Bacterial abundance on the skin, gills and intestines of *Cyprinus carpio* in Lake Naivasha, Kenya: Implications for public health and fish quality

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Abstract

Cyprinus carpio is the most important fish species in the Lake Naivasha fishery, comprising 51% of the total catch in the lake. Microflora, especially enteric bacteria of human or animal origin, are the causative agent for fish contamination and spoilage. Poor sanitation standards and poor sewage treatment and disposal methods within Lake Naivasha and its catchment pose a great threat for degrading the quality of *C. carpio*. The potential impact is rejection of the fish in the local, regional and international markets, risking the collapse of the Lake Naivasha fishery. This study determined the bacterial quality of water and *C. carpio* from three different sites within Lake Naivasha, namely Malewa River mouth, sewage discharge point and a mid-lake site, based on plate count techniques. Physicochemical parameters characterizing the lake water also were also measured *in situ*. This study results indicated that both the fish and water in Lake Naivasha exhibited poor bacterial quality. All the physicochemical parameters were within the recommended range for fish culture, although they also were conducive to the proliferation of bacteria. Most of the sampling sites exhibited significant spatial variation in their bacterial abundance ($P < 0.05$). The sewage discharge sampling site exhibited the highest mean density values for bacterial densities and clearly degrade the quality of the fish in the lake. Proper sewage treatment, and the installation of modern sanitation facilities, is recommended to improve the bacterial quality of the fish.

Key words

bacterial abundance, *Cyprinus carpio*, faecal contamination, Lake Naivasha, quality.

INTRODUCTION

Lake Naivasha is a freshwater lake located in the Eastern Rift Valley of Kenya. It is a shallow lake, with a surface area of 160 km^2, bordered by papyrus (*Cyperus papyrus* L.), with the aquatic macrophytes being in a state of flux (Adams *et al.* 2002). The lake contains introduced fish species, with a variable catch composition. Since 2000, *Cyprinus carpio* have dominated the fish catch of the lake, being 51% of the total catch, followed by *Oreochromis leochosticus* (21%) (Hickley *et al.* 2004). Traditionally known as common carp, *Cyprinus carpio* is an invasive fish species in Lake Naivasha (Cucherousset & Olden 2011). It has been one of only eight fish on the International Union of Conservation of Nature (IUCN) list of the world's worst 100 invaders (Lower *et al.* 2000). This listing is based on a combination of their invasive potential and their ecological impacts. Their invasive potential is based on their life-history traits, which facilitate their colonization of new water system, including their capability for fast growth, early maturity and high fecundity (Sivakumaran *et al.* 2003; Smith & Walker 2004; Britton *et al.* 2007). Ecological impacts from their invasions arise from their function as a bioengineering species that impacts water quality, including loss of submerged vegetation and increased turbidity (Koehn 2004; Zambrano *et al.* 2006; Matsuzaki *et al.* 2007). Invasive populations have been reported in relatively warm countries, including Australia (Koehn 2004), Mexico (Zambrano *et al. 2006*) and parts of the United States (Weber & Brown 2009). They have not been reported in temperate countries such as England (Britton *et al.* 2010c),

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suggesting there may be a strong relationship between the ability of the carp to develop invasive populations and the ambient climatic conditions of the area being invaded.

It has been demonstrated that intestinal micro-organisms are the causative agents for food spoilage (Kaneko 1971). Contamination of fish from enteric bacteria of human or animal origin also may be responsible for various fish spoilages (Geldreich & Clarke 1966). Fish encounter a large number of bacteria from the water, sediment and food materials in a water body (*Sugita et al.,* 1988), with several studies demonstrating the bacterial flora in fish reflects the sanitation status of its aquatic environment (Shewan 1967). It also has been shown that both fresh and brackish water fishes can harbour human pathogenic bacteria, especially the coliform group (Leung *et al.* 1990; Pulella *et al.* 1998; Ramos & Lyon 2000). Faecal coliforms such as *Escherichia coli* usually originate from the faeces of humans and other warm-blooded animals. Faecal coliform in fish can signify the level of pollution of their environment, mainly because coliforms are not normal inhabitants in fish (Cohen & Shuval 1973). The enteric bacilli include *E. coli*, *Klebsiella* spp., *Citrobacter* spp., *Enterobacter* spp., *Serratia* spp. and *Edwarsiella* spp. (Noble *et al.* 2003; Doyle & Erickson 2006).

