International Journal of Development and Sustainability
ISSN: 2186-8662 – www.isdsnet.com/ijds
Volume 3 Number 10 (2014): Pages 1971-1987
ISDS Article ID: IJDS14041401

Effects of spreading patterns of water hyacinth (Eichhornia crassipes) on zooplankton population in Lake Naivasha, Kenya

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Abstract

This study sought to examine the effects of spreading patterns of water hyacinth on zooplankton populations of Lake Naivasha, Kenya. Water hyacinth (*Eichhornia crassipes*) was introduced into Lake Naivasha basin in 1986 and its presence continues to affect zooplankton population. For species diversity, Shannon-Weiner Diversity Index (H') and Simpson Diversity Index (D) were applied to the habitats of the 10 sampling sites for the sampling dates (between October 2003 and November 2004). The Simpson Diversity Index (D) of zooplankton was found to be significantly lower (P< 0.005) under water hyacinth mats (D=0.50) than in water hyacinth-free zones (D=0.79). The study appears to suggest that water hyacinth has significantly reduced the abundance and diversity of zooplankton in the lake. It is therefore recommended that critical intervention strategies be undertaken to control further spread of water hyacinth in the lake so as to prevent both ecological and economic losses as a result of biodiversity loss.

Keywords: Freshwater invertebrates; Zooplankton; Water hyacinth (Eichhornia crassipes); Invasive species

Cite this article as: Mironga, J.M., Mathooko, J.M. and Onywere, S.M. (2014), "Effects of spreading patterns of water hyacinth (Eichhornia crassipes) on zooplankton population in Lake Naivasha, Kenya", *International Journal of Development and Sustainability*, Vol. 3 No. 10, pp. 1971-1987.

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1. Introduction

The negative consequences of the activities of man on the biological conditions in fresh water ecosystems are becoming more and more pronounced. Introductions of alien plants and animals into the lentic hydrosystems are common occurrences in Kenya and also in many parts of the world. In many cases, this has led to the disappearance of indigenous vegetation and uncontrollable growth of the introduced plant species. In Africa, proliferation of aquatic weeds has been enhanced by increased enrichment of water bodies by nutrient runoffs from human and agricultural wastes. The physical presence of the weeds hinders human activities such as boating and fishing and interferes with the ecological functioning of the water ecosystems. The most severe problems are caused by free-floating plant species that form moving, impenetrable mats. The most deleterious of the free floating plant species and which is also listed among the ten most notorious weeds in the world is the water hyacinth (*Eichhornia crassipes* Solms-Laubach (*Pontederiaceae*) (Pieterse, 1990). This weed is commonly known as the "queen flower'' because of its attractive rosette leaves and beautiful pale violet flowers. The plant has continued attracting the attention of aquarists world-wide because of its ornamental value. The weed has, however, caused considerable damage to lakes and rivers around the world. It clogs waterways and impedes navigation, presents a safety hazard to boating and water-skiing, and leads to full damage when boats collide with obstructions hidden under water hyacinth (Little, 1969; Ogutu-Ohwayo et al., 1996; Gonzalez, 2004). Water hyacinth still remains the world's most problematic waterweed despite various widespread approaches to control it (Hill et al., 1999; Heard and Winterton, 2000).

Water hyacinth occurs in habitats of widely differing water depth and nutrient levels (Gopal, 1987). In permanent lakes and reservoirs the plants are subjected to large water level fluctuation and wave action. In riverine habitats, seasonal variations in the flow velocities are crucial in explaining changes in the mass of water hyacinth for given points of time.

According to Adams et al., (2002) water hyacinth became common in Lake Naivasha in 1990. By 1992 the water hyacinth had established itself tremendously becoming the most dominant floating plant species in the lake. This was the period when 'Kariba weed' the aquatic fern, *Salvinia molesta* had declined rapidly in response to the introduction of a biogent, Salvinia weevil, *Cyrtobagus salviniae*. Due to its elaborate root system and above water architecture, the water hyacinth, fully out competed *Salvinia molesta* in Lake Naivasha by the late 1990s (Adams et al., 2002). Currently, water hyacinth is found at varying locations in the lake with the smallest plants found in exposed floating mats while the large plants are associated with sheltered areas close to papyrus fringes. Most of the weed is found concentrated along the western shore and to the north of the lake around the mouth of River Malewa. It is also common to find it rooted in shallow water and the exposed muddy beaches of the lake.

Zooplanktons are known to constitute a major component of food chain in aquatic ecosystems as they play an important role in channeling primary production into fish production (Dejen et al., 2004). There is therefore an urgent need to carry out zooplankton studies in order to establish the role they play in water ecosystems (Aoyagui, 2003).

