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Outa N. Otieno
Egerton University, Department of Biological Sciences, P.O. Box 536-20115, Egerton, Kenya.

N. Kitaka
Egerton University, Department of Biological Sciences, P.O. Box 536-20115, Egerton, Kenya.

J.M. Njiru
University of Eldoret, Department of Fisheries and Aquatic Sciences, P.O. Box 1125-30100, Eldoret, Kenya

Correspondence:
Outa N. Otieno
Egerton University, Department of Biological Sciences, P.O. Box 536-20115, Egerton, Kenya.
Email: nichouta@gmail.com,
Tel: +254723052865

Some aspects of the feeding ecology of Nile tilapia, *Oreochromis niloticus* in Lake Naivasha, Kenya

Outa N. Otieno, N. Kitaka, J.M. Njiru

Abstract
A study was done on feeding ecology of re-introduced *Oreochromis niloticus* (L.) in Lake Naivasha, Kenya between November 2013 and February 2014. The main focus of the study was on fish size, diet, habitat, and diel feeding regime. 434 fish samples were collected every two weeks from five stations covering the entire lake by use of gill nets (50 mm to 150 mm mesh size) and beach seines (< 10 mm). Stomach contents of the 434 fish sampled were analysed using point method. The major diet of fish <10 cm total length was zooplankton and algae for bigger fish. There was spatial variation in diet with insects and algae dominating in the near shore and open water habitats respectively. Data on diel feeding regime indicated that *O. niloticus* is a diurnal feeder. The fish preferred Chlorophyceae but avoided Bacillariophyceae and Cyanophytes while copepods and cladocera were preferred to rotifers.

Keywords: Feeding, Fish, Naivasha, tilapia, herbivorous, reintroduced.

1. Introduction
Nile tilapia (*Oreochromis niloticus*) is of great commercial importance often forming the basis of commercial fisheries in many African lakes [2]. This species was introduced in Lake Naivasha around 1967 but disappeared in 1971 and the reasons for the disappearance are not clear to date [6]. The fish was then reintroduced by the Government in 2011 under the Economic Stimulus Program (ESP). The earlier introduced Tilapia of 1950s and 1960s were *Tilapia zillii* (Gervais) and *Oreochromis leucostictus* (Trewevas) but they did not respond positively to their new environment. Nile tilapia is still not the commercially most important fish in Lake Naivasha, three years after reintroduction since the common carp (*Cyprinus carpio*) which is more of an invasive species is still present in large populations [16]. However, the establishment and survival of *O. niloticus* in Lake Naivasha could face challenges due to high populations of the invasive *C. carpio* which is a bottom feeder, thus interfering with the breeding grounds of *O. niloticus* (a gravel spawner). Anthropogenic disturbance of the littoral vegetation, particularly through clearance and burning could have previously reduced its spawning areas as reported by Hickley *et al.*, (2008) [6] resulting to its disappearance in the 1970s.
O. niloticus is an important fish in the ecology of tropical waters as well as aquatic systems in Africa and other subtropical regions [18]. This is mainly because it feeds mainly on algae and other plant materials as well as detritus making it a link between lower and upper trophic levels in the aquatic food webs. *Oreochromis niloticus* feeds mainly on algae and other plant parts [25, 26]. The fish therefore plays an important ecological role as a primary consumer in many lakes. However, *O. niloticus* has been observed to diversify its diet under different conditions to include detritus, small insects as well as some fish parts [16, 17, 27]. In addition the fish is capable of filter feeding by capturing food particles in the water column. *Oreochomis niloticus* tends to show shift in diet due to ecological and environmental changes, especially pollution within the lake as suggested by [17].
The type and size of food item consumed changes with age and size of the fish. This is mainly because fish can only feed on food items that can fit into their mouth and what their gut can digest. As fish grow the digestive system becomes more developed in terms of having more developed digestive enzymes, coupled with the gut length becoming longer and larger. This makes it possible for the fish to digest more complex food, items like plant materials which cannot be digested at young ages.

