Effect of Water Hyacinth Infestation on the Physicochemical Characteristics of Lake Naivasha

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Abstract

Water hyacinth (Eichhornia crassipes) is an invasive aquatic macrophyte associated with major negative economic and ecological impacts in the Lake Naivasha region since the plant's introduction into the lake in 1986. The study hypothesized that water hyacinth had significantly affected water quality of Lake Naivasha. Field measurements were done to determine the impact of water hyacinth on water quality. Two sampling sites were selected (one under water hyacinth and another at shore line without water hyacinth) to compare the results of the measurements. At each of these habitats 10 sampling areas were randomly selected. Water quality variables from the two habitats were compared by means of one-way analysis of variance (ANOVA). The sample analysis showed that free carbon dioxide was significantly higher ($P<0.05$) in water hyacinth infested areas (26.45 ± 1.02 mgL^{-1}) than in open water (12.86 ± 1.92 mgL^{-1}). Dissolved oxygen was significantly lower ($P<0.05$) in the infested areas (1.96 ± 0.71 mgL^{-1}) when compared with open water (5.98 ± 0.85 mgL^{-1}). Similarly pH was significantly lower ($P<0.05$) in water hyacinth infested area (6.92 ± 0.04) than in open water (7.71 ± 0.05). Although the temperature was higher in the infested areas (27.5 ± 0.60^0C) than open water (26.7 ± 0.52^0C) the difference was not significant ($P>0.05$). It can therefore be concluded that the presence of water hyacinth was found to have affected the ecology of Lake Naivasha and therefore it's utility. Effective control of water hyacinth in Lake Naivasha is important, in order to prevent both ecological and economic loss due to loss of biodiversity.

Keyword: Water quality, ecological impact, Water hyacinth (Eichhornia crassipes), Invasive species

Introduction

Water bodies continue to endure water hyacinth (*Eichhornia crassipes*) invasions globally. The intricate and unique structure of *Eichhornia crassipes* makes it one of the most resilient aquatic plants enabling it to infiltrate major water systems throughout the world (Cohen, 1995). The resilient water hyacinth like many invasive non-native species continues to invade waterways and ecosystems throughout Kenya. Numerous methods of controlling the invasive plant have been developed throughout the world such as biological, mechanical, physical, and chemical treatments (Wade, 1990).

The first case of water hyacinth in Kenya was reported in Lake Naivasha (Figure 1) in 1988 (Njuguna, 1991). By early 1989 the plant had progressively spread in the lake and in 1992 it became the dominant weed species (Harper *et al.* 1992). So far, the weed has adversely affected lake transport and the fishing industry. Water hyacinth has the ability to root in damp mud and so in Lake Naivasha, as in other locations it has colonized the littoral zone which is overwhelmingly dominated by the plants (Adams *et al.* 2000). The dominance has a physical stability, for, as water level changes, rooted plants can float and vice versa.

It is thus possible that the classic zonation of vascular plants from land to the open water (Figure 2), described for Naivasha by Gaudet (1977), has been altered. Gaudet classified 108 plant species in a primary successional sequence from lake edge to dry land after a period of naturally low water levels that occurred between 1971 and 1973. The zones were: the seedling zone dominated by *Nymphae nouchali* (Adams *et al.* 2000) seedlings that did not survive further drying; the sedge zone dominated by *Cyperus papyrus* (Adams *et al.* 2000) the composite zone dominated by *Conyza, Gnaphalium* and *Sphaeranthus.*

Changes to water hyacinth density have the potential to affect other ecological and human communities in areas where it is established; these changes may be perceived as positive or negative depending on the designated or beneficial uses of the waterbody (Gibbons *et al.*, 1994). Water hyacinth is extremely difficult to eradicate once established. Therefore, the goal of most management efforts is to minimize economic costs and ecological change. Recent literature on the management of water hyacinth focuses on techniques to remove the weed; however, little has been done to assess the full extent of ecological changes (i.e. abiotic and biotic) that may occur in response to the establishment and management of this non-native species. Determining the consequences of controlling an established water hyacinth population is contingent on our ability to understand how water hyacinth affects the systems that it inhabits.

The main objective of this paper is to provide a concise description on how the presence of water hyacinth has influenced the physicochemical environment of Lake Naivasha. The paper also offers suggestions for future management of the lake that will promote stronger understanding of water hyacinth dynamics and there implications on its ecological health.

