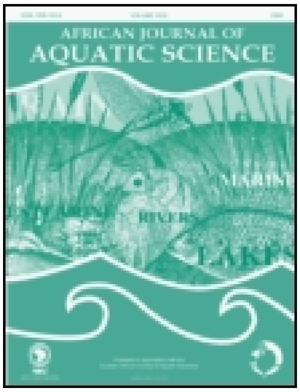

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Human impact on lake ecosystems: the case of Lake Naivasha, Kenya

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Lake Naivasha is a wetland of national and international importance. However, it is under constant anthropogenic pressures, which include the quest for socioeconomic development within the lake ecosystem itself as well as other activities within the catchment. The lake is an important source of fresh water in an otherwise water-deficient zone. It supports a thriving fishery, an extensive flower-growing industry and geothermal power generation. It is home to a wide range of aquatic and terrestrial flora and fauna, including vegetation, birds, fish and mammals. The adjacent area is ideal for horticulture, which plays a crucial role in the development of both the local and national economy, providing employment to more than 30 000 people. The Lake Naivasha area produces up to 70% of Kenya's total horticultural output and contributes significant foreign exchange to the national economy. However, the lake and its surrounding areas are fragile ecosystems that face increasing threats from irrigated agriculture, water abstraction, the fast-growing Naivasha Township, and human population growth throughout the basin. Agricultural and livestock farming activities within the 3 376km² catchment area are also a threat to the lake ecosystem. This paper reviews some of the adverse socioeconomic activities that exert pressure on the lake, as well as bioindicator data that may be useful in assessing the overall quality of the lake as an important wetland ecosystem.

Keywords: agriculture, alien species, bioindicator species, environmental degradation, human activities, lake fisheries, Ramsar site, water abstraction, waterbirds, water resources

Introduction

Physical characteristics

Lake Naivasha (0°45'N, 36°20'E) is an endorheic shallow freshwater lake with a water surface elevation of approximately 1 890m above mean sea level. It is situated in the Eastern Rift Valley of Kenya, approximately 90km north-west of Nairobi. Lake Naivasha is one of a series of seven major lakes in the Eastern Rift Valley of Kenya. Listed from north to south, these lakes are Turkana, Baringo, Bogoria, Nakuru, Elmentaita, Naivasha and Magadi (Figure 1). Although Lake Naivasha (hereafter also referred to as 'the lake') is often considered as one lake, geologically it comprises four main lakes (Figure 2, Table 1), the boundaries of which were determined by the tectonic activities associated with the formation of the Rift Valley (Richardson and Richardson 1972).

The Lake Naivasha Basin is bordered by the Nyandarua Mountains (previously known as the Aberdare Range and Kinangop Plateau) to the east, the Mau Escarpment to the west, Mount Longonot to the south, and the Eburru Hills to the north (Figure 2). It is considered to be one of the remains of a once-larger lake that existed thousands of years ago and which covered the area between Mount Longonot and Menengai Crater. The other lakes, separated from Lake Naivasha by the Eburru Hills, are Lakes Nakuru and Elementeita, both of which have remained highly alkaline. The surface inflow to Lake Naivasha enters through three distinct river systems, the Malewa, Gilgil and Karati Rivers. The Malewa River is the largest, with a catchment area of c. 1 730km², and contributes approximately 90% of the inflow to the lake (Ase *et al*. 1986). The Gilgil River has a catchment area of 527km² and provides the second largest inflow. The Gilgil River has perennial flows down to at least the 2 100m contour, but abstraction for irrigation and natural losses make the flow unreliable during certain times of the year, often diminishing the flow before it reaches the lake. The Karati River, which often does not reach the lake directly, drains a catchment area of about 149km² and, together with the Gilgil River, contributes the remaining 10% of discharge into the lake (Ase *et al*. 1986, Lukman 2003). In combination, the lake and the surrounding catchment that is drained by ephemeral streams — which disappear underground before reaching the lake — have a total catchment area of approximately 1 000km². Together, the total area of the Lake Naivasha Basin is estimated to be about 3 376km².

The lake has no surface outlet and it is thought that water from the lake seeps into the underlying volcanic rocks and probably moves both southwards, towards Mount Longonot, and northwards towards Gilgil and Lake Elementeita (Clarke *et al*. 1990, Ojiambo *et al*. 2001). The freshness of the lake water, with a pH range of 7.3–9.2 in some areas, has been attributed to (1) dilution from incoming permanent discharges from the Malewa River, and other seasonal rivers; (2) sodium salts extraction by *Cyperus papyrus* and other aquatic plants;

Figure1: Position of Lake Naivasha in relation to other wetland lakes in Kenya

(3) underground seepage (inlet to the north, outlet to the south); and (4) subterranean seepage of rainwater from the Nyandarua Mountains (Gaudet and Melack 1981).

Lake Naivasha is an important lake within this part of the East African Rift Valley, since it serves the following purposes: (1) a readily accessible natural reservoir of freshwater used for intensive irrigation, potable water, livestock and wildlife watering, and the generation of hydro-electricity; (2) commercial fishing and sport angling, and (3) recreation and tourism.

