ECOHYDROLOGY & HYDROBIOLOGY

DOI: 10.2478/v10104-009-0036-6
Vol. 9
No 1, 83-97
2009

UNESCO-IHP
Demonstration
Projects
in Ecohydrology

Ecohydrological principles to underpin the restoration of *Cyperus papyrus* at Lake Naivasha, Kenya

Edward H. J. Morrison, David M. Harper

Department of Biology, University of Leicester, Leicester LE1 7RH, UK
e-mails: ehjm1@le.ac.uk; dmh@le.ac.uk

Abstract

Degradation of *C. papyrus* (papyrus) at Lake Naivasha is the result of a combination of lowered lake levels and destruction by large grazing mammals, buffalo and cattle, followed by several smaller species, in addition to more limited direct human clearance. Restoration of papyrus is considered to be of great importance for the future sustainability of the lake ecosystem. Two different interventions for papyrus (wetland) restoration have been proposed: one located around the delta of the Malewa river, based on ecohydrological principles, the other on land adjacent to the Gilgil river, adopting more of an ecological engineering approach. Both interventions are ecologically feasible. However, the principal limitations of both projects relate to anthropogenic factors and, in this respect, restoration of the Gilgil river is regarded as the more pragmatic of the two proposals at the present time. Future action should facilitate the involvement of local communities in any restoration projects at Lake Naivasha, with particular emphasis placed on the development of economic goods derivable from papyrus swamps.

Key words: Wetland degradation; Riparian zone; Drawdown; North Swamp; Ecological restoration.

1. Introduction

Lake Naivasha (0º 45' S, 36º 26' E) lies in the Eastern Rift Valley of Kenya, approximately 80 km northwest of Nairobi at 1890 metres above sea level with a surface area fluctuating but presently about 100 km^2 (Fig. 1) (Harper, Mavuti 2004). Three river systems provide the main surface inflow to the lake, entering around the northern shore (Fig. 2). The Malewa river is the largest system with a mean annual flow of 153 million m^3, the Gilgil the second largest (24 million m^3), whilst the Karati flows only intermittently during the rainy season (Everard *et al*. 2002).

Lake Naivasha is one of the most important freshwater resources in Kenya; its hydrology and biological community have been studied for over 30 years (Harper *et al*. 2002). Most of the shoreline was once covered with a narrow fringe of the giant and highly productive sedge, *Cyperus papyrus* L. (Boar *et al*. 1999). Plant species in the land-water ecotone, and papyrus in particular, regulate incoming materials, especially soluble and particulate nutrients (Gaudet 1978a), according to classical ecohydrological principles (Zalewski 2002; Harper, Mavuti 2004); when intact, they can be thought of as "natural purifiers of water" (Kivaisi 2001).

The lake is now eutrophic (Kitaka *et al*. 2002) and a functioning swamp ecotone, protecting both lake shallows from runoff in the hinterland and the whole lake from the negative inputs from its catchment, no longer exists (Everard, Harper 2002; Harper, Mavuti 2004). Nutrient enrichment constitutes part of a wider set of environmental pressures

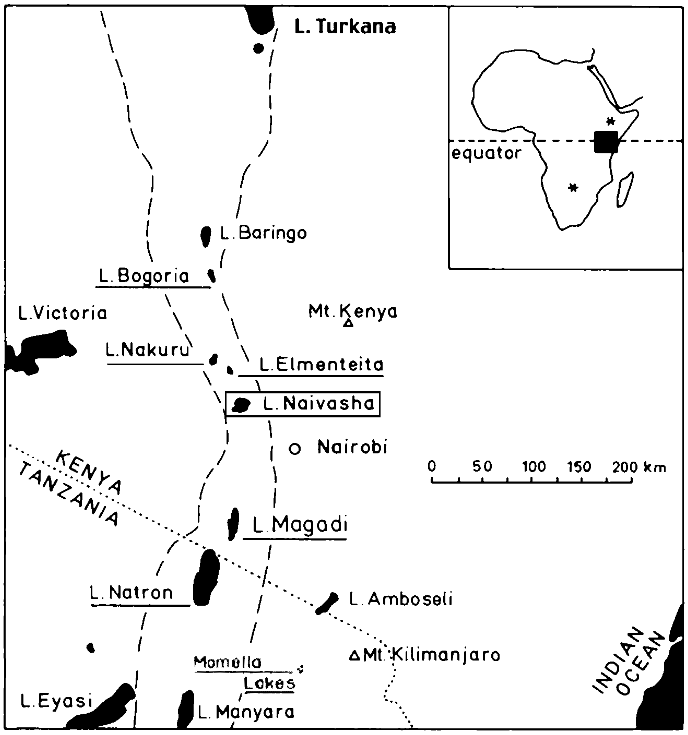

Fig. 1. Lakes of the Kenyan Eastern Rift Valley, Naivasha marked in frame. Saline lakes are underlined to highlight the importance of Lake Naivasha as a freshwater resource in this semi-arid region (modified from Vareschi 1978).

(including, *inter alia*, the introduction of alien species, catchment deforestation, overgrazing and erosion, over-abstraction of water and the addition of human wastes from unplanned settlements) acting upon the lake, summarised in Becht *et al.* (2006).

The loss of papyrus now dominates the lake ecosystem processes and is likely to be the reason for its continued eutrophication, accelerated by land use changes. It is potentially the most serious future issue of the lake; if over-abstraction continues in the absence of restoration efforts, the lake will be reduced in size to around a third (~30 km^2) of its present area to effectively resemble no more than an "alien-dominated muddy pool" (Harper, Mavuti 2004). Such a trajectory clearly carries disastrous consequences for the lake's biodiversity and the livelihoods of the hundreds of thousands of people who depend upon it.

The greatest area of papyrus at Lake Naivasha was the former North Swamp (11.7 km^2), spanning some 4 km of the north shore and fed primarily by the Malewa river (Gaudet 1979). Prior to entering the lake, the river diverged into a dendritic pattern and disappeared into floating mats of papyrus (Gaudet 1978a) (Fig. 3).

The land-water ecotone ('drawdown zone') contained a few other emergents such as *Cyperus immensus* and *C. dives*, as well as a few climbing species, although the majority of these were found only at the land and water edges, the insides of mature papyrus swamps being "virtual monocultures" of *C. papyrus* (Thompson 1976).

Papyrus has a high photosynthetic and productive potential due to the presence of C_4 photosynthesis, a characteristic shown by many high yielding tropical grasses (Jones 1986). Jones and Muthuri (1997) calculated the net primary production of a *C. papyrus* swamp at Lake Naivasha to be 6.28 kg dry weight m^{-2} yr^{-1} , which is amongst the highest recorded productivities for natural ecosystems; Gaudet (1978b) had estimated the total net production of the former North Swamp to be in the order of 5.85 kg C m^{-2} yr^{-1} . The highly efficient use of radiation, water and nitrogen by C_4 species is considered to have an important impact on the functioning of wetlands dominated by these species, such as *C. papyrus* (Knapp, Medina 1999).

The ecology of Lake Naivasha was formerly regulated through ecohydrological control exerted on the inflowing hydrochemistry by the papyrus of the erstwhile North Swamp. The once extensive floating mats trapped sediments, incorporated nutrients into plant and microbial biomass, removed nitrogen by denitrification in the swamp mat and released (over a much longer time period) soluble and organic-bound nutrients into the submerged and free-floating macrophyte zones and ultimately the open lake. Gaudet (1979) estimated the minimum amount of nitrogen fixed in the upper more aerobic regions of floating mats of papyrus in the North Swamp to be 567 kg ha^{-1} yr^{-1} ; a later study by Brix (1994) showed that *C. papyrus* can have an uptake capacity of nearly twice this, reaching peaks of 1100 kg N ha^{-1} yr^{-1} and 50 kg ha^{-1} yr^{-1} for phosphorus.