Younger fish tend to feed more on zooplankton, which are easier to digest compared to phytoplankton and other plant materials. It has been hypothesized by Benavides *et al.,* (1994) [1] that because juvenile fish have higher protein mass demand due to their high specific growth rate and greater mass specific metabolism. Therefore, they may not satisfy this demand by consuming plant based diet only. Small fish may therefore be forced to consume animal prey, which have greater content of protein and energy per unit weight compared to plant based diet. Whereas as Nile tilapia grows the food item changes to mainly phytoplankton and other plant materials [19]. This is because the digestive system is more developed and the enzymes can break the cell walls of plant materials like algae. This change in diet as the fish grows is called ontogenetic shift and has been documented in Nile tilapia by several authors including Oso *et al*., (2006) [20] and Zaganini *et al*., (2012) [27].

Fish tend to show preference for some food items over others within their environment. Selection of a particular food item depends on food size, availability and palatability (Clements and Livingston, 1984). Selection of food of fish also depends on the age or size of the fish, since smaller fish tend to select smaller food items and vice versa. Fish can also select some food items depending on conditions within its environment. There are several approaches of determining food selectivity. Strauss (1979) [22] has proposed a linear index of food selection (Strauss linear index of food selection) which eliminates most of the statistical and mathematical inadequacies of traditional electivity indices.

The main focus of this paper is on the feeding habits and behaviour of *O. niloticus* in Lake Naivasha taking into account the spatial differences in contribution of different food items in the diet of the fish and 24 hour feeding regime.

2. Methods

2.1 Study area

This study was carried out in Lake Naivasha in Kenya. Lake Naivasha lies in latitude of 0° 46' 10" (0.7694), longitude of 36° 20' 25" (36.3403) and altitude 1890 m, within the Eastern Rift Valley. It is the second-largest freshwater lake in Kenya after the Kenya portion of Lake Victoria [13]. It has a surface area of 139 km² and an average depth of 3.35 m, with the deepest area being 7 m [6] though these values vary with extreme conditions.