Lake Naivasha receives large pollutant loads from anthropogenic activities in its heavily populated catchment (Harper & Mavuti 2004). Lake contamination results from inadequate sanitation, as communities surrounding the lake utilize bushes, pit latrines and septic tanks for sewage disposal. Furthermore, the available municipal sewer system is not adequate for the ever-increasing basin population (Mireri 2005; Onyango & Rieck 2010). Concerns about the safety of fish from Kenya first emerged in November 1997, when Spain and Italy both banned fish imports from Kenya, claiming the presence of *Salmonellae* in the fish. Although some European Union member states continued to import fish from Kenya on the basis of bilateral agreements, Kenya's fish exports to the EU nevertheless have declined by 34%, resulting in an accompanying decline in foreign exchange earnings by 13% between 1996 and 1997, particularly because of reports of a cholera outbreak in Kenya and neighbouring countries. The EU again banned imports of chilled fish products from Kenya in January 1998, citing poor hygiene standards, resulting in a 66% decrease in fish exports to the EU and a 32% decrease in foreign exchange earnings from the previous year (Richard 2003).

The bacterial quality of fish is an important monitoring tool in the public health arena, especially when considering the quality of the fish for local and international marketing within the context of import and export quality regulations. The sanitation status of the aquatic environment from which fish are obtained also is important in considering fish-marketing quality standards. The areas around Lake Naivasha, however, as well as other fishing beaches and villages in developing nations, lack basic modern sanitation facilities (M'CLeen 2001). Thus, the effects of faecal contamination on the bacterial quality of fish species in Lake Naivasha resulting from the discharge or raw sewage into the lake have never been documented. The purpose of this study, therefore, is to investigate the bacterial quality of the water and the major commercial fish species in Lake Naivasha (*Cyprinus carpio*) at three different sampling sites within the lake. The implications of these findings on public health and consequently to fish marketability also are discussed.

MATERIALS AND METHODS

Study area

This study was conducted between June and September 2012 within Lake Naivasha, which is located in the Rift Valley Province of Kenya (Fig. 1). The lake is one of the major water bodies in Kenya. It is a freshwater lake, although it lacks a well-defined water outlet, and its watershed covers parts of both the Rift Valley and the Central Provinces. The lake basin extends 6° north from the equator, lying between 36°07′ and 36°47′ east of Greenwich Meridian. Lake Naivasha is located in the rain shadow of the Aberdare Mountain Range, which receives a mean annual rainfall of about 650 mm. It experiences 'long rain' from March to May, and 'short rain' from September to October. The mean annual precipitation in the Lake Naivasha area as well as in the Aberdare Mounting Range is 1350 mm. The mean temperature around Lake Naivasha is ~25 °C, with a maximum temperature of 30 °C. The months from December to March are the hottest period, while July is the coldest month with a mean temperature of 23 °C. The Lake Naivasha watershed is drained by only two perennial rivers, namely Malewa River and Gilgil River, with catchment areas of 1700 and 400 km^2, respectively (Mireri 2005).

Fish and water sample collection

The geographical locations of the sampling sites were determined with a GPS meter (GPS 12, GARMIN Olathe, KS, USA). Fish and water samples were aseptically obtained from three sampling sites on the lake, including (i) the mouth of the Malewa River (S 00°43′ 39.6′; E 36° 21′ 17.85′); (ii) the sewage discharge point (S 00° 46′