The significance of this control is that healthy papyrus swamps act as ecological buffer zones, moderating changes occurring along river systems by regulating nutrient flow and recycling. At Lake Naivasha, however, an effective buffer zone no longer exists. Harper and Mavuti (2004) hypothesised that lake-wide decline in *C. papyrus* was due to a combination of lowered lake levels, increased access by large herbivores - buffalo (*Syncerrus cafer*) and cattle with, in places, complete human destruction. This was an interpretation of changes that had occurred particularly since 1988, the last year in which there had been significant new ger-

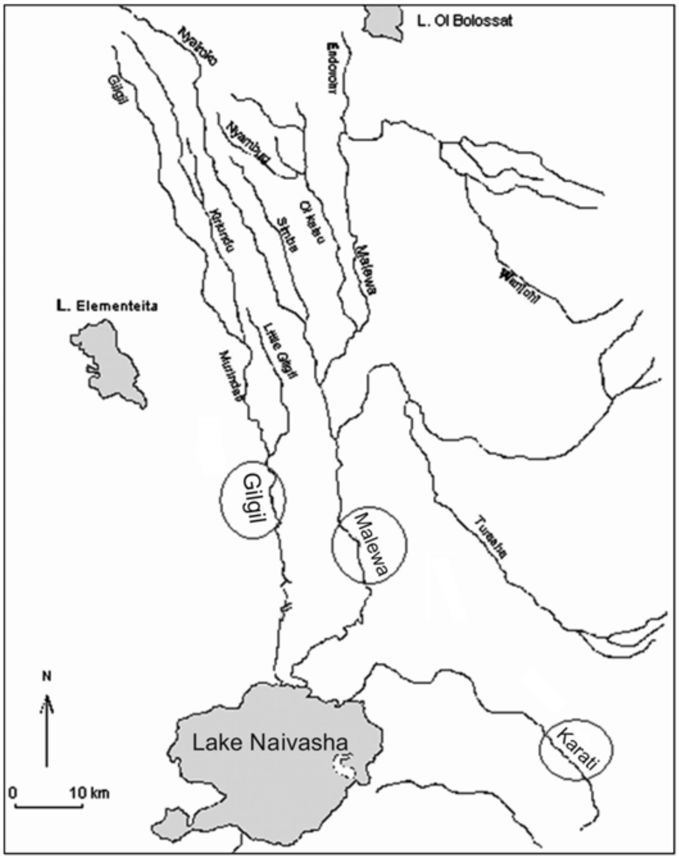

Fig. 2. The Lake Naivasha catchment. The three principal tributaries are circled (modified from Everard *et al*. 2002).

mination of papyrus when a 1 metre vertical rise in lake level occurred during May 1988, following a 3-year drought (Everard, Harper 2002).

The present study has three purposes: (i) to provide evidence to test the hypothesis of Harper and Mavuti (2004), (ii) to assess the feasibility of proposals (Zalewski, Harper 2001; Githaiga 2008) to restore papyrus at Lake Naivasha, and (iii) to discuss recommendations for the lake's sustainable management.

2. Materials and methods

Four sites around the lake (Fisherman's Camp, *FC*; Kilendegwe, *KD*; Manera Estate, *ME* and Kenya Wildlife Service Annex, *KWS*) were studied (Fig. 4). They were selected because of known differences in the recent occurrence of buffalo and other large mammals. The species and numbers of animals, as well as the approximate duration of their presence, were established for each site following informal discussions with landowners at FC (N. Carnelley), KD (J. Root) and KWS Annex (Kenya Wildlife Services); Nakuru Wildlife Conservancy (NWC) surveys (unpublished) were used for Manera, in addition to personal observations (D. M. Harper). Each site was then ranked on an 'impact index' between 1 (low) to 4 (high) (Table I).

Data were then recorded at each site along transects running through papyrus stands (ranging from 20-246 m in length) recording the parameters shown in Table II. The purpose of these measurements was to make a comparison between the condition of papyrus at the four sites in relation to their accessibility to buffalo and other animals. Height above lake level was recorded using a theodolite. All other measurements were made using tape measures, in a series of 10 m^2 quadrats along every 10 m of the transect.

3. Results

The transects at sites on opposite sides of the lake confirmed that papyrus had formed a fringing swamp at a similar vertical height above lake level

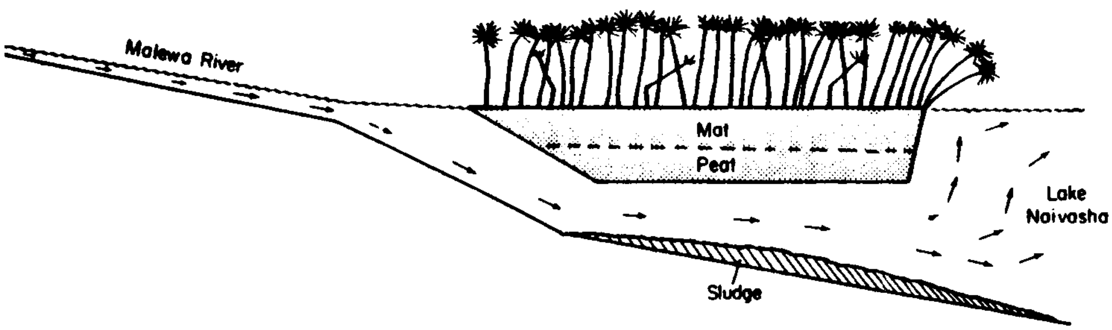

Fig. 3. Flow of river water under floating mats of papyrus (modified from Gaudet 1978a).

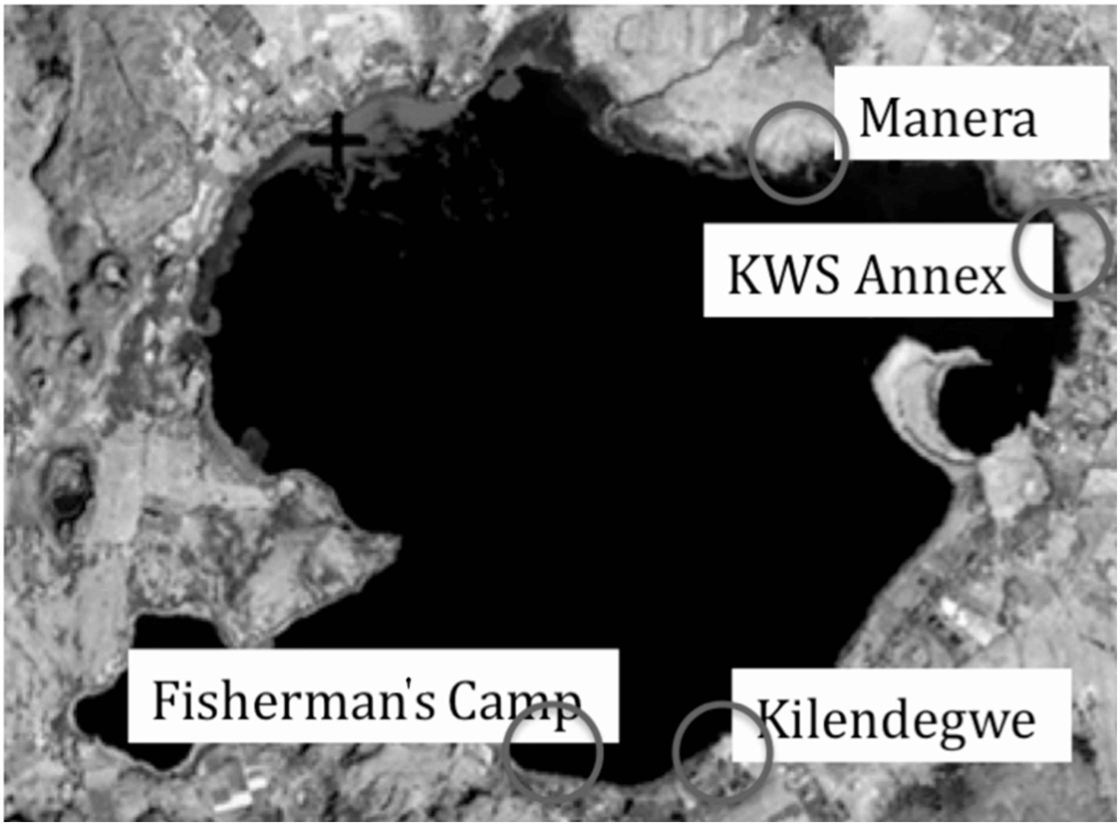

Fig. 4. Locations of the four study sites around the lake.

at all four sites (Table II), with means that were not significantly different (overall mean 0.98±0.22 m). The papyrus stands were of a similar density of 'clumps' (distinguishable units of papyrus, whether living or dead), with a mean of 6.1±0.6 10^2 clumps ha^{-1} . The average distance between clumps varied between 1.10-1.71 m but not significantly differently, with a mean of 1.31±0.45 m ($F_{3, 36}$=1.802, P<0.05; ANOVA).