The above features, coupled with fertile volcanic soils and the large number of intensive floricultural and horticultural enterprises in the surrounding area, have attracted a large and inexpensive labour force to the flat lands around the lake shore zone and to its inflowing river floodplains (Everard and Harper 2002). The wider Lake catchment on the rain-fed slopes of the escarpment is also under intensive small-scale subsistence farming, consisting mostly of cash crops such as wheat, maize, potatoes, beans, sunflowers, and livestock enterprises. As a result of these proliferating and intensive activities, Lake Naivasha, like all other tropical lakes, is very vulnerable to degradation, with consequent loss of its valuable wetland services and functions.

In this paper, we review the socioeconomic values of the Lake Naivasha Basin, identify from the literature the existing socioeconomic degrading activities that threaten the lake, and review bioindicator data that may be useful in assessing the overall wetland ecosystem quality.

Socio-economic importance of Lake Naivasha

Being a freshwater resource in a country where about 80% of the land surface is arid or semi-arid, Lake Naivasha is of immense socioeconomic importance to the local and national economy. The lake provides a source of water for irrigated agriculture that supports a thriving flower and horticulture industry that yields up to 70–75% of the total national horticultural output (Dinham 1998) and provides local employment to thousands of people.

The lake provides water for domestic use and shares the same water table with key groundwater aquifers that provide borehole water for the rapidly-expanding human population in Naivasha town and surrounding areas. The population in the area around Lake Naivasha has grown from 50 000 to about 250 000 in less than 20 years (Enniskillen 2002), and this has precipitated several major impacts and threats to the lake ecosystem. The lake is also an important source of water for the drilling of geothermal steam wells and also for condensing excess steam during geothermal power generation, which provides some 109 megawatts per annum of power to Kenya's national electricity grid. The fishery of the lake is also an important source of livelihood to scores of fisherfolk and their families and provides the main source of food to many families within the lake basin.

Tourism is also a major activity in the area: the lake ecosystem falls within one of the key tourism circuits in the country, linking the Maasai Mara Game Reserve with Lake Nakuru National Park. There are a number of hotels and campsites situated in close proximity to the lake and these host large numbers of guests, especially over the weekends. Adventure boating, water skiing, and sport fishing for black bass are among the major tourism activities and are becoming increasingly popular in the main lake. Sonacchi Crater Lake is located inside a private wildlife sanctuary with tourist campsites and lodges. Other socio-economic activities conducted along the lake's shore include livestock production and small-scale farming.

Review of major human impacts on the lake

The human impacts on the lake are linked to the many social and economic activities carried out by the numerous stakeholders found within the lake basin (Table 2). These impacts include water pollution, inter-basin water transfer, water abstraction from the lake and from inflowing rivers, forest destruction in the catchment, siltation of the lake and inflowing rivers, habitat destruction, lake level and surface area recession, decline in fisheries resources and waterbird populations, introduction of alien species of plants and animals, and the destruction of fringing papyrus beds. Most of these impacts have resulted in the destruction of the riparian/littoral zone around the lake shore — which is one of the most important portions of the lake system (as a habitat for wildlife) and which provides a natural filtration system for surface water run-off that enters the lake.

Water pollution

Pollutants entering the lake come from point and non-point sources include semi-treated municipal sewage, agrochemical surface run-off from Naivasha town and surrounding horticultural farms in the catchment, particularly River Malewa (Kitaka 2001, Berihun 2003, Permatasari 2004). The levels of nitrogen (N) and phosphorus (P) in the