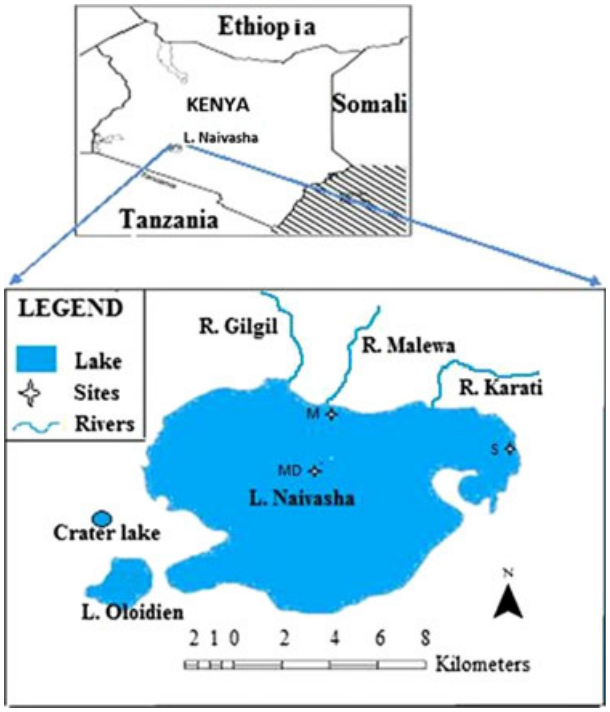

Fig. 1. Location of Lake Naivasha and sampling sites (M = Malewa River mouth; S = sewage disposal point; MD = mid-lake site).

21.1″; E 36° 24′ 48.9″) and (iii) mid-lake (S 00° 48′ 40.5″; E 36° 20′ 40.8″). *Cyprinus carpio* of 28.72 ± 5.35 cm and 519.38 ± 259.10 g (mean ± SEM) for total length and total body weight, respectively, were aseptically collected. Sterilized 500 mL polyethylene water sample bottles were used to collect the water samples, which were taken at a depth of 30 cm below the lake surface. Both the water and fish samples were put into an icebox and taken to the laboratory for analysis within 6–8 h, being maintained at a temperature at 4 °C (APHA 2005). Samples were processed for bacteriological analyses within 8–12 h of sampling, utilizing aseptic techniques. Samples from the skin, gills and intestines of the collected fish were separately examined for each specimen.

Measurement of physicochemical parameters

Water temperature, dissolved oxygen concentration, salinity and pH were measured *in situ*, using a WTWÒ microprocessor meter. The meter was calibrated for a pH value of 4 and 7, using standard buffer solutions according to manufacturer's instructions (WTW; Vienna, Austria). The meter electrode was rinsed with distilled water between samples. The electrical conductivity was measured with a WTWÒ microprocessor conductivity meter calibrated at 25 °C.

Analyses of fish sample

Plate count agar was used to prepare the culture medium for the detection of total heterotrophic bacteria (THB). A subsample of 1 g was taken from homogenized tissue of each sample and mixed with 9 mL sterile PBS solution to prepare a 10G1 dilution. Subsequent serial dilutions were prepared from 10G2 to 10G5 levels. The spread plate method was used to enumerate the THB density (APHA 2005; Hasan and Bart, 2007). A subsample of 100 μL samples from each dilution, with three replicates, was used to count bacteria, expressed as colony-forming unit (CFU) per g of sampled fish. Bacterial density, expressed as cfu g^{-1} for 3 replicates, was initially averaged and used for final calculations. All equipment and chemicals were sterilized prior to use. To detect total coliform, 100 μL samples of serially diluted solutions was spread on the mFC plate and incubated at 37 °C for 18–24 h. Blue colonies were considered to be total coliform (APHA 2005). For enumeration of *E. coli*, 100 μL samples of serially diluted solutions was spread on MacConkey agar plates and incubated at 44 °C for 18–24 h. Pink colonies were counted as *E. coli,* (APHA 2005).

Analyses of water samples

Each water sample was analysed to determine total heterotrophic bacteria (THB), total coliforms (TC), faecal coliforms (FC) and *E. coli*, following procedures outlined in APHA (2005). To enumerate TBC in water, 100 μL water sample was mixed with 900 μL normal saline (0.85% NaCl solution) to prepare 10G1 dilution. One hundred μL of diluted water samples was then dropped on plate count agar plates, which was incubated at 37 °C for 24 h. For TC and FC and *E. coli*, 100 mL of water samples was filtered through a membrane filter (0.22 μm pore-size) (Millipore Corp., Bedford, MA, USA). The filters were then placed on membrane faecal coliforms (mFC) agar plates for determination of TC and FC and on MacConkey agar plates for determination of *E. coli*. The mFC plates were incubated at 37 and 44 °C for 24 h for TC and FC, respectively. The MacConkey agar plates were incubated at 44 °C for 24 h. The characteristic blue colonies observed on the mFC plates were counted as TC and FC and expressed as colony-forming units (CFU) per 100 mL. Pink colonies on MacConkey agar plates were counted as *E. coli*, being expressed as CFU per 100 mL of water (APHA 2005).

