EFFECT OF PHYSICOCHEMICAL FACTORS AND DYKE ON CONSERVATION OF *Oreochromis esculentus* AND *Oreochromis variabilis* IN LAKE KANYABOLI, KENYA

BY

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DECLARATION

I hereby declare that this thesis is my own work and has not been submitted for any other qualification at Maseno University or any other institution.

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DEDICATION

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ABSTRACT

Lake Victoria witnessed mass extinction of native fish species that coincided with introductions of *Lates niloticus* and *Oreochromis niloticus* about five decades ago. Small populations of *O. esculentus* and *O. variabilis* that are locally extinct in L. Victoria are found in Lake Kanyaboli, a satellite lake of L. Victoria. L. Kanyaboli thus has potential to serve as a refugium where cichlid relics are protected from the invasive *L. niloticus*. However, the status and thus factors that may negatively impact the survival of the two cichlids are presently not known. In addition, although a dyke that divides the lake into two components was constructed in 2003, its effects on key trophic levels such as phytoplankton species are not known. The goal of this study was to investigate physicochemical factors and effect of the dyke that may constrain the conservation of both *O. esculentus* and *O. variabilis* in L. Kanyaboli. Specifically, the study aimed to: compare present and previous estimates of temperature, dissolved oxygen (DO), pH and turbidity; determine whether temperature, dissolved oxygen, pH and turbidity predict the distribution of *Oreochromis esculentus* and *O. variabilis*; compare size of *O. esculentus* and *O. variabilis* in the lake against their respective sizes published by International Union of Conservation of Nature (IUCN); and determine effect of the dyke on phytoplankton species diversity in L. Kanyaboli. Levels of DO, pH, temperature using Environmental Multiparameter Monitoring System YSI Hydrolab and Secchi depth were measured using Secchi disk and compared to previous estimates from the lake to determine the extent which the four physicochemical factors have changed and whether they predicted the distribution of each of the two species. The study employed a cross-sectional study design. Lengths of fish caught during the study were measured and compared against respective lengths of each species published the IUCN. Diversity of phytoplankton was determined from water samples. The study found that DO and temperature are decreasing but pH and Secchi depth are increasing, which suggests that quality of water in the lake is deteriorating. The results showed that Secchi depth was positively proportional to the abundance of *O. variabilis* ($z = 2.000$, $p < 0.0455$). None of the four physicochemical factors predicted the distribution of *O. esculentus*. The results also showed that *O. esculentus* and *O. variabilis* in L. Kanyaboli were significantly shorter than their respective lengths published literature by IUCN ($t = -19.564$, $p < 0.0001$ and $t = -45.960$, $p < 0.0001$ respectively). The small size of fish may arise from high fishing pressure and deteriorating quality of the water. Results on the effect of the dyke showed that the western component of the lake had a lower phytoplankton species diversity compared to the smaller component, $H = 3.033$ vs. $H = 1.281$. All species of phytoplankton that were abundant in the larger component are associated with polluted waters. In contrast, species that were more abundant in the smaller component of the lake are associated with relatively less polluted waters. Results on phytoplankton species diversity suggest that the two components of the lake may be under different limnological processes. In the aggregate, conservation efforts should aim at improving water quality and regulating both fishing effort and fishing gear in Lake Kanyaboli so as to safeguard its roles as a biological refugium for endangered fishes in L. Victoria.

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CHAPTER ONE

Introduction

1.1 Background

The collapse of native fisheries and population declines of cichlid species in Lake Victoria is one of the well-documented biodiversity disasters in modern times (Kaufman, 1992; Pringle, 2005). The introduced species, most notably *Lates niloticus*, dramatically altered the ecosystem of the lake and consequently led to the extinction of over 300 haplochromine cichlid species in L. Victoria (Ogutu-Ohwayo, 1990). Today two tilapiine species, *Oreochromis esculentus* and *Oreochromis variabilis,* have disappeared from L. Victoria (Twongo, 1995; Aloo, 2003; Balirwa; 2003) and are now classified as critically endangered (IUCN, 2015). The disappearance of *O. esculentus* and *O. variabilis* from L. Victoria might have been caused by predation by *L. niloticus*, competitive exclusion by *O. niloticus* or by ecological displacement by introduced fishes and overfishing (Twongo, 1995). However remnant populations of *O. esculentus* and *O. variabilis* still persist in L. Kanyaboli, a satellite lake of L. Victoria (Abila, 2005; Angienda, 2011).

Biodiversity in L. Kanyaboli just like that of L. Victoria is under several threats. One of the major threats that L. Kanyaboli faces is overexploitation of its fish resources. In 2003, the active number of boats in the lake was estimated at 65 (Abila, 2003), which was quite high for a lake of 10.5 km^2 in size and is thought to have exerted considerable pressure on fish population in the lake. Lake Kanyaboli acts as refugium for L. Victoria fishes (Abila, 2005) and thus may serve as a potential source for future reintroductions of native fishes to L. Victoria. Despite the importance of the lake and its cichlids to the local community, empirical data on the status of prevailing physicochemical characteristics (temperature, dissolved oxygen, pH and turbidity) was last determined in 2003 (Aloo, 2003) which is over a decade ago. This is worrying particularly given the fact that the maintenance of conducive aquatic ecosystem is dependent on the ecosystem's physicochemical properties (Venkatesharaju *et al.*, 2010). For instance, the interactions of both the physical and chemical properties of water play a significant role in the composition, distribution, abundance, movements and diversity of aquatic organisms (Mulongaibalu *et al.*, 2014). A study by LVEMP (2002) showed that *O. esculentus* in L. Kanyaboli were smaller in size compared to those in L. Ikimba and L. Kyoga because physicochemical characteristics in L. Kanyaboli adversely changed because of diversion of River Yala, which originally drained into the lake. Although physicochemical factors in aquatic ecosystems continue to change more so in the face of climate change, whether the same trends are occurring in L. Kanyaboli and the extent to which they influence distribution of *O. esculentus* and *O. variabilis* is not known.

Overexploitation of the world's fisheries is the subject of great concern (FAO, 2002). Furthermore, although the global demand for fish and fishery products continues to grow, the harvest from fisheries has stagnated over the last decade. Numerous fish stocks and species have declined since their historical peaks, and some have even collapsed leading to call for stringent management and the establishment of protected areas (Robert, 2003). In 2003, for example, fishing pressure was high in L. Kanyaboli in terms of increasing number of fishing boats and small mesh-size of fishing nets (Abila, 2003). However, effects of such threats to biodiversity including a reduction in size of fish of the suspected high fishing pressure are yet to be investigated.

In addition to changing physicochemical factors and fishing pressure and the effects on aquatic life including that of fish, habitat alterations including the construction of dykes have been shown to disrupt connections between rivers and valuable floodplain habitats (Hassan *et al.*, 2006). Dykes are used to control flooding of land behind the dyke in order to protect homesteads and also to reclaim wetlands for crop cultivation (Ellery, 1994). Some of the effects of dykes include deterioration of water quality which involves accumulation of pollutants, sediments and minerals due to low circulation of water in water bodies (Djkema, 1987). Dykes may also lead to loss of natural habitats for some species as they lead to habitat fragmentation (Combes, 2003).

In L. Kanyaboli, a dyke was constructed by Dominion Farms in 2003 to facilitate land-based transport between two communities, Alego and Yimbo, on either side of the lake. However, the effects of the dyke on aquatic life in the lake are not known. More specifically, the effects of the dyke on primary producers such as phytoplankton, which are also the natural food for fish, have not been evaluated.

1.2 Statement of the problem

Despite the potential role of L. Kanyaboli as a refugium for some tilapiine species of L. Victoria, knowledge of factors that may threaten *O. esculentus* and *O. variabilis* in the lake is incomplete. In addition, effect of the dyke, contrasted in 2003, on biodiversity in the lake remains unknown. More specifically, first, whether physicochemical factors in the lake have changed and the extent to which they predict the distribution *of O. esculentus* and *O. variabilis* is not known. Second, the effects of increasing fishing pressure on the size of *O. esculentus* and *O. variabilis* is not known. Third, the effect of the dyke that separates the lake into two components on biodiversity in the lake is yet to be determined.

1.3 Justification of study

Although L. Kanyaboli has the potential to act as a refugium for L. Victoria, major research gaps persist and these limit the extent to which decision makers including the Kenya Marine and Fisheries Institute can formulate targeted conservation action plans to manage fish species in the lake. Specifically, data on the physicochemical and dyke that threaten *Oreochromis esculentus* and *Oreochromis variabilis,* cichlids presently thought to be extinct in L. Victoria, are needed in order to formulate a holistic and sustainable management and conservation program of these critically endangered species in L. Kanyaboli.

1.3 General objective

To investigate physicochemical factors and effect of the dyke that may constrain the conservation of both *Oreochromis esculentus* and *Oreochromis variabilis* in Lake Kanyaboli.

1.4 Specific objectives

1. To compare present and previous estimates of temperature, dissolved oxygen, pH and turbidity in L. Kanyaboli.
2. To determine whether temperature, dissolved oxygen, pH and turbidity predict the distribution of *Oreochromis esculentus* and *Oreochromis variabilis* in L. Kanyaboli.
3. To compare size of *O. esculentus* and *O. variabilis* in L. Kanyaboli against size published by IUCN.
4. To determine differences in phytoplankton species diversity between the two components of L. Kanyaboli.

1.5 Null hypotheses

1. Present and previous estimates of temperature, dissolved oxygen, pH and turbidity in Lake Kanyaboli are not different.
2. Temperature, dissolved oxygen, pH, and turbidity do not influence the distribution of *Oreochromis esculentus* and *Oreochromis variabilis* in L. Kanyaboli.
3. Lengths of *O. esculentus* and *O. variabilis* in L. Kanyaboli at adult stage are not different from the species' reference sizes as published by the International Union for the Conservation of Nature.
4. There are no differences in phytoplankton species diversity between the two components of L. Kanyaboli.