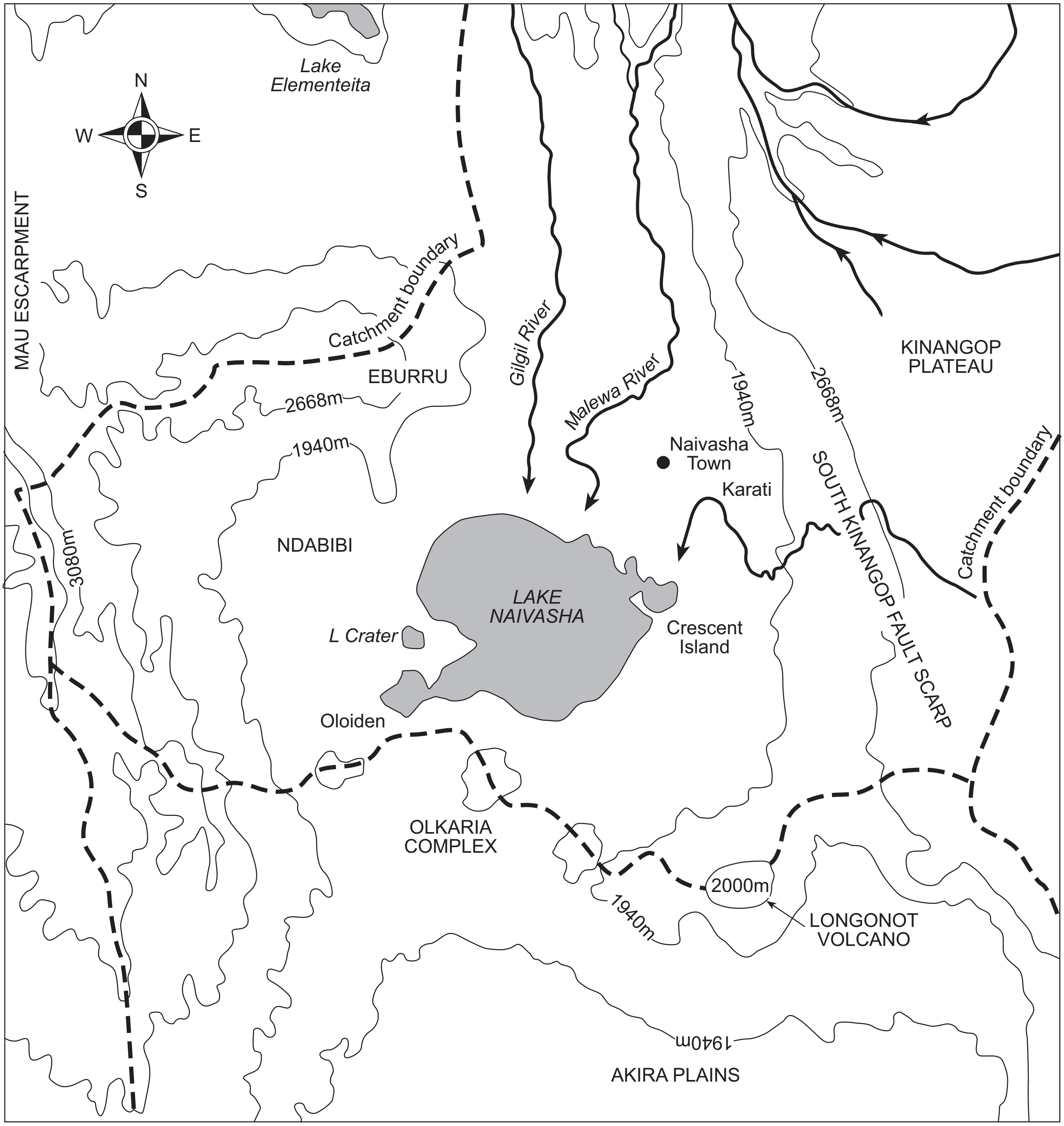

Figure 2: The catchment of Lake Naivasha, showing the direction of its surface water inflows and other physical details (modified after Clarke *et al.* 1990)

water give an indication of the levels of nutrients and organic matter from these pollution sources in the catchment. The high concentrations of N and P enhance primary productivity, sometimes resulting in algal blooms. In the past 30 years, the lake has become autrophic, as is evident from the increased phytoplankton levels (Hubble and Harper 2002). This, together with increased silt loads — as a result of soil erosion in the catchment (Kitaka 2001) — has resulted in increased levels of turbidity in the lake (Kitaka et al 2002. Permatasari 2004, Harper and Maruti 2004). Table 3 shows an obvious trend of increasing N and P concentrations from the early 1980s to the late 1990s. However, the increases are not the same for N and P.

Apart from the increase in nutrient levels, available evidence suggests that the lake is contaminated with bacterial pathogens, viruses and parasites from partially-treated

Table 1: The four components of Lake Naivasha (Harper *et al*. 1990, LNROA 1995)

Component of Lake Naivasha	Area (km²)	Volume (m³ x 106)	Mean depth (m)	Water quality
Main lake	145	680	4.7	Fresh (pH 8.7)
Crescent Island	2.1	23	16–18	Fresh (pH 8.7)
Oloidien	5.5	31	5.6	Alkaline (pH 9.2)
Sonachi (Crater lake)	0.6	0.62	3.8	Sodic (pH 10.2)
Total	153.2	734.62		

Table 2: Summary of the impacts of primary stakeholders on the Lake Naivasha ecosystem

Stakeholders	Impacts
Large-scale flower farmers	Water abstraction
Horticultural farmers	Water abstraction
Fishermen	Fishing pressure (overfishing)
Municipal council	Waste disposal, water abstraction
Conservation agency and groups	High density of wildlife – carrying capacity
Pastoralists and ranchers	Overgrazing – siltation
Local communities (urban)	Water abstraction, domestic and solid waste
Upstream communities	Poor land practices – nutrient overload
Geothermal production (KenGen and Or Power)	Water abstraction

Table 3: Trends in N and P concentrations in Lake Naivasha (modified after Tang 1999)

Year	Soluble N (mg/l)	Soluble P (mg/l)	Data source
1984	0.045	0.005	Harper (1990)
1988	0.125	0.012	Harper (1990)
1997	0.452	0.13	Morgan (1998)
1998	3.6	0.18	Tang (1999), Kitaka (2001)

municipal sewage, animal faecal waste and pit latrines at the settlements that dot the lake shoreline (Mwachiro *et al*. 2001). The greatest microbial risks to humans are associated with the ingestion of water. Faecal contamination is a source of pathogenic micro-organisms linked to the high incidences of waterborne diseases (typhoid, bacillary dysentery and other diarrhoeal diseases) reported from medical institutions around Naivasha (GEOO pers. obs.). The evidence available indicates that heavy metals (lead, cadmium and iron), pesticides (organochlorines and organophosphates) and other toxic chemicals are also contaminants (Tang 1999, Gitahi *et al*. 2002). Water pollution, especially of agricultural origin and that derived from the organic matter from the human population living around the shores, will remain a serious threat to the lake, since the extent of the papyrus cover that previously acted as a natural filter for the lake has been greatly reduced, due to direct destruction by humans for settlement and agriculture and by the receding lake level, which further exposes the papyrus to damage from the wildlife that roam around the lake edge and its hinterland (Harper and Mavuti 2004).

