African lake management initiatives: The global connection

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Abstract

There is a global dimension to lake management in Africa and elsewhere that will require a concerted action not only from individual riparian states, but also from regional, continental and global communities. The current global lake threats arise from climate change, regional land degradation and semivolatile contaminants, and share the common feature that the atmosphere is the vector that spreads their impacts over large areas and to many lakes. The Great Lakes of Africa (Malawi, Victoria and Tanganyika) are particularly sensitive to these problems because of their enormous surface areas, slow water flushing rates, and the importance of direct rainfall in their water budgets. Their response times might be slow to yield a detectable change and, unfortunately, their recovery times might also be slow. It is possible for atmospheric effects to act antagonistically to the impacts of catchment change, but antagonistic effects could become synergistic in the future. Improved understanding of the physical dynamics of these lakes, and development of models linking their physical and biogeochemical behaviour to regional, mesoscale climate models, will be necessary to guide lake managers.

Key words

African Great Lakes, climate change, Global Environment Facility, Lake Malawi, Lake Tanganyika, Lake Victoria, mercury, nutrient loading, organochlorines.

INTRODUCTION

All African lakes, large and small, have great significance to their riparian populations, and the nations within which they occur, for providing protein from fisheries, water for agricultural, domestic and drinking use, transportation for commerce, and recreational use. The three largest lakes in Africa: Victoria, Tanganyika and Malawi/Nyasa (the latter hereafter referred to as Malawi), offer similar benefits, and their very size certainly amplifies the numbers of people, and the number of countries, depending on them for beneficial uses. The Lake Victoria catchment is inhabited by ˜ 30 million people living in five countries, and the lake also exports critical quantities of water downstream to the Nile River, as well as fish to a global market. The other two lakes are shared by three (Malawi) and five (Tanganyika) countries, being the headwater lakes to the Zambezi and Congo Rivers, respectively, whose outflows sustain downstream benefits to many other users outside their catchments. These three great lakes also have evolved remarkable endemic biodiversity, with nearly 10% of all the planet's freshwater fish species occurring within them, and making them globally significant gene banks. Lakes everywhere, including great lakes, come under stress as human populations and economies in their catchments increase. However, the multinational distribution of ecosystem benefits, and the potential losses of such benefits if the lakes are degraded, places these great African lakes in a class of their own in regard to their management challenges. In recognition of the international scope of the management challenge posed by these great lakes, and the global benefits they provide, the Global Environmental Facility (GEF), and its national and international funding partners, has funded extensive studies and analyses of these lake ecosystems, ranging through the mid- to late-1990s and extending to the present time.

The achievements and shortcomings of these GEF projects are reviewed in case studies presented in the Lake Basin Management Initiative. In aggregate, those studies and other studies around the world have revealed that some challenges to successful management of these great lakes extend beyond their catchments, and that regional or even global action will be necessary to maintain or restore

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many of the lakes' beneficial uses. Smaller lakes are likely also being impacted by these same regional and global scale threats, although other more immediate impacts might be of greater concern at present. The thesis of this paper is that there is a global dimension to lake management in Africa and elsewhere that will require concerted action not only from individual riparian states, but also from regional, continental and global communities. Current lake threats arise from global climate change, land degradation and contaminants, and they share the common feature that the atmosphere is the vector spreading their impacts over large areas and to many lakes.

HYDROLOGICAL SENSITIVITIES

The African Great Lakes occupy a large proportion of their catchments. Their huge surface area allows precipitation (P) directly on their water surface, and evaporation (E) from their surface, to dominate the gains and losses in their water budgets (Table 1). This is true of the deep Rift Valley lakes, as well as the shallower Lake Victoria, which occupies a depression between uplifted highlands bordering the rift valleys. Unlike Lake Victoria, however, the deeper lakes are permanently stratified, resulting in accumulation of high nutrient concentrations in their slightly cooler and anoxic deep waters (Bootsma & Hecky 1993). Direct rainfall accounts for >50% of all water inputs for all three lakes, with Lake Victoria being the most extreme because inflowing rivers (I) account for only 15% of its total water input. In terms of the water budget, E is the greatest water loss, with river outflow (O) accounting for 15% or less of its total water loss in Victoria.

Table 1. Morphometric and hydrological data for Africa's three largest lakes (after Bootsma & Hecky 1993)

	Malawi	Tanganyika	Victoria
Catchment area (km^2)	100 500	220 000	195 000
Lake area (km^2)	28 000	32 600	68 800
Maximum depth (m)	700	1 470	70
Mean depth (m)	292	580	40
Volume (km^3)	8 400	18 900	2 760
Outflow (O) (km^3 $year^{-1}$)	11	2.7	20
Inflow (I) (km^3 $year^{-1}$)	29	14	20
Precipitation (P) (km^3 $year^{-1}$)	39	29	100
Evaporation (E) (km^3 $year^{-1}$)	55	44	100
Flushing time (V/O) (year)	750	7 000	140
Residence time (V/(P + I)) (year)	140	440	23

Maintenance of the lakes as open drainage basins, however, is dependent on their river inputs, as the P/E balance over the lake surface area is negative for the two deep lakes, and just in balance for Lake Victoria.

Rainfall in eastern Africa is relatively low over most of the terrestrial catchments of these lakes, although the lakes themselves generate higher rainfall over the lakes than the average rainfall over the catchment (Nicholson & Yin 2002). Evaporation is highly sensitive to still poorly known over-lake wind regimes. The most recent estimates of evaporation over the lake are higher than the published values, largely because of better definition of diurnal and offshore wind regimes (Hamblin *et al.* 2002; Verburg & Hecky 2003). The water-level history of these lakes, as recorded for the past century (Fig. 1) and inferred from historical accounts over the previous century, indicates that the water balance of the lakes can be very dynamic. Lake Malawi was a closed basin from 1915 to 1930 (and nearly again in the late 1990s), Lake Tanganyika was closed when the Lukuga outlet was first observed by Europeans, and Lake Victoria had its highest documented water level at about the same time in the early 1880s (Nicholson 1998). The variability of lake levels is even more dramatic over longer periods, with Lake Victoria desiccating ca 12 000 years ago (Johnson *et al.* 1996). Lake Tanganyika (Haberyan & Hecky 1987) also had much lower levels, and many smaller lakes in eastern Africa had low water stands or were also desiccated. Grove *et al.* (1996) previously commented on two apparent synchronies in the level records of these three large lakes: (i) the very high stands of the early 1960s (a period of record high rainfall in eastern Africa), and (ii) declining levels (and associated river discharges) since the 1980s. Both Lakes Tanganyika and Malawi have returned to their pre-1960s water levels, although Lake Victoria has not. The persistence of Lake Victoria at higher than the 1960 levels is still anomalous, although it has engendered optimism that the lake has found a new long-term water level that can be harvested for increased hydroelectric generation at the Owen Falls generating stations at its outlet. It is hoped that this optimism is well founded.

CLIMATE CHANGE

The water level records of the three lakes over decades, centuries and millennia indicate that the lakes respond sensitively to changes in rainfall and evaporation. Even in their modern condition, they are barely open lakes, with flushing times of >100 years for Lake Victoria, to >7000 years for Lake Tanganyika (Bootsma & Hecky 1993). When they fall below their outlet, they will decrease to a level where evaporative losses are balanced by water inputs, making the lakes very sensitive recorders of P/E over geological time. The lakes can also be affected, however, by changes in their surface heat budget, even when levels are relatively constant. Verburg *et al.* (2003) have recently shown that Lake Tanganyika has been warming through the last century, and at relatively high rates since 1980, in response to globally (and regionally) rising air temperatures. As water density change per degree of warming increases rapidly as temperatures rise, small temperature changes in tropical lakes can result in significant changes in the stability of thermal stratification (Hecky 2000). As Lake Tanganyika does not mix throughout its depths annually, its upper waters have warmed more rapidly than its deep waters, with the result that the density stratification of the lake has been strengthened, with the interchange with the deeper metalimnion and hypolimnion having been slowed. This might have resulted in reduced internal nutrient loadings from the deeper waters and decreasing primary productivity in the lake (Verburg *et al.* 2003). O'Reilly *et al.* (2003) also suggest that this might have resulted in reduced fish production in Lake Tanganyika, although Sarvala *et al.* (2006) disagree that fish production decreased during this period of warming.

Vollmer *et al.* (2005) have also documented the rising temperatures over the last 60 years in Lake Malawi, as well as the measured reduced ventilation of the deep waters since 1980 (Vollmer *et al.* 2002). As the internal nutrient
4 loading is a significant source of silicon and phosphorus, two critical plant nutrients (Bootsma *et al.* 2003), Lake Malawi would have reduced the internal loading of these nutrients for over the past 20 years. Lake Victoria also had warmer deep-water temperatures in its seasonal hypolimnion in the 1990s, relative to those temperatures in the 1960s (Hecky *et al.* 1994). Its more stable stratification at present, compared to 1960 (Hecky 1993), could partly be a consequence of warmer air temperatures and reduced nocturnal cooling. However, changing wind strengths might also affect Lake Victoria, which still mixes throughout its depths in July and August. Lorke *et al.* (2004) found that the recent lava flows in 2002 into Lake Kivu did have a local effect on water temperatures down to 100 m, but had lesser effect on the water column structure than on the climatic warming over the last three decades that increased the water temperature by 0.5 °C in the upper 250 m. Across all the African Great Lakes for which historical data are available, there is clear evidence for climate warming over the past few decades and longer.

Meteorological events, especially the periods of high rainfall and river inflows, could affect the deep-water ventilation in Lake Malawi (Vollmer *et al.* 2005) and other deep tropical lakes. Many of the inflowing rivers entering the northern end of Lake Malawi plunge below the warm epilimnion because they are cooler and more turbid than the mixed layer. The river plumes plunge to depths
determined by their densities (Bootsma *et al.* 2003), and 5
can potentially plunge below the depth of annual mixing (≈110 m), dispersing into the large volumes of the metalimnion and hypolimnion and cooling the deep waters. These deeper, cooler water layers subsequently slowly exchange with upper warmer water layers, and the incoming nutrient loads might not affect the mixed water layer for decades (Vollmer *et al.* 2002). Thus, the sediment and nutrient loads carried by these rivers might bypass the mixed layer with little effect. In southern Lake Malawi, the plunging is confined by the shallower bottom depths, thereby remaining above the depth of annual mixing, with the fluvially transported loads being available to affect surface waters during annual mixing. Similarly, riverine loads enter into shallow water in shallow Lake Victoria, and the lake mixes throughout its depth annually. Thus, the incoming loads do affect the water quality of the whole lake on an annual basis.

