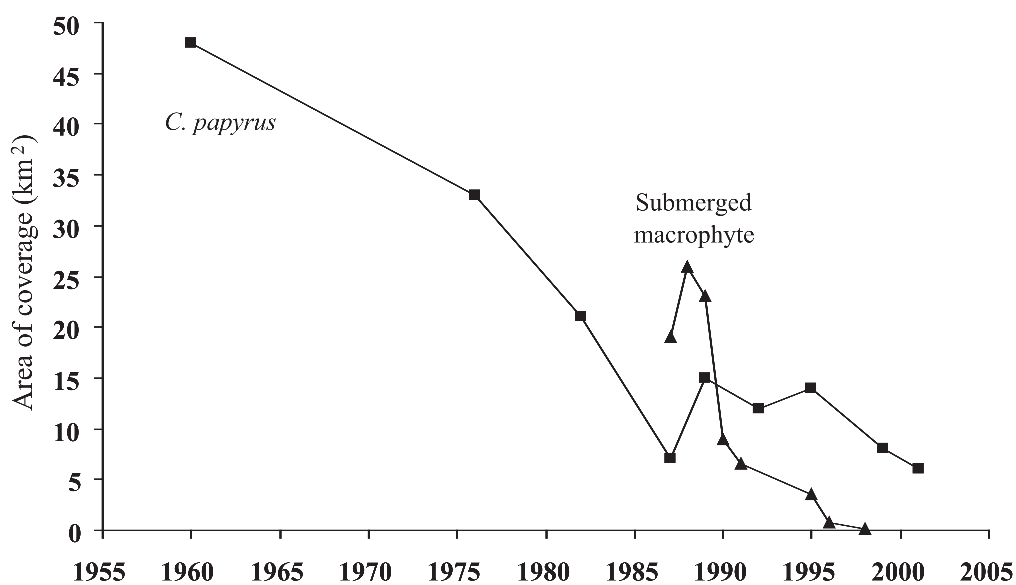

Fig. 5. Change in area of Lake Naivasha covered by *C. papyrus* (data from Boar *et al.* 1999; Boar, Harper 2002; Everard, Harper 2002) and by submerged macrophytes (data from Hickley, Harper 2002).

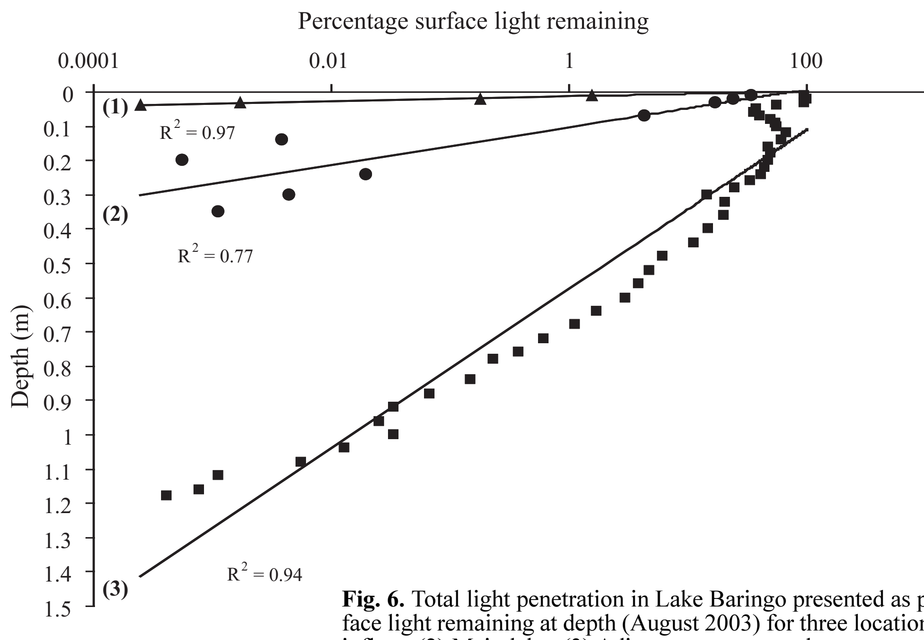

Fig. 6. Total light penetration in Lake Baringo presented as percentage of surface light remaining at depth (August 2003) for three locations (1) River Molo inflow; (2) Main lake; (3) Adjacent to swamp edge.

almost no submerged macrophytes at the present time although clear water and macrophytes have been present in the past (Roberts unpubl.).