Water abstraction

It is estimated that Lake Naivasha contains approximately 680 x 10^6 m^3 of water (Abiya 1996). The onset of declining water levels coincided with the commencement of floriculture and other related anthropogenic activities linked to human population increase (Goldson 1993, Becht and Harper 2002). Apart from the irrigation of large flower and vegetable farms, a number of other activities require substantial volumes of water: domestic and industrial demands, wildlife needs, and geothermal power generation at the Ol Karia Geothermal Power Stations (comprising about 30% of the total volume of water used from the lake: Goldson 1993). Using various modelling methods based on water balances that calculate the basic hydrological process of rainfall, groundwater and river inflow and evaporative groundwater and deep water seepage, it has been estimated that the total surface water abstraction from the lake is between 46.4 and 60 million cubic metres per year (Mmbui 1999, Becht and Harper 2002).

A number of studies have been carried out on the water balance of Lake Naivasha (Mmbui 1999, Becht and Harper 2002, Rupasingha 2002). It is quite clear that there are substantial differences in the values obtained for the water balance, which can be explained by the different times of the periods, as is evident in Table 4. Water quantity and levels usually rise during the wet periods. However, during the El Nino rains of 1997–1998, the water level was reported to have risen by more than 3m (Becht and Harper 2002), and the lake effectively performed the important role of flood control, which otherwise would have wreaked havoc in the densely-populated Naivasha town. The rapid rise in Lake level created suitable breeding, nursery and feeding

Table 4: Annual water budget for Lake Naivasha (all values x$10^6 m^3$) (modified from IUCN/LNRA 2005)

	Wet conditions	Average conditions	Dry conditions
Inputs			
Direct rainfall over the lake	140.8	72.9	45.0
Inflowing rivers (Malewa, Gilgil, Karati)	458.5	179.1	56.5
Ungauged watershed area	117.8	77.9	34.2
Seepage in	54	54	32
Total inputs	771.1	383.9	167.7
Outputs			
Evapotranspiration	38.5	26.7	21.9
Evaporation	229	183.5	177.8
Seepage out	54	54	32
Estimated abstraction	33.8	44.6	53.2
Total outputs	355.3	308.8	284.9
Balance	+415.8	+75.1	–117.2

grounds for fish and a consequent rise in fish landings was recorded during the following year (KMFRI 2002, Hickley *et al*. 2004). Currently, the lake level has dropped by almost 3m, leaving behind drying papyrus swamps along the shoreline, with the subsequent loss of extensive fish breeding and nursery grounds (GEOO pers. obs.). Lower water volumes also make it more difficult for the waterbody to assimilate the inflowing pollution loads, because there is less flow-through of water.

Inter-basin water transfer

In an attempt to satisfy the growing human needs for water, and to meet the increasing water needs of nearby towns such as Nakuru, the rivers that drain the catchment have been increasingly exploited for water abstraction. In the Greater Nakuru Water Project Phase 1, a weir was built on the Turasha River, a major tributary of the Malewa River which flows into Lake Naivasha. The weir, which began operation in 1992, has the capacity to divert up to 18 000m^3 of water a day (Abiya 1996), of which 13 300m^3 is supplied to the town of Nakuru, and the remaining 4 700m^3 is piped to the nearby town of Gilgil (LNROA 1995, LNRA 1997). The Greater Nakuru Water Project Phase 2 was intended to divert 113 000m^3 of water per day from the Malewa River to meet the Nakuru town water needs for the first two decades of the 21st century. This was, however, hotly contested and the plan has been shelved indefinitely (LNRA 1999, IUCN/LNRA 2005).

Catchment and watershed disturbances

The largest part of the lake's catchment area comprises the catchments of the Malewa and Gilgil Rivers, which arise on the Aberdare range and the Kinangop plateau. The Eburru forest also provides an important catchment area for water conservation (through its hydrological functions and services) and further serves as an important wildlife habitat. Conservation of the catchment areas is crucial to the continued existence of the lake (Kitaka 2001, Everard *et al*. 2002). However, some human activities are in conflict with the ideals of catchment and watershed conservation and would most likely have adverse effects on the lake level and water quality, since some 90% of the lake's water comes from the Malewa River.