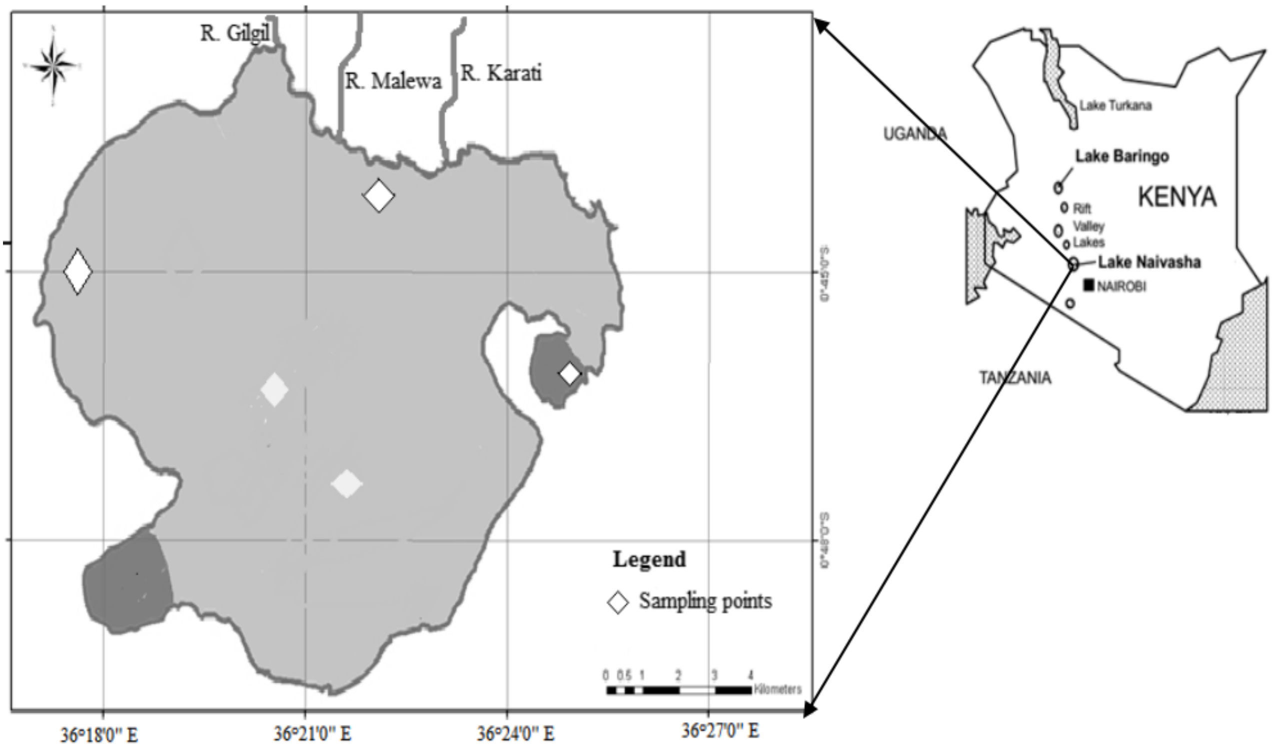

Fig 1: Map of Lake Naivasha showing sampling sites (Edited from Hickley *et al*., 2008) [6].

2.2. Sample collection and analysis

Fish samples were collected weekly between November 2013 and February 2014 using gill nets with head rope 50 m and coded mesh size 150 mm, 125 mm, 100 mm, 75 mm and 50 mm from five sampling stations. The sampling sites were (Korongo, Hippo point, Oserian, Sher Bay and Crescent Island). Korongo and Hippo point stations are near the shore and characterized by water hyacinth (*Eichhornia crassipes*) and papyrus (*Cyperus papyrus*) vegetation comprising of muddy substrate, decayed plant materials and silt. The average depths of the stations are 1.6 m and 2.1 m respectively. Oserian Bay, Sher Bay and Crescent Island Crater Lake are situated in the open waters and are characterized by occasional invasion by the floating mats of *Eichhornia crassipes* and detached *Cyperus papyrus* especially during strong winds at high water levels. The average depths in these stations are 3.7 m, 3.5 m and 4.9 m respectively. The substrate is mainly silt and sand.

The nets were set at the sampling sites for four hours before retrieving. Immediately after retrieving, fish guts were removed, fullness index determined following a modified method of Hyslop (1980) [9] and preserved in plastic vials with 4% formalin for further analysis in the laboratory. The vials were labeled with the fish length, sampling point, date and time of sampling for easy identification in the laboratory.

To establish when the fish fed, a 24-hour sampling regime was conducted every 4 hours by seining. Individual fish caught were weighed (g) and TL (cm) measured. The stomachs were preserved in 4% formalin in labeled vials. In the laboratory, the gut contents were weighed (g) to the nearest 0.1 g using an electronic balance. Stomach fullness (SF) was then expressed as percentage of fish weight as below;

$$SF = \frac{SC}{\text{Fish weight (g)}} * 100$$

Where,
SF is stomach fullness and SC is the stomach contents in grams

In the laboratory, the stomach contents were analysed using a modified point method according to Hynes (1950) [8] as reviewed by Hyslop (1980) [9].

Each stomach was awarded an index of fullness from 0 to 20; empty stomach scored 0; a quarter full 5; half full 10; three quarter full 15 and full 20.

