Ecotoxicological assessment of pollutants in Lake Victoria fishery, Kenya: Proof of fish consumption?

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Abstract

This study set out to survey and document pollution in fishing grounds and thereby provide necessary information on environmental quality for purposes of management of the fishery in Lake Victoria, Kenya. The monitoring survey was conducted between June 2010 and June 2013 to identify changes or trends in water quality over time, collect information on biotic indicators of water quality as well as identify fish parasites in *Lates niloticus*. Physico-chemical parameters were monitored *in situ* using portable water quality meter while nutrients and trace metals were analyzed using standard methods. Dissolved oxygen concentrations ranged from 3.42 to 6.47 mg l^{-1} in Asembo Bay and Kowuor, respectively with a mean of 5.26 mg l^{-1}. The Gulf was more eutrophic than the open waters. Soluble reactive phosphorus showed significant positive correlations ($r = 0.65$; $P < 0.01$) with conductivity and a significant negative correlation ($r = -0.53$; $P < 0.01$) with transparency. Based on Effect Range Low (ERL) and Effect Range Mean (ERM) scheme, surface sediments had concentrations above ERL for Pb, Zn, Ni and Hg respectively and 1% for Ni was above ERM. The results showed that the effects of most metals of ecotoxicological importance in the sediments were of acceptable levels except for Pb, Zn, Ni and Hg with lead having the highest risk. The fish larval assemblage of Lake Victoria Kenyan waters was dominated by the *R. argentea*, with the highest numbers within Lwanda Gembe, attributed to the water clarity and reproductive strategy of the fish. The study recommends restoration of wetlands, especially those at the mouths of major rivers draining the lake to serve as buffers and filters.

Key Words: Pollution, Nyanza Gulf, Lake Victoria, ecotoxicology

Introduction

Lake Victoria is the largest tropical lake in the world with a surface area of 68,800 km^2 shared between Tanzania (51%), Uganda (43%) and Kenya (6%). The lake is relatively shallow, with a mean depth of 40 m. The Lake has high ecological value and is used for transport, recreation, fisheries, and as a water supply for drinking, industry and agriculture. The major commercial fish species include exotic Nile perch (*Lates niloticus* L.), native cyprinid (*Rastrineobola argentea* (Pellegrin)), and introduced Nile tilapia (*Oreochromis niloticus* L.) (Cowx 2005; Njiru *et al*. 2007). The lake is a major transport route within the region, and an important aquatic habitat containing rich biodiversity (Witte *et al*. 1992). Lake Victoria also is a source of employment, food and income to riparian communities (Bokea & Ikiara 2000). The lake's watershed supports a rapidly growing human population, estimated to be >30 million people (Yongo *et al*. 2005), whose activities intensely influence the lake. Over the past decade, Lake Victoria has undergone dramatic ecological changes associated with physical, chemical and biological processes (Witte *et al*. 1992; Lung'ayia *et al*. 2000; Mugidde *et al*. 2005). Environmental degradation, exotic introductions and increased fishing pressure have led to a decline in fish catches, and changes in the lake's biodiversity, threatening the sustenance of the lake fishery upon which millions depend on for their livelihoods.

The water quality and aquatic biota are strongly influenced by disturbances in the watershed (Carignan *et al*, 2000). High levels of toxic compounds in the water, from the use and discharge of wastes from the catchment may cause severe degradation of the lakes' environmental quality (Werimo *et al*, 2009). The disturbances in the catchment lead to increased primary production and potentially large changes in the freshwater communities.

Lake Victoria is stressed with increased water pollution from industries, agriculture, solid wastes and urban runoff/untreated liquid wastes altering its hydrological and ecological processes. Pollution accelerates eutrophication, destroys fish spawning areas impacting negatively on-fish stocks, diversity and fish distribution. Pollution of lake water is also known to increase bacterial loads that have the potential to contaminate fish and fishery products, which could pose a health risk to consumers. Hence the need for continuous monitoring of pollution in fishing grounds to reduce environmental stress and water pollution in the Lake Victoria Basin cannot be overemphasized**.** Monitoring of environmental pollution will provide critical information for management of the fishery. The data will give a clear view of the management of the lake ecosystem in relation to pollution from agricultural activities within the catchments and the risk of their discharge into the lake. Hence the objective of the study was to investigate the status of physical-chemical parameters, nutrients, heavy metals and indicator organisms such as *E.coli* among others in the Kenyan part of Lake Victoria.

2.0 MATERIALS AND METHODS

2.1 Study area

Figure 1 provide the sampling locations within the Kenyan part of Lake Victoria. The sampling was focused on location influenced by urban areas, river mouths and fishing grounds. The sampling was done within the Nyanza Gulf and those stations located offshore of north and south of Kenyan part of Lake Victoria. A total of 24 stations were sampled during this survey. All the stations were geo-referenced using Magellan Global Positioning System (GPS).

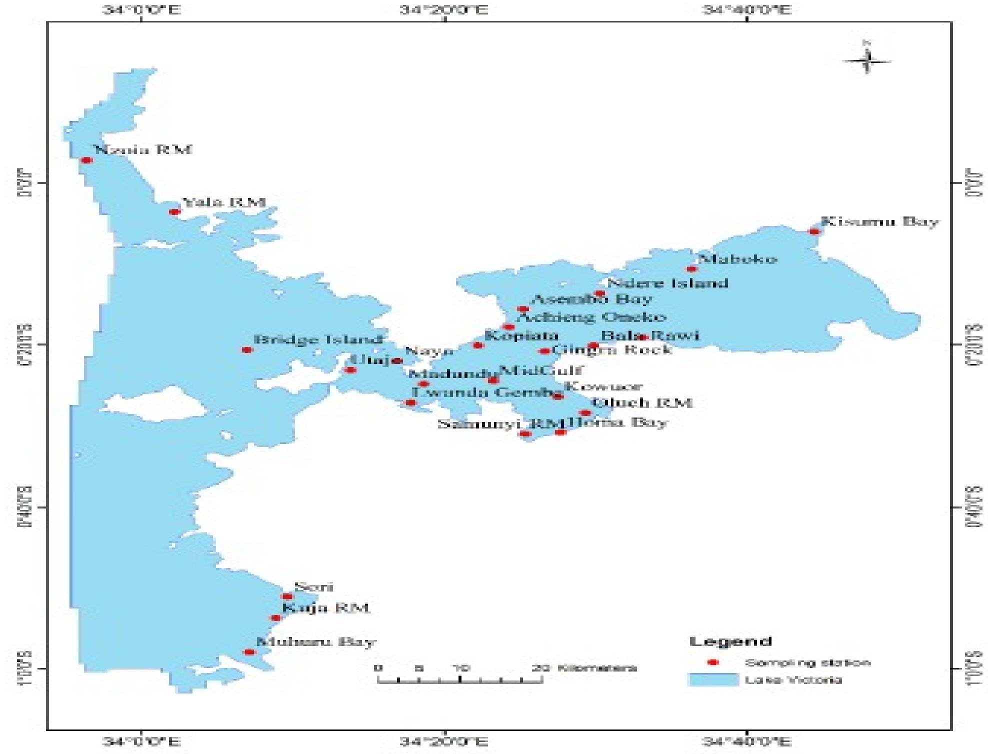


Figure 1. Map showing the study area and the sampling stations in Lake Victoria, Kenya.

2.2 Sample collection

2.2.1 Physico-chemical parameters

Physico-chemical parameters were monitored *in situ* using a portable water quality meter (model WQC 24). Chemical analysis of dissolved nutrients which included Soluble Reactive Phosphorus (SRP, PO_4^{3-}-P), Total Phosphorus (TP), Nitrate-N, Nitrite-N, Ammonium-N, and Total Nitrogen (TN) were carried out in the laboratory using photometric methods (APHA 2005). Ammonium and Silica were analyzed using phenate and heteropoly blue methods respectively following the methods adopted from APHA (2005).

2.2.2. Trace Metals

Subsurface water samples for heavy metal analysis were collected using Van Dorn water sampler at depths of about 20 cm. Sediments were collected using Poner grab after which extraneous material was removed. Each sample was divided into two portions in plastic ziplock bags that were half filled and sealed. These were shaken before preservation in ice boxes. Samples were analyzed for Mercury using Cold vapour AAS techniques (EPA 2001) while analysis of the other metal elements: Pb, Cu, Ag, Cr, Sn, Zn, Cd, Mn, Co, Mg,Ca, Fe, Ni, Cu, and Hg, followed standard procedure. The innermost portions of the wet sediments were used for gravimetric (% water) determinations as per Hakanson and Jansson (1983).

2.2.3. Plankton

Samples for phytoplankton analysis were collected with a 2-litre Van Dorn sampler and phytoplankton cells were identified to species level where possible and counted using an inverted microscope (Zeiss Axioinvert 35) at X400 magnification. The taxa were identified using the methods of Huber – Pestalozzi (1942) and from publications on East African lakes such as Talling (1987).

Zooplankton was collected using a simple cone shaped 1 metre long net of 50 µm mesh. The specimens were identified to species level whenever possible using relevant identification keys: Korovchinsky (1992) and Smirnov (1996) were used to identify Cladocera identification while Koste (1978) and Koste and Shiel (1987) were used for the rotifers.

The number of individuals per litre of lake water (D) was determined using the formula:

$D = N/V$

Where

N = number of organisms in sample

= (number in sub-sample x Volume of sample)/sub-sample volume

V = volume of lake water filtered = $\pi r^2 d$, where

r = radius of mouth of net (15 cm)

d = depth of haul

2.2.4. Macroinvertebrates

Sampling of macroinvertebrates was done using a Poner grab. In each sampling station, three replicate macroinvertebrates samples were collected and washed at the site of collection then preserved in absolute ethanol. In the laboratory they were sorted and identified to genus level according to Merritt and Cummins (1996) and Quigley (1977).

2.2.5. Micro contaminants

Membrane filtration technique (US EPA, 2002) was used to determine levels of coliforms. At each station, sterile water sampling cup was used to collect surface water. A volume of 1-100 ml of the lake water, depending on turbidity, was filtered using a cellulose membrane filter of pore size 0.45µm by use of a vacuum hand pump unit of Del agua water testing kit (OXFAM Delagua). Sampling at each site was carried in duplicate. Filtered samples were incubated by use of lauryl membrane sulphate broth for 18 – 24Hrs at 37°C and 44°C after which the total and faecal coliforms were established, respectively. Discreet colony forming units were counted manually with the help of the grids and arithmetic mean used to interpret the data.

2.2.6. Fish and fish parasites

Fish larvae were sampled by horizontal tows using conical plankton net with circular ring with a mouth diameter of 50 cm and 500 µm mesh size. The towing time was 5 minutes. All the ichthyoplankton caught were sorted, identified to species level and counted. Fish specimens were obtained using a bottom trawl aboard *RV Utafiti* moving at an average speed of 3 nautical miles. Fish was also obtained from multi size gillnets (2 fleets of size 1 to 10 inches) set overnight (methods after Asila, 2000; LVFO, 2012) in shallow and rocky areas which were accessed using a canoe mounted with an outboard engine. Information on physico-chemical variables was obtained before trawling or setting of nets was carried out. Other observable habitat characteristics were also noted.

All fish landed were identified and sorted to species level. For each fish caught, total length (TL, cm), standard length (SL, cm) and weight (W, g) were taken and recorded. The fish were then dissected, gutted, sexed and maturity status determined. The gonads were removed, weighed and categorized according to the developmental stages. The eviscerated mass of the fish was recorded. Stomach contents for the bigger specimens were determined immediately while the smaller specimens were examined thereafter under a stereo microscope (X40 magnification).

Fresh samples of *Lates niloticus* were examined for the presence of the Myxospoean parasites. The preparation and the description of the spores followed the guidelines of Lom & Arthur (1989). The external body parts; fins, eyes and gills were examined microscopically. Gills were removed and observed individually. Smears were made on cysts and examined using Olympus CH-2microscope at X1000 magnification. Measurements were made on some spores with a micrometer objective. Permanent preparations were fixed with methanol and stained using Giemsa method.

2.3 Data Analysis

Data was explored using descriptive statistics and visualized using graphs. Differences in observations in various sample sites were tested using ANOVA and significant difference determined at $\alpha = 0.05$ and 0.01. Relationship and significance correlations between variables were tested using linear models. Regression and multivariate analysis were used to determine relationships between variables. To assess the contamination degree of sediments and estimate their potential ecological risk, Effects Range-Low

(ERL) and Effects Range-Median (ERM) (Long *et al.,* 1995) were used as interpretive tools for relating ambient sediments data. The anthropogenic contribution of contamination in the waters was estimated through calculation of enrichment factors (Salomons and Forstner, 1984). The identified benthic macroinvertebrates, larvae and phytoplankton were analysed using the Shannon-Weiner index (*H'*) (Shannon & Weaver, 1963). Principal Component Analysis (PCA) was carried out using PAST programme (Hammer *et al.,* 2001) to group stations with similar attributes. Spatial maps for different thematic areas were produced using Arc GIS 10.0.

