The effect of water Hyacinth, *Eichhornia Crassipes,* infestation on phytoplankton productivity in Lake Naivasha and the status of control

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Abstract

The paper presents data collected in an assessment of effects of water hyacinth infestation on phytoplankton productivity in Lake Naivasha. A summary of the status of control and strategies for the future is given. The ecological effects of water hyacinth, Eichhornia crassipes, on Lake Naivasha have received little attention compared to the large body of work available on the weed's socioeconomic impact on the country's water ways and methods for its removal. This study was conducted to determine if water hyacinth infestation in Lake Naivasha affects phytoplankton productivity. Several sampling stations were set up in the lake at sites where the floating mats of the weed were present and sites where the weed was absent. Phytoplankton chlorophyll-a concentration and dissolved oxygen were measured at each station and used as proxies for phytoplankton productivity. The study findings show that phytoplankton productivity is reduced when water hyacinth is present, suggesting that the water hyacinth is not only a nuisance but that it can also alter the ecology within a lake by changing species composition and biodiversity. Although water hyacinth has continued posing serious ecological consequences, there is hope that the control strategies already adopted will continue to reduce deleterious impacts and allow sustained development in the Lake Naivasha Basin. There is, however, a great need to undertake research to quantify the levels of damage, and the costs of control, loss of livelihood, disease, and disruption of normal operations caused by water hyacinth.

Key words: Water hyacinth, Ecological Effects, Phytoplankton

Introduction

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms. - Laubach (Figure 1) is considered one of the world's worst water weeds (Holm *et al*., 1977), invading lakes, ponds, canals, and rivers. It was introduced into many countries during the late 19th and early 20th centuries, where it spread and degraded aquatic ecosystems. It has such a high growth rate that, according to Ntiba *et al.,* (2001), it can double its area in only five days. It is still rapidly spreading throughout Africa, where new infestations are creating life-threatening situations as well as environmental and cultural upheaval (Cock *et al*., 2000).

The water hyacinth first appeared in Lake Naivasha, in 1988. It subsequently spread throughout the entire lake but was particularly prevalent in northern shallow inshore waters. The present-day cover by water hyacinth has remained relatively stable. It usually forms a narrow fringe 5-15 meters wide around much of the lake. *Eichhornia crassipes* remains the world's most problematic water weed despite widespread and various approaches to its control (Heard & Winterton, 2000). Its control at Lake Naivasha has focused upon biological control measures with the introduction of the Eichhornia weevil (*Neochetina spp.*) in the late 1990s. Because the enormous floating mats of the weed interfered with boat navigation, fishing, and even clogged up irrigation canals around the lake (Adams *et al*., 2002), much of the attention devoted to the water hyacinth in the literature has been concerned primarily with its socio-economic impact and methods for eradicating it from the lake. In contrast, fewer studies have focused directly on its ecological effects. It is known, however, that mats of water hyacinth reduce light to submerged plants, thus depleting oxygen in aquatic communities (Ultsch, 1973). The conditions under the water hyacinth mats are highly anoxic because of dead plant matter (Ntiba *et al*., 2001). The resultant lack of phytoplankton (McVea & Boyd, 1975) alters the composition of invertebrate communities (O'Hara, 1967; Hansen *et al*., 1971), ultimately affecting fisheries. Drifting mats scour vegetation, destroying native plants and wildlife habitat. Water hyacinth also competes with other plants, often displacing wildlife forage and habitat (Gowanloch, 1944). Higher sediment loading occurs under water hyacinth mats due to increased detrital production and siltation. In addition, the roots of the water hyacinth have been found to provide new habitat for gastropods that are intermediate hosts of the waterborne parasite that causes schistosomiasis (Masifwa, 2001).

Water hyacinth is known to cause a reduction on productivity of a lake's phytoplankton since the weed mats shade out any photoautotrophs (both phytoplankton and also submersed macrophytes) beneath them (Scheffer *et al*., 2003). The calming of the water by the floating mats reduces upwelling of nutrients from the sediments by wind action, making them less available to phytoplankton in the photic zone, and large aggregations of *Eichhornia crassipes* rapidly remove nitrogen and phosphorus from the water column (McVea & Boyd, 1975), out competing the phytoplankton for these vital nutrients. Exploitative competition among aquatic plants occurs for limiting resources, e.g. light, nutrients and suitable substrates (Barrat-Segretain, 1996). In addition to competition for limiting resources, aquatic plants sometimes compete with allelopathy, i.e. actively suppressing their neighbours by release of chemical compounds (Gopal & Goel, 1993). Novel mechanisms of competition, such as allelopathy, can affect native plants to a much larger extent than the alien's natural competitors (Callaway & Aschehoug, 2000). There is evidence of allelopathy by water hyacinth on phytoplankton (Yang *et al*., 1992).

