NATIONAL FISHERIES RESOURCES RESEARCH INSTITUTE (NaFIRRI)

Technical Report on the Environmental Monitoring of the Cage Area at the Source of the Nile (SON) Fish Farm for Quarter 4: October – December 2017

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EXECUTIVE SUMMARY

The monitoring of water quality and biotic communities at Source of the Nile (SON) fish farm area, for quarter 4 (October – December) was undertaken in December 2017. The activity aimed at assessing possible changes in the water environment at SON cage area. The following parameters were assessed: water physico-chemicals and nutrients, algae, zooplankton, benthic macro invertebrates, and fish communities.

Total depth was above 5.0 m (range: 5.63 – 9.74 m) at all sampled points and decreased towards the downstream of cages. Water transparency ranged from 1.26 – 1.48 in the cage area and 1.08 to 1.34 m away from the cages. Within the cage area, Dissolved Oxygen ranged from 5.7 – 6.4 mg/L at the surface, and 5.1 – 6.4 mg/L at the bottom, while in the non-cage areas, the range was 5.5 – 7.5 mg/L at the surface and 2.6 – 7.0 mg/L at the bottom. Temperature ranged from 27.0 – 28.0 ^{o} C at the surface and 25.5 – 27.5 ^{o}C at the bottom waters for all sites, and were within the optimal range (25 – 32 ^{o} C). pH in both surface and bottom waters was above 7.0 (range: 7.5 – 9.2) at all sites. Conductivity within cage area ranged from 100.5 – 102.6 μScm^{-1} in surface water and 101.8 – 112.1 μScm^{-1} in bottom water. In the non-cage areas conductivity ranged from 11.0 – 104.4 μScm^{-1} in surface water and 100.2 – 110.0 μScm^{-1} at the bottom.

Ammonium nitrogen concentration during December was less than 0.02 mg/L at all sites (0.007 – 0.018 mg/L within the cage sites, and 0.012 – 0.019 mg/L in the non-cage sites). Nitrite nitrogen ranged from 0.002 – 0.169 mg/L in the cage area, and 0.003 – 0.057 mg/L in the non-cage areas. Similar to previous records of June and September 2017, nitrate nitrogen concentration generally increased towards the downstream site, being lowest at RPT (0.041 mg/L) and highest at DSC (0.204 mg/L). Soluble reactive phosphorus was less than 0.005 mg/L at all sites, and varied within narrow margin (range: 0.003 – 0.0048 mg/L in cage sites, and 0.0032 – 0.0047 mg/L in non-cage sites). The TP concentration ranged from 0.085 – 0.107 mg/L in the cages, and 0.090 – 0.118 mg/L in the non-cage sites and was higher than recorded in September (0.038 – 0.044 mg/L in the cages and 0.04 to 0.109 mg/L away from cages). Total nitrogen concentration was in the range of 0.138 – 0.553 mg/L within cage area and 0.421 – 0.513 mg/L in non-cage areas. The concentration of TSS ranged from 0.76 – 4.33 mg/L in the cage area and 0.57 – 2.76 mg/L in the non-cage areas.

The phytoplankton community was composed of blue-green algae, green algae and diatoms, dominated by blue-green algae. The abundance of algae was higher in the non-cage areas (mean:

7.20 ± 2.14 mm^3L^{-1}, Range: 5.15 – 10.20 mm^3L^{-1}) than recorded in the cage areas (mean: 6.0 ± 0.71 mm^3L^{-1}, Range: 5.30 – 6.98 mm^3L^{-1}), similar to observations of September 2017 (< 5 mm^3L^{-1} within the cages and >5.6 mm^3L^{-1} in the non-cage sites). At all sampled points, blue-green algae contributed >70% of total abundance.