Data analyses

Bacterial density data were transformed into natural log before statistical analyses. The means of the bacterial abundance were compared, using ANOVA, followed by Tukey's *post hoc* for multiple comparisons. The Statistical software SPSS (version 17; SPSS Inc., Chicago, IL, USA, Patent No. 7,023,453) was used to analyse the data, with a level of significance of $P < 0.05$.

RESULTS

Physicochemical parameters of Lake Naivasha water

Water quality parameters in Lake Naivasha were found to be suitable for the survival of fish (Table 1). The Malewa River mouth exhibited the highest dissolved oxygen (DO) concentrations. The sewage discharge point exhibited the highest values for pH, electrical conductivity and salinity. The salinity of the water from all three sampling sites was nearly zero. All the physicochemical parameters exhibited significant variation with regard to sampling sites ($F = 0.234$, 0.424, 0.524, 0.244 and 0.344, respectively, for DO, pH, electrical conductivity, salinity and temperature; d.f. = 2, 47 and $P < 0.05$).

Bacterial densities in *Cyprinus carpio*

Total heterotrophic bacteria (THB) density

The densities of total heterotrophic bacteria are shown in Figure 2. Mean density values from the skin and gill were higher than the values from the intestines. The sewage discharge point exhibited the highest mean density values, followed closely by the Malewa River mouth sampling site, while the mid-lake site exhibited the lowest values. There was significant variation in the density of THB between sampling sites for all the different body organs of *Cyprinus carpio* (skin, gills, intestines) ($F = 0.862$, 0.422 and 0.340, respectively, for skin, gills and intestines; d.f. = 2, 47 and $P < 0.05$).

Total coliform density

The densities of total coliform bacteria are summarized in Figure 3. Mean density values from the skin and gills were higher than the values from the intestines. The sewage discharge point exhibited the highest mean density values, followed closely by the Malewa River mouth site, while the mid-lake site exhibited the lowest values. There was significant variation in the density of total coliform bacteria between sampling sites for all the different body organs of *Cyprinus carpio* (skin, gills, intestines) ($F = 0.624$, 0.342 and 0.234, respectively, for skin, gills and intestines; d.f. = 2, 47 and $P < 0.05$).

Faecal coliform density

The densities of faecal coliform bacteria are presented in Figure 4. Mean density values from the skin and gill were higher than those for intestines. The sewage discharge point exhibited the highest mean density values for the skin, followed closely by the Malewa River mouth site, while the mid-lake site had the lowest values. The Malewa River mouth exhibited the highest mean density values for both the gills and intestines, followed closely by the sewage discharge point, while the mid-lake point exhibited the lowest values. Only the skin exhibited a significant variation in the faecal coliform bacteria density between all three sampling sites. For the gills and intestines, however, the total coliform density within the Malewa River mouth site and the sewage discharge site did not vary significantly ($F = 0.462$, 0.482 and 0.530, respectively, for skin, gill and intestine; d.f. = 2, 47 and $P < 0.05$).

E. coli density

The *E. coli* bacteria densities are summarized in Figure 5. The mean skin and gill density values were higher than the intestine values. The sewage discharge point exhibited the highest mean density values for skin, followed closely by the Malewa River mouth sampling site,

Table 1. Physicochemical parameters (means ± SEM) of water samples from different sites in Lake Naivasha

	Physicochemical parameters				
Sampling site	Dissolved oxygen concentration (mg L^{-1})	pH	Electrical conductivity (μs cm^{-1})	Salinity (ppm)	Temperature (°C)
Malewa River mouth	5.05 ± 0.02A	8.45 ± 0.35A	375.05 ± 1.05A	0.05 ± 0.001A	19.5 ± 0.05A
Sewage discharge point	4.45 ± 0.06B	8.70 ± 1.05B	415.00 ± 1.35B	0.08 ± 0.005B	20.0 ± 0.04B
Mid-lake site	4.65 ± 0.03B	8.15 ± 0.65C	390.00 ± 0.95C	0.02 ± 0.003C	21.2 ± 0.08C

Values with different letters in same column are significantly different between sites; $P < 0.05$, $n = 16$.