1.6 Significance of study

The findings of the study will help first, to provide baseline data on the status of water quality in the lake that may form an important guideline for future monitoring by agencies such as the Kenya Marine Fisheries Research Institute. Second, to come up with factors that may negatively impact on the growth of the two species of fish to their maturity in L. Kanyaboli. Third, to find out the effect of dyke on primary producers such as phytoplankton in L. Kanyaboli

CHAPTER TWO

Literature review

In Lake Victoria, the two introduced species, *Lates niloticus* and *Oreochromis niloticus*, have altered the ecosystem of the lake causing extinction of over 300 haplochromine species (Ogutu-Ohwayo, 1990; Barilwa, 2003). A huge predaceous fish, the Nile perch (*Lates niloticus*) from the Nile River, was introduced to improve fish market. However, its introduction into L. Victoria provoked mass extinction of native fishes.

Remnant populations of the native tilapiine species such as *Oreochromis esculentus* and *Oreochromis variabilis* that are now extinct in the main L. Victoria still persist in waters of L. Kanyaboli (Loiselle, 1996; Aloo, 2003; Angienda; *et al*. 2011). Such peripheral waters are thought to play an important role in conservation and even speciation of fishes and other aquatic organisms (Mwanja *et al*. 2000). However, these satellite lakes are also facing several threats to their biodiversity thus limiting their potential future role as biological refugia in the L. Victoria basin.

Of the major threats that face biodiversity, biological invasion ranks second after habitat fragmentation in contributing to species extinction in aquatic environment worldwide (USEPA, 2008). Invasive species increase competition for food and living space, physically or chemically modify aquatic habitats, hybridize with native species and decrease biodiversity by removing native species (Sala *et al.*, 2000). Aquatic invasive species thrive due to lack of natural predators and they have high reproductive rates compared to native species, resulting in a shift in native species distribution and transformation of ecosystem structure and function (Lockwood, 1999). In L. Victoria, the introduction of *Lates niloticus* has been associated with serious ecological problems including rapid declines in the richness and diversity of endemic cichlids species (Schofield, 2011). For instance, the local extinctions of over 300 native species coincided with the introduction of *L. niloticus* (Schofield, 1999). In addition to the direct effects of *L. niloticus*, it has led to massive algal blooms in the lake partly caused by a top down effect due to the disappearance of the phytoplanktivorous and detritivorous haplochromine cichlids attributed to predation by *L. niloticus* (Schofield, 1999).

In addition to biological introductions, changes in physicochemical factors particularly in the face of increased effluents from industries and farmlands and climate change, although not the focus of this research study, have been shown to negatively influence aquatic life (Ellery,1994).

2.1 Physicochemical characteristics of aquatic ecosystems

The use of a particular habitat by fish is influenced by changes in the physicochemical factors (Braeton and Guy, 1999) and the choice relates to how fish are able to locate food, mate, avoid predators, reduce competition for the same resources and promote successful reproduction, growth and development. However optimal conditions in aquatic ecosystems are influenced by pollution. Water pollution is a major challenge brought by urbanization, industrialization and modern agricultural practices. It leads to alteration in physical, chemical and biochemical properties of water bodies (Shiddamallaya and Pratima, 2008). High human and livestock population accelerate rates of deforestation, erosion, sedimentation, siltation and nutrient loading and degrade fish habitats in East African lakes (Hecky, 1993; Odhiambo and Gichuki, 2000). In L. Kanyaboli, livestock droppings, urine and chemicals from farms around the lake that are swept by overflow during the rainy season into the lake may alter the physicochemical parameters which eventually affect life in the lake. Effect of land use around East African lakes prompted the Lake Victoria Environmental Management Programme (LVEMP) in 2002 to determine and compare physicochemical parameters in Lakes Kanyaboli

(Kenya), Kahanja (Uganda) and Ikimba (Tanzania) (LVEMP, 2002). The study noted that River Yala which drained into L. Kanyaboli was partly diverted and part of the swamp that surrounds the lake was reclaimed for rice cultivation, this made the lake to shrink in size. The lake is surrounded by large rice farms grown by Dominion Farms. Inorganic fertilizers used during planting and chemicals sprayed to control diseases are finally washed down the lake, the chemicals may finally change the physicochemical factors in the lake affecting biological lives in water. The extent to which such habitat changes and land use systems have influenced physicochemical factors such as temperature, dissolved oxygen, pH, and turbidity and whether these factors in turn influence distribution of *Oreochromis esculentus* and *Oreochromis variabilis* in the lake is not known. As much as the two native species are still found in L. Kanyaboli, they may still encounter ecological threats like competition from other related species like *Oreochromis niloticus* and adverse physicochemical conditions which may still engineer their extinction if not checked. Sometimes it's difficult to notice which factor actually influences the distribution of the two native species, because the species may move to riparian zone not because of adverse physicochemical factors in open waters but because they are escaping fishermen from catching them.

2.1.1 Dissolved oxygen

Dissolved oxygen (DO) is the relative measure of the amount of oxygen dissolved in water. Oxygen gets into the water by diffusion from the atmosphere, aeration of the water as it tumbles over rocks, and it also dissolves as a product of photosynthesis by submerged aquatic plants. The minimum DO requirements of tilapia species is 5 mg/L and if its concentration decreases below 5mg/L, key biological processes in fish such as respiration and reproduction also decrease (Mullya, 2007). A reduction in such physiological processes leads to a reduction in fish growth and to increased risk of disease outbreak. Furthermore, species of tilapia are unable to assimilate food when DO is low (Torn, 1998). In L. Victoria, eutrophication induced decrease in DO which started in the early 1960s. This contributed to the 1980s collapse of indigenous fish stocks by eliminating suitable habitats for certain deep-water cichlids (Ogutu-Ohwayo, 1990).

Nutrient enrichment of L. Victoria led to pronounced blooms of algae especially of the toxic blue-green algae (Lung'ayia *et al.*, 2000). Consequently, the lake witnessed a reduction in DO over the years, at times as low as 1.9 mg/L, a level considered lethal to cichlid fishes (Mhlanga *et al.*, 2006). For example, low DO concentrations have contributed to fish mortality in the Nyanza Gulf of L. Victoria in 1987 (Ochumba, 1990). According to Okemwa (1981), northern section of L. Kanyaboli had adequate DO supply (7.2 mg/L) to support fish, but the southern section of the lake had less DO (3.6 mg/L), which could not support fish. However, how 2014 measurement of DO compares to DO measurements of 1981 and 2002 and how DO may influence the distribution of *O .esculentus* and *O. variabilis* in the lake has not been determined.

2.1.2 pH

The concentration of hydrogen ions in a solution, pH, is an important abiotic factor in aquatic environments. It is known that acid rain induces the acidification of inland waters, which results in damage to aquatic ecosystems including habitats of fish. A negative effect of low pH on fish manifests as the production of mucus on the gill epithelium, which interferes with the exchange of respiratory gases and ions across the gill leading to respiratory distress and osmotic imbalance that are the primary physiological symptoms of acid stress in fish (Ellis, 1937). Below a pH of 5.0, mortality occurs in some life stages of certain fish species. Although some fishes can be acclimated to pH levels below 4.0, pH can also affect fish indirectly through its negative effects on macro-invertebrates that some fishes feed on (Ellis, 1937). More generally, the primary productivity of fresh water ecosystems is reduced considerably below pH of 5.0, which in turn reduces the food supply for higher aquatic organisms (Alabaster and

Lyod, 1980).

The majority of freshwater fishes and macro-invertebrates experience harmful effects at one or more life stages at extreme pH levels (Wiebe, 1931; Alabaster and Lyod, 1980). In salty fishponds, a pH of 9 begins to depress appetite of tilapia (Popma and Lovshin, 1995). Opiyo and Dadzie (1994) demonstrated that large quantities of phytoplankton ingested by *Orechromis esculentus* in L. Kanyaboli, the bulk of the blue green algae passed out of the gut undigested. The indigestibility of blue green algae in the stomach of *O. esculentus* was attributed to the pH of the stomach (4.0- 8.0), which is not acidic enough to lyse the cell walls of many algae. For L. Kanyaboli, however, whether the level of pH has changed over the years and how pH may influence the distribution of *O. esculentus* and *O. variabilis* in the lake has not been studied.

2.1.3 Temperature

Temperature exerts a major influence on aquatic organisms (Myrick and Cech, 2005). In general, high temperature is associated with increased levels of biological activity including growth rate. The optimal temperature for growth of most tilapiine species is 25- 28^{0}C. Feeding stops at temperature below 20^{0}C and reproduction at 22^{0}C (Wohlfarth and Hulata, 1983). Generally, extreme temperatures impair growth and increase susceptibility to diseases (Myrick and Cech, 2001).

In addition, the rate of chemical reactions within water increases as water temperature increases, resulting in increase in the rate of biological activities (Michuad, 1991). This leads to increase in oxygen use by organisms such that warm water holds less oxygen, resulting in oxygen shortage. Spotted tilapia, (*Tilapia mariae*), a native of west coast of Africa, prefers temperatures between 25 and 33°C, and can tolerate temperatures of up to 37°C beyond which its metabolic rate decreases (Siemien and Stauffer, 1989). According to Maithya (1998), the temperature range of Lake Kanyaboli waters was between 20.5-33.2^{o}C, which was thought to be conducive for cichlids such as *Oreochromis esculentus* that was found to be abundant at the time of this report. However, the current estimate of temperature, how it compares to previous estimates, and how temperature may influence the distribution of *O. esculentus* and *O. variabilis* in the lake is not known.

