International Journal of Fisheries and Aquatic Studies 2015; 3(1): 179-184

ISSN: 2347-5129
(ICV-Poland) Impact Value: 5.62
(GIF) Impact Factor: 0.352
IJFAS 2015; 3(1): 179-184

www.fisheriesjournal.com
Received: 24-07-2015
Accepted: 26-08-2015

James Njiru
Kisii University, Department of Applied Aquatic Sciences, P.O. Box 408, Kisii, Kenya.

George Morara
Kenya Marine and Fisheries Research Institute, P.O. Box 81651, Mombasa, Kenya.

Edna Waithaka
Kenya Marine and Fisheries Research Institute, P.O. Box 837, Naivasha, Kenya.

James Mugo
Kenya Marine and Fisheries Research Institute, P.O. Box 837, Naivasha, Kenya.

Correspondence
James Njiru
Kisii University, Department of Applied Aquatic Sciences, P.O. Box 408, Kisii, Kenya.

Fish kills in lake Naivasha, Kenya: What was the probable cause?

James Njiru, George Morara, Edna Waithaka, James Mugo

Abstract
Fish kills were detected in Lake Naivasha in February 2010. Physico-chemical parameters and pesticide residue screening were done to ascertain if they contributed to the kills. Mean (±SD) dissolved oxygen, temperature, pH and conductivity were 4.06 ± 1.97 mgl^{-1}, 24.63 ± 1.58 ^{0}C, 8.74 ±0.85 and 303.29 ± 76.20 μScm^{-1} respectively. Except for conductivity, all parameters were significantly different between months ($p<0.05$), but not between sampling points ($p>0.05$). There were detectable levels of organochlorines in fish fresh while sediment samples had pesticides below limit of detection. The majority of dead fish were *Cyprinus carpio.* Fish examined showed no external damage and on dissection, appeared to be in good physical condition, pointing to the effects of water quality rather than poisoning on their deaths. There are indications that Lake Naivasha is becoming hyper-eutrophic. Firm measures to reduce nutrients entry into the lake should be instituted to reduce deterioration in water quality.

Keywords: *Cyprinus carpio*, dissolved oxygen, blooms, pesticides

1. Introduction
The fishery of Lake Naivasha is based on introduced exotic species [1, 2]. Currently the fishery is composed of four main species namely; common carp, *Cyprinus carpio* (L.), Nile tilapia, *Oreochromis leucostictus* (Trewavas), *Tilapia zillii* (Gervais) and Black bass, *Micropterus salmoides* (Lacépède). Also present in the lake is a riverine cyprinid, the Longfin barb *Barbus amphigramma* (Boulenger), and crayfish, *Procambarus clarkii* (Girard) both of which supported a significant part of the fishery until the 1980s [1, 2]. Cyprinodonts, *Gambusia* sp., and *Poecilia reticulata* (Peters) were introduced into the lake to control mosquitoes but no longer occur.

Lake Naivasha has experienced considerable changes in water quality attributed to both anthropogenic and climatic conditions [3, 4, 5, 6]. Change in water quality is attributed to pollution from agricultural activities and degradation of the shoreline and the upper catchment, although the full extent of pollution is unknown [6, 7]. Numerous studies dealing with the limnological characterization of the lake have been carried out and showed deteriorating water quality conditions [3, 5, 6]. Although there is major concern about the ecological status of Lake Naivasha, until February 2010 no incidences of fish kills had been reported. This paper reports on the fish kills in the lake and discusses possible reasons for the mortalities observed.

2. Materials and Methods
2.1 Study area
Lake Naivasha is a shallow freshwater basin lake (mean depth *ca* 4-6 m), situated in the Eastern Rift Valley of Kenya (0 ° 46'S and 36 ° 20'E) at an altitude of about 1890 m above sea level. It covers a surface area varying between 120 and 150 km^2 depending on the dry and wet spells respectively [8]. It freshness is maintained by surface water inflow, biogeochemical sedimentation and underground seepage [4]. The Rivers Malewa and Gilgil, with catchment areas of about 1730 km^2 and 420 km^2 respectively are the most important inflows (Fig 1) with River Malewa accounting for up to 90% of the water inflow with ephemeral streams and direct rainfall on the lake make up for the balance. The climate of Naivasha is warm and semi-arid with monthly mean air temperatures varying from 15.9 to 18.5 ^{0}C [4]. Rainfall varies between 600 mm at Naivasha town to 1700 mm in the upper catchment on the slopes of the Nyandarua mountains. Evaporation from the lake's open water is approximately 1720 mm year^{-1}. The area