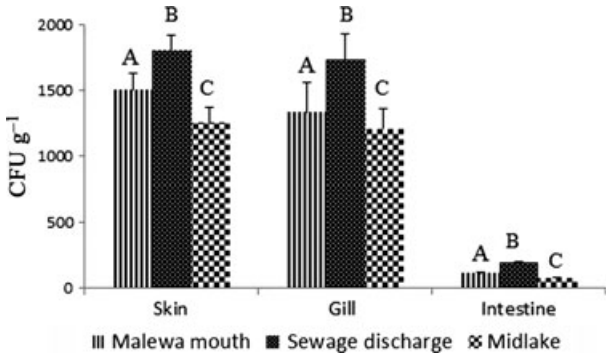

Fig. 2. Density of total heterotrophic bacteria (10^2 cfu g^{-1}) on skin, gills and intestines of *Cyprinus carpio* from sampling sites in Lake Naivasha (bars (mean ± SEM) with different letters corresponding to a particular organ are significantly different between sites; $P < 0.05$, $n = 16$)).

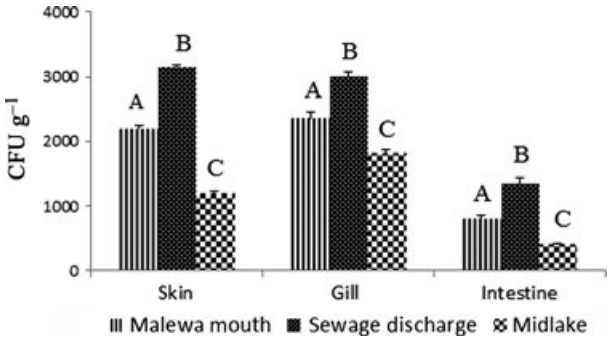

Fig. 3. Density of total coliform (cfu g^{-1}) on skin, gills and intestines of *Cyprinus carpio* from sampling sites in Lake Naivasha (bars (mean ± SEM) with different letters corresponding to a particular organ is significantly different between sites; $P < 0.05$, $n = 16$).

while the mid-lake site had the lowest values. The Malewa River mouth site exhibited the highest mean density values for both the gills and intestines, followed closely by the sewage discharge point, while the mid-lake site had the lowest values. The skin exhibited significant variation in the total coliform bacteria density between all the sampling sites. For the gills and intestines, however, the total coliform density within the Malewa River mouth and sewage discharge sites did not vary significantly ($F = 0.230$, 0.652 and 0.432, respectively, for skin, gills and intestines; d.f. = 2, 47 and $P < 0.05$).

Bacterial abundance in water

The densities of all bacterial parameter loads in the water samples are presented in Figure 6. The water samples from the Malewa River mouth and sewage discharge sites exhibited higher values than the mid-lake site for all the parameters. The detected THB in water from all

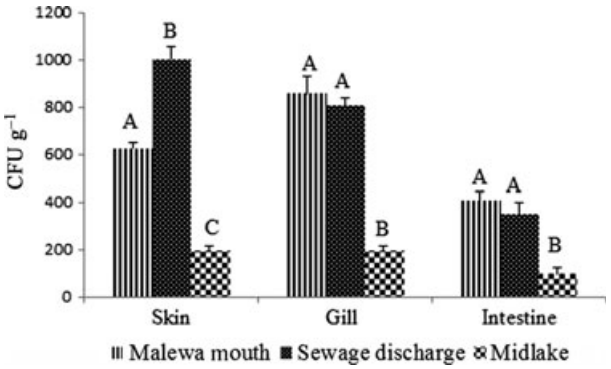

Fig. 4. Density of faecal coliform (cfu g^{-1}) on skin, gills and intestines of *Cyprinus carpio* from sampling sites in Lake Naivasha (bars (mean ± SEM) with different letters corresponding to a particular organ is significantly different between sites; $P < 0.05$, $n = 16$).