2.1.4 Turbidity

Extremely turbid waters can directly affect fish growth and survival by interfering with gill function (Bash *et al.*, 2001). Turbidity limits fish vision, which may interfere with social behavior (Berg and Northcote, 1985), foraging, and predator avoidance (Gregory, 1993). High concentrations of particulate matter can modify light penetration, cause shallow lakes and bays to fill in faster, and smother benthic habitats, thereby negatively impacting across life history stages of fish. For example, as particles of silt, clay and other organic materials settle to the bottom, they can suffocate larvae and fill in spaces between rocks that may alter important fish microhabitats. Fine particulate material also clogs or damages sensitive gill structures, decrease resistance of fish to diseases, prevent proper egg and larval development and potentially interfere with feeding activities (Michuad, 1991).

Indirectly, if light penetration is reduced significantly, both macrophyte and microphyte growth may decrease to levels that may negatively impact organisms that rely on them for food and cover. Moreover, at lower trophic levels, adequate amount of light that is conducive for phytoplankton and thus important for primary production may influence the number of fish that rely on phytoplankton for food. According to Okemwa (1981), northern part of L. Kanyaboli had a Secchi depth of 1 m and the southern part of the lake had a Secchi depth of 0.5 m. Okemwa (1981) found that there were more fish in the northern part of the lake compared to the southern part of the lake, which may have arisen from differential light penetration and thus primary productivity across the lake. However, how current estimate of turbidity compares to previous estimates, and how turbidity may influence the distribution of *O .esculentus* and *O.*

variabilis in the lake is not yet known.

2.2 Factors that influence size of *Oreochromis esculentus* and *Oreochromis variabilis*

Many fish species survive within a certain range of temperature, dissolved oxygen, pH and turbidity (Muyodi *et al.*, 2011). Factors such as water pollution leads to alteration of these physicochemical factors hence directly or indirectly affect growth and reproduction of fish in water (Shiddamallaya and Pratima, 2008). A study by LVEMP (2002) shows that River Yala which drained into L. Kanyaboli was partly diverted and part of the swamp reclaimed for rice cultivation, which resulted in a reduction in the size of the lake. In particular, diversion of the river resulted in a reduction in water level in the lake, which may have altered levels of physicochemical factors in ways that may impacted fish growth and thus size.

In addition to the influence of abiotic factors on fish in the lake, fishing pressure and use of illegal fishing gear are thought to have negative effects on fish in the lake. According to Fryer (1961), previous gillnet mesh size of 10cm introduced in1956 in L. Victoria was to be used to catch *O .esculentus* and *O .variabilis* following unprecedented decrease in fish stocks. Although the introduction of *Lates niloticus* and the non-native tilapiines *O. niloticus,* that performed better than native species, was meant to reduce fishing pressure on native cichlids, that was not to be so due to the invasive nature of the introduced species (Ogutu-Ohwayo, 1984). In any case, fishing pressure continued while catch rates decreased in L. Victoria and surrounding waters. In 2003, it was estimated that there were over 65 fishing boats in L. Kanyaboli (Abila, 2003). In addition, a majority of fishermen used gillnets of mesh sizes ranging in size from 2.5cm to 5 cm, which together with the high fishing effort (even if estimated coarsely from the number of active fishing boats in the lake) is thought to have caused a rapid decline in the size of fish in the lake (Abila, 2003).

Competition and predation may also limit some species to areas where their competitors are found. Among the six species of cichlids in L. Kanyaboli (*O. esculentus* and

O. variabilis included) found to have a certain degree of overlap in the diet (Abila *et al.*, 2008), no species fed exclusively on a single food item. This suggests either that such food items occurred in high abundance or that there was some level of competition for food in the lake. Regardless of cause, small size of fish is indicative of the presence of constraining factors. Size of fish may be changing due to changes in physicochemical factors, food types or any other pressures, therefore it's necessary to investigate the real causes of changes in fish size. However, how the size of *Oreochromis esculentus* and *Oreochromis variabilis* in L.Kanyaboli compares to the sizes of these species as published by the International Union for the Conservation of Nature is not known.

2.3 Human activities

Fresh water ecosystems throughout the world are threatened by human activities such as construction of physical barriers including dykes, dams, and flood walls (Combes, 2003). These activities can lead to changes in aquatic habitats. Barriers have been shown to disrupt connections between rivers and floodplain habitats, which among other things serve as refugia and spawning grounds for many aquatic organisms (Combes, 2003).

Dykes are used to control flooding of land behind the dyke in order to protect homesteads and also to reclaim wetlands for crop cultivation (Ellery, 1994). Some of the effects of dykes include deterioration of water quality which involve accumulation of pollutants, sediments and minerals due to low circulation of water in water bodies (Djkema, 1987). Dykes may also lead to loss of natural habitats for some species as they lead to habitat fragmentation (Combes, 2003).

In L. Kanyaboli, a dyke was constructed by Dominion Farms in 2003 to facilitate land-based transport between Alego and Yimbo, the two communities on either size of the lake. The dyke thus divides the lake into two components separated by weir that remains closed throughout. Consequently, water circulation between the two components of the lake has been constrained.

Construction of the dyke was done without carrying out ecological impact assessment of the dyke on biodiversity in L. Kanyaboli. It would be shocking to find that the adverse ecological effects of the dyke to the lake ecosystem may out way its benefits to the community. However, the ecological effects of the dyke have never been evaluated. Phytoplankton species are an important key aspect of aquatic ecosystems not only because there are important indicators of habitat health but also because they are the primary producers that support a wide range of foragers including fish. Consequently, their identity and diversity may highlight the status of water quality in aquatic ecosystems. In particular, species of phytoplankton are useful indicators of pollution in aquatic ecosystems. For instance, previous studies have demonstrated that arrange of phytoplankton species associated with with less polluted water include *Chroocccus turgidus* (Witton *et al*. 2002), *Cyclotella ocellata* (Kadri,1998), *Euglena acu*s (Haughey, 1970), *Kirchnella obese* (Frank, 2014), *Nitzschia recta* (Batni*et al*. 2015), *Pediastum boryanum* (Komarek, 2001), *Planktolybya limnetica* (Komarek, 2001). In constrast, The phytoplankton species associated with polluted water are: *Aulacoseira schroidera* (Akunga *et al.* 2014), *Coelomoron vestitus* (Naziriwo, 2011), *Monoraphidium sp.*(Basci *et al*. 2015), *Navicula sp.*(Elisa *et al*. 2009), *Nitzschia sub-acicularis*, *Nitzschia acicularis*, *Nitzschia pale*, *Nitzschia recta* (Batni *et al*. 2015), *Oocystis parva, Pediastrum tetras, Pediastum boryanum* (Komarek, 2001), *Trachelomonas armata*, and *Trachelomonas volvocina* (Komarek, 2015). In L. Kanyaboli, despite the obvious limnological processes including water turbulence that are likely to have been impacted by the construction of the dyke, research gaps on the ecological effects of the dyke persist.

2.4 General Biology of *Oreochromis esculentus* and *Oreochromis variabilis*

2.4.1*Oreochromis esculentus*

Oreochromis esculentus is an indigenous tilapiine species in Lake Victoria. It has somewhat pointed head with body not conspicuously spotted (Graham, 1929). It uses cross flow filtration to extract food items during suspension feeding (Goodrich *et al.*, 2000; Sanderson *et al*., 2001). During cross-flow filtration, hydrodynamic forces such as inertial lift causes particles to remain suspended but become concentrated in the fluid travelling parallel to filter surface (Brainerd 2000; Sanderson *et al*., 2001). The particles are then swallowed with very little accompanying water (Sanderson *et al*., 2001). It is expected that turbid waters may negatively affect feeding in this species. The species prefers a somewhat narrow pH range of between 7.2 and 8.6.With regards to temperature, *O. esculentus* is able to withstand temperature of 10^{0}C for short periods, but its temperature range is 23-28^{o}C (Fryer and Iles, 1972).

In terms of size, male total length (TL) measure 35 cm at adult size compared to 30 cm(TL) for females (IUCN, 2015). Both sexes reach sexual maturity when they are about 8.75 cm. Males are more colourful while breeding (exhibit an overall pink red colour). Females when breeding are tinged pink. Breeding fish are found throughout the year (Graham, 1929), and distinct spawning areas can be identified in the water such as sandy bottoms in shallow water. Open waters are the preferred habitat for adults and sexual maturity occurs within six months after hatching but adult size is reached after 9 to 10 months (Graham, 1929). Adults school in open waters where they forage for plankton blooms while the young inhabit inshore waters in areas of dense aquatic vegetation (Fryer and Iles, 1972). Brooding females raise their young in their mouth for up to two weeks in these macrophyte areas where growth is rapid. In the wild, *O. esculentus* forages on plankton and detritus from the muddy bottom (Fryer and Iles, 1972). The females are mouth-brooders (Fryer and Iles, 1972). Threats faced by *O. esculentus* are displacement by introduced fishes, predominantly *O. niloticus*, intense fishing pressure, siltation of spawning grounds and pollution from domestic and agricultural effluents (Abila, 2003).

Plate 1: *Oreochromis esculentus*. Note: Head somewhat pointed, snout with relatively steep forehead, body not conspicuously spotted.