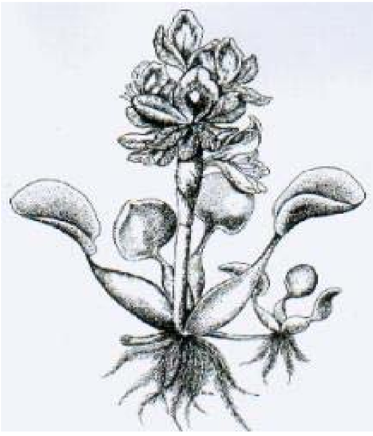

Figure 1. Water hyacinth.

The study findings show that phytoplankton productivity is reduced where water hyacinth is present in the lake. This is discussed in the context of water hyacinth altering the ecology of Lake Naivasha by changing species composition and biodiversity. In addition the current control strategies being used to combat water hyacinth are reviewed. There is, however, a great need to undertake research to quantify the levels of damage, and the costs of control, loss of livelihood, disease, and disruption of normal operations caused by water hyacinth in Lake Naivasha.

Study area

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

There are four, chemically distinct, basins at Naivasha (Gaudet & Melack, 1981). Crescent Island Basin, a small extinct volcanic cone, is the deepest part of the lake (up to 18m depth) and is half submerged and usually connected to the main lake over a shallow lip. The main lake has a maximum depth of 6m at its southern end. Oloidien is a smaller crater lake with a depth of 5m to the south end of the main lake, which has been distinct from it since 1982, increasing in conductivity from 250 to 3000µS cm^{-1} in this time. Crater Lake or Sonachi is located on the southwestern part of the lake and, in its own distinct volcanic crater, is a soda lake, fully independent from the main lake but its levels are believed to oscillate in harmony with the main lake as a result of groundwater connection. Table 1 illustrates some of the characteristics of the four water bodies.

Table 1. Water bodies characteristics.

Water body	* Area (Km^2)	* Volume ($m^3 \times 10^6$)	Mean depth (m)	Maximum depth (m)
Lake Naivasha	145	680	4.7	7.3
Basin	2.1	23	11.0	17.0
Oloiden	5.5	31	5.6	6.1
Sonachi	0.6	0.62	3.8	6.1
Crescent Island				

(* Area and volume will depend on the lake level) Source: Melack (1976) cited in Goldson, (1993)

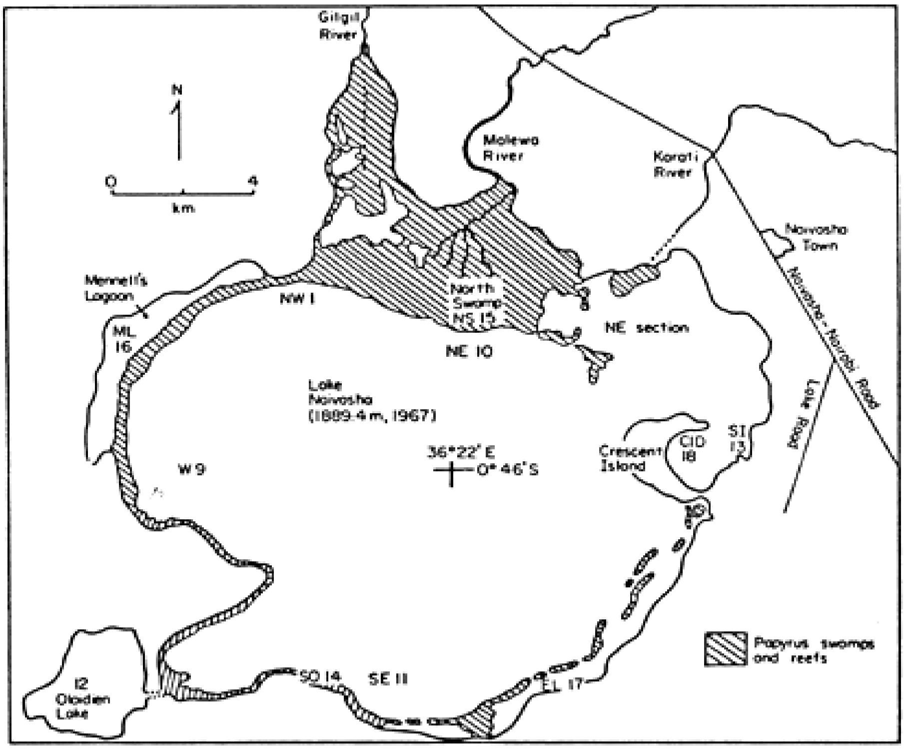

Figure 2. Lake Naivasha.