Several studies have confirmed that zooplankton distribution is dependent on many factors such as turbulence, light, temperature chlorophyll-a and food availability (Mironga et al., 2011, Kiorboe and Saiz, 1995). This implies that reduced phytoplankton productivity can lead to a decrease in zooplankton abundance (Richards et al., 1985; Maceina et al., 1992). According to Arora and Mehra (2003) the complex structure of water hyacinth can provide more microhabitats for epiphytic zooplankton thus greater food availability and refuge from predators.

This paper examines the effects of spreading patterns of water hyacinth on zooplankton populations of Lake Naivasha, Kenya. The study was conducted during two sampling seasons: dry and wet seasons with the objective to determine whether the density, taxonomic richness, and assemblage composition of zooplanktons in the lake water varied between the open water and the water infested with water hyacinth mats.

2. Materials and methods

Sampling sites were selected to facilitate comparison between the two environments namely one under the cover of stationary or floating fringes of water hyacinth and open water (water hyacinth free zone). At each of the two sites (open water and water hyacinth covered water), sampling was at 10 m intervals along two parallel transects set at roughly right angles to the shoreline, approximately 5 m apart. Triplicate samples of water hyacinth were collected at each sampling site.

2.1. Sampling and Zooplanktons' sample processing

A square quadrant of 0.25 m^2 was laid over the floating water hyacinth mats. A large, strong nylon net (0.04 mm pore size) mounted on a rectangular metal frame connected to a long handle was placed carefully underneath the floating mats and the rhizomatous root mass was cut at the water surface around the edges of the quadrant using a pair of shears. The cut block of water hyacinth plants with the intact root mass was lifted carefully out of the water with the help of the net, which trapped any Zooplankton dislodged by the operation. The 0.25 m^2 blocks of water hyacinth were collected in triplicates and placed in separate polythene bags for sorting in the laboratory. For the open water, sampling was done using dip-net method. A D-shaped dip-net with a 0.04 mm pore size mesh was used to collect benthic macro-fauna. Dip-net hauls were taken for one minute.

The bulk of the Zooplankton in the samples were dislodged from the root masses by washing the material with tap water through sieves of 0.2 mm and 0.04 mm. The water hyacinth root material was then flushed with 95% alcohol to excite and dislodge any remaining organisms. Larger Zooplankton were picked up with forceps and preserved in formalin in vials. Sediments were washed with tap water through sieves. The fine sediment residues containing the smaller organisms were spread into large white plastic trays where drops of 95% ethanol were added. They were then removed with forceps for preservation. The contents of the vials were flushed with tap water through a 0.04 mm sieve to wash off the preservative before sorting into taxonomic groups and enumeration.

2.2. Statistical analysis

With the limited resources for identification of Zooplankton, identifications were considered at the family level (1, 30). To determine the diversity and abundance of Zooplankton, the Shannon–Weaver Diversity Index (H') was applied on the families using the following formulae:

- Shannon's Index

$$H' = -\sum_i p_i \ln p_i$$

where, p_i is the proportion of all the Zooplankton which belongs to the i^{th} species