2.4.2 *Oreochromis variabilis*

Oreochromis variabilis is an indigenous tilapiine species in Lake Victoria. It is grey-green in colour and margin of dorsal fin is orange in females and non-breeding males. It occasionally forms schools. Adults feed predominantly on bottom algae; some of the plankton organisms that have been found in their stomach are probably those which have settled on the bottom or were washed shore-wards from open waters but they do not feed directly on plankton (Trewavas, 1983), and may graze on algae from rocks and aquatic plants (Witte and Wanink, 1995).The length of males is 26.7 cm (TL) at adult stage whereas that of females is 24.8 cm (TL) (IUCN, 2015). The margin of the dorsal fin is orange in females and non-breeding males but turns to an intense hue of orange and scarlet in breeding males (Fryer, 1961). The species is most abundant on exposed and sandy shores where there is considerable water movement and also occurs in the calm waters with aquatic plants such as water lily swamps (Lowe, 2000*)*. The species used to be found at depths ranging from 0-40 m in L. victoria but most commonly at depths of less than 10 m in L. Victoria (Witte and Wanink, 1995). Young *O. variabilis* feed on planktonic algae on rocks in shallow waters and may ingest small copepods (Fryer, 1961). Young are brooded until when they are about 1.5cm in length (Fryer, 1961). Brooding females have been caught in the rushes and among vegetation near the edges of the lake and their nests are built on sandy bottoms in shallow waters. Female lays batches of eggs after which she picks them up and sucks at the male genital tassel to collect sperms to fertilize eggs (Fryer, 1961). *O. variabilis* can survive pH range of between 7.2 and 8.6 (Trewavas, 1983). The female broods the eggs in the mouth for 3 weeks before releasing them in shallow waters (Fryer 1961).Adults are distinguished from immature stages by their characteristic orange to red dorsal fin lappets (Trewavas, 1983).

Plate 2:*Oreochromis variabilis*. Note: Although not quite visible on the plate, it has two rows of scales on cheek. Body colour is grey-green and margin of dorsal fin is orange in females and non- breeding males.

CHAPTER THREE

Materials and methods

3.1 Study site: Lake Kanyaboli

The study was conducted in Lake Kanyaboli (Figure1), a satellite lake of L. Victoria. Lake Kanyaboli is located between latitudes $0^{\circ}1'30''$N- $0^{\circ}4'30''$N and longitudes $34^{\circ}8'0''$E- $34^{\circ}4'30''$E. It is a fresh-water lake lying to the northeast of L. Victoria in Kenya. The lake is about 10.5 km^2 in area and has an average depth of 2.5m and a maximum depth of 4.5m (Crafter *et al*. 1992). The lake is separated from L. Victoria by a papyrus swamp (the Yala Swamp). The lake is home to *Oreochromis esculentus* and *Oreochromis variabilis,* the two cichlids that are locally extinct in L. Victoria (Kaufman,1992) and are presently listed as critically endangered (IUCN, 2015). One species of antelope, Sitatunga (*Tragecephalusspekei*) and a wide range of birds live in the papyrus swamp that surrounds the lake. Human activities around the lake include settlement, cultivation of vegetables, sweet potatoes, and maize. In addition to these, other land-use types include aquaculture and livestock keeping. In recent years, habitat restoration primarily involving planting of trees has also been undertaken by the Lake Victoria Environmental Management Program (LVEMP).

The lake is divided into two components by a dyke running from south to north. The dyke measuring 6 m width by 2600 m length was constructed by Dominion Farms in 2003. The dyke therefore divides the lake into eastern waters and western waters. The eastern part is larger compared to the western part. There is a weir constructed at the northern end to allow water to flow from east to west; a wire mesh laid over the weir is meant to stop fish moving between the components of the lake. However, the weir remains permanent closed and so movement of water between the two components does not occur. Although the lake was previously fed directly by River Yala, the water entering the lake is currently via a weir since much of the water is diverted into neighboring commercial rice farm.

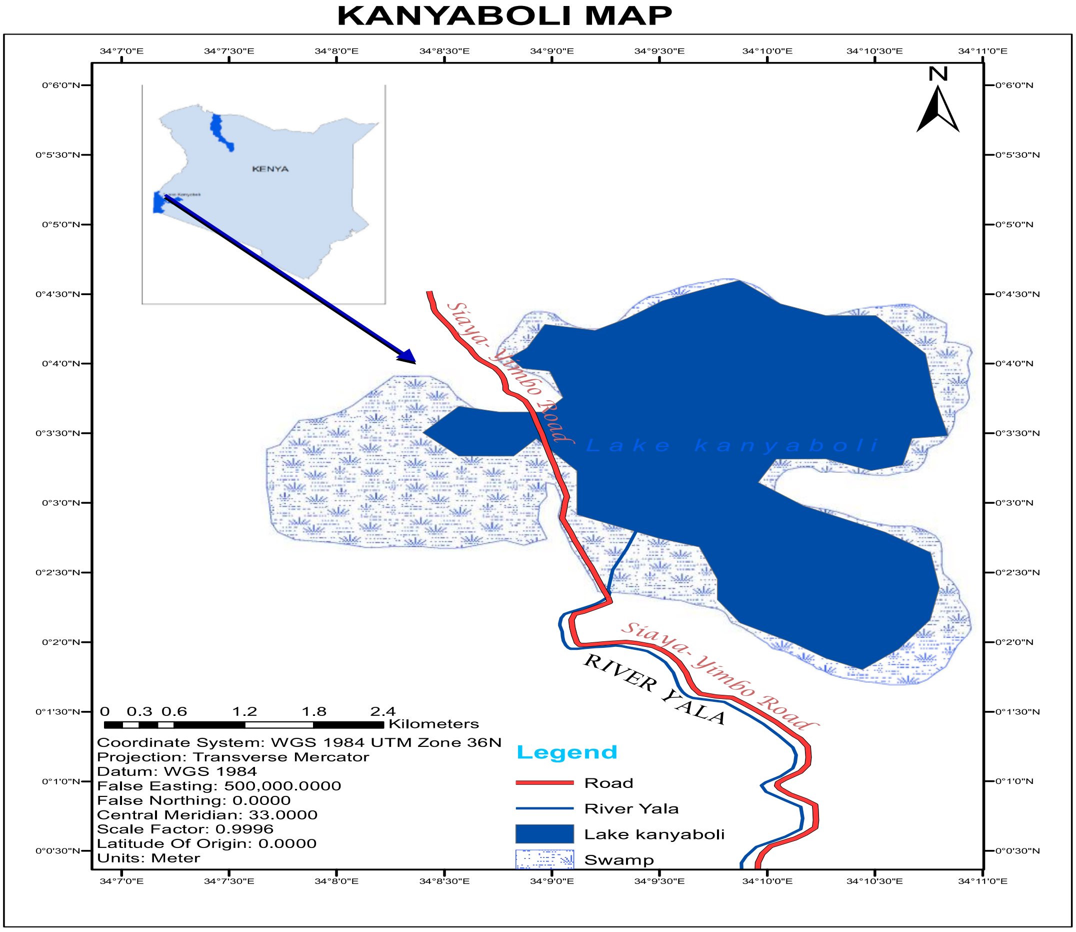

Figure 1: Location of L. Victoria and its proximity to L. Kanyaboli. The location of the dyke (in red) and the extent of papyrus swamp (in thatched blue) around the lake are indicated.

3.2.0 Methods of data collection

In order to collect data for objectives 1, 2, and 3, the lake was divided into 10 blocks that were in turn divided into 5 sampling sites; Figure 2. For objective 4, the lake was divided into 4 blocks as shown in Figure 3. Sampling sites were selected so as to cover the whole range of habitat characteristics that may influence the distribution of fish in the lake. In this study the number of fish caught in each sampling site was assumed to reflect the suitability of the site to the two species of fish. In each sampling site, DO, pH, temperature and turbidity, was measured. Sampling for fish was carried out between 0700-1100 hours on each field day because external factors like wind and time of day are known to influence the physicochemical characteristics (Tallic 1966).

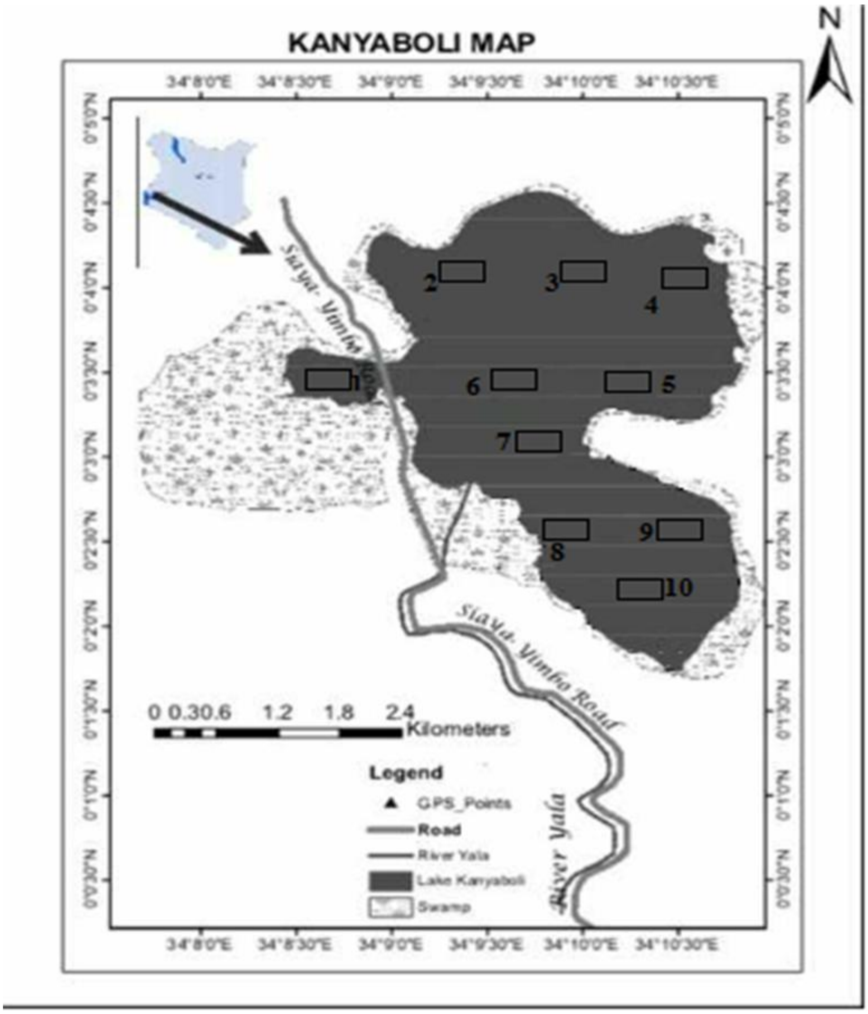

Figure 2. Map of Lake Kanyaboli showing 10 sampling blocks (black rectangles).

