Perceived and real sources of pollution in Lake Naivasha

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Abstract

Lake Naivasha, a Ramsar site, is threatened by the recent development of the horticultural industry along its shores, overpopulation, upper catchment activities, and invasive species. We aimed to determine the community's perception of the pollution to the lake, and how this related to real sources of organic pollution. 32% of the residents considered the lake to be polluted, mostly blaming the flower farms (55%) and settlement discharge (21%). Perceptions of pollution varied between occupational sectors and location of interview. Levels of organic pollution estimated by chlorophyll-a concentrations, water parameters and water hyacinth characteristics showed that the studied locations were highly differentiated. Although contrasting information between parameters hampered determining the main source, the flower farm area appeared to harbour high levels of organic pollution. The community's perception is therefore true to some extent, although probably overestimated. As people mostly blamed the causes they were involved in, awareness-raising programs for all stakeholders will be an important step towards lake conservation.

INTRODUCTION

Like many of the great East African lakes, Lake Naivasha is of international biodiversity value and as such in 1995 it became Kenya's second Ramsar wetland site. This shallow freshwater lake supports a high but uneven biodiversity – rich in birds and plants but no native fish, for example (Harper *et al.,* 1990). It is situated in the Eastern Rift Valley (0.45ºS, 36.26ºE), altitude 1890 m, and, covering approximately 150 km², is the second largest freshwater lake in Kenya. Given the overall semi-arid climate of the Eastern Rift Valley, the lake is unique when compared to the other lakes in the region, which are alkaline or saline.

Yet the lake also supports a growing human population and over the last two decades has become the main site of Kenya's horticulture industry, which is close to being the nation's largest earner of foreign currency (Harper and Mavuti, 2004). In recent times, the lake has come to face a number of challenges, namely excessive fishing pressure, enrichment of nutrients by different sources, the introduction of alien species such as an exotic crayfish (*Proambarus clarkii*), and the invasion of the water hyacinth, *Eichornia crassipes.*

Of the invasive species, the Louisiana crayfish has helped to destroy the native lily beds and all submerged plants, while the water surface has been filled by the exotic *Salvinia molesta* (Floating Water Fern) in the 1980s and later *E. crassipes* (Water Hyacinth) in the 1990s (Harper, Adams and

Mavuti, 1995). Since its arrival in 1988, the water hyacinth initially spread slowly, though by 1992 was dominant to *S. molesta* that had decreased following introduction of a biological control agent (Harper, Adams and Mavuti, 1992).

Being a surface-floating aquatic macrophyte, *E. crassipes* is not affected by water depth and therefore not limited to a particular zone in the hydrosere (Mitchell, 1985). It can double in biomass every 15 days, with the capacity for vegetative growth in conditions where nutrients are non-limiting. Furthermore, it can have serious ecological implications, starving fish and plankton of oxygen and sunlight and reducing the diversity of important aquatic plants. The plants tend to dominate offshore margins, when wind or current does not remove them.

The water hyacinth's recent rapid proliferation in Lake Naivasha is directly attributed to the enrichment of the lake water with nutrients. The lake is now considered to be moderately eutrophic, with increased phytoplankton biomass (Hubble and Harper, 2002), nutrient levels (Kitaka, Harper & Mavuti, 2002) and reduced transparency (Harper *et al,*. 2002). These changes have various potential sources, including untreated effluent from the expanding population around the lake, as well as discharge from the booming horticulture industry in the area.

As the boundary of the Ramsar site is set within the road that surrounds the lake, some of the horticultural enterprises lie inside and others outside of the area. Since the first flower farms of the 1980s, there has been a fairly constant increase in the area of land cultivated, which 4,000 ha in the last five years (Becht, *unpublished data*). Although there is evidence for fluctuations in lake level partly due to an increase in demand of water for irrigation, the authors are not aware of any study into potential pollution discharge from the horticulture industry.

The arrival of the labour-intensive horticultural industry to the area has also brought with it a large number of employment opportunities. Because of this, the human population of the town of Naivasha and the lake hinterland has increased fifty-fold over the past three decades. A total of six new settlements, housing an estimated 50,000 people, poses further threats to the lake with its lack of waste treatment facilities or piped water supply in the majority of areas. The lakeshore near these settlements is also degraded by human use for washing, domestic stock watering and laundry.