The first three rows of data in Table II therefore describe a band of papyrus growth around the lake of near-equal density, occurring within a limited vertical range, defined by the May 1988 water level rise. Sites in the northeast have a much wider horizontal extent, as the gradient is far slighter than at sites in the south or west.

The average height of those papyrus stems which were near-vertical was significantly higher

Table I. Relative accessibility to buffalo and other species at the four sites.

	Site			
	FC	KD	ME	KWS
Description	Fisherman's Camp	Kilendegwe	Manera Estate	Kenya Wildlife Service Annex
Impact index	1 (Very Low)	2 (Low)	3 (High)	4 (Very High)
Duration of animal presence	Never	3 months before sampling	3-5 years	5+ years (continuous)
Species and numbers	None	Buffalo ~20 head	Cattle up to 1000 head, buffalo ~100 head	Many herds of buffalo, cattle, waterbuck, zebra, and impala

Table II. Parameters recorded along transects through papyrus stands at each of the four sites.

Parameter	Site			
	FC	KD	ME	KWS
Impact index (from Table I)	**1**	**2**	**3**	**4**
Vertical distance of papyrus fringe above lake (m)	1.08	1.01	1.05	0.77
Frequency of clumps (per 10 m^2 quadrat)	6.24	5.57	6.45	6.14
Mean distance between clumps (m)	1.32	1.71	1.10	1.11
Horizontal extent of papyrus (m)	15	32	190	246
Gradient through papyrus fringe (%)	7.2	3.2	0.6	0.3
Mean height of stems (m)	2.67	2.69	1.87	0.48
Stems with flowering heads (%)	87.50	26.09	19.54	0.00
Broken stems (%)	15.01	35.22	84.35	100.00
Ratio of living: dead clumps of papyrus	1:0	1:0	1:2	0:1
Frequency of dead clumps (per 10 m^2 quadrat)	0	0	4.40	6.14
Mean diameter of dead clumps (m)	-	-	2.39	1.89
Total number of species of plants colonising C. papyrus	3	2	16	19
Mean number of colonising species (per m)	0.14	0.24	1.43	1.30

in FC and KD (the two sites never, or recently visited by buffalo but never visited by cattle) than the other two ($F_{3, 36}$=4.006, P<0.05) (Fig. 5a). The percentage of stems with flower heads (umbels) was significantly higher only at FC (Fig. 5b) compared to the other three sites ($F_{3, 36}$=8.483, P<0.05), indicating that damage by buffalo visiting in small herds, sporadically over three months, is enough to reduce stems with flower heads to a quarter of the total of upright stems. The process of opening up the swamp, to light and to other animals, had also commenced by a doubling of the proportion of broken stems within 3 months, to one third of the total at KD (Fig. 5c).

Continuous access to large mammals, without any respite of a rise in water level, caused an opening of the swamp and continued grazing of young papyrus shoots, which had re-grown from the centre of clumps to replace damaged photosynthetic tissue. This was apparent at ME, containing young, shorter shoots, which reduced the average height, but this site had only two-thirds of its papyrus clumps still living (Table II) and most were overgrown with *Pennisetum clandestinum* (Kikuyu grass).

The most damaged site, KWS, was an unfarmed property to the south of Naivasha town, adjacent land either side held small settlements for farm workers. The lake-edge areas of KWS therefore, were refuges for wildlife from the surrounding farms, which meant that their presence was more or less permanent. This resulted in complete destruction of the papyrus, with 100% mortality of the clumps (Table II), all stems dead and broken, merely sticking out of half-metre high mounds covered in *P. clandestinum* and acting as a 'climbing frame' for 19 other terrestrial species.

4. Discussion

These trends allow a scenario for the decline of papyrus within the former North Swamp, over the past decade, to be established:

1. The papyrus fringe at Naivasha occupied the horizontal extent of approximately 1 vertical metre (this was the level of water level rise in May 1988): the four sites sampled contained recognisable papyrus between 0.77 and 1.08 m. This extends for only a few horizontal metres at FC and KD, but hundreds of metres in the northern shore, where the gradient is much less. Nevertheless, the papyrus swamp on all gradient shores was naturally intact.
2. Drawdown exposes former lakebed soils, causing them to dry out and so become more accessible to herds of buffalo. Harper and Mavuti (2004) suggested that this was caused by two linked effects. The first was the over-abstraction of water from the whole basin which has left the lake approximately 3 vertical metres lower than it should be naturally since about 1980 (Becht, Harper 2002). The second was the down-cutting of the Malewa river through the unconsolidated alluvial sediments of its delta (cross section shown in Harper, Mavuti 2004), as the lake level lowered and also perhaps as a result of more extreme flood flows from a progressively deforested catchment.
3. Large animals enter the swamp as the soils dry, trampling papyrus in order to access its green stems and flowering heads and, in the process, creating paths that remain permanent in the drier surface sediment. Cattle were observed at the lake edge on the two northern sites KWS and ME. They are able to move relatively freely between private property at the lake edge because

in this northern area of the lake landowners draw water from boreholes rather than lake water; thus no large ditches interfere with movement at property boundaries and no fences extend through the legal riparian zone down to the lake edge. The herdsmen were frequently observed cutting papyrus flower heads for their livestock.

4. Cattle, and other wild animals, such as zebra (*Equus burchelli*), waterbuck (*Kobus ellipsiprymnus*) and giraffe (*Giraffa camelopardalis*), subsequently follow the buffalo paths on the landward edge; individuals of these species graze off new shoots that would otherwise enable the papyrus to photosynthesise and so survive until re-flooded. Increased light availability provided by the absence of tall stands of papyrus enables climbing plants and creeping grasses (such as *P. clandestinum*) to overgrow the remaining *C. papyrus*, by now reduced to mounds just a few feet high, within what becomes an open, hummocky grassland, with the papyrus soon dying.