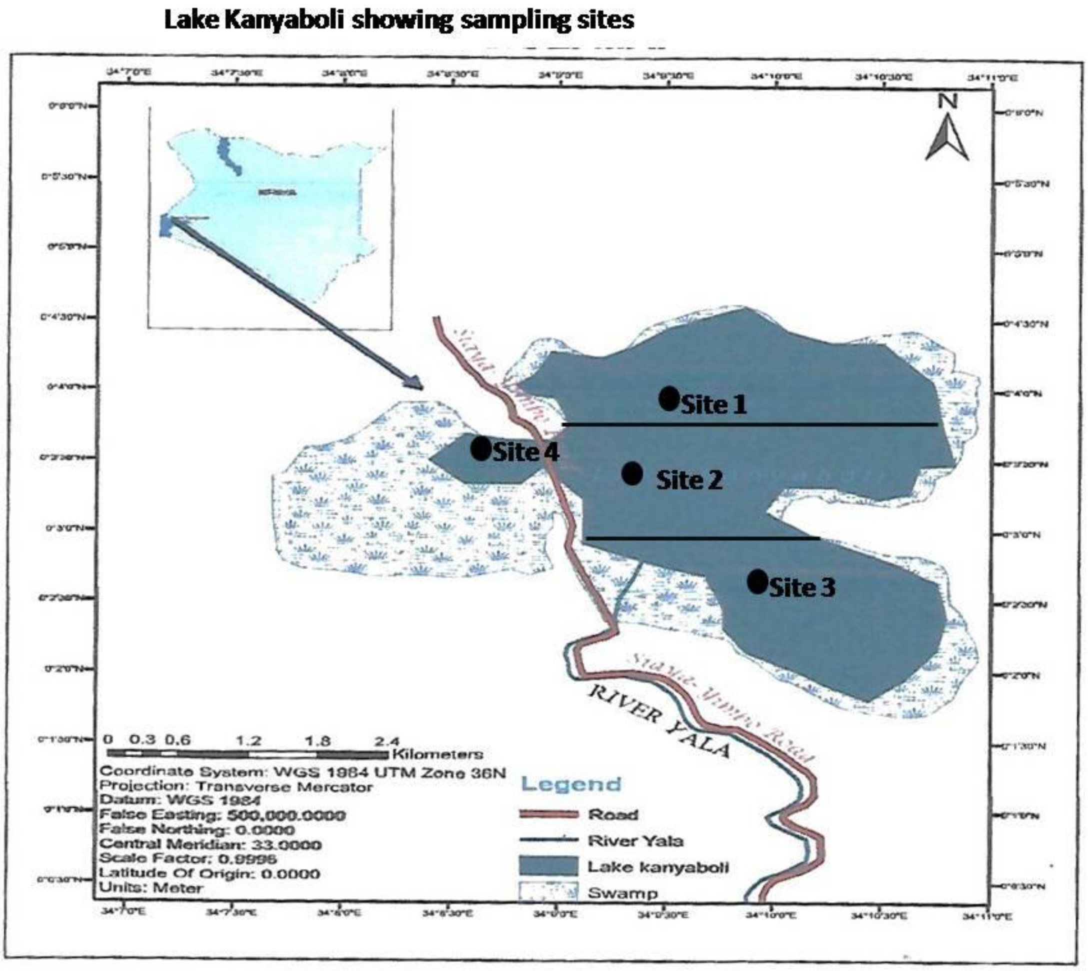

Figure 2. Map of L. Kanyaboli indicating the positions of the four sampling units.

3.2.1 Measurements of DO, pH, temperature and turbidity

Dissolved oxygen, pH and temperatures were measured using Environmental Multiparameter Monitoring System YSI Hydrolab (YSI inc., OH, USA). The probe of the Hydrolab that holds the sensors was dipped in water and stirred until readings stabilized according to manufacturer's instruction and then recorded. Secchi depth was measured using a Secchi disc (Department of Zoology, Maseno University). The standard procedure for measuring Secchi depth using the Secchi disc was followed. In brief, the disc was lowered into the water to a point it was no longer visible to the observer and the depth at which this occurred was recorded. Next, the disc was then pulled up to a point that it reappears to the observer and, again, the depth at which this occurred was recorded. The average of the two depths, Secchi depth, was calculated and recorded for each sampling site. Secchi depth is a measure of the transparency of the water (Secchi depth is thus inversely related to turbidity).

3.2.2 Determining size of fish in Lake Kanyaboli

Fish was caught by beach seine method using a nylon fishing net measuring 40 m by 4 m with mesh size of 2.5 cm (manufactured by Johnflies Fly Factory Ltd. in Kenya). The number of fish caught per sampling site was recorded. The length and weight of each fish caught were measured and recorded. Total fish length, measured from tip of mouth to tip of tail fin, was measured using a 30 cm ruler whereas the weight of fish was measured in grams using a simple spring balance manufactured by Desco Company, China.

3.2.3 Determining phytoplankton species diversity in Lake Kanyaboli

Phytoplankton species diversity and differences between the two lake components was estimated from water samples. From Figure 3, sampling unit 4 formed western component of the lake while sampling units 1, 2 and 3 were merged to represent the eastern component of the lake. Water samples were collected early in the morning before sun rise using glass vials measuring 40 cm^3 from each sampling site. Each water sample was fixed using Lugol's solution and then transported to Kenya Marine and Fisheries Research Institute (KEMFRI) in Kisumu for laboratory analysis. In the laboratory, 2 ml of water from each sampling unit was placed in a raft cell and then mounted on alight microscope (Sony model No. 436605, Japan) and examined at a magnification of ×400. Phytoplankton was classified up to species level using identification key (Agriculture and Agri- food Canada, 2011).

3.3 Data analysis

Each physicochemical characteristic obtained in the present study was compared to values obtained in previous studies by Lake Victoria Environmental Management Programme 2002 (LVEMP 2002) and Okemwa 1981 using one sample t- test. In each case, previous estimate was set as the µ.

The one sample t - test was calculated using the formula:

$$t = \frac{\bar{X} - \mu}{SE}$$

In order to determine the extent to which physicochemical factors predicted the distribution of the two species, data was separately analyzed, for *Oreochromis esculentus* and *Oreochromis variabilis*, using generalized linear model with temperature, pH, DO and turbidity as factors and number of fish caught in each block as the response variable. Chi-square test was used to determine differences in frequency of each species between the two components of the lake. The Shannon-Weiner diversity index, H, was used to determine species diversity of phytoplankton in each component of the lake. The index was calculated using the formula:

$$H = -\sum_{i-1}^{n} pi \ln pi$$

where H is the Shannon-Weiner diversity index, *pi* is the relative abundance of species *i*. Values of the H typically range from 1 to 4 such that values close to 1 indicate low diversity and higher value of H indicates a large number of species with similar abundances (Jost, 2006). In order to more meaningfully interpret H, it was converted, by finding its exponent, into effective number of species (Jost, 2006). The one sample t- test was used to compare data on size of the two fishes against their size in published literature by IUCN. Statistical significance was evaluated at $p \leq 0.05$. All data were analyzed in R version 2.14.1.

CHAPTER FOUR

Results and Discussion

A summary of measurements of physicochemical factors and the number of fish caught in each sampling block are shown in Table 4.1.

Table 4.1: Measurements of physicochemical factors, number of *O. esculentus* and *O.variabilis* per sampling bock.

Sampling block	Mean Temp(^{0}C)	Mean DO(mg/L)	Mean pH	Mean Turbidity(m)	No. of *O. esculentus*	No. of *O.variabilis*
1	25.3	4.9	7.5	0.62	0	0
2	26.5	4.8	8.7	0.52	0	0
3	24.6	4.9	7.8	0.57	2	6
4	25.9	4.8	8.6	0.68	1	3
5	26.1	5.0	8.7	0.68	0	0
6	27.0	4.5	8.3	0.73	0	0
7	24.4	4.6	8.0	0.72	1	0
8	25.5	4.5	8.4	0.71	0	0
9	25.6	4.6	8.6	0.72	0	0
10	25.5	4.7	8.4	0.71	0	0
Overall Mean	**25.6**	**4.7**	**8.3**	**0.67**	**04**	**9**

4.1 Comparison of measurements of physicochemical factors between 2014 and 1981-2002 studies

The mean temperature in L. Kanyaboli during the present study period was 25.6°C (range 23.9°C to 28.9°C); mean pH was 8.3 (range: 7.0 to 8.8); mean Secchi depth was 0.67 m (range 0.13m to 0.81 m); and mean dissolved oxygen was 4.7 mg/L (range 4.3 mg/L to 5.1 mg/L); Table 4.1. Comparisons of levels of the four physicochemical characteristics obtained in the present study against those from previous studies done by LVEMP (2002) and Okemwa (1981) showed that DO, temperature, and turbidity have significantly changed over the years.

More specifically, pH appeared to have increased from 1981 to 2002. In contrast, both DO and turbidity have declined over the years as shown in Table 4.2.

Table 4.2: Comparisons between present and previous measurements of physicochemical factors in L. Kanyaboli.

