

The ecological state of Lake Naivasha, Kenya, 2005: Turning 25 years research into an effective Ramsar monitoring programme

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Introduction

Lake Naivasha (0. 45°S, 36. 26°E), altitude 1890, lies in the Eastern Rift Valley and currently covers approximately 100 km². It is the second-largest freshwater lake in Kenya (after the Kenya portion of Victoria). It is one of a series of 23 major lakes in the Eastern Rift Valley – eight in central Ethiopia, eight in Kenya and seven in Tanzania – spanning latitudes from approximately 7° N to 5° S. The overall climate of the Eastern Rift Valley is semi-arid. Most Eastern Rift Valley lakes are thus alkaline or saline. Lake Naivasha is unique within the central latitudes of the valley in being fresh, and indeed within the Kenyan series of lakes (from north to south are Turkana, Baringo, Bogoria, Nakuru, Elmenteita, Naivasha, Magadi), with a conductivity fluctuating between 250-450 $\mu\text{S cm}^{-1}$ (Figure 1, Figure 2).

The lake has international value as a Ramsar wetland, which in the last two decades has grown to become the main site of Kenya's horticultural industry, one of the largest earners of foreign currency (Harper & Mavuti, 2004).

Lake Naivasha has no surface outlet and the natural fluctuation in water levels over the last 100 years has been in excess of 12 metres. The lake fills a shallow depression with gentle slopes, so an increase in lake level greatly increases the lake surface area and consequently increases evaporation and it shows a very dynamic behaviour (Figure 3). The water levels of the lake respond to long-term wet and dry climatic cycles, with annual variations of the water levels are superimposed on these long-term variations. The water level can change several metres within a few months, causing a horizontal change of several kilometres. These hydrological dynamics add an extra dimension to the riparian ecosystem as well as to the water resource management issues. British colonial law defined the lake edge by the level at 6,210 ft a.s.l. (1892.8m a.s.l.) and enabled riparian owners to cultivate the lake bed below this contour, but with no permanent structures. The lake water was used at this time to irrigate only small areas of fodder crops and vegetables, provide water for cattle, and the domestic supply to a small population. In 1929, the Lake Naivasha Riparian Owners Association

(LNROA), was formed and had the legal right to resolve disputes between adjacent landowners over their use of this riparian lake bed (Enniskillen, 2002).

In the early 1980s, successful experiments in production of cut flowers led to the growth of a horticultural industry dependent upon irrigation water. Since the first flower farms started there has been a fairly constant increase of the area cultivated, more rapidly in the last five years, to occupy now about 4,000 ha (Becht, unpublished). There now is uncertainty as to whether the lake can sustain the corresponding increase in demand for irrigation water, because the lake water is treated as a 'common good' available to all, when it is a very finite resource.

Around 1990 the LNROA became more proactive, commissioning two consultants' reports on the scientific status of the lake (Goldson, 1993, Khrodha, 1996), lobbying for the declaration of the lake as a Ramsar site (then Kenya's second), which was achieved in 1995. It changed its name to Lake Naivasha Riparian Association (LNRA) and added Associate member level to bring in a wider membership. In 1999, the LNRA's 70th anniversary, the organisation received the prestigious Ramsar Wetlands Conservation Award in the NGO category, for their conservation work on the lake (LNRA, 1999).

At the end of the 20th Century, a major international conference – 'Science and the Sustainable Management of Tropical Waters' – was held in Naivasha KWS Training Institute and the two publications that followed (Harper & Zalewski, 2001; Harper *et al.*, 2002b) brought all the scientific studies of the past decade into the public domain. Since that time a summary of the management issues that are needed to be implemented in order to make the lake sustainable has been published (Harper & Mavuti, 2004). This present 2005, 11th World Lakes Conference, offers another opportunity for synthesis of knowledge in order to move into a sustainable phase. The present paper summarises the state of ecological knowledge in the lake based upon the research of the teams of Harper & Mavuti, funded by the Earthwatch Institute since 1987. It suggests how the research knowledge should drive the Ramsar monitoring programme that is now evolving.