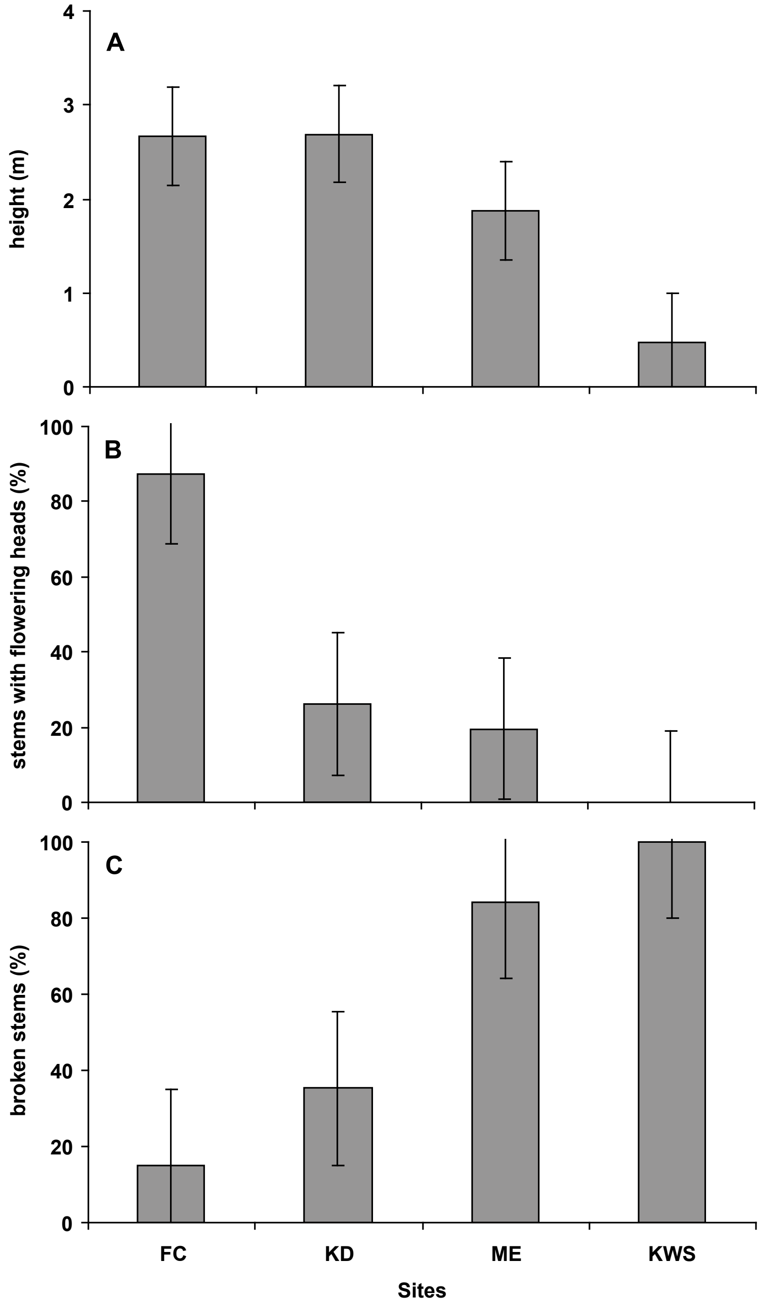

Fig. 5. Selected parameters of papyrus stems at four sampling sites (see text for site abbreviations). A - mean height (in metres, standard error bars); B - percentage of stems possessing flowering heads; C - percentage of broken stems.

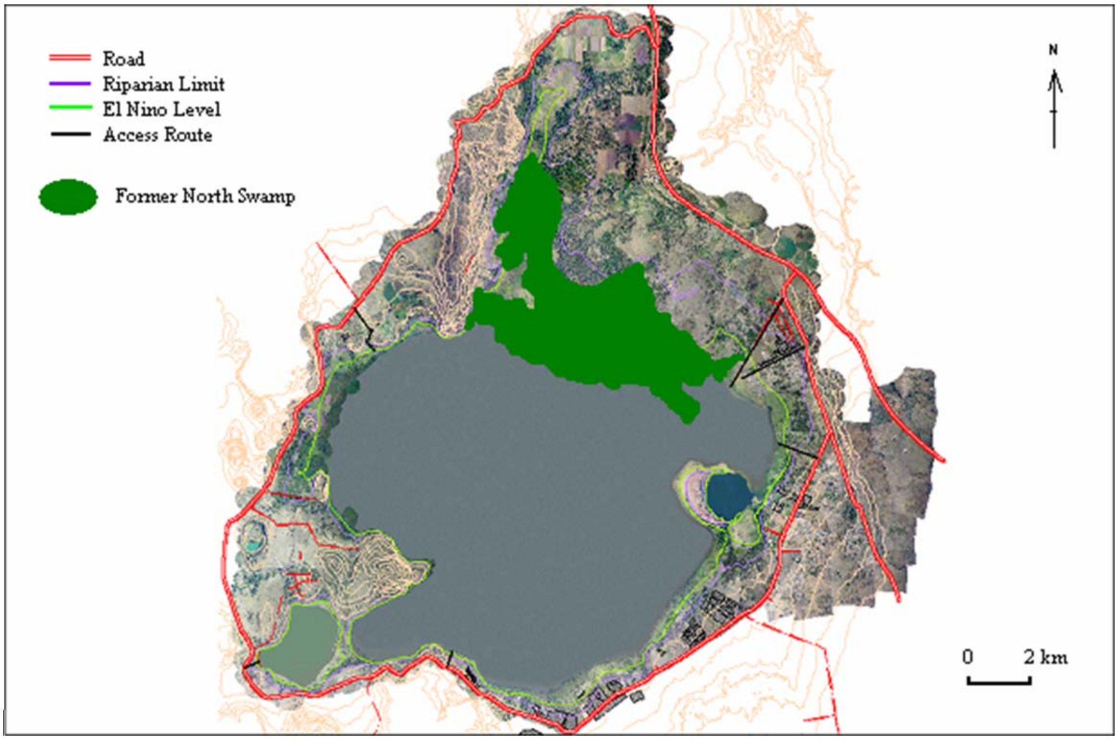

Fig. 6. Aerial photograph of Lake Naivasha with an overlay of the approximate boundaries of the former North Swamp as it would have appeared in the 1970s (modified from LNRA Aerial Survey 2001 and Gaudet 1977a).

Fig. 7. Detailed aerial photograph of the northern shore taken in 2001 revealing the decline in papyrus cover; what remains of the once extensive North Swamp is circled in red (modified from LNRA Aerial Survey 2001).

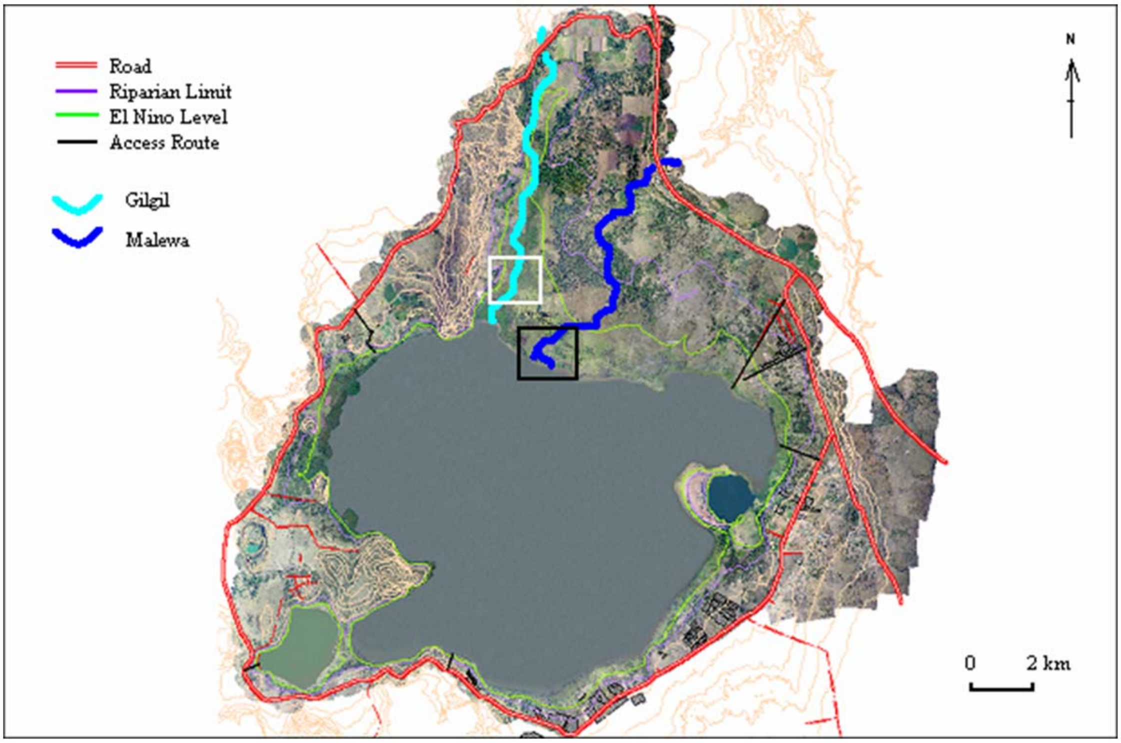

Fig. 8. Aerial photograph of Lake Naivasha with the Malewa (dark blue) and Gilgil (light blue) rivers highlighted; the site proposed by Zalewski and Harper (2001) lies within the black box, that of Githaiga (2008) within the white (modified from LNRA Aerial Survey 2001).