Each of the stomach contents was emptied into a Petridish and the different food items identified and sorted into categories. Each category was assigned a number of points proportional to the estimated contribution. The importance of each food category was expressed as a percentage by dividing the total points awarded to all food types into the number of points awarded to the food type in question. Food items such as insects and fish remains were identified and counted using a binocular (x50) microscope while the smaller components such as phytoplankton and zooplankton were sorted and counted using an inverted compound microscope at x200 and x400 magnification after dilution to 100 ml. The gut contents were assessed separately for every 5cm class length to be able to compare the contribution of

each food item in the different length classes (ontogenetic shift). The phytoplankton and zooplankton obtained both in the gut samples and in the water samples were identified to genera level using keys by Jung (2004) [10] and Lizeth (2001) [11] respectively for the calculation of The Straus Linear index based on Equation 1;

$$L_i = r_i - p_i \quad [22] \quad \ldots\ldots\ldots\ldots\ldots\ldots \text{(Equation 1)}$$

Where:
ri is the proportion of prey taxon *i* in the guts of predators and *pi* is the proportion of the same taxon in the environment. The means of *ri* and *pi* weighed by the number of prey in each sample will be used to calculate *Li*

3. Results

3.1. Overall contribution

During the study period a total of 415 guts of *O. niloticus* were examined. The fish examined ranged from 3 cm TL to 45 cm TL. The major diet ingested by *O. niloticus* was algae (56 %,) plant material (15%) and detritus (14%) (Figure 2).

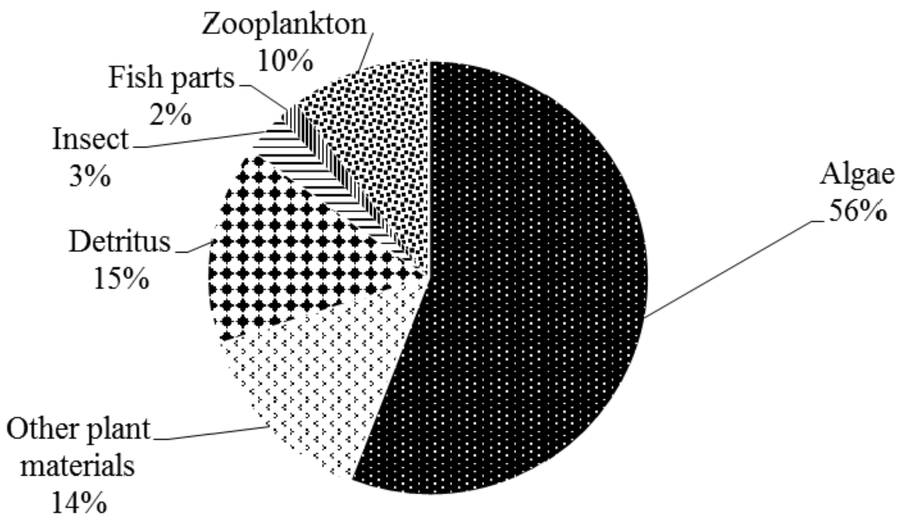

Fig 2: Contribution of different food items in the diet of *O. niloticus* in Lake Naivasha

3.2 Spatial contribution

Algae contributed the biggest proportion of the diet in all the sites with Cresscent recording the highest (68%) and Korongo recording the least (43%) (Table 1).

Table 1: Contribution of food items in the diet of *Oreochromis niloticus* in the different sampling stations in Lake Naivasha

	Korongo	Hippo point	Crescent Island	Oserian	Sher Bay
Algae	43	48	68*	53	59
Other plant materials	28*	26*	7	13	7
Detritus	13	12	15	14	18
Insects	8	5	2	2	1
Fish parts	1	0	2	2	2
Zooplankton	7	9	6	17	13

Kruskall Wallis test showed that in all the sampling stations the contribution of algae was significantly higher than that of other food items (P <0.05). Post Hoc- Kruskall Wallis lm test revealed that significantly higher percentages of other plant materials (higher plants) were consumed in the shallow parts of the lake (Hippo point and Korongo) than in the open lake (P <0.05). The percentage of detritus consumed by the fish did not differ significantly among the sampling sites within the lake (Kruskall Wallis test, P<0.05). More insects were consumed in the shallow parts of the lake (Hippo point and Korongo) recording compared to the deeper parts of the lake. The percentage of fish parts consumed by the fish was very low with no significant difference among the sites (Kruskall Wallis test; P> 0.05). The contribution of zooplankton in the diet of *O. niloticus* was very low and did not differ significantly among the sites (Kruskall Wallis test; P>0.05).