of the lake covered by Papyrus swamp is dwindling [1] and corresponds with the increasing horticultural activity around the lake. A total area, *ca*. 3154 ha, of the lake basin is currently under irrigation for large-scale production of flowers, vegetables and fruit mainly for export [7]. To sustain intensive horticulture fertilizers and pesticides are applied and these, coupled with extensive deforestation, contribute polluted runoff to the lake [6]. The lake also receives sediment from cultivated farmland and untreated effluent from Naivasha town's domestic and industrial activities.

2.2. Sampling

Water temperature, pH and conductivity were measured from October 2009 to December 2010 in seven sampling sites, 1. Crescent Island, 2. Malewa River mouth, 3. Midlake, 4. South lake (Off Sher), 5. South west lake (Oserian Bay), 6. West Lake (Hippo point) and 7. North West Lake (Korongo) (Figure 1). Due to logistics challenges, no measurements were taken in June and November 2010. Measurements were made at about 50 cm below the water surface, using a multi-parameter water quality meter (Hanna HI 991300). Water samples for dissolved oxygen were collected in 100 ml clear glass bottles, and later analysed by titration against sodium thiosulphate [9]. Water transparency was measured using a 20 cm diameter secchi disc. Single factor Analysis of Variance (ANOVA) was used to compare physico-chemical parameters between months and between stations. Data on lake level were obtained from the Water Resources Management Authority, Naivasha, who routinely monitor

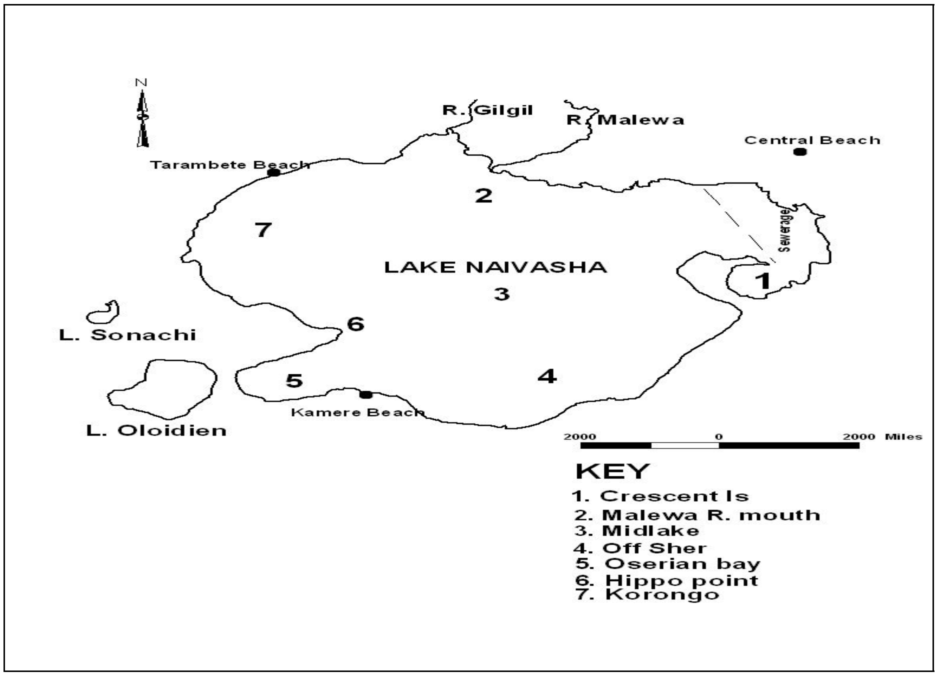


Fig 1: Map of Lake Naivasha showing the sampling sites

water level changes at designated sites around the lake. In February 2010, 100 dead fish floating on water were collected using scoop nets and their total length measured to the nearest 0.1 cm. Only fish which were not seriously mutilated by birds or badly rotten were used. The proportion consisted about 10% of the total reported dead fish. Dead fish were identified to species and classified according to the condition of the gills and body. The gills were examined for any gelatinous algae. The fish were dissected and a general internal appearance accessed. Body tissue of 500 g each of *C. carpio* and *M. salmoides* and 223 g of sediment from site of fish kills were submitted to KEPHIS (Kenya Plant Health Inspectorate Service) analytical chemistry laboratory for pesticide residue analysis.