Literature Review

Prior research on water hyacinth's effects on water quality has focused mainly on the consequences of the dense mats formed by the interlocking of individual plants. The most commonly documented effects are lower phytoplankton productivity and dissolved oxygen concentrations beneath mats (Mironga *et al.*, 2011; Rommens *et al.*, 2003; Mangas-Ramirez & Elias-Gutierrez, 2004; Perna & Burrows, 2005). Other water quality effects include higher sedimentation rates within the plant's complex root structure and higher evapotranspiration rates from water hyacinth leaves when compared to evaporation rates from open water (Gopal, 1987). Water hyacinth also has been found to stabilize pH levels and temperature in experimental lagoons, thereby preventing stratification and increasing mixing within the water column (Giraldo & Garzon, 2002). Photosynthesis is limited beneath water hyacinth mats, and the plant itself does not release oxygen into the water as do phytoplankton and submerged vegetation (Mironga *et al.*, 2011; Meerhoff *et al.*, 2003), resulting in decreased dissolved oxygen concentration. The extent of dissolved oxygen reduction is dependent on the capacity of the water hyacinth mat to prevent light infiltration into the water column.

Water hyacinth was associated with significantly lower concentrations of dissolved oxygen when compared to *Hydrilla verticillata* and *Sagittaria lancifolia L.* (Troutman *et al.*, 2007). Similarly, water hyacinth had lower dissolved oxygen concentrations when compared to *Myriophyllum spicatum*, *H. verticillata*, and *Potamogeton spp.*, and it was the only plant associated with average dissolved oxygen concentrations less than 5 mg L-1 (Toft *et al.*, 2003). Masifwa *et al.* (2001) found an inverse relationship between dissolved oxygen concentrations beneath water hyacinth mats and the distance to open water. The percent cover, or mat size, of water hyacinth that causes notable decreases in dissolved oxygen is not known but likely varies with the system. McVea and Boyd (1975) found that up to 25% cover of 0.04-ha experimental ponds did not cause dissolved oxygen to reach levels that threaten fish survival (less than 2mg l- 1, although they did find an inverse negative relationship between dissolved oxygen and water hyacinth cover.

Water hyacinth also absorbs heavy metals (Tiwari *et al.*, 2007), organic contaminants (Zimmels *et al.*, 2007), and nutrients from the water column (Aoi & Hayashi, 1996). In California, water hyacinth leaf tissue was found to have the same mercury concentration as the sediment beneath, suggesting that plant harvesting could help mediate mercury contamination if disposed of properly (Greenfield *et al.*, 2007). On a similar note, water hyacinth's capacity to absorb nutrients makes it a potential biological alternative to secondary and tertiary treatment for wastewater (Ho, 1994; Cossu *et al.*, 2001).

In a laboratory-based experiment designed to mimic nutrient conditions of Lake Chivero, Uganda, Rommens *et al.* (2003) tested water hyacinth's uptake capacity to absorb nitrate (NO_3), ammonium (NH_4), and phosphate (PO_4) from the water column.

The average water hyacinth plant absorbed 2.36 mg of ammonium, 1.13 mg of nitrate, and 0.39 mg of phosphate per kilogram of water hyacinth (wet weight) each hour. From a management perspective, these results could be used to estimate potential nutrient response in systems where water hyacinth has been introduced or where it has been removed.

Water hyacinth's uptake capacity has been validated in several field studies as well. It has a high nutrient uptake rate compared to other macrophytes (Rodríguez-Gallego *et al.*, 2004); therefore, it has the potential to significantly reduce nutrient concentrations in a water body depending on the extent of cover and density (Pinto-Coelho & Greco, 1999). Overall, nutrient uptake is thought to vary by season, with greater uptake in the summer when temperatures are higher and more favorable for plant growth (Rommens *et al.*, 2003; Rodríguez-Gallego *et al.*, 2004). Rommens *et al.* (2003) found that littoral sites with water hyacinth in Lake Chivero, Zimbabwe, had significantly less ammonium, nitrate, and dissolved oxygen (mg l-1) than limnetic sites or than littoral sites without water hyacinth; however, chlorophyll-a concentrations were higher in sites with water hyacinth. This may have been attributed to the ability of water hyacinth to trap existing phytoplankton and detritus, but it is unlikely that chlorophyll-a concentrations would remain high as water hyacinth density increased and light penetration decreased (Mironga *et al.*, 2011). Greenfield *et al.* (2007) found significantly higher total nitrogen and phosphorus in the water column following the shredding of water hyacinth.