3.3. Ontogenetic shift

The importance of zooplankton in the diet of *O. niloticus* decreased with increase in fish length (Figure 3). The contribution reduced and remained almost constant from length 16 cm to 35 cm but disappeared completely from 36 cm onwards. As the fish became larger, the diet was dominated by algae and plant materials. Plant materials and detritus tend to remain the same (from 11-15 cm length class) in the diet with no significant difference in their contribution. Fish were ingested by fish from 11-16 up to 36-40 TL cm length classes while insects were preferred by 16-20 to 36-40 TL cm length classes and with above 41-45 cm TL length class recording none of these food items in their diets. The only food items that were present in all the length classes are algae and detritus. Plant materials and zooplankton were absent in the 0-5 cm and 41-45 cm length classes respectively

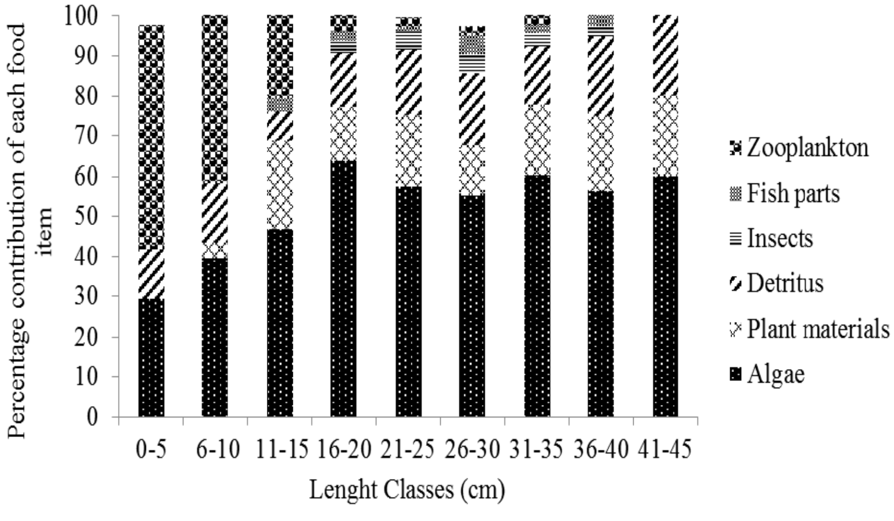

Fig 3: Ontogenetic shift in the feeding of *O. niloticus* in Lake Naivasha

3.4. Diel feeding regime

A diel feeding study showed that *O. niloticus* feeds mostly during the day and very little food is ingested at night. The highest stomach content (SC) value (7.8) recorded was at 12.00 hrs. The SC then decreased progressively during the day with the lowest values recorded at 12.00hrs (midnight) and 04:00 hrs (Figure 4). The SC rose again from 08:00 hrs on the following day.

3.5. Straus Linear index of food selection

Straus Linear index of food selection showed that Chlorophyceae (*Pediastrum*, *Scenedesmus* and Strautum) were preferred (positive values) while the Bacilarophytes with the exemption of Aulacoseira and Cyanophytes were avoided by the fish among the algal food items (negative values) (Figure 5). For the zooplankton food items, the indices showed that Copepods and Cladocera were selected (positive values) as compared to most of the Rotifers which were avoided by the fish in their diet (negative values). However, among the Rotifers, Filinia and Polyathra were selected (Figure 6).