Whereas loss of macrophytes in Baringo is assumed to be as a result of low light penetration (see below) this is not the principal cause in Lake Naivasha. A certain degree of eutrophication has been recorded for Lake Naivasha (Kitaka *et al.* 2002), induced by less papyrus to interrupt nutrient and noxious run off, and the associated decrease in transparency is likely to have contributed to macrophyte disappearance. It has been demonstrated, however, by Hickley, Harper (2002) that the submerged plants are decimated by crayfish when bass predation is not sufficient to control their density.

Secchi disk readings for Lake Baringo over the past twenty years have been in the range 3.5 - 13 cm; the clearest period being in 1998 following the El Nino rains. Kallqvist (1987) recorded 5-7 cm in 1976-77 and 20 cm in 1979. The 1979 value was the same as that reported by Beadle (1932) for 1931. In August 2003 the comparative secchi disk reading was approximately 3 cm. Detail of this extreme turbidity is indicated by the plots of total light penetration (Fig. 6). For the main lake the extinction coefficient, K (i.e. the amount of the available light absorbed), was 3.3 m^{-1}. The transparency of the lake at the inflow of the Molo River was even lower at K = 25 m^{-1} and only at the very edge of the swamp did the transparency increase (K = 0.71 m^{-1}). Secchi disk readings at the same sites were: main lake, 3.1 cm; Molo River, 0.6 - 1.5 cm; swamp edge, 32 cm.

Fisheries

Lake Naivasha originally contained only 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 (Muchiri, Hickley 1991) and, prior to the appearance of carp (*Cyprinus carpio* L.) in catches during 2002 (Hickley *et al.* 2004), the only fish species in the lake were *Oreochromis leucostictus* (Trewavas), *Tilapia zillii* (Gervais), *Micropterus salmoides* Lacépède (largemouth bass), *Barbus amphigramma* Blgr. and *Poecilia reticulata* Peters. Also present is the Louisiana red swamp crayfish, *Procambarus clarkii* (Girard). A commercial gill net fishery opened in 1959. The mean annual species composition of the fin-fish catch for the period 1987-2000 was *O. leucostictus* 71.7%, T. zillii 8.8% and *M. salmoides* 19.5%. There have been great fluctuations in the amount of fish landed from the fishery of Lake Naivasha. Its status and future was examined by Hickley *et al.* (2002) and three phases of development identified: an initial "boom and bust", a period of stability and, most recently, a fishery performing poorly. Annual catches for the last 20 years are presented in Fig. 7a and selected statistics in Table I. The maximum recorded total catch of 1150 t yr^{-1} was attained during 1970 (Hickley *et al.* 2002) in contrast with 21 t yr^{-1}, the lowest ever, in 1997. Survey gill net catch per unit effort (CPUE) values since 1987 are shown in Fig. 7b and the trend prior to fishery closure, like that for the commercial fishery for the same period, is downward ($p<0.05$).