On the north-eastern shores of the lake lies the town of Naivasha with a population of approximately 70,000. As the town's sewage collection system only covers part of its area, much of the town has open drains that carry waste during heavy rains. Given the low level of the lake in the past decade, the urban edge is several hundred metres away from the water, so untreated waste and partially-treated sewage effluent seep into the former lake-bed soils. It is not known whether this urban effluent locally enriches the water shallows.

As for the catchment area, there have been few studies on the levels of pollution of the rivers that feed the lake, although WWF has had a short pilot project in the upper Malewa community. The catchment area of the two main, permanent inflow rivers Gilgil and Malewa (contributing over 95% of total inflow) to the north is now devoid of most natural vegetation. Remnants of the original forest exist only in small patches, and cultivation often extends right down to stream level. As such, the inflow of rivers at the northern end of the lake may contain a large amount of sediment and conductivity may change very rapidly in a few hours (Kitaka *et al.,* 2002).

Given these potential sources of pollution to the lake, the aim of this study was to (i) find out whether the community was aware that the lake was polluted and identify what they considered to be the major source of pollution, and to (ii) measure organic pollution at key locations to determine the real sources of pollution, in order to (iii) determine whether the community's perception corresponded to the real situation.

METHODS

Perceived pollution

In order to assess perception of pollution in the lake, brief surveys of over 300 members of the population surrounding Lake Naivasha were carried out. Over five days, we interviewed people that live and work near the lake, in Naivasha town and those who work in tourism and conservation in the area. Having sampled a large number of workers from the flower farms and business-people from various settlements near the lake, we then targeted survey locations so that we could speak to a substantial number of people that harvest the natural resources surrounding the lake (pastoralists and fishermen) as well as those involved in conservation and tourism. The people involved in these sectors worked for either Elsamere Field Study Centre, Hell's Gate National Park, Crayfish Camp, Carnelly's Camp, Sopa Lodge or the Lake Naivasha YMCA.

Each survey lasted a few minutes and involved the following questions, presented orally and subsequently recorded on a non-intrusive voice recorder:

1. What do you do for a living?
2. Do you think the lake is polluted?
3. Where do you think the pollution comes from?

4. Are there any other sources of pollution?
5. How long have you lived in the area?

A scoring system was applied to each interview in order to give the same total score (100) to each person who confirmed that the lake was polluted. It also gave greater importance to people's initial response, over answers given after prompting (question 4). Values given to each answer were calculated using the following formula:

m = number of initial answers; a = number of answers after prompting;

x = average score per initial answer; y = average score per prompted answer;

If $a = 0$, $mx = 100$;

If $a > 0$, $mx + ay = 100$; $x = 3y$.

We compared the number of people who thought that the lake was either polluted or not using chi-square tests, both overall and comparing between sex, occupation and location. Turning then to the subset of people who thought that the lake was polluted, we examined the sources of pollution blamed. We used the same comparisons for total scores for each answer, standardised as a score per person.

Lake pollution levels

On the morning of Thursday 16th August 2007, we visited five predetermined locations on the shore of Lake Naivasha by boat. The following sites were chosen in order to try to determine the main source of pollution to the lake (Fig.1):

- C Control 1: on the southern shore, between Elsamere Conservation Centre and Djins Palace,
- P Control 2: Crescent Island lagoon,
- F Southwest shoreline, bordering flower farm (Sher),
- T Northwest Kihoto Shoreline (Naivasha town sewage outlet area),
- R Northern shoreline, where Rivers Gilgil and Malewa enter the lake, indicative of upper catchment areas.

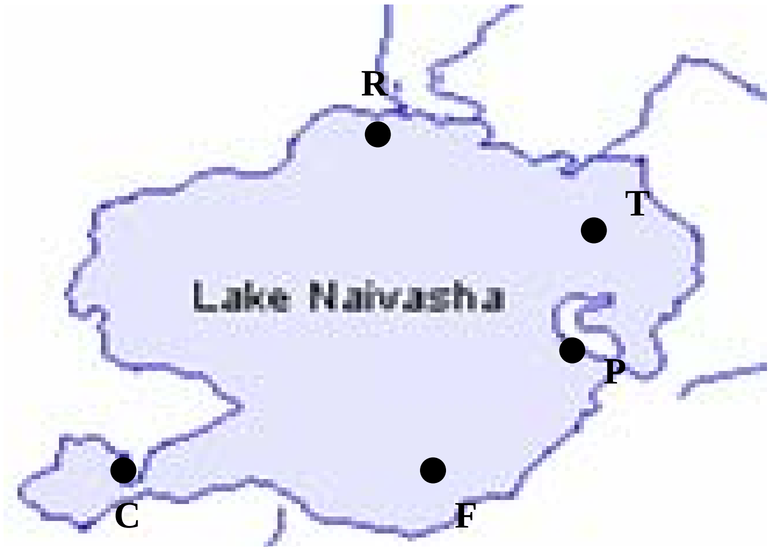

Fig. 1 Map of Lake Naivasha with sampling sites (R = river, T = Naivasha town, P = pristine, F = flower farm and C = control).