A warming climate, such as has occurred over the past
century in eastern Africa, will warm rivers more rapidly 6
than the deep waters of Lakes Tanganyika and Malawi, and might have reduced the cooling effect from these plunging rivers, thereby contributing to the warming trends in the

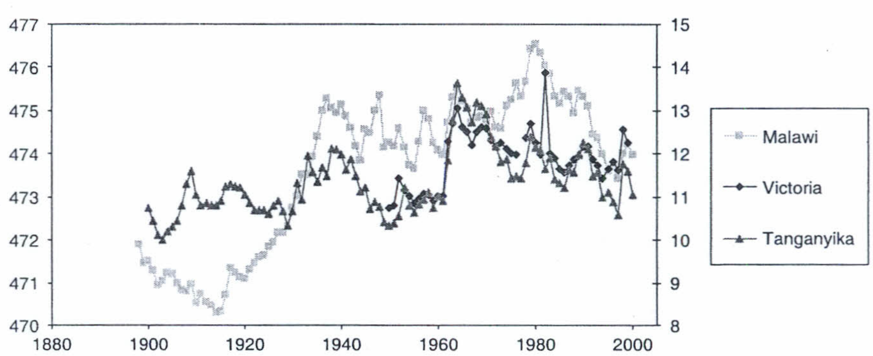

Fig. 1. Annual mean water levels for the African Great Lakes (expressed in m a.s.l.), relative to Lake Malawi elevations (left-hand axis) or Lake Victoria datum (right-hand axis) to allow direct comparison of interannual variation.

lakes' hypolimnions (Vollmer *et al.* 2005). The potential climatic effects on lake behaviour, including the distribution of incoming nutrient loads, are complex, and cannot be adequately modelled at present because of a lack of data, especially on river temperatures and material loads. The lakes are warming, however, with the full consequences yet undefined. The reduced internal circulation, as measured in Lake Malawi, and inferred for Lake Tanganyika, could reduce the internal nutrient loading, offsetting increases in the external loading from rivers and the atmosphere. Although this would be a positive benefit that ameliorates cultural eutrophication, it could also mask the evolving problems in the catchments if they are adding more nutrients than they did historically (Hecky *et al.* 2003). A future reduction in the warming trend would allow deep-water temperatures to increase, relative to the mixed layer, eventually resulting in rapidly increasing nutrient loadings if cultural eutrophication is neglected. As a result of the slow response rates of these lakes to changes in heat fluxes and nutrient inputs, it is important that the implications of these changes are understood before their impacts are fully manifested, because the lakes' response rates to mitigation also will be slow (Bootsma & Hecky 1993). Managing the nutrient loading of these large systems is only partially controllable through managing their external loads. Global climate change, and dependent changes in internal loading, can certainly delay the response of the lakes to catchment management, as well as potentially overwhelm and reverse positive trends in the external nutrient loading. The challenge is aggravated by the current projections that climate warming over the next century in the tropics will be three to five times greater than that observed over the last century (Hulme *et al.* 2001).

NUTRIENT LOADING

The rapidly growing human populations in eastern Africa require increased agricultural production, with this production increasingly encompassing marginal lands and increased elevations and slopes. It is well known that the transformation of land from forest or natural continuous savanna to grazed grasslands and tilled agriculture increases water and sediment yields from the land surface into waterways (Sundborg & Rapp 1986). Basin-scale estimates of the impacts of land clearance and changing land uses are less common. Hecky *et al.* (2003) compared the forested catchments with the extensively cultivated catchments, concluding that the nutrient yields increased six to ninefold, and the sediment yields from 10- to 40-fold, depending on catchment slopes over predisturbance yields. Land use, topography, soils and hydrology interact to determine the watershed export, and these aspects can be modelled to predict future changes in land uses, or to guide landscape restoration to reduce the nutrient loading (e.g. Lam *et al.* 2002). The sediment and nutrient yields at the basin scale represent costly depletions of natural soil capital that ultimately reduce farmers' yields. This negative effect at the farm scale can provide the motivation to undertake lake basin management initiatives to improve farming practices and maintain soil fertility and crop productivity, while also reducing losses of soil and nutrients downstream where there are negative impacts on receiving waters.

Tropical Africa has the highest rate of biomass burning in the world, being especially high in savanna areas (Hao & Liu 1994). Agricultural practices in Africa are very dependent on fire to clear the land, regenerate nutrients from agricultural debris and on grazing lands, and to control pests. Fire is also heavily used for domestic heating and cooking. Fire mobilizes fine ash and volatile elements into the atmosphere, where these materials can travel widely. Ash from such fires is rich in phosphorus (Lewis 1981), which is often the limiting nutrient for plant growth in lakes and on land. Fires export nutrients from the burned lands and transport them down-wind, and frequently into lakes. Recent studies suggest the nutrients' possible transport over hundreds and even thousands of miles (Jickells *et al.* 1998), although the highest deposition rates in wild fires and windstorms could be closer to the source fire, as the coarser ash will be removed more rapidly from the atmosphere. In the planting season, the soil surface is exposed to wind erosion after clearing and tilling, with exposed soils being a source of fine soil and ash particles to the atmosphere until a vegetation cover is re-established after the rains commence (Bootsma *et al.* 1996). Measurements in eastern Africa on Lake Malawi and around Lake Victoria indicate that the phosphorus deposition rates in rain and dry fall are among the highest that have been measured (Table 2), but which are not exceptionally high for tropical areas undergoing land clearance. Because of the large lake surface area available to receive dry fall, and the dominance of rain in the water budget of the great lakes, the atmospheric deposition of phosphorus is an important external phosphorus source to Lake Malawi (Fig. 2), and also appears to be the dominant external phosphorus-loading source to Lake Victoria (Table 3). Phosphorus is not the only nutrient mobilized, with others, such as sulphur, nitrogen, iron and potassium (Crutzen & Andreae 1990), also are transported through the atmosphere, potentially affecting the lakes that receive these inputs. Atmospherically borne nitrogen and phosphorous have been documented to enrich

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oligotrophic lakes far from the origins of the atmospheric nutrients (Lewis 1981; Jassby *et al.* 1994; Sickman *et al.* 2003), and to have been transported long distances (Jickells *et al.* 1998; Brunner & Bachofen 1998).

The similarity of atmospheric phosphorus deposition rates between the stations on Lake Malawi and around Lake Victoria (including the stations with dominant winds offshore and dominant winds onshore from the lake), and in the protected area of Serengeti National Park, is consistent with the widespread and relatively uniform atmospheric phosphorous concentrations (Tamatamah *et al.* 2005). Bootsma *et al.* (1999) compared the nutrient deposition rates at three locations in Lake Malawi, finding that the deposition rates of most nutrients were similar at all stations, although particulate carbon, nitrogen and phosphorous deposition was greater at an inland location.

Table 2. Total phosphorus loading rates by precipitation from selected global sites relevant to tropical lakes (expressed in kg ha^{-1} $year^{-1}$; data sources in Tamatamah *et al.* 2005)

	Wet	Dry	Wet + dry
Mwanza, Lake Victoria	0.5	2.2	2.7
Bukoba, Lake Victoria	0.6	1.3	1.9
Seronera, Lake Victoria	0.3	1.5	1.8
Duma, Lake Victoria	–	1.8	–
Jinja, Lake Victoria	0.7	–	–
West Coast of Africa	1.2	–	–
Lake-Valencia, Venezuela	–	–	1.68
Lake Malawi, Africa	0.3	2.1	2.5
Ontario Canadian Shield	–	–	0.32
Colorado Mountains, USA	–	–	0.26

Table 3. Provisional total nitrogen (TN) and total phosphorus (TP) nutrient budget for Lake Victoria (precipitation data from Tamatamah (2002); nitrogen fixation from Mugidde *et al.* (2003); river data extrapolated from Linthipe River, Lake Malawi from Hecky *et al.* (2003)

Flux	Water (mm $year^{-1}$)	TN (kt $year^{-1}$)	TP (kt $year^{-1}$)
Rainfall	1790	83	4.8
Dryfall		110	13
Rivers	338	43	9.8
External total		236	27.6
Nitrogen fixation		480	
Total inputs		716	27.6

Areas of higher rainfall tend to have higher wet deposition rates and lower dry-fall deposition, and the same is true when comparing rainy season deposition rates with dry season rates (Tamatamah *et al.* 2005), the result being that the annual deposition rates are remarkably similar throughout East and southern Africa, despite the quite different climatic conditions and land uses at the monitoring stations.

Despite the apparently similar and high rates of phosphorous deposition around southern Africa, both the number of monitored stations and their geographical distribution are still quite limited. What is needed is a regional monitoring network to define spatial and temporal trends and significant source areas. Furthermore, extrapolation of these rates over large areas, such as the surface area of Lake Victoria, requires confirmation by monitoring on the lake itself before full confidence can be given to estimates such as those presented in Table 3. The atmospheric and ecological consequences of biomass burning in the tropics, and the potential for disrupting nutrient cycles and the productivity of the burned terrestrial systems, have been known for some time (Crutzen & Andreae 1990). Less appreciated is the possible effect of these mobilized nutrients on lakes. In terms of atmospheric transport and deposition, lakes are the receiving systems, functioning as effective sinks for the mobilized nutrients. Except for very conservative ions (e.g. chloride), whatever material enters the Great African Lakes will remain in the lakes. Nutrients such as sulphur, nitrogen, silicon and phosphorous are highly retained in these poorly flushed systems, even when compared to Lake Superior, which has the longest water-flushing time of the Laurentian Great Lakes (Hecky 2000). Such high retention times mean that any pollutant entering these lakes will remain in the water or sediment of the lakes, with potentially prolonged effects on the aquatic systems (Bootsma & Hecky 1993). As the water-flushing times decrease in smaller lakes and reservoirs, the importance of atmospheric deposition in the nutrient budgets should decline, although nutrient management in the great lakes still will require addressing atmospheric deposition which, in turn, will require a regional approach to maintaining or restoring air quality. Biomass burning also produces other atmospheric hazards, such as ground-level ozone, that can reduce plant productivity (Ashmore *et al.* 1994; Maggs *et al.* 1995), and can cause respiratory problems. For farmers to change their current practices, benefits will have to accrue at the farm scale, as well as at the basin scale. Lake managers will have to work closely with their partners in managing land uses and agricultural practices to facilitate such changes.