3.0 RESULTS

3.1 Physico-chemical parameters

Dissolved oxygen had a spatial variation ranging from 3.42 to 6.47 mg l^{-1} in Asembo Bay and Kowuor, respectively with a mean of 5.26 mg l^{-1}. The oxygen concentrations were generally high in the gulf than in the open lake. For Soluble Reactive Phosphorus (SRP) concentrations ranged between 14.86 and 90.57 µg l^{-1} in Kuja RM and Oluch RM, respectively with mean concentration of 60.82 µg l^{-1}. All stations within the Nyanza Gulf had concentrations above 55 µg l^{-1} while those of the open lake had concentrations less than 55 µg l^{-1}. Concentrations of SRP showed significant positive correlations with conductivity ($r = 0.65$; $P < 0.01$); nitrite ($r = 0.67$; $P < 0.01$) and a significant negative correlation with secchi ($r = -0.53$; $P < 0.01$). Total nitrogen concentrations measured between 204.18 and 2349.64 µg l^{-1} at Bala Rawi and Kisumu Bay respectively; and with a mean concentration of 511.61 µg l^{-1} (Fig. 2a). Maboko had the second highest concentration of TN. Higher TN concentrations were observed within the gulf than in the open lake. TN showed significant positive correlation with conductivity ($r = 0.57$; $P < 0.01$) and a very strong positive correlation with ammonium ($r = 0.92$; $P < 0.01$).

The concentrations of Total Phosphorus (TP) varied from 26.29 to 192.00 µg l^{-1} in Kuja RM and Oluch RM respectively with mean of 92.75 µg l^{-1} (Fig. 2b). The open lake had lower concentrations than Nyanza Gulf stations. The concentration of TP had significant positive correlation with the nitrite ($r = 0.59$; $P < 0.01$) and SRP ($r = 0.82$; $P < 0.01$). The TN in 2013 sampled stations was higher only in Kisumu Bay and Maboko than in the 2012

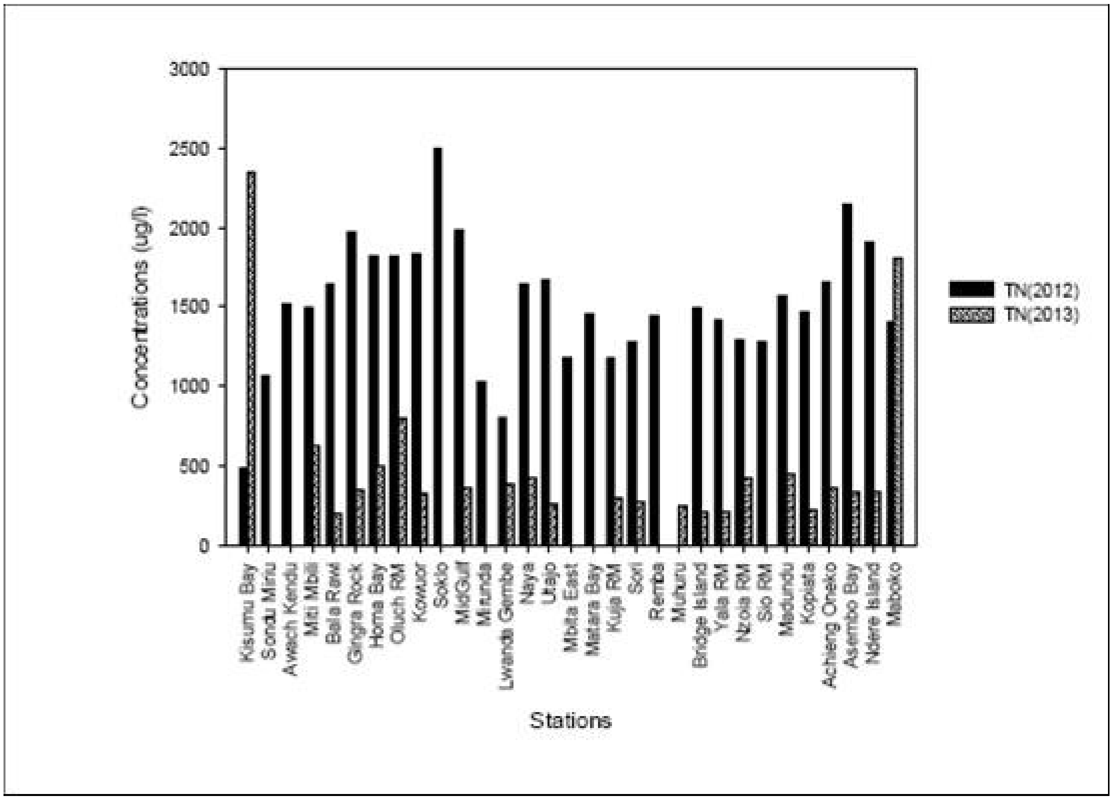


Figure 2a: Spatio-temporal distribution of Total Nitrogen (TN) between sampled stations

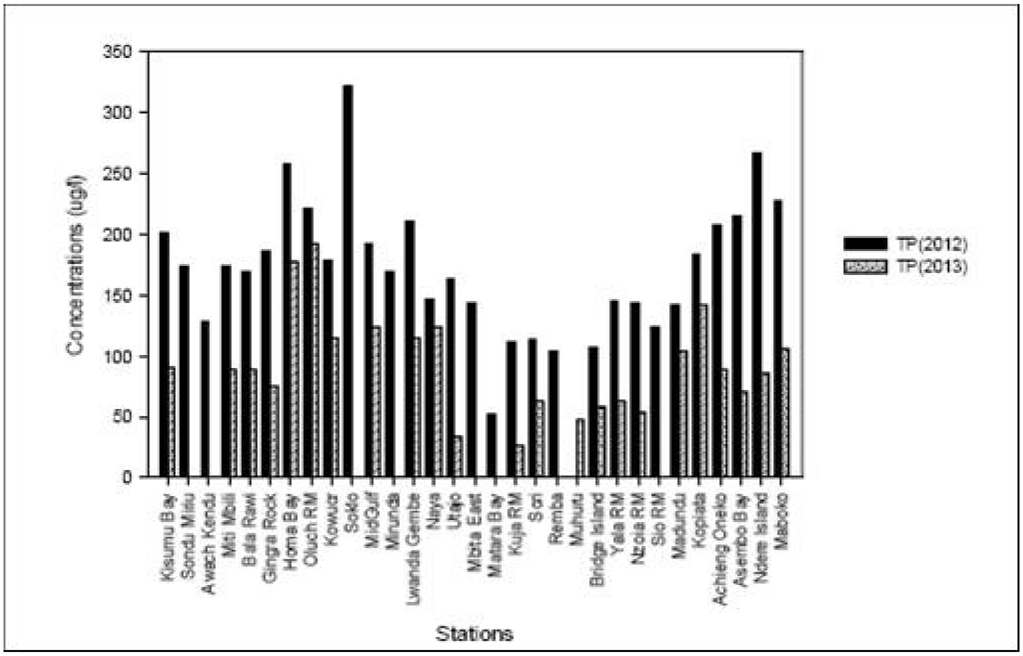


Figure 2b: Spatio-temporal distribution of Total Phosphorus (TP) between sampled stations

Nitrate concentrations had a spatial variation ranging between 11.30 and 197.97 µg l^{-1} at Utajo and Kisumu Bay, respectively with a mean of 56.17 µg l^{-1}. Nitrate concentrations were more than the ammonium concentrations in all the stations except the outer gulf stations of Lwanda Gembe, Naya and

Utajo; Oluch RM, Yala RM and Kuja RM; and stations along the advection current pathway of Kisumu Bay and Maboko. Most mid gulf stations had higher concentrations of nitrates than those of NH_4^+. Nitrates had a significant positive correlation ($r = 0.79$; $P < 0.01$) with conductivity. Nitrite concentrations varied between 2.52 and 21.30 µg l^{-1} at Utajo and Homa Bay, respectively with a mean of 11.94 µg l^{-1}. Nyanza Gulf exhibited higher concentrations of nitrite than the open lake stations. Nitrite showed significant negative correlation with temperature ($r = -0.63$; $P < 0.01$) and secchi ($r = -0.69$; $P < 0.01$); significant positive correlation with conductivity ($r = 0.54$; $P < 0.01$); SRP ($r = 0.67$; $P < 0.01$); TP ($r = 0.59$; $P < 0.01$) and Silica (SiO_4^-) ($r = 0.53$; $P < 0.01$). Ammonium concentrations recorded varied from 2.50 to 390.63 µg l^{-1} at Achieng Oneko and Kisumu Bay respectively; and with a mean of 66.52 µg l^{-1}. Maboko station had the second highest concentration. The open lake waters had lower concentrations compared to the gulf. Apart from stations influenced by sewage transport pathway and river mouths; the outer gulf exemplified higher concentrations of ammonium than mid and inner gulf stations. Ammonium had a very strong positive correlation ($r = 0.92$; $P < 0.01$) with TN. Silica ranged between 1.35 and 23.41 mg l^{-1} at Muhuru and Ndere Island, respectively with a mean of 13.02 mg l^{-1}. There was progressive decrease in silica concentrations from the inner gulf to the outer gulf. The gulf concentrations were generally higher than the open lake. Silica exemplified significant negative correlation with depth ($r = -0.51$; $P < 0.01$) and secchi ($r = -0.58$; $P < 0.01$); and a significant positive correlation with conductivity ($r = 0.54$; $P < 0.01$) and nitrite ($r = 0.53$; $P < 0.01$).

Chlorophyll *a* concentrations ranged from 1.45 to 38.86 µg l^{-1} with a mean of 13.50 µg l^{-1} (Fig. 3). The highest concentration was recorded at Asembo Bay while the least concentration was at Oluch RM and Nzoia RM. Generally, river mouths had low concentrations of chlorophyll *a* while the bays had high concentration than other stations. Chlorophyll *a* in 2013 was higher only in Kowuor and Kuja RM than in 2012

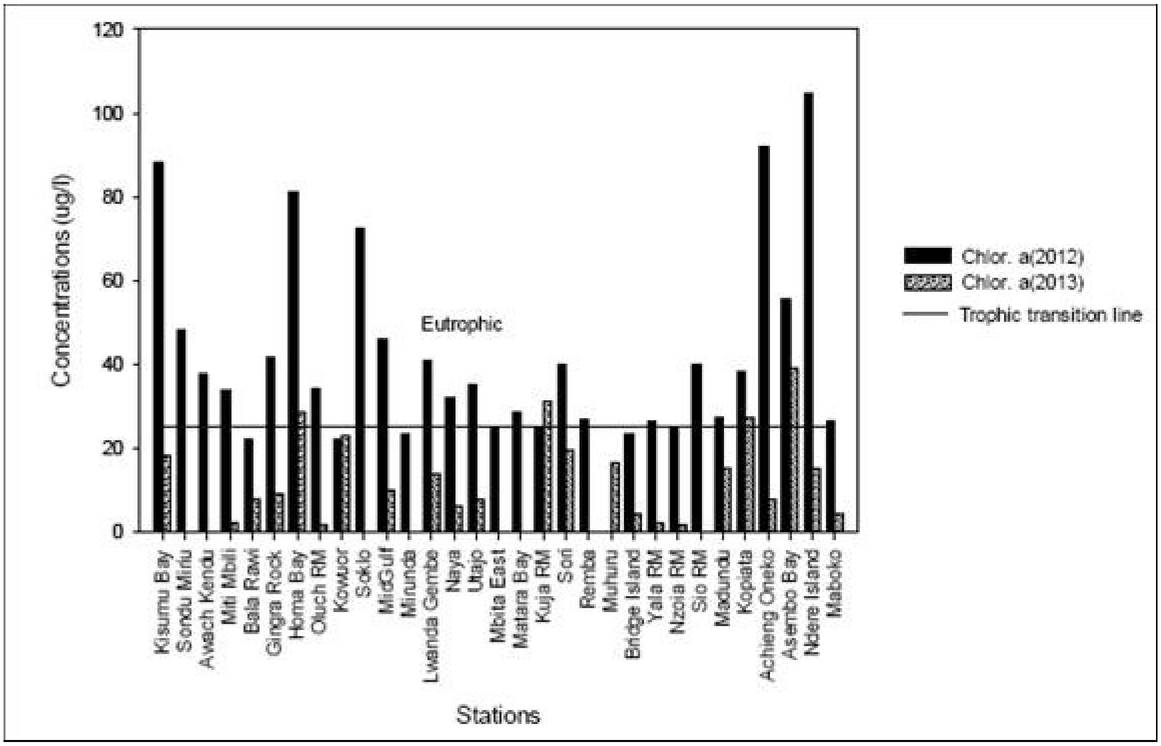


Figure 3. Spatio-temporal variations of chlorophyll-*a* in the sampled stations.