Fig. 9. Healthy fringing papyrus swamp close to Fisherman's Camp (photo. E. Morrison).

These trends are largely natural and no doubt occurred at lower lake levels in the past, such as during the first half of the 20^{th} Century and earlier, but would then have been countered by subsequent water level rises flooding the paths and revitalising the papyrus. However, an important distinction between this century and the last has been the sharp increase in the human population of the town of Naivasha and the lake hinterland; numbers have risen tenfold over the past three decades as employment opportunities have increased in the labour-intensive floricultural industry around Lake Naivasha's shores - from around 7000 in 1969 to around 67 000 in the town alone in 2002 (Lahmeyer 2002). The actual lakeside population in 2009 is estimated at close to 500 000 people (R. Ndetei, pers. comm.). The effects of an increased human population on the lake's ecotone are manifest in three ways:

- The area of *C. papyrus* cover around the whole lake has been severely reduced to around 10% of its former area (Harper, Mavuti 2004) such that the processes outlined above occur within a far smaller area of swamp and thus are more damaging.
- Even in areas where human access on riparian land is limited, papyrus is now subject to repeated human damage arising from: (i) the activities of both legal fisherman and fish poachers, who camp overnight on lake shores and light fires for protection against buffalo (ii) the use of fires and mechanical means to facilitate the clearing of swamp for cultivation, (iii) the removal of papyrus by tourist operators desirous of a view of the lake, (iv) the destruction of fringing swamps on those sites where the general public has wide access, and (v) the free movement of domestic livestock around the lake edge, particularly in droughts when Maasai move farther from traditional pastures.
- The number of buffalo counted around the northern shores of the lake has increased dramatically - from a few hundred in the early 1990s to recent peaks of around 1500 individuals (NWC, unpubl.). It is believed that these animals have been driven down from the Eburru hills to the west (in response to an increase of people, cultivation and deforestation) and now permanently occupy the land of the former North Swamp (H. Simpson, pers. comm.). It follows, then, that what remains of the papyrus here is soon to be entirely removed by herds of buffalo and other grazing species (extrapolating in this way, conditions recorded at ME will ultimately reflect those at KWS: Table II).

Restoration of the inflow papyrus swamps is considered to be of prime management importance for the future sustainability of the lake ecosystem (Jones, Humphries 2001). Two different interventions have been proposed: one located around the delta of the Malewa river, based on ecohydrological principles, the other on land adjacent to the Gilgil river, adopting more of an ecological engineering approach. The relative feasibility of these two proposals is evaluated.

Proposed project sites

Both sites lie within an area of the northern shore formerly occupied by the North Swamp as described by Gaudet (1979). The approximate area that this swamp once covered in the 1970s has been overlaid on an aerial photograph taken in 2001 (Fig. 6); what little remains today is shown in Fig. 7. The 'riparian limit' demarcation denotes that land (below the lake level of 1893 metres above sea level) that was put into the custody of landowners in 1933 under the Lake Naivasha Riparian Owners Association and on which no permanent structures are permitted (Becht *et al*. 2006). Natural fluctuations in water levels over the last 100 years have been in excess of 12 metres (Harper, Mavuti 2004); the last major rise was caused by the heavy 'El Niño' rains that fell over Eastern Africa in 1998, causing the lake level to rise by 2 vertical metres (Kitaka *et al*. 2002) (Fig. 7).

Zalewski and Harper (2001) proposed that the conversion of the Malewa river delta into a sequential wetland should be the first stage of an integrated restoration program. The deltas of both the Malewa and Gilgil rivers lie within the boundaries of two large, privately owned cattle ranches. One of these ranches, Marula Estate (*c* 25 000 acres) plans to restore a similar area of wetland to the west of the Malewa, ~2 km inland along the course of the smaller Gilgil river (F. Natta, pers. comm.); the sites of both proposals are indicated in Fig. 8.

Interventions required

An ecosystem can be considered restored when it contains sufficient biotic and abiotic resources to continue its development without further assistance or subsidy (SER 2004); the majority of projects will therefore require the initial manipulation of both biotic and abiotic conditions.

Abiotic interventions

Zalewski and Harper (2001) suggested that the construction of a 'treatment wetland' either side of the Malewa could be the first component of an integrated strategy of restoration. The intervention would consist of three wetlands of a sequential structure, passing downstream on the Malewa to the lake in its final flows through the former North Swamp. The lowest wetland would have the highest efficiency of organic matter and nutrient trapping and be located close to the lake, designed to carry river overflow arising from frequent, short floods. The second stage would be an overflow weir which took the heavier rains that fall during the annual rainy season, and a third stage taking overflow of floods from the intensive rainy periods that occur every 5-7 years. Rock-filled gabions would be incorporated into the design to raise the height of the river channel at each weir; the main channel would subsequently be linked to a series of smaller channels carrying water into the intended wetland areas.

Githaiga (2008) described a proposal by Marula Estate to restore an area of the former North Swamp fed by the smaller Gilgil river to the west of the Malewa, approximately 2 km inland from the lake (Fig. 8). Here, the intervention would involve the construction of a barrier (making "limited use of concrete and steel") across the Gilgil to create overspill from the main channel in order to wet former swamp land either side of the river, as would have occurred naturally in times of flood before the process of down-cutting drained the swamp (Harper, Mavuti 2004). The proposal described the additional downstream installation of temporary levees and dykes (made from "compacted earth materials") to reduce flow velocities and so raise the height of water within the channel; a fish ladder was also incorporated into the proposal to facilitate upstream migration (Githaiga 2008).

Despite their design differences, the shared objective of the two interventions is the emulation of a flooding regime across former lakebed soils. The rationale for this is that papyrus seeds are known to germinate quickly in rewetted sediment (Gaudet 1977a; Harper, Mavuti 2004); episodic germination events suggest that *C. papyrus* at Lake Naivasha has a persistent seed bank adapted to take rapid advantage of fluctuations in lake level (Boar 2006), which the above interventions would artificially recreate. Sedimentation processes and biogeochemical trapping provided by the restored papyrus swamps should act to significantly reduce the load of suspended matter and nutrients entering the lake (Zalewski, Harper 2001).

Biotic interventions

Biotic interventions would be minimal since the seed bank of papyrus in the North Swamp is likely to have remained viable and seedlings should re-establish once the sediment is wetted. The anoxia caused by flooding and the high productivity of *C. papyrus* will act as stressors to maintain the integrity of the wetland by discouraging the further establishment of competitive species such as climbing plants and creeping grasses (Harper, Mavuti 2004).

That said, the emergent *Typha latifolia* (Common Cattail) has a similar capability to papyrus in terms of its assimilation of N, but is at least three times as efficient in its uptake of P (180 kg ha^{-1} yr^{-1} compared to 50 kg ha^{-1} yr^{-1} : Brix 1994) and, in view of the high concentration of total phosphorus in the lake recorded by Kitaka *et al*. (2002), this species could be considered as an early biotic addition to the restored wetland. However, its development would have to be carefully monitored since, as with other C_3 species, *T. latifolia* tends to increase evaporative loss of water (having a lower water use efficiency than C_4 species such *C. papyrus*) and its unchecked spreading could jeopardize efforts to keep the area wet (Jones, Humphries 2002).

Kariuki *et al*. (2001) suggest that papyrus could be utilised on a sustainable basis (e.g. as a renewable fuel source: Jones 1983) if a harvesting strategy was established to take advantage of its high rate of productivity. A carefully planned biotic intervention of this sort would also be beneficial in terms of maximising the nutrient uptake capacity of papyrus, reducing returns to the lake through leaching and decomposition of dead material (Gaudet 1977b).