At each location, water parameters were measured from the side of the boat at six sites approximately ten metres apart, two metres from the edge of the floating plant mass. The parameters measured in situ were pH, temperature, transparency and depth. 500 ml water samples were also taken for laboratory analysis. As water hyacinth growth is often associated with enrichment of water by nutrients (NEMA 2006), we estimated the relative abundance of floating water hyacinths. This was done at the six sites using 1 x 1 m quadrat frames placed on the vegetation surface from the side of the boat. A random sample of ten water hyacinths was also taken from sites 3 and 4 at each location.

In the laboratory, the water samples were tested for conductivity and analysed in a spectrophotometer for chlorophyll-a levels. Chlorophyll extraction was done using ethanol as by Porra *et al.* (1989) and Seely and Jensen (1965). The samples of water were forced through a 2cm diameter filter paper which was then transferred into a dark vessel (to prevent chlorophyll degradation due to light) and 30ml of boiling ethanol poured in to the vessel. The content of the vessel was placed in a spectrophotometer cuvette and analysed for absorbance at 665 nm and 750 nm, both before and after acidification treatment. Chlorophyll-a was calculated as:

$$\text{Chl-a} = 29.6*(E^{b}665-E^{a}665)*v/V*I$$

Where: Chl-a = concentration of chlorophyll-a in $mg.m^{-3}$

$E^{b}665$ = Extinction of extract at 665nm before acidification

$E^{a}665$ = Extinction at 665nm after acidification (values corrected for turbidity by subtraction of the 750nm reading)

V = Volume of water filtered, expressed in litres

v = Volume of solvent used to extract the sample, in ml

I = Path length of spectrophotometer cuvette in cm.

Transparency, pH and chlorophyll results were analysed across locations using an ANOVA, but as water hyacinth density and conductivity were not normally distributed in all locations, these two parameters were analysed using a Kruskal-Wallis test. In order to look at whether each location had a distinct set of characteristics, a principal component analysis was used. We measured individual wet weight and area of leaves and bulbs of the water hyacinths to give an indication of their health. These measures were summed to give a total value for the ten individuals at each location. ANOVA tests were used to compare total area of leaves and bulbs across the five locations, while a Kruskal-Wallis test was used for the total weight of the plants.

RESULTS

Perceived pollution

We interviewed a total of 327 people, of which 216 thought Lake Naivasha was polluted, 105 thought it was not, and four did not know. Although men and women had the same opinion about the presence of pollution in the lake (X^2=0.581, DF=1, P=0.446), the occupational sector of the interviewee did affect his or her perception of pollution (X^2=26.845, DF=8, P=0.001). People involved in tourism, conservation and healthcare thought the lake was more polluted than expected, whereas the majority of unemployed perceived the lake to be unpolluted. The location of the interviews also influenced the results (X^2=8.568, DF=2, P=0.014), as the proportion of positive answers was much higher in tourism and conservation areas than in the areas close to the lake and in Naivasha Town.

The results for each source of pollution blamed are summarised in Table 1. Overall, when asked what people perceived as sources of pollution, the flower farms were most often held responsible, with an average score of 55 out of 100 per person. Settlement discharge (score: 21; sewage and general rubbish produced by settlements) and run-off (score: 10; any sediment carried by surface run-off) were the next most frequent answers. The scores between men and women were similar overall, although men mentioned the flower farms more often, whereas women put more emphasis on settlement discharge and domestic activities such as washing and bathing in the lake. Scores differed quite substantially between occupational sectors, and differences were found between locations (see bold numbers in Table 1).

Table 1. Average score for each source of pollution per person that considers Lake Naivasha is polluted. Scores are displayed as a mean of all interviewees (total), as well as per sex, occupational sector and location of the interview. *N* is the number of people in each group. The numbers in bold are the most striking differences between occupational groups.