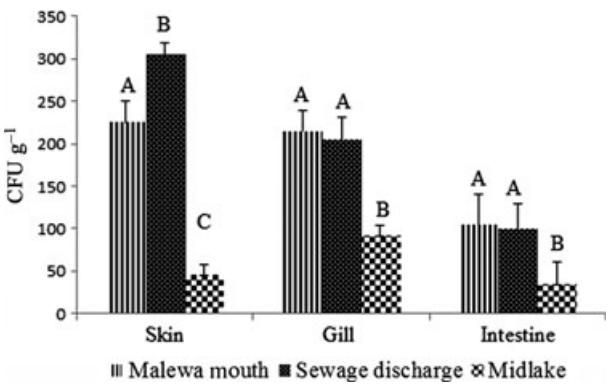

Fig. 5. Density of *E. coli* (cfu g^{-1}) on skin, gills and intestines of *Cyprinus carpio* from sampling sites in Lake Naivasha (bars (mean ± SEM) with different letters corresponding to a particular organ is significantly different between sites; $P < 0.05$, $n = 16$).

three sampling sites were beyond the lower limit considered suitable for fish culture. The TC, FC and *E. coli* loads also were significantly high. Only THB and TC exhibited significant density variations between all the sampling sites. The FC load from the Malewa River mouth and sewage discharge sampling sites exhibited no significant variation. The *E. coli* load also exhibited no significant variation between the Malewa River mouth and mid-lake sites ($F = 0.241$, 0.726, 0.234 and 0.530, respectively, for total heterotrophic bacteria (THB), total coliforms (TC), faecal coliforms (FC) and *E. coli*; d.f. = 3, 63 and $P < 0.05$).

DISCUSSION

The higher dissolved oxygen (DO) concentrations observed at the Malewa River mouth sampling site could

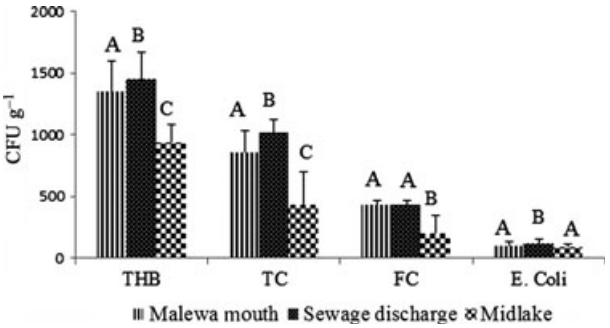

Fig. 6. Density (10^2 cfu g^{-1}) of bacteria (total heterotrophic bacteria (THB), total coliform (TC), faecal coliform (FC) and *E. coli* in water from sampling sites in Lake Naivasha (bars (mean ± SEM) with different letters corresponding to a particular parameter is significantly different between sites; $P < 0.05$, $n = 16$).

be attributed to continuous aeration by the inflowing river water. In contrast, the lower values observed at the sewage discharge point may be attributable to the high decomposition of organic materials brought into the lake in sewer effluents and overland flows (Downing & Truesdale 2007). The DO and pH of the water from all three sampling sites were within the tolerance limit for fish (Hussain 2004). This finding indicated that, at the time of this study, Lake Naivasha water was found to be suitable for survival of the common carp. At the same time, however, the physicochemical water quality variables from all the sampled sites also were suitable for bacterial proliferation, with the water temperature being very suitable for the growth of coliform bacteria. The observed high bacterial counts detected in fish and water samples taken from all the sampling sites therefore can be attributed to the favourable physicochemical conditions for their growth and reproduction (Kensa 2011).

The higher level of all the bacterial parameters on the skin and gills in most cases, compared with the intestines, may be due to the occurrence of more favourable physicochemical conditions, including DO and pH, which are necessary for the proliferation of bacterial microflora (Denev *et al.* 2011). The higher THB values in the fish and water samples taken at the Malewa River mouth and sewage discharge sampling sites could be the result of the high load of raw sewage and other organic wastes into the lake from the Malewa River and the Naivasha Municipality sewer system (Mahalakshmi *et al.* 2011).