3. Results

3.1 Physical chemical parameters

The lowest and the highest dissolved oxygen (DO) of 2.2 and 10.2 mgl^{-1} was recorded at station 7 and 4 in February and August 2010 respectively. The lowest and highest mean (± SD) DO of 4.06 ± 1.97 mgl^{-1} and 8.66 ± 0.59 mgl^{-1} was recorded in February and in September 2010 respectively (Fig 2a). DO showed a significance difference between months ($F = 7.40$, $df = 10$, $p = 0.00005$), but not between stations ($F = 0.660$, $df = 6$, $p = 0.683$).

The lowest and highest temperatures of 19.1 and 27.1 ^{0}C were recorded at station 2 and 7 respectively. Temperature had a mean (±SD) of 22.40 ± 1.82 ^{0}C with the lowest and highest values of 19.65 ± 0.45 ^{0}C and 25.43 ± 0.57 ^{0}C recorded in July and April 2010 respectively (Fig 2b). The variations in temperature were significantly different on temporal scale ($F = 8.370$, $df = 12$, $p < 0. 000$), but not on spatial ($F = 1.04$, $df = 6$, $p = 0.409$).

The lowest and highest pH of 6.63 and 9.61 was recorded at station 2 and 7 in December 2009 and January 2010 respectively. The mean pH (±SD) was 8.18 ± 0.94, with the lowest and the highest pH of 7.06 ± 0.25 and 9.42 ± 0.3 recorded in October 2010 and November 2009 respectively (Fig 2b). There was a sharp drop in pH between December 2009 and February 2010. There was a significance difference in pH between months ($F = 17.13$, $df = 12$, $p < 0. 000$), but not between stations ($F = 0.740$, $df = 6$, $p = 0.618$).

The mean (±SD) conductivity was 303.29 ± 76.20 μScm^{-1} with the lowest and the highest conductivity of 163 and 453 μScm^{-1} recorded at stations 2 and 4 in October and February 2010