Physicochemical characteristic	**2014 measurements (n=50)**	**Year and previous measurements**		**t-statistic**	**p-value**
		Year	**Mean measure**		
Dissolved oxygen (mg/L)	4.7	Okemwa1981	5.4	-25.449	<0.0001
		LVEMP2002	6.79	-78.885	<0.0001
pH	8.3	Okemwa1981;	7.7	10.667	<0.0001
		LVEMP2002	8.28	0.2026	>0.05
Temperature (°C)	25.6	LVEMP2002	25.8	-9.907	<0.0001
Turbidity (m)	0.67	Okemwa1981	0.75	-5.516	<0.0001
		LVEMP2002	0.48	12.647	<0.0001

With regards to pH levels in the lake, high and increasing basicity in the lake may be attributed to a rise in the rate of photosynthesis by blue green algae possibly as a result of fertilizer discharge from farms around the lake (Gichuki *et al.*, 2006). Increased fertilizer use in agricultural farms around the lake, as is the case throughout the African continent where fertilize use continues to increase (FAO, 2012) will continue to adversely affect quality of water in L. Kanyaboli.

The low DO in the lake may be attributed partly to papyrus swamps that are characterized by severe oxygen depletion (Carter, 1955). In addition, the low DO may arise from blooms of algae associated with increased discharge of effluents into the lake by the local community; blooms of blue green algae have been associated with depletion of oxygen in aquatic systems (Chapman *et al.*, 1995). Although investigating the direct effects of low DO on fish in the lake was beyond the scope of the present study, the low and declining levels of DO in the lake are of great concern because of adverse physiological functions associated with low levels of DO. In particular, fish experience slow rates of growth, increased susceptibility to disease under low DO (Torn, 1998).

Measurements of temperature showed that temperature declined since 2002. Although the decline in temperature was found to be significant, it is important to note that the analysis was based on comparison with only one previous estimate, (LVEMP, 2002), and so the comparison must be interpreted with caution. A potential source of the difference between present and previous measurement of temperature is difference in sampling times between studies. In the present case, the current study was conducted during the months of April to July whereas the previous study was done in the months of January and March. Between months of May and July there is normally heavy rains hence streams of water are released in to the lake, which often causes high water circulation that affect, among other things, physicochemical factors of the lake. Between months of January and March normally there is drought accompanied by very little rain, which is associated with low run off into the lake and thus low rate of water circulation in the lake. Reduction in temperature may be caused by high cover of water surface by papyrus swamp and adequate wind blowing over open water surface to cause upwelling. Nonetheless, it was noted that the present range of temperature has shifted to the lower range of the optimal range, $29^{o}C$ to $31^{o}C$, for growth of tilapia (Teichert-Coddington *et al*., 1997). However, *O. niloticus* a closely related species has been reported to tolerate temperatures as low as between $11^{0}C$ and 13^{0} C (Chervinski, 1976), hence the decrease in temperature might have not affected the fish significantly. The temperature range of both *O. escullentus and O. variabilis* is $25^{0}C – 28^{0}C$.

4.2 Influence of physicochemical factors on the distribution of *O. variabilis* and *O. esculentus*

Turbidity predicted the distribution of *O. variabilis* such that abundance of this species increased with increase in Secchi depth ($z = 2.000$, $p < 0.045$); Table 4.3 and Appendix I. In contrast, temperature, DO, and pH did not significantly predict the distribution of *O. variabilis* in L. Kanyaboli, Table 4.3. Turbid waters can directly affect fish growth and survival by interfering with gill function (Bash *et al.*, 2001). Turbidity also limits fish vision, which may interfere with social behavior (Berg and Northcote, 1985), foraging, and predator avoidance (Gregory, 1993). Fine particulate matter also clog or damage gill structures, decrease their resistance to diseases, prevent proper egg and larval development and potentially interfere with feeding activities (Michuad, 1991). If light penetration is reduced significantly, macrophyte growth may decrease to levels that may negatively impact organisms that rely on them for food and cover. These effects of turbidity on fish may explain why distribution of *O. variabilis* is influenced by turbidity such that fish preferred areas with high light penetration.

Table 4.3: Influence of physicochemical factors on distribution of *O. variabilis* in L. Kanyaboli

Variable	**Estimate**	**Std Error**	**Z-value**	**P-value**
Temperature(^{0}C)	-0.2437	0.9747	-0.2500	0.8026
DO (mg/L)	2.6078	3.2265	0.8080	0.4189
pH	-0.5981	1.5688	-0.3810	0.7030
Turbidity (m)	16.6632	8.3306	2.0000	0.0455

None of the four physicochemical factors predicted the distribution of *O. esculentus*, Table 4.4; Appendix II. Although the results suggest that the variation (after accounting for the effect of month on sampling) in the four physicochemical factors in the lake was not substantial to influence the distribution of *O. esculentus*, it must be pointed out that the number of this species that were caught was so low. The low catch success for this species may account for the fact that none of the four physicochemical factors significantly predicted the distribution of this species. The role of small sample size in influencing the foregoing results is supported by the fact that one of the physicochemical factors, turbidity, predicted the distribution of the closely related *O. variabilis* as discussed earlier. More *O. variabilis* than *O. esculentus* were caught during the present study. Perhaps the four physicochemical did not affect the distribution of *Oreochromis escullentus* because their range is still within the tolerable range (Trewavas, 1983).

Table 4.4: Influence of physicochemical factors on distribution of *O. esculentus* in L. Kanyaboli.

Variable	**Estimate**	**Std Error**	**Z-value**	**P-value**
Temperature(^{0}C)	-1.3434	1.1456	-1.1730	0.2410
DO (mg/L)	2.3511	3.6423	0.6460	0.5190
pH	0.7578	1.8520	0.4090	0.6820
Turbidity (m)	-1.7172	3.8681	-1.4440	0.6570

4.3 Comparison of size of *O .esculentus* and *O. variabilis* in L. Kanyaboli against size published by IUCN

The mean total length of *O.esculentus* obtained in the present study was 16.5 cm (range: 12.0 to 21.8 cm) n = 30 whereas the mean weight was 79.2 g (range: 23.4 to 170.8 g) n = 30. The mean length of *O. esculentus* in L. Kanyaboli was significantly shorter than the length of this species published by IUCN ($t=-19.564$, $p < 0.0001$).Results of the present study on the length of the two species compared to their length as published by IUCN (2015) show that the lengths of *O. esculentus* have decreased. This is consistent with findings of (LVEMP, 2002; Okemwa 1981). None of the four physicochemical factors predicted the distribution of *O. esculentus*.

For *O. variabilis*, the mean total length was 14.1 cm (range: 11.5 to 17.1 cm, n= 38) and the mean weight was 44.0 g (range: 25.0 to 71.5 g, n = 38). It was found that *O. variabilis* in L. Kanyaboli is significantly shorter compared to length of the species published by IUCN ($t = -45.960$, $p<0.0001$).

The findings of the present study must be interpreted in a broader context. For instance, the findings of LVEMP (2002) showed that there were no *O .variabilis* in L. Kanyaboli suggesting that the species was depleted from the lake. According to the Fisheries Manager at Dominion Farms, the Dominion Farms Limited introduced 500,000 fingerlings of *O. variabilis* into L. Kanyaboli in 2011. The reintroduction could account for the presence of *O. variabilis* during the present study as opposed to 1981 and 2002, which further underscores the magnitude of threat it faces in the lake.

The small size of the two species in the lake may be due to widespread use of fishing nets with small mesh size and increased number of fishing boats. Between 2003 and 2014, there has been 46% increase in the number of active fishing boats in the lake; from 65 boats in 2003 (Abila, 2003) to 95 boats in 2014. Although the number of fishing boats per se is not a direct indicator of the intensity of fishing pressure, it can be argued that it indirectly does so. In other words, the small size of fish in the lake may be attributed to high fishing pressure. The mesh size used in 2003 averaged 4.0 cm but has declined to 2.5 cm in 2014. The result of both high intensity of fishing and the use of fishing nets with extremely small mesh size is that small sized fish including those that have not yet reached age and size of reproductive maturity are removed from the population.

The small size of fish in L. Kanyaboli as shown in Appendix III may also be as a result of changes in physicochemical characteristics including those that affect water quality, which ultimately retard the growth of fish in the lake. For instance, Myrick and Cech (2001) found that changes in physicochemical characteristics in aquatic environment affects growth of fish. Alternatively, an argument can be made that the small sizes of fish that were caught could be attributed to an over-representation of immature fish in the fish that were caught through systematic sampling as well as those purchased from local fishermen. However, this argument is not supported by the experiences of the local fishermen.

4.4 Effect of the dyke on phytoplankton species diversity

The result shows that the western component of L. Kanyaboli has higher phytoplankton species diversity (H = 3.033) compared to eastern component (H = 1.281), Table 4.5 and Table 4.6 in the appendix. When the diversity index in each component was translated to effective species number (Jost, 2006), the results indicated that the eastern part of the lake had 4 equally abundant species compared to the western part that had 21 equally abundant species.

The results indicate that out of the 21 species of phytoplankton compared between the two components of the lake, 60% (13 out of 21) were more abundant in the larger eastern component. Perhaps more interesting is the fact that all of the 12 species that occurred at higher abundance in the eastern component than in the western component are associated with polluted waters; Table 4.7. In contrast, all species that occurred in greater abundance in the western component than in the eastern component of the lake are associated with less polluted waters, Table 4.7.The table shows that phytoplankton species that thrive in polluted water are the ones found in eastern component of the lake, suggesting that eastern waters of the lake is polluted. The phytoplankton species found in western component of the lake are associated with less polluted water, indicating that western water of the lake is less polluted. The result is that as a result of dyke construction the two components of the lake experience different pollution levels.