Similarly, Marshall (1997) noted an increase in nitrogen and phosphorus after water hyacinth was controlled biologically in Lake Chivero during the 1990s; prior to control, water hyacinth covered 30% of the lake. Although there is potential for water hyacinth to provide phytoremediation in highly eutrophic systems (Rodríguez-Gallego *et al.*, 2004), the nutrient reductions would depend on the density of water hyacinth cover. Therefore, the net benefits of a phytoremediation approach would also depend on other impacts by water hyacinth. As previously discussed, biological respiration increases with increasing plant density and could lead to anaerobic conditions beneath water hyacinth mats. Moreover, upon senescence plants release nutrients back into the water column (Rodríguez- Gallego *et al.*, 2004), thereby negating the benefits of nutrient removal from highly eutrophic systems (Giraldo & Garzon, 2002).

Study Area

The Naivasha basin is situated in the Kenyan Rift Valley, about 80 km North West of Nairobi. The basin is located approximately between 0° 08' to 0° 55' S and 36° 00' to 36° 45' E. This part of the Rift Valley covers the three lakes of Nakuru, Elementeita and Naivasha to the south. The highest of the Rift Valley lakes, Naivasha (Figure 1) lies at about 1880 meter (6168 feet) above sea level, the lake level varies quite considerably - in 1926 it was reported to be 6 m higher. Lakes in the Rift Valley are normally saline unless water can escape through an outlet; however there is now no visible outlet to the Naivasha Lake. The supposition is that there is underground seepage maintaining the movement of fresh water brought into the lake by the Gilgil and Malewa rivers in the north.

The Lake consists of the main lake, a small separated Lake Oloidien and a smaller Crater Lake Sonachi. The total catchment of the lake is approximately 3200 km^2 (Morgan, 1998). The main lake (water surface) is approximately 120-150 km^2 plus 12 - 18 km^2 of swamp. LNROA (1996) reported that the lake has a mean depth of 4.7 m, with the deepest part at the Oloidien Bay (9 m) and around Crescent Island (17 m). In 1997 the mean depth of the lake was calculated at 3.8 m (Donia, 1998). Rupasingha (2002) have done the bathymetric survey during October 2001 and the result of calculated mean depth was 3.41 m at the level of 1886.38 m.a.s.l.

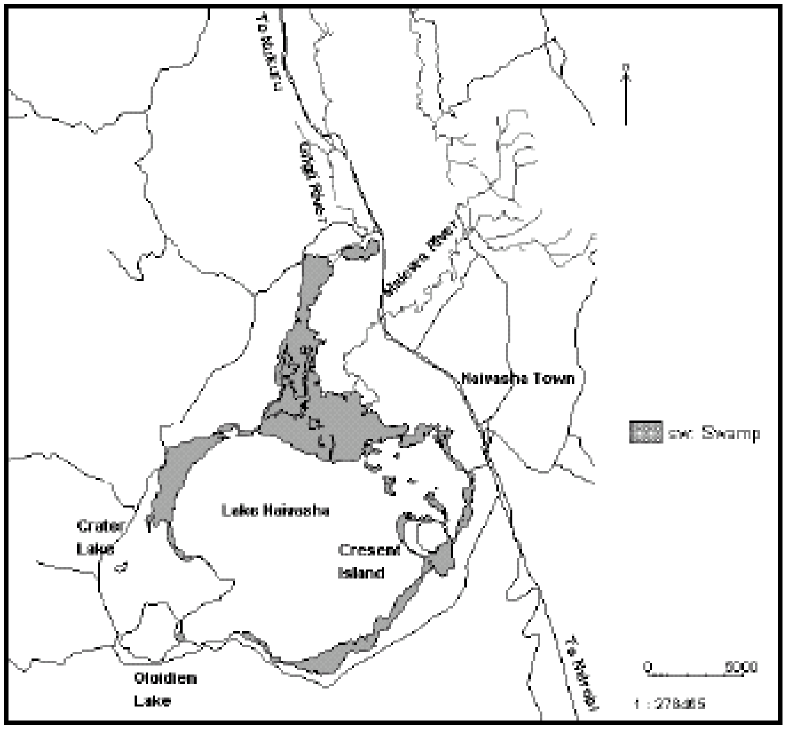

Figure 1: Lake Naivasha

The ecology of Lake Naivasha is forever changing (Harper and Muchiri, 1986). The changes are brought about by alien invasive floating aquatic weed species (*S. molesta, E. crassipes* and to a limited extent, *P. stratiotes*) among other factors. The weeds have infested the lake ecosystem in the last three decades, suppressed and occupied ecological niches previously inhabited by native flora such as papyrus and water lilies, and thus disrupted plant-animal-physical environment interactions and balance. The formation and movement of their floating mats have influenced the whole lake and even led to re-distribution of seral stages - in that plant succession no longer follows a predictable sequence as predicted by Guadet (1977) (Figure 2).