Total zooplankton abundance ranged from 982,213 – 1,310,830 $ind.m^{-2}$ in the non-cage sites, and 740,601 – 1,503,130 $ind.m^{-2}$ in the cage areas. Similar to observations of September 2017, the upper cage site (WIC3 and WIC4) presented lower zooplankton abundance (mean: 788,954 ± 68,381 $ind.m^{-2}$) when compared to the lower cage site with mean abundance of 1,128,232 ± 530,186 $ind.m^{-2}$. Like in the previous sampling periods, copepods were the numerically dominant group (92.69 – 97.22 % of total zooplankton abundance) at all sampled points, with no major differences between cage and non-cage areas. The high abundance of copepods was attributed to the abundance of the juvenile stages (copepodites and Nauplius larvae) which contributed 83.72 – 92.78% of the total zooplankton abundance and this was mainly due to the Nauplius larvae (66.4 – 83.2 %). Cladocera relative abundance ranged from 0.32 – 3.98% while that of rotifers ranged from 1.55 – 3.74%. The macro-benthic community comprised molluscs, annelids and arthropods. Taxa richness ranged from 5 – 11 taxa in the cage area, and 7 – 9 taxa in the non-cage areas. The abundance of benthic invertebrates within the cage area ranged from 1,134 – 2,416 $ind.m^{-2}$ and this was higher than previously recorded in September (294 – 1,415 $ind.m^{-2}$). In the non-cage sites abundance was in the range of 420 – 3,992 $ind.m^{-2}$. Oligochaete annelids which are reported to be very tolerant to pollution contributed 0 - 28 % of the abundance of benthos at cage sites and 3 - 20% at the non-cage sites. Diptera made the greatest contribution at almost all sites, with the percent abundance being higher in non-cage sites (40 – 86%) than what was recorded in the cage sites (37 – 82%). *Chironomus* spp. and *Chaoborus* sp. were the main contributors to the observed Diptera abundance at all sites.

Six fish species, including haplochromines (Nkejje) as a single species group, were recorded in the vicinity of the cages during December 2017. Five fish species were recorded from upstream the cage site, four species from within cage area, and two species from downstream the cages. Overall mean catch rates were 1.8 fish/net/night and 148.6g/net/night compared to 1.7 fish/net/night and 175.4g/net/night recorded in September 2017. By weight, catch rates in December 2017 were highest upstream the cage site (312.1g/net/night) and also by numbers (3.1

fish/net/night). Four species of haplochromines were recorded in the vicinity of the cages during the survey of December 2017 compared to six species recorded in September 2017. The overall catch rate for the haplochromines, in December 2017 was 1.7fish/net/night and 27.5g/net/night compared to 3.4 fish/net/night and 62.3g/net/night recorded in the previous survey of September 2017. Among the fish species examined during December 2017 survey, most of the haplochromine cichlids (88.9%) were mature but only 50% breeding. Only one specimen of *L. niloticus* was mature and breeding. All *S. afrofischeri* and *S. victoriae* specimens examined were mature and in breeding condition while *M. kannume* was immature.

The diet of fishes encountered comprised mostly of fish and insects, which are known natural foods of the fish species. Infection by fish parasites during the survey of December 2017 was not noticed in any fish recorded from the experimental gillnets.

The overall observation on concentrations of nutrients, levels of physico-chemical variables, and biotic communities indicated minimal impact of cages on water quality. The farm should therefore continue adhering to the best environmentally sustainable aquaculture practices, especially continuing with fallowing or rotation of cages to allow resident organisms maintain their natural population densities, distribution and community structure in the area; reducing excess uneaten feed and other suspended materials which would impact on nutrient status and biota; as well as wise use of any chemicals in the area.

1.0 GENERAL BACK GROUND

National Fisheries Resources Research Institute (NaFIRRI) undertakes quarterly monitoring of the water environment at Source of the Nile (SON) fish farm. The activity which is through a collaborative arrangement between SON fish farm and NaFIRRI aims at assessing possible changes in the water environment at SON cage area. The fish rearing activity at SON fish farm involves keeping fish in cages often under high stocking densities and feeding them on artificial feeds that are not the natural food eaten by wild fish. Cages being open systems means that all wastes such as faeces, uneaten feed and fish excretes such as ammonia are shed into the water column (Fernandes et al., 2001). The consequence is increased nutrient input which may result into high algal growth (bloom). Although this may mean more food available to primary consumers such as zooplankton, blooms caused by blue-green algae may be harmful as certain species are associated with production of toxins. In addition, the degradation of excessive phytoplankton biomass can lead to anoxic conditions in sediments underlying the cages thus changing the abundance and composition of the resident fauna.