CONTAMINANTS

The atmosphere can also be a transport medium for volatile contaminants, such as organochlorines (e.g. DDT, PCBs), mercury, and other semivolatile gaseous and dust-borne toxic compounds (e.g. polynuclear aromatic hydrocarbons). The organochlorines have caused serious biotic degradation to the Laurentian Great Lakes, especially affecting fish-eating birds because of bioaccumulation of organoclorines in food webs. Banning the manufacture and use of the most persistent and toxic organochlorines, such as DDT and PCBs, has led to a slow downward trend in the concentrations of these compounds, from high concentrations in the Laurentian Great Lakes biota in the late 1970s. Even after 30 years, however, PCB concentrations in some fish remain above the levels considered acceptable for consumption (Lamon *et al.* 1999). Mercury is also toxic, particularly as its methylated species, methyl mercury (CH_3Hg^+), that can bioaccumulate in food webs and exceed acceptable concentrations in piscivorous fish when the concentrations in water are at sub-nanogram per litre concentrations. The lucrative Lake Erie fishery, for example, was closed in the early 1970s because mercury concentrations in predatory fishes exceeded the market acceptability. Removal of mercury from industrial point sources allowed rapid recovery and reopening of the commercial Lake Erie fishery. However, mercury concentrations still remain sufficiently high in the Laurentian Great Lakes to prompt fish consumption advisory statements urging people to limit the consumption of many predatory fish species. Atmospheric mercury concentrations have risen through the past century and, even in remote lakes, mercury deposition has increased by approximately a factor of two all over the globe. Recognition of this historical contamination of the atmosphere and aquatic ecosystems has led to the international efforts to further reduce or eliminate the economic use of mercury in industrial processing and in manufactured products. Similarly, organochlorine concentrations have been rising in remote Arctic lakes and coastal marine systems because of their atmospheric transport from lower latitudes where their historical use was high, or remains high. The volatility of these organochlorine compounds leads to a 'grasshopper' effect, moving the compounds from warmer ecosystems to colder ecosystems, and eventually to accumulation in continuously cold lipid-rich aquatic food webs at high latitudes (Wania & Mackay 1993). The transboundary dimension of this problem has led to recent global

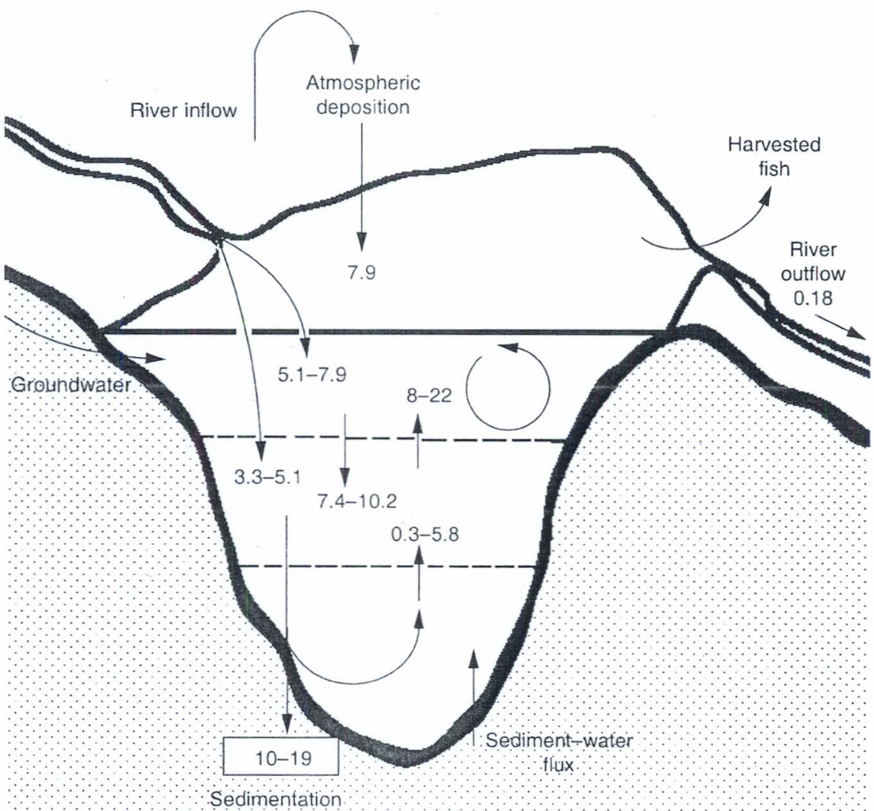

Fig. 2. Total phosphorous fluxes to and from Lake Malawi (numerical units are mmol m^{-2} year^{-1}; ranges are given for high and low estimated fluxes for the rivers, based on different approaches to extrapolation to unmonitored terrestrial catchments (Bootsma and Hecky 1999); riverine inputs are split on the basis of the density of the inflowing stream into fluxes to the mixed layer, and likely fluxes to the metalimnion).

protocols for reducing and eliminating organochlorines, and should encourage the developed countries in higher latitudes to assist tropical and subtropical developing countries to find alternatives to the use of persistent, toxic organochlorine compounds.

Organochlorines, especially DDT, are still used in tropical countries, being detectable in the air at stations in Uganda (Fig. 3) and in air, water and aquatic biota of Lake Malawi (Karlsson *et al.* 2000; Kidd *et al.* 2001) at concentrations well above those found at higher latitudes. Fortunately, volatilization (and perhaps degradation) of these compounds keeps their concentrations low in tropical waters and biota (Kidd *et al.* 2001), and well below concentrations of concern for fish consumers. Nevertheless, the disturbing trend over time, as recorded in a sediment core from Lake Victoria (Lipiatou *et al.* 1996), is for increasing concentrations in sediment. Thus, careful monitoring, and eventually elimination of the use of these persistent organic pollutants, will be the only way to eliminate the risk of contamination of aquatic organisms while these pollutants are still used. Although pesticide use has been historically limited by the poor economic conditions in Africa, wise use of such pesticides might be necessary to boost the agricultural production, especially the valuable export crops, as well as to control health risks, such as disease-bearing insects. Thus, the future use of pesticides is likely to increase in the developing countries.

Eliminating mercury from the atmosphere of eastern Africa and its lakes will not be possible. Mercury is a naturally occurring element, being found everywhere and in every environmental media. Metallic or inorganic mercury itself can be toxic, but rarely at environmental concentrations. Inorganic mercury compounds can be excreted by the kidneys of higher organisms, thereby not bioaccumulating to any significant degree. The production of methyl mercury by bacteria in the environment, however, can lead to efficient bioaccumulation and biomagnification of methyl mercury in food webs, often by a factor of >1 million times above water concentrations, and can cause potentially unacceptable concentrations in top predators (Campbell *et al.* 2003a). Surveys of African fisheries have found generally acceptable mercury concentrations in fish for marketing and frequent human consumption, except for very large piscivorous Nile perch in Lake Victoria, or as a result of long food-chains such as found in Lake Albert, Uganda (Fig. 4; Campbell *et al.* 2002). This positive outlook is tempered by the recognition that mercury deposition has increased over time for Lake Victoria (Fig. 5), and that the capacity of bacteria to methylate mercury can be modified both by the addition of more mercury to an ecosystem, and by the enhanced rates of bacterial methylation (Hecky *et al.* 1992). The total mercury concentrations are actually higher in Lake Victoria waters (Campbell *et al.* 2003b) than they are in the Laurentian Great Lakes, although the fishes in the African lakes have lower concentrations of methyl mercury in their flesh than do the temperate Great Lakes fishes, for reasons that are currently unclear. Biomass burning is likely the greatest mercury source to Lake Victoria (Campbell *et al.* 2003a), and its reduction would reduce the mercury loading to the lake. More problematic is determining what controls the rates of bacterial methylation of mercury. Any increase in mercury methylation could cause mercury concentrations in top predatory fish to rise to unacceptable levels for frequent

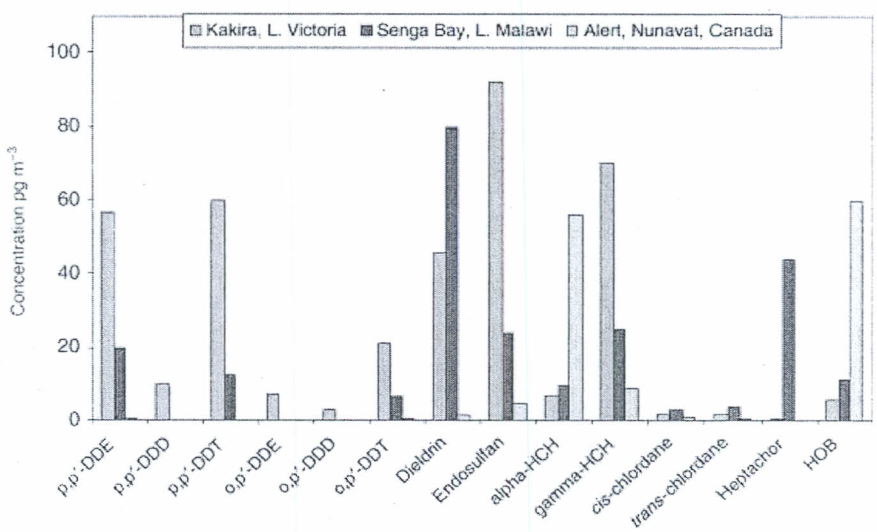

Fig. 3. Atmospheric concentrations of selected pesticides and some degradation products for two monitoring stations in eastern Africa, Kakira, Uganda and Senga Bay, Malawi, compared to a remote monitoring station in the high Arctic, Alert, Canada (data from Wejjuli *et al.* 2002).

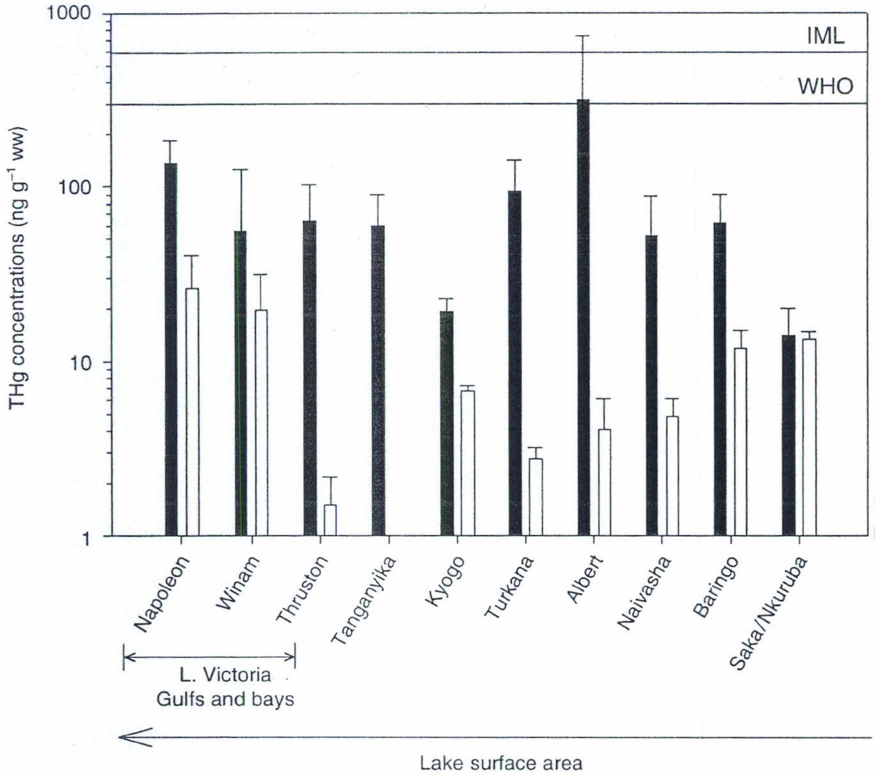

Fig. 4. Mercury (Hg) concentrations in top predator fishes (solid bars) and herbivorous/detritivorous fishes (light bars) in African lakes (note the logarithmic scale; from Campbell *et al.* (2002). IML, acceptable Hg level for marketing fish internationally; WHO, guideline concentration for frequent fish consumption by sensitive groups (e.g. nursing mothers and children).