Poor farming methods — the intensive use of fertilisers for enhanced crop production, farming along the river banks, poor siting of cattle dips and livestock overgrazing along the catchment rivers in the drainage basin — as well as sand mining, have led to soil erosion and increased nutrient loads and siltation (sediments) entering the lake (Harper *et al*. 1993, Kitaka *et al*. 2002, Rupasingha 2002). The available data suggest that the Malewa and Gilgil Rivers currently discharge up to 7.07 x 10^6 tonnes of sediment into the lake each year, 20% of this load being organic matter (Rupasingha 2002). Sedimentation is known to make lakes shallower, to diminish their flood-control capacity, shorten their lifetime, and destroy aquatic habitats, thereby reducing the productivity of the lake ecosystem. However, at the present time, sediment load does not pose a serious threat, in terms of sedimentation deposition, to Lake Naivasha (Rupasingha 2002).

Unmonitored water abstraction from the rivers, coupled with the use of wasteful irrigation methods, is also common along the inflowing rivers. The Gilgil River is particularly affected by these practices, in which unsustainable abstraction from the upper catchment results in almost no water reaching the lake, particularly during spells of dry weather (GEOO pers. obs.).

Overfishing

The fishery of the lake has been under constant human pressure, mainly due to increasing market demands from the growing population of migrant workers, most of whom originate from the nearby flower farms. Fishing has been excessive and inadequately controlled, as is evident from the number of poachers, illegal boats and nets, thereby seriously affecting the natural recruitment rates (Fisheries Department 1998, Hickley and Harper 2002, Hickley *et al*. 2004b, IUCN/LNRA 2005). Many illegal fishermen drag nets with undersized mesh through the littoral zone where fish breed, thus reducing fish stocks and damaging macrophyte beds. Kenya's fisheries regulations prohibit fishing within 100m of the shoreline, as these areas are considered breeding and nursery grounds for fish (Fisheries Department 1998).

Fish stocks in the lake have experienced a rapid decline in the past decade, with the situation worsening in late 2000 and January 2001. This led to the Fisheries Department imposing a year-long ban on fishing activities, in an effort to enable the stock to regenerate. Prior to the imposition of the fishing ban, surprise checks had revealed that, in addition to the low weight of catches being recorded, all landed fish were smaller than the regulated sizes, with fishers using gill-nets as small as 50mm stretched mesh, which is well below the recommended mesh size of 100mm (Fisheries Department 1998, KMFRI 2002). Illegal fishing activities using seine nets were widespread, with high numbers of boats and high numbers of both legal and illegal fishermen on the lake.

During the fishing ban period, the Kenya Marine and Fisheries Research Institute assessed the changes in the population structure of the fish and provided advice on the sustainability and rational management of the Lake Naivasha fishery. The specific research issues that were addressed included catch composition by species and various mesh sizes, length distributions, breeding biology, growth and mortality parameters, recruitment patterns, and relative abundance of each species. The effects of environmental factors on the fisheries were also evaluated (KMFRI 2002). Today, based on these research findings, the Fisheries Department has imposed an annual four-month closed season from June–October, to allow the lake's fish stocks to stabilise.

Alien species introductions

Several exotic plant and animal species have entered the lake, mainly through human interventions and introductions, thereby posing potentially serious threats to the indigenous species (Harper *et al*. 1990). *Salvinia molesta*, an aquatic floating weed that covered 30% of the lake in the 1970s–1980s, was eventually reduced to insignificant levels (using a biological control method) only to be replaced in 1998 by yet another noxious weed, *Eichhornia crassipes*, the water hyacinth. The latter is currently being controlled biologically using a weevil (*Neochetina eichhorniae*), which specifically feeds on it (Gitonga *et al*. 2001). Both weed species reduced light penetration and interfered with patterns of primary productivity in the lake.

The North American red swamp crayfish, *Procambarus clarkii*, a voracious omnivore, was introduced into the lake in the 1970s (Oluoch 1990) in an attempt to diversify the commercial fishery. This animal is blamed for the reduction of some of the native species of submerged macrophytes such as the water lily *Nymphaea nouchalli* (Smart *et al*. 2002) and certain aquatic invertebrate populations (e.g. leeches) (Clark *et al*. 1989, Harper and Mavuti 2004). Prior to 1925, there was only one species of fish in the lake, the toothed carp *Aplocheilichthys antinorii*. This low level of ichthyodiversity is considered very unusual for a tropical lake, where the fish fauna can be expected to be quite diverse. *Aplocheilichthys* seemed to have disappeared from the lake by 1962, possibly as a result of introductions of alien species (Elder *et al*. 1971).

Fish species that have been deliberately introduced include the blue spotted tilapia *Oreochromis leucostictus* and the red breasted tilapia *Tilapia zillii*, both introduced in 1956. Other tilapiine species, such as *O. niloticus*, *O. variabilis* and *O. spirulus*, were also introduced, but did not persist (Muchiri and Hickley 1991). The North American Black Bass, *Micropterus salmoides*, was introduced in 1929 and has also established itself as a species of commercial importance (Harper *et al*. 1990, Muchiri and Hickley 1991). Recently, yet another fish species, the common carp *Cyprinus carpio*, has successfully invaded the lake, and its ecological impacts are yet to be fully understood. It was swept in by the El Nino rains of 1997/1998 by flooding streams draining an aquaculture farm in the catchment, and subsequently appeared in the lake in 2001 (Hickley *et al*. 2004a). A sharp rise in monthly landings of the common carp emerged in February 2002, when the fishing ban was partially lifted (KMFRI 2002), and today this species accounts for 90% of the total fish landings from the lake (J Ojouk, Kenya Marine and Fisheries Research Institute, pers. comm.)