Napoleon Gulf being a shallow bay at the exit of River Nile from Lake Victoria harbours a wide variety of wild fish species that are cherished by riparian human populations. The wild fishes living close to cages are bound to be affected by activities associated with this method of fish farming. Cage farming is likely to affect the presence, abundance, diet and residence time of organisms in given vicinity (Carss, 1990; Dempster et al., 2002). Floating structures including cages may act as Fish Attracting Devices (FADs) and most pelagic fishes are known to be strongly attracted to floating objects (Freon and Dagorn, 2000; Castro et al., 2002). Wild fish could be attracted to these sites by for example plenty of food available to the cultured fishes (Bjordal & Skar, 1992). In the process, other ecological interactions between cultured and wild fish may be possible. Wild fish may also be instrumental in cleaning the environment close to the cages through eating any excess uneaten food left by cultured fishes. Caged fish under crowded conditions is susceptible to water-borne diseases and could infect wild fish or vice versa. While diseases breaking out among cultured fishes may be controlled through treatment, the wild fishes cannot undergo treatment and may thus spread diseases to other fishes, hence affecting yields from capture fishery. Furthermore, escape of cultured fish may cause genetic dilution hence decreasing genetic diversity of fish. These and other possible impacts of cages on the water environment may consequently result into conflicts

with other resource users especially due to deteriorating water quality and effect on wild fishes, consequently affecting the cage aquaculture industry.

Therefore, the following were established as key parameters to be monitored: water temperature, dissolved oxygen, pH, conductivity, water transparency, total suspended solids, nutrient status, algae, zooplankton, benthic macro invertebrates and fish communities. The present report presents field observations made at the two cage sites of Source of the Nile fish farm including upstream, downstream and reference points, for the third quarter (July to September) undertaken in September 2017. The report provides a scientific interpretation and discussion of the results with reference to possible impacts of the cage facilities on the water environment and the different aquatic biota in and around the fish cage site.

2.0 METHOD AND MATERIALS

2.1 Study area

The current survey was conducted at Source of the Nile Fish Farm, located at Bugungu area at the western end of the Napoleon gulf in northern Lake Victoria (Figure 1). The farm lies a few kilometers south of the source of the River Nile and is presumed to be influenced by the headwaters of the river as it flows downstream from its lake origin to the nearby Owen Falls and Nalubaale Dams. The farm currently comprises more than 500 fish cages of varying dimensions, arranged in rows, anchored by weights and buoyed by large plastic floaters. Over the years of operation of the farm, the number of cages increased and the area under cages expanded. Currently, the farm has two cage sites and between these sites is a navigation route from Bugungu landing site to Jinja town across Napoleon gulf.

Collection of nutrient, algae, zooplankton, benthic macroinvertebrates and fish samples, as well as related physico-chemical data was carried out along the established transect running from cage site 2 (upper/new cage site) to cage site 1 (old cage site), incorporating both sites into the monitoring plan. Sampling was carried out at the following sampling points: RPT (Reference point), WIC1 and WIC2 in cage site 1 (old cage site), WIC3 and WIC4 in cage site 2 (upper/new cage site), BCS located in the area (navigation route) separating cage site 1 and cage site 2, USC (upstream of cages) and DSC (downstream of cages) located at 100 m distance off the edges of outer cages in cage site 2 and cage site 1 respectively (Figure 1).