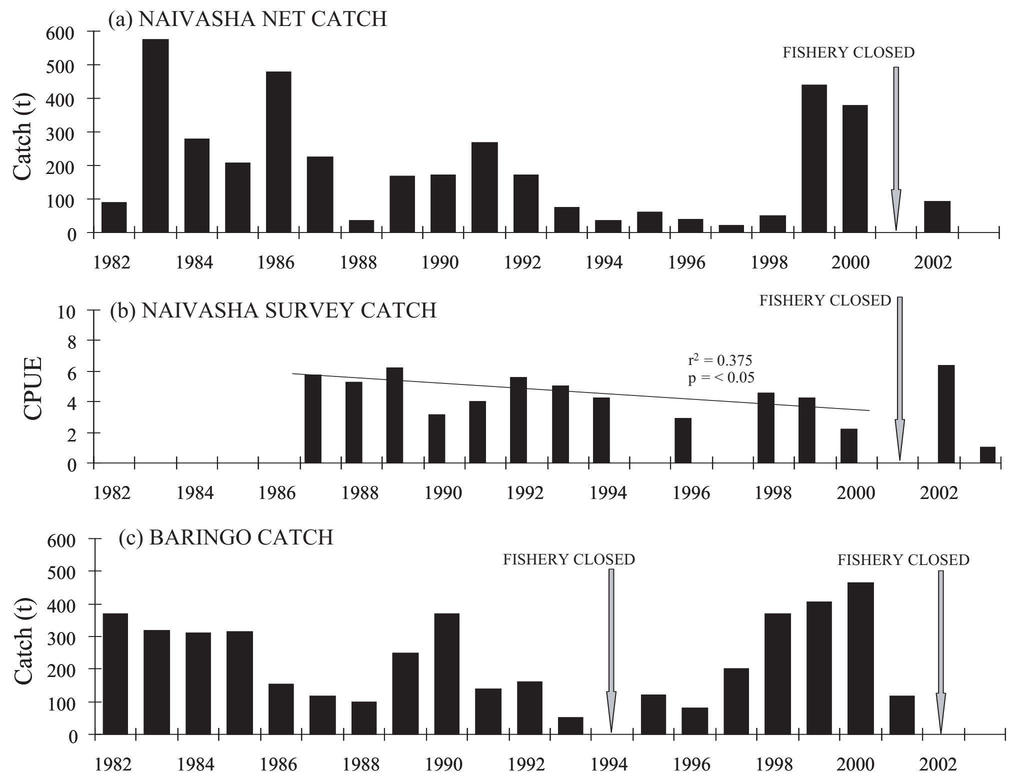

Fig. 7. (a) Total annual fish catch (t) for the Lake Naivasha gill net fishery since 1982; (b) Catch per unit effort (CPUE) for Lake Naivasha survey gill nets since 1986 with trend line fitted for the pre-closure period; (c) Total annual fish catch (t) for the Lake Baringo gill net fishery since 1982. Periods of fishery closure are indicated with arrows.

The fish community of Lake Baringo comprises only seven species. The fishers use gill nets and long lines. Predominant is the endemic *Oreochromis niloticus baringoensis* and this forms the basis of the commercial fishery. This was the only cichlid fish present in 1931 (Worthington, Ricardo 1936) and again in 1969 (Ssentongo, Mann 1971), reports of other species being unsubstantiated. Aloo (2002) reports *O. n. baringoensis* to comprise 80% of the catch. Other species present in the fishery (Aloo 2002), % catch in brackets, are: *Protopterus aethiopicus* (7.6%), *Clarias gariepinus* (8.9%), *Barbus gregorii* (3.1%), *Labeo cylindricus* (0.1%), *Barbus lineomaculatus* and *Aplocheilichthys* spp. Of the last three species, *L. cylindricus* is classed as endangered and the other two, rare (Ramsar 2001). It should be noted, however, that measures of abundance and the consequent conservation designations can vary according to mesh size and season. For example, *B. lineomaculatus* is small and largely riverine so can give the impression that it is rarer than other species simply through not being caught by commercial fishers. De Vos *et al.* (1998) commented that the first landings of *Protopterus* were noticed in 1984 but that nowadays, alongside a decrease in the tilapia size and numbers, landings of the lungfish can exceed 50% of the catch. In 1957, enough fish were being caught for a fish processing factory to be opened; North-Lewis (1998) states 1500 good specimens a day. For the next twenty years or so fish remained plentiful at about 600 - 1000 t yr^{-1} but by 1989 catches had dropped to the point where the filleting plant was closed (TVE 2003). Fig. 7c and Table I show the comparatively low annual catch in recent years.

Fishing pressure has added to the environmental stresses on the fish populations and commercial catches have been affected detrimentally. Accordingly, periods of fishery closure are now imposed upon both lakes. After lengthy consultations with fishers and other stakeholders, fishing in Lake Naivasha was banned throughout 2001. On 18th February 2002 the fishery was re-opened with 43 canoes, just over one third of the previous fleet, being allowed to fish. A second period of closure was imposed from 1 June - 1 October 2003 and this closed period is now expected to be an annual event. The Lake Baringo fishery was closed for from May 1993 to April 1994 and at a stakeholder workshop in October 2001 it was agreed to suspend fishing again for an indefinite period from February 2002.

Table I. Estimates of theoretical and actual fish yields calculated for Lakes Naivasha and Baringo:

(a) Theoretical yields based on various predictive models. For formulae and data sources see methods;

Model	Parameters used	Theoretical annual Yield t yr^{-1}	
		Naivasha	Baringo
Crul 1992	Surface area	902	790
Henderson, Welcomme 1974	Morpho-edaphic index (MEI)	716	729
Schlesinger, Regier 1982	Air temperature ^oC	344	600
Schlesinger, Regier 1982	Air ^oC & MEI (for depth<25m)	1105	1949
Schlesinger, Regier 1982	Air ^oC, MEI & effort (low)	358	597
Schlesinger, Regier 1982	Air ^oC, MEI & effort (high)	727	1190
MEAN of estimates		692	976

(b) Average annual catches compared with mean theoretical estimates.

LAKE	YEAR	Maximum catch t yr^{-1}	Average catch t yr^{-1}	Theoretical annual Yield t yr^{-1}
Naivasha	1962-1973	1150	639	692
Naivasha	1974-1987	576	279	692
Naivasha	1988-2002	439	158	692
Baringo	1982-1998	380	200	976

4. Discussion

Both lakes are shallow enough to be affected adversely by water level fluctuations. The different shapes of the hypsographic curves (Fig. 2) suggest that, as a consequence of reduction in water level, Lake Naivasha is more prone to exposure of the littoral zone whereas for Lake Baringo the greater impact is on lake volume.