Table 4.7 Phytoplankton species frequency distribution in the two components of L. Kanyaboli

Name of species	**Eastern Component**	**Western Component**	**Chi-square statistic**	**P- value**	**High Abundance in Eastern Component**	**Thrives in polluted water**
Aulacoseira schroidera	5733276	66666	5536342.0	< 0.05	Yes	Yes
Chroocccus turgidus	1133322	13049869	10012140.7	< 0.05	No	No
Coelomoron vestitus	1866648	1133322	179257.4	<0.05	Yes	Yes
Cyclotella ocellata	199998	399996	66666.0	< 0. 05	No	No
Euglena acus	199998	633327	225331.1	< 0. 05	No	No
Kirchnella obese	99999	533328	296488.2	< 0. 05	No	No
Monoraphidium sp.	999990	583327	109648.3	< 0. 05	Yes	Yes
Navicula sp.	1499985	322219	761239.0	< 0. 05	Yes	Yes
Nitzschia sub-acicularis	899991	49999	760520.0	< 0. 05	Yes	Yes
Nitzschia acicularis	399996	33333	310253.3	< 0. 05	Yes	Yes
Nitzschia palea	2099979	1155544	273982.8	< 0. 05	Yes	Yes
Nitzschia recta	399996	4566621	3495487.4	< 0. 05	No	No
Oocystis parva	1599984	566661	492815.6	< 0. 05	Yes	Yes
Pediastrum tetras	2099979	33333	2002063.3	< 0. 05	Yes	Yes
Pediastum boryanum	566661	799992	39837.0	< 0. 05	No	No
Planktolybya limnetica	866658	899991	629.0	< 0. 05	No	No
Planktolybya talingi	1766649	166665	1324124.7	< 0. 05	Yes	Yes
Romeria elegans	99999	222220	60888.3	< 0. 05	No	No

Synedra cunningtonii	1433319	316663	712532.8	< 0. 05	Yes	Yes
Trachelomonas armata	599994	133332	296966.7	< 0. 05	Yes	Yes
Trachelomonas volvocina	4766619	899991	2638404.9	< 0. 05	Yes	Yes

Highly abundant phytoplankton species in the eastern component are associated with polluted waters in contrast to those abundant in the western component of the lake.

Major changes in phytoplankton assemblages have long been associated with increasing pollution of aquatic ecosystems. In L. Victoria, an increase in certain species of blue-green algae was attributed to increased discharge of effluents into the lake (Hecky *et al*., 1993). In other words, different phytoplankton species, including toxic ones, prefer specific ranges of nutrient ratios such that shifts in nutrient ratios result in changes in the relative abundance of phytoplankton sometimes with catastrophic effects in aquatic ecosystems (reviewed in Anderson *et al*., 2002). The major sources of nutrients in aquatic ecosystems include runoffs from farms and industries as well as discharges from sewage treatment plants. Increasing use of agrochemicals such as fertilizers throughout Africa (FAO, 2012; Anderson *et al.*, 2002) including farms around L. Kanyaboli is expected to result in shifts in nutrient ratios and thus phytoplankton communities in ways that may have serious biodiversity consequences. The eastern component of L. Kanyaboli is more exposed to pollutants from agricultural farms than the western component. As mentioned earlier, the mostly closed weir that separately the two components of the lake may exacerbate the effect of pollutants between the two components of the lake.

CHAPTER FIVE

Summary, conclusions, and recommendations

5.1 Summary

Four major findings arose from the current study. First, the study found that the quality of water in the lake has deteriorated. In particular, the amount of dissolved oxygen, temperature, and turbidity decreased whereas measurement of pH suggests that the water is becoming more basic. Second, of the four physicochemical factors studied, only turbidity influenced the distribution of *Oreochromis variabilis*. In contrast, none of the four physicochemical factors influenced the distribution of *O. esculentus*. Third, the two species of fish studied in the present study were found to be smaller in size compared to their respective sizes as published by the IUCN. Fourth, results on phytoplankton species diversity suggest that the dyke, which divides the lake into two has resulted in differences in phytoplankton species diversity. Although the eastern component of the lake had a lower species diversity of phytoplankton, species that were abundant in this component of the lake have been found to be associated with polluted water compared to species that were abundant on the western component of the lake.

5.2 Conclusion

1. Declining water quality in L. Kanyaboli is likely a result of the dyke that was constructed in 2003 by the Dominion Farms Limited.

2. Although results from the present study suggest that water quality in the lake is deteriorating, the fact that only turbidity influenced the distribution of one of the two study species, *O. varibilis*, suggests that the physicochemical factors are still within the respective ranges preferred by the two species of fish.

3 .The small size of both species of fish, *O. variabilis* and *O. esculentus* is evidence that there is pressure that either limits growth rate of the fish or removes fish at a relatively small size.

With regards to pressures that might limit growth rate of fish, the study contends that the changes in physicochemical factors, in particular turbidity, in the lake may be involved in determining size of fish. As for preferential off-take, observed and documented evidence suggest that the level of fishing pressure and use of fishing nets with extremely smaller mesh size are the main potential causes.

4. Differences in phytoplankton diversity between the eastern and western components of the lake may derive from changes in limnological processes following the construction of the dyke.

5.3 Recommendations

5.3.1 Recommendations from present study

1. In order to address the issue of deteriorating water quality in the lake, it is recommended that responsible local, regional, and national agencies including the Kenya Fisheries and Marine Research Institute identify the sources of pollution so as to put in place measures to mitigate their influence on biodiversity in the lake.

2. Local, regional, and national agencies must address the issue of small size of fish in the lake. In particular, concerned agencies must regulate fishing in the lake so as to limit fishing pressure and discourage the use of fishing nets with small mesh sizes.

3. To the extent that differences in phytoplankton species diversity may have arisen from differences in limnological processes between the two components of the lake, it is recommended that water flow between the components be increased. Secondly, changes in key limnological processes that may derive from the diversion of River Yala to the nearby commercial rice farm be regulated to increase water flow into the lake.

5.3.2 Recommendations for future studies

1. It is recommended that monitoring of physicochemical factors be regularized. Routine monitoring will require the engagement of concerned agencies such as the Kenya Marine and Fisheries Research Institute. In addition, future research should focus on the causes of changes in physicochemical factors in the lake.

2. Longitudinal research is needed to fine-tune the extent to which key trophic levels may be influenced by changes in physicochemical factors in the lake.

3. Experiments to more specifically investigate the effects of fishing pressure and physicochemical factors on the size of fish in the lake. For instance, use of cages in the lake such that fish in cages are not subject to the same fishing pressure yet exposed to the same physicochemical factors may decouple the effects of fishing pressure and physicochemical factors on size of fish in the lake.

4. Expand on the preliminary findings on diversity of phytoplankton species in the lake. A potential next step would be to investigate how differences in phytoplankton diversity impact organisms that forage on them.

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APPENDICES

APPENDIX I

```
> Model=lmer(no_var~temp+do+ph+secci depth+(1|month),family=poisson)

>summary(Model)

Generalized linear mixed model fit by the Laplace approximation

Formula: no_var ~ temp + do + ph + secci depth + (1 | month)

AIC  BIClogLik deviance

 37.63 49.1 -12.81    25.63

Random effects:

Groups Name        Variance Std.Dev.

month  (Intercept) 2.811    1.6766

Number of obs: 50, groups: month, 5


Fixed effects:

            Estimate Std. Error z value Pr(>|z|)

(Intercept) -15.8181    33.2980  -0.475   0.6348

temp         -0.2437     0.9747  -0.250   0.8026

do            2.6078     3.2265   0.808   0.4189

ph           -0.5981     1.5688  -0.381   0.7030

secci depth    16.6632     8.3306   2.000   0.0455 *

---

Signif. codes:  0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1


Correlation of Fixed Effects:

        (Intr) temp   do ph

temp      -0.787
```

do	-0.776	0.528		
ph	0.058	-0.540	-0.256	
secci depth	-0.436	0.053	0.106	0.436

APPENDIX II

```
>Model=lmer(no_esc~temp+do+ph+secci depth+(1|month),family=poisson)

>summary(model)

Generalized linear mixed model fit by the Laplace approximation

Formula: no_esc ~ temp + do + ph + secci depth + (1 | month)

   AIC   BIC logLik deviance

 27.92 39.39 -7.959    15.92

Random effects:

Groups Name        Variance Std.Dev.

month  (Intercept)  0        0

Number of obs: 50, groups: month, 5



Fixed effects:

            Estimate Std. Error z value Pr(>|z|)

(Intercept)  15.0521    22.9318   0.656    0.512

temp         -1.3434     1.1456  -1.173    0.241

do           2.3511     3.6423   0.646    0.519

ph           0.7578     1.8520   0.409    0.682

secci depth    -1.7172     3.8681  -0.444    0.657

Correlation of Fixed Effects:

         (Intr) temp   doph
```

temp -0.551

do -0.513 -0.323

ph 0.130 -0.687 0.169

secci depth -0.041 -0.030 0.410 -0.516

APPENDIX III

Size of *O. esculentus* and *O. variabilis*in L. Kanyaboli

Oreochromis variabilis		***Oreochromis esculentus***	
Length (cm)	Weight (g)	Length (cm)	Weight (g)
12.0	30.0	16.5	70.0
11.5	25.0	21.0	137.3
14.0	50.0	17.1	78.0
14.5	50.0	18.0	110.3
15.0	47.8	16.6	71.9
17.1	43.2	19.6	119.1
14.6	43.0	21.8	170.8
17.0	61.1	17.0	96.8
16.3	51.1	19.0	134.9
14.0	35.3	17.0	83.5
13.2	31.3	16.9	76.9
14.6	50.4	16.2	70.0
14.3	48.0	18.2	101.4
14.9	46.4	17.5	84.7
13.5	36.7	17.5	101.8
13.7	37.3	15.6	63.8
15.5	59.3	16.2	77.9
16.0	51.7	16.5	76.9
14.8	55.6	17.1	102.1
14.7	55.0	14.0	40.0
15.0	47.4	12.0	30.0
14.3	53.4	12.5	28.8

11.5	25.0	16.6	69.3
12.0	30.0	16.7	75.7
12.0	30.0	17.3	78.4
14.0	40.0	15.4	55.7
12.0	30.0	15.5	55.8
13.7	42.5	15.9	62.3
13.6	44.5	12.5	28.8
12.1	27.6	12.0	23.4
13.7	38.6		
13.4	36.3		
14.4	40.2		
13.1	42.8		
14.1	46.3		
13.9	48.0		
15.3	68.0		
15.5	71.5		
Mean= 14.1cm	**Mean= 44.0g**	**Mean= 16.5cm**	**Mean=79.2g**

APPENDIX IV

Table 4.5: Phytoplankton species diversity in eastern component of L. Kanyaboli.