		Sex		Occupational sector									Location		
	Total	Women	Men	Business	Flower farm	Tourism	Conservation	Healthcare	Education	Unemployed	Resource user	Other	Local	Naivasha	Tourism and Conservation
N	212	58	154	81	42	34	16	12	9	7	6	5	112	59	41
Source of pollution															
Flower farm	55	43	59	54	54	54	54	48	**39**	60	96	46	56	55	52
Settlement discharge	21	30	18	22	24	14	24	29	29	20	**0**	**11**	19	**29**	18
Run-off	10	10	9	8	12	11	10	8	17	14	**0**	10	10	**7**	13
Water weeds	6	6	6	3	4	11	**0**	**15**	**13**	**0**	4	10	6	4	8
Washing/Bathing	3	7	2	4	2	2	5	**0**	2	4	**0**	**10**	5	**0**	3
Fishing activities	2	1	3	2	2	**5**	**4**	0	1	0	0	0	2	2	5
Agriculture	2	2	2	3	1	3	2	0	0	2	0	2	2	3	2
KenGen	1	1	1	1	0	0	1	0	0	0	0	**11**	1	1	0

Lake pollution levels

All water parameters were significantly different across all locations (Table 2). pH differed significantly across all locations except between the flower farm and pristine location; transparency differed between all locations except flower farm and control. Chlorophyll-a was found to be different between the river and flower farm and the river and control locations. The PCA (Fig. 2a) confirmed these strong differences, as the different locations clustered together according to the two first components, explaining over 80% of the variance (PC1: 57.2%, PC2: 25.9%). The main contributors (Fig. 2b) to the first component of the PCA were transparency, conductivity and pH, clearly differentiating river, town and pristine. The second component, driven by chlorophyll-a and water hyacinth density, further allowed distinguishing flower farm from control.

As weight and total area (sum of leaf and bulb areas) did not correlate, they were considered separately in the following analysis (Fig. 4). Furthermore, although leaf and bulb area were correlated when considered across all locations (Pearson: $r = 0.92$, $p<0/001$), this was not the case for the individual locations (Fig. 3). River and flower farm demonstrated different trends from the other locations. Therefore, we used leaf to bulb ratio as a third measure of water hyacinth growth.

Table 2. Mean (± S.E.) water parameters at each of the five locations, with result of the Kruskal-Wallis tests or ANOVAs (where applicable) for each parameter across location (respectively H or F, with four degrees of freedom). Where ANOVAs were performed, a Tukey's Test distinguished the significant differences between locations, and for Kruskal-Wallis we tested the significance of individual pairs of differences comparing z-values for ten comparisons (^{R} = River, ^{T} = Town, ^{F} = Flower Farm, ^{C} = Control and ^{P} = Pristine).

Location	Temperature (°C)	pH	Transparency (cm)	Water hyacinth density	Conductivity (uS.cm^{-3})	Chl-a (mg.m^{-3})
River	16.1 ± 0.0	$7.28 \pm 0.03^{T,F,P,C}$	$16.9 \pm 0.7^{T,F,C,P}$	47.8 ± 6.4	$70 \pm 1^{P,T}$	$18 \pm 49^{C,F}$
Town	21.6 ± 0.1	$7.93 \pm 0.04^{R,F,P,C}$	$31.3 \pm 1.1^{R,F,C,P}$	45.0 ± 2.7	266 ± 3^{R}	201 ± 34
Flower Farm	22.0 ± 0.1	$8.80 \pm 0.00^{R,T,C}$	$39.5 \pm 2.2^{R,T,P}$	$63.7 \pm 4.2^{P,C}$	232 ± 2^{P}	361 ± 33^{R}
Control	24.0 ± 0.1	$8.12 \pm 0.00^{R,T,F,P}$	$43.4 \pm 1.1^{R,T,P}$	29.3 ± 4.2^{F}	251 ± 1	278 ± 78^{R}
Pristine	22.9 ± 0.2	$8.70 \pm 0.07^{R,T,C}$	$68.3 \pm 1.1^{R,T,F,C}$	30.7 ± 2.4^{F}	$325 \pm 2^{R,F}$	166 ± 63
K-W/ANOVA		F=248 ***	F=197 ***	H=19.88 **	H=27.45 ***	F=5.67 **