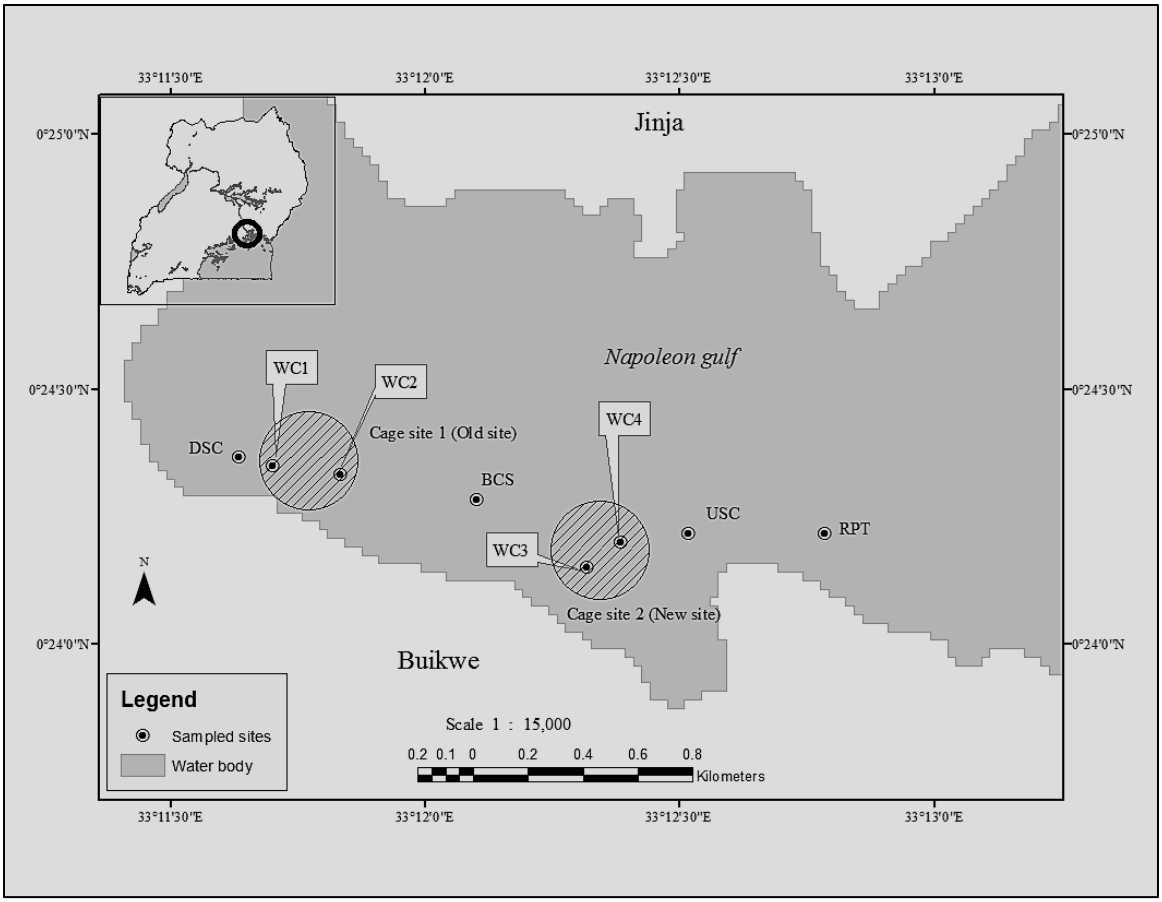

Figure 1. Schematic presentation of the study area showing location of SON Fish Farm sites and study sampling points: RPT- Reference point, USC- upstream of cages; WC- within cages and DSC- downstream of cages.

2.2 Depth profiles and water transparency determination

A handheld Echo Sounder (LCD portable sounder, Vexillar inc.) was used to determine the total depth at each study site. Water transparency (m) was measured by a standard Secchi disk of 20 cm diameter, with quadrants painted black and white, by taking the average of the depths at the disappearance and reappearance of the disk.

2.3 Physico-chemical parameters

Physico-chemical parameters (temperature, dissolved oxygen, pH and conductivity) in the water column were measured in-situ with a submersible multiparameter probe (Sea-Bird Electronics, Model 19-03). All in-situ measurements were made in triplicate for the purpose of assessing variation in each parameter at each sampling point.

2.4 Nutrient and phytoplankton status

Water samples for the analysis of nutrients and phytoplankton status were collected using a 3L Van Dorn water sampler. Water samples for nutrient analysis were then preserved on ice pending analysis in the laboratory. Phytoplankton samples were collected at 0.5 m below the water surface and preserved in Lugol's solution for laboratory analysis. In the laboratory, standard methods were used to analyze key nutrients: Total phosphorus (TP) and Total nitrogen (TN) were analyzed by Persulfate digestion method; Soluble reactive phosphorous (SRP) by Ascorbic acid method; nitrate nitrogen (NO_3–N) by Cadmium reduction method, nitrite nitrogen (NO_2-N) by Colorimetric methods; ammonia nitrogen (NH_4–N) by Indophenol blue method; soluble reactive silicon (SRSi) was determined as yellow molybdate-silicic acid (Wetzel & Likens 2000); and Chlorophyll *a* concentrations by cold methanol extraction method. Concentrations of these nutrients and Chlorophyll *a* were determined by spectrophotometry. For phytoplankton analysis, a sub-sample of 2 ml was placed in an Utermöhl sedimentation chamber and left to settle for at least three hours. Phytoplankton species were identified and counted at 400X magnification using an inverted microscope, following the method of John et al. (2002). For each taxon, cell length and width were measured and algal bio-volume calculated using geometric approximations (Wetzel & Likens, 2000).