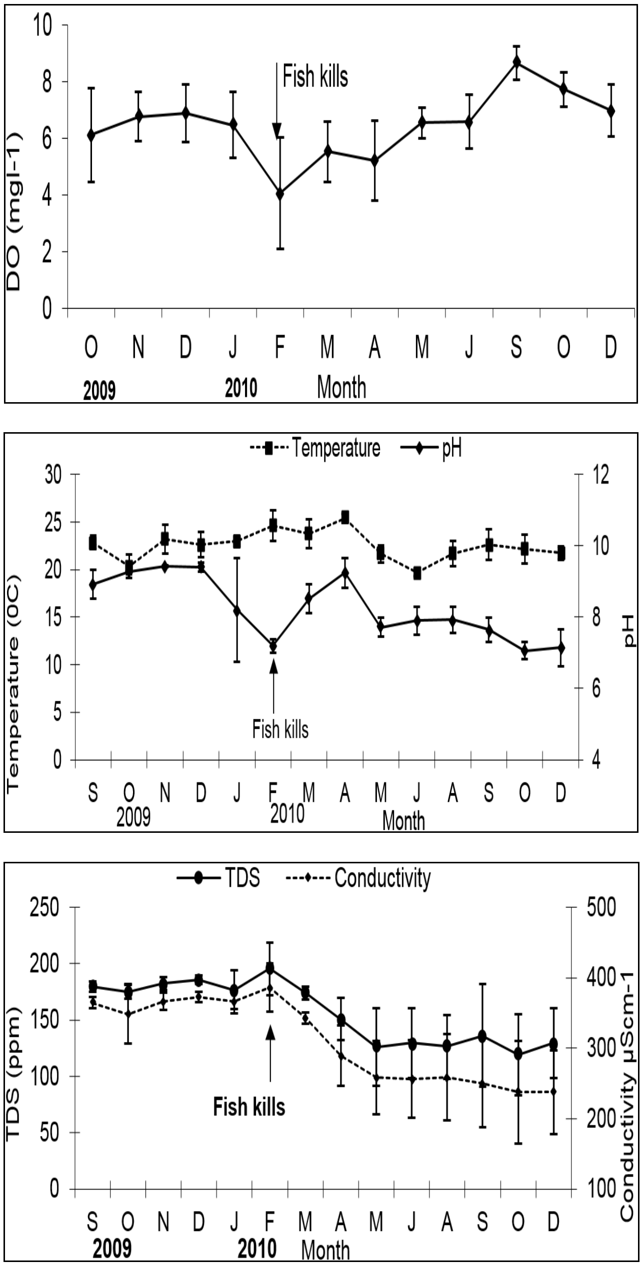


Fig 2: Some aspects of water qualilty in Lake Naivasha, a) dissolved oxygen (DO), b) pH and temperature, c) total dissolved solids (TDS) and conductivity. Vertical bars represent standard deviation.

respectively (Fig 2c). There was significance difference in conductivity between months ($F = 22.57$, $df = 12$, $p < 0.\ 0005$) and between stations ($F = 15.20$, $df = 6$, $p < 0.005$). The mean (± SD) total dissolved solids (TDS) was 153.28 ± 34.47 ppm with the lowest and highest TDS of 100 and 242 ppm
recorded at stations 2 and 4 in December and January 2010 respectively (Fig 2c). There was significance difference in TDS between months ($F = 16.68$, $df = 12$, $p < 0.005$) and between stations ($F = 11.21$, $df = 6$, $p < 0.005$). Conductivity and TDS followed a similar pattern, increasing from September 2009 to February 2010, thereafter decreasing (Fig 2c).

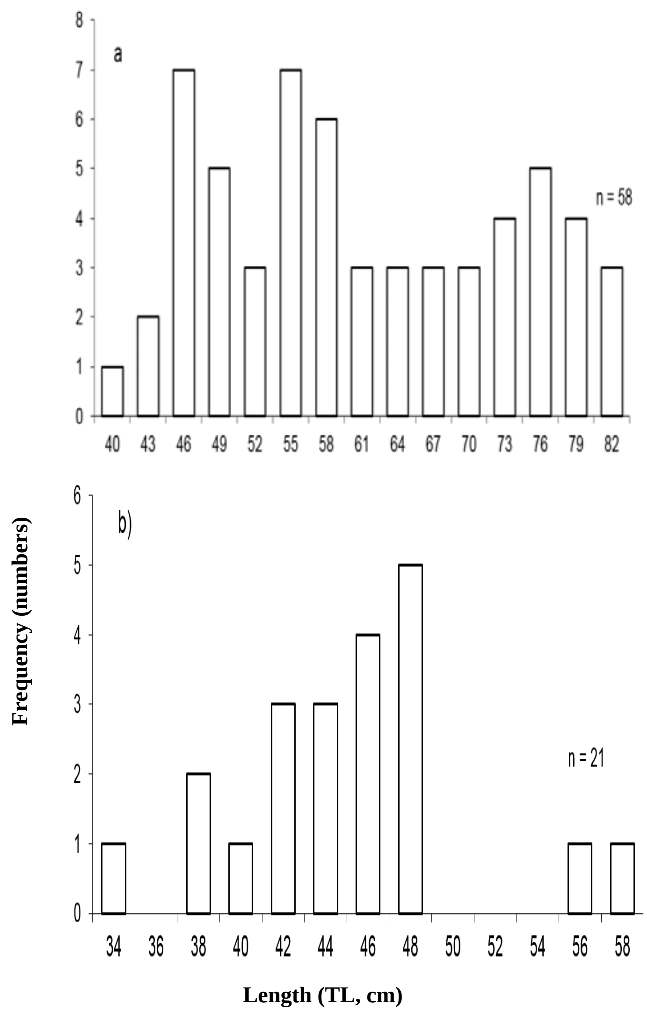
Results of pesticide residue screening analysis using GC-ECD and GC-M by KEPHIS reviewed undetectable levels of organochlorines, organophosphates, pyrethroids and PCBs in the sediment sample while only organochlorines were detected in the fish samples (Table 1).