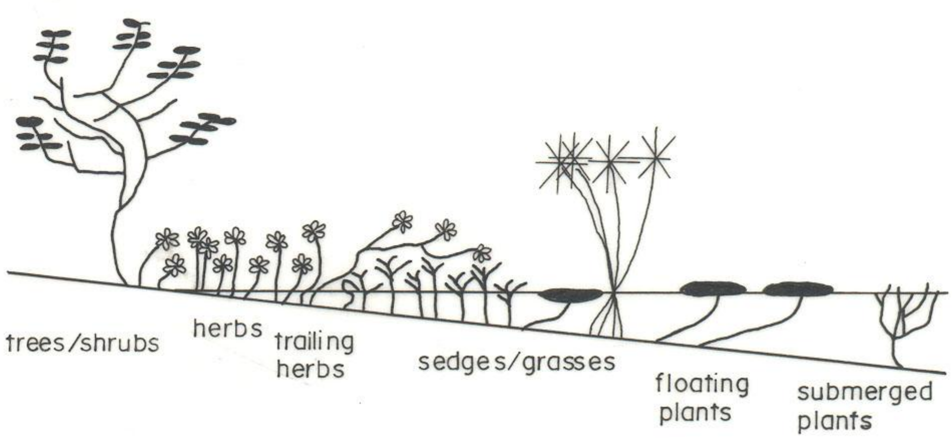

Figure 2: Hydroseral succession of plant species around the shore of Lake Naivasha in the 1970s after Gaudet (1977).

These floating aquatic weeds (FAWs) are known to affect water resource management, the continued existence of human, riverine and wetland communities, and conservation of biodiversity. Waterways can be blocked; level of floodwaters increased substantially, water loss increased through evapotranspiration and the efficiency of irrigation and hydro generation impaired. People are affected by a reduction in the fish catch, difficulties in travelling by boat and consequent isolation from water sources, gardens, markets and health services, and also change in populations of vectors of human and animal diseases.

Biodiversity can be reduced and conservation value affected. *E. crassipes, S. molesta* and *P. stratiotes* colonize open water at the margins of water bodies or occur as floating "islands". As the biomass increases, mats are formed, islands coalesce, and the infestation spreads to cover more open water. The area of an infestation will increase until prevented by wind and wave action. A dense cover of FAWs drastically reduces and may prevent light penetration of the water. Without light, phytoplankton and submerged plants cannot photosynthesize (Mironga *et al.*, 2011). Oxygen levels decrease and carbon dioxide increases with catastrophic effects on the aquatic fauna (Howard and Harley, 1998). The uptake of nitrogen and other nutrients by FAW may affect normal nutrient cycling by native plants, for example papyrus, and mineral elements will probably be immobilized (Terry, 1991 cited in Howard and Harley, 1998).

Methods

This study sought to examine how the presence of water hyacinth influences the physicochemical environment of Lake Naivasha. Sampling sites were selected to compare two environments namely one under the cover of stationary, floating fringes of water hyacinth and the second one without water hyacinth (open water). At each of these locations 10 sampling areas were randomly selected totaling 20. Ten sampling occasions were done at each of these sites. Triplicate sampling samples of physicochemical parameters were collected at each sampling area. Sampling was done between October 2003 and November 2004.

Collection of water samples

Water samples were collected directly from each sampling areas with 2mL plastic containers washed with nitric acid to remove any form of contaminants. These were stored immediately in a cooler in order to ensure that the physical properties of the water samples were maintained and transported to the laboratory for analysis.

Determination of physicochemical parameters

The following measurements were made:

- **Water temperature:** the temperatures of the sampling areas were determined using mercury-in-glass thermometer and reading taken.
- **pH:** Metrohm Herisau E520 pH meter was used for the pH measurement.
- **Dissolved oxygen:** dissolved oxygen concentration of the sampling areas was determined using Winklers titrimetric method (Mackereth, 1963). Water samples were collected in a 250 mL dissolved oxygen bottle below the surface of the water. Two milliter of manganous sulphate followed by 2 mL Potassium iodide (KI) solution were added to water samples in order to fix the oxygen. The bottle was carefully closed with a stopper to exclude air bubbles and mixed by thoroughly shaking the bottle. The formed precipitate was taken to the laboratory for analysis.
  In the laboratory, 2 mL of H_2SO_4 was added and the bottle shaken thoroughly to dissolve the precipitate. 10 mL of this solution was placed into conical flask and titrated against 0.0125 $Na_2S_2O_3.5H_2O$ (sodium thiosulphate solution) using 2 drops of starch solution as indicator. Dissolved oxygen (mgL^{-1}) was calculated as follows:

$$\textbf{DO } (mgL^{-1}) = \frac{\text{Vol. of } 0.0125\ Na_2S_2O_3.5H_2O\ (mL) \times 101.6}{\text{Volume titrated}}$$

- **Determination of free carbon dioxide:** water samples were collected using a 50 mL pyrex bottle. It was completely filled to leave no air space. The samples were siphoned into a 100 mL graduated cylinder and five to ten drops of phenolphthalein indicator was added. Titration was carried out into the cylinder with standard alkali solution and stirred gently until pink colour persisted for 30 seconds. A colour comparison is provided by adding 5-10 drops of phenolphthalein indicator to 10 mL $NaHCO_3$ solution in a similar graduated cylinder.