Livestock watering

Large numbers of livestock are driven by the local pastoral herdsmen to Lake Oloidien (part of the Naivasha system) for daily watering (Ouma 2001). This is proving to be detrimental to the health of the lake ecosystem, due to heavy trampling and grazing on the vegetation and the increase of nutrients in the form of dung and urine. Lake Oloiden is renowned for its spectacular birdlife, including a large breeding colony of cormorants. The lake was once a sanctuary and enjoyed protection from local landowners. However, since access to the main lake is very limited, because most of the riparian land around it is privately owned, Lake Oloidien has served as an alternative for local pastoralists who were not able to get complete access to the main lake. In future, a compromise should be sought between land owners and local pastoralists, to allow the latter group greater access to the main lake.

Use of bioindicators to assess lake environmental quality

There has been a need to derive simple bioindicators that can be readily used to assess the state of the environment and ecosystem health of wetlands. Such indicators provide relevant information for decision-makers and assist the public, private sector and communities, who depend directly on natural resources of the lake, to become more aware of biodiversity loss and related impacts. To scientists, bioindicators help to guide the design and execution of monitoring and research activities, thereby providing a vehicle of communication in a common language.

In a Biodiversity Indicators for National Use (BINU) study carried out between 2002 and 2005 in Kenya, the state of four inland wetland ecosystems, including Lake Naivasha, was assessed using available data and indicators developed through wetland-based taskforces (Bubb *et al*. 2005). In the case of Lake Naivasha, several possible indicators were evaluated but only four were developed on the basis of their flexibility, level of data and information available, and the specific ecological needs of the lake. The main indicators identified during this study were the catch per unit effort (CPUE) of fish, the waterbird species population trends, the change in macrophyte (*Cyperus papyrus*) cover and changes in lake levels (Bubb *et al*. 2005).

Analysis of the fish CPUE was based on the three key introduced fish species: *Oreochromis leucostictus*, *Tilapia zillii* and *Micropterus salmoides*. It can be noted that the trends in CPUE (as measured by individual fishers) are closely linked (or inversely related) to the effort levels in the whole fishing community (Figure 3). As the number of boats (i.e. effort) increases, the catch per boat decreases, since the exertion of more pressure on the fishery reduces it to unsustainable levels. In terms of the present management situation in Lake Naivasha, a high CPUE indicates a healthy fishery (improved fisheries management in terms of enforcement of fisheries regulations and recruitment or successful spawning), while a low CPUE signifies a poor fishery (over-exploitation of the fisheries resource, high demand and uncontrolled effort). However, it is important to note that not all the catch is reflected in the total landings and the effort expended is seldom constant, because factors such as lake level, the presence of fish predators, the use of illegal fishing gear, and unrecorded landings from poaching, all influence the fishery production.

Over 150 species of resident and migratory birds have been recorded in and around Lake Naivasha, although only eight species were used to calculate a multi-species trend indicator, using the Living Planet Index (LPI) framework that was used to track environmental changes that have occurred over the years (Bubb *et al*. 2005) (Figure 4). The Living Planet Index (LPI) was used to calculate the indicators as follows:

$$LPI = Log ((yi...n/\alpha)* 100)).$$

Where

LPI = Living Planet Index = 0 –100, yi...n = Numbers counted in any given year

and

α = Baseline value for baseline year.

Several species like the Great Crested Grebe and Maccoa Duck are endangered, while the African Darter, Great Egret, Saddle-billed Stork, White-backed Duck, Baillon's Crake and African Skimmer are vulnerable (Bennun and Njoroge 1999). The results further showed that key indicator species for this lake were the African Fish Eagle and the Red-Knobbed Coot.

The LPI for Lake Naivasha, based on the population trends of eight waterbird species between 1981 and 2000, indicates the following changes in the state of environmental health within the lake ecosystem: (1) a sharply-declining state of environmental health between 1981 and 1991; (2) a fairly stable to gradually fluctuating state of environmental health between 1991 and 1998; and (3) a slightly improving state of environmental health between 1998 and 2000.

Macrophyte cover is very important, especially that of papyrus, which is one of the dominant species comprising the vegetation of Lake Naivasha, and this species occurs at the land-water transition (ecotone) zone. As with most tropical lakes, the climatic conditions of Lake Naivasha favour continuous growth of the papyrus, which dominates the vegetation of the littoral zone. The plant can be used as an indicator because it helps to moderate the influence of the catchment on the ecology of the wetland. It has been shown that there has been a serious decline in the area covered by this macrophyte (Figure 5) (Everard and Harper 2002, Bubb *et al*. 2005).