Table 1: Pesticide residue screening of fish and sediment samples from Lake Naivasha by KEPHIS. LOD = Limit of Detection

Concentration (mg/kg)		
Pesticides	***C. Carpio*/*M. salmoides***	**Sediment**
Organochlorines	Detected	<LOD
Organophosphates	<LOD	<LOD
Pyrethroids	<LOD	<LOD
PCBs	<LOD	<LOD
Atrazine	<LOD	<LOD

3.2 Dead fish

Department of Fisheries reported over 1000 fish to have died within a week. At the time of collection, most of the fish were rotten or eaten by birds making it difficult to measure their lengths. The majority of the dead fish measured were *C. carpio*, followed by *M. salmoides* and *O. leucostictus* (Fig 3). Samples of *C. carpio* had sizes ranging from 42 to 82 cm TL (mean ± SD, 60.4 ± 10.9), while those of *M. salmoides* ranged from 34 to 57 cm TL (44.6 ± 5.5) and *O. leucostictus* from 16 to 21 cm TL (19.3 ± 3.0). Most of the dead fish were collected in the western part of the lake (station 4, 5, 6, and 7) in the morning. Of the fish examined, none showed external damage, and on dissection, the fish appeared to be in good physical condition. The water where the fish were collected was deep brown and colonies of gelatinous algae were found on the gills of some of the dead fish. There were no dead juveniles or fingerings of the fish recorded.



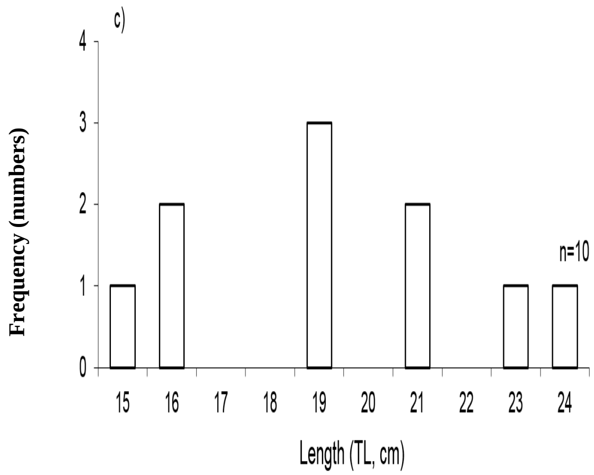


Fig 3: Length frequency distribution of the dead fish from Lake Naivasha in mid February 2010, a) *Cyprinus carpio,* b) *Macropterus salmoides,* c) *Oreochromis leucostictus.* n= sample size.

4. Discussion

Most dead fish were found in the morning in the west side of the lake where levels of DO below 3 mgl^{-1} were recorded. Sudden, fish kills in water bodies are often as a result of fish suffocation caused by night time oxygen depletion [10, 11]. Occasional fish kills are attributed to natural causes such as; change in climatic conditions that can lead to deoxygenation of the water, diseases, stress, toxic algae, thermal shock and salinity shock among others factors [12]. Prolonged drought conditions, excessive algal or other plant growth and high water temperatures are common factors that combine to cause fish kills [11]. During night time, algae switch from photosynthesis to respiration, thereby consuming oxygen. Thus, such fish kills from oxygen depletion usually occur in the early morning hours in algae-rich waters following the die-off of a large algae bloom, the decay of submerged water plants, turnover of oxygen-poor bottom waters following heavy rains or due to polluted runoff from agricultural or industrial land.

Physico-chemical parameters may have contributed to fish kills in Lake Naivasha. Algal blooms and large changes in water quality were observed from mid-2009 to February 2010 preceding the fish kills. Oxygen concentrations in station with large number of fish kills fell below 3 mgl^{-1}. These stations also recorded low pH, and increased conductivity in February. Water temperature was unusually high reaching an extreme of 27.1^{0}C in February 2010 on some days compared to an average of 20^{0}C over other months. Heavy rainstorms occurred between December 2009 and January 2010, which increased water levels after a prolonged drought. This could have led to an influx of organic material to the lake including dead shoreline vegetation. Low water levels from January to December 2009 (Fig 4) attributed to low rainfall and high temperate in the tropical environment may have accelerated decomposition of organic material. Subsequent increase in lake levels from January 2010 inundated the rotting material. High lake turbulence observed the day before the fish kills could have caused turnover of potentially anoxic bottom water.