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

Materials and methods

The study was conducted during the rain season in April 2004. Sampling took place in the lake at ten sites in a monitoring program previously established by the Kenyan Marine and Fisheries Research Institute, five of which were covered by the water hyacinth. Those stations that had no water hyacinth were used as controls. Chlorophyll-a concentrations and oxygen concentrations were measured at each station two times per week in the morning and in the evening for a total of five weeks. Chlorophyll-a concentrations were used as a proxy for phytoplankton production. As per Lung'ayia *et al*., (2000), 0.5 ml saturated magnesium carbonate ($MgCO^3$) suspension was added to water samples of 50-500 ml and then the samples were immediately filtered through glass fiber filters. The filters were then extracted in cold 90% acetone for 18 to 24 hours. Dissolved oxygen at the surface was ascertained through Winkler titration as in Hecky *et al*., (1994). A Hydrolab SVR-II profiling system, calibrated with the surface dissolved oxygen (DO) measured through Winkler titration was used to measure DO at depths of zero, 1, and 2 m at the shallower stations 1, 2, 3, 4, and 5 and at 5 meter intervals at station 6, 7, 8, 9 and 10 which was considerably deeper. The concentrations for each depth at each station were averaged at the end of the five weeks and the standard deviation for each was calculated.

Results

Impact of water Hyacinth on Phytoplankton productivity

Average surface chlorophyll-a concentrations at stations 1, 2, 3, 4 and 5, the stations with water hyacinth mats, were 4.6, 3.8, 5.0, 11.2, and 9.3 mg•m^{-3}, respectively. At the stations that were free of the water hyacinth, stations 6, 7, 8, 9 and 10, mean surface chlorophyll-a concentrations were 15.1, 14.6, 15.2 13.4, and 16.8 mg•m^{-3}, respectively (Figure 3). Mean dissolved oxygen concentrations at the stations under floating *Eichhornia* mats, sites 1, 2, 3, 4, and 5, were consistently lower than at control stations 6, 7, 8, 9 and 10 (Table 2).

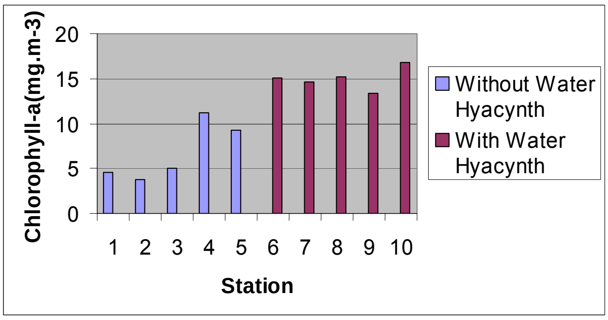

Figure 3. Bar graph of surface chlorophyll-a concentrations given in mg•m^{-3} at each station in Lake Naivasha. Lower chlorophyl-a concentrations were measured at the stations with *Eichhornia crassipes* cover, indicating lower productivity.

Table 2. Mean dissolved oxygen concentrations for each station at different depths.

Depth(m)	**Stations**									
	1	2	3	4	5	6	7	8	9	10
0	3.30	6.62	3.10	4.04	6.76	7.16	6.8	8.9	6.1	6.3
5	2.6	2.8	1.89	2.24	2.43	4.40	6.6	7.16	6.8	6.14
15	1.8	4.33	1.34	1.12	2.2	2.6	2.8	3.2	3.1	3.6

Water Hyacinth control strategies in lake Naivasha

Although water hyacinth has continued posing the above discussed impact on the phytoplankton productivity in Lake Naivasha basin, there is reason to hope that the control strategies adopted will eventually permit effective management of the weed.

Biological control

Since 1996, Kenya Plant Health and Inspectorate Services allowed KARI to import adult *N. bruchi* and *N. eichhorniae* from Uganda, South Africa and Australia for the biological control of water hyacinth in Lake Naivasha (Table 3). KARI established a second weevil rearing facility in December 1996, at the National Fibre Research Centre (NFRC), Kibos, near Lake Victoria. 'Breeding stock' for the Kibos rearing facility was obtained from the quarantined mass rearing facility at the National Agricultural Research Centre, Muguga, near Nairobi. The breeding material consisted of mature adult *Neochetina* weevils and host plants inoculated with weevil eggs. Later, adult *Neochetina* weevils were imported from Uganda for mass rearing. Julien *et al*., (1999) describe in detail rearing and harvesting techniques for *Neochetina* weevils from plastic tubs, rearing pools and galvanized corrugated iron sheet tanks, all of which have been in use at the Kibos rearing facility.