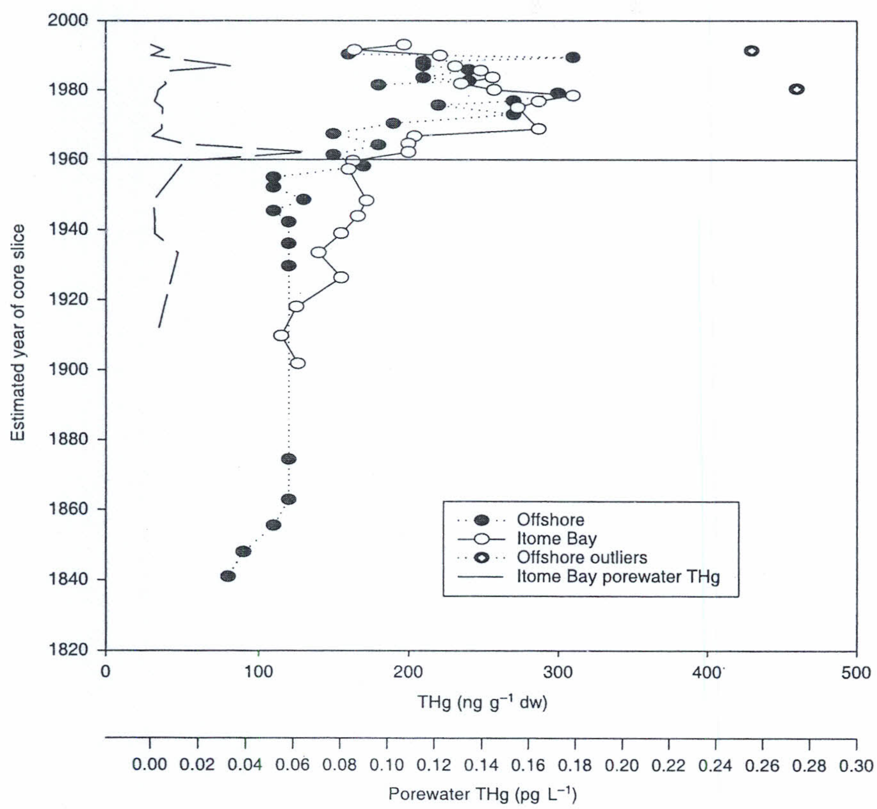

Fig. 5. Total mercury (THg) concentrations in two sediment cores (offshore and inshore) in Lake Victoria (dashed line = porewater THg concentration in inshore core; from Campbell *et al.* 2003b).

consumption or even for export. Research is needed to address this issue for tropical ecosystems. Sulphate-reducing bacteria are often implicated in elevated rates of bacterial methylation, and the low concentrations of dissolved sulphate in the African Great Lakes could be limiting the methylation rates. Biomass burning will also increase the sulphur loading to the lakes (Crutzen & Andreae 1990), and could act synergistically with increased mercury loadings to increase methyl mercury production over time.

Careful monitoring of mercury and organochlorine concentrations in fish can protect fish consumers, as well as the international market place for fish products from the African lakes, and hopefully allow for the detection of any upward trend before mercury concentrations in fishes become unacceptable. If upward trends are detected, regional action to reverse those trends in these great lakes and their fisheries will be likely required.

CONCLUSION

Many environmental risks to African lakes arise within their catchments and can be addressed by riparian states in the catchment through appropriate basin management initiatives, bolstered with adequate funding. However, other risks arising from atmospheric change can affect lakes over broad areas, and will require regional or even global action to address them. Evidence from the Great African Lakes indicates that climate change, intensifying land use (mobilizing nutrients) and toxic substances are increasingly affecting the atmosphere over the African Great Lakes. The Great Lakes are particularly sensitive to these changes because of their enormous surface areas, slow water-flushing rates and the importance of direct rainfall in their water budgets. Their response times might be slow to yield a detectable change and, unfortunately, their recovery times also might be slow. It is possible for atmospheric effects to act antagonistically to impacts of catchment change (e.g. evidence for lower productivity in Lake Tanganyika despite ongoing catchment degradation), but antagonistic effects could become synergistic in the future (e.g. the positive effect that increasing atmospheric sulphur deposition might have on mercury methylation). Improved understanding of the physical dynamics of these lakes, and development of models that link their physical and biogeochemical behaviour to regional, mesoscale climate models, will be necessary to guide lake managers.

The inherent hydrological sensitivity of the African Great Lakes, and the attention they have received from GEF-sponsored studies as international waters requiring cooperative management among riparian states, have now highlighted the risks inherent in atmospheric change. However, the scale of the risks, the rates of change and, most importantly, the regional and global management responses are yet to be defined. The GEF programmatic focal areas are international waters, biodiversity, climate change, ozone depletion, land degradation, and persistent organic pollutants. Clearly, the transboundary issues regarding the African Great Lakes are appropriate for further GEF action. At the same time, however, the states of eastern Africa that enjoy the benefits from these lakes will increasingly have to collaborate to engender a regional, or possibly even continental, approach to resolve many of these issues. In particular, climate change will have to be addressed at a global scale in order to safeguard the African Great Lakes. The challenge to lake management will be to unravel the causation of undesirable changes, in order to determine whether local catchment impacts are the main cause of the changes, or whether atmospherically mediated and/or climatically driven changes are responsible. The scale of response, and the possibility of effective management intervention, requires resolution of that challenge for all the lakes of Africa.

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Lake Baringo: Addressing threatened biodiversity and livelihoods

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Abstract

Lake Baringo is a shallow, internal drainage, freshwater lake located in the Kenyan Rift Valley. The lake is an important source of water for humans and livestock, as well as a significant income source for local communities through activities such as tourism, biodiversity conservation, and fish sold in local markets. The lake has been subject to overfishing, as well as to greatly enhanced sedimentation as a result of land use changes in the drainage basin. This paper provides an overview of the conditions prevailing at Lake Baringo, and examines in detail the management response to the problems facing the lake. The roles of the many and varied institutions in the lake basin's management are discussed, and an analysis of internationally funded projects designed to ameliorate the situation is provided.

Key words

biodiversity, fishing moratorium, Global Environment Facility, Lake Baringo, lake basin management, land use change, sedimentation.

INTRODUCTION

Lake Baringo is named after the local word 'Mparingo', which means lake. It is located in the eastern Rift Valley in Kenya, being one of the seven inland drainage lakes within the Rift Valley drainage basin. The lake has a surface area of about 108 km^2 and drains a total area of 6820 km^2 (Fig. 1). It is located in the administrative district of Baringo at 1000 m a.s.l., with its basin extending to the neighbouring districts of Koibatek, Laikipia and Nakuru. Several seasonal rivers drain into the lake, including Ol Arabel, Makutan, Tangulbei, Endao and Chemeron. Perkerra and Molo are perennial rivers, although they exhibit significantly reduced water discharges during dry seasons. Lake Baringo experiences very high annual evaporation rates of 1650–2300 mm, compared to an annual rainfall of 450–900 mm. Thus, its survival depends on the inflows from rivers originating from the humid hill slopes of the drainage basin, where the annual rainfall varies between 1100 and 2700 mm.

As a freshwater body, Lake Baringo is important to the communities in its basin as a source of water for domestic use and livestock consumption. Other important uses are income generation through tourism, biodiversity conservation and fishing activities. The composition of the lake's fish species includes *Oreochromis niloticus*, *Protopterus aethiopicus*, *Clarias gariepinus*, *Barbus intermedius* and *Labeo cylindricus*. Three indigenous human communities live in the basin; namely, the Ilchamus, Pokots and Tugens. These communities earn their living through pastoralism and agro-pastoralism. As pastoralists, they maintain large numbers of cattle, which overgraze the catchment vegetation, leading to enhanced soil erosion, sedimentation in streams and the lake, and frequent flash floods. Other activities causing degradation are deforestation and conventional agricultural practices. Together with other forms of degradation, including loss of biodiversity and declines in fisheries, these activities have drawn the attention of the government, non-governmental organizations (NGOs) and other stakeholders of the need to carry out management interventions, with the aim of minimizing further degradation of the lake. Past interventions for the resource management in the lake drainage basin include:

- Baringo semi-arid project for land rehabilitation (1980–1989)
- African Land Development for grazing schemes and provision of water (1940s)

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• Kenya Livestock Development Programme for group ranches (1960–1970)

• FAO project for fuel and fodder (1982–87)

The approaches adopted by the stakeholders for the sustainable management of the lake basin include empowering the local communities for natural resource management, diversification of agriculture, agroforestry systems, and microenterprises. Furthermore, fishing moratoria, and soil and water conservation practices, also are in place in the lake and its basin. These practices tend to reduce the degradation either by reducing pressures on certain resources, especially land, through the provision of alternative sources of income, or by effecting direct conservation measures. The institutions involved in carrying out these management activities include:

• Public institutions – Kenya Marine and Fisheries Research Institute (KMFRI); Kenya Forestry Research Institute; Baringo County Council; Ministry of Agriculture (MoA); Ministry of Water Resources and Development; Ministry of Environment and Natural Resources; Ministry of Livestock and Fisheries; and Kenya Agricultural Research Institute

• Private organizations – Block Hotels

• NGOs – World Vision; Rehabilitation of Arid Environment Trust

• Community-based organizations (CBOs) – Honey Care; Women's Groups

The past management of the lake and its basin carried out by the above-noted institutions was mainly sectoral in nature. The need for integrated management was realized from lessons learned from past projects. Thus, the involvement of UNEP and the Global Environmental Facility (GEF), through the Lake Baringo Community-Based (LBCB) Land and Water Management Project, has facilitated integrated management of the lake and its basin. In this programme, capacity-building and creation of awareness of local communities were undertaken, together with coordination and facilitation of the stakeholders, to facilitate sound management of Lake Baringo and its drainage basin.