Nutrient concentrations were generally high in the 2012 data than in the 2013

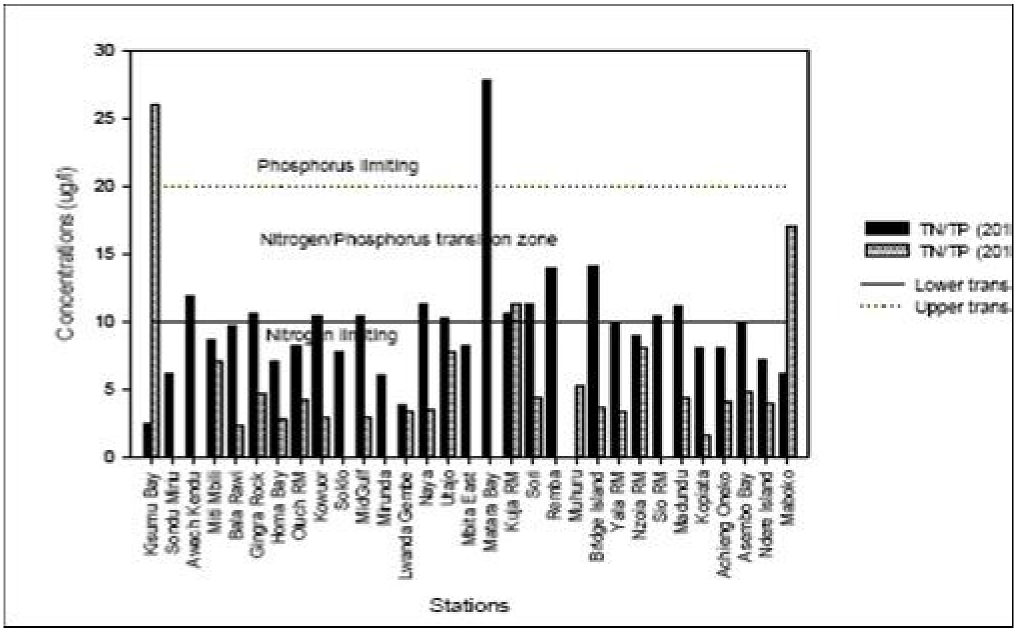


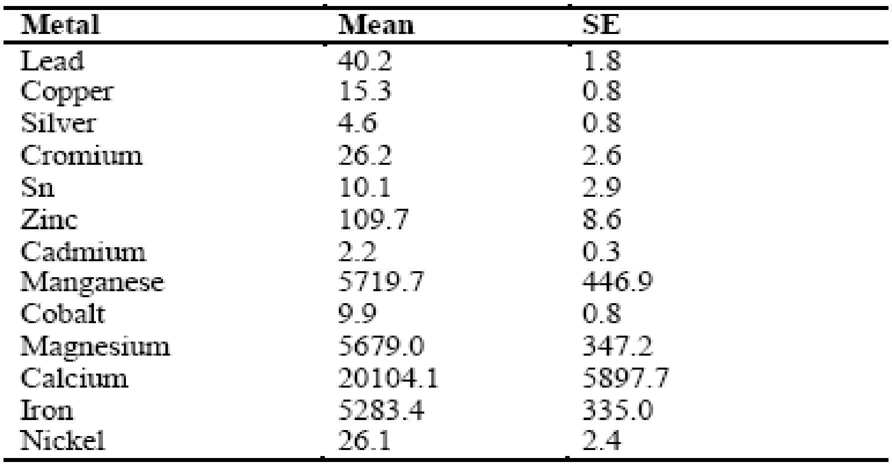
Figure 4. TN: TP ratios as a measure of nitrogen or phosphorus limitation across sampled stations.

3.2 Trace Metals

Table 1 shows the mean concentration levels of metals tested in the < 63 µm surficial lake sediments.

Mean concentration of Pb ranged from 18.3 to 59.3 µg g-1 DW at Yala RM and Bala Rawi, respectively with a mean of 40.2± 1.8 µg g^{-1} DW. The concentration of Cu was lowest at Yala RM with a concentration of 3.5 µg g^{-1} DW and highest at Utajo (20.8 µg g^{-1} DW) with a mean of 15.3± 14.8 µg g^{-1} DW. The mean value of Nickel concentration was 26.1± 2.4 µg g^{-1} DW with the highest of 59.3µg g^{-1} DW recorded at Achieng' Oneko and the lowest of 9.3 µg g^{-1} DW at Yala RM.

Table 1. Mean and SE for metal concentrations in the sediments



Metal	Mean	SE
Lead	40.2	1.8
Copper	15.3	0.8
Silver	4.6	0.8
Cromium	26.2	2.6
Sn	10.1	2.9
Zinc	109.7	8.6
Cadmium	2.2	0.3
Manganese	5719.7	446.9
Cobalt	9.9	0.8
Magnesium	5679.0	347.2
Calcium	20104.1	5897.7
Iron	5283.4	335.0
Nickel	26.1	2.4

The stations with the most strikingly high sediment metal values for lead are Kisumu Bay, Miti Mbili, Muhuru Bay and Gingra. Miti Mbili also had the highest concentration of lead in water than all the other stations (Fig. 5). 57.1% of Pb values had EF values of < 1, while the highest EF was 1.47. The stations that showed the highest enrichment were Muhuru Bay (1.47), Bala Rawi (1.14), Kopiata (1.13), Kisumu Bay (1.28), Gingra and Kuja RM (1.24).

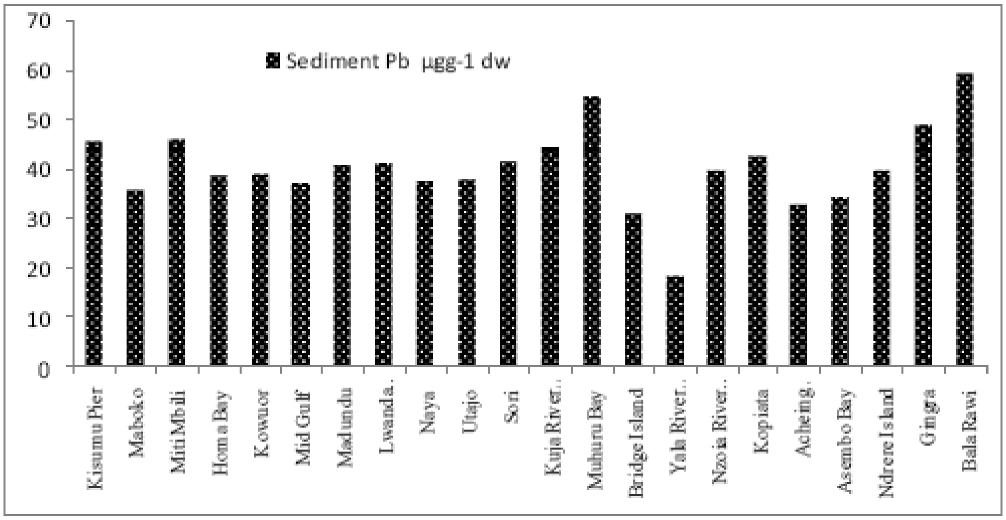


Figure 5. Concentrations of Pb in sediments at different sampling stations

Nzoia RM and Kopiata were the most enriched in Chromium concentrations in sediments than other stations followed by Kowuor and Miti Mbili. 61.9% of the samples had Chromium EF of less than 1. The highest enrichment of EF of 2.32 was observed at Kopiata with Miti Mbili, Kowuor, Nzoia River Mouth, Bala Rawi, and Asembo Bay also having EFs of 1.19, 1.25, 2.29, 1.11 and 1.15, respectively.

Undetectable levels (ND) of elemental Tin was recorded in sediments collected in many stations such as Maboko, Miti mbili, Utajo and Nzoia RM as well as Ndere Island. In water Mid Gulf had the highest figures followed by Yala RM. The highest sediment tin concentrations were recorded at Gingra and Asembo Bay followed by Sori and Kowuor. Sn showed indication of over enrichment in some stations while a few also had evidence of depletion. About 66.6% of the samples had EF below 1. While Kisumu Bay and Yala RM exhibited Tin depletion of -85.79 and – 0.94 respectively, the former being strikingly so high, other stations like Kuja RM, Muhuru Bay, Asembo Bay, Gingra, Bala Rawi, Bridge Island and Sori had over enrichment with tin. The highest EF (18.46) for tin recorded at Kuja RM was well out of range with the rest of the stations with Tin enrichment. There were also some stations where the presence of tin in the sediments was not detectable. This could imply that the quantities present were too low to be measured by instrumental analysis.

Cadmium was mostly found in sediments from Lwanda Gembe, Homa Bay, Kowuor, Naya and Gingra in that order (Fig.6). The values measured for Cadmium showed enrichment above EF of 1 in 53% of the stations with the highest EF of 1.86 at Lwanda Gembe. Mercury concentrations in sediments showed an increasing trend down the transect from Kisumu Bay to the open waters and the Northern shores with the highest values being recorded at Gingra, Ndere, Asembo Bay, Achieng' Oneko, Kopiata, Nzoia RM and Yala RM. In the Southern Shoreline, Sori and Kuja RM had the highest values. About half 50% of the measured stations for Mercury (Hg) indicated no enrichment (EF < 1). The highest enrichment of EF = 1.54 was observed at Gingra. Also exhibiting EF > 1 for mercury are Asembo Bay (1.31), Ndere Island (1.29), Achieng Oneko (1.28), Sori (1.25), Kopiata (1.22), Nzoia RM (1.13), Kuja RM (1.11).

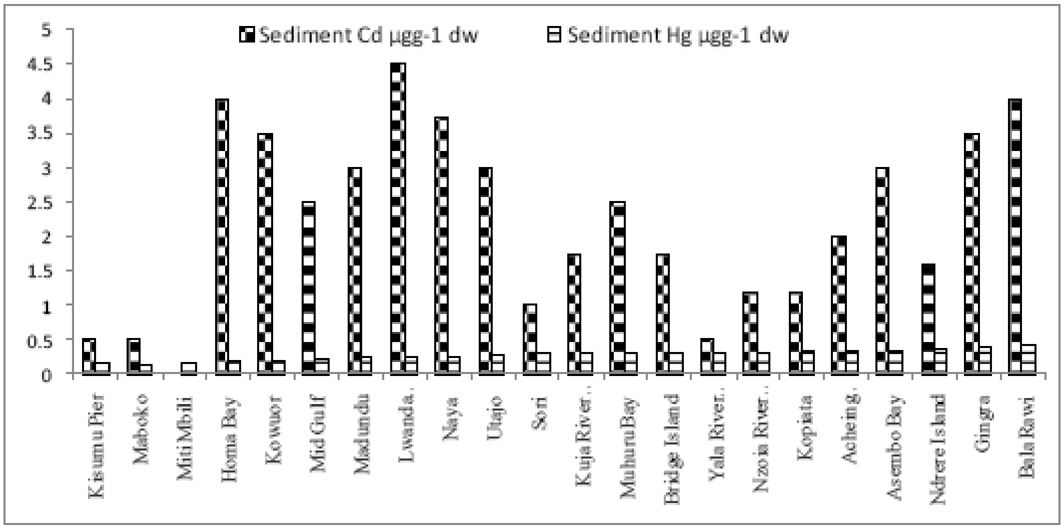


Figure 6. Concentrations of Cadmium and Mercury in sediments at different sampling stations

Lwanda Gembe sediments had the highest concentrations of Manganese followed by Kowuor, Homa Bay and Sori. Kuja RM had the least concentrations (Fig.7). Manganese showed the highest enrichment of EF = 1.44 at Kisumu Bay which was among some 67% of samples with EF above 1. Iron was highest in Achieng' Oneko followed by Miti Mbili and Kowuor (Fig 7). Iron (Fe) had only 47% of the values falling below EF of 1. However, only Achieng Oneko had a strikingly high EF of 1.45.