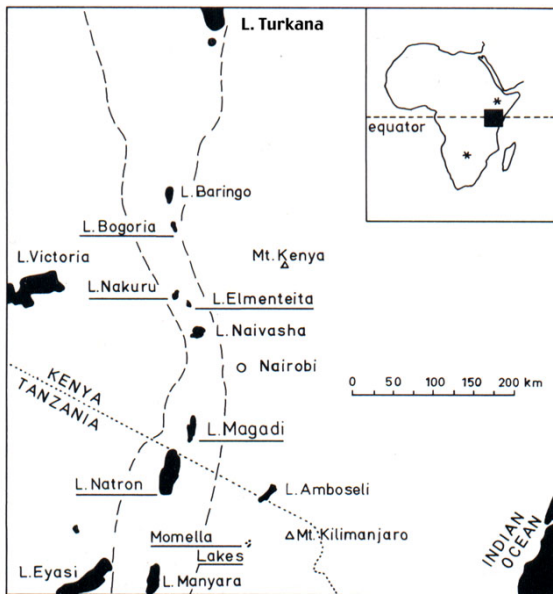
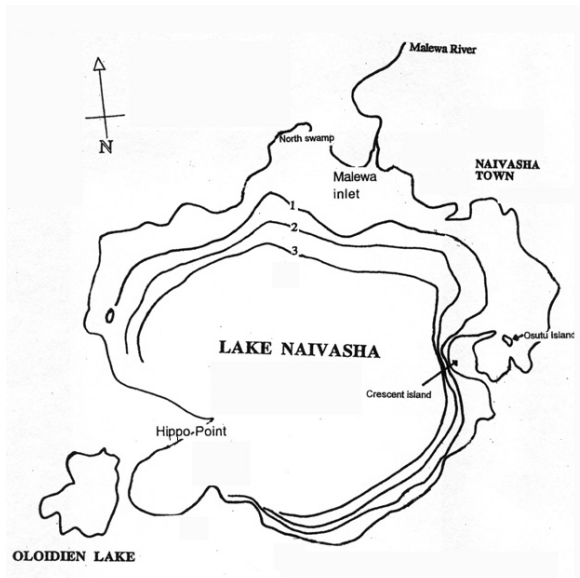
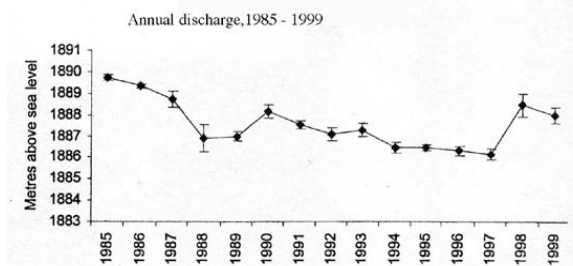


Figure 1. Lakes of the Kenyan Eastern Rift Valley. Saline lakes are underlined. From Harper et al,

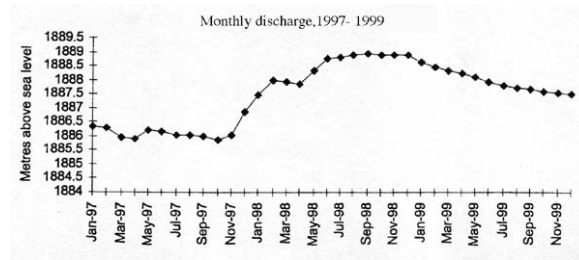


2003.

Figure 2. The Lake Naivasha catchment, showing the spatial arrangement of the three main inflowing rivers. (From Harper & Mavuti, 2004).



Lake level, 1985-99.



Monthly lake level, 1997-99

Figure 3. Bathymetry of lake Naivasha in 1991 (upper, depth in metres), annual lake level changes (middle) and monthly changes during the 'El Niño' rains (lower). From Kitaka, Harper & Mavuti, (2002).

Present day ecology

The lake supports an ecosystem with high but uneven biodiversity – rich in birds and plants but no native fish, for example (Harper, Mavuti & Muchiri, 1990). The artisanal commercial fishery is dependant upon exotic species and is currently in severe decline due to overfishing (see Britton et al, this volume). An exotic crayfish, introduced in 1970 to diversify the fishery, has completely re-structured the lake's ecology (Harper *et al*, 2002a).