Muchiri, Hickley (1991) attributed some of the observed fluctuations in the Lake Naivasha fish catches to both excess fishing pressure and changing lake levels, the latter because the pattern of overall fish catches appeared to more or less follow level changes. Similarly, the lake level fluctuations, siltation and the peturbed inflow regime have influenced the downturn of the Baringo fishery. Fig. 8 for Lake Naivasha implies that change in water level has an impact ($p<0.01$). Fish catches increasing with increase in lake level is likely to be because the legal nets can better exploit the margins in a period of deeper water. A similar link with water level fluctuation can be demonstrated for Lake Baringo (Fig. 9) although the relationship is not as strong ($p<0.05$) whereas water clarity (Fig. 10) does relate closely to total fish catch ($p<0.01$).

Lake Baringo's extreme turbidity has led to near extinction of submerged macrophytes and a lake bed virtually devoid of benthic fauna (Ssentogo 1995). In Lake Victoria, turbidity interferes with mate choice in cichlid fishes by constraining colour vision (Seehausen *et al.* 1997). The installation of dams on the inflow rivers is likely to have contributed to the severe decline of Labeo cylindricus and *Barbus gregori*, these fishes being potamodromous and needing to undertake spawning migrations. *Clarias gariepinus* and the lungfish are both much more tolerant of environmental stresses than the other species.

Although submerged macrophytes are important in terms of overall lake quality (Jeppesen *et al.* 1994, 1997), their absence in Lake Naivasha would be unlikely to have any direct effect on the availability of fish spawning sites. This is because *O. leucostictus* is a female mouth-brooder (Greenwood 1966) and both bass (McClane 1978) and *T. zillii* (Greenwood 1966) excavate nests in the substratum. Macrophyte beds are, however, likely to be important as refuges and feeding areas. Whilst only suppositions can be made about submerged macrophytes, the importance to fish of the papyrus marginal fringe can be demonstrated. Table II presents CPUE for the survey gill nets used in three different habitats. For all three species, the numbers of fish caught were greatest in the nets which were set proximal to the papyrus fringe. In addition, the difference in catches

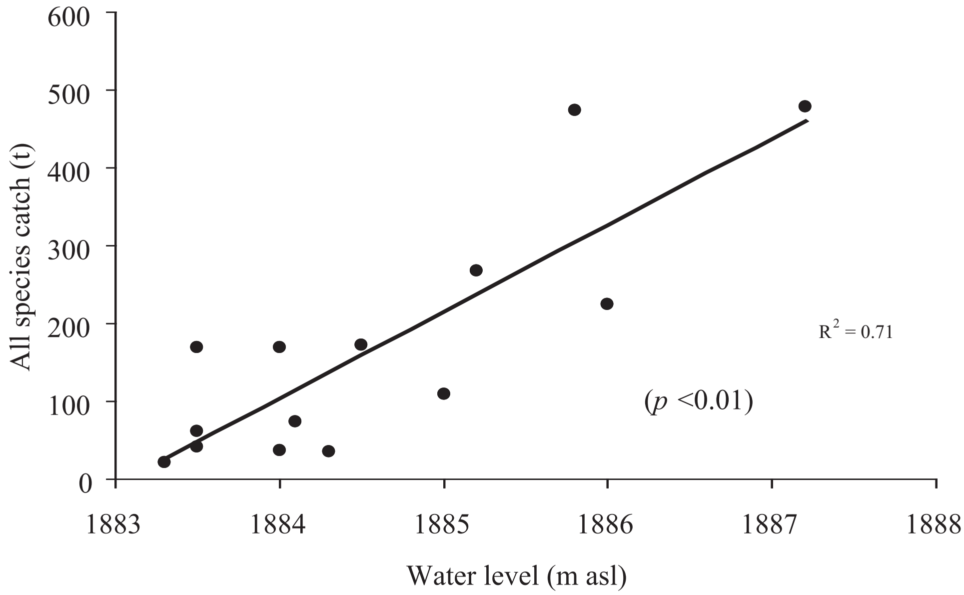

Fig. 8. Annual total fish catch (t) from Lake Naivasha plotted against water level (after Hickley, Harper 2002).

between nets set near papyrus and those set in open water was significant for both *O. leucostictus* (p=<0.05) and *T. zillii* (p=<0.01). Catches of *M. salmoides* and *T. zillii* near rocky shores were also higher than from open water but the amount of rocky shore available as habitat is restricted to only a few km (less than 10% of the lake perimeter).