Lower THB values for fish and water samples from the mid-lake sampling site could be attributed to die off resulting from a deterioration of proliferation conditions (Ekhaise & Omavwoya 2008). High FC density values for fish and water samples from the Malewa River mouth sampling site could be attributed to direct discharge of faecal waste into the Malewa River as it flows across villages from the source to the river mouth. Furthermore, the higher values recorded for the sewage discharge sampling point indicated the discharge from the Naivasha Water and Sewerage Company (NAWASCO) wastewater treatment plant contained higher densities of viable faecal bacteria (Steven & Charles 2002; Olutiola *et al.* 2010). High *E. coli* densities for fish and water samples from the Malewa River mouth sampling site could be due to the direct discharge of human origin faecal waste into the Malewa River as it flows through informal settlements from the source to the river mouth. Furthermore, the higher values for fish and water samples from the sewage discharge sampling site indicated the effluent from the NAWASCO wastewater treatment plant contained higher densities of viable faecal bacteria of human origin (Mireri 2005; Onyango & Rieck 2010; Denev *et al.* 2011).

The results of the present study are consistent with those of several other studies. Nahiduzzaman *et al.* (2000), for example, reported a similar finding, with total bacteria numbering from 2.1×10^3 to 7.1×10^5 and 2.3×10^3 to 4.1×10^6 cfu mL^{-1} in water samples taken from two different fish ponds Maugeri *et al.* (2000) reported a 6.0×102 to 1.0×104 cfu mL^{-1} heterotrophic bacterial abundance in brackish water, similar to the findings of the present study. It also has been reported that coliform densities of 10 per mL of water is suitable for pond aquaculture (WHO 1989). The higher density of bacteria on fish organs may be attributable to their high consumption of bacteria through food and water. The major physical parameter favouring the proliferation of bacteria is temperature (Kensa 2011). The poor bacteriological quality of the lake water, especially at the Malewa River mouth and sewage discharge sampling points also could result from anthropogenic activities around the river and lake. In fact, several in-stream and lake-shore activities, including laundry work and watering of wild and domesticated animals directly from the rivers and lake, were noted during the present study. Similar pollution practices also have been reported for other water bodies in which cows were dominant contributors of faecal contamination to most rivers, raising public health concerns as well (Mokaya *et al.* 2004; Yillia *et al.* 2009).

Fish considered to be of good quality should exhibit THB counts of less than 100 cfu g^{-1}, while faecal coliforms and total coliforms should not exceed 10 cfu g^{-1} and 100 cfu g^{-1}, respectively (Food & Agricultural Organization (FAO) 1979). Total coliform, faecal coliform and *E. coli* counts exhibited by *Cyprinus carpio* examined in

the present study exceeded the acceptable limit recommended by both FAO and the World Health Organization (WHO) (Food & Agricultural Organization (FAO) 1979; World Health Organization (WHO) 2002), indicating human health risks from consumption of *Cyprinus carpio* from Lake Naivasha. Thus, actions should be taken to reduce or prevent contamination of the lake and the rivers and water systems draining into it. Depending on the bacterial sources and other environmental factors, a wide range of variation in the distribution of microflora in fish has been reported (Shankar *et al.* 2009), consistent with the findings regarding the variation in bacterial counts in *C. carpio* noted in the present study.

The poor quality of water and fish in the present could be attributed to anthropogenic activities in the catchment, and along the lakeshore itself. The major observed pollution practices included in-stream and lake-shore activities such as laundry washing, wastes from cars and donkeys in the lake and/or influent rivers by vendors to fetch, and large herds of cattle and wild animals that defecate and urinate when they access this water system to drink or graze on the riparian vegetation. Mokaya *et al. (*2004) and Yillia *et al. (*2009) reported similar pollution practices for other Rift Valley lakes and reservoirs. There is a need, therefore, to adopt measures to improve the water quality of both Lake Naivasha and its drainage basin, particularly as other studies also report increased faecal pollution loads as the influent river flows into the lake from field containing grazing livestock, residential areas and flower farms. To this end, the gradual increase in bacterial counts from upstream to downstream in this water system is attributed to domestic and municipal wastewater discharges, as well as agricultural effluents (Niewolak 1999; Shawky & Saleh 2007; and Donde *et al.* 2013).