Calculations

$$CO_{2\ Mg/L} = \frac{V\ M\ 44{,}000}{\text{mL of sample used}}$$

Where, V = mL of Na_2CO_3 used for the titration of the sample
M = Molarity of the standard Alkali

- **Conductivity:** water sample conductivity was measured using HACH conductivity meter. This meter was standardized using distilled water and the probe inserted into the sample. The conductivity value was displayed on the meter and value recorded.
- **Turbidity:** turbidity was determined using Varian UV-Visible Spectrometer. The spectrometer was standardized with distilled water at a wavelength of 830 nm (infra red). Turbidity was then determined by reading value shown on the meter.
- **Nitrate-nitrogen (NO_3^-):** fifty milliliter of water sample was added into a flask, equivalent amount of Cl^- ion determined was added to the standard Ag_2SO_4 solution to remove any Cl^- that may interfere as AgCl precipitate. A clear sample of the water was then evaporated to dryness over a hot water bath.

The residue was then rinsed with 1 ml Phenol disulphonic acid reagent and was heated mildly to dissolve all solids. Ten milliliter of distilled de-ionised water was added, followed by 3 ml of concentrated ammonium hydroxide solution. The solution was then transferred to a 50 ml volumetric flask. Absorbance readings were taken at wavelength of 410 nm with SP_6-200 Spectrometer. Concentration of nitrate in water sample was deduced from the calibration curve.

Statistical analysis: water quality variables (pH, free carbon dioxide, dissolved oxygen, nitrates, and phosphates) from the two sampled habitats (with water hyacinth and open water) were compared by means of one-way analysis of variance (ANOVA).

Results

Water hyacinth infested areas and shoreline without water hyacinth in Lake Naivasha were sampled fortnightly between October 2003 and November 2004. This was carried out to examine the effect of water hyacinth infestation on the physico-chemical properties of the lake. From each of the two habitats (with water hyacinth and shoreline without water hyacinth) 10 sites were randomly selected totaling 20. The physicochemical parameters assessed in the study are as shown in Table 1. Values presented in this table are the averages of ten replicates taken form the different sampling sites around Lake Naivasha.

Table 1: Variations in water quality between water hyacinth infested and shoreline without water hyacinth areas in Lake Naivasha (October 2003 and November 2004.) Mean value ± S.E (n=10)

Parameter	Water hyacinth infested	Shoreline without water hyacinth	Probability level
Dissolved oxygen (mg L^{-1})	1.92±0.29	5.89±0.85	0.00•
Temperature (^0C)	27.16±0.64	26.7±0.52	0.281NS
pH	6.92±0.04	7.72±0.05	0.001
Turbidity	31.75±1.23	18.67±1.99	0.001
Conductivity (µs/ cm)	323.8±2.32	290.3±4.39	0.001
Total Nitrate (mg L^{-1})	6.91±1.09	12.36±1.07	0.01
Phosphate (mg L^{-1})	2.67±0.21	2.62±0.19	0.001
Chloride (mg L^{-1})	6.73±1.23	5.0±0.52	0.001
Total suspended solids (mg L^{-1})	92.48±4.00	12.36±1.07	0.01
Free carbon dioxide (mg L^{-1})	26.45±1.02	12.89±1.92	0.001

NS- not significant, p>0.05

Water temperature

Water temperature values in the water hyacinth infested areas were in the range of 25 to 30^{0}C, while in shoreline without water hyacinth temperature values ranged from 24 to 29^{0}C. Mean water temperature of the infested area (27.5±0.60^{0}C) was slightly higher than that of the shoreline without water hyacinth (26.7±0.52^{0}C). The analysis of variance showed that there was no significant difference between water hyacinth infested area and shoreline without water hyacinth area ($p>0.05$). This slight increase in temperature is as result of the dense mats of water hyacinth over the water surface, which blocks the exchange of heat between the lake surface and the atmosphere. At the same time the decaying of organic matter from water hyacinth results in heat generation and therefore the rise in temperature. These findings imply that water hyacinth mats may have a strong influence on the temperature fluctuations of Lake Naivasha.