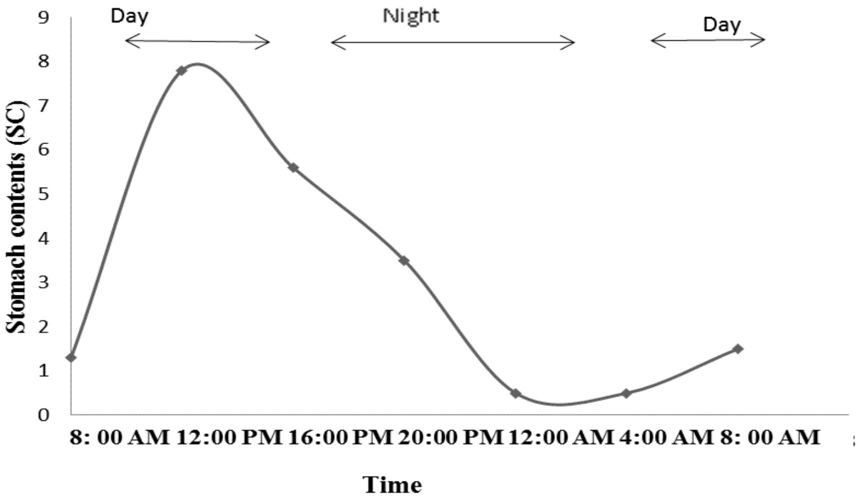

Fig 4: Diel feeding regime of *O. niloticus*

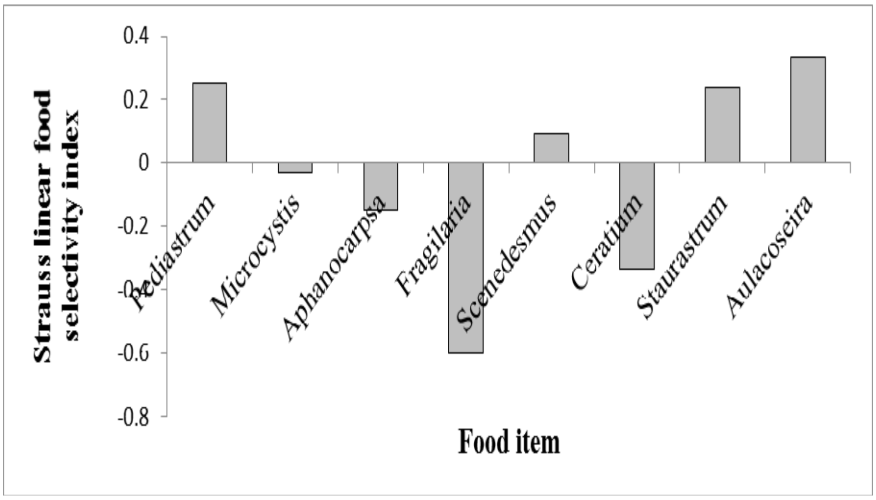

Fig 5: Straus Linear index of food selection for phytoplankton

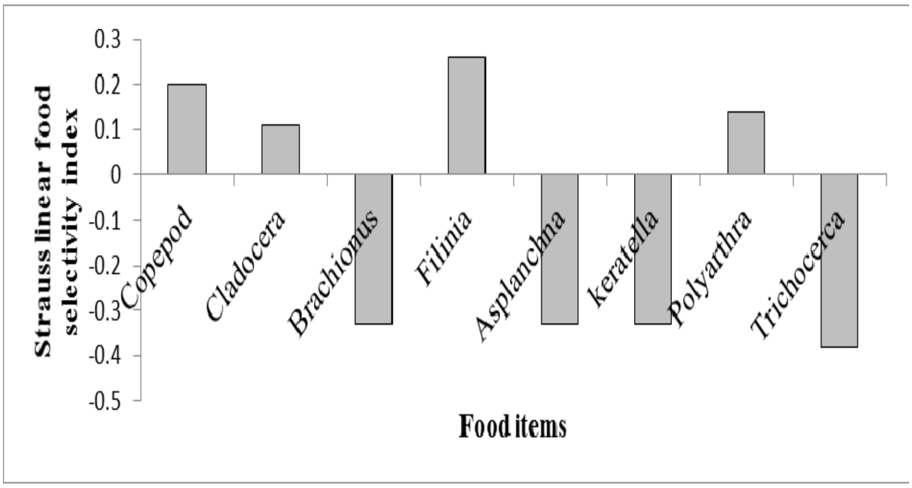

Fig 6: Straus Linear index of food selection for zooplankton

4. Discussions

4.1. Contribution of food items in the diet of the fish

Algae contributed the highest proportion in the diet of *O. niloticus* in all the sampled sites. These results compare well with several studies that have classified *O. niloticus* as being predominantly herbivorous. These studies include that by Moreira (2002) [14], Njiru *et al* (2004) [17], Shalloof and Khalifa (2009) [21]. All these researchers agree that despite *O. niloticus* having diversified its feeding habit to include other food items like fish, insects and others, phytoplankton still contributed the largest proportion of food items consumed by the fish. The highest proportion of phytoplankton was consumed in the open waters compared to the areas closer to the shore. This could be due to the openness of these off shore sampling stations (Sher

Bay, Oserian and Crescent Island) allowing for more light penetration hence more phytoplankton biomass compared to areas closer to the shore where macrophytes shade the water from direct sunlight hence inhibiting phytoplankton development. Other researchers including Bwanika *et al* (2004) [3] and Njiru *et al* (2004) [17] recorded similar results in two Ugandan crater lakes and the Kenyan portion of Lake Victoria respectively.

Higher ingestion of plant materials was recorded in the near shore areas (Korongo and Hippo point) than in the sites located in the open deeper areas of the lake (Sher Bay, Oserian and Crescent Island). This could be due to the infestation and presence of water hyacinth, papyrus and other macrophytes as compared to the open lake which only receives floating macrophytes (water hyacinth and papyrus mats). These