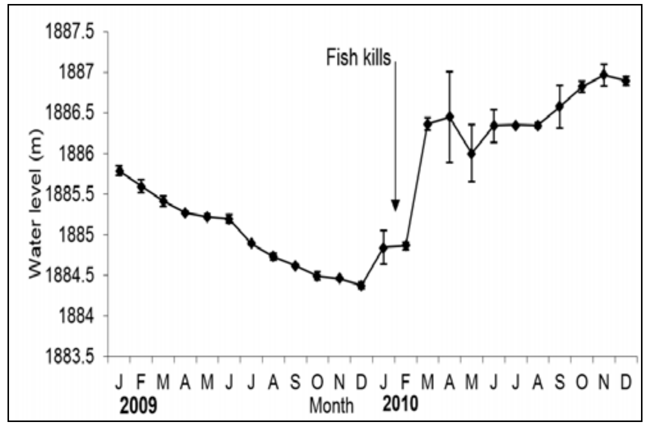


Fig 4: Trends in Lake Naivasha water levels between 2009 and 2010. Vertical bars represent standard deviation.

Large scale fish kills as a result of low dissolved oxygen concentration have been detected in several parts of the world [11 12]. In Maryland, USA over 200 000 fish were reported to have died due to dissolved oxygen associated with night time respiration and partial die-off of cyanobacterial blooms [12]. Most of the deaths were reported in warmer months and after rainy weather**.** Fish kills have also been reported in Lake Victoria after heavy storms, algal blooms and depletion of oxygen as algae decayed [10]. Most frequently, however, fish become stressed during a low DO period and become susceptible to viral or bacterial infections. There were no indications of parasites or diseases in the fish collected in Lake Naivasha. Although no attempt was made to identify the composition of the algal bloom, the possible effects of toxic blue-green algae should not be overlooked. Studies in in Arabian Sea found that asphyxiation and abnormal mucus secreted by the algae, *Karenia mikimotoi* (Miyake & Kominami ex Oda) Gert Hansen & Ø.Moestrup led to clogging of gills that accentuated the mass fish kills [13].

Early work in Lake Naivasha showed that the phytoplankton community was composed of Chlorophyta, Cyanophyta and Bacillariophyta [14]. Since early 2000s, algal blooms have been common in the lake mostly composed of Cyanophyta [15]. Some cyanobacteria in eutrophic lakes are known to produce toxins that are poisonous both to humans and livestock [16]. In the recent past the lake experiences hypoxic conditions in water below 4 m (Fig 5).

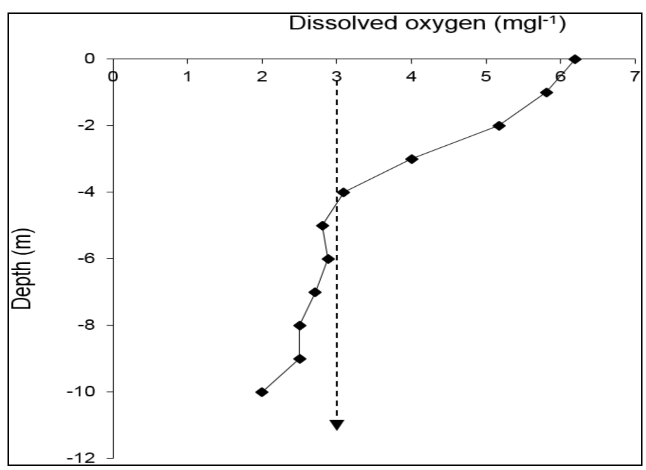


Fig 5: An oxygen profile in one of the deepest stations in Lake Naivasha in April 2009. Source: Kenya Marine and Fisheries Research Institute (KMFRI). Unpublished data.