Dissolved oxygen

The infested areas showed low values of dissolved oxygen in the range of 1.02 to 3.60 mg L^{-1}. The shoreline without water hyacinth had high concentrations of dissolved oxygen (1.96±0.71) while shoreline with water hyacinth had a mean of 5.89±0.85. These results when subjected to one-way ANOVA showed significant differences at 5% level between the values of the sampling areas. The fact that dissolved oxygen levels were lower in water hyacinth infested areas could be due to formation of the dense mat of water hyacinth and metabolic activities of epiphytic organisms in the lake. Based on these it can be deduced that water hyacinth dense mats has affected the aquatic biota of Lake Naivasha by reducing the levels of dissolved oxygen available to them. Therefore, the presence of water hyacinth implies continued decline in the levels of dissolved oxygen which will lead to low biodiversity in the lake.

pH

The values of the sampled areas are shown in Table 1. Water hyacinth infested area showed low pH values ranging between 6.7 and 7.1 (6.92±0.04), while shoreline without water hyacinth had higher values ranging from 7.4-7.95 (7.71±0.05) as shown in Table 5.6. ANOVA result showed that pH was significantly lower in water hyacinth infested area compared to shoreline without water hyacinth at 5% level.

Free carbon dioxide

Free carbon dioxide was higher in the water hyacinth infested areas with values ranging from 23.97-34.97 mg L^{-1} (26.45±1.02) mg L^{-1} when compared to shoreline without water hyacinth values which ranged between 3-20 mg L^{-1} (12.86±1.92) as shown in Table 1. One-way ANOVA results showed that free carbon dioxide values were significantly higher in water hyacinth infested areas than shoreline without water hyacinth ($p<0.05$). The high values of carbon dioxide in the water hyacinth infested areas were caused by the respiration process and decomposition or decay of water hyacinth tissues. At the same time it could be due to water hyacinth mats preventing entry of oxygen into the lake water. The findings imply that the oxygen demand of most aquatic organisms has been affected and for this reason only those vertebrates that depend upon aerial respiration (like water snakes) or those that can supplement air breathers (e.g. frogs) and air breathing fishes (e.g. *Clarias* sp.) can inhabit water hyacinth infested areas.

Conductivity

The range of values for the infested areas was between 314-338 µs cm^{-1} (328.8±2.32) while shoreline without water hyacinth values ranged between 270-312 µs cm^{-1} (290±4.39) as shown in Table 1. Analysis of variance showed that conductivity values in water hyacinth infested areas was significantly higher ($p<0.05$) than shoreline without water hyacinth. These results indicate that water hyacinth in Lake Naivasha is found in areas where there is mineralization and a high level of nutrients. Thus, water hyacinth proliferation in Lake Naivasha can profoundly be influenced from domestic, industrial and agricultural runoff.

Total suspended solids (TSS)

Turbidity fluctuations in water hyacinth infested and shoreline without water hyacinth areas. Infested areas showed high values of total suspended solids ranging between 75.40-112.22 mg L^{-1} (92.48±4.00) while shoreline without water hyacinth areas had lower value in the range 32.01-86.62 (54.0±5.85) as shown in Table 1. There was significant difference when these values of water hyacinth infested areas were compared to shoreline without water hyacinth area at 5% level. This is due to the fact that water hyacinth mats trap detritus and phytoplankton. The high level of turbidity as a result of suspended particles will therefore not favour the abundance of zooplankton organisms in Lake Naivasha. The role of zooplankton in the energy transfer from primary producers to organisms of higher trophic levels cannot be overemphasized.

Nitrate

Nitrate concentration values for water hyacinth infested areas ranged from 2.58-12.24 mg L^{-1} while shoreline without water hyacinth areas ranged from 9.02-19.26 mg L^{-1}. The mean value (6.91±1.09) of infested area was lower than shoreline without water hyacinth mean values (12.36±1.07). The analysis of variance revealed that nitrate concentration values of infested areas were significantly lower ($p<0.05$) than shoreline without water hyacinth (Table 1). This shows that water hyacinth took up nitrates from the lake water and this may potentially result in a significant impact on the concentrations and turnover rates of nutrients in Lake Naivasha.

Discussion

This study aimed to understand how the presence of water hyacinth had influenced the physico-chemical environment of Lake Naivasha ecosystem. The analysis of variance on the physicochemical parameters revealed that there was no significant difference with respect to temperature between water hyacinth infested and open water areas; however infested area had a higher temperature. This slight increase in temperature is a result of dense mats of water hyacinth over the surface, which blocks the exchange of heat between the water column and the atmosphere (Navarro and Phiri, 2000). Mehra *et al.* (1999) have also shown that floating water hyacinth mats may have a profound influence on the diurnal temperature fluctuation.