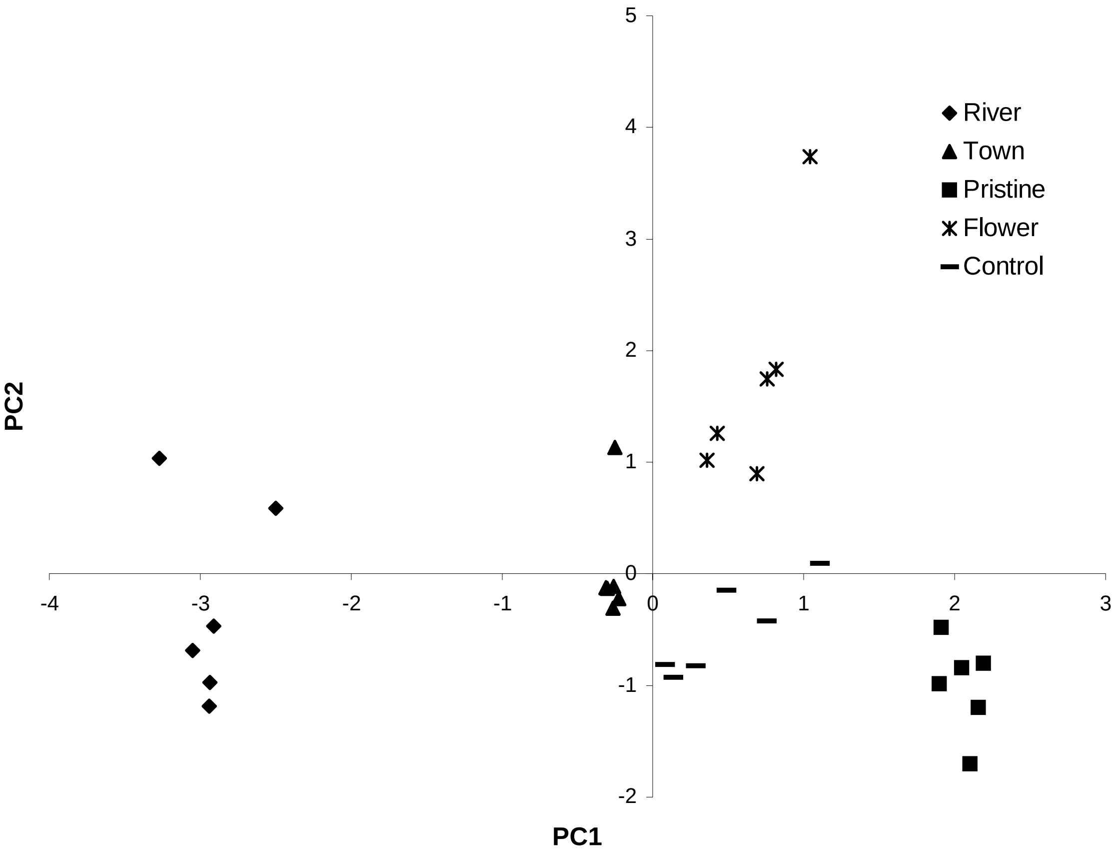

Fig. 2a Principal component analysis across all locations (PC1: 57.2% and PC2: 25.9%) .

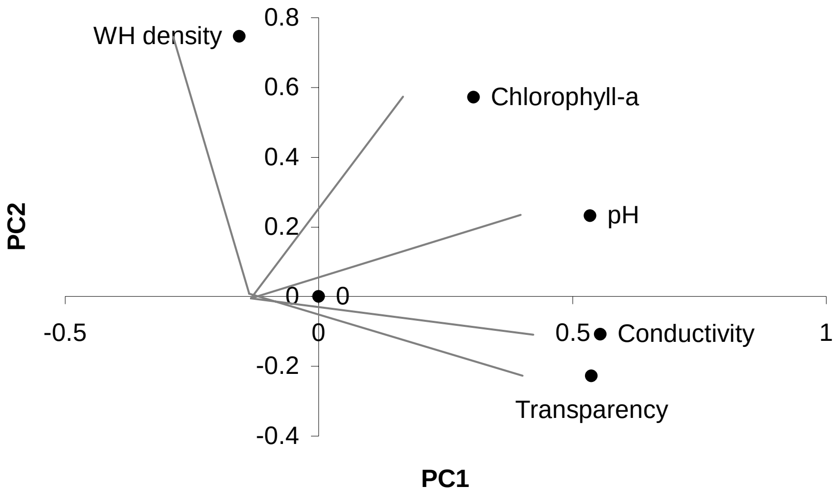

Fig. 2b Loading plot of the PCA, indicating the contribution of each parameter to the two first components.