There are four, chemically distinct, basins at Naivasha (Gaudet & Melack, 1981). Crescent Island Basin, a small extinct volcanic cone, is the deepest part of the lake (up to 18m depth), usually connected to the main lake over a shallow lip. The main lake has a maximum depth of 6m at its southern end (see Figure 3). Oloidien is a smaller crater lake with a depth of 5m to the south end of the main lake, which has been distinct from it since 1982, increasing in conductivity from 250 then to 3000 μ S cm⁻¹ now. Crater Lake or Sonachi is located on the southwestern part of the lake and, in its own distinct volcanic crater, is a soda lake, fully independent from the main lake but its levels are believed to oscillate in harmony with the main lake as a result of groundwater connection.

Little natural vegetation is left in the catchment. The headwaters of the Malewa are situated in the Aberdare National Park and the adjoining gazetted forest. The vegetation consists of humid Afro-montane forest and bamboo. The Kinangop plateau was once large, grassland plains, but now an estimated 30% is now covered with maize or vegetables and scattered exotic, fast-growing tree species. Cultivation often extends right down to stream level and livestock freely water from streams in all but the gorges cutting through successive rift escarpments (Everard *et al.*, 2002) Remnants of the original forest exist in only small patches on the escarpment. The loss of native tussock-grassland threatens the endemic *Macronyx sharpei* (Sharpe's Longclaw) (Muchane, 2001). The Rift Valley floor was an open savannah landscape in the past, which is now only retained in Hells Gate National Park immediately to the south of the lake, and converted to ranch land or settlement elsewhere.

Little native aquatic vegetation exists in the lake any more. Gaudet (1977) described the floral biodiversity of a lake that was, then, largely unaffected by human impact. He showed how the diversity was dependent upon the hydrological fluctuations, which created a series of dynamic vegetation zones through the land-water ecotone. The most landward zone was occupied by *Acacia xanthophloea* (Fever Tree) woodland, its roots reaching the water table and its extent marking the highest water levels of the early 20th Century. This was succeeded by a rooted *Cyperus papyrus* (Papyrus) zone, which together with shallow water Papyrus 'reefs', had been created by germination following rapid water level rises, 3 times in the first half of the 20th Century. Extensive swamps, reefs and floating islands of Papyrus existed until the 1980s, with lagoons of the submerged aquatic plants *Potamogeton* spp., *Najas horrida*, *Ceratophyllum demersum* and the macroalgae *Chara* spp under 'carpets' of floating-leaved *Nymphaea nouchalii*. When water level declined, the exposed lakebed soils germinated many semi-aquatic species of grasses, sedges and herbs dominated by Compositae.

The situation in the water over the last twenty years has deteriorated markedly, almost entirely as a consequence of the introduction in 1970 of *Procambarus clarkii* (Louisiana Crayfish), which had destroyed the Lily beds and all submerged plants within 10 years (Harper, Mavuti & Muchiri, 1990). The water surface has been filled in their place by exotic aliens; first *Salvinia molesta* (Floating Water Fern) in the 1980s, latterly *Eichhornia crassipes* (Water Hyacinth) in the 1990s (Harper, Adams & Mavuti, 1995; Adams *et al.*, 2002). The submerged plants and small remnant populations of the water lily return to the lake through a sediment seed-bank germination when the crayfish population crashes through predation. This has happened twice recently, in 1987-94 and 2000-02.