Expected benefits of restoration

Improvements that are anticipated following restoration pertain to ecological, economic and educational benefits.

Ecological benefits

Restoring the swamp would facilitate the recovery of *C. papyrus* to a level that enabled the lake ecotone to once again function as (1) a land-water buffer, protecting lake shallows from surplus sediments arriving in the Malewa and Gilgil rivers, thereby reducing siltation, (2) a biophysical filter, assimilating and recycling excess nutrients from the catchment, which presently cause the lake to be eutrophic, and (3) valuable habitat for wildlife including fish, hippos and birds, amplifying biodiversity and improving food chain support.

A functioning papyrus wetland would increase the supply of clean, fresh water into the lake and, at the same time, help to maintain its volume since, under suitable hydrological conditions, water loss by evaporation from papyrus vegetation is considerably less than from corresponding areas of open water (Jones, Humphries 2002).

Economic benefits

Maclean *et al*. (2003) showed the positive economic value of goods derived from papyrus swamps in Uganda. At Lake Naivasha, the financial benefit of restoration can be seen in the 'natural service' provided by healthy, functioning swamps i.e. the introduction of cleaner water into the lake system – which provides the domestic needs of thousands of people living around the shore, as well for the irrigation requirements of an intensive floricultural industry. The restoration of *C. papyrus* would also be of economic benefit to the lake's commercial fishery, which is dependent upon healthy populations of *Oreochromis leucosticus*, *Tilapia zillii* and *Micropterus salmoides*; the importance of the swamp was demonstrated by Hickley *et al*. (2004) who found that all three species were caught in greatest abundance in nets close to the papyrus fringe, compared to other shore types.

An additional economic benefit would come from improvements in aesthetic quality and biodiversity enjoyed by tourists continuing to visit the lake, bringing in valuable foreign currency. Lake Naivasha was once described as "one of the world's top 10 bird-watching sites" and "the most beautiful of the Rift Valley lakes" (Williams 1967); restoring the intrinsic natural beauty of the shoreline would help to prevent such descriptions being confined to the past.

Finally, the high biomass production of papyrus presents a potentially enormous economic resource and several attempts have been made to exploit it in the past (e.g. Jones 1983), most of which have involved paper or board manufacture, although none were economically viable (Jones, Muthuri 1985). However, given the high rate of deforestation in the catchment, and in light of recent advances in briquette-making technology (e.g. Legacy Foundation 2009), further investigations into the potential use of papyrus as a fuel source at Lake Naivasha are likely to be positive.

Educational benefits

Educational benefits may arise from advances in environmental literacy and awareness that individuals gain from participating in, or learning about, ecological restoration (Clewell *et al*. 2005). In the case of Lake Naivasha, public participation in the project may be facilitated through cooperation with organizations such as the Lake Naivasha Riparian Association (LNRA) and the Kenya Wetlands Forum.

Scientific benefits can accrue if a restoration project is used for demonstration of ecological principles and concepts or as an experimental area (Clewell *et al*. 2005). Indeed, Lake Naivasha is part of a worldwide network of 'Ecohydrology Demonstration Sites' (UNESCO 2006) and successful restoration of the North Swamp, *sensu* Zalewski and Harper (2001), would help to make the lake basin a perfect demonstration site for showing ecohydrological principles in the tropics (Harper, Mavuti 2004).

Logistics and limitations

Using theodolite measurements, Kahurani (unpubl.) demonstrated that the topography of the land either side of the Malewa delta is favourable with respect to the intervention described by Zalewski and Harper (2001), in that overspill from the river would flow away from the main channel to re-wet former lakebed soils as it would have in the past, prior to the onset of down-cutting. Similarly, Githaiga (2008) used a laser-based topographical survey to reveal the surface configurations of old channels, semi-basins and undulations either side of the Gilgil river, demonstrating that land previously inundated during flooding events would receive the overspill created by the intervention proposed by Marula Estate.

However, whilst feasible *in situ*, the principal limitations common to both projects are external and anthropogenic, relating to: (i) sources of funding, (ii) permits required by government agencies, and (iii) labour sources and equipment needs.

Funding

In July 2007, WWF-EARPO (Eastern Africa Regional Programme Office) launched an investigation into the feasibility of a 'Payments for Environmental Services' (PES) scheme in the Naivasha catchment. Under this scheme it is envisaged that companies in the floricultural sector, which benefit from a plentiful supply of water provided by the upper catchment, will make small payments to upstream land-owners and communities. In return, recipients of these payments will implement land conservation measures that ultimately benefit the whole of the Lake Naivasha catchment. The scheme additionally seeks to finance rehabilitation of the riparian zone and, in particular, restoration of the North Swamp, vis-à-vis the design of Zalewski and Harper (2001) planned at the Malewa delta (M. Ellis-Jones, pers. comm.).

The PES scheme is now operational, supported by the Lake Naivasha Growers Group (LNGG) - the organisation that represents the region's major commercial horticultural and floricultural companies. However, given the range of catchment conservation measures that need implementing (see Harper, Mavuti 2004) and the divergent priorities of different water users, what proportion of these funds becomes available for restoration of the lake's riparian zone remains to be seen.

The financial situation in regard to the proposal associated with the Gilgil river (Githaiga 2008) is distinctly different. Here, the planned project location lies entirely within the boundaries of the privately owned Marula Estate, the owner of which has set aside adequate finances for the installation and subsequent management of the intervention proposed (F. Natta, pers. comm.).

Permits

In accordance with the Kenyan Water Act 2002 (*Rules 23, 24, 71, 72*), before any restoration of the North Swamp can be conducted, the proposals outlined by Zalewski and Harper (2001) and Githaiga (2008) would have to be met with the approval of the Water Resources Management Authority (WRMA) and the issuing of relevant

Water Permits. Both proposals would require: (1) "an authorisation to construct works for the use of water" (Category 004), and (2) permits for "abstraction, diversion, in-stream and conveyance works" (Category 001B) (WRMA 2006).

The WRMA may also ask applicants to submit a Hydrological Assessment Report, to be prepared by a qualified water resource professional. Proposals to reclaim an area of wetland (*Rule 52*) may additionally require an Environmental Impact Assessment (EIA), to be conducted by an independent environmental consultant; any EIA would subsequently have to be approved by the National Environment Management Authority (NEMA) prior to work commencing. However, an EIA is likely to be approved as the proposed restorations would broadly constitute a 'Soil and Water Conservation Plan', required by the WRMA for the "conservation of riparian and catchment areas" (outlined in Part IX of the Water Resource Management Rules 2006).

Finally, since restoration is proposed on riparian land, where the excavation of soil is prohibited (*Rule 118*), the applicants would have to make a separate written request to the WRMA before commencing restoration; any person who undertakes a proscribed activity on riparian land without the approval of the Authority is liable to a maximum fine of Ksh 50 000 or 3 months imprisonment (WRMA 2006).

Labour

Ideally any intervention should carry a high level of public participation, involving the efforts of local volunteers acting under the supervision of an appointed restoration practitioner. As SER (2004) assert, ecological restoration "encourages and may indeed be dependent upon long-term participation of local people"; this is especially true in parts of Africa where "restoration is untenable unless it manifestly bolsters the ecological base for human survival".

However, both proposed interventions are situated on privately-owned ranches and, as such, public participation is likely to be strictly limited. That said, land lying to the east of the Malewa delta may, in the near future, be subdivided and sold off as family plots (R. Ndetei, pers. comm.). Whilst this would clearly increase public access to the site, the increase in human activity, and in particular the intensive subsistence cultivation that would follow, may only act to jeopardize restoration efforts. The proposal to restore wetlands around the Gilgil river, on the other hand, has been made by Marula Estate, a large cattle ranch that employs around 2000 individuals - the vast majority of which are residents of Naivasha and the surrounding area. Here, local people would be directly engaged in the intervention and its subsequent management (F. Natta, pers. comm.).