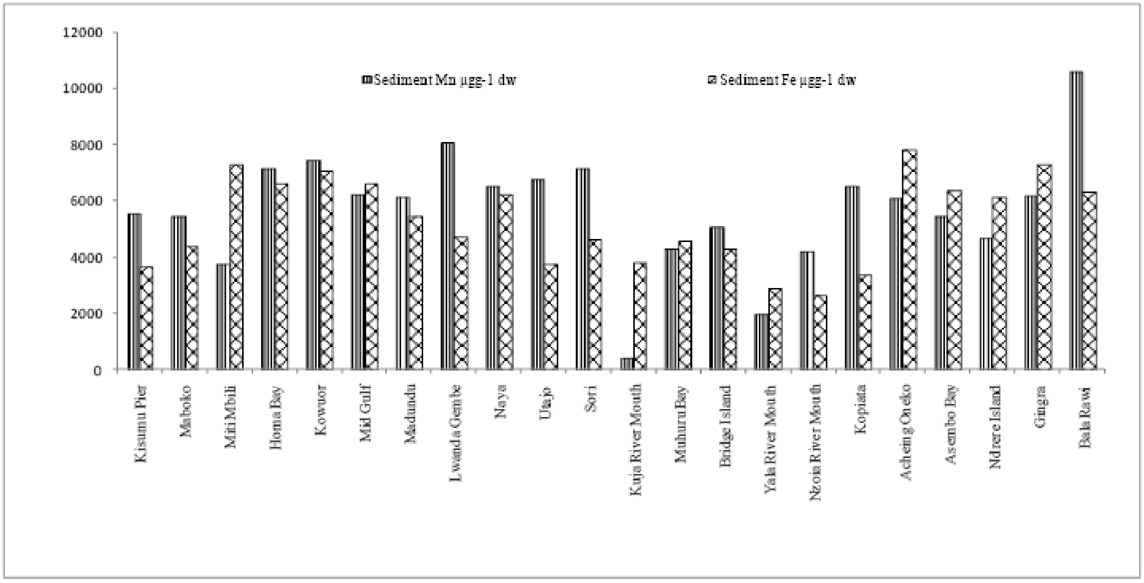


Figure 7. Concentrations of Iron and Manganese in sediments at different sampling stations

3.2.1 Risk assessment

Effects Range-Low (ERL) Effects Range-Median (ERM)

Based on ERL and ERM scheme, 89%, 34.4%, 30.1% and 1% of surface sediment samples had concentrations above ERL for Pb, Zn, Ni and Hg respectively and 1% for Ni was above ERM. There were no values near or above TET for Pb, Cu, Zn and Ni. About 24% of the values for Cd were above TET. This indicates that the effects of most metals of ecotoxicological importance in the sediments are of acceptable levels except for Pb, Zn, Ni and Hg with lead having the highest risk of over-enrichment and hence the risk adverse effects on the biota.

3.3 Phytoplankton composition, distribution and relative numerical abundance

Cyanophyceae were the most dominant group, contributing up to 98.7 % in some sites with an average of 56% to the total phytoplankton density in all sites (Fig.8). Average contributions of other taxonomic groups were, Bacillariophyceae (22%), Chlorophyceae (21%) with Euglenophyceae, Dinophyceae and Zygnematophyceae contributing < 5% of the total phytoplankton density. Although Cyanobacteria were widespread throughout the lake, they were more abundant in the gulf (26-99%) with a few exceptions (Miti Mbili, 0% and Lwanda Gembe, 8%) compared to the open lake. The most dominant blue-green algae in the lake were *Microcytis aeruginosa* and *Anabaena* spp. Other prevalent blue-greens were *Planktolynbya* spp, *Aphanocapsa* spp, *Cylindrospermosis* sp, *Coelomoron* sp and *Merismopedia* sp.

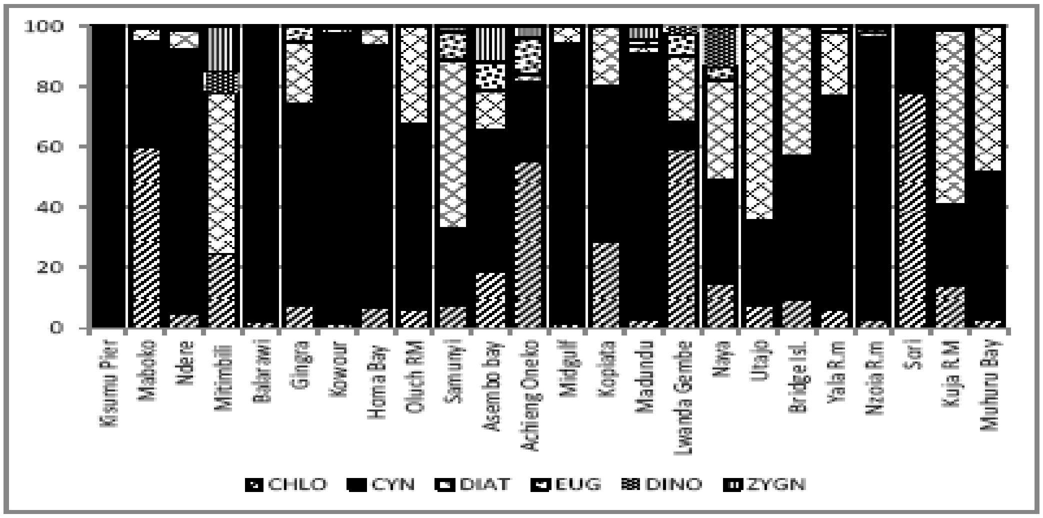


Figure 8. Percentage composition of phytoplankton (cells l^{-1}) at different sampling stations

3.3.1 Phytoplankton numerical abundance

Higher numerical algal abundances were recorded in the Nyanza Gulf stations compared to the open lake (Fig. 9). The abundance in the gulf ranged between 5.3 x 106 cells l^{-1} at Lwanda Gembe to a maximum of 287.7 x 106 cells l^{-1} at Kowuor with an average of 61x106 cells l^{-1}. The abundances in the main lake ranged from 5.9 x 106 cells l^{-1}at Muhuru Bay to a maximum of 14.6 x x106 cells l^{-1} at Sori.

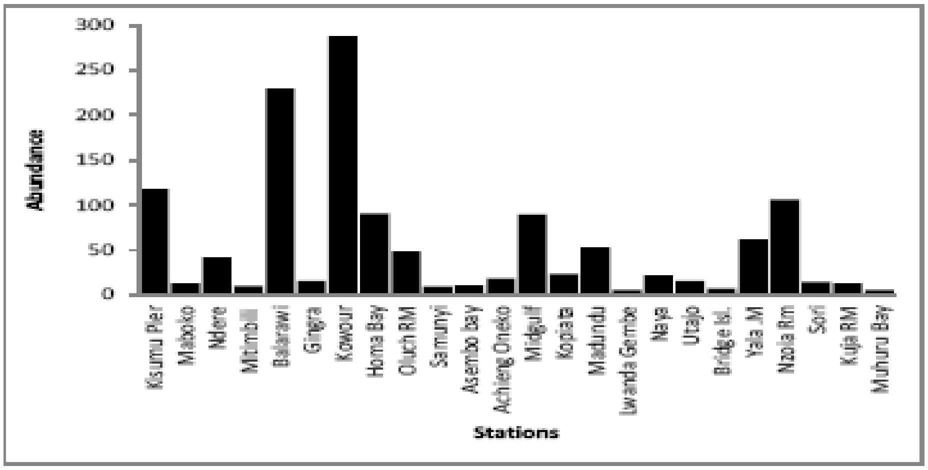
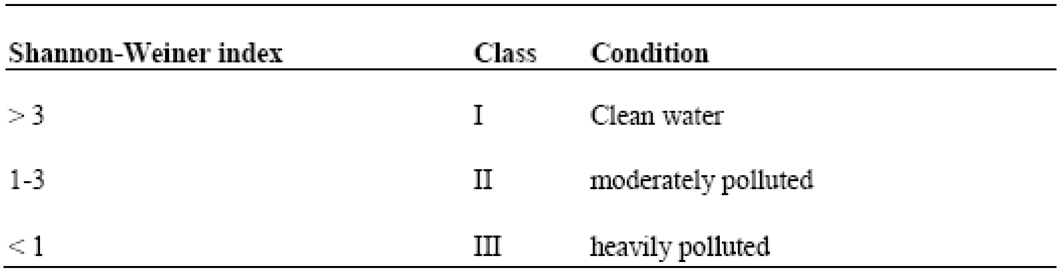


Figure 9. Phytoplankton density in cells per litre (cells x 10_6) at different sites of the lake.

3.3.2 Species Diversity indices

The *H'* values in the sampled stations of the lake ranged between 0.24-1.11. Generally lower values were realized in stations with high algal abundance (e.g. Kisumu Bay (0.41), Bala Rawi (0.52), Kowuor (0.36), Homa Bay (0.40), Madundu (0.52) Mid Gulf (0.24) all in the gulf and Nzoia RM (0.46) in the open waters. Wilhum (1975) define three water quality classes for Shannon-Weaver diversity index as shown in Table 2, which implies that the high *H'* value suggests the more healthy ecosystem (less pollution) while the low *H'* value suggests poor diversity in a community and a less healthy ecosystem (more pollution). Given the classification in the table and the value derived in this study, it is apparent that Lake Victoria, Kenyan waters can only be classified into class II and class III as moderately and heavily polluted.

Table 2. Water quality classes for Shannon-Weiner index



Shannon-Weiner index	Class	Condition
> 3	I	Clean water
1-3	II	moderately polluted
< 1	III	heavily polluted

3.4 Zooplankton composition, distribution and abundance

The highest number (density) of total zooplankton recorded was 475 and 192 individuals' l^{-1} at Kisumu pier and Oluch river mouth, respectively. The lowest abundance was realized at Muhuru Bay with a density of 41 individuals l^{-1} (Fig. 10). Zooplankton abundance was generally higher in the gulf than in the open waters. It was also noted that all the peak abundances in the lake were at river mouths and sheltered bays.

The highest number of taxa (s) was found in Kisumu Bay followed by Maboko with a total of 15 and 13 species, respectively while the lowest was in Bala Rawi and Madundu both realising 6 species. Cladocera and rotifer contributed 6 and 12 species, respectively. Shannon-Weiner index (*H'*) was on the other hand highest in Maboko and lowest in Naya with indices of 1.79 and 1.09, respectively.

Copepoda dominated zooplankton community in all the stations sampled with a composition ranging from 81.4% to 97.7% at Kisumu and Bridge Island respectively (Fig. 11). The proportions of Cladocera ranged from 1.77 to 16.1% in Bridge Island and Bala Rawi, respectively while rotifer composition ranged between 0.3 to 7.9 % in Mid Gulf and Samunyi, respectively.

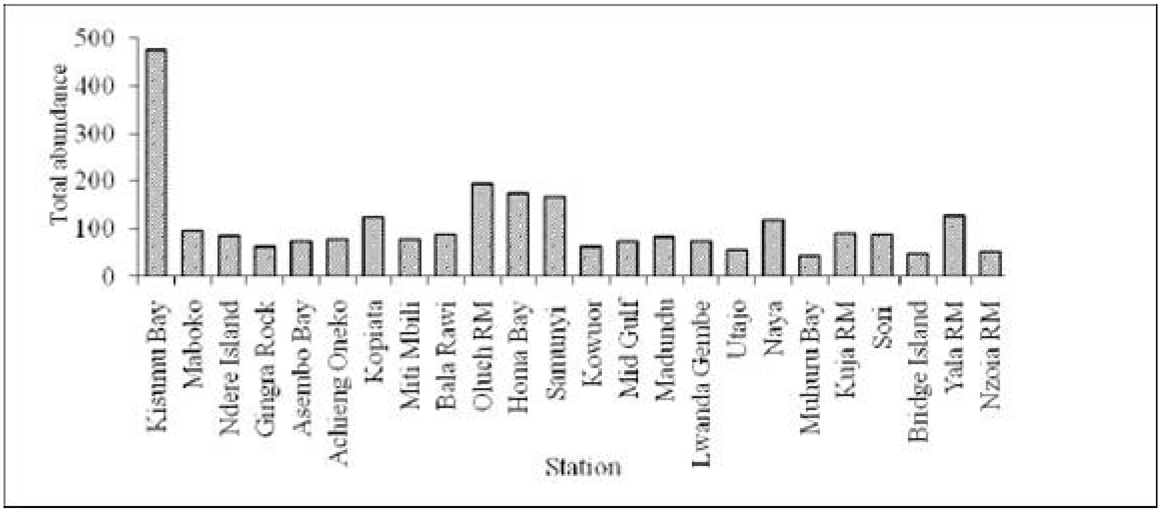


Figure 10. Total abundance of the zooplankton in stations sampled

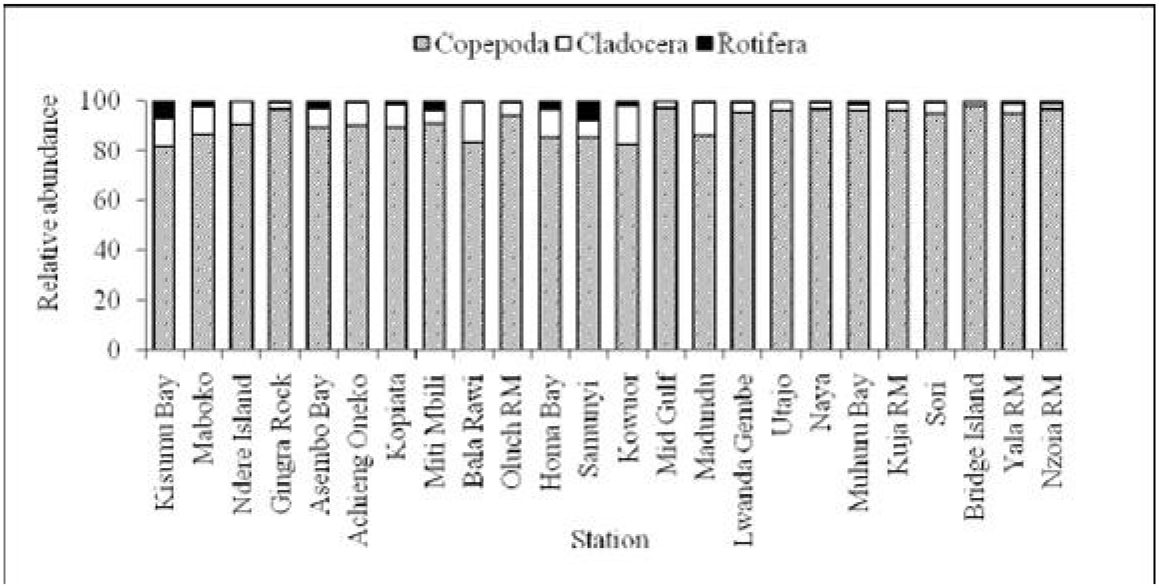


Figure 11. Relative abundance of major groups of zooplankton, in the stations sampled.

