

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 the effects of water hyacinth (*Eichhornia crassipes*) infestation on phytoplankton productivity in Lake Naivasha. A summary of the status of control and strategies used is given. The ecological effects of water hyacinth on the lake have received little attention compared to the large body of work available on the weed's socioeconomic impact. This study was conducted to determine the effect of hyacinth infestation on the phytoplankton productivity. Several sampling stations were set up in the lake at sites containing floating mats of the weed and at 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 findings show that phytoplankton productivity in weed covered areas is reduced with significant change in species composition and biodiversity suggesting that water hyacinth can alter the ecology of the lake. Although water hyacinth has continued posing serious ecological consequences, the control strategies already adopted will continue to reduce deleterious impacts and allow sustained development in the Lake Naivasha Basin. There is need however to undertake research to quantify the level of ecological damage and the costs of control. There are other effects such as livelihood loss, diseases, and disruption of normal operations that also need to be quantified.

Key words: Water hyacinth, ecological effects, phytoplankton.

1. Introduction

Water hyacinth, *Eichhornia crassipes* (Mart.) Solms-Laubach (Fig. 1) is considered one of the world's worst weeds [1], 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 a very high growth rate that according to Ref. [2], 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 [3].

The water hyacinth first appeared in Lake Naivasha, in 1988. It subsequently spread throughout the entire lake but was particularly prevalent in the northern

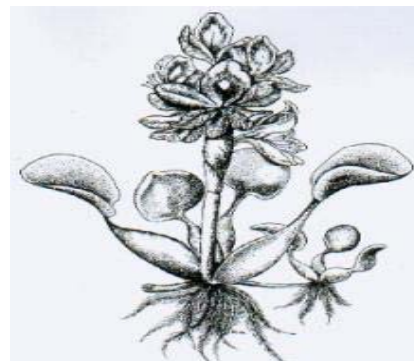


Fig. 1 Water hyacinth.

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shallow inshore waters. The present-day water hyacinth cover 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 [4]. Its control at Lake Naivasha has focused on 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 [5], 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. 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 [6]. The conditions under the water hyacinth mats are highly anoxic because of dead plant matter [7]. The resultant lack of phytoplankton [8] alters the composition of invertebrate communities [9, 10], 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 [11]. 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 [12].

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 [13]. 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 [8], out competing the phytoplankton for these vital nutrients. Exploitative competition among aquatic plants occurs for limiting resources, e.g. light, nutrients and suitable substrates [14]. In addition to competition for limiting resources, aquatic plants sometimes compete with allelopathy, i.e. actively suppressing their neighbours by release of chemical compounds [15]. Novel mechanisms of competition, such as allelopathy, can affect native plants to a much larger extent than the alien's natural competitors [16]. There is evidence of allelopathy by water hyacinth on phytoplankton [17].

The study reviews how the phytoplankton productivity has been affected by the presence of water hyacinth in Lake Naivasha. 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.

2. Study Area

Lake Naivasha (1886 metres above sea level–2002 level) is a Ramsar site of wetlands of international importance (Kenya 1KE002-1995). It is located in a trough between Eburru and Olkaria/Longonot volcanic massifs centred at 00°46'S, 36°22'E. The lake is at the highest part of the Rift Valley floor, from where the floor slopes towards the south and north, attaining low altitudes at Lake Magadi (600 metres above sea level) to the south, and Lake Bogoria (985 metres above sea level) to the north of the area. The Lake (Fig. 2) currently covers approximately 134 km². It is the second-largest freshwater lake in Kenya (after the Kenya portion of Lake Victoria). It is one of a series of 23 major lakes in the Eastern Rift Valley system-eight in central Ethiopia, eight in Kenya and seven in Tanzania—spanning the latitudes approximately 7° N to 5° S. Within the Kenyan series from North to South are