Table 3. Importations into Kenya of *Neochetina* weevils for biological control of water hyacinth in Lake Naivasha and Victoria.

Species	Year imported	Number	Purpose	Source
Neochetina bruchi	1996	1300	Mass rearing	Uganda
	1997	2000	Mass rearing/releases	Australia
	1998	1000[a]	Releases	South Africa
Neochetina eichhorniae	1997	5000	Mass rearing/releases	South Africa
	1997	2000	Mass rearing/releases	Australia
	1998	1000	Releases	South Africa
Total		12,300		

[a]Batch did not survive

From December 1996 to December 1999, the Kibos rearing facility and community rearing facilities produced approximately 100,000 adult weevils, of which 25,000 were for ‘breeding stock’ and for releases in Lake Naivasha. Between January 1998 and December 1999, approximately 23,200 adult weevils were released at several sites in Lake Naivasha.

Monitoring the establishment and spread of *Neochetina* weevils

Visual observations and pre and post-release sampling protocols have been used to monitor and evaluate the establishment, spread and impact of the *Neochetina* weevils on water hyacinth in Lake Naivasha. Weevils are now fairly established in all affected areas and have spread several metres from points of release. These natural enemies on the weed have been observed to have a significant impact and localised complete suppression of resident water hyacinth mats has been recorded at some sites some years after release Importation and mass rearing of additional biological control agents, the moth *Niphograpta albiguttalis* (previously called *Sameodes albiguttalis*) and mite *Orthogalumna terebrantis,* was attempted, but these did not establish well.

Evaluation of the impact of *Neochetina spp.* weevils on water hyacinth

In general, post-release sampling data collected (November 2003 to May 2004) at four selected release sites in the lake, indicated a suppression of plant growth parameters (fresh weight, leaf laminar area and leaf length) and substantial increases in number of feeding scars and adult weevils per plant. Fresh weight reduction was noted at a single site, mouth of River Malewa. Leaf length reduction was noted at two sites, while leaf laminar area reduction was evident at Hippo point and Crescent. The number of feeding scars and adult weevils per plant increased at all sites.

Estimations of weevil populations

Post-release sampling of water hyacinth at six selected sites in the lake (May–December 2004), gave a combined mean number of 6.0 *Neochetina* weevils per plant, with actual number of weevils per plant ranging from 0 to 32. *N. bruchi* was the dominant of the two weevil species, accounting for 73.3% of the total weevil population.

Physical control

Manual removal

The fisher-folk communities around Lake Naivasha have identified key sites for manual removal. These include fish-landing beaches, ports and piers, irrigation canals and water supply points and sources. Fish landing beaches in most of the affected areas are the prime targets for manual removal operations.

Mechanical control

Mechanical control operations are not common in Lake Naivasha and have so far consisted solely of chopping and dumping of the chopped pieces of water hyacinth and other weeds into the lake. Regrowth of the chopped weed is likely to take place, especially if most of the natural enemies are destroyed during chopping. In addition, shallow areas of the lake are likely to fill up with vegetation, especially along the shoreline, leading to drying up and subsequent reduction in the size of the lake. The future of mechanical control options in Lake Naivasha should be reassessed.

Ecological succession

Ecological succession (progressive displacement of one or more species of plants by other species) has made a significant contribution to the control of stationary mats of water hyacinth along the shores and banks of rivers entering Lake Naivasha. In the lake, pure mats of water hyacinth were invaded initially by aquatic ferns/ sedges (*Cyperus papyrus* and *Ipomea aquatica*) often to be followed by hippo grass (*Vossia cuspidator*) which invariably eventually started dominating and shading out the stressed and dying/rotting water hyacinth. By November 2004, stunted and disintegrated mats of water hyacinth and invading weed succession were clearly evident. Although water hyacinth will be a permanent feature in Lake Naivasha, currently hippo grass and not water hyacinth might form the dominant weed. The hippo grass is expected to die once the nutrients from dying water hyacinth are depleted.

Discussion and conclusion

Impact of Water Hyacinth on the Phytoplankton productivity

Invasions of water hyacinth have become a nuisance worldwide (Drake and Mooney, 1989). Originally perceived as a practical problem for fishing and navigation, water hyacinth is now considered as well a threat to biological diversity, affecting fish faunas, plant diversity and other freshwater life and the food chains, which depend upon it (Luken & Thieret, 1997).