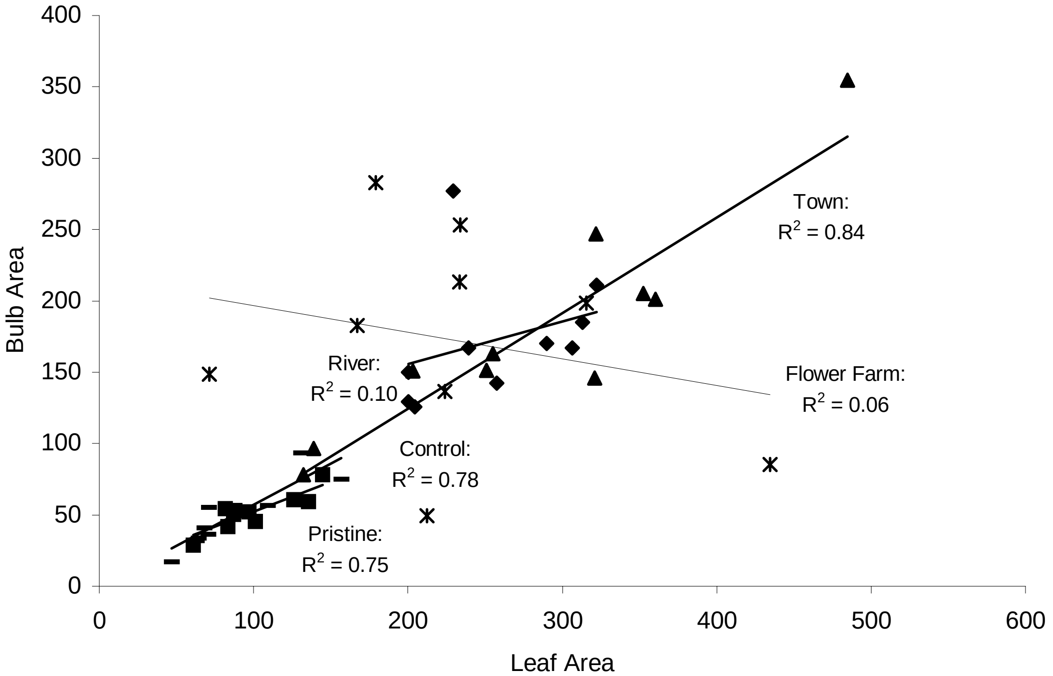

Fig. 3 Individual regressions of bulb against leaf area. Triangles: town; stars: flower farm; lozenges: river; squares: pristine; bar: control.

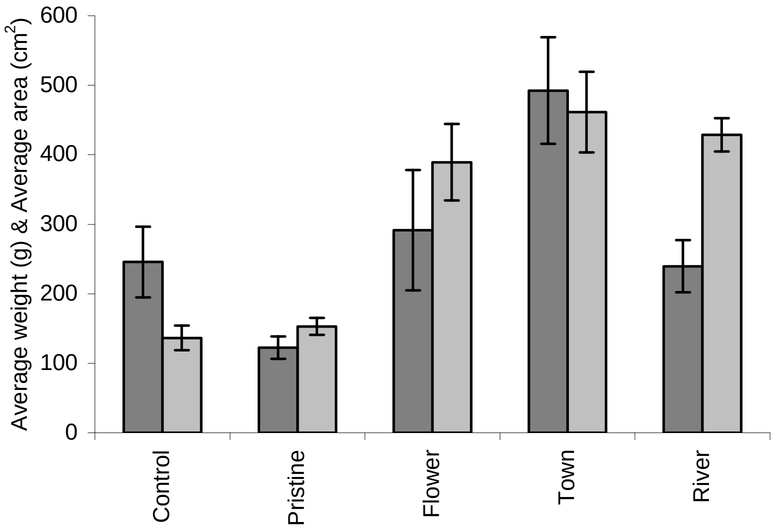

Fig. 4 Average weight (dark bars) and average leaf and bulb area (light bars) of water hyacinth at each location.

Individual weight (Kruskal-Wallis: H=17.4, df=4, p<0.01), leaf and bulb area (ANOVA: F=8.97, df=4, p<0.001) and leaf to bulb ratios (ANOVA: F=16.43, df=4, p<0.001) were significantly different between locations. However, the patterns were not consistent for these three measures. A Tukey's test on total area distinguished flower farm, town and river from control and pristine (Fig. 4). The ratio at the flower farm was significantly lower than at both the control and pristine locations, and the river was significantly lower than the pristine location (Fig. 5).