Copepoda, was dominated by nauplii with a composition ranging from 28.5% in Achieng' Oneko to 76.4% in Samunyi RM. Cyclopoida proportion ranged from 21.5% to 52.9% in Miti Mbili and Utajo, respectively while Calanoida ranged from 0.85 to 8.37 in Samunyi and Bridge Island, respectively. Rotifers were dominated by *Keratella tropica.* The only species encountered in Sori, Bridge Island and Ndere was *K. tropica*. Another station where only one species of rotifer was found was Bala Rawi (*Euchlanis* sp). *B. quadridentatus* was only found in Kisumu Bay while *Lecane* spp, littoral species, were recorded in two deep stations in the gulf; Ndere and Kopiata.

3.5 Micro-contaminants

3.5.1 Levels of total and fecal coliforms in gulf waters

It was established that the concentration of total coliforms in the 18 stations sampled in the gulf waters ranged between 3 and 800 (± 424) cfu/100ml in Madundu and Kisumu Bay respectively (Fig.12). On the other hand, fecal coliforms levels were highest in Kisumu Bay ranging from undetectable levels to 150 (±70) cfu/100ml. Homa Bay station also had some remarkably high levels of fecal coliforms of 120 (±56) cfu/100ml. The rest of the stations had low levels of fecal coliforms with stations such as Kowour, Utajo, Kopiata, Achieng Oneko, Asembo Bay, Ndere Island and Bala Rawi recording no coliforms counts (Fig.12).

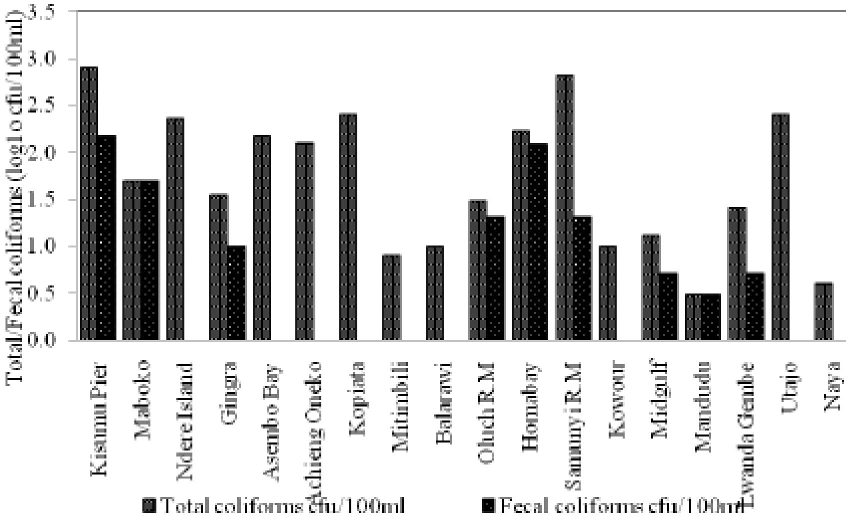


Figure 12. Stations in the gulf waters showing the levels of total and fecal coliforms expressed as log10 cfu/100 ml.

3.5.2 Levels of total and fecal coliforms in the open waters

In the open waters, total coliforms counts ranged between 1-50 (±14) cfu/100 ml. Sori Bay and Yala RM had high levels of 50 (±14) cfu/100 ml and 45 cfu/100 ml respectively. Nzoia RM had 12 cfu/100 ml while Muhuru Bay, Kuja and Bridge Island recorded 2 cfu/100 ml. Fecal coliforms were only detected in Yala RM with a count of 5 cfu/100 ml (Fig .13).

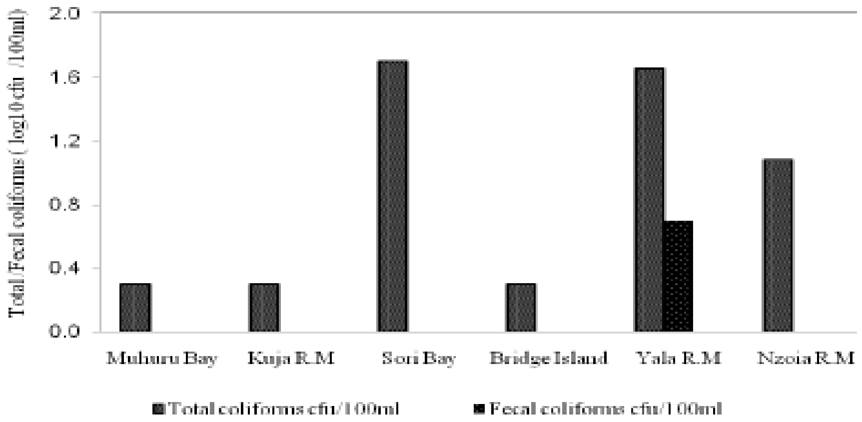
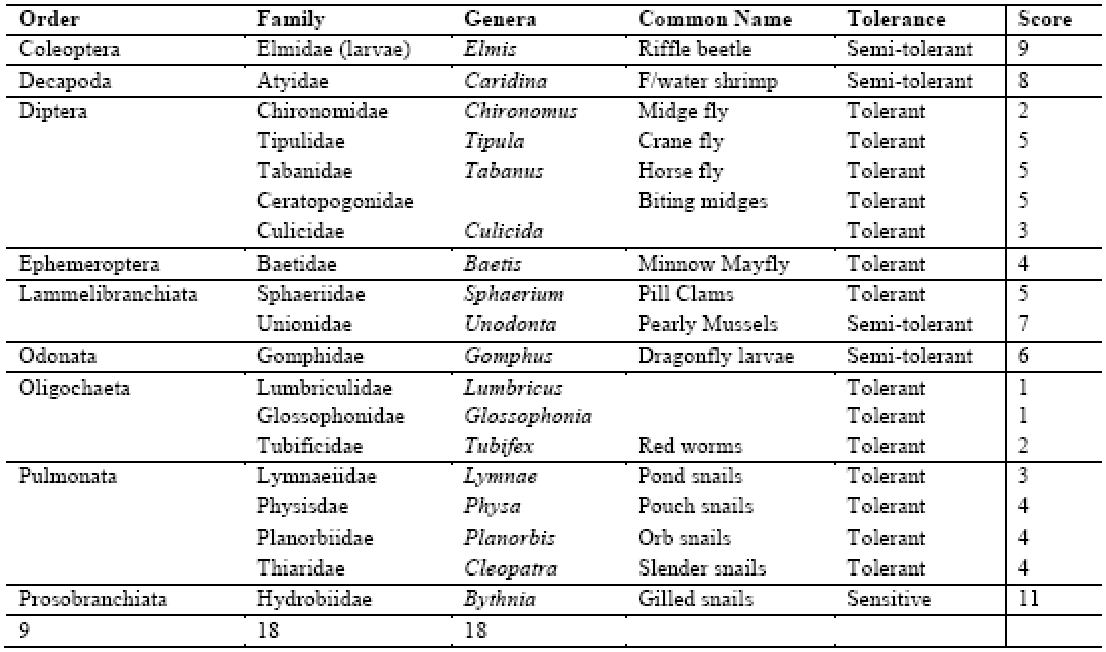


Figure 13. Stations in the open waters showing the levels of total and fecal coliforms expressed as log10 cfu/100 ml.

3.6 Macroinvertebrate Composition

A total of 9 orders, which were further grouped into 18 families and 18 genera were sampled during the period (Table 3). The orders Diptera and Pulmonata had the highest number of genera (4 and 5 respectively). Out of the 18 genera identified, 13 were pollution tolerant, while 4 were moderately tolerant. The only sensitive genus sampled was *Bythnia* sp. (Gilled snail).

Table 3. List of Macroinvertebrates realized from sampled stations in Lake Victoria. (Scores 1-5 are tolerant taxa, 6-10 are semi-tolerant while 11-15 are pollution sensitive)



Order	**Family**	**Genera**	**Common Name**	**Tolerance**	**Score**
Coleoptera	Elmidae (larvae)	*Elmis*	Riffle beetle	Semi-tolerant	9
Decapoda	Atyidae	*Caridina*	F/water shrimp	Semi-tolerant	8
Diptera	Chironomidae	*Chironomus*	Midge fly	Tolerant	2
	Tipulidae	*Tipula*	Crane fly	Tolerant	5
	Tabanidae	*Tabanus*	Horse fly	Tolerant	5
	Ceratopogonidae		Biting midges	Tolerant	5
	Culicidae	*Culicida*		Tolerant	3
Ephemeroptera	Baetidae	*Baetis*	Minnow Mayfly	Tolerant	4
Lammelibranchiata	Sphaeriidae	*Sphaerium*	Pill Clams	Tolerant	5
	Unionidae	*Unodonta*	Pearly Mussels	Semi-tolerant	7
Odonata	Gomphidae	*Gomphus*	Dragonfly larvae	Semi-tolerant	6
Oligochaeta	Lumbriculidae	*Lumbricus*		Tolerant	1
	Glossophonidae	*Glossophonia*		Tolerant	1
	Tubificidae	*Tubifex*	Red worms	Tolerant	2
Pulmonata	Lymnaeiidae	*Lymnae*	Pond snails	Tolerant	3
	Physisdae	*Physa*	Pouch snails	Tolerant	4
	Planorbiidae	*Planorbis*	Orb snails	Tolerant	4
	Thiaridae	*Cleopatra*	Slender snails	Tolerant	4
Prosobranchiata	Hydrobiidae	*Bythnia*	Gilled snails	Sensitive	11
9	18	18			

A total of 2723 macroinvertebrate individuals were recorded during the monitoring. The order Lamellibranchiata (Bivalves) accounted for over 70%. Certain orders such as Ephemeroptera, Ampipoda, Odonata and Coleoptera, though observed had a relative abundance less than 1% (Fig. 14).

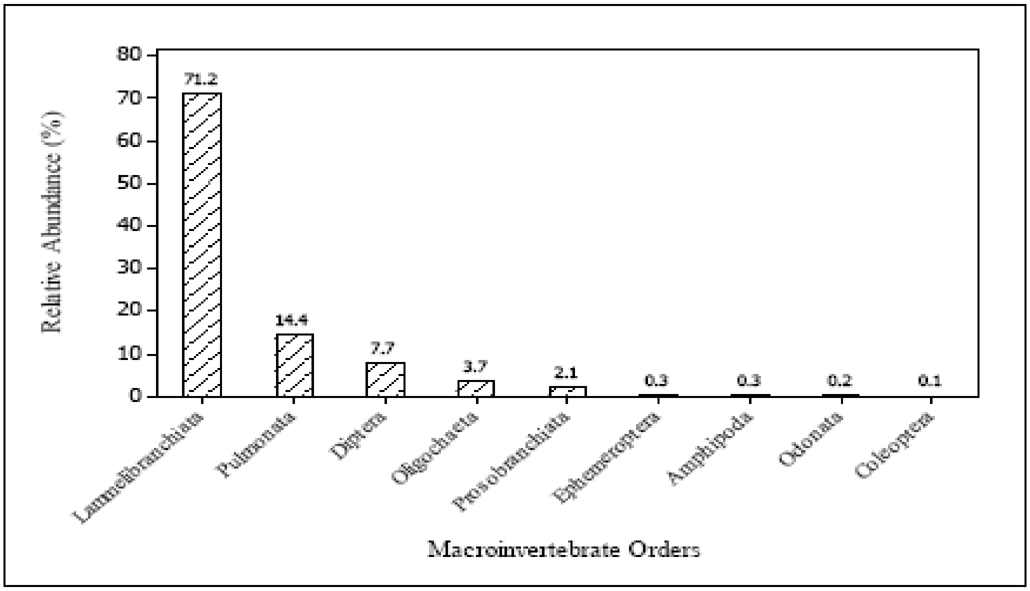


Figure 14. Relative abundance of macroinvertebrate orders sampled within Lake Victoria

3.6.1 Tolerance Status

Based on the results, majority of the benthic macroinvertebrates sampled were pollution tolerant (94.6%). The intolerant and semi-tolerant taxa accounted for the remaining 5.4% (3.2% and 2.2%, respectively). Bride Island and Homa Bay stations differed from other stations as sites with few tolerant taxa. Bridge Island however had almost equal proportion of tolerant and semi-tolerant taxa while Homa Bay had only the tolerant ones. All the river mouths clustered together depicted an extent of similarity.