The situation on the landward side of the ecotone, has also deteriorated markedly over the same time period, entirely due to the direct and indirect consequences of human impact. Papyrus has been reduced to around 10% of its former area (Figure 4; Harper & Mavuti, 2004) by a sequence of natural causes which have followed the lake level decline – the lake is estimated to be 3 vertical metres below its natural level (Becht & Harper, 2002). This lowers the water table under the papyrus, which dries out the swamp. It is then susceptible to extensive trampling of herds of *Syncerus cafer* (Buffalo) or cattle. Buffalo is a species which has increased 3-fold (to about 1500) in the riparian zone the past ten years, believed to be a result of forest clearance in

the Eburru hills driving animals down to the lakeside (Harper & Mavuti, loc. cit.). Cattle have increased to many thousands, Maasai herds, which access the lake shore at one or two sites and then are driven along the lake edge with the tacit agreement of many landowners as long as they stay in the riparian zone. Once cattle and buffalo 'walkways' are made through the swamp, smaller animals follow, grazing any fresh shoots off, so the papyrus clumps die from lack of ability to photosynthesise once all the reserves in the rhizome are exhausted. Aggressive clearance by some horticulturalists using mechanical means or burning has added to the decline and there is severe destruction on those three lakeside sites where the general public has wide access.

These twin 'pincers' of degradation have combined to make the lake eutrophic since the early 1990s. Its phytoplankton has showed a seasonal shift between diatom and cyanobacterial dominance and its assemblage is now dominated by a persistent *Aulacoseira italica* population, both numerically and in terms of contribution to overall primary production. The concentrations of chlorophyll-a have increased from 30 $\mu\text{g l}^{-1}$ in 1982 to 110 $\mu\text{g l}^{-1}$ in 1988, and 178 $\mu\text{g l}^{-1}$ in 1995 and transparency has correspondingly declined to about 60 cm (but briefly rose to 160 cm in 1998-9 due to the diluting effect of the 'El Niño' rains) (Harper *et al.*, 2002b). 170 algal and cyanobacterial species have been identified (Hubble & Harper, 2002). Most of the diatoms are indicators of moderate to high nutrient conditions. Total primary productivity of this phytoplankton population is approximately 160 $\text{mg C m}^{-3} \text{ hr}^{-1}$ (Hubble & Harper, 2000). The sediments form a sink for phosphorus (Kitaka *et al.*, 2002), because they are rich in iron (Harper *et al.*, 1995) and the main lake is well mixed and does not deoxygenate enough to release this store of nutrients. However, Crescent Island lagoon does stratify temporarily and hypolimnetic deoxygenation occurs. Phosphorus is then released from the sediments, a process not yet seen in the main lake. This indicates that the rate of primary production in the water column could double if conditions change to allow lake-wide nutrient release from sediments (Hubble & Harper, 2000). Kitaka, Harper & Mavuti (2002) showed that the lake did become 'hyper-eutrophic' on the OECD classification after the 'El Niño' rains in 1998, reverting back to eutrophic in 1999; this emphasises that most of the increase in trophic state of the lake comes from the wider catchment in the absence of the 'buffering' formerly provided in the North Swamp at the river inflows. The more alkaline Oloidien and Sonachi lakes are highly productive and *Arthrospira fusiformis* is significant in the latter.

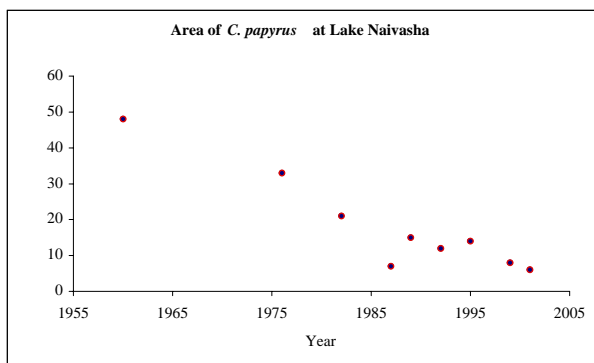


Figure 4. The area of *C. papyrus* at Lake Naivasha since 1960. Small increases occurred in the past decade, against the general decline, which correspond to wet seasons which caused rapid lake level rise (c.f Figure 4), re-flooding bare former lake bed, leading to new germination of new *C. papyrus*. From Harper & Mavuti, (2004).