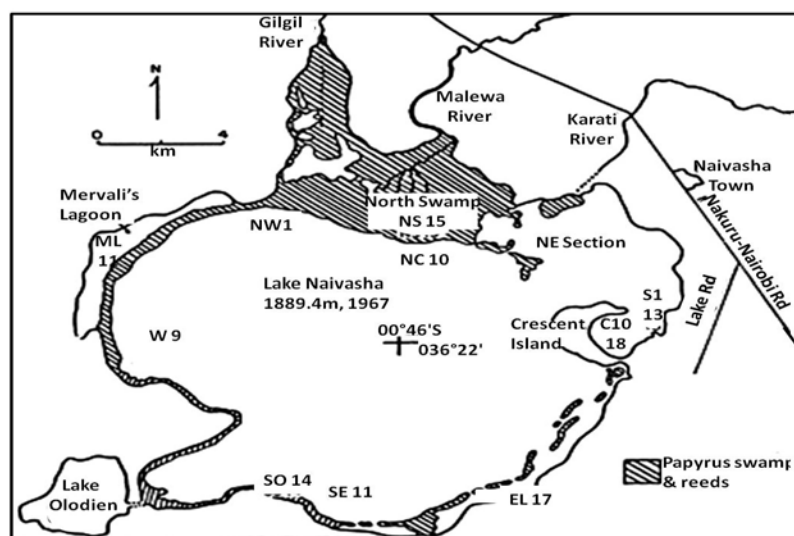


Fig. 2 Lake Naivasha.

lakes Turkana, Baringo, Bogoria, Nakuru, Elmenteita, Naivasha and Magadi. The overall climate of Eastern Rift Valley is semi-arid with most of the lakes being alkaline. Lake Naivasha is unique within the central latitudes of the Kenyan Rift Valley with it being fresh with a conductivity fluctuating between 250-450 $\mu\text{S}\cdot\text{cm}^{-1}$.

Lake Naivasha has four chemically distinct basins [18]. Crescent Island Basin (18 m deep), a small extinct half submerged volcanic crater, is the deepest part of the lake. It is connected to the Main Lake over a shallow lip. The Main Lake has a maximum depth of 6 m at its southern end. Lake Olodien occupies a crater like structure at the southern end of the Main Lake and although up to 1982 it had been connected to it and has since been cut off. Its conductivity has since increased to 3000 $\mu\text{S}\cdot\text{cm}^{-1}$ on account of high levels of alkalinity. The fourth basin is the Crater Lake or Lake Sonachi which is located on the southwestern part of the lake in a distinct volcanic crater 15 m above the Main Lake. The lake 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.

Since the early 1990s, the lake has become eutrophic. Its phytoplankton has showed a seasonal shift between

Table 1 Water bodies characteristics.

Water body	*Area (km ²)	*Volume (m ³ × 10 ³)	Mean depth (m)	Maximum depth (m)
Lake Naivasha	145	680	4.7	7.3
Basin	2.1	23	11.0	17.0
Oloidien	5.5	31	5.6	6.1
Sonachi	0.6	0.62	3.8	6.1
Crescent Island	1.2	10	2.6	8.0

* Area and value depend on the lake level. Source: Ref. [19].

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 [20]. The concentrations of chlorophyll-a have increased from 30 $\mu\text{g}\cdot\text{L}^{-1}$ in 1982 to 110 $\mu\text{g}\cdot\text{L}^{-1}$ in 1988, and 178 $\mu\text{g}\cdot\text{L}^{-1}$ in 1995 and transparency has correspondingly declined to about 60 cm (but briefly rose to 160 cm in 1998-1999 due to the diluting effect of the "El Niño" rains) [21]. 170 algal and cyanobacterial species have been identified [22]. 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 [22]. The sediments form a sink for phosphorus [23], because they are rich in iron [24] and the main lake is well mixed and does not deoxygenate enough to release 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 [22]. Harper et al. [23] 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 emphasizes 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 Olodien and Sonachi lakes are highly productive and *Arthrospira fusiformis* is significant in the latter.

3. 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 a 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 shown in Ref. [25], 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 Ref. [26]. 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 0, 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.