Multivariate analysis (PCA) showed that Bridge Island was associated more with the semi-tolerant taxa, which made the station completely different from other stations (Fig. 15). Although all the other stations associated with the tolerant, Kisumu Bay was relatively more associated with the tolerant taxa than other stations.

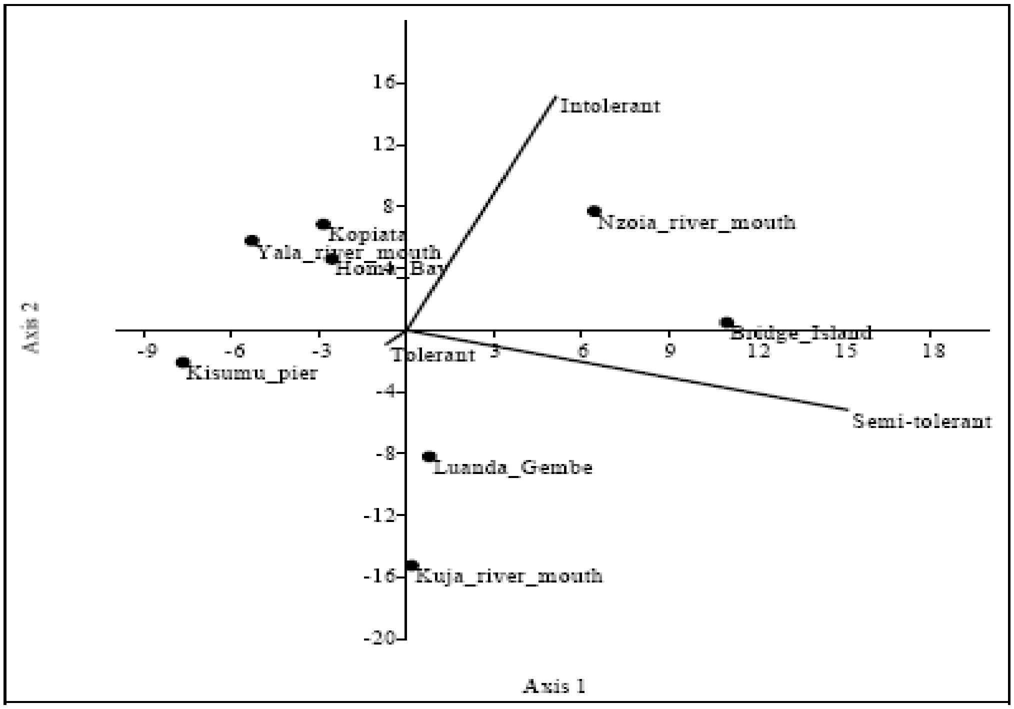


Figure 15. Relationship between tolerance status and sampling stations within Lake Victoria

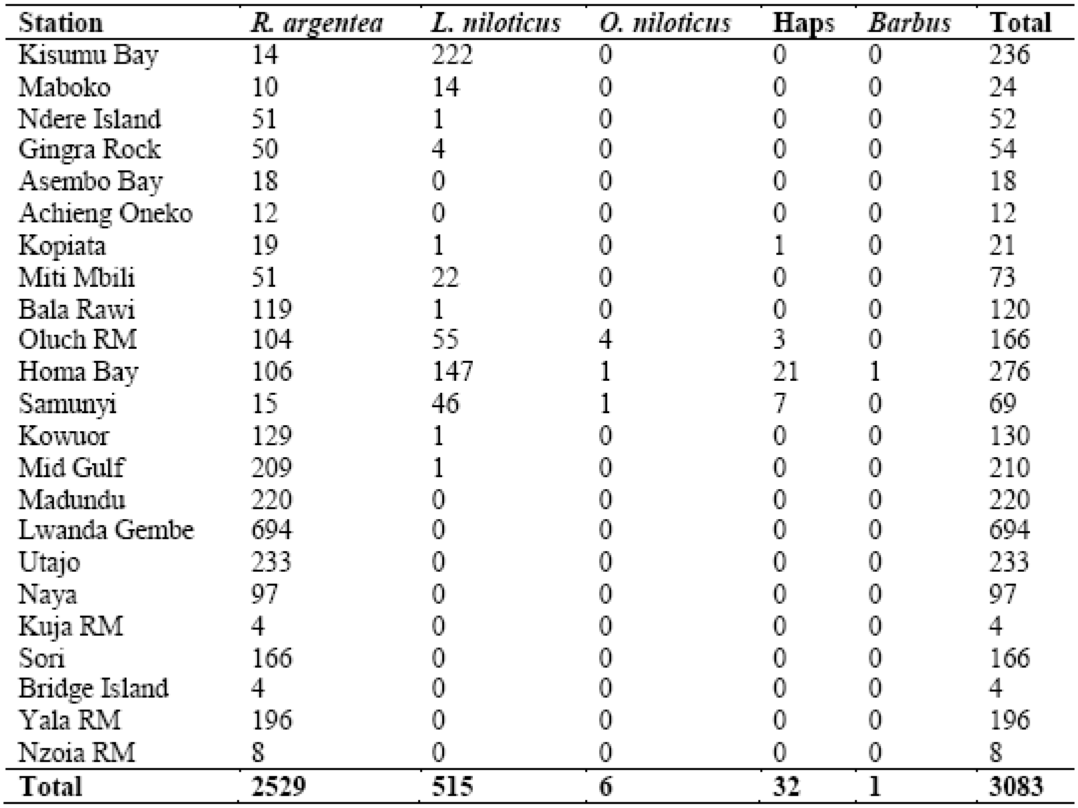
3.7 Fisheries

3.7.1 Larvae abundance and distribution

A total of 3083 fish larvae were caught from ichthyoplankton tows using 500µm and 100 µm nets (Table 4). The egg and larval survey, collections were done at 23 different stations resulting into five categories of fish larvae. These included *Rastrineobola argentea*, *Lates niloticus*, *Oreochromis niloticus,* haplochromines and *Barbus* spp. *R. argentea* were encountered in all the 23 stations, *L. niloticus* in 12 stations, haplochromines in four stations, *O. niloticus* in three stations, and *Barbus* spp. was caught in one station only. The highest number of species i.e. 5 spp., was caught at Homa Bay sewage. Samunyi and Oluch RM realised 4 species. Three fish species were encountered at Kopiata. Nineteen (19) stations (8 had between two and one species (8 and 11 spp. respectively).

Bottom trawl surveys realized a total of 9 fish species: *R. argentea, L. niloticus, O. niloticus, S. victoriae, Bagrus docmak, Barbus* spp, *Brycinus sadleri, Clarias gariepinus, Barbus neumayeri* and the young of *Schilbe intermedius* together with *Caridina nilotica* were also recorded in the cod end trawl net. *Lates niloticus* dominated the fish catches in most areas sampled, with more fish realized in the open water stations than in the gulf.

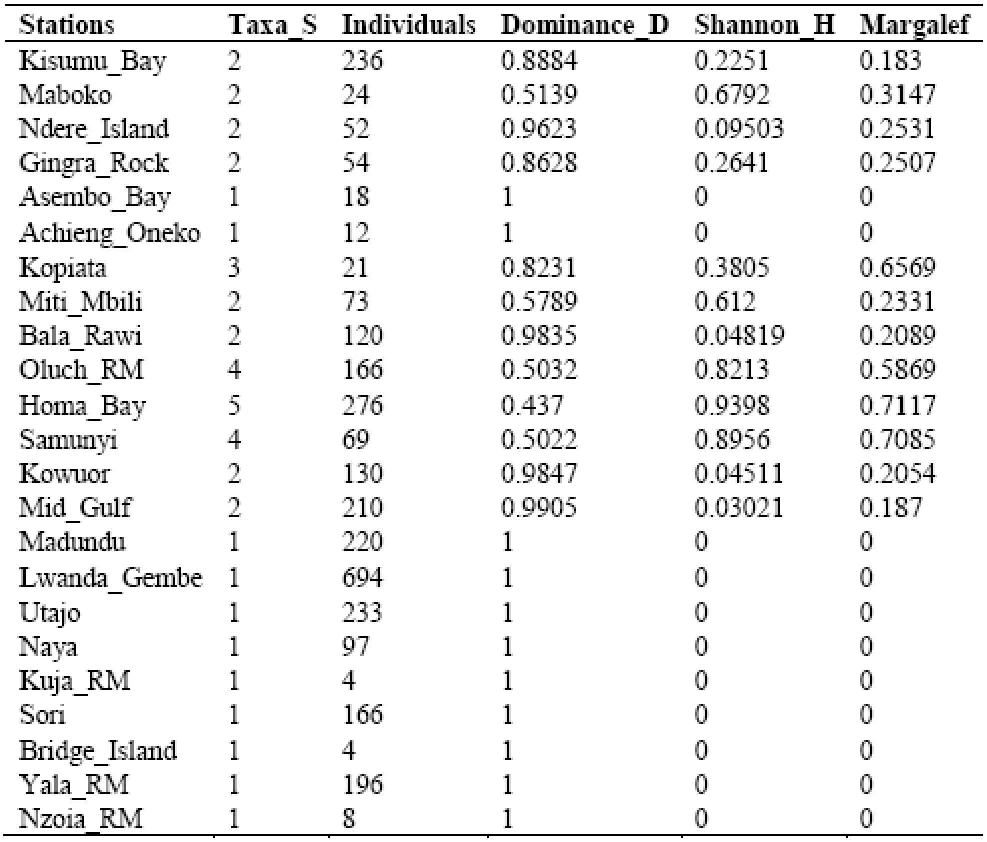
Table 4. Ichthyoplankton fish species counts and totals at stations sampled in Lake Victoria, Kenya



Station	*R. argentea*	*L. niloticus*	*O. niloticus*	Haps	*Barbus*	Total
Kisumu Bay	14	222	0	0	0	236
Maboko	10	14	0	0	0	24
Ndere Island	51	1	0	0	0	52
Gingra Rock	50	4	0	0	0	54
Asembo Bay	18	0	0	0	0	18
Achieng Oneko	12	0	0	0	0	12
Kopiata	19	1	0	1	0	21
Miti Mbili	51	22	0	0	0	73
Bala Rawi	119	1	0	0	0	120
Oluch RM	104	55	4	3	0	166
Homa Bay	106	147	1	21	1	276
Samunyi	15	46	1	7	0	69
Kowuor	129	1	0	0	0	130
Mid Gulf	209	1	0	0	0	210
Madundu	220	0	0	0	0	220
Lwanda Gembe	694	0	0	0	0	694
Utajo	233	0	0	0	0	233
Naya	97	0	0	0	0	97
Kuja RM	4	0	0	0	0	4
Sori	166	0	0	0	0	166
Bridge Island	4	0	0	0	0	4
Yala RM	196	0	0	0	0	196
Nzoia RM	8	0	0	0	0	8
Total	**2529**	**515**	**6**	**32**	**1**	**3083**

The Shannon diversity index of fish larvae ranged from 0 to 0.9398 among stations (Table 5) with the highest value observed in Homa Bay. Simpson's Dominance ranged from 0 to1 while Margalef index ranged from 0 to 0.7117 in Homa Bay.