Name of species	**Average no. of individuals(i)**	**(pi)**	**In(pi)**	**(pi) × In(pi)**
Cosmarium minimum	199998	0.0009	-6.9531	0.0062
Cosmarium regnelii	466662	0.0002	-8.4084	0.0016
Crucigenia menenghiana	33333	0.0001	-8.7448	0.0008
Crucigenia sp	99999	0.0004	-7.6462	0.0007
Cyclotella ocellata	399996	0.0019	-6.2599	0.0118
Cymbella cistula	33333	0.0001	-8.7448	0.0008
Cymbella cistulla	266664	0.0012	-6.6654	0.0079
Diatoma elongatum	699993	0.0033	-5.7003	0.0188
Diatoma hemiale	1266654	0.0060	-5.1072	0.0306
Diatoma hiemiale	199998	0.0009	-6.9531	0.0062
Dictyosphaerium reniforme	1833315	0.0087	-4.7375	0.0412
Euglena acus	633327	0.0030	-5.8004	0.0174
Fragilaria athiopica	633327	0.0030	-5.8004	0.0174
Fragilaria binods	133332	0.0006	-7.3585	0.0044
Glenordinium pulvasistoz	399996	0.0019	-6.2599	0.0118
Glenodinium pernardii	277775	0.0013	-6.6245	0.0086
Glenordinium pernadii	99999	0.0004	-7.6462	0.0233
Glenordinium pernardii	566661	0.0027	-5.9116	0.0159
Gomphocymbella beccari	933324	0.0044	-5.4126	0.0238
Kirchnella lunaris	344441	0.0016	-6.4094	0.0102
Kirchnella obesa	533328	0.0025	-5.9722	0.0449
Kirchneriella dianae	299997	0.0014	-6.5476	0.0091
Merismopedia punctata	3466632	0.0165	-4.1004	0.0676
Microcystis aeruginosa	157909532	0.7545	-0.2816	0.2124
Microcystis wasenbergii	366663	0.0017	-6.3469	0.0107
Monoraphidium griffitnii	466662	0.0022	-6.1058	0.0134
Monorapidium sp	233331	0.0011	-6.7989	0.0074
Monoraphidium sp	583327.5	0.0027	-5.8826	0.0178
Navicula contenta	1133322	0.0054	-5.2182	0.0281
Navicula granatum	155554	0.0007	-7.2044	0.0050
Navicula merostoides	233331	0.0011	-6.7989	0.0074
Navicula pupula	266664	0.0012	-6.6654	0.0079
Navicula sp	322219	0.0015	-6.4761	0.0097
Navicula sp.	566661	0.0027	-5.9116	0.0178
Nitzchia lucastris	399996	0.0019	-6.2599	0.0118
Nitzchia recta	233331	0.0011	-6.7989	0.0074
Nitzschia sub -acicularis	4099959	0.0195	-3.9326	0.0766
Nitzschia sub-acicularis	49999.5	0.0002	-8.3394	0.0016

Nitzschia acicularis	33333	0.0001	-8.7448	0.0008
Nitzschia dissipata	1866648	0.0089	-4.7195	0.0420
Nitzschia palea	1155544	0.0055	-5.1990	0.0285
Nitzschia recta	4566621	0.0218	-3.8248	0.0833
Nitzschia sub- acicularis	766659	0.0036	-5.6093	0.0201
Oenephis sp	199998	0.0009	-6.9531	0.0062
Oocystis parva	566661	0.0027	-5.9116	0.0159
Pediastrum tetras	33333	0.0001	-8.7448	0.0008
Pediastum boryanum	799992	0.0038	-5.5668	0.0211
Phacus sp	466662	0.0022	-6.1058	0.0134
Planktolyngbya circumcreta	133332	0.0006	-7.3585	0.0044
Planktolyngbya limnetica	899991	0.0043	-5.4490	0.0234
Planktolyngbya talingii	166665	0.0007	-7.1354	0.0049
Pseudoanabaena sp	266664	0.0012	-6.6654	0.0079
Rhopalodia gracillis	566661	0.0027	-5.9116	0.0178
Rhopalodia sp	33333	0.0001	-8.7448	0.0008
Rhopalodia vermicularis	299997	0.0014	-6.5476	0.0091
Romeria ankensis	2166645	0.0103	-4.5704	0.0470
Romeria elegans	222220	0.0010	-6.8477	0.0068
Scenedesmus curvatus	33333	0.0001	-8.7448	0.0008
Stephanodiscus sp	266664	0.0012	-6.6654	0.0079
Straurastrum dickiei	116665.5	0.0005	-7.4921	0.0037
Straurastum limnetica	266664	0.0012	-6.6654	0.0079
Synedra cunningtonii	316663.5	0.0015	-6.4935	0.0097
Tetraedron infratum	99999	0.0004	-7.6462	0.0030
Tetraedron arthromisforme	199998	0.0009	-6.9531	0.0062
Tetredron trigonum	1066656	0.0050	-5.2791	0.0263
Trachelemonous armata	633327	0.0030	-5.8004	0.0174
Trachelomonas armata	133332	0.0006	-7.3585	0.0044
Trachelomonas volvocina	899991	0.0043	-5.44900	0.0234
TOTAL	**209275682**			**1.2809**

Table 4.6: Phytoplankton species diversity in western component of L. Kanyaboli.

Name of species	Average no. of individuals (i)	(pi)	In(pi)	(pi) × In(pi)
Anabaena flos-aquae	2933304	0.0538	-2.9209	-0.1571
Ankistrodesmus falcatus	999990	0.0183	-3.9971	-0.0731
Ankistrodesmus fulcutus	699993	0.0128	-4.3537	-0.0557
Aulacoseira ambigua	399996	0.0075	-4.9133	-0.0368
Aulacoseira nyansenssis	2399976	0.0440	-3.1216	-0.1373
Aulacoseira schroidera	5733276	0.1053	-2.2503	-0.1053
Chodatella armata	566661	0.0104	-4.5650	-0.0474
Chroococcus turgidus	1133322	0.0208	-3.8718	-0.0805

Coelastum microphorum	33333	0.0006	-7.3982	-0.0044
Coelomoron vestitus	1866648	0.0342	-3.3729	-0.1153
Crucigenia rectangularis	466662	0.0085	-4.7592	-0.0404
Cyclotella ocellata	199998	0.0036	-5.6065	-0.0201
Cylindrospermopsis africana	233331	0.0042	-5.4523	-0.0228
Dictyosphaerium pulchellum	1333320	0.0244	-3.7094	-0.0905
Euglena acus	199998	0.0036	-5.6065	-0.0201
Euglena virids	233331	0.0042	-5.4523	-0.0228
Euglena vivds	233331	0.0042	-5.4523	-0.0228
Fragilaria crotonensis	433329	0.0079	-4.8333	-0.0381
Kirchnella obesa	99999	0.0018	-6.2996	-0.0113
Kirchneriella pseudoaperta	399996	0.0073	-4.9133	-0.0358
Monoraphidium sp	999990	0.0183	-3.9971	-0.0731
Monoraphidium carbeum	33333	0.0006	-7.3982	-0.0044
Navicula sp	1499985	0.0275	-3.5916	-0.0987
Nitzschia sub-acicularis	899991	0.0165	-4.1024	-0.0676
Nitzschia acicularis	399996	0.0073	-4.9133	-0.0358
Nitzschia palea	2099979	0.0385	-3.2551	-0.1253
Nitzschia recta	399996	0.0073	-4.9133	-0.0358
Oocystis lucastris	266664	0.0048	-5.3188	-0.0255
Oocystis nageli	299997	0.0055	-5.2010	-0.0286
Oocystis parva	1599984	0.0293	-3.5270	-0.1033
Pediastrum tetras	2099979	0.0385	-3.2551	-0.1253
Pediastum boryanum	566661	0.0104	-4.5650	-0.0474
Pinnularia brauni	2599974	0.0477	-3.0415	-0.1450
Plankolyngbya circumcreta	266664	0.0048	-5.3188	-0.0255
Planktolyngbya limnetica	866658	0.0159	-4.1402	-0.0658
Planktolyngbya talingii	1766649	0.0324	-3.4280	-0.1110
Rhombcystis lacrymas	1866648	0.0342	-3.3728	-0.1153
Romeria elegans	99999	0.0018	-6.2996	-0.0113
Selenastrum gracile	99999	0.0018	-6.2996	-0.0113
Sorastrum hathoris	199998	0.0036	-5.6065	-0.0201
Straurastrum gracile	499995	0.0091	-4.6902	-0.0426
Synedra cunningtonii	1433319	0.0263	-3.6370	-0.0956
Synedra nyassae	233331	0.0042	-5.4523	-0.0228
Synedra ulna	33333	0.0006	-7.3982	-0.0044
Tetredron arthromisforme	566661	0.0104	-4.5650	-0.04740
Tetraedron trigonum	733326	0.0134	-4.3072	-0.0577
Trachelomonas armata	599994	0.0110	-4.5079	-0.0495
Trachelomonas volvocina	4766619	0.0875	-2.4354	-0.2130
TOTAL	**54439516**			**3.0325**