CONCLUSION

The bacterial quality of *Cyprinus carpio* measured in this study was below the quality standards and guidelines of FAO and WHO, which should raise local, regional and international concern. This study indicated raw domestic sewage discharges into the lake and the rivers draining into the lake contributes to the poor bacterial quality of *C. carpeo* in Lake Naivasha, a situation that poses a health threat to individuals consuming the fish and water. This pollution also results in degradation of the bacterial quality of *Cyprinus carpio* in Lake Naivasha to levels below recommended market standards, thereby also negatively impacting its market acceptability. The town of Naivasha, which boarders the lake, is experiencing rapid growth, including expanded horticulture farming businesses. The region also exhibits a mild climate and natural beauty for tourism, and a productive fishery that provides jobs, protein and income to local and international communities. The result of this study on the bacterial quality of fish and water, therefore, provides useful monitoring information upon which to base corrective actions. It is especially useful therefore for the development and implementation of integrated water management practices in the lake basin, as well as any other lake basin experiencing the same conditions. The reported faecal contamination and resultant indication of degraded fish and water should highlighted the need for further sampling and investigation of potential pollutant sources, such as inadequate waste treatment and/or deficiencies in the integrity of the distribution system. It also should further enhance actions directed to protection and conservation of Lake Naivasha and its riparian zone and catchment, as the lake also is a Ramsar site.

Other studies on Lake Naivasha and its basin indicate the major source of pollution into the lake, and rivers within the basin, to include both humans and warm-blooded animals. The findings of this study therefore should facilitate lake eco-health management, as microbial contamination of water and food is associated with gastrointestinal illnesses in many studies. In fact, 88% of such reported cases occur as a result of contaminated food and water, poor hygiene and poor sanitation. Furthermore, understanding the quality of fish and water in Lake Naivasha is of paramount importance to aquatic environmental health managers, mainly because it focuses on ensuring riparian vegetation and catchment conservation and protection, as well as creating public awareness among lake communities about their responsibilities in regarding to maintaining good water quality. These results also are of benefit to the Naivasha Water and Sanitation Company (NAWASCO), Lake Naivasha Water Resource Users Association (WRUA) and Lake Naivasha Riparian Association (LNRA), being consistent with their goals of upgrading the water quality of Lake Naivasha and associated reservoirs within its catchment.

Due to various risk factors involved in the occurrence and transmission of fishborne and water-related illnesses, interventions for their prevention will not only enhance water availability, but also improve prospects for the proper disposal of human faeces and improve fish and water quality, as well as general personal and environmental hygiene. Thus, the results of this study should be considered and applied within the context of managing and conserving other similar lakes and reservoirs at the local, regional and international level for improved fishery quality and enhanced public health.

RECOMMENDATIONS

Care must be taken to prevent contamination of Lake Naivasha water, as well as that in the rivers draining into it, through proper and efficient municipal sewage treatment, and the use of modern sanitation facilities in handling faecal and other organic wastes. There is clearly a need to further examine of the impacts of horticulture industrial waste discharges into the lake, and particularly their impacts on the bacterial quality of Lake Naivasha fish. Creating awareness regarding personal and environmental hygiene, including maintaining high sanitation standards, also is necessary within the lake and its catchment, as well as fish landing points within the lake. There also is a need for proper sewage disposal and treatment measures to meet the water demands of a rising basin population, including reducing the quantity of raw sewage that drains into the basin water courses. Both lakeside and lake basin communities must be supplied with clean piped water at the household level, as a means of reducing the direct contact of the basin population with the lake and its influent water systems. There also is an urgent need to focus on means for controlling pollution of the lake and its influent water systems by other organic and inorganic materials through such measures as proper solid and liquid waste disposal and regular water monitoring programmes for water sources in the basin. The use of faecal contamination source tracking approaches, such as molecular techniques for fish and water, also is recommended in order to increase the reliability and accuracy in tracking possible faecal contamination sources. Emphasizing affordable, cheap and locally available and environmentally friendly fish and water treatment technologies, such as solar driers and pasteurization kits, also is recommended. In particular, such technologies are urgently required for rural and informal urban settlement the Lake Naivasha basin. Similar studies also should be carried out for other fish species within the lake, as well as examining the bacterial impacts on fish attributable to the flower farms surrounding the lake. These proposed actions collectively will facilitate enhanced production of high-quality fish with high market acceptability and prices, as well as reducing fish-related public health concerns.

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