2.3. Study site

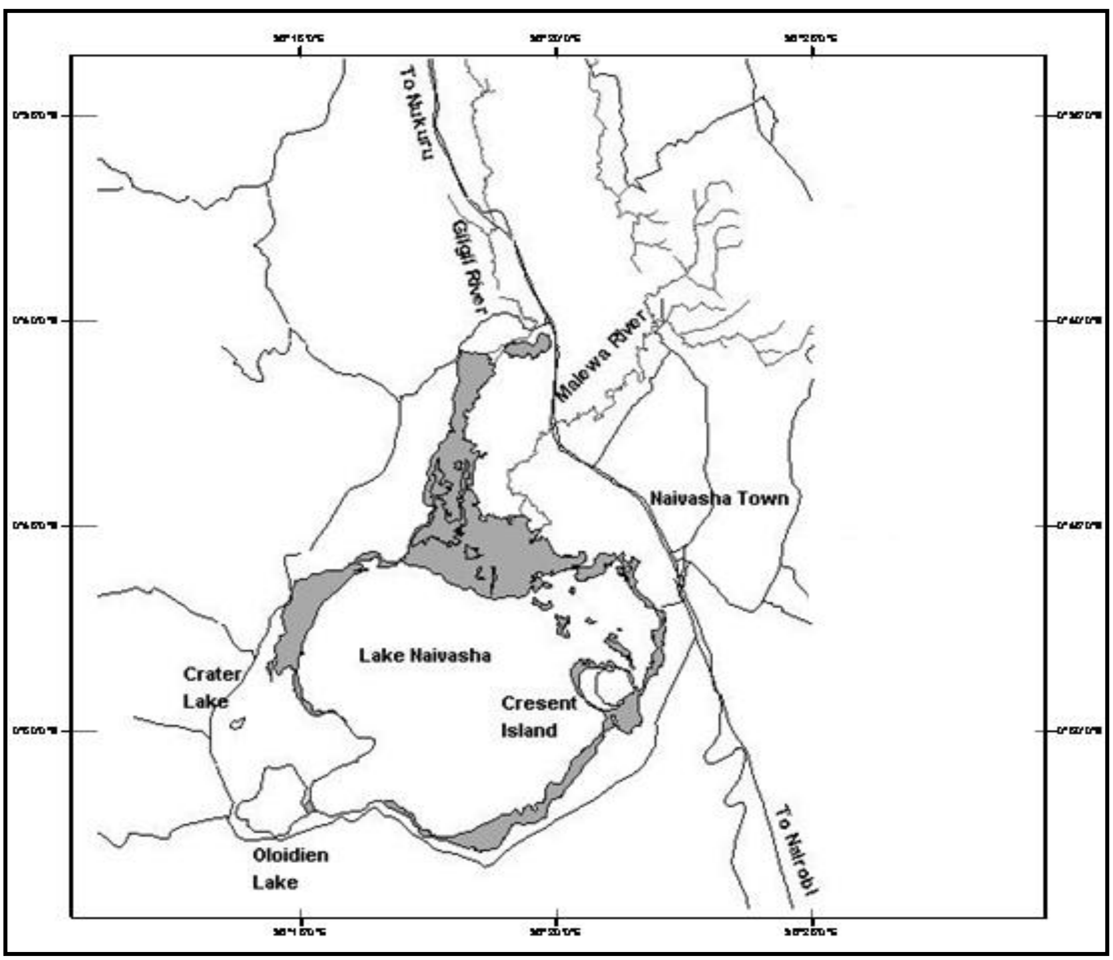

Figure 1. Lake Naivasha

Lake Naivasha hydro-system is about 80 km North West of Nairobi City between 0° 08' to 0° 55' S and 36° 00' to 36° 45' E. Most of the Rift Valley lakes such as lakes' Nakuru, Elementaita among others are alkaline except for lake Naivasha which has no known surface outlet and is therefore assumed to be discharging underground (Gaudet and Melack, 1981) with seepage maintaining the movement of fresh water brought into the lake by the Gilgil and Malewa rivers.

The Lake consists of the Main Lake, a small separated lake, Lake Oloidien and a smaller crater lake, Lake Sonachi. The total catchment of the lake is approximately 3200 km^2 (Rupasingha, 2002). The Main Lake water surface area is approximately 120-150 km^2 plus 12 - 18 km^2 of swamp. Donia (1998) 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) did a bathymetric survey during October 2001 and the result of calculated mean depth was 3.41 m at the lake level of 1886.38 masl.

According to Harper (1992) the ecology of the lake has been changing mainly due to presence of alien invasive floating aquatic weed species such as *S. molesta, E. crassipes* and to a limited extent, *P. stratiotes* among other factors. This according to Gaudet (1977) has eventually influenced the plant succession in the lake.

3. Results

3.1. History and spread of water hyacinth on Lake Naivasha

Information available from Kenya Agricultural Research Institute (KARI), the Fisheries Department and Kenya Marine and Fisheries Research Institute (KMFRI), show that a few rafts of water hyacinth were present in Lake Naivasha in mid-1986. These were trapped among *Salvinia molesta* at the mouth of River Malewa. By 1989 the water hyacinth had progressively spread along the western shore from Malewa to Elsamere Bay (Figure 2) but none was present in Lake Oloidien, which has a higher alkalinity (Njuguna, 1992). During this time it was associated with *Salvinia molesta* rafts or grew on the lake's edge (Plate 1).

According to Adams et al., (2002) water hyacinth became common in Lake Naivasha in 1990. By 1992 the water hyacinth had established itself tremendously becoming the most dominant floating plant species in the lake. This was the period when 'Kariba weed' the aquatic fern, *Salvinia molesta* had declined rapidly in response to the introduction of a biogent, Salvinia weevil, *Cyrtobagus salviniae*. Due to its elaborate root system and above water architecture, the water hyacinth, fully out competed *Salvinia molesta* in Lake Naivasha by the late 1990s (Adams et al., 2002).

Currently, water hyacinth is found at varying locations in the lake with the smallest plants found in exposed floating mats while the large plants are associated with sheltered areas close to papyrus fringes (Plates 2 and 3). Most of the weed is found concentrated along the western shore and to the north of the lake around the mouth of River Malewa. It is also common to find it rooted in shallow water and the exposed muddy beaches of the lake.