The majority of the fish killed was the common carp followed by *M. salmoides* and finally *O. leucostictus.* The high death of common carp could be attributed to a higher requirement of DO. Activities like feeding, growth and reproduction of common carp occurs best at more > 6 mgl^{-1} of DO [17, 18]. When dissolved oxygen concentrations drop below 3 mgl^{-1} common carp stop feeding and search for better oxygenated water [19], while respiration is elevated at 3-5 mgl^{-1} DO (13-23° C) [17]. In Australia, carp have been found to have a greater tolerance of low dissolved oxygen conditions than many fish species, surviving levels of oxygen availability as low as 7% saturation at 5 °C [20]. However, at higher temperatures, oxygen requirements increase, so that survival near the upper thermal limit requires close to 100% oxygen saturation. Ecologically, the common carp is a demersal fish, frequently associated with the bottom and feeding from the sediments on the bed of the lake [21]. Their feeding style involves disturbing of the bottom while in search of food and hence opening possibilities of very low oxygen and highly rotten material in the bed lifting into the water column. The larger the fish the more disturbances it causes in the debris on the lake bed and possibly the more exposure to low dissolved oxygen concentrations which may have led to their death. This could account for death of larger fish. Black bass have acute lethal dissolved oxygen levels between 1 and 2 mgl^{-1}. The bass became stressed at DO level of 5 mgl^{-1}, especially in warm water. In Oregon, higher numbers of *M. salmoides* were caught in areas with more than 3 mgl^{-1} DO, with fish dying when oxygen fell below 2 mgl^{-1} [22]. Adult black bass feed in the inshore waters mainly on algae, fishes, crayfish, frogs and insects [23, 24, 25]. The inshore shallow water of Lake Naivasha rarely experiences deoxygenation. Tilapias are hardy fish and can survive in water up to 2 mgl^{-1} DO [26], with *O. leucostictus* tolerating considerable deoxygenation of waters [26]. The food and feeding behaviour of both tilapia and black bass do not necessarily expose them to bottom deoxygenated water as do common carp. Occasional fish kills of large individuals severely threaten the reproductive success of the species. In Lake Naivasha, the size at which fifty percent (Lm_{50}) of *C. carpio* is sexually mature is estimated at 36 cm TL (Ojuok pers. comm.) and most of the fish that died were between 42 and 82 cm TL. The length at Lm_{50} of *M. salmoides* and *O. leucostictus* is around 25 cm TL and 10 cm TL respectively in Lake Naivasha (Ojuok pers. comm.). Most dead samples of *M. salmoides* and *O. leucostictus* ranged between 34 – 57cm TL and 16 to 21 cm TL respectively.

Nutrient and particulate loading into Lake Naivasha is likely to increase without systematic management and proper regulation of agriculture, horticulture and sewage effluents [6]. The water quality conditions measured over the period reported were likely to have caused physiological stress and if extreme hypoxia was sustained, possibly mortality but the effects of direct toxicity cannot be discounted.

5. Acknowledgements

This study was funded by the Government of Kenya. We are indebted to Water Resources Management Authority, Naivasha, for providing water levels data and KEPHIS for pesticide analysis.