Table 5. Fish larvae diversity indices



Stations	Taxa_S	Individuals	Dominance_D	Shannon_H	Margalef
Kisumu_Bay	2	236	0.8884	0.2251	0.183
Maboko	2	24	0.5139	0.6792	0.3147
Ndere_Island	2	52	0.9623	0.09503	0.2531
Gingra_Rock	2	54	0.8628	0.2641	0.2507
Asembo_Bay	1	18	1	0	0
Achieng_Oneko	1	12	1	0	0
Kopiata	3	21	0.8231	0.3805	0.6569
Miti_Mbili	2	73	0.5789	0.612	0.2331
Bala_Rawi	2	120	0.9835	0.04819	0.2089
Oluch_RM	4	166	0.5032	0.8213	0.5869
Homa_Bay	5	276	0.437	0.9398	0.7117
Samunyi	4	69	0.5022	0.8956	0.7085
Kowuor	2	130	0.9847	0.04511	0.2054
Mid_Gulf	2	210	0.9905	0.03021	0.187
Madundu	1	220	1	0	0
Lwanda_Gembe	1	694	1	0	0
Utajo	1	233	1	0	0
Naya	1	97	1	0	0
Kuja_RM	1	4	1	0	0
Sori	1	166	1	0	0
Bridge_Island	1	4	1	0	0
Yala_RM	1	196	1	0	0
Nzoia_RM	1	8	1	0	0

3.8 Multivariate analysis

The PCA analysis indicated that there was a clear separation of gulf and open lake stations (Fig. 16). On PCA 1, the variation was best explained by the quantity of fecal coliforms, *L. niloticus* larvae and most of the zooplankton groups. Kisumu Bay and Homa Bay were clearly apart from the rest of the station exhibiting high levels of the mentioned attributes. On PCA 2 the separation of gulf station and open lake station was largely due to nitrites, turbidity, PO4, TP, temperature and secchi depth. Gulf stations exhibited high levels of nutrients with Homa Bay being the highest. On the other hand open lake stations had high secchi depth and temperature.

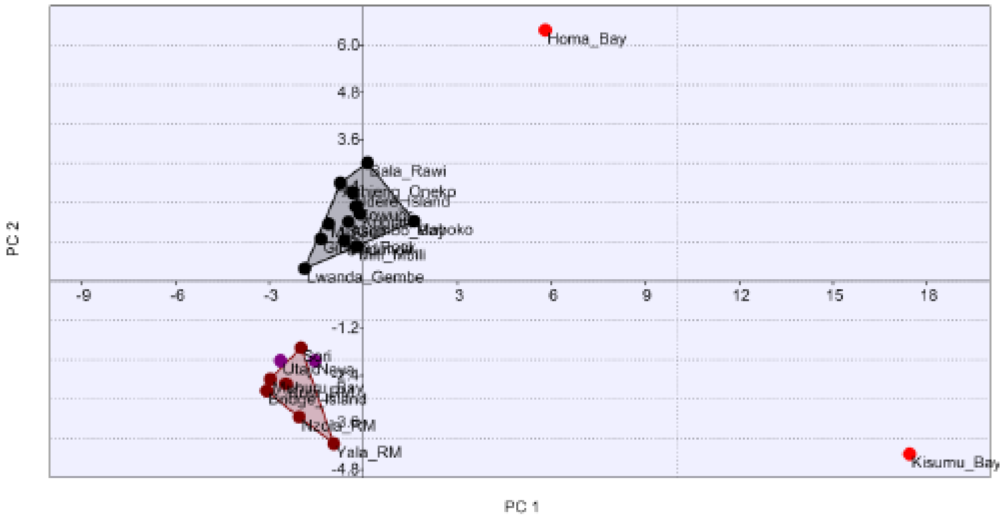


Figure 16. PCA on environmental and biological variables of samples stations in Lake Victoria, Kenya.

4.0 DISCUSSION

4.1 Physico-chemical.

The trophic characterization of the polymictic Lake Victoria and the subsequent productivity is highly influenced by the annual and diurnal variation in the lake's hydrology (Okely *et al*., 2010; Guya, 2013). The shallow gulf is greatly impacted upon by wind stresses remobilizing the sediment nutrients (Guya, 2013), which elevates nutrient concentrations (Fig. 5). Phosphorus levels were higher within the gulf i.e. Mid Gulf stations, than in the open lake (Fig.2b). The elevated concentrations of SRP and TP within the Mid Gulf stations are due to vigorous mixing and the high presence of labile bio-available particle associated phosphorus (see also Gikuma-Njuru *et al*., 2009; Okely *et al*., 2010 & Guya, 2013). During particle-associated nutrients regeneration, the cation ligands of Fe, Al, Mn and Ca are also remobilized back to the water mass. The significant correlations between phosphorus, nitrite, conductivity, and secchi readings suggest regeneration as the major source of SRP ($PO4^{3-}$). There was also significant correlation exemplified by silica to depth, conductivity, secchi and nitrite, signifying intense vertical mixing as a significant mechanism to the regenerated nutrients. Internal loading of phosphorus exceeded external loading through STP discharges as evidenced in Oluch RM., Homa Bay, Kowuor, Mid Gulf, Madundu and Kopiata, which are Mid Gulf stations, having higher concentrations of SRP and TP than Kisumu Bay that receives raw sewer from Kisumu Municipality (Fig. 2b).

Nitrogen species speciation is influenced both by external and internal loadings. They are generated especially from the bacterial decomposition of the organic matter both from the STP and aquatic biota. The high external loading, increased residence time and high remobilization rates contributed to the higher mean concentrations of NH_4^+, NO_2^-, NO_3^- and TN in the gulf than in the open lake waters (Fig. 2a). The higher NH_4^+ concentrations than NO_3^- observed generally off river and at sewerage discharge advection pathways (Kisumu Bay and Maboko) are believed to emanate from the wetlands at the river mouths and from human wastes from Kisumu Municipality STP, respectively. The bacterial degradation of the increased organic matter from the water hyacinth (*Eichhornia crassipes*) is believed to generate high NH_4^+ except within the Mid Gulf stations where the reduced nitrogen fractions are oxidized to NO_3^- due to intense mixing. The significant correlation between the nitrogen species, phosphorus and the *in situ* physico-chemical variables are strong indicators of nutrient recycling driven by strong vertical mixing. Chlorophyll-*a* distributions are influenced by the hydrological regimes of various ecozones. The bays with less perturbed waters had a general higher concentrations due to less drifting while river mouths had low concentrations due to high drifting by the currents.

The annual turn-over in Lake Victoria affects nutrient concentrations and limitations; and primary productivity. The 2012 data, which probably was collected after the onset of the annual turn-over, had elevated concentrations of all nutrient components except nitrite which was nearly the same (Fig. 2a & 2b). The elevated nutrient levels during 2012 increased primary productivity compared to 2013 (Fig. 4). Hydrological shifts are also believed to influence the algal species diversity due to transformations of N: P ratios. The lake is generally nitrogen limiting thus favouring the proliferation of obnoxious nitrogen fixing cyanophytes (Fig. 9) compared to 2012, when the lake tended to phosphorus limitation thus favouring diatom dominance. External loadings also influenced the N: P ratios especially in Kisumu Bay.

Using Ryding and Rast (1989) classification on SRP, Nyanza Gulf would be classified as eutrophic while the open lake as mesotrophic (Table 2 & Fig. 2). Comparison of 2013 and 2012 trophic characterization using chlorophyll-*a* according to Straškraba *et al*. (1993), suggests eutrophic waters in 2012 and mesotrophic during 2013. Trophic enrichment is thus enhanced by the strength of the mixing. The analysed physico-chemical variables fell within recommendable ranges for fisheries. Dissolved Oxygen values were within range except for Kisumu Bay, Homa Bay, Achieng Oneko and Asembo Bay. The bays are less mixed and with high algal biomass The SRP and nitrites concentrations fell within recommendable levels while nitrates were below recommendable levels for fisheries. N ammonium concentrations were within recommendable levels except for Kisumu Bay and Maboko.

4.2 Heavy Metals

The sediment Pb data generated in this study fall within the range of values recorded in previous studies (KMFRI, 2012) but indicate lower enrichment compared to Enrichment factors reported by

KMFRI (2010). The data shows that Kisumu Bay, Miti Mbili had the highest values of Pb, which could be attributed to anthropogenic enrichment. The known environmental sources of Pb contamination are battery disposal, use of and spillage of leaded fuel and scratch card use, erection of car washes inside or close to the lake. It is possible that the sources of lead for the identified hot spots are from the transport industry. There is a large road network with busy vehicular traffic around the shores of Lake Victoria especially in the southern shores and Kisumu. The high concentrations of Pb in Miti Mbili and Gingra could it be due to their locations in the Mid Gulf, where there is lack of complete mixing of the gulf and open waters. There are usual cases of vehicles being washed right inside the lake waters especially in Kisumu and Homa Bay. Open field garages may also generate some quantities of metal especially lead that disintegrate fast into soil and runoff.

Total mercury concentration fell within the range of values recorded in 2010, and 2012 and the levels reported for open lake sediment cores by Ramlal *et al.* (2003). Generally the open waters recorded higher values compared to the Gulf. This observed pattern of sediment mercury distribution is peculiar and may require a more detailed study on redistribution mechanisms. Mercury is known to be widely used in the artisanal gold mines of Macalder and residues may end up in the lake through Kuja River and diffuse runoff. By redistribution mechanisms of sediment other sites around the gulf are the likely recipients. Another possible source of mercury that would be the origin of the observed northern gulf shoreline mercury enrichment is the Asembo goldmines and other widespread artisanal gold mining fields in the northern shores.

There were slight departures from the observations of the immediate previous report in peaks for various metals such as Pb which was highest in Homa Bay but peaked at Miti Mbili and Kisumu Bay. This observation can be explained by possible localized variations in the sediment characteristics at the times of sampling or the possibilities of sediment metal redistribution by biota. Of greatest suspicion is water hyacinth which is an invasive macrophyte in Lake Victoria. Macrophytes play an important role in nutrient and heavy metal recycling of many aquatic systems (Pip & Stepaniuk, 1992). Excess heavy metals are bound to plant cell walls in a process called metathiolate formation through mercaptide complexes (Grill *et al*., 1985). Prior to the sampling expedition, water hyacinth infestation had covered wide areas of the lake and concentrated around the sheltered bays like Homa Bay. Eventually the plants died and sunk with gradual drift towards the gulf and Kisumu Bay (Pers Obs.). It is therefore possible that metals that were taken up by the plants at one place were deposited elsewhere in the sediments upon the death of the macrophytes.

From this study it was evident that peak metal concentrations were recorded at urban proximate stations than in stations remote from urban development. There is an undocumented report that a ship wreck in the proximity of Achieng’ Oneko (Gudwa and Kunya beaches). The high concentrations of Nickel and iron could be attributed to the wearing away of the sunken ship. River mouth stations, especially Yala RM, had low metal concentrations.

Yala RM indicated the lowest accumulation of most of these metals. The salient characteristic of the Yala RM is the extensive wetland through which the incoming river water passes before the Lake. The occurrence of macrophytes along the water discharge route results in the uptake of the contaminants which include metals by the plants. The reduction of metal contaminant concentration may also be achieved by the retention of sediments by the wetlands.

Potential impacts of contaminated sediments to benthic organisms include both acute and chronic toxicity with individual-, population-, and community- level effects, bioaccumulation of contaminants and the potential to pass contaminants along to predators of benthic species (Marcus, 1991; Adams *et al*., 1992; Milleman and Kinney, 1992). Chemistry, toxicity and bioaccumulation tests are frequently used to evaluate risks of contaminated sediments to environmental receptors (USEPA, 2005). Whereas chemistry measurements can provide quantitative information on contaminants, toxicity tests provide direct measures of biological impacts (ASTM, 2009). A combination of these approaches through comparison of chemistry data to toxicity effect-based sediment quality guidelines are used to evaluate the severity of sediment contamination (Wenning *et al*., 2005).

Exploration of the data for risk assessment resulted in instances of high ERL and ERM for Pb, Zn, Ni and Hg. However as demonstrated in toxicological studies (O’Connor, 2004) there is no basis for assuming that multiple concentrations above an ERL increase the probability of toxicity. ERM and ERL are themselves not chemical concentrations at the threshold of sediment toxicity and therefore not an indicator of adverse risk to the ecosystem. The result of the examination of the metal contaminant data for Toxic Effect Thresholds (TET) and Probable Effect Thresholds (PEC) revealed that there were no values near or above TET for Pb, Cu, Zn and Ni. Considering the implication of the combination of these analyses it is intuitive to infer that the observed metal concentrations generally indicate no ecological risks of toxicity (TET and PEC) but in few cases the values recorded are high enough to arouse ecotoxicological concerns based on ERL and ERM analyses. Based on the study such risks would only be anticipated with continued enrichment.