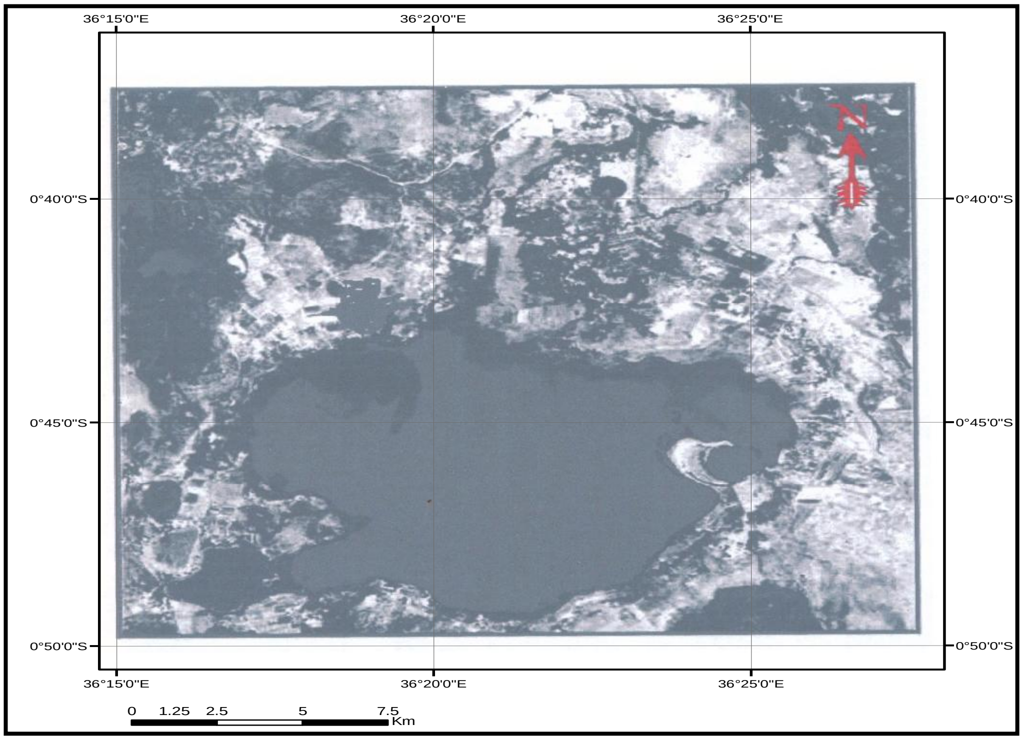

Figure 2. March 1986 Landsat TM Band 4 image of the Lake Naivasha basin. Arrow shows the extent of the fringe of water hyacinth (*Eichhornia crassipes*)

Plate 1: A fringe of water hyacinth (*Eichhornia crassipes*) at the lake-papyrus interface. The photograph was taken in early April 1986 from the lake shore indicating the site shown by the arrow in Figure 2. *Photograph courtesy of LNRA*

By distribution classes, the water hyacinth is of two groups at the lake; resident and mobile mats. Resident water hyacinth occur in sheltered shallow bays and inlets with muddy bottoms where it forms shoreline strips of 5 to 15m wide, extending to 30m or more in sheltered inlets at the mouth of River Malewa. Mobile water hyacinth exists in a variety of mat sizes, from solitary plants to huge concentrations (Plate 4) tossed about by the waves created by diurnal and seasonal winds. These mats are lodged or dismantled from anywhere along the shoreline by the wind. Mobile water hyacinths are the most extensive proportion of all.

Plate 2. Water hyacinth in association with papyrus vegetation in Lake Naivasha

Plate 3. Water hyacinth in sheltered sections of Lake Naivasha

Plate 4. Wind blown water hyacinth in Lake Naivasha

3.2. Status and distribution of water hyacinth in Lake Naivasha

Surveys of the distribution and abundance of water hyacinth in Lake Naivasha was carried out between October 2003 and November 2004. The map showing the current distribution of water hyacinth on Lake Naivasha (Figure 3) was drawn based on information derived from analysis of historical information, satellite imageries and field surveys. The area of the lake covered by water hyacinth ranged from 0.469 ± 0.019 km^2 (0.30% of the lake area) during the dry season to about 0.647 ± 0.029 km^2 (0.40% of the lake area) during the rainy season. The surface area of water hyacinth on the lake was computed from the classification result using ILWIS (Integrated Land and Water Information System). Water hyacinth was present on the lake and around the shore in shallow water, in varying densities (34.3 ± 5.35 and 33.0 ± 6.21 plants per m^2). The northern shore, from Marula to Loldia Farm, including the mouths of both Malewa and Gilgil Rivers had the largest cover of water hyacinth. At the time of this study water hyacinth mostly occurred in mud flats or in very shallow water and was in most cases rooted into the mud (water level had risen by 1m by mid April 2004). It formed a fringe against the papyrus belt, on the lake-ward side the water hyacinth was the most prominent plant taking about 70% of cover where it occurred.