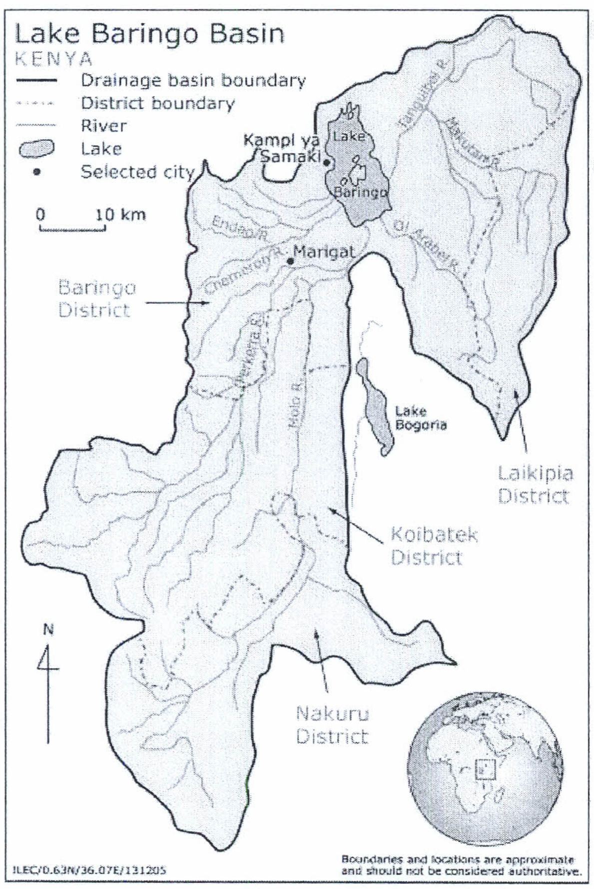

Fig. 1. The Lake Baringo drainage basin.

Background

Lake Baringo is a freshwater lake with importance to the population of its drainage basin as a source of water for domestic use and for watering livestock. It is also a source of food, especially fish, to the community. The current species composition of the lake is as follows: *O. niloticus* (80.4%), *P. aethiopicus* (7.95%), *C. gariepinus* (9.8%), *B. intermedius* (0.96%) and *L. cylindricus*. *Barbus* rarely appears in the fishermen's catches, while *Labeo* has almost disappeared from the lake since the damming of its inflowing rivers, which interfered with its breeding habits (Aloo 2002). The lake also is a source of vegetation products (e.g. *Aeshynomena elephroxylon*), which is used for boat construction, and water lily for making domestic bread (ugali). About 500 families live in Kampi ya Samaki, a centre that has grown mainly because of fishing activities in the lake. Half of the population in this centre is fishermen, with 300 being fish handlers. Others earn their living through such activities as boat construction. As a result of an overdependence on fishing, there has been a remarkable fluctuation in fish production (Fig. 2). The estimated economic value of the fishery for the year 2002 was based on experimental fishing, whereas that for 2001, the year of establishment of a fishing moratorium, was derived through interpolation of data.

Fish is a food source, and the sale of fish to nearby urban centres also generates income for the local people. Through fishing activities, the lake provides employment to the fisherfolk, and to the young tour operators who own boats. The boats are used by tourists for navigation in the lake. The lake also is an important tourist attraction because of its rich biodiversity, which comprises hippos, birds and crocodiles, among others. Its shoreline also is used as a grazing ground for livestock, especially during dry seasons when the catchment is dry and grass is scarce. The local people also use the lake for navigation to link the eastern and the western parts of Baringo District.

Records indicate that between 1969 and 1972, the average depth of the lake was 8 m. In early 2003, before the onset of the long rains, the average depth was 1.7 m. The current average depth is 2.5 m, with the deepest end of the lake being 3.5 m. This increase in water depth was the result of the prolonged long rains during 2003, especially in the humid upper catchments. The surface area of the lake has exhibited a decreasing trend. Studies by Onyando (2002) revealed that the area of the lake was 219 km^2 in 1976, 136 km^2 in 1986, 114 km^2 in 1995, and 108 km^2 in 2001. Based on these trends, the author extrapolated the lake's surface area into the future, suggesting that the surface area will be reduced by 50% by 2025 if the current trend continues (Fig. 3).

The boundary of the drainage basin lies on the Tugen Hills to the west, the Eldama Ravine ranges to the south, and the Laikipia Plateau to the east. These hills rise as high as 2800 m above mean sea level (a.m.s.l.), while the lake is at ≈1000 m a.m.s.l. The geology of the area is mainly undifferentiated volcanic rocks, while the soils are of clay type. The landscape is characterized by steep slopes from the Tugen Hills and Eldama Ravine Highlands to the Perkerra River, grading in to gentle slopes, and finally to the floodplains of Marigat and Lake Baringo.

Although Lake Baringo is located in a semiarid zone, its catchment covers a range of climatic zones, from semiarid through semihumid and subhumid, to a small portion in the humid zone. The mean annual rainfalls in these zones are 450–900 mm (semiarid), 800–1400 mm (semihumid), 1000–1600 mm (subhumid), and 1100–2700 mm (humid). The mean annual potential evaporation amounts for these areas are 1650–2300 mm (semiarid), 1450–2200 mm (semihumid), 1300–2100 mm (subhumid), and 1200–2000 mm (humid). The risk of crop failure is 25–75% in the semiarid zone, 5–10% in the semihumid zone, 1–5% in the subhumid zone, and <1% in the humid zone. Similarly, the potential for plant growth in these zones can be classified as medium to low, high to medium, high, and very high, respectively. These figures indicate that the semiarid zone, in which Lake Baringo is located, is a fragile environment with low natural life-sustaining properties, thereby requiring urgent conservation attention.

The rainfall characteristic of the basin is bimodal, intense, and erratic. The long rains occur in the months of April to August, whereas the short rains fall from October to November. Daily rainfall monitoring in the basin dates back to 1903. Since that time, a total of 101 stations have been installed in the catchment by various organizations, including the Kenya Meteorological Department, research organizations and individuals. However, only 66 stations are currently operational. This translates into a den- 3
sity of 97 km^2 $gauge^{-1}$, which is less than the World Meteorological Organization's recommendation of 17 km^2 $gauge^{-1}$. Stream flow monitoring started as early as 1926, with a total of 26 river-gauging stations having been installed at different times since that time in various locations in the rivers flowing into Lake Baringo. Most of 4
the above stations are not currently operational because of poor maintenance of the gauges. Thus, the available data contain many gaps, which are a significant drawback in managing the basin's water resources.

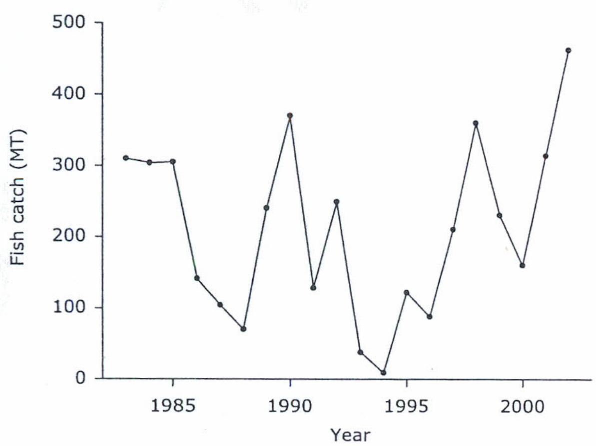

Fig. 2. Trend of fish production in Lake Baringo (comprising *Oreochromis, Clarias, Barbus, Protopterus* and *Labeo*)

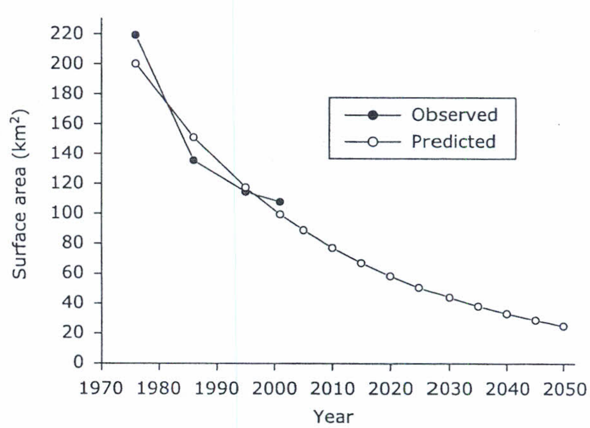

Fig. 3. Observed and predicted surface area of Lake Baringo tables.

Lake Baringo is the lifeline of the communities in its basin, especially in the vicinity of the lake. These communities include the Pokots to the north, the Tugens to the east, and the Ilchamus on the south and eastern sides. The Ilchamus form about 50% of the riparian population, being mainly pastoralists. The Ilchamus and Pokots mainly practise agro-pastoralism, with emphasis on pastoralism, while the Tugens are primarily agriculturalists. These communities are politically marginalized, especially the Ilchamus and the Pokots. Thus, their poverty level is high, and they have limited access to tap water, health facilities and other services. Livestock over-grazing is a major problem in this area, because the pastoralists are not willing to reduce the number of their herds to conform with the available food biomass. Their livestock is comprised of cattle, sheep and goats. Dry seasons are critical periods for raising livestock because the grass is rare at that time and most cattle graze along the lakeshore, thereby interfering with the lake's ecosystem. The land tenure system is group ranch, with grazing being communal. This accelerates soil erosion because the cattle graze together and are driven together from place to place in search of pasture. Another area of conflict is cattle rustling, which creates friction between communities in the basin, hence limiting the collective responsibility in managing the lake and its basin.

The streams flowing into Lake Baringo originate from humid and subhumid hill slopes, where the annual rainfall is >1000 mm. Although these hill slopes are the major recharge areas, they belong to administrative districts that, while located within the basin, are not riparian to the lake (the lake is surrounded by the Baringo District). This creates restrictions in river basin management, as the administration in every district is unique. Although some low level of interaction exists between the districts, it must be further enhanced to facilitate effective management of the basin's natural resources. The hill slopes, which are located in the water recharge areas, have undergone deforestation in the recent past, through land conversion to create more land for agriculture, and through harvesting of forest products for timber, wood fuel and charcoal. The forested areas of the catchment have decreased by ≈50% since 1976. Consequently, groundwater recharge has decreased, with streams drying up more often during the dry seasons, whereas they cause flash floods during the rainy seasons. As a result of the floods, loss of property and displacement of people have been prevalent in the lower reaches of the basin.

The benefits accruing from the lake include water for domestic and livestock use, fisheries, tourism and biodiversity. Irrigated agriculture is another major benefit derived from the water resources of Lake Baringo basin, mainly through water abstraction from the Perkerra, Endao and Chemeron Rivers. The crops grown in the irrigation schemes include, among others, maize, water melons, tomatoes, onions, pawpaws and oranges.

The Lake Baringo drainage basin is endowed with rich terrestrial and aquatic biodiversity, including natural vegetation, wildlife, birds and fisheries. There are about 400–500 different bird species (Gichuki 2000), for example, most of which reside in areas with intact woodland and grassland and rehabilitated lands. Such areas also contain a variety of plant species. Reports also indicate that there are about 40–60 hippos in the lake, while about 20 crocodiles also reside there. In addition to the lake, the biodiversity offers a resource base for tourism attraction. Through tourism activities, the area has been opened to other regions, both nationally and internationally. This has promoted business enterprises and the interchange of knowledge and technologies through interactions between the locals and foreigners. By attracting foreigners, the lake and its basin have attracted markets for local agricultural and livestock products.