Although the difference in survey net catches of bass from papyrus and open water was not significant, marginal vegetation is a crucial habitat for nest sites during the bass spawning season. Traditionally considered as building nests on firm bottom substrata such as sand or gravel, bass are known to nest and guard their young within vegetation as an alternative where, as in Lake Naivasha, firm substrata are not available. In Florida lakes, bass are known to migrate to vegetated areas outside their normal home range for spawning in preference to remaining in open water (Mesing, Wicker 1986). Bruno, Gregory (1990) found bass nests on rhizomes or on firm detritus in stands of *Nuphar luteum* and emergent grasses *Panicum hemitomon* and *Paspalidium geminatum.* Bass nests were observed in the papyrus fringe of Lake

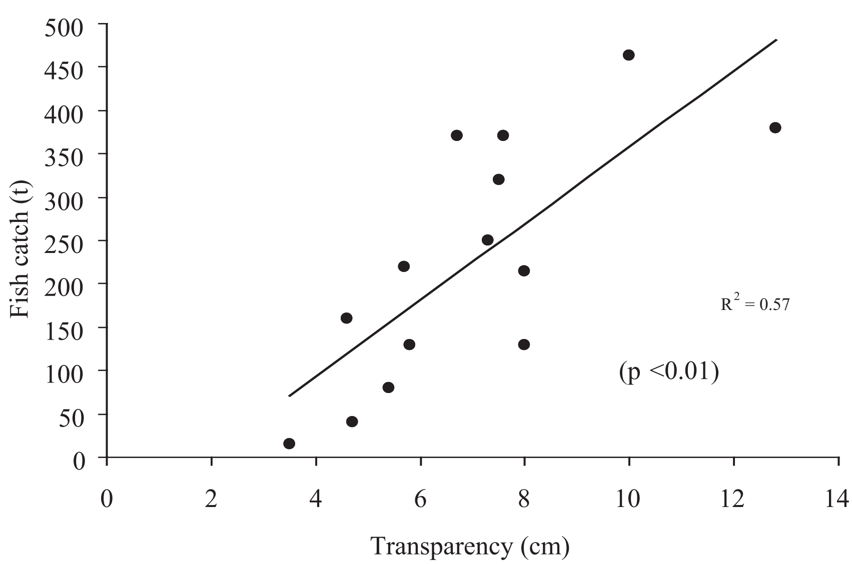

Fig. 9. Annual total fish catch (t) from Lake Baringo plotted against water level.

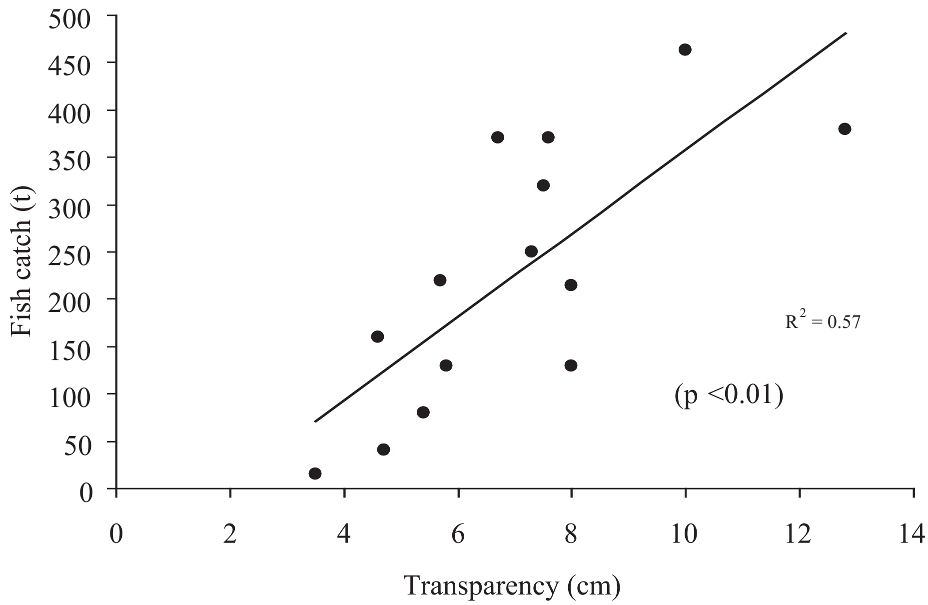

Fig. 10. Annual total fish catch (t) from Lake Baringo plotted against water transparency (Secchi disc, cm).

Naivasha during the late 1980s when samples of bass fry were being collected for gut analysis (Hickley *et al.* 1994).