Along the shore from Loldia Farm to Kibokoni, there was water hyacinth in a fairly constant width of 5 - 30m and covering approximately 75 - 80 % of the shoreline. The water hyacinth seemed to prefer the sheltered papyrus bays. The other sections with water hyacinth growth were the shoreline between Fisherman's Camp and Sanctuary Farm/Crescent Island boundary, and from the central fish landing channel towards Malewa. The width of the weed here varied between 3m and 20m wide and also seemed to take advantage of water abstraction channels (Plate 5).

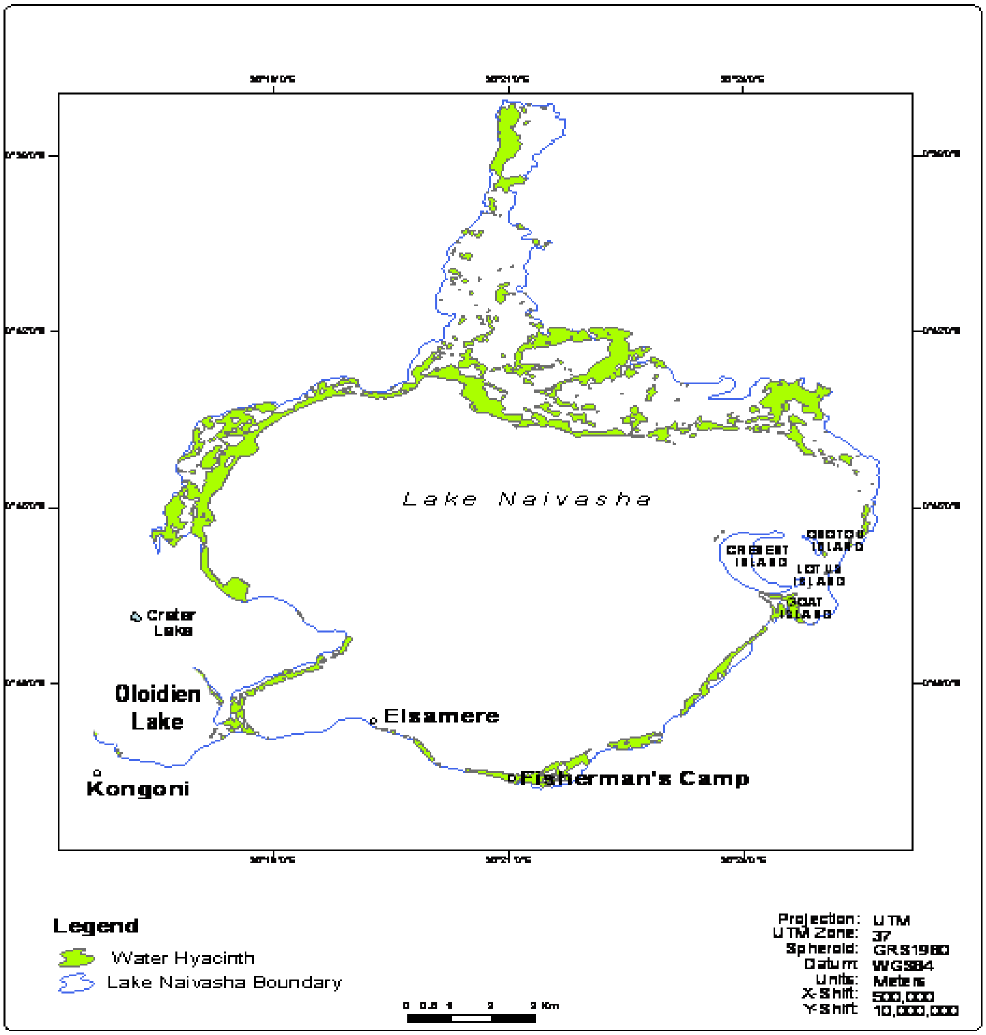

Figure 3. Distribution of water hyacinth in Lake Naivasha, October, 2004

The shoreline in Kibokoni area to Hippo Point (rocky shore, hardly any papyrus) and between Kamere fish landing beach and Fisherman's Camp, and between Burch's marina area and Kihoto showed no presence of water hyacinth. In most cases, there was plenty of dry water hyacinth on the dry ground, indicating that it had been left by the receding lake. This was generally drying out, but stakeholders indicated that with the rains the plants were likely to re-grow particularly if the exposed areas were re-flooded.