2.5 Zooplankton composition

Three replicate zooplankton samples were collected with a conical net of 0.25m diameter and 60 µm mesh. Filtered samples were placed in clean plastic bottles and fixed with 4% sugar formalin solution. In the laboratory samples were rinsed in tap water over a 50 µm Nitex mesh and diluted to a suitable volume depending on the concentration of each sample. A series of 2, 2, and 5 sub-samples were taken from a well agitated sample using a calibrated automatic bulb pipette, each placed on a plankton counting chamber and examined under an inverted microscope at x100 magnification. Individual organisms were taxonomically identified using taxonomic manuals by Boxshall & Braide (1991), Korinek (1999) and Koste (1978). Members of each species were enumerated.

2.6 Benthic macro invertebrate composition

Three replicate macro invertebrate hauls were taken using a Ponar grab (open jaw area, 238cm^2) at each sampling point. Benthic macroinvertebrate sampling preceded sediment sampling for grain

size analysis. The bottom type and texture were determined by visual examination and feel between two fingers. Each haul was concentrated, placed in clean, labeled sample bottle, and preserved with 5% formalin solution. In the laboratory, each replicate sample was rinsed with tap water and spread out on a white metallic tray. Benthos were sorted from the sediment using forceps and each sample examined under a dissecting binocular microscope at x400 magnification. Identification was done using taxonomic manuals by Pennak (1953), Mandahl-Barth, (1954), and Merritt & Cummins (1997). All taxa were recorded and individuals of each taxon enumerated.

2.7 Fish community

Three fleets of gill-nets comprising panels of mesh sizes 1" to 5.5" in 0.5" increments, and 6 to 8 in 1" increments were set overnight at Upstream of cages (USC), Within cages (WIC) and Downstream of cages (DSC) sites. The nets were set between 1800hr to 1900hr and retrieved the following day between 0600hr and 0700hr. Fish caught by different nets in each fleet were sorted and identified as in Greenwood (1966). Specimens of haplochromines that are not easily identifiable in the field were given field names, and preserved for more detailed laboratory taxonomic procedures as in Greenwood (1981). For each species, the number, total weight (g) and individual lengths (cm) of the fish were recorded. Fork length (FL) was measured for all fish species with forked caudal fins, and Total Length (TL) for fishes with entire fins. Biometric data (Total and Standard length, body weight, sex and gonad maturity state, stomach fullness and fat content) were recorded for individual fishes. Fish stomachs were preserved for laboratory analysis of the contents. The fish were further examined for any infection (parasitic or bacterial) both on the surface and within the visceral cavity.

3.0 RESULTS AND DISCUSSION

3.1 Physical and chemical conditions

Water physico-chemical variables: temperature, dissolved oxygen (DO), conductivity, pH, total depth (TD), and water transparency measured as secchi depth (SD) were recorded during December 2017 sampling period. Table 1 shows the levels of physico-chemical conditions recorded at the sampling points around SON fish cage farm.

Table 1. Physico-chemical variables at the sampling points, December 2017

Site	Depth	DO (mg/L)	Temp (ºC)	Cond (uS/cm)	pH	TD (m)	SD (m)
RPT	Surface	7.5	27.7	104.4	9.2	9.5	1.08
	Bottom	7.0	27.5	105.0	8.0		
USC	Surface	6.2	28.0	102.2	8.3	9.4	1.34
	Bottom	2.6	27.4	104.0	8.3		
WIC4	Surface	6.2	27.4	102.6	8.8	9.7	1.44
	Bottom	6.0	26.9	105.3	7.5		
WIC3	Surface	5.7	27.9	102.6	9.1	9.0	1.48
	Bottom	5.1	25.5	112.1	7.8		
BCS	Surface	6.1	27.0	101.0	8.9	8.5	1.30
	Bottom	5.9	26.8	110.0	8.0		
WIC2	Surface	6.4	27.0	100.5	8.3	8.4	1.26
	Bottom	6.4	26.5	110.0	8.0		
WIC1	Surface	5.7	27.7	101.7	9.0	6.0	1.34
	Bottom	5.4	26.9	101.8	8.1		
DSC	Surface	5.5	27.1	101.3	8.9	5.6	1.34
	Bottom	5.6	26.4	100.2	8.0		