For recent years, both the average and maximum actual catches for the Naivasha and Baringo fisheries were considerably lower than the calculated theoretical annual yields of 692 t yr^{-1} and 976 t yr^{-1} respectively (Table I). This suggests that the two fisheries could be under-performing, as addressed for Lake Naivasha by Hickley *et al.* (2002). Whilst the equations used were basic, and for Lake Naivasha it has been advocated already (Muchiri *et al.* 1994) that more detailed work is needed, the order of magnitude of the derived values is likely to be correct. For example, Muchiri *et al.* (1995) showed that calculations of maximum sustainable yield (MSY) using sophisticated catch-effort analysis software (MRAG 1992) produced similar estimates to the simple Shaefer model (Pauly 1983; Ricker 1975). Also, although the theoretical fish yields given in Table I were based only on limnological data, this is acceptable according to Welcomme (1999) who considered methods for estimating the potential output from

Table II. Catch per unit effort (CPUE) as No. fish per standard net gang per hour 1987-1999.

SPECIES	HABITAT	CPUE	% CATCH
Micropterus salmoides	Papyrus margin	2.94	37.3
	Open water	1.96	28.2
	Rocky shore	2.38	34.5
Oreochromis leucostictus	Papyrus margin	1.27	62.1
	Open water	0.17	13.0
	Rocky shore	0.41	24.9
Tilapia zillii	Papyrus margin	2.45	41.6
	Open water	0.92	18.2
	Rocky shore	2.37	40.2

SPECIES	*P* values for t test:	Open water	Rocky shore
M. salmoides	Papyrus margin	0.085	0.199
	Rocky shore	**0.037**	
O. leucostictus	Papyrus margin	**0.027**	0.083
	Rocky shore	0.091	
T. zillii	Papyrus margin	**0.007**	0.445
	Rocky shore	**0.003**	

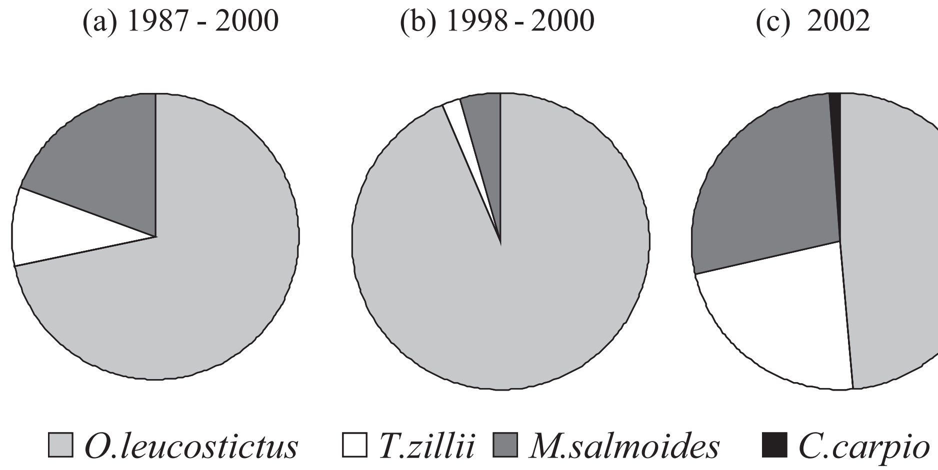

Fig. 11. Average composition (%) of the catch from the Lake Naivasha gill net fishery (a) overall, 1987 - 2000; (b) three years before closure of the fishery, 1998 - 2000; (c) the year after re-opening of the fishery, 2002.

fisheries and concluded that there is no system as yet to predict the symptotic level at which Ymax will occur other than the generalised predictors such as MEI. The higher values for Lake Baringo produced by the Schlesinger, Regier (1982) equations are because, although Lakes Naivasha and Baringo are of similar physical size, the latter is approximately 5^{o}C warmer. Tropical lakes typically support many species of fish, the number being broadly correlated with basin area (Welcomme 1999). Lakes Naivasha and Baringo can each be expected to contain 20 or so species according to Vanden Bosch, Bernacsek (1990) where, based on 160 tropical lakes, No. species = 5.9 lake area (km^2) $^{0.2684}$. Therefore, some under-performance could be assigned to low species richness. By far the most likely detrimental influence, however, remains ecohydrological habitat degradation. Moreover, this view is supported by the evidence presented thus far.

Fig. 11 shows species composition of the Lake Naivasha fish catch overall, immediately before closure of the fishery and after fishing recommenced. Species composition in the 3 years before closure reflects over-fishing of *T. zillii* with illegal seine nets during a period of low lake levels, the effect of which was to reduce the size of the legitimate catch. Following reopening of the fishery, and notwithstanding the new appearance of carp (Hickley *et al.* 2004), the species composition of the catch seems to have returned to a more equitable distribution.