3.3. Effects of spreading of water hyacinth infestation on the zooplankton population of Lake Naivasha

The effects of water hyacinth infestation on the distribution, abundance and species composition of zooplankton in Lake Naivasha were investigated. From the ten sampling sites from each of the two sites a total of 20 samples were obtained. Sorting and identification of organisms to the lowest possible level were done using the taxonomic keys proposed by (Jeje and Fernando, 1986). A total of 15 species of zooplankton were identified in the study (Table 1). The total number of species and individuals present at the water hyacinth infested areas and within the open water were 9 and 15 respectively (Table 2). Analysis of Variance (one way ANOVA) showed that the number of species at water hyacinth infested area was significantly different ($p<0.05$) than the shoreline without water hyacinth area. Rotifers were found to be dominant zooplankton group in both water bodies accounting for 63.1% in the water hyacinth infested waters and 42.1% in the open waters. Cladocerans at 15.9% and 28.8% were the next common group of zooplanktons in each of the water bodies respectively; the least was Copepoda at 21.1% and 29%, respectively.

Table 1. Presence of zooplankton species in water hyacinth infested areas and along shoreline without water hyacinth infestation in Lake Naivasha

Taxa	Species	Water hyacinth infested area	Shoreline without water hyacinth infestation
Cladocera	*Ceriodaphania* sp.	+	+
	Chydorus sp.	+	+
	Diaphanosoma sp.	-	+
	Leydiga sp.	-	+
	Moina sp.	+	+
	Pleuroxus sp.	-	+
Copepoda	*Cycloid* sp.	+	+
	Copepodo sp.	+	+
	Calanoid sp.	-	+
Rotifera	*Asplanchna* sp.	+	+
	Trichocera sp.	-	+
	Filinia sp.	+	+
	Polyarthra sp.	-	+
	Brachionus sp.	-	+
	Lecane sp.	+	+

Key: *+ Present, - Absent*

The following cladocerans families were found to be present: Moinidae (*Moina* sp.), Daphnidae (*Ceriodaphnia sp.*) and Chyroridae (*Pleuroxus sp.*) which was missing in the water hyacinth infested areas of the lake (*Chydorus* sp. and *Leydigia* sp. were also not represented in the water hyacinth infested areas). Cladocerans had a density of 14 org L^{-1} in the water hyacinth infested areas compared to shoreline without water hyacinths infestation 60 org L^{-1}.

Six families of Rotiferans were found to be present; Asplanchidae (*Asplanchna* sp.) Trichocerchidae, Synchaetidae and Brachionnidae comprised of a genus and were represented by *Trichocerca* sp., *Polyarthra* sp. and *Brachionus* sp., respectively. This genus was absent in the water hyacinth infested areas of Lake Naivasha. Filinidae and lecanidae were represented by *Filinia* sp. and *Lecane* sp., respectively. In the water hyacinth infested area Rotiferans were 54 org L^{-1} while shoreline without water hyacinth infestation had 90 org L^{-1} (Table **2**).

Table 2. Percentage composition and abundance of zooplankton in water hyacinth infested areas and along shoreline without water hyacinth infestation in Lake Naivasha

Taxa	**Zooplankton Species**	**Water hyacinth**		**Shoreline without water hyacinth infestation**	
		Frequency	%	**Frequency**	%
Cladocerans	*Ceriodaphania* sp.	3	3.2	8	3.0
	Chydorus sp.	3	3.2	8	3.6
	Diaphanosoma sp.	0	0.0	4	1.3
	Leydiga sp.	0	0.0	4	1.3
	Moina sp.	10	10	35	18
	Pleuroxus sp.	0	0.0	4	1.6
Copepoda	*Calanoid* sp.	0	0.0	4	1.7
	Copepodo sp.	7	7.2	4	2.2
	Cycloid sp.	0	0.0	4	1.8
Rotifera	*Asplanchna* sp.	3	3.2	2	1.0
	Brachionus sp.	0	0.0	6	1.7
	Filinia sp.	4	4.2	4	1.8
	Lecane sp.	50	53.0	76	32.7
	Polyarthra sp.	0	0.0	4	1.8
	Trichocera sp.	51	50.7	77	32.2

Copepodans comprised of one family: Cyclopidae which was made up of three species namely *Cycloid copepods, Copedite* and *Calanoid copepods*. Copepods in water hyacinth area accounted for 21 org L^{-1} while in the shoreline without water hyacinth infestation it accounted for 63 org L^{-1} (Table 2).