It was observed that from November 2003 to February 2004, the old leaves of water hyacinth turned brown and gradually started decaying but the mat remained intact with entangled root masses and trapped detritus, largely composed of dead hyacinth plants. This marked the onset of the flowering season for water hyacinth in the lake. Due to its great thermal inertia and decomposition, the thick root masses and detritus tended to damp temperature fluctuations in the infested water areas. Furthermore, the dense leaf canopy protected the water surface from direct sunlight. During the rainy season, the dense hyacinth mat gradually expanded with the shoreline area of water, allowing more penetration of sunlight in comparison to other seasons. For this reason both water areas showed more or less an isothermic condition during the rainy season.

The pH values were generally lower for most seasons in the infested portions of the lake than in the uninfested water areas. Average values of pH for all the seasons of the year were found to be low in the water hyacinth covered areas (average value of pH 7) in comparison to open waters (average pH 8). The water hyacinth plants can stand both highly acidic and highly alkalinic conditions, but more vibrant growth is supported by neutral water bodies (Gopal, 1987). According to Gopal (op. cit.), water hyacinth plants do not survive in water media with pH equal to or less than 4.0 and given that in Lake Naivasha the average value for all seasons is 7, this is one of the contributing factors as to why water hyacinth continues to proliferate.

In this study dissolved oxygen was found to be low under the mats of water hyacinth (1.96±0.71 mg/l) while in uninfested water areas it was fairly high with an average value of 13.8 mg/l. With the increase in temperature, profiles for dissolved oxygen under water hyacinth showed a decreasing trend, mainly because of the metabolic activity of epiphytic organisms. It remained low throughout dry seasons when the oxygen demand of most aquatic organisms (mostly poikilotherms) is greatest. Therefore most of the vertebrates found in the water hyacinth infested water areas were either purely dependent upon aerial respiration like water snakes or were supplemental air breathers such as frogs and air breathing fishes like *clarias sp* (Kasulo, 1999). Free carbon dioxide remained quite high in the lake in comparison to dissolved oxygen. It showed rather a constant level throughout the different seasons, except during the rainy season when it gave a maximum value in both the infested area and uninfested area (50 ppm in clear waters and 45 ppm in water hyacinth covered areas).

The high sustained levels of free carbon dioxide and comparatively much low dissolved oxygen levels recorded in this study reflect the nature of the physical and chemical environment of Lake Naivasha. According to Kasulo (1999) the water hyacinth mat effectively prevents the vertical diffusion of dissolved gases and plays a more important role in preventing the entrance of oxygen into the water than carbon dioxide going out, as the latter gas is highly soluble in water. The large biological input of carbon dioxide by the anaerobic decomposition of the decaying water hyacinth leaves or detritus on the bottom and within the mat, as well as the repeated respiratory activities of its inhabiting organisms, are responsible for the high sustained levels of this gas as reported by Mathooko (2000) in riverine ecosystems. Although some of the dissolved carbon dioxide is utilized in photosynthetic fixation by the water hyacinth (Robarts *et al.* 1982) or part remains unutilized. It can therefore be deduced that water hyacinth mats have altered the physico-chemical properties of Lake Naivasha and should be eradicated.

Phosphate and nitrate concentrations were found to be significantly lower under water hyacinth than elsewhere in the lake (average values were 2.67 mg L^{-1} for phosphate and 6.9 mg L^{-1} for nitrate). Water hyacinth took up nitrate preferentially to phosphate in the lake as indicated by the study's results. This was under the prevailing conditions and at the concentrations of nutrients in the lake during the sampling period. Further, the relative difference between nitrate concentrations at areas with water hyacinth and at sites without water hyacinth was larger than between phosphate concentrations at these sites.

Such a local decrease appears to be generally more pronounced in nutrient rich lakes, like was the case with the study area, than in oligotrophic lakes (Maine *et al.* 1999; Rodriguez and Betancourt, 1999). In comparison with early records of the water quality in Lake Naivasha presented by Adams *et al*. (2002) some marked differences with this study's measurements were noted: pH values in this study (averages ranging between 7.4 and 7.95) were much higher than in the earlier records (pH 7.1–7.2). Also nutrient levels increased drastically: NO_3-N values increased 10 -fold while PO_4-P values were about 20 – 25 times higher in this study. Only the ammonium levels in the littoral zone were similar to the earlier records, but the values in the limnetic zone were about 5 times higher. These drastic changes related to the ongoing eutrophication process that already occurred in the early nineties and were also reported by Kitaka (2000) and Mireri (2005).