Biophysical environment

Water quality conditions

The water quality of Lake Baringo has deteriorated over time. The main concern is turbidity, which has increased because of high rates of sedimentation from increased soil erosion in the catchment. The turbidity values recorded in recent analysis range between 350 and 900 NTU, which are rather high values. Related to the increased turbidity is reduced water transparency, which is <0.1 m, as measured by Secchi disc. The physiochemical analyses of the lake have been carried out in the past, with the most recent and reliable analysis done between June 2001 and May 2002 (Ballot *et al.* 2003). The parameters analysed in this latter study are shown in Table 1.

As shown in Table 1, the physical conditions of Lake Baringo are characterized by high temperature and low transparency. The pH of the lake is relatively high because of the alkaline hot spring discharge from Kokwa Island, which is located in the lake. The conductivity and salinity indicate the subsalinity of the lake (Hammer 1986), whereas the high total nitrogen (TN) and total phosphorus (TP) concentrations reflect the lake's hypereutrophic condition.

Biomass production

The turbid water of Lake Baringo is characterized by a greenish colour related to the presence of the

cyanobacterium, *Microcystis aeruginosa*, which dominates the lake's phytoplankton community. As a result of the turbid nature of the lake water, primary production in the open water is very low. Thus, the phytoplankton population is limited only to the positively buoyant species, including *M. aeruginosa*, *Melosira granulata* and *Anabaena carcinalis*. The lake's high turbidity limits light penetration into the water column, resulting in low biomass production. The recent analyses revealed the concentration of phytoplankton biomass to range between 1.5 and 8.2 mg L^{-1}
5 (Ballot *et al.* 2003). The main phytoplankton groups in Lake Baringo are shown in Table 2.

Microcystis aeruginosa dominates in Lake Baringo, compared to the other phytoplankton, mainly because it can develop gas vacuoles in its cells, allowing it to regulate its buoyancy. This ability to control vertical location enables it to locate itself in a position in the water column where it can receive relatively more light in the turbid water of Lake Baringo. Other factors contributing to the dominance of *Microcystis* are temperature and nutrient loading. The growth rates of bloom-forming cyanobacteria such as *Microcystis* are optimal at 25°C, which falls within the temperature range measured in Lake Baringo (i.e. 23.7–26.3°C). The TP and TN concentrations of 1.0 and 2.8 mg L^{-1}, respectively, indicate high nutrient loading to the lake. The production of cyanobacteria at levels between 0.2 and 5.5 mg L^{-1}, however, is not commensurate with the lake's TP and TN concentrations. Hartebeesport Reservoir in South Africa, with similar TP and TN concentrations, for example, has *Microcystis* production levels between 20 and 50 mg L^{-1} (Zohary & Robarts 1990). This latter production level is about 10 times that of Lake Baringo, thereby illustrating the degree that high turbidity can limit lake production.

Table 1. Physiochemical conditions of Lake Baringo, June 2001–May 2002

Parameters	June 2001	November 2001	January 2002	May 2002
Water temperature (°C)	26.3	26.1	23.7	24.9
Secchi depth (m)	<0.1	<0.1	<0.1	<0.1
pH	9.0	8.8	9.1	9.1
Conductivity (mS cm^{-1})	1.66	1.39	1.51	1.67
Salinity (‰)	0.7	0.5	0.6	0.7
Total nitrogen (mg L^{-1})	8.0	1.8	1.0	0.5
Total phosphorus (mg L^{-1})	1.3	1.0	0.6	1.0

Source: Ballot *et al.* (2003).

Table 2. Mean biomass production of the main phytoplankton groups in Lake Baringo, June 2001–May 2002

Phytoplankton groups (mg L^{-1})	June 2001	November 2001	January 2002	March 2002	May 2002
Cynopyceae	5.45	1.64	0.67	0.22	2.53
Bacillariophyceae	0.26	0.19	0.04	0.46	0.03
Chlorophyceae	1.84	0.52	0.34	0.8	0.17
Euglenophyceae	0.62	0.08	0.56	0.03	0.0
Cryptophyceae	0.0	0.04	0.07	0.03	0.05
Total biomass	8.17	2.47	1.68	1.54	2.77

Source: Ballot *et al.* (2003).

Land use changes

Although industrial and urban development in the basin has gradually increased over time, agricultural development has increased rapidly, particularly in the upper reaches, where the climate is conducive for such activities. The natural forest in this region also has been exploited for timber, wood fuel and settlement. The benefits being lost as a result of deforestation include the functioning of the forest as a moisture reservoir. Forests store 100 times more water than grasslands, capture air moisture and increase the incidence of rainfall, regulate river flow and prevent flooding, reduce the sediment load in river water, and regulate rainfall patterns. In addition to these benefits, forests are a centre for biodiversity and attract tourism. The Lake Baringo drainage basin has lost >50% of its natural forest cover, decreasing from 829 km^2 in 1976 to 417 km^2 in the 2001. Thus, the same proportion of the benefits derived from the forests also has been lost.

The undergrowth in natural forest cover, and the humus-rich soil, encourages groundwater retention and recharge. This feature ensures a regulated stream flow throughout the year, compared to deforested catchments with short durations of high magnitude flows during the rainy seasons, and reduced low flows during the dry seasons. This phenomenon leads to faster drying of rivers, as observed in Lake Baringo's drainage basin. It is worth noting that the tree species also are important. Eucalyptus, for example, consumes more water and has little undergrowth, thereby leading to faster depletion of subsurface water reserves. When cut, such trees can cause water flows to increase. Other species, such as *Luceana leucocephala*, use less water and encourage undergrowth, soil water retention, and groundwater recharge in a manner similar to natural forests. When cut, such trees and forests can cause increase the incidence of low
water flows. 6

The effects of climate change in the region are evident from the decreasing snow coverage on Mounts Kenya and Kilimanjaro. This is attributed to global warming, which increases the temperature of the air. Deforestation facilitates the accumulation of greenhouse gases, such as carbon dioxide, in the atmosphere. These gases can cause global warming and, hence, higher atmospheric temperatures. Increased air temperatures can lead to increased evaporation from the lake, causing a decreased water level in the lake. Overall, the potential effects of climate change on Lake Baringo are not yet been well understood because of a lack of reliable data.

Sedimentation

Sedimentation is considered to be the main environmental threat to the lake. It reduces both the depth and the surface area of the lake, in addition to destroying the habitats of aquatic animals. The parts of the catchment that produce the most sediment are the steep slopes with erodable soils. Such areas include the footslopes of Tugen Hills around Cheberen and Tenges. The rates of soil erosion in these areas are as large as 205.79 MT ha^{-1} $year^{-1}$. In other areas, soil erosion is low, being $\approx$2.21 MT ha^{-1} $year^{-1}$. The eroded soils are deposited on the flat lower reaches of the drainage basin and in the lake. The estimated sediment yield of the Lake Baringo basin, as extrapolated from erosion studies of the Perkerra catchment, is 10.38 million MT $year^{-1}$ (Onyando 2003). Other estimates made three decades ago indicated sediment yields of 13.5 million MT $year^{-1}$ (Pencol Engineering Consultants 1981).

Water abstractions and impacts on biodiversity

The reduced recharge and damming of rivers also pose a threat to the lake. The dams are meant to accumulate water for irrigation, and for rural and urban water supply. The Kirndich Dam, for example, which covers an area of 2 km^2 on the Endao River, supplies water to the town of Kabarnet. Other dams include Chemeron Dam (area of 1 km^2), which is used for irrigation. Water diversions for irrigation also have been made from the Perkerra, Molo and Ol Arabel Rivers, and also have contributed to reduced stream flows. Both the lake and its rivers have been used throughout their history to water animals at various points. Thus, the decreased water levels have significant impacts, especially on the livelihoods of the communities living downstream. This problem is likely to continue as long as the population in the upper catchment continues to increase.

The reduced water inflows to the lake resulted in a low lake depth of $\approx$1.7 m early in 2003. Only a limited number of aquatic animals can survive under such conditions. The fish community, for example, has been very much impacted by this situation, with overfishing also threatening their survival. The mean size of *O. niloticus* decreased to 15 cm, necessitating a fishing moratorium in 2001. Other fish species (e.g. *Barbus* and *Labeo*, which migrate upstream to spawn) are presently close to extinction in the lake.

Socioeconomic factors

Socioeconomic factors also have had both direct and indirect impacts on the lake. These include:

1. Increased demands for developing and using lake resources such as fish, water and tourist facilities.
2. Limited public awareness and understanding of human impacts on the lake including low literacy levels, cultural beliefs and stratification within communities.
3. Insufficient governance and accountability systems that involve inadequate consultation, a lack of expertise and insufficient mobilization of institutions to address problems.
4. High poverty levels, which compound disasters caused by droughts and floods, low crop yields and low livestock returns.
5. Poor land management with cultivation of river banks and cultivation of steep slopes without conservation measures.

Other problems

Other environmental and sustainability problems associated with the lake include invasive species, especially *Prosopis juliflora*, a fast-spreading shrub with hairy evergreen leaves. Introduced in 1982, it has spread to cover much of the grazing land in Baringo District, especially around the lake. The shrub forms an extensive and impenetrable thicket that gradually chokes out other plants, including the acacia tree and grass, leaving much of the soil bare and prone to erosion. It has deep roots, and is likely to be linked to the lowering of the water table in the areas it colonizes. It has aroused concern among the pastoralists, especially the Ilchamus, as it chokes out all the grass on which their cattle depend.

Management environment

Institutional roles

The goal of management of the lake and its basin is its sustainability and that of its biotic communities, at the same time benefiting the populace through wise use of its resources. For effective management of Lake Baringo's resources, a management plan is necessary, but has not yet been developed. The management efforts in the past have been sectoral. The involved institutions and their roles in managing the lake and its basin are outlined below.

Kenya Marine and Fisheries Research Institute. This is a public research institution with the responsibility of carrying out research on fish production and the quality of the lake water as related to fish production. It provides statistics on fish trends and lake productivity, with its operation enshrined in the Fisheries Act.

Kenya Forestry Research Institute. This also is a public research institution mandated to carry out research on agroforestry systems, preservation of indigenous tree species, and development of environmentally friendly tree species. The trees are planted in the catchment and used for various purposes, depending on the species. Some of their uses include conservation of soil and water, as wind breaks, and as sources of fodder, wood fuel and timber.

Ministry of Livestock and Fisheries. This ministry was created recently as part of government reforms to further streamline the fisheries and livestock departments. The Fisheries Department in this ministry operates under the Fisheries Act. The department's role is to prevent illegal fishing and the use of illegal gear sizes. It also recommends provision of licenses to fishermen and transporters. The Livestock Department provides extension services on livestock management. It also is involved in re-seeding of degraded rangelands, livestock improvement and marketing. The ministry also has affiliated research institutions, both national and international, which are involved in livestock research.