Future prospects and the need for monitoring

One may summarise the ecological deterioration of Lake Naivasha in the latter 20th Century by a melodramatic “The Invasion of the Aliens” on water and the 21st Century as “The Invasion of the Wreckers”. The LNRA is striving to promote sustainable wise use of the lake but is thwarted by the short-termism of individuals with selfish interest who can make money from the deteriorating ecological situation of the lake. The government is slow in implementing conservation legislation that would help arrest the deterioration. Nevertheless, there are certain ‘bright spots’ in the lake’s ecosystem; for example the population of fish eagles, which had reduced to a little over 25 pairs in the mid-1990s due to shortage and availability of food, had increased by 50% on this low by 2000 after the ‘El Nino’ rains raised the lake level forming shallow lagoons in which fish bred rapidly. It increased again 2002-5 due to the ready availability of *C. carpio* (Britton et al., this volume) and its percentage of juvenile and sub-adult birds was as high as it has ever been in October 2005 (M. Harper pers. comm.; Figure 5).

Despite the ‘bright spots’, there is now an urgent need to quantify the (mostly negative) changes which are happening at Naivasha. The discussions of this paper, together with those of Becht (this volume) indicate 3 areas of monitoring:-

- Hydrology; quantifying the physical limits of the system and the balance between uses for humans/nature;
- Lake Ecology, quantifying whether the departure from naturalness (post-1970) is becoming worse or better and
- Land-Water Ecotone, quantifying the degree of degradation/recovery.

The hydrology and water balance has been dealt with by Becht (this volume) and earlier Becht & Harper (2002), with little change since that was written. The two ecological parts of the triad above should be undertaken as follows, from the new laboratory (2005) constructed for the LNRA by Sarah & Mike Higgins:-

Lake Ecology. The basis for this would be quarterly boat survey undertaken by LNRA. This could also incorporate volunteer survey of birds for key bird species. Components of the survey would be:

- Oxygen, conductivity, pH, alkalinity and Secchi depth (in boat)
- Chlorophyll ‘a’, Phosphate and total P, Nitrate and Total N, dominant phytoplankton species. Dry weight and dominant species of zooplankton (in lab)
- Crayfish catch/unit effort, Hyacinth vigour, Hyacinth beetle damage, beetles/hyacinth plant, submerged plant density & distribution (in boat).
- Key birds – coot, and fish eagle; other piscivorous aquatic birds; other aquatic (in boat)

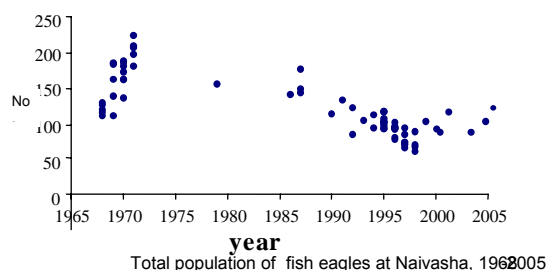
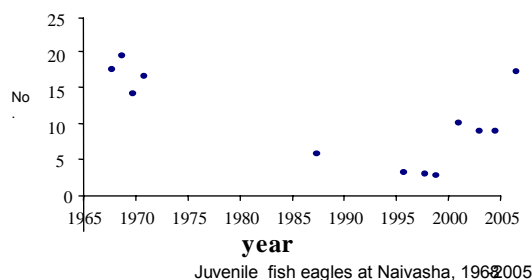


Figure 5. Population of all *Haliaeetus vocifer* (fish eagle) at Lake Naivasha (lower) and percentage of non-adult birds (upper picture) 1965-2005.

Land-Water Ecotone. The basis for this is the annual Earthwatch Institute research teams, which focus upon the following:

- Biodiversity in Papyrus and Acacia
- Fish eagle population structure, hippopotamus schools location & approximate size and shore vegetation

C. Riparian vegetation at fixed transect sites – it is suggested that Fishermans' Camp, Manera, KWS Annexe, and Oloidien lake provide a suitable range of stages of papyrus degradation.

D. Fish population structure (see Britton et al, this volume)

These should be superimposed upon the economic measures of lake health, such as commercial fishery

and revenue streams from tourism, horticulture. The whole should be reported in the Annual Reports of the Lake Naivasha Management Committee, which is a legal entity enshrined by the Government of Kenya in November 2004, but at the time of writing not yet in force because of legal wrangling in Nairobi courts caused by few, selfish individuals from the Naivasha community.

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