Recommendations and strategies for management

Ecological restoration is meaningless without reasonable assurance that the project site will be protected and properly managed into the indefinite future (Clewell *et al*. 2005). Given adequate resources, the initial work proposed by either intervention should take no more than a matter of weeks. However, a carefully planned program of monitoring and management is essential if the restoration is to be considered a success in the long term.

Short term

In the first instance, it is recommended that the physical components of the intervention be installed to coincide with the arrival of the long rainy season, which typically falls between April and June. The reason for this is twofold: (1) to ensure maximum discharge in the inflowing rivers, making water available for diversion across former lakebed soils, and (2) to provide good grazing opportunities for buffalo and livestock offsite, in an attempt to reduce pressure on newly germinated papyrus. In order to completely exclude these animals, it would be necessary to dig wide ditches or erect fences around the project site at a significant cost, the feasibility of which has not been assessed.

Intermediate term

In trials conducted by Boar (2006), it was found that papyrus seeds germinated and survived best when sediment was saturated or where water level was just below the surface, poorly in sediment that was drying and that seeds did not germinate at all where sediment was flooded. This suggests that the saturation state of the newly wetted soils will have to be carefully monitored and, where possible, modified. This could be achieved by adjusting the height of any channels, dykes and levees installed (and/or creating new ones where necessary) in order to maximise the germination rate of papyrus and so the regeneration of wetland. To some extent this will be controlled naturally, by the recession of floodwater back to the main channel as discharge decreases, and via overland flow along existing (but presently dry) surface channels leading towards the lake.

Long term

It is strongly recommended that any intervention adhere to the Society for Ecological Restoration International (SER) *Guidelines for Developing and Managing Ecological Restoration Projects* (Clewell *et al*. 2005); indeed, Cairns and Heckman (1996) believe that efforts coordinated by SER are to be "used as a model by all restorationists".

Particular attention should be paid to the identification of restoration goals. The written expression of goals provides the basis for all restoration activities and later they become the basis for project evaluation (Clewell *et al*. 2005). Specific ecological and cultural goals of the present proposals merit careful consideration should the decision to begin restoration be made.

Two further recommendations of urgency are:

1. Identification of the **reference ecosystem**: a model on which to base restoration that will later serve in the evaluation of the project. Typically the reference represents a point of advanced development that lies somewhere along the intended trajectory of the restoration (Clewell *et al*. 2005); the fringing papyrus swamp at Fisherman's Camp (0º 49' 29" S, 36º 20' 09" E) on the south shore of the lake could be one such reference (Fig. 9).
2. Preparation of **performance standards**: specific states of ecosystem recovery that indicate that an objective has been obtained (Clewell *et al*. 2005). Some of these criteria may be satisfied by a single observation, for example to determine whether a channel has been filled; others will require a program of repeat monitoring to document trends towards the attainment of a specified threshold, for example a particular level of papyrus abundance or rate of nutrient uptake.

Whilst the proposal of Marula Estate is perhaps the most straightforward route to restoration (having funds and labour sources in place), it is important to note that the Gilgil contributes considerably less to the total inflow of Lake Naivasha (around 20%) than the Malewa (around 80%: Becht *et al*. 2006); it therefore seems intuitive to restore the wetland formerly associated with the delta of the larger river. However, in light of Naivasha's history of detrimental anthropogenic changes to the lake ecosystem (e.g. Harper, Mavuti 2004; Becht *et al*. 2006), those responsible for the intervention may be forgiven for undertaking a smaller scale project before embarking upon one considerably larger. With an 8 km stretch of the Gilgil river flowing through privately-owned land, ample opportunities exist for the testing of ecological theories and the appropriate modification of designs prior to embarking upon a larger scale project at the Malewa delta:

"All changes in a complex mechanism involve some risk and should be undertaken only after careful study of all the facts available. Changes should be made on a small scale first so as to provide a test before they are widely applied" (Buchsbaum, Buchsbaum 1957).

However, it should be emphasized that the restoration of papyrus is just one of a wider set of conservation measures required for sustainable management of the whole Lake Naivasha ecosystem, well documented in the literature (see Harper, Mavuti 2004). For example, successful restoration of the North Swamp depends in part on making ecological improvements elsewhere in the catchment; simultaneous efforts need to be made to, amongst other things (i) reduce rates of deforestation, (ii) find economically viable alternatives to the conversion of grassland for small-scale agriculture, and (iii) restore degraded riparian habitat along the course of the Malewa river - all of which currently act to increase the amount of sediment and phosphorus flowing from the catchment (Kitaka *et al*. 2002).

Because restoration is proposed within a Ramsar site, those conducting the intervention should seek the approval of the Lake Naivasha Management Implementation Committee (incorporating Kenya Wildlife Services, the LNRA, the LNGG and other stakeholders including representatives from the Maasi community), since they are the organization responsible for the site's overall management. Indeed, public appreciation of the project is essential if long term, lake-wide restoration of papyrus is to be successful. If the public favours the restoration, they will protect it and vest it with their support; if however they are unaware of the restoration and its (public) benefits they may continue to degrade it or otherwise disrespect it (Clewell *et al*. 2005).

Future research should therefore focus on facilitating the involvement of local communities in any restoration projects at Lake Naivasha, with particular emphasis placed on the development of economic goods derivable from papyrus swamps, such as the manufacture of biomass fuel briquettes using simple screw press technology (e.g. Legacy Foundation 2009) within the frame of a sustainable cottage industry. Although it seems counterintuitive to remove biomass from restored plots, a monitored harvesting strategy is in fact desirable if one is to maintain the nutrient uptake capacity of papyrus *sensu* Gaudet (1977b). In this way, restoration can be seen to have both ecological and financial benefits.

What's important is that some form of intervention is made, since the present state of the lake no longer allows the luxury of waiting on a future lake level rise to regenerate papyrus in the way described by Gaudet (1977a); indeed, at the time of writing (January 2009), the level of the lake is "visibly dropping" (P. Nicklin, pers. comm.).

5. Conclusions

Degradation of *C. papyrus* at Lake Naivasha has been shown to be the result of a combination of lowered lake levels and destruction by buffalo and other grazing species, in addition to human clearance.

The restoration of papyrus in the erstwhile North Swamp is considered ecologically feasible, both at the delta of the Malewa and around the

Gilgil river. However, the present study has shown that the most patent route to restoration currently lies with the proposal forwarded by Marula Estate. The justification for this is three-fold: (i) sufficient funds and labour sources are available to conduct the intervention proposed; (ii) permits required by WRMA have been already been applied for (F. Natta, pers. comm.) and an independent EIA completed and submitted to NEMA (Githaiga 2008: NEMA Certificate #0905), and (iii) Marula Estate has the *ab initio* support of roads and other infrastructure (including machinery) needed to facilitate project implementation. In other words, restoration of the Gilgil is, at the time of writing, socio-economically the more pragmatic of the two proposals.

Acknowledgements

The authors thank the Kenyan Ministry of Education, Science and Technology for the Research Permission to DMH to carry out this work, to Professor Kenneth Mavuti, University of Nairobi and to Sarah Higgins and Mbogo Kamau of the Lake Naivasha Riparian Association, who partner the research activities and to the Earthwatch Institute which funded them, 2002-5. Several Earthwatch volunteers but particularly Naomi Kahurani, Patrick Casement, Rory, and Mayumi assisted the field work. Mrs Velia Carn, James Njoroge and Reuben Ndolo made the work logistically possible. This paper is dedicated to Mrs Joan Root, owner of Kilendegwe Conservancy and ardent protector of Lake Naivasha's ecosystem, who was murdered in January 2006 in her house on the conservancy.

6. References

Becht, R., Odada, O.E., Higgins, S. 2006. *Lake Naivasha: Experience and Lessons Learned Brief* (available from http://www.iwlearn.net/publications/ll/lakenaivasha_2005.pdf/view) accessed 8th March 2008.

Becht, R., Harper, D.M. 2002. Towards an understanding of human impact upon the hydrology of Lake Naivasha. *Hydrobiologia* **488**, 1-11.