Species richness was calculated according to Margalef's Richness Index (D=(S-1)/log (N), where S is the number of taxa and N is the number of individuals, and was found to be significantly lower (D=1.53) under water hyacinth mats at 5% level. The Shannon-Weiner Diversity Index was calculated according to the equation $H' = -\sum_i p_i \, \mathrm{In} p_i$, where 'p' is the proportion of the sample belonging to the taxon '*i*'. The index was significantly lower ($p<0.05$) in the water hyacinth infested areas (H' = 0.65) when compared to shoreline without water hyacinth (H' = 0.84). The total number of individual species of zooplankton caught in water hyacinth infested (8 species) area was also significantly lower ($p<0.05$) in water hyacinth infested area when compared to shoreline without water hyacinth (15 species).

The results indicate that abundance of zooplankton were lower in water hyacinth infested area when compared to shoreline without water hyacinth in Lake Naivasha during the study period. The reason could be due to the formation of the dense mats of water hyacinth on the water surface, thus a reduction of dissolved oxygen content of the infested area. The implication of this is that water hyacinth infestation did not support zooplankton abundance and diversity in the lake.

4. Discussion

It was established from the interviewees and existing documentary evidence that water hyacinth invaded Lake Naivasha in 1986 and that by 1992 water hyacinth had established itself tremendously, becoming the most dominant floating species in the lake. This was also the time when *Salvinia molesta* had declined rapidly in response to the introduction of a bioagent, Salvinia weevil, *Cyrtobagus salviniae*. However, the water hyacinth out-competed *Salvinia molesta* in Lake Naivasha in the late 1990s (Adams et al. 2002), probably due to its elaborate root system. Research on the lake (Kitaka, 2000; Adams et al., 2002; Mireri, 2005) observed significant increases in the nutrient concentrations and this is likely to have accelerated water hyacinth infestation on the lake. Onywere (1997) observed that the depletion of the forests on the Kinangop, Mau and Eburru escarpments were the main cause of such increased nutrient loads to the lake. Twongo (1993) made similar observations in Lake Victoria as water hyacinth out-competed other water plants. In contrast, Mitsch (1975) noted that in water bodies with low nutrient levels the probability of the water hyacinth growth being out-competed by other aquatic species exists.

Surveys aimed to establish the distribution and abundance of water hyacinth in Lake Naivasha were carried out between January and April 2005. It was established that water hyacinth was present around the lake and around the shore in shallow water, in varying densities (34.3 ± 5.35 and 33.0 ± 6.21 plants per m^2). The northern shore, from Marula to Loldia Farm, incorporating the mouths of both Malewa and Gilgil Rivers had the largest cover of water hyacinth (taking 70% of the total cover of water hyacinth in the lake). This could be explained by the fact that these rivers transport suspended sediments from upstream during flood events and therefore bring nutrients that favour the proliferation of water hyacinth at these points. Similar observations were made by Hubble and Harper (2002) that Lake Naivasha showed a seasonal shift between diatom and cyanobacterial dominance, which are indicators of high nutrient levels on the lake surface and at the shores; this explained the observed proliferation of water hyacinth in this study. In Lake Victoria, Twongo (1993) identified sheltered mouths of rivers and streams flowing into lake, and sheltered bays especially Murchison, Entebbe and Macdonald Bays as those sections that contained large expanses of the water hyacinth and established that these bays served as major recipients of industrial and municipal effluents.

Along the Lake Naivasha shore from Loldia Farm to Kibokoni, there was water hyacinth in a fairly constant width of 5 - 30m and covering approximately 75 - 80 % of the shoreline. The other sections with significant water hyacinth growth were the shoreline between Fisherman's Camp and Sanctuary Farm/Crescent Island boundary, and from the central fish landing channel towards Malewa. The convoluted formation of Lake Naivasha's shores on these sections enabled the water hyacinth to easily establish itself as these provided shelters for growth with minimal interruption from strong winds and thus the observed constant width coverage. This is comparable to the study findings of Willoughby et al., (1993) that concluded that the shores of Lake Victoria in Uganda were the most severely infested with water hyacinth due to the large numbers of shallow, sheltered, and mostly papyrus-fringed bays and inlets.