6. References

1. Hickley P, Muchiri M, Britton JR, Boar RR. Discovery of carp, *Cyprinus carpio,* in already stressed fishery of Lake Naivasha, Kenya. Fish Manage Ecol 2004; 11:139-142.
2. Ojuok J, Njiru M, Mugo J, Morara G, Wakwabi E, Ngugi, C. Increase dominance of common carp, *Cyprinus carpio* L: the boom or the bane of Lake Naivasha fisheries? Afri J Eco 2008; 46(3):445-448.
3. Milbrink G. On the limnology of two alkaline lakes (Nakuru and Naivasha) in the East rift valley system in Kenya. Int Revue Gas Hydrobio 1977; 62:1-17.
4. Gaudet JJ, Melack JM. Major ion chemistry in a tropical African lake basin. Freshwater Biol 1981; 11:309-333.
5. Harper DM, Phillips G, Chilvers A, Kitaka N, Mavuti KM. Eutrophication prognosis for Lake Naivasha, Kenya. Ver Internat Verein Limnol 1993; 25:861-865.
6. Kitaka N, Harper DM, Mavuti KM. Phosphorus inputs to Lake Naivasha, Kenya, from its catchment and the trophic state of the lake. Hydrobiologia 488 (Development in Hydrobiology) 2002; 168:73-80.
7. Gitahi SM, Harper DM, Muchiri M, Tole M, Ng'ang'a P. Organochlorine and organophosphorus pesticide concentrations in water, sediment, and selected organisms in Lake Naivasha (Kenya). Hydrdrobiologia 2002; 488:123-128.
8. Harper DM. The ecological relationships of aquatic plants at Lake Naivasha, Kenya. Hydrobiologia 1992; 232:65-71.
9. American Public Health Association [APHA]. Standard methods for analysis of water and wastewater. 18th ed. Port City Press, 1995.
10. Ochumba PBO. Massive fish kills within the Nyanza Gulf of Lake Victoria, Kenya. Hydrobiologia 1990; 208:93-99.
11. Pearl HW, Pinckney JL, Fear JM, Peierls BL. Ecosystem responses to internal and watershed organic matter loading: consequences for hypoxia in the eutrophying Neuse riverestuary, North Carolina, USA. Mari Ecol Progr Ser 1998; 166:17-25.
12. Helfrich LA, Smith SA. Fish Kills: Their Causes and Prevention. Virginia cooperative extension. http://www.pubs.ext.vt.edu/420/420-252/420-252.html. [Accessed 21 October 2010], 2009.
13. Robin RS, Kanuri VV, Pradipta RM, Rajani KM, Jaikumar M, Karthikeyan P *et al*. Dinoflagellate Bloom of *Karenia mikimotoi* along the Southeast Arabian Sea, Bordering Western India. J Ecosyst 2013. http://dx.doi.org/10.1155/2013/463720.
14. Lind DT. The phytoplankton of some Kenyan waters. J EA. Nat Hist Soc 1968; 25:91-96.
15. Ballot A, Kotut K, Novelo E, Krienitz L. Changes of phytoplankton communities in Lakes Naivasha and Oloidien, examples of degradation and salinization of lakes in the Kenyan Rift Valley. Hydrobiologia 2009; 632 (1):359-363.
16. Moreno I, Camean A, Tavares MJ, Pereira P, Franca S. Toxicity of cyanobacteria isolated from the Guadiana river. J Aquat Ecosys Health Manage 2003; 6(4):409- 413.
17. Davis JC. Minimal dissolved oxygen requirements of aquatic life with emphasis on Canadian species: A review. J Fish Res Board Can 1975; 32(12):2295-2332.
18. Dunham RA, Chatakondi N, Nichols A, Chen TT, Powers DA, Kucuktas H. Survival of F2 transgenic common carp (*Cyprinus carpio*) containing pRSVrtGH1 complementary DNA when subjected to low dissolved oxygen. Mar Biotechno (NY) 2002; 4(3):323-7.
19. Bauer C, Schlott G. Reaction of common carp (*Cyprinus carpio*, L.) To oxygen deficiency in winter as an example for the suitability of audio telemetry for monitoring the

reaction of fish to stress factors in pond aquaculture. Aquacult Res 2006; 37:248-254.
20. Ott ME, Heisler N, Ultsch GR. A re-evaluation of the relationship between temperature and the critical oxygen tension in freshwater fishes. Comp Biochem Phy 1980; 67:337-340.
21. Parkos J, Santucci VJ Jr, Wahl D. Effects of common carp (*Cyprinus carpio*) on multiple trophic levels in shallow mesocosms. Can J Fish Aquat Sci 2003; 60:182-192.
22. Ziller SJ. (Factors that limit survival and production of Largemouth bass in upper Klamath and agency lakes, Oregon.http://www.fishlib.org/library/Documents/ Oregon/ DFW/i nforept91-6.pdf [accessed 31 Oct. 2010), 1991.
23. Howick GO, Brien J. Piscivorous Feeding Behavior of Largemouth Bass: An Experimental Analysis. Trans Ame Fish Soc 1988; 112:508-51.
24. Hickley P, North R, Muchiri M, Harper DM. The diet of the largemouth bass *Micropterus salmoides* in Lake Naivasha, Kenya. J Fish Biol 1994; 44:607-619.
25. Hickley P, Bailey R, Harper DM, Kundu R, Muchiri M, North R *et al*. The status and future of the Lake Naivasha fishery, Kenya. Hydrobiologia 2002; 488:181-190.
26. Kaufman L. Catastrophic change in species rich freshwater ecosystem: lessons of Lake Victoria. Bioscience 1992; 42:846-858.
27. Trewavas E. Tilapiine fishes of the genera *Sarotherodon*, *Oreochromis* and *Danakilia*. British Mus Nat Hist London, UK, 1983, 583.