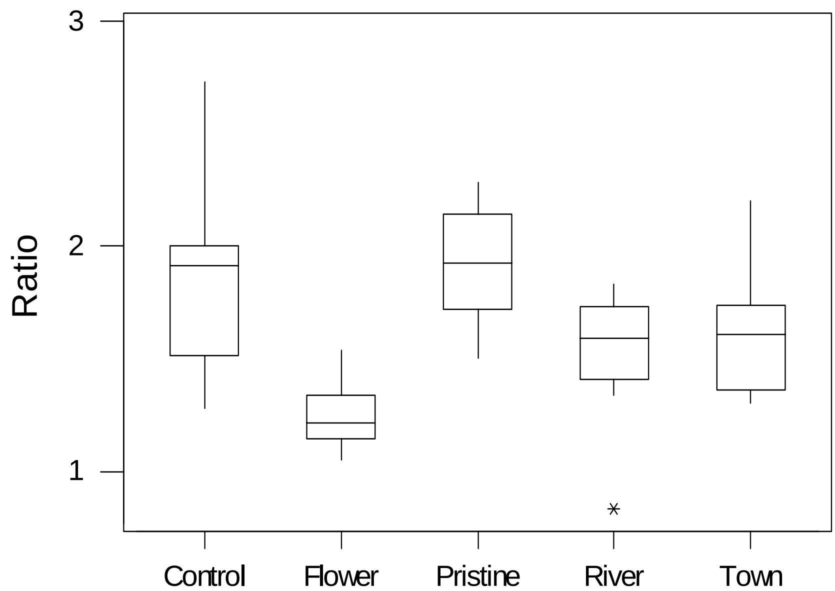

Fig. 5 Boxplot of the leaf to bulb ratio per location.

DISCUSSION

Although most people perceived the lake as polluted, 32% were unaware of any pollution to the lake. Since the lake has been considered eutrophic since the early 1990s (Becht *et al.,* 2004), this lack of awareness is quite alarming, for environmental reasons such as ecosystem services as well as direct health issues. Indeed, the average pH value alone exceeds WHO limits for drinking water (pH < 8.0), although most people extract their drinking water from the lake, frequently without treating it. The perception of the presence of pollution was strongly dependent on occupational sector, with people involved in tourism, conservation and healthcare considering the lake to be more polluted on average. These sectors are probably most exposed to environmental and health issues.

The main sources of pollution identified by people were the flower farms, settlement discharge and run-off (Table 1). It is advantageous that our choice of locations for the water quality study (Fig. 1) should be indicative of the three main sources held responsible by the community. While the scores differed quite substantially between occupational sectors, the flower farms were always considered to be the main source, with scores ranging from 39 for healthcare workers to 96 for natural resource users (fishermen and pastoralists).

Interestingly, it appears that people's perception of pollution in the lake is directly dependent on the relationship they have with the lake. Overall, people tended to blame the source(s) of pollution to which they were directly contributing (Table 1). Women blamed the settlement discharge and domestic activities (washing and bathing) more than men, who pointed towards the flower farms more often. People living in Naivasha Town did not mention any domestic use of the lake, and often pointed out they hardly ever visit it. KenGen workers (majority of the 'Other' category) considered KenGen an important contributor. Against our expectations, people were not trying to 'cover up' either their own contribution to the lake's pollution or their employer's.

As this study focused on analysing levels of organic pollution, the measurement expected to give the strongest indication was chlorophyll-a (chl-a) concentration. It is a measure of phytoplankton standing crop biomass, which increases with increased nutrient (nitrates and phosphates) input. Between 1982 and 1995, Lake Naivasha's open water chl-a concentration increased from 30 to 178 mg.m^{-3} (Becht *et al.,* 2004). At the sites sampled in this study, chl-a ranged from 18 at the river outlet to 361 mg.m^{-3} in front of the flower farm (Table 2). This indicates that the highest nutrient input is from the flower farm area. Moreover, the flower farm also had the highest water hyacinth density, which proliferates in nutrient rich environments (Njuguna, 1985), and the highest pH, which is indicative of higher plant and algae growth (Table 2).