Although water hyacinth had colonized 32% of Lake Naivasha shoreline during the study period, the rate of its growth was slow, for instance, water hyacinth plant with 450cm^2 basal area was observed to grow into a coverage equal to 1.0827m^2 after 40 days compared with its invasion and persistence in other water bodies like Lake Victoria where Twongo (1993) estimated its intrinsic rate of growth to be in the range of 0.04 to 0.08m^2 per day. Another important feature of water hyacinth in Lake Naivasha was that individual plant biomass was generally low and that the plant did not colonize the open lake in large mats. High exposure to winds and relatively low water temperature (21^{0}C) constrained its spreading in the lake. Water hyacinth is at its most productive at water temperatures of around 28^{0}C (Bock, 1969). The annual mean water temperature in Lake Naivasha (at an altitude of 1890 m) is around 21^{0}C (Muthuri et al., 1989) and is thus rather low for rapid growth of water hyacinth. A genetic basis for differences between productivity of particular clones of water hyacinth may also exist (Gerber et al., 2009). The observed slow growth rates of water hyacinth in Lake Naivasha indicate that control measures are likely to succeed within a short period of time.

This study further shows that the presence of water hyacinth mats has a detrimental effect on both the abundance and diversity of benthic invertebrates in Lake Naivasha. The decrease in biodiversity affects the ability of the ecosystem to function normally. Reduced diversity in an ecosystem also makes it vulnerable to disturbance as the average number of interspecific interactions is decreased (Hurlbert, 1971; Fullick, 2002). Although Pfisterer and Schmid (2002) argue that decreased diversity does not decrease stability, the extremely low abundance of macrobenthos under water hyacinth mats and the fact that more than half the samples from under water hyacinth mats had no interspecific interactions (number of taxa < 2), can only result in decreased stability (Hurlbert, 1971). Six taxa collected from under water hyacinth mats had such low abundances ($U=796.5$, $P<0.001$), that they would have influenced the ecosystem functioning significantly. While the minimum number of individuals needed for a species to be ecologically significant is in most cases unknown, a 243-fold decrease in the mean abundance of the major detritivore, the Chironomidae, below water hyacinth mats will influence the system dramatically. This reduction is also unexpected, for two reasons: firstly, Chironomidae are known to survive anoxic conditions, which are typical of water hyacinth infested systems; and, secondly, water hyacinth mats produce large quantities of detritus. For these reasons, a reduction in detritivores was not expected.

This study concurs with the assertion by Luken and Thieret (1997) that despite the onslaught of non-indigenous species worldwide, it is often difficult to determine what the congruent ecological effects are of such invasions. Oftentimes, sufficient monitoring is not available to document changes caused by a specific invading organism. Water hyacinth was characterized by distinctly different invertebrates. Therefore, presence of water hyacinth in Lake Naivasha is associated with minor to major shifts in invertebrate assemblages depending on the site. Such community level effects are typical of habitat-altering invaders like the case of water hyacinth (Bertness, 1984) which is not only widely abundant, but also provides structurally complex substrate to other organisms in both the aquatic and terrestrial zones of Lake Naivasha.

5. Conclusions

From this study we conclude that

- 1) the presence of water hyacinth in Lake Naivasha affected invertebrate distribution and habitat use;

- 2) the presence of water hyacinth generally increased density of dominant invertebrates, with the exception of rotifers;
- 3) water hyacinth may have affected invertebrates in open water as well as those directly associated with the plant;
- 4) the density and size of water hyacinth mats appear to have played an important role in determining invertebrate density, diversity, and assemblage composition, but additional sampling during times of high water hyacinth cover is needed to validate this claim.

In general, the differences detected in density and species richness were during wet season when water hyacinth density was still relatively high. During the wet and dry seasons, the physical differences among habitat types were clearly defined. As the percent cover decreased, mat size decreased and patches were interspersed with greater open water areas. The fragmentation and decreased size of mats likely contributed the study's results, but these factors were not explicitly measured. Furthermore, water hyacinth mats were extremely mobile. Patches of water hyacinth often joined shoreline mats, making it difficult to decipher among habitat types. In this study we assumed an immediate invertebrate response to the presence of water hyacinth but expect the persistence of water hyacinth at a given site may have contributed to invertebrate density and assemblage composition. We used seasonal water hyacinth means to try to account for the effect of water hyacinth persistence. Future studies should try to explicitly incorporate site-level water hyacinth persistence as a potential factor influencing invertebrate assemblages by sampling each site more than once a season.

This study is relevant on a worldwide scale, particularly in aquatic systems outside of water hyacinth's native range where the plant poses a threat. Water hyacinth never covered the entire surface of Lake Naivasha like it has in smaller waterbodies worldwide (Navarro and Phiri, 2000; Mangas-Ramirez and Elias-Gutierrez, 2004); therefore, the results of this study are most applicable to similar systems that experience moderate coverage.

Acknowledgements

The work was supported by Egerton University, Division of Research and Extension Internal Research Funds. The authors are also grateful to the Government of Kenya for the permission to carry out this work.

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