4. Results

4.1 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 $mg \cdot m^{-3}$, 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 $mg \cdot m^{-3}$, respectively (Fig. 3). Mean dissolved oxygen concentrations at the stations under floating *Eichhornia* mats in sites 1, 2, 3, 4, and 5 were consistently lower than at control sites 6, 7, 8, 9 and 10 (Table 2). Lower chlorophyll-a concentrations were measured at the stations with *Eichhornia crassipes* cover, indicating lower productivity.

4.2 Water Hyacinth Control Strategies in Lake Naivasha

Although water hyacinth has continued to 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. Since 1996, Kenya Plant Health and Inspectorate Services allowed Kenya Agricultural

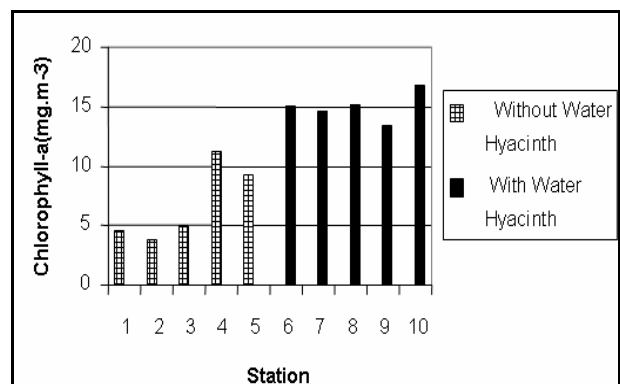


Fig. 3 Bar graph of surface chlorophyll-a concentrations given in “ $mg \cdot m^{-3}$ ” at each station in Lake Naivasha.

Table 2 Mean dissolved oxygen concentrations for each station at different depths (mg·L⁻¹).

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

Research Institute (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. The “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. [27] described 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.

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 to Lake Naivasha. Between January 1998 and December 1999, approximately 23,200 adult weevils were released at several sites in Lake Naivasha.

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 localized 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, such as the moth *Niphograpta albiguttalis* (previously called *Sameodes albiguttalis*) and mite *Orthogalumna terebrantis*, was attempted, but these did not establish well.

4.2.1 Evaluation of the Impact of *Neochetina* spp. Weevils on Water Hyacinth

A sampling protocol for the evaluation of the impact of the *Neochetina* weevils on water hyacinth in Lake Naivasha developed by KARI was used in this study. A quadrat (0.5 m²) was placed randomly on mats of water hyacinth from selected sites (Table 4). For each of 10 randomly selected plants per quadrat, the following parameters were recorded: fresh weight, leaf lamina area, petiole length, percentage and

Table 3 Importations into Kenya of *Neochetina* weevils for biological control of water hyacinth in Lake Naivasha and Victoria (source: Ref. [27]).

Species	Year imported	Number	Purpose	Source
<i>Neochetina bruchi</i>	1996	1300	Mass rearing	Uganda
	1997	2000	Mass rearing/releases	Australia
	1998	1000 ^a	Releases	South Africa
<i>Neochetina eichhorniae</i>	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.

Table 4 Impact of weevils on water hyacinth at six sites in Lake Naivasha, May-December 2004.

Site	Fresh weight (g)	Leaf length (cm)	Laminar area	Feeding scars	Weevils/plant
Elsamere	1685 ± 958	132.2 ± 14.9	195.4 ± 9.7	2.5 ± 1.9	0.4 ± 1.4
Oloidien	3550 ± 1755	77.8 ± 23.0	110.2 ± 12.5	100.3 ± 9.6	1.8 ± 2.6
Hippo Point	2270 ± 935	162.9 ± 16.5	178.6 ± 0.7	2.5 ± 2.1	0.2 ± 0.6
Western shores	251 ± 128	19.9 ± 4.8	49.0 ± 5.0	19.4 ± 6.9	0.4 ± 0.5
North swamp	2510 ± 127	100.3 ± 33.1	124.8 ± 13.1	268.3 ± 52.4	6.0 ± 3.0
Fisherman's camp	482 ± 271	31.3 ± 15.8	74.6 ± 12.8	138.8 ± 28.3	4.5 ± 3.9

At all other sites n = 10.

number of petioles with larval mines, number of feeding scars and number of adult weevils per square metre (mean number of weevils per plant × number of plants·m⁻²). The objectives of the sampling were to confirm the presence of the growth stages of the weevils (larvae, pupae and adults), to quantify the damage due to larvae and adults on the plants and to evaluate the impact of weevil on water hyacinth in Lake Naivasha.