3.1.1 Total depth (TD) and secchi depth (SD)

Figure 2 shows the total depth of the sampled points in the current and previous months. Total depth (TD) was above 5.5 m at all sampling points in the current month of December and was therefore above the 5.0 m suitable for setting up floating fish cages (Kasozi et al., 2016). Within the cage areas, TD ranged from 6.00 – 9.74 m, being highest in the upper cage area (range: 9.00 – 9.74 m). Generally, TD decreased towards the downstream direction, being lowest (5.63 m) at the downstream sampling point (Figure 2). Water transparency measured as Secchi depth (SD) ranged from 1.26 – 1.48 m in the cage area (WIC1 to WIC4) and 1.08 – 1.34 m in sites away from the cages (RPT, USC, BCS and DSC). The SD was highest in the upper cage area (Figure 3). The

lowest SD (1.08 m) was recorded at the reference point (Figure 3). Temporal variation indicated a decline in SD at this point (reference point) being highest in March and lowest in December (Figure 3). However, in all sampling points, mean SD was still above 1.0 m.

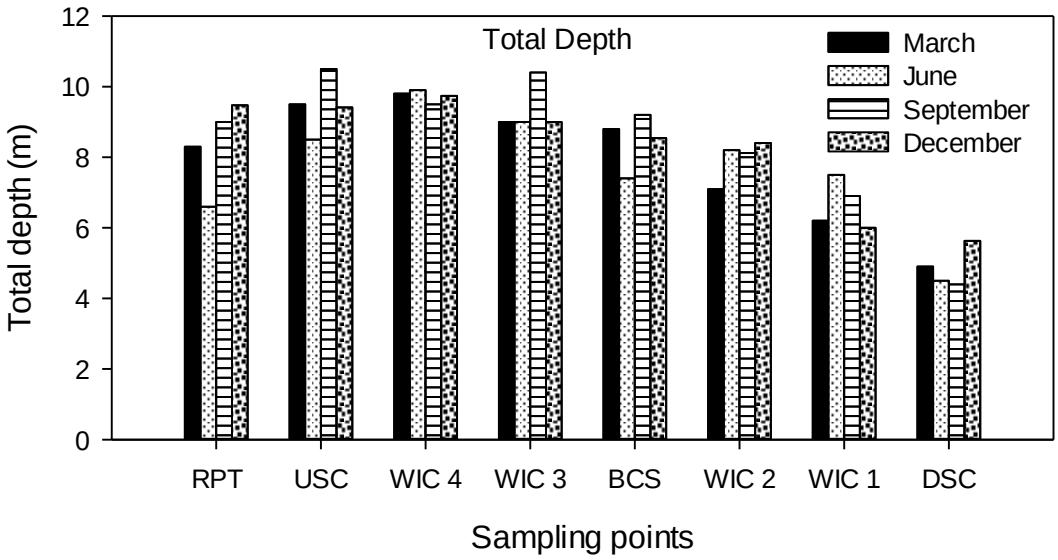

Figure 2. Mean total depths recorded at SON fish farm, March to December 2017.