The coverage of the papyrus vegetation can be summarised as follows; a downward trend can signify human interference (through burning and clearing for agriculture, access to the water, fishing grounds and grazing by wildlife and livestock), reduced (insufficient) nutrients to sustain growth, and lack of water due to reduced lake levels. Furthermore, a decline in papyrus cover indicates that there will be increased through-flows from the catchment to the lake and therefore a higher proportion of sediments, nutrients and other organic material entering the open lake waters. In contrast, an upward trend means that the lake will support a higher plant biomass/primary production. An upward trend occurs when the effects of human interference are minimal, the lake level is high, and the nutrients that are brought into the wetland are effectively taken up by the papyrus vegetation. An upward trend of the papyrus will also mean reduced siltation, lower rates of eutrophication of the open water due to lower inflowing loads of nutrients and sediments, increased availability and diversity of habitat niches, and a corresponding increase in biodiversity.

Lake Naivasha and the aquifers that surround it are important water resources in the area — these are a cause for concern, given the continued rate of development in the irrigated agricultural sector, the growing demands for water for the domestic and industrial sectors, and biodiversity

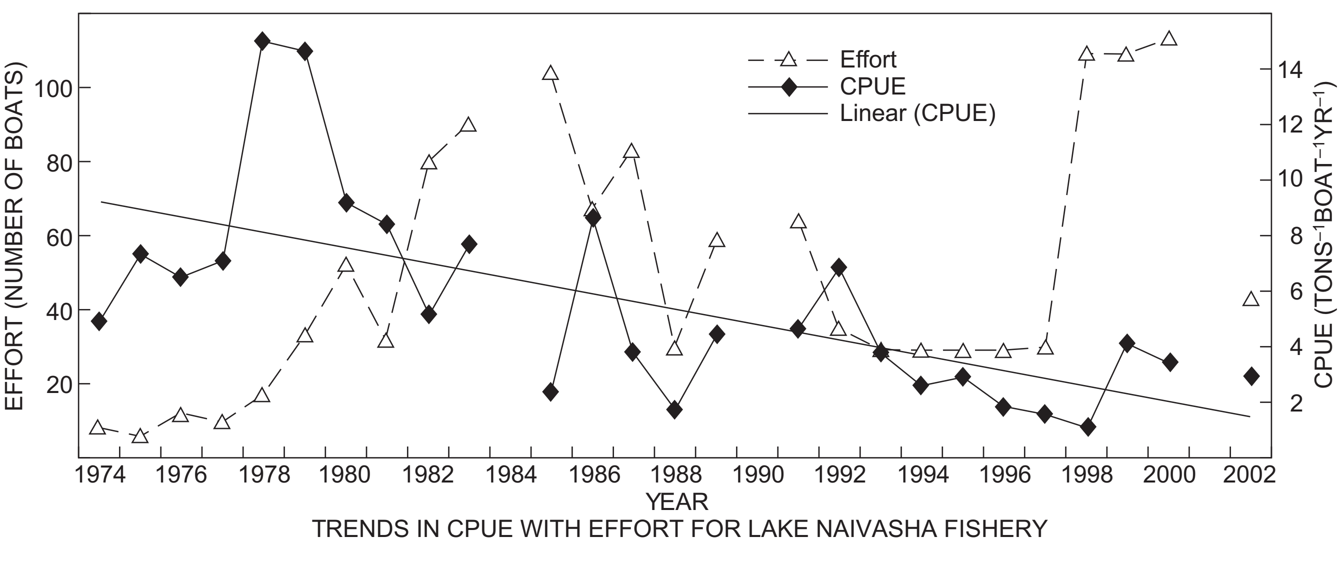

Figure 3: CPUE trends in the Lake Naivasha Fishery (from Bubb et al. 2005)

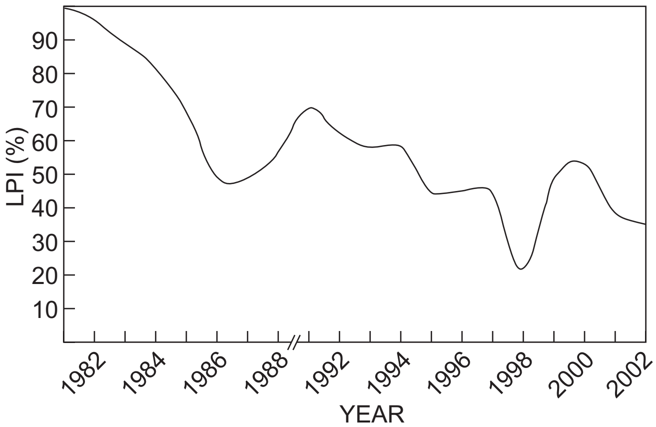

Figure 4: Composite index for eight bird species on Lake Naivasha, 1981-2002 (Bubb et al. 2005). LPI = Living Planet Index