Kenya Agricultural Research Institute. This is a public research institution under the MoA. It is responsible for agriculture-based research, including developing drought-resistant crops, fast maturing crops, and disseminating research findings.

Ministry of Water Resources Development. This ministry is responsible for water resources management and development within the lake basin. It operates under the Water Act and provides guidelines on water abstraction and borehole development, among other topics.

*Ministry of Environment and Natural Resources.*This ministry is responsible for environmental conservation in the catchment, including its rivers and the lake. It advises the Government on the use of natural resources in such a way as to minimize environmental degradation. It also promotes environmentally friendly management interventions. Its activities are enshrined in the Environmental Act.

Ministry of Agriculture. This is a public institution responsible for improving food production, while at the same time conserving the resources to ensure a sustainable supply of food needs. Its activities involve carrying out extension services on modern farming techniques, creating awareness on the sustainable use of resources, and educating farmers, among other tasks.

Kenya Wildlife Services. This is a public institution responsible for wildlife management. It controls, as necessary, the population of predators to minimize human–wildlife conflict.

Baringo County Council. This council is composed of elected leaders from the district. It owns the trust land where the lake is located, and collects taxes from revenue generated from the lake. The taxes are ploughed back, through facilitation of its personnel, who oversee the general management of the lake.

Rehabilitation of Arid Environment Trust. This is an NGO, which undertakes planting and regeneration of indigenous trees and grasses in badly eroded lands within the basin.

World Vision. World Vision is an NGO that provides famine relief to families affected by extended droughts and which have lost crops and other resources. Assistance also is given to those who have lost property to floods. The objective is to enable them to recover from their losses, and resume their livelihood activities, as rapidly as possible.

Honey Care. This is a CBO responsible for promoting honey production and sale. Honey is an important resource in the Baringo District, providing an alternative income source to the local people.

Women's Groups. These comprise CBOs composed of women, with the common goal of improving livelihoods. They operate microenterprises as alternative sources of income. Such enterprises relieve consumption pressures on the lake and its resources, thereby contributing to improved resource management.

Block Hotels. This is a private organization operating the three-star hotel, Lake Baringo Club, near the lake. The lake and its rich biodiversity attract tourists, from which the hotel generates income. In turn, the Block Hotels, as a direct beneficiary, participates in lake management, thereby also contributing to the sustainability of the lake. This activity also helps sustain its business.

Legislation

The lake management programme operates on the basis of government legislation and policies. It is linked to other programmes, such as the National Action Plan on Desertification, National Biodiversity Action Plan, Poverty Reduction Strategy Paper, and National Wetland Management. All these have the common objective of sustainable use of natural resources to meet livelihood needs. The legislative framework to enforce management initiatives operates under various acts of the Kenya Government, including the Fisheries Act, Water Act, Agriculture Act, Forest Act, Land Control Act, and Land Planning Act.

The enforcement laws are contained in the acts which, in the past, have been implemented sectorally. The Environmental Management and Coordination Act was enacted in 1999, however, to harmonize all the environmental management laws scattered throughout the various existing acts. The implementation of this Act is overseen by the National Environment Management Authority. At the local level, district environmental committees and village environmental committees have been established to ensure that environmental management initiatives are implemented. These committees operate by encouraging the local communities to participate in environmental management activities.

In cases where serious degradation is taking place, or where it is anticipated as a result of human activities, gazettment can be done by the concerned minister, as a measure to stop the degradation. This has been done in forest areas following extensive felling of trees for timber, and recommendations have been made to the central Government for timber to be imported.

In other cases in which there is a deliberate illegal use of resources, law enforcers are encouraged to keep vigilance and arrest the involved parties. In cases of illegal fishing, scouts carry out surveillance in the lake and arrest poachers. The scouts are armed in order to eradicate forceful poaching. Apart from scouts, local chiefs, the administrators in the localities, have the mandate from the provincial administration to enforce legislation. Cases of arrests have been recorded in the Lake Baringo area, with illegal gear sizes of <4 inches being burned in public.

Research and science

Research and science are prerequisites for effective resource management. Through research and scientific studies, inferences from analysis of statistics of natural phenomena and biodiversity can be made and incorporated in management plans. As an example, the provision of data on bird life, allowing the numbers of various birds of different species to be determined, is essential for establishing bird sanctuaries.

Research linkages have been made with both local and international universities. Examples include Egerton and Kenyatta Universities in Kenya and the University of Uppsala in Sweden. The research findings have been disseminated to rural communities through participatory rural appraisal (PRA). Such research findings provide a basis for recommendations for sustainable resource management, based on available resources and capacity. The fish ban, for example, was a recommendation based on research findings, resulting in improved quality and quantity of the fish catch. The improved catches made the practice readily acceptable to fishermen.

Management strategies

Mitigation measures undertaken to control degradation in the basin include control of soil erosion through terracing, contour farming and gully control, among other actions. Stone walls and desert plants (e.g. cactus) also are used to trap sediments in the floodplains. Construction of check dams and semicircular bands to reduce overland flow rate also was undertaken. Afforestation and control of tree cutting are other control measures done to minimize degradation. These techniques, however, are long-term interventions requiring time, up to a decade or more in some cases, to counteract the lake's degradation.

Other management measures include re-seeding with high-yielding pasture, conservation of wetlands around the lake, and agroforestry practices in the lake's catchment using fodder trees. In addition to these measures, water harvesting and groundwater supplies are undertaken to provide alternative sources of water. Diversification of alternative livelihood opportunities is encouraged to reduce exploitation pressures on lake resources, one possible way of doing this is through the facilitation of microenterprises.

A fishing moratorium involving the local communities was implemented to improve fish stocks in the lake. The moratorium was instituted after recognition of dwindling fish stocks, based on monitoring efforts by the KMFRI and the Fisheries Department. The fisherfolk were experiencing income losses due to dwindling fish stocks. It was not difficult for them therefore to accept the moratorium in anticipation of better yields in the future. When a monitoring report was presented by the KMFRI and the Fisheries Department, they readily agreed to impose the moratorium, which involved instituting a fishing ban until the fish stock improved. The moratorium was enforced by the Fishermen Cooperative and the Fisheries Department. It involved regular surveillance to control illegal fishing, as well as ensuring the use of recommended gear ratios when the ban was lifted. Although fishing is a major income-generating activity for the communities around the lake, they are not entirely dependent on it, but also engage in agropastoralism and microenterprises. During the fishing ban therefore they concentrated on these other livelihood opportunities. However, regulated subsistence fishing, using hooks, was allowed to continue among the communities living on the island. Some opposition to the moratorium was noted from a few individuals, who continued to poach. This situation, however, diminished with time, following community participation in surveillance and education facilitated by the LBCB's land and water management project.

The progress in increasing fish production during the moratorium was monitored by the Fisheries Department and the KMFRI. The outcome of the exercise was disseminated to stakeholders through quarterly reports and stakeholder forums. Recent spot checks showed that the ban, instituted about 2 years ago, has allowed tilapia (*O. niloticus*) to grow to an average size of 29 cm, from the previous average of 15 cm. To prevent future moratoria, overfishing should be minimized by requiring the use of the correct-sized fishing gear, regulating the number of licensed fishermen, and ensuring regular surveillance to prevent illegal fishing. In contrast to the fish moratorium, erosion control in grazing lands has had little success. This is because, when compared to the lake, a common resource, the cattle that cause overgrazing are individually owned by pastoralists, who are reluctant to control herd numbers to conform with the land's carrying capacity.

Wildlife conservation and community-based water projects also are being undertaken to further reduce degradation of the lake and its resources. Some of the biodiversity conservation activities are fish and bird counts, protecting endangered species, prohibition of illegal poaching, and establishment of a Ramsar site for Lake Baringo.

The current management initiatives in the Lake Baringo drainage basin are mainly sectoral. Activities currently receiving the most attention include fishing, soil conservation and agroforestry, tourism development and biodiversity, microenterprises and water resources management. Through its designation as a Ramsar site in 2001, Lake Baringo is now recognized as a wetland of international importance, therefore open to funding opportunities to conserve its resources, support livelihood opportunities and reduce land degradation. The management plan under development is aimed at integrating all the sectoral plans, and is in accordance with the Ramsar Convention. Lake Baringo itself is in trust land, with its management under the jurisdiction of the Baringo County Council. The Council focuses on income-generating activities (e.g. tourism, fishing), however, with little attention given to catchment conservation. Thus, with the development and implementation of an integrated management plan, it is anticipated that the management of the lake and its basin will be diversified, and include both income and non–income-generating activities, as well as incorporating all stakeholders.

Conflicts and constraints

The institutions responsible for managing Lake Baringo are not devoid of constraints, thereby hindering sound management of the lake. One constraint is the lack of resources, such as boats for surveillance. The Fisheries Department, for example, has been incapacitated and could not carry out regular surveillance for an extended period of time, because of the lack of motorized boats. This has resulted in cases of illegal fishing during the period of the ban. Coordination of stakeholder activities is another constraint in managing the lake, mainly because every stakeholder has a programme of activities that might not conform to others, in regard to a common goal of sustainable management of natural resources. Conflict of interest is another drawback in lake management. This is particularly so with the local communities, who exploit the resources of the lake and its basin to meet their livelihood needs. The fishing ban could conflict with the interest of the fishermen to meet their livelihood needs through fishing activities.

Cattle grazing along the lakeshore, especially during dry seasons, is another area that generates controversy. The pastoralists keep large herds of cattle, which cannot be sustained by the available biomass, especially during dry seasons. Thus, they enter the lakeshore areas, where their cattle graze and destroy the habitats of other plants and animal species. Control of the number of the herds as a management strategy is an unacceptable practice to the pastoralists. As an alternative, a participatory range management plan that regulates access to grazing lands and movement of herds could be developed and implemented. The plan could be derived from traditional systems, with involvement of pastoralists and enforcement by elders. Through CBOs, rotational grazing can be introduced, in which herds are rotated to allow re-vegetation. This is likely to increase the carrying capacity of the rangelands, and will readily be accepted by the pastoralists. Lack of support, ineffective legislation, lack of transparent decision-making systems, lack of qualified personnel in environmental management and lack of sufficiently trained personnel are additional drawbacks affecting the institutions.

The lack of a management plan for the lake and its drainage basin is another constraint to its management. As the current management initiatives are sectoral in nature, the negative impacts that could occur from an activity also are likely to influence other sectors. Such sectors might have difficulty in formulating solutions to problems whose origin they might not know. The construction of dams upstream for domestic water supply, for example, resulted in reduced flows downstream and into the lake.

Consequently, the downstream population suffered from inadequate water supplies, which they need both for domestic use and for irrigation. Fish production also decreased partly because of reduced inflows into the lake. Siltation of Chemeron Dam is another side-effect that has reduced the capacity of the dam and, hence, the reliability of the downstream water discharge to meet irrigation needs. As there is interconnection between the activities of various sectors, however, involvement of all stakeholders is inevitable, which requires a management plan and a clear government policy, especially on lake management, which is unfortunately still lacking.