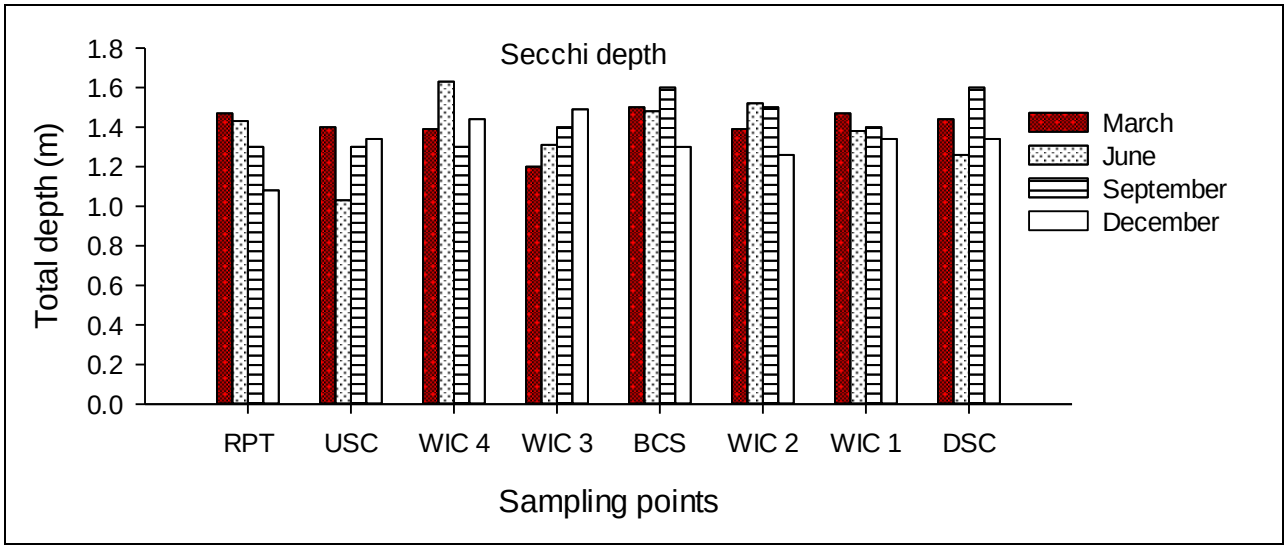

Figure 3. Mean secchi depth recorded at SON Fish farm, March to December 2017.

3.1.2 Dissolved oxygen (DO)

Dissolved oxygen at the surface waters was above 5.0 mg/L at all sites, with the highest value recorded at RPT sampling point. In the bottom water, dissolved oxygen was highest at RPT (7.0 mg/L) and lowest at USC (2.6 mg/L). Within the cage area, DO ranged from 5.7 – 6.4 mg/L at the surface, and 5.1 – 6.4 mg/L at the bottom, while in the non-cage areas, the range was 5.5 – 7.5 mg/L at the surface and 2.6 – 7.0 mg/L at the bottom (Table 1). Mean DO concentration was higher in September than observed in December at all sites (Figure 4). The DO concentration above 4.0 mg/L is required for fish farming with the operating levels ranging from 5.0 to 7.5 mg/L being recommended (ESRF, 2015). The observed oxygen concentrations therefore suggested favorable oxygen environment for fish and other fauna within the cage area.