However, the flower farm also exhibited the lowest water hyacinth leaf to bulb ratio (Fig. 5). Uneven growth rates could be an indication of stressful growing conditions, as the water hyacinth exhibits modifications in growth habit according to conditions. In disturbed conditions, the water hyacinth grows as leaf rosettes, which may be less than 5 cm in diameter, whereas healthy individuals in undisturbed conditions are more robust, with larger leaves (Mitchell, 1985). Considering the nutrient input is at its highest at the flower farm, the stresses on the water hyacinth might be due to inorganic pollutants hampering normal plant development, for example.

Surprisingly, the next highest location for chl-a was the control location. In the principal component analysis (Fig. 2a), the results for the control location cluster quite closely to the town and flower farm. This indicates that these locations are similar with regard to the water parameters analysed. However, the water hyacinth characteristics at the control location, in terms of density, weight and area index, were similar to the pristine location, and significantly lower than the other three locations (Table 1 and Fig. 4). This conflicting information between water hyacinth 'health' and water parameters might be explained by the proximity of this location to settlements and flower farms, which might have compromised its quality as a proper control.

The town also exhibited high chl-a concentration, and the highest water hyacinth weight and area indexes (Table 2 and Fig. 4). Nutrient input is therefore most probably high, and since the water hyacinth leaf to bulb ratio is quite high (Fig. 5) the development conditions are probably good.

The river, indicative of the upper catchment's contribution to lake pollution, had the lowest chl-a concentration and the lowest transparency (Table 2), due to high sediment discharge. The weight, area index, leaf to bulb ratio and density of water hyacinth were high at the river (Fig 4 and 5), which contrasts with the findings for chl-a. It is interesting to note that there was no relationship between chl-a and water hyacinth parameters, both at this site and at the control. Mats of water hyacinth move across the lake due to their ability to form floating mats (Mitchell, 1985), and could therefore be blown towards the river entrance with the southerly prevailing winds at this time of the year.

The signals given by the different parameters, both water and water hyacinth related, give an indication of the presence of pollution at the flower farm, town, river and control locations, but determining the relative levels of pollutions is made ambiguous due to conflicting information. However, the high chlorophyll-a, water hyacinth density and pH levels at the shoreline near the flower farm (Table 2) all point towards the finding that the flower farms release the most substantial amount of pollution into Lake Naivasha. This concurs with the community's overall perception of the main source of pollution (Table 1).

A monitoring programme as suggested by Mavuti and Harper (2005) would enable us to determine with more confidence where the principal sources of pollution are. An investigation into the presence of inorganic pollutants could also allow clarifying whether the different sites pollute the lake in different ways. However, there are still interesting implications that may be drawn from the comparison between perceived and real data in this study.

The dominant perception that the flower farms are the main contributor to lake pollution appears, to some extent, to be true. However, given the measures of pollution at the town and river locations are also quite high, the recorded level of blame to the flower farms (55%) is probably an overestimation of the actual situation. Furthermore, only 68% of the population living near the lake are actually aware of the issue at all. Over all the categories we used, it can be noted that people tend to blame the sources of pollution that they are involved with, be it women living near the lake washing and bathing, or flower farm workers seeing the effluent pipes leaving the farms. This shows, somewhat unsurprisingly, that it is primarily people's limited knowledge of the issue that shapes their perception of the problem. This implies that awareness-raising could certainly change the attitude of the local population towards the problem of pollution in the lake.

The major drivers for the pollution threat to the lake stem from the increasing population in the area, the discharge they produce, as well as the extraction of water and release of products from the horticulture industry. Globally, it has been estimated that anthropogenic demand for water has led to 50% loss in wetlands habitats in the last century (Duggan 1990). This survey revealed the local population's dependence on the lake, in the large proportion of people working in industries reliant on it, or in their daily demands for domestic use. The local demands of the population and industry have generated other ecological problems, including water abstraction leading to reduced water levels (Becht and Harper, 2002), and over-fishing (necessitating a four month annual fishing ban over recent years to reduce the depletion of fish stocks).

Given the need for remedial action to address these issues, and the finding that awareness of pollution sources is mostly restricted to one's own actions, increased stakeholder participation and awareness-raising of the issues within the community would certainly be beneficial. Interventions at the community level might include Payment for Environmental Services and training in water conservation strategies. The development of industry in the area must be integrated with water resource considerations. This may begin with an economic valuation of the habitat, as has been done in Nakivubo Swamp in Uganda (IUCN Water and Nature Initiative, 2003). Finally, effective conservation of the freshwater of Lake Naivasha must also incorporate the protection of river catchment areas, to allow this Ramsar site to remain a wetland of international importance for future generations.

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