The results of this study revealed that there was a high growth of the water hyacinth in all the sampled areas especially during the wet season. The reduction in phosphate and nitrate ion concentrations noted in areas covered with water hyacinth in this study was possibly due to the absorption of these ions by the water hyacinth present in the lake and therefore their consequent high growth rates. Ogunlade (1996) reported that water hyacinth has the ability to remove nutrients and heavy metals from aquatic environments. The selective uptake of these nutrients by water hyacinth was probably responsible for the increasing growth of water hyacinth (Ultseh, 1973). Thus, the total N and P nutrients stored in the water hyacinth could be more. However, water hyacinth was not analysed to ascertain the concentration of these nutrients on the plant. The total amount of nitrogen and phosphorus accumulated in the plant biomass is, however, usually low compared to those of the sediments and water column (Aoyama and Nishizaki, 1993). Furthermore, a net loss of phosphorus from the water column to the sediments is likely to occur due to sedimentation. Degradation of water hyacinth is hampered because of the low nutritional value of its tissue and the presence of a waxy-cutin resistant outer layer (Battle and Mihuc, 2000).

Although the nutrient uptake rate of water hyacinth is high compared to that of other macrophytes, which may potentially result in a significant impact on concentrations and turnover rates of nutrients in a lake (Pinto and Greco, 1999), the total impact on nutrient dynamics of Lake Naivasha is likely to be low. This is due to the small cover noted in this study (3.2% of the lake surface). This paper has thrown light on the physico-chemical properties of water hyacinth infested parts of Lake Naivasha. Biologically the presence of water hyacinth has been shown to lead to a condition of eutrophication; a process of low dissolved oxygen due to the respiratory activity of the masses of the roots of water hyacinth. The reduced dissolved oxygen creates an in-conducive environment for aquatic organisms and consequently leads to decrease in growth, fauna abundance and activity.

Recommendations

1. There is need for improvement of land use management in the catchment and along the rivers so as to reduce silt and nutrient loads as a mechanism for controlling the proliferation of water hyacinth. Agricultural development in the Lake Naivasha drainage basin and removal of lakeshore vegetation for horticultural development has contributed to the increase in runoff leading to increases in sediment load to the lake. This status was reflected in the measurements of turbidity of the lake waters done during the study period (Secchi disc transparency average measure of 5.5m). The degradation of the Lake Naivasha's catchment can be rehabilitated by planting trees like *Tarchonantus cambhoratus, Acacia drepanolobium* and indigenous grasses, like star grass that are common in the area. This can improve the quality of the land cover, grass availability and thus reduce surface runoff.
2. It is recommended that all stakeholders of Lake Naivasha be involved in water hyacinth control attempts. This is in cognizance of the fact that elsewhere the local communities have been involved successfully in the planning and implementation process of the water hyacinth control (Epelle and Farri, 1993; Greathead and de Groot 1993). The local riparian communities of Lake Naivasha need to be made aware of the process of biological control, recognition of the biological control agents and their impact, and when and how to distribute infested plants to new areas which lack biological control agents.
3. The management and control of water hyacinth in Lake Naivasha should involve a multidisciplinary approach and should be designed in a way that the highest political and administrative levels recognize the potential seriousness of weed infestation. Researchers should come out with safer herbicides and carry out post release assessment studies on bio-agents.
4. Enlightenment campaigns should be carried out to sensitize and mobilize riparian communities on the impact of water hyacinth infestation in Lake Naivasha. This will ultimately raise the consciousness of the people on the dangers inherent on transferring water hyacinth to another water body or using it as ornamentals.

The enlightenment campaign should involve all stakeholders who are involved with the management of Lake Naivasha. There is a need for strengthening collaboration efforts in the management and control of water hyacinth among the Ministries and Institutions responsible in Kenya.

5. There is need to promote efficient farming practices around Lake Naivasha in order to guarantee safe use and disposal of agro-chemicals. The members of the Lake Naivasha Growers Group (LNGG) should be sensitised and encouraged by the National Environmental Management Authority (NEMA) through enforcement of EMCA 1999 Act (GoK, 2000) to carry out environmental impact assessments on their activities so as to have best practises in their farms. The members of LNGG need to be advised by NEMA on the means for environmental emergency plan to prevent against mismanagement of fertilizer applications. Other issues of concern are metering of targeted fertilizer application through drip feed, and delivery only of sufficient nutrient as determined by soil condition as a strategy both for reducing chemical costs and preventing leakage to the Lake Naivasha ecosystem.

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