Other constraints to the management of Lake Baringo and its drainage basin include the following:

- Lack of local expertise, lack of coordination, retrenchment of staff, especially in government institutions, and low incentives, which demoralize personnel responsible for effective management of resources
- Inadequate understanding by the public and decision-makers on the effects of human activities on the lake and its drainage basin
- Lack of data and information about the problems facing the lake and it drainage basin
- Inaccessibility to information on past studies and research on the lake and its drainage basin
- Lack of understanding by many lake basin inhabitants, especially among those who live on the hill slopes at a considerable distance from the lake, about their individual roles in causing lake problems
- Lack of knowledge by most of the indigenous communities of what actions to take to help solve lake problems
- Lack of feedback of information to government officials
- Frequent droughts and floods
- Inadequate accessibility to safe water
- Livestock diseases
- High land preparation costs
- Limited market opportunities
- Lack of public awareness
- Land tenure system and cultural values

Some constraints can be minimized through environmental educational programmes. The conflicts, however, are resolved from two possible approaches. One way is through the provincial administration, whereby the district security teams from different districts organize roundtable discussions to find amicable solutions to the conflicts, or to enforce law and order among the conflicting groups. The other approach is through village elders from the conflicting groups. The elders usually can easily identify the root causes of the problem and help find solutions acceptable to the conflicting groups.

Capacity building and public participation

Capacity-building efforts undertaken to manage the lake and its drainage basin include training of farmers to create awareness, so that they become receptive to resource management initiatives. These activities include involvement of local communities in the tree-planting process, participation in programmes such as the Kenya–Finland Livestock Development Programme Bull Scheme, which also entails empowering women's groups in land rehabilitation. Other activities include on-farm demonstrations by extension workers, village environmental committees to oversee the day-to-day implementation of the on-farm management practices, and training extension staff regarding new technologies. Strengthening institutions through facilitating support of microenterprises on income diversification and educational visits to demonstration sites are additional capacity-building initiatives.

As part of capacity-building activities, an excursion to Lake Bogoria resulted in passing resolutions that were to be used as guidelines to ensure good management of the lake, as follows:

- Formation of beach committees
- Joint patrol and surveillance with the Fisheries Department
- Supporting research to determine the rate of recovery of the lake's fishery
- Participation in tree planting
- Involvement of women groups in fodder farming and zero grazing

One of the experiences of stakeholder involvement is that they tend to participate in activities in which they will get direct benefits, or if the activities are linked to their livelihood needs. Creation of awareness among stakeholders on the importance and value of the lake, and the need to conserve it, has been made possible through training, sensitization and mobilization using PRA methods. Such methods include field days, workshops, seminars and demonstrations in which the stakeholders learn through participation.

Financial investment

Financial investments made to help solve the problems associated with the sustainable use of the lake and its resources include:

- Ministry of Livestock and Fisheries – $US30 000 between 1998 and 1999
- Local Afforestation Scheme – $US52 000 for 1.8 million seedlings for planting during 1999 and 2000
- UNICEF, various NGOs – $US107 000 in 1999–2001 to undertake community-based water projects
- Kenya–Finland Livestock Development Programme Bull Scheme for cow rotation – ≈$US74 000

• UNEP/GEF, through the LBCB project – ≈$US750 000 during 2001–2003 for capacity building and rehabilitation of degraded Lake Baringo basin areas

UNEP/GEF LBCB project

Environmental degradation was identified as a major constraint to the development of the Lake Baringo basin. The increase in both human and animal population beyond the land carrying capacity, and unsuitable land use activities in the drainage basin, resulted in a decrease in the natural resource base that supports livelihoods and biodiversity. The environmental status of Lake Baringo has been the concern of the Government of Kenya (GOK), NGOs and local communities for a long time. In 2000, the GOK forwarded a proposal to UNEP to fund the LBCB project, with the main objective of building the capacity of the local communities and institutions to respond positively in addressing the impacts of land degradation, through the demonstration of best land use practices. The project was formulated with line ministries, in consultation with the local communities and other stakeholders. The entry point to the communities was through PRA and socioeconomic surveys, with the main problems focusing on land degradation, biodiversity conservation, and aquatic resources.

The approach adopted was to facilitate institutions to build their capacity for sustainable environmental management. The advantages of this approach include involvement of stakeholders in a participatory manner, strengthening of institutional partnerships/synergies, resource mobilization and ownership.

The disadvantages of this approach include weak partners, little budgetary harmonization, ownership of credit concerns, lack of transparency and high stakeholder expectations.

The entry point of the UNEP/GEF project was to build capacity for managing natural resources, and improving income through facilitation of various stakeholders. One such activity to which UNEP/GEF funds were committed is microenterprise, which was introduced to assist organized community groups to engage in environmentally friendly income-generating activities, in order to relieve land use pressures and, at the same time, raise people's livelihood standards. Other activities include environmental education and conservation programmes, facilitation of stakeholder forums, and policies and facilitation of research.

Lessons learned

Stakeholder involvement

Lake management programmes should involve all relevant stakeholders and all other parties interested in the sustainable use of a lake and its resources. This practice will not only minimize the duplication of activities, but also ensure wise and efficient resource use. Through the sharing of information, knowledge will be generated and appraised. The interests of the community, preferences and values also will be taken into account in the management plan, thereby minimizing conflicts of interest. This approach also makes the community more receptive to lake management efforts. To ensure that their interests are adequately considered, care should be taken to involve members of the community from all strata in the management efforts.

Improvement of livelihood security

Local people will tend to support interventions they perceive to favour their aspirations, especially those that improve their livelihood security. Most farmers in the lake basin, for example, were not willing to construct terraces and other water conservation structures until they saw the successful harvest obtained by those who did so. Similarly, they do not see direct gains in natural resource conservation and management. This is exacerbated by the lack of critical mass with interest in resource conservation, communal land ownership and high poverty levels. Thus, it is important to develop environmental awareness packages with incentives, in order to build a conservation constituency at a grassroots level.

Diversification of income

Income diversification offers more alternatives for meeting livelihood needs. It reduces overdependence on one resource, which often can lead to environmental degradation. The Pokots and the Ilchamus, for example, are mainly pastoralists and keep large herds of cattle that do not match the carrying capacity of the grazing land. This causes problems of overgrazing, with increased soil erosion and the siltation of rivers and lakes. In addition to land degradation, their animals die during drought periods, thereby reducing their livestock products. Other income-generating activities (e.g. bee keeping, microenterprises) are necessary because they reduce pressure on land and minimize risks.

Biodiversity – a source of income and food

From the perspective of the local people, biodiversity in arid and semiarid areas involves a pastoral risk management strategy. From their perspective, biodiversity is a source of food and income. During severe droughts, pastoralists hunt wildlife to supplement their protein supplies. Similarly, they burn acacia and other trees to produce charcoal for sale to compensate for livestock losses. Biodiversity conservation is acceptable to the local people if it can generate socioeconomic benefits higher than the subsistence utilization, a mentality caused by a lack of awareness. It is worth noting that improved rangeland can attract more biodiversity with more gains. As an example, four animal species have returned to a piece of land rehabilitated for a period of 12 months. Similarly, birds have built nests on trees in demonstration plots set up by a local NGO, whereas there are no nests on trees in nearby degraded areas. Thus, it is important to have sufficient information on biodiversity in the lake basin, including the social dimension of its conservation.

Conservation to focus on the means of achieving the end result

Conservation projects should focus not only on producing physical end products, such as the total area and species conserved, but also on the means of achieving the end result. This is especially critical when multiple stakeholders are involved. As a means of enhancing the conservation of natural resources in the Lake Baringo drainage basin, the LBCB project applied the participatory approach and formation of partnerships among key stakeholders to create synergy and increased sense of ownership. While it is prudent to take an integrated approach involving various development partners and stakeholders, it also is important to critically examine some of the underlying assumptions. Most development agencies share the same vision of livelihood improvement, but have their own preconceived ideas about community approach and implementation strategy. They also operate on different budgets and time scales. If the operations of these partners are not regulated and harmonized, it can create confusion for the local communities, and scrambling for recognition at the expense of conservation. The UNEP/GEF project played a pivotal role in the synchronization of activities among the stakeholders through a participatory approach.

Awareness creation, capacity building and sustainable resource use

Creation of stakeholder awareness and education on various management scenarios are the major aspects of building capacity for implementing and addressing the principles of sustainable lake management. The local communities that are the direct beneficiaries, and who exploit the resources to meet their livelihood demands, should be made aware of the risks involved in such exploitation. In the majority of cases, they only consider the short-term benefits, at the expense of the long-term ones. In addition to the excessive exploitation of fish, the forest reserves also have been exploited not only in the hill slopes of the Lake Baringo drainage basin, but in all forest areas of Kenya. The forest area of Kenya is currently <2%, much less than the 9% forest coverage characterizing Africa and 20% forest coverage of the world. The GOK targets a forest coverage of 10%. As the Government plans to achieve this goal, the education of the masses to live in harmony with the natural resources is essential.

Inclusion of the entire drainage basin in the lake management plan

Management of Lake Baringo should not concentrate only on the waterbody itself, but should also extend to the whole basin that drains into the lake. In most cases, the administrative boundaries do not coincide with the river basin boundaries, as is the case for the Lake Baringo drainage basin, which is located in four districts of Baringo, Koibatek, Nakuru and Laikipia. The LBCB project, however, was only designed only for the Baringo District. This made it difficult to involve other districts in resource management efforts, even though activities in parts of these latter districts in the catchment directly affected management of the lake. Thus, management programmes should be designed to include the entire drainage basin.

Financial investment in lake basin projects

Financial constraints made the UNEP/GEF-funded LBCB project focus mainly on the Baringo District. The project was a medium-sized project (MSP), for which the upper funding limit at the time was $US750 000. One lesson learned in this effort is that financial investments larger than that available through the MSPs are needed for formulating effective integrated lake basin management programmes. Furthermore, time frames longer than 3 years, the average duration of an MSP, are needed to bring about changes in the management of an entire lake drainage basin.

Water conservation for domestic and livestock use

Alternative water resources, such as rainwater harvesting through roof catchment, should be explored to supplement river water for domestic use. This will reduce water abstractions through damming, thereby also allowing more water to flow downstream and into the lake. This should be practised not only in the semiarid downstream area, but also in the humid upstream area as well. This is because the people located upstream use more water, whereas those located downstream, as well as the lake, are most affected by water shortages. Thus, the upstream population should rely more on rainwater for domestic use, so that most of the river water can flow downstream and into the lake.

Documentation and extension

The information and data gained from lake management programmes and experiences can be disseminated to national and local governments, lake management practitioners, NGOs and other stakeholders through reports, seminars, workshops and the Internet. All should be available in libraries as well, where they can be easily accessed. Field days through PRA also are an avenue for disseminating the information, particularly to local communities.

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