Boar, R.R. 2006. Responses of a fringing *Cyperus papyrus* L. swamp to changes in water level. *Aquatic Botany* **84**, 85-92.

Boar, R.R., Harper, D.M., Adams, C. 1999. Biomass allocation in *Cyperus papyrus* in a tropical wetland. *Biotropica* **31**, 411-421.

Brix, H. 1994. Functions of macrophytes in constructed wetlands. *Water Science and Technology* **29**, 71-78.

Buchsbaum, R.M., Buchsbaum, M. 1957. *Basic Ecology*. Boxwood Press, Pittsburgh.

Cairns, Jr., J., Heckman, J.R. 1996. Restoration Ecology: The State of an Emerging Field. *Annual Reviews in Energy and the Environment* **21**, 167-189.

Clewell, A., Rieger, J., Munro, J. 2005. *Guidelines for Developing and Managing Ecological Restoration Projects, 2nd Edition.* Society for Ecological Restoration International, Tucson, Arizona (available from http://www.ser.org) accessed 8th March 2008.

Everard, M., Harper, D.M. 2002. Towards the sustainability of the Lake Naivasha Ramsar site and it catchment. *Hydrobiologia* **488**, 43-55.

Everard, M., Vale, J.A., Harper, D.M., Tarras-Wahlberg, H. 2002. The physical attributes of the Lake Naivasha catchment rivers. *Hydrobiologia* **488**, 13-25.

Gaudet, J.J. 1977a. Natural drawdown on Lake Naivasha, Kenya, and the formation of papyrus swamps. *Aquatic Botany* **3**, 1-47.

Gaudet, J.J. 1977b. Uptake, Accumulation, and Loss of Nutrients by Papyrus in Tropical Swamps. *Ecology* **58**, 415-422.

Gaudet, J.J. 1978a. Effect of a tropical swamp on water quality. *Verhandlungen der internationale Vereinigung für Limnologie* **20**, 2202-2206.

Gaudet, J.J. 1978b. *Nutrient dynamics of papyrus swamps.* Paper presented at the Second International Congress of Ecology, September 10-16th, 1978, Jerusalem, Israel.

Gaudet, J.J. 1979. Seasonal changes in nutrients in a tropical swamp: North Swamp, Lake Naivasha, Kenya. *Journal of Ecology* **67**, 953-981.

Githaiga, J.M. 2008. *River Gilgil Wetlands Rehabilitation Intervention Environmental Impact Assessment*. School of Biological Sciences, University of Nairobi, P.O. Box 30197, Nairobi, Kenya.

Harper, D.M., Harper, M.M., Virani, M.A., Smart, A.C., Childress, R.B., Adatia, R., Henderson, I., Chege, B. 2002. Population fluctuations and their causes in the African Fish Eagle, (*Haliaeetus vocifer* (Daudin)) at Lake Naivasha, Kenya. *Hydrobiologia* **488**, 171-180.

Harper, D.M., Mavuti, K.M. 2004. Lake Naivasha, Kenya: Ecohydrology to guide the management of a tropical protected area. *Ecohydrology & Hydrobiology* **4**, 287-305.

Hickley, P., Muchiri, S.M., Boar, R.R., Britton, R., Adams, C., Gichuru, N., Harper, D.M. 2004. Habitat degradation and subsequent fishery collapse in Lakes Naivasha and Baringo, Kenya. *Ecohydrology & Hydrobiology* **4**, 503-517.

Jones, M.B. 1983. Papyrus: a new fuel for the third world. *New Scientist* **99**, 418-421.

Jones, M.B. 1986. Wetlands. In: Baker, N. R., Long, S. P. [Eds] *Photosynthesis in Contrasting Environments, Vol. 7, Topics in Photosynthesis*. Elsevier, Amsterdam. pp. 103-138.

Jones, M.B., Humphries, S.W. 2001. The impacts of papyrus on ecosystem functioning. In: Harper, D.M. and

Zalewski, M. [Eds] *Ecohydrology: Science and the Sustainable Management of Tropical Waters*. IHP-V Technical Documents in Hydrology 48. UNESCO, Paris.

Jones, M.B., Humphries, S.W. 2002. Impacts of the C_4 sedge *Cyperus papyrus* L. on carbon and water fluxes in an African wetland. *Hydrobiologia* **488**, 107-113.

Jones, M.B., Muthuri, F.M. 1985. Canopy structure and microclimate of papyrus (*Cyperus papyrus* L.) swamps. *Journal of Ecology* **73**, 481-491.

Jones, M.B., Muthuri, F.M. 1997. Standing biomass and carbon distribution in a papyrus (*Cyperus papyrus* L.) swamp on Lake Naivasha, Kenya. *Journal of Tropical Ecology* **13**, 347-356.

Kariuki, F.W., Muthuri, F.M., Jones, M.B. 2001. Sustainable harvesting of *Cyperus papyrus* L. in Lake Naivasha, Kenya. In: Harper, D.M., Zalewski, M. [Eds] *Ecohydrology: Science and the Sustainable Management of Tropical Waters*. IHP-V Technical Documents in Hydrology 48. UNESCO, Paris. p. 42.

Kitaka, N., Harper, D.M., Mavuti, K.M. 2002. Phosphorus inputs to Lake Naivasha, Kenya, from its catchment and the trophic state of the lake. *Hydrobiologia* **488**, 73-80.

Kivaisi, A.K. 2001. The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecological Engineering* **16**, 545-560.

Knapp, A.K., Medina, E. 1999. Success of C_4 photosynthesis in the field: lessons from communities dominated by C_4 plants. In: Sage, R.F., Monson, R.K. [Eds] *C_4 Plant Biology*. Academic Press, San Diego. pp. 251-282.

Lahmeyer, J. 2002. *Kenya: historical demographical data of the urban centers* (available from http://www.populstat.info/Africa/kenyat.htm) accessed 8th March 2008.

Legacy Foundation. 2009. *Biomass fuel briquette production, environmental conservation and income generation for sustainable development*. Available from http://www.legacyfound.org, accessed 20th January 2009.

LNRA 2001. *Aerial Survey*. Lake Naivasha Riparian Association, P.O. Box 1011 Naivasha, Kenya.

Maclean, I.M.D., Tinch, R., Hassal, M., Boar, R. 2003. *Towards optimal use of tropical wetlands: an economic valuation of goods derived from papyrus swamps in southwest Uganda*. CSERGE Working Paper ECM 03-10. University of East Anglia, Norwich.

SER. 2004. Society for Ecological Restoration International Science & Policy Working Group. *The SER International Primer on Ecological Restoration*. Society for Ecological Restoration International, Tucson, Arizona (available from http://www.ser.org) accessed 8th March 2008.

Thompson, K. 1976. Swamp development in the headwaters of the White Nile. In: Rzóska, J. [Ed.] *The Nile, Biology of an Ancient River*. W. Junk, The Hague. pp. 177-196.

UNESCO. 2006. United Nations Educational Scientific and Cultural Organization. *International Hydrological Programme: Ecohydrology* (available from http://www.typo38.unesco.org/en/ecohydrology.html) accessed 3rd March 2008.

Vareschi, E. 1978. The ecology of Lake Nakuru (Kenya) I. Abundance and feeding of the lesser flamingo. *Oecologia* **32**, 11–35.

WRMA Rules 2006. *Water Resources Management Authority (Water) Rules*, Water Resources Management Authority, P.O. Box 45250 – 00100, Nairobi, Kenya.

Williams, J.G. 1967. *A Field Guide to the National Parks of East Africa*. Collins, London.

Zalewski, M. 2002. Ecohydrology – the use of ecological and hydrological processes for sustainable management of water resources. *Hydrological Sciences Journal* **47**, 825-834.

Zalewski, M., Harper, D.M. 2001. A "sequential wetland" as a primary tool for the restoration of Naivasha. In: Harper, D.M., Zalewski, M. [Eds] *Ecohydrology: Science and the Sustainable Management of Tropical Waters*. IHP-V Technical Documents in Hydrology 48. UNESCO, Paris. P. 21.