In general, the data collected (November 2003 to May 2004) at six selected release sites in the lake indicated a suppression of plant growth parameters: fresh weight, leaf laminar area and leaf length (Table 4) and substantial increases in number of feeding scars and adult weevils per plant. Fresh weight reduction was noted at the mouth of River Malewa. Leaf length reduction was noted at two sites, while leaf laminar area reduction was evident at Hippo point and Crescent Lake. The number of feeding scars and adult weevils per plant increased at all sites.

Measurements from the six selected sites in the lake (May-December 2004) gave a combined mean 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 (Table 5).

Weevils were found to be fairly established in all sampled areas and had spread several metres (on average 15 m) from points of release. The effect of these weevils was evident on some of the sampled water hyacinth plants.

4.2.2 Physical Control

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 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. Re-growth of the chopped weed is likely to take place, especially if most of the natural enemies are

Table 5 *Neochetina* weevil populations on water hyacinth estimated from six sites in Lake Naivasha, May-December 2004.

Site	Mean No. of weevils/plant ± SE	Mean No. of weevils by species		Range
		Nb	Ne	
Elsamere	2.5 ± 2.3	1.8 ± 0.9	0.7 ± 0.3	1-4
Oloidien	6.3 ± 4.5	5.1 ± 3.3	1.2 ± 1.1	0-7
Hippo point	14.3 ± 6.7	14.0 ± 6.7	0.0 ± 0.0	0-15
Western shores	18.1 ± 15.3	15.4 ± 7.2	2.7 ± 2.3	0-32
North swamp	18.1 ± 15.3	15.4 ± 7.2	2.7 ± 2.3	0-32
Fisherman's camp	7.5 ± 4.4	3.7 ± 2.9	1.7 ± 2.3	1-13
Grand	6.0 ± 5.3	4.4 ± 3.1	1.6 ± 0.9	-
Mean %age	-	73.3	26.7	-

At all other sites n = 10. Nb = *Neochetina bruchi*. Ne = *N. eichhorniae*.

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 lake. The future of mechanical control options in Lake Naivasha should be reassessed.

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 the rivers entering Lake Naivasha. In the lake, pure mats of water hyacinth were invaded initially by aquatic ferns and 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.

5. Discussion and Conclusion

5.1 Impact of Water Hyacinth on the Phytoplankton Productivity

Invasions of water hyacinth have become a nuisance worldwide [28]. Originally perceived as a practical problem for fishing and navigation, water hyacinth is now considered a threat to biological diversity, affecting fish faunas, plant diversity and other freshwater life and the food chains, which depend upon it [29].

Due to its physical presence water hyacinth greatly blocks sunlight and oxygen exchange and hence prevents growth of emerged 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 spread of water hyacinth in the lake, submerged and rooted floating-leaved macrophytes were common in shallow parts [30]. 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 [31].

The presence of water hyacinth in Lake Naivasha has so far affected the productivity of the phytoplankton. Lower chlorophyll-a at the stations under water hyacinth cover 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 [32]. The trends that Talling et al. [33] noted show that chlorophyll concentrations are higher nearshore than offshore. This is 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 et al. [33] observed in his study. Dissolved oxygen at these deep stations averaged $1.79 \text{ mg}\cdot\text{L}^{-1}$.

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 [34]. MCvea et al. [8] 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 [8]. 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. [17] 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 anti-algal activity than the common algaecide CuSO_4 [17, 35]. As a result of decreased phytoplankton production, MCvea et al. [8] 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 Ref. [8]. 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 [17].

5.2 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 assist in the redistribution and spread to non-release sites. Wind and water currents are 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 [27]. 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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