4.3 Phytoplankton

The results show higher phytoplankton abundance within the gulf compared to open waters with *Microcystis* and *Anabeana* spp being the most dominating in both the gulf and open lake respectively. The high phytoplankton abundance in the gulf could be attributed to high nutrient loading into the lake which is more pronounced in the gulf compared to the main lake. The high algal abundance particularly in the Nyanza Gulf stations (e.g Kisumu Bay, Kowuor, Homa Bay and Mid Gulf) together with high concentrations of nutrients and chlorophyll-*a* indicate eutrophication in the lake. The corresponding distribution pattern (spatial variation) observed, is associated with the changes of various environmental factors in play within the gulf and in the open waters over time and at the time of this study. The dominance of the Cyanophyceae during this study (Fig. 1) is in consistence with observations made by other workers (Lung'aiya *et al.*, 2000; Gakuma-Njuru *et al.*, 2005; Sitoki *et al.*, 2012) and concur with reported shift in phytoplankton community in Lake Victoria from that dominated by diatoms to the present assemblage dominated by the blue green algae (Hecky, 1993; Lehman & Branstrator, 1994). Cyanophyceae taxa, especially *Microcytis* spp have features that make them well adapted to the more turbid waters in the gulf. These include being buoyant and therefore remain suspended in water, their superior light capturing mechanism and sensitivity to flushing allow them to thrive in such situations as they remain in the euphotic zone faster than the other species. They are also known to be able to form mucilage that help them form large colonies thus resist sinking and remain afloat (Reynolds, 2006). Lower abundance of diatoms could be either due to variability of major physico-chemical factors such as nutrients and turbidity amongst others or due to selective feeding by the phytoplanktivores in the aquatic system.

The low species diversity indices recorded for lake's phytoplankton assemblage at most sampling stations is attributed to the dominance by a few species of Cyanophyceae (e.g. *Microcystis* sp, *Anabaena planktolygnbya* spp.) and diatoms (*Nitzschia acicularis*, *Cyclotella* spp., *Synedra cunningtonii* and *Auleucosiera* spp.) which is a common characteristic of eutrophied aquatic systems.

The present findings are in agreement with Lungaiya *et al.*, (2001), Ochumba & Kibaara (1989), Gikuma-Njuru & Hecky (2005) who observed that the Cyanophyceae are usually favored by increased nutrients and dissolved organic material characterizing areas subjected to input from discharge. Due to the pronouncedly high concentrations of nutrients in the Nyanza Gulf, there was markedly high phytoplankton abundance that showed significant correlation with nitrates. Welch (1980) indicated that N/P varies with trophic status of an aquatic system and decreases with increased eutrophication. This is in agreement with present values of N: P ratios which regardless of its wide fluctuation in the gulf were mostly lower and thus give cyanobacteria advantage over other groups.

Cyanobacteria dominance and significant positive correlation with turbidity (P = 0.012), could be explained by their adaptive features such as positive buoyancy, superior light capturing ability and the ability to form colonies using mucilage which allow them to remain buoyant and so thrive in the more turbid situations in the gulf. The significant positive correlation shown by cyanobacteria with nitrates (P = 0.0207) reflects the effects of nutrients concentrations/ratios on the micro-flora in a given aquatic system. Other positive correlation were found with cladocerans *Ceriodaphnia cornuta* (*P* = 0.017), *Daphnia barbata* (*P* = 0.045). Diatoms, on the other hand had significant correlations with macroinvertebrates such Odonata (*P* = 0.003) and Ephemeroptera (*P* = 0.013), Euglenophyceae with silicates (*P* = 0.049).

The current occurrence of algal blooms and potentially toxic algal species in Lake Victoria and more especially the Nyanza Gulf coupled with the continued nutrient loadings in the lake is a course of concern and therefore calls for urgent strategic management approach in order to bring under control further degradation of water quality.

4.4 Zooplankton

The high abundance of total zooplankton in the gulf could be attributed to the habitat's high productivity. Nyanza Gulf receives water from five major rivers running through rich agricultural areas in the catchment. These waters are the major sources of pollution. Other sources of pollution are sewage and municipal wastes especially from the two major towns of Kisumu and Homa Bay. The high number of species in Kisumu Bay could be attributed to both the productivity of the habitat, which possibly attracts more organisms, and to its high turbidity which reduces predation for predators, which feed by sight.

Dominance of Copepoda has been highlighted in the tropical waters (Green, 1971; Mavuti and Litterick, 1991) and this was corroborated in the present study. Cyclopoida usually dominates the group. Higher proportions of calanoids in freshwaters have been used as indicators of low eutrophy while higher nauplii: mature copepods indicate a more productive habitat (Green, 1971). The present results show that Samunyi RM is the most eutrophic habitat while Bridge Island was the least eutrophic with calanoid relative abundance 0.85 and 8.37%, respectively. The occurrence of *Lecane* spp in the inner waters in the gulf could be attributed to the presence of algal blooms, which have also been reported to offer refuge for *Lecane* spp in Lake Turkana (Hopson, 1982).

From the results, it may be predicted that areas where the small sized *B. longirostris* and *C. cornuta* occur are the nursery grounds in Lake Victoria. This is on assumption that in these areas juvenile zooplanktivorous fishes have decimated larger zooplankters. Attention should also be directed to changes in the composition of Cladocera in the past decade. Previously turbid water species, *D. barbata,* was found only at the mouth of River Awach (Kendu) (Omondi, 2003). That the species is now widespread and is found in all the gulf stations except Samunyi, Lwanda Gembe and Utajo is a clear indication that the turbidity of the lake is increasing probably as a result of anthropological activities in the catchment. The absence of the species in the turbid swampy Samunyi may, however, be attributed to predation by planktivorous juvenile fishes. Adult swamp-loving *C. gariepinus* have also been reported to feed on large numbers of *D. barbata* in turbid lakes (Dadebo, 2009; Omondi *et al*., 2013).

4.5 Micro-contaminants

Generally, the gulf waters were more contaminated in terms of both the total and fecal coliforms than the open waters. Stations like Kisumu Bay and Homa Bay in the gulf which indicated high levels of fecal coliforms compared to the other stations are located in areas of urban sewage and industrial effluent (Odada *et al.*, 2006). The high levels at Homa Bay conforms well to the findings by Kotut *et al*. (2011), that indicates high fecal levels of up to 3.0 x 103 to 7.4 x 105 cfu/100ml from Homa Bay household, which in most cases end up into the lake. The open waters fecal contamination seemed to be diminishing over the last 3 years. The absence of fecal coliform in all the stations of the open lake except for Yala RM that realized minimal counts is an indication that the open waters are not polluted with coliforms of fecal origins.

There is no clear trend on the levels of fecal coliforms in the gulf waters from this study as compared to the previous surveys of 2012 and 2010 (Fig. 3). The 2010 survey was done at a different season from the 2012 and 2013 surveys, this could be the reason for the differences in levels of both total and fecal coliforms observed. Generally, from Fig. 3 it can be seen that the survey done on 2012 had lower fecal coliforms contaminations with exception of Gingra compared to 2013 and 2010 surveys. The sudden increase of fecal coliforms in Oluch RM in 2013 could be attributed to the agricultural land use and human settlement in this area whereby the fecal coliforms loadings come from surface runoff.

4.6 Macroinvertebrates

Total abundance was found highest at the river mouths and lowest at Bridge Island. This finding is probably due to food availability as a result of nutrient influx from rivers. The low water depth at river mouths could also be a contributing factor. Water depth has been shown to have a negative correlation with temperature and DO (Margolis *et al.*, 2001). Bridge Island which had the lowest abundance had a DO of less than 4mg l-1. Mason (2002) found high abundance of benthic macroinvertebrates in shallow depths as compared to deep areas and attributed it to low DO and temperature. Availability of food is positively correlated with abundance (Wang and Lyons, 2003) and stations with high invertebrate abundance have been attributed to food availability (Masese *et al.*, 2009). Kisumu Bay had the lowest index of 0.2108 hence concluded to be the poorest in terms of diversity. Kisumu Bay had high turbidity and nutrients; parameters that do not support diversity.

The entire lake was dominated with tolerant taxa with a relative abundance of over 94%. This result could partly show that the lake cannot support sensitive taxa or that the sampling depth was too deep for them to be found. Presence of sensitive taxa in a region is a sign of good health but its absence does not depict the opposite unless in circumstances where it was once found then it disappeared (Masese *et al.,* 2009). In terms of stations, all stations except Bridge Island associated with tolerant taxa. Bridge Island on the other hand is associated with the semi-tolerant taxa. There was a positive correlation between nutrient levels and the tolerant taxa which indicates that increase in nutrient levels leads to dominance of tolerant taxa. Aura *et al.*, 2010 found similar results and concluded that high nutrient levels wipes out sensitive taxa in a system. Studies done by Masese *et al*., (2009); Raburu (2003) and Orwa *et al*., (2013) after comparison with water quality parameters attributed dominance of tolerant taxa to human disturbance and pollution and this could be a likely scenario in this case.

4.7 Fisheries (Larvae & Fisheries)

The fish larval assemblage of the Lake Victoria Kenyan waters was dominated by the *R. argentea* in the present study with representation in all the 23 stations sampled. The larvae of other species of commercial importance included *L. niloticus* and *O. niloticus*, with the highest numbers of the former being found in the Kisumu Bay and Homa Bay. This could be attributed to the calm waters and high densities of zooplankton which is the prime food item for fish juveniles. However, abundance of *R. argentea* was highest at Lwanda Gembe. This could be attributed to the water clarity and reproductive strategy of the fish. This is also true for the outer gulf stations, which are relatively deeper with clear waters. According to Nyamweya et al. unpublished data, abundances of *R. argentea* in the Kenyan waters are highly correlated to water turbidity levels and are therefore directly impacted upon by other pollution indicators such as algal blooms and increased sediment loads. This is a scenario, which is extremely important in studies on pollution since fish composition and abundance are considered important indicators of the health of ecosystems over a longer period of time, including the health of the system before and after pollution occurrences (Subhendu and Jana, 2002). In addition, diversity indices are based on the principle that species diversity decreases in an ecosystem under stress due to pollution.

Larval fish utilize zooplankton as their first external food with most fishes exhibiting ontogenic shift in their feeding behavior (Helfman *et al*., 2005). In Lake Victoria, Nile perch at later stages of growth feeds on *C. nilotica* and fish while *R. argentea* is an obligate zooplanktivore and assorted invertebrates. Changes in the composition, abundance and size structure of zooplankton and macroinvertebrate communities of Lake Victoria are influenced by fish predation, eutrophication and pollution levels. Owing to the fish’s inability to metabolically regulate their own temperature, the ambient environmental temperature is an all-pervasive regulator of their physiological processes. In addition to temperature, pH also directly affects the fish physiology as well as influence the physico-chemical nature of water (Finn, 2007).

In longer food-webs with more trophic levels, the amount of Methylated mercury (MeHg) in top predator can be higher than for the same species in food-webs with fewer trophic transfers. Different species at the base of the food-webs do not bio accumulate mercury to the same extent. Prey ultimately affects the mercury concentrations in predators (Linda *et al.,* 2004). Less predation could be attributable to higher turbidity in some stations. High Turbidity has been observed to impair the vision of zooplanktivorous fish species (Steiner, 2003). Pollutants and chemical changes in the water often result in larval abnormalities which can be used to monitor environmental quality. But even natural variation in temperature, oxygen content, light intensity, photoperiod or CO2 can affect development.

Nyanza Gulf had low densities of Nile perch. This is a habitat characterized by dense algal blooms and presence of extensive mats of water hyacinth. Nile perch being a visual predator may not thrive in turbid waters currently characterising the gulf. Presence of high densities of macrophytes and algae in this environment causes extreme fluctuations in DO concentrations diurnally. At night, respiration of algae and macrophytes uses oxygen from the water column thus deprives fish of oxygen. Nile perch has high oxygen requirements (> 4mg l-1) (Schofied and Chapman, 2000) and as such tend to avoid areas of low DO concentrations giving room for other fish species which can withstand such habitats to thrive. This probably explains the high species diversity recorded inside the gulf (Ojwang *et al.,* 2011).

5.0 CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

The survey found out that the Gulf was more eutrophic than the open waters and temporal and spatial trophic status of L. Victoria is influenced mainly by the hydrodynamic regimes. Notably, nutrient sources were both from external and internal loadings. The effects of most of the metals in the sediment are of acceptable levels except for lead and mercury in a few of the sampled stations. From the fish consumptition perspective, fecal coliforms in fishing waters in Kenya are within normal standards. The bays and river mouths are important breeding and nursery grounds for Nile perch and other species.

5.2 Recommendations

1 The study recommends basin-wide multi-sectoral management (including Non State Actors-NSAs) of the lake environment to improve water quality. Notably, Concurrent monitoring of fisheries stocks including larval stages, their abundances and distribution, and general fish biology is highly recommended This will enable early determination and or detection of effects of pollution on fisheries and general fish biology (including presence of parasites) and appropriate mitigation undertaken to avoid any long-term emergence of bad traits as a result of stress related adaptive changes: less

fecundity, reduced growth and size at first maturity. It is considered important to identify the presence of pollution related fish parasites and susceptibility, and undertake periodic bioaccumulation studies: heavy metals levels especially on different sizes of predatory fishes such as Nile perch.

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