5. The way forward

Limited remedial action is feasible and, supported by Government in the context of both lakes' Ramsar Wetland status, some local stakeholders are introducing mitigation measures.

Lake Naivasha

A plan for the management of Lake Naivasha has been written by the Lake Naivasha Riparian Association (LNRA), an association of about 150 owners of riparian land. The Plan (LNRA 1999) was adopted by Nakuru District Development Committee in July 1997 and endorsed by the President of Kenya in August 1997. The Association's Management Implementation Committee has members from Kenya Wildlife Service, the Kenya Electricity Generating Company, The World Conservation Union, the Municipal Council of Naivasha, Government Ministries and the horticultural, tourism, livestock and fishing industries. Using international standards, Kenyan law and scientific studies of Lake Naivasha, the LNRA has made recommendations about how the lake's resources should be used, the aim being to prevent the lake and its fore shore from being "damaged, polluted or wasted". All categories of users have been encouraged to write their own Codes of Conduct for their industry according to the Plan's guidelines and these Codes are included in the Plan. Codes of Conduct and LNRA recommendations are followed voluntarily. Regrettably, not all users follow the Plan and not all have joined the LNRA but they are being encouraged to do so. The Plan targets everyone: residents, farmers, growers, hotel and curio shop owners, casual workers, people watering their animals, tourists, scientists, fishers and the purchasers of fish. Of particular importance in terms of lake quality and the fishery are the three Codes of Conduct for growers, the power industry and fishers. Key features of the riparian guidelines contained therein are:

- Papyrus should not be cleared or burned;
- A minimum of 100 m of land must be left between farmed land and the water and there

should be at least 50 m of fringing papyrus swamp;
- Untreated sewage and chemicals such as fungicides, pesticides and fertilizers must not enter the lake or groundwater;
- Water must be used responsibly, efficiently and economically;
- Water use and lake level and weather should be monitored;
- Soil erosion will be managed and minimised.

Specifically for the protection of the fishery, when open, the regulations and recommendations adopt a traditional approach (Gulland 1971) including gear specification, size limits and closed areas:
- Fish must be landed at one of the designated landing beaches;
- Numbers and size of fish caught must be reported to the Fisheries Department;
- Each licensed fisher can use not more than ten 100 m gill nets with a minimum mesh size (stretched) of 4 inches (100 mm);
- Tilapia landed or sold must exceed 18 cm in length;
- Seine netting and fishing in the dark is prohibited;
- No fishing in bays or lagoons or within 100 m of the shoreline or papyrus;
- The Department of Fisheries will educate the public and use community participation to curb illegal fishing.

Lake Baringo

For Lake Baringo there is a sustainable management approach being adopted by the stakeholders including empowering local communities for natural resource management, diversification of agriculture and agro-forestry systems. Much has been facilitated through UNEP and the Global Environmental Facility (GEF) through the Lake Baringo Community Based (LBCB) Land and Water Management Project. The management institutions include the local councils, community based organisations, hotels, the Fisheries Department and the Kenya Forestry and Marine & Fisheries Research Institutes (KFRI and KMFRI). These institutes need to operate to a management plan in a similar way to the riparian interests of Naivasha and accordingly, since the recent designation of Lake Baringo as a Ramsar site, a management plan is in preparation. Meanwhile, some steps have already been taken to address soil erosion such as the creation of over 30 km of terraces for slope stabilisation, facilitated by the Department of Agriculture. In addition, certain Non-Governmental Organisations (NGOs) have been pro-active, a good example being the Rehabilitation of Arid Environment (RAE) Trust. The RAE is a charitable trust that has been active in the Baringo District since 1982. RAE partnerships with the community develop practical solutions to dryland restoration that involve fencing degraded areas from livestock, rain-fed water harvesting and planting of indigenous grasses and trees. The grasses used to curb erosion whilst providing a worthwhile product are the thatching grasses *Cenchrus ciliaris* and *Eragrostis superba*. The trees planted comprise mainly introduced *Prosopis* spp. Partnerships have been successful and some 1820 ha of land across 175 sites have now been reclaimed and 430 000 drought-resistant seedlings have been distributed both locally and elsewhere in Kenya. The aims of the RAE initiative are to produce sustainable returns from livestock grazing, fuelwood, thatching grass, seed, honey and traditional food, fruits and medicines. Environmental aims are centred upon reducing soil erosion in the catchment of Lake Baringo and protection of the Lake's freshwater resources.