Due to its physical presence water hyacinth greatly blocks sunlight and oxygen exchange and hence prevents growth of emersed and submerged plants. As a result, submerged macrophytes are scarce or absent in Lake Naivasha, while floating species dominate the macrophyte community in the littoral zones of the lake. Before the expansion of water hyacinth in the lake, submerged and rooted floating-leaved macrophytes were common in shallow parts (Gaudet, 1977). The loss of submerged macrophytes is dramatic as they have an important structuring and regulating role in the ecosystem: they stabilize the sediment (reduction of turbidity), compete for nutrients with phytoplankton; they increase the sedimentation rate and provide shelter from planktivorous predators for zooplankton species (Jeppesen *et al*., 1997).

The presence of the water hyacinth in Lake Naivasha has so far affected the productivity of the phytoplankton. Lower chlorophyll-a at the stations with the water hyacinth present indicates lower productivity by the phytoplankton in the water column. Dissolved oxygen was also reduced under the water hyacinth mats. This indicates reduced production by the phytoplankton and increased bacterial respiration from increased organic matter produced by the macrophytes (Voulion, 2004). The trend that Talling noted (1957), that chlorophyll concentrations are higher nearshore than offshore, is still evident in the water hyacinth free sites in Lake Naivasha. At all sites that were relatively deep there was a persistence of the hypolimnetic anoxia that Talling (1957) observed in his study. Dissolved oxygen at these deep stations averaged 1.79 mg O2•liter-1.

The reduced phytoplankton productivity in the presence of water hyacinth can be the result of a combination of factors, the most evident being the shade created by the floating mats (Rommens *et al*., 2003). McVea and Boyd (1975) found that water hyacinth mats hinders phytoplankton photosynthesis by shading out the algae. In addition, water hyacinth may be a better competitor than phytoplankton for limiting nutrients; in McVea and Boyd (1975), both phosphate and total phosphorus in the water column were quickly reduced once a small number of the floating plants established themselves, depriving the phytoplankton of this crucial nutrient and inhibiting their growth. Yang *et al*., (1992) found that water hyacinth can exhibit allelopathic effects on algae, biosynthesizing three kinds of algaecidal compounds in its roots and secreting them into the water to inhibit algal growth. They emphasize that the three compounds have a higher antialgal activity than the common algaecide $CuSO_4$ (Yang *et al*., 1992; Callaway & Aschehoug, 2000)). As a result of decreased phytoplankton production, McVea and Boyd (1975) observed a decline in the numbers of phytoplanktivorous fish in the small ponds that they studied. The effects of decreased algal productivity in Lake Naivasha could therefore extend all the way up to the piscivorous fish species at the top of the food web, and could pose a threat to the lake's fishery if the water hyacinth continues to thrive.

This study recommends that there is need for more research work to be done to understand why algal productivity decreases with water hyacinth cover in Lake Naivasha. This should be supported by other studies to measure total phosphorus and phosphate under the water hyacinth mats in order to confirm if the phytoplanktons are deprived of these nutrients by water hyacinth plants as stated in McVea and Boyd (1975). Finally, new surveys should be designed to do species counts to ascertain which kinds of phytoplankton persist in Lake Naivasha under the water hyacinth mats for similar studies elsewhere indicate that blue-green algae give way to Chlorophyta under water hyacinth cover (Yang *et al*., 1992).

Biological control of Water Hyacinth in lake Naivasha

Importation of additional biological control agents, the moth *Niphograpta albiguttalis*, the mite *Orthogalumna terebrantis* and the hemipteran bug *Eccritotarsus catarinensis*, to augment biological control efforts by *Neochetina* weevils, is recommended. Rearing pools, which are easier to manage and have a larger capacity, are preferred to be established near the lake. Releases on floating mats assisted in the redistribution and spread to non-release sites. Wind and water currents were responsible for the spread of weevils on floating mats of water hyacinth. Under the environmental conditions of Lake Naivasha, weevils established fairly slowly.

Ecological succession of water hyacinth by emergent plant species, mainly papyrus (*Cyperus papyrus*) and hippograss (*Vossia cuspidata*), has been noted. This phenomenon has also been observed in Lake Kyoga, Uganda, following the successful biological control of water hyacinth by Neochetina weevils (Julien *et al*., 1999). However, this is short-lived and the secondary vegetation will disappear after the degraded hyacinth substratum supporting it eventually sinks. The long-term approach to water hyacinth management should focus on curbing the discharge of effluents into Lake Naivasha from surrounding urban settlements, agricultural and industrial activities.

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