results compare with those obtained by Njiru *et al*., (2004) [17] for Nile tilapia in Lake Victoria. There was no significant difference in the contribution of detritus, though slightly higher values were recorded in the near shore areas. This could be attributed to the decaying of plant materials abundant at the littoral zone. Occasionally, the decayed plant materials and other sediments are usually carried to the deeper waters through lake mixing particularly by wind, thus distributing the detritus throughout the lake (Ndungu *et al*., 2013). This could explain the almost equal contribution of detritus in all the sampling sites within the lake.

Although insects contributed very little to the diet of *O. niloticus* in the lake, more were consumed in the near shore areas. This could be attributed to presence of macrophytes in the near shore sampling stations compared to those in the open lake. These macrophytes served as surfaces for orientation by the insects after emergence. The insects found in the fish guts may be those which had fallen into the water immediately after emergence as suggested by Strayer and Findlay (2010) in a study of the ecology of freshwater shore zones of four lakes in USA. Odonata were the dominant group of insects present in the fish guts. These results agree with those recorded by other researchers in other water bodies like Njiru *et al* (2004) [17] and Oso *et al* (2006) [20] who have studied the feeding habits of *O. niloticus* in Lake Victoria and a dam in Nigeria respectively. Fish remains reported in this study included scales and eggs which might have been ingested by the fish during feeding. Although some researchers have recorded fish in the diets of *O. niloticus* in some systems, no whole fish was recorded in the guts analyzed in this study. This then could mean that *O. niloticus* in Lake Naivasha did not actively go for fish as food but might have consumed the broken parts from the water during their feeding.