Pathways to rehabilitation

An ecohydrological approach is appropriate to resolving the environmental quality and fisheries issues outlined and discussed in this paper. A schematic diagram showing feasible, albeit optimistic, pathways to rehabilitation for Lakes Naivasha and Baringo is presented in Fig. 12. Although highlighting only the more obvious mechanisms, both pathways work on the principle of addressing riparian activity, aiming towards the ultimate consequential benefit of restored and sustainable fishery performance.

For Lake Naivasha one of the most important contributions will be to facilitate recovery of the papyrus fringe. *C. papyrus* seeds germinate quickly and, given a return to favourable conditions, a papyrus fringe is capable of regenerating and reaching maturity within six months (Muthuri 1989). As well as providing important habitat for all fish species, this should stimulate recruitment to the bass population. Increased predation by bass should better control crayfish numbers to relieve grazing pressure on the aquatic macrophytes and thus aid their recovery. In parallel, a restored papyrus margin should induce an overall reduction in eutrophication and a reduction in algal blooms which will also aid recovery of aquatic macrophytes. Management of the fishery on a sustainable basis then becomes more realistic. Indeed, according to some e.g. Higgins (unpubl.) all conditions are present for Lake Naivasha to become one of the first basins in Africa with a sustainably managed lake according to World Lake Vision principles (International Lake Environment Committee Foundation & United Nations Environment Programme 2003).

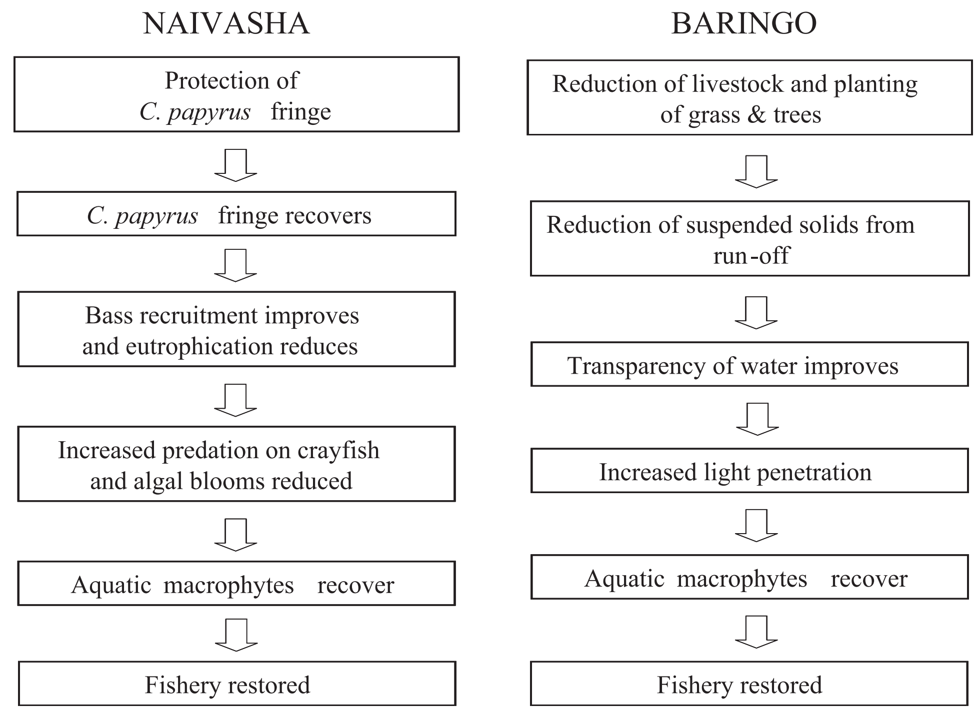

Fig. 12. Schematic diagram indicating primary rehabilitation pathways for fishery restoration for Lakes Naivasha and Baringo.

For Lake Baringo the ecohydrological approach to fishery restoration is equally challenging but the pathway is more straightforward and better understood. It is quite clear, therefore, that mitigation work in the Lake Baringo catchment will produce noticeable environmental benefits. Reducing erosion, and thus suspended solids, should ultimately improve transparency and allow aquatic macrophytes to return to the point where a sustainable fishery can be managed. It must be remembered, however, that anthropogenic activity is not the sole contributor to the lake's turbidity; the landscape is such that natural erosion risk will remain high.

Although physical habitat improvement is the key component of the rehabilitation pathway for both lakes it should be noted, however, that fishery restoration cannot be successful without stakeholder consultation and support. Indeed, the sustainable development of society is very much part of the over-arching ecohydrology concept (Zalewski *et al.* 1997).

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