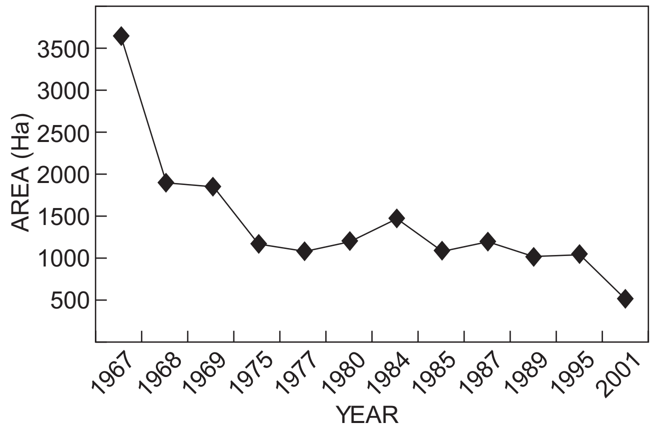

Figure 5: Trends in *Cyperus papyrus* cover in Lake Naivasha

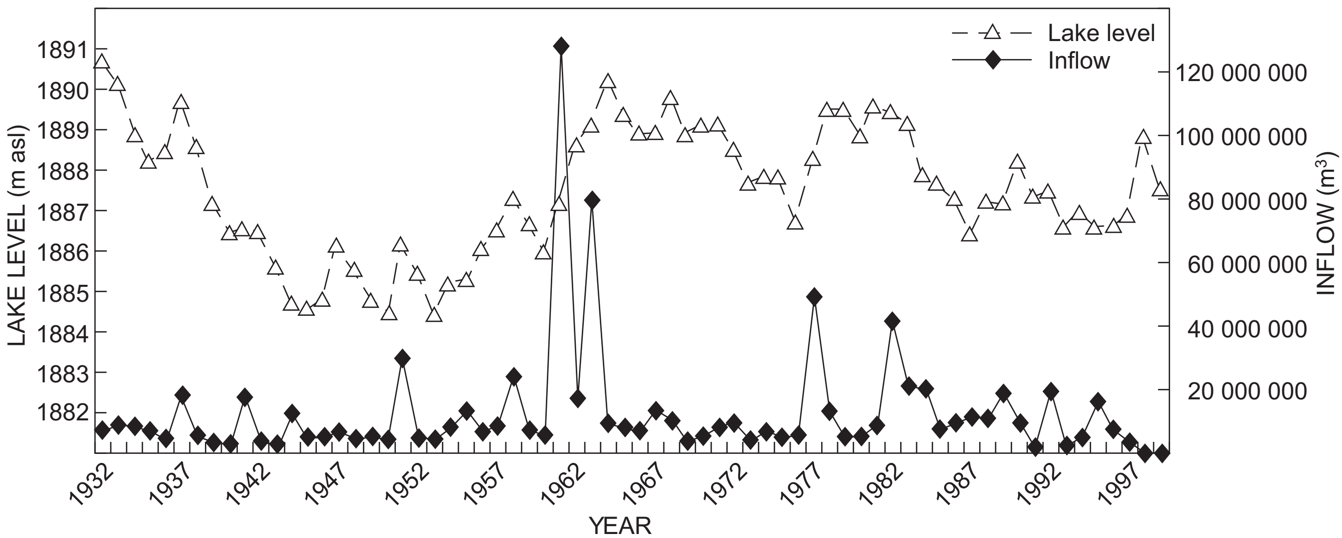

Figure 6: Trends in lake level and annual inflow for L. Naivasha (Bubb et al. 2005)

sustainability. The lake's water balance has been calculated from a model based on the long-term meteorological data of rainfall, evaporation and river inflows (Becht and Harper 2002) (Figure 6). It can be seen that the lake level and the total inflow reflect a direct relationship. Whenever the inflows increase, there is a corresponding increase in the lake level. It has to be realised that the inflows reflect the overall weather patterns being experienced in the entire catchment, and also respond to water resource management activities, including abstraction in the upper catchment. When lake levels are low, this is associated with increased damming and abstraction of river flows, inter-basin water transfers, groundwater recharge, and excessive abstraction in the wider catchment.

Conclusions

The importance of Lake Naivasha to the national and local economy cannot be over emphasised. This review summarises some of the impacts on the lake and highlights some of the biological indicators that can be used to evaluate the environmental integrity of the ecosystem. The lake is under serious threat from human activities, and the loss of the lake would be an ecological and social tragedy. It is therefore imperative that human impacts on the lake and its resources should be moderated and made sustainable if the lake is to survive and continue to perform its functions and services as a wetland. It is for this reason that a group of stakeholders, comprising 'users of the lake', formed the Lake Naivasha Management Committee, whose primary role was to develop a management plan for the system. The plan was gazetted in October 2004 and aimed to ensure that the use of natural resources was equitable, as well as ecologically and economically sustainable. However, in December 2004, a group of stakeholders challenged the plan in court and its implementation has been stalled.

To improve the environmental health of the lake ecosystem, the following issues urgently need to be addressed:

- documentation of the volumes of water that are abstracted by users, including those located along its inflowing rivers, through a metering system;

- restoration and facilitated recovery of macrophytes, especially *Cyperus* spp. at the mouths of the inflowing rivers and along the marginal zones, and the development of strategies to prevent further destruction of the remaining papyrus by humans and wildlife;
- restriction and reduction of the number of settlements around the shore to prevent uncontrolled water usage and pollution (i.e. nutrient overload);
- conservation education and awareness for the communities that live in the catchment, especially those along the banks of the Malewa and Gilgil Rivers;
- regulation and facilitation of sustainable artisanal fisheries activities;
- assessment of other human influences on the lake through the monitoring of concentrations of specific chemicals, derived from adjacent floricultural and horticultural enterprises, in the lake water.

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