4.2 Ontogenetic shift

Zooplankton contributed considerably to the diet of *O. niloticus* in fish of length class 0-15 cm TL. The feeding behaviour of *O. niloticus* in Lake Naivasha demonstrated an ontogenetic shift in feeding behaviour. This agrees with a study by Tengjaroenkul *et al.* (2002) [24] who reported an ontogenic change in the development of intestinal enzymes in cultured *O. niloticus* providing evidence that ontogenetic shift is not just a behavioural phenomenon but is controlled by enzymes in the fish gut. Benavides *et al* (1994) [1] also hypothesized that since juvenile fish have higher mass protein demand due to their higher specific growth rate and greater mass specific metabolism, they may not satisfy this demand by consuming plant based diet. Thus, younger fish tend to feed more on zooplankton (animal based foods and change to more plant based foods as they grow. Similar results were recorded in Lake Victoria by Njiru *et al*., (2004) [17]. Zaganini *et al*., (2012) [27] however, obtained higher proportions of zooplankton in the guts of *O. niloticus* of lengths longer than 35 cm TL as opposed to this study in which the contribution of zooplankton was very low from 16 cm TL. Bwanika *et al*., (2004) [3] recorded a dominance of algae compared to zooplankton in the diet of fish of length class 6-10 cm in Lake Nyamusingiri and Lake Kyasanduka in Uganda.

4.3 Diel feeding regime

The results showed that *O. niloticus* feeds mostly during the day. This could be attributed to the fact that it is a visual feeder and depends on sight for food selection. The results are in agreement with those recorded by Martins *et al*., (2011a) [12] who while studying the consistency of individual feeding behaviour of *O. niloticus* reported that the fish fed more at around midday and just before dusk. Oso *et al*., (2006) [20] recorded higher stomach contents in fish guts during the day than at night in Ero reservoir in Nigeria on the feeding behaviour of *O. niloticus*. These results, evidently prove that *O. niloticus* is a visual feeder and relies much on sight for food acquisition similar to results obtained in this study. The empty stomachs or low SC recorded from around midnight is mainly due to the completion of digestion of the food consumed before dusk. Several researchers including Njiru *et al*., (2004) [17] recorded similar results in Lake Victoria, although they recorded two high peaks in the SC of the fish at 11.00hrs and 19.00hrs. However, this study recorded a peak at 12.00hrs noon, one hour later than recorded in their studies. The differences might have been brought about by the time interval used. The rise in SC at 08.00hrs could be a response of intensive feeding by the fish at dawn since they could identify the prey and had exhausted the food eaten at dusk the previous day. This agrees with the studies by Njiru *et al.*,(2004) [17], Shalloof and Khalifa, (2009) [21] who recorded similar results in their studies in Lake Victoria again supporting that *O. niloticsus* is a visual feeder.

4.4 Straus Linear index of food selection

The fish preferred Chlorophyceae but avoided algae in the other genera (Bacilariophycea and Cyanophytes). This could be attributed to the fact that diatoms have tough cell walls that are harder to digest as compared to green algae. Cyanobacteria are filamentous and hence more difficult to handle during feeding and can lead to clogging of fish gills. Some Cyanobacteria are also known to produce toxins. This could explain the avoidance of some of them by the fish in their diet. Other researchers including Huchette *et al*., (2000) [7], Figueredo and Giani, (2005) [5] and Zaganini *et al*., (2012) [27] recorded avoidance of diatoms and Cyanobacteria by caged Nile tilapia in Uganda, Tiete River and Furnas reservoir in Brazil respectively

Copepods and cladocera were chosen by fish over most rotifers. This could be due to the relatively larger size of copepods and cladocera as compared to rotifers which are generally smaller in size. The law of optimal foraging could explain why the bigger zooplanktons were selected by the fish over the smaller ones based on the net energy gain from the two choices [27]. With *O. niloticus* being a visual feeder (feeds more during the day than at night) as reported by Martins *et al*., (2011a) [12], the bigger sizes made the copepods and cladocera easier to spot and pursue as a food source while the rotifers could have been filtered with the water during feeding due to their small sizes.

5. Conclusions
Results from the study showed that *O. niloticus* has a diverse feeding habit that includes algae, zooplankton, fish parts, insects, plant materials and detritus with algae being the dominant food item consumed by the fish contributing up to 56% of the diet. The fish showed an ontogenetic shift in their feeding habits with zooplankton being important in the diet of fish below 16 cm TL. The results also showed that the feeding was more intense at around midday and very low at night showing that Nile tilapia depends on sight for food acquisition.

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