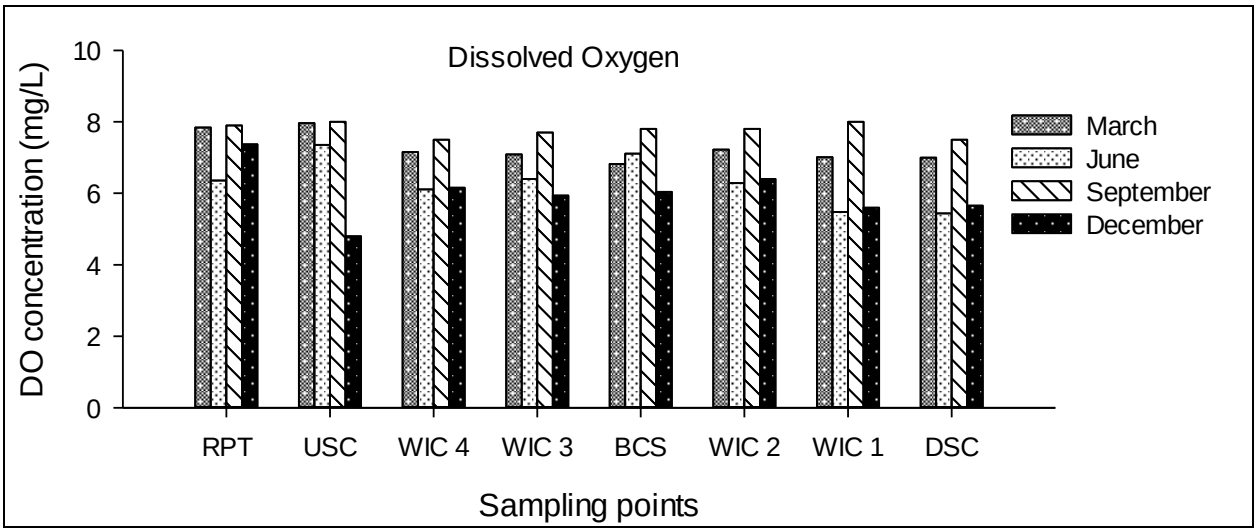

Figure 4. Mean DO concentrations recorded at farm and control sampled points, March to December 2017.

3.1.3 Temperature

Temperature for December 2017 period ranged from 27.0 – 28.0 ^{o} C at the surface and 25.5 – 27.5 ^{o}C at the bottom waters for all sites, and were within the optimal range (25 – 32 ^{o} C) for the cultured fish (Bhatnagar & Devi, 2013; Kane et al., 2015). Comparison of March, June, September and December 2017 periods, indicated higher temperature in March and December than was recorded in June and September at all sites (Figure 5).

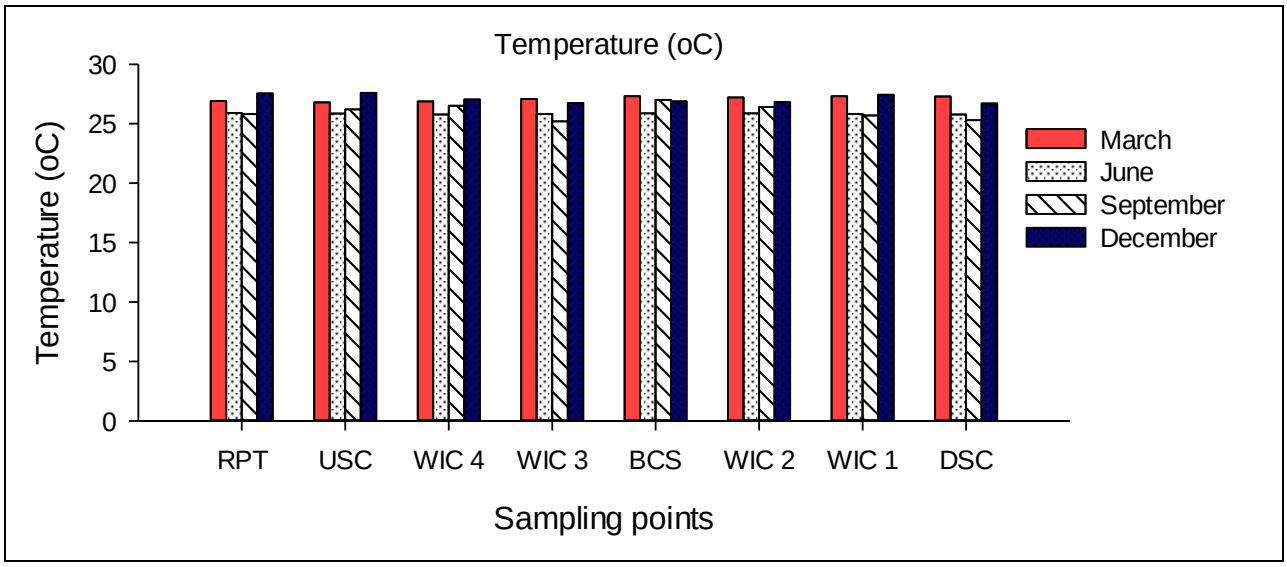

Figure 5. Mean temperature recorded at SON cage area, March to December 2017.

3.1.4 pH

The pH both in surface and bottom waters was above 7.0 at all sites (Table 1). In both surface and bottom waters, pH ranged from 7.5 – 9.2, being higher in the surface than bottom water at all sites (Table 1). The pH recorded in December was higher than that recorded during September period across all sampling points (Figure 6). Generally, pH was higher in December and June than was recorded in March and September (Figure 6). At all sites and for all sampled months, pH was within the optimal range (6.0 – 9.0) considered suitable for most fish including tilapia (Kasozi et al., 2016; Masser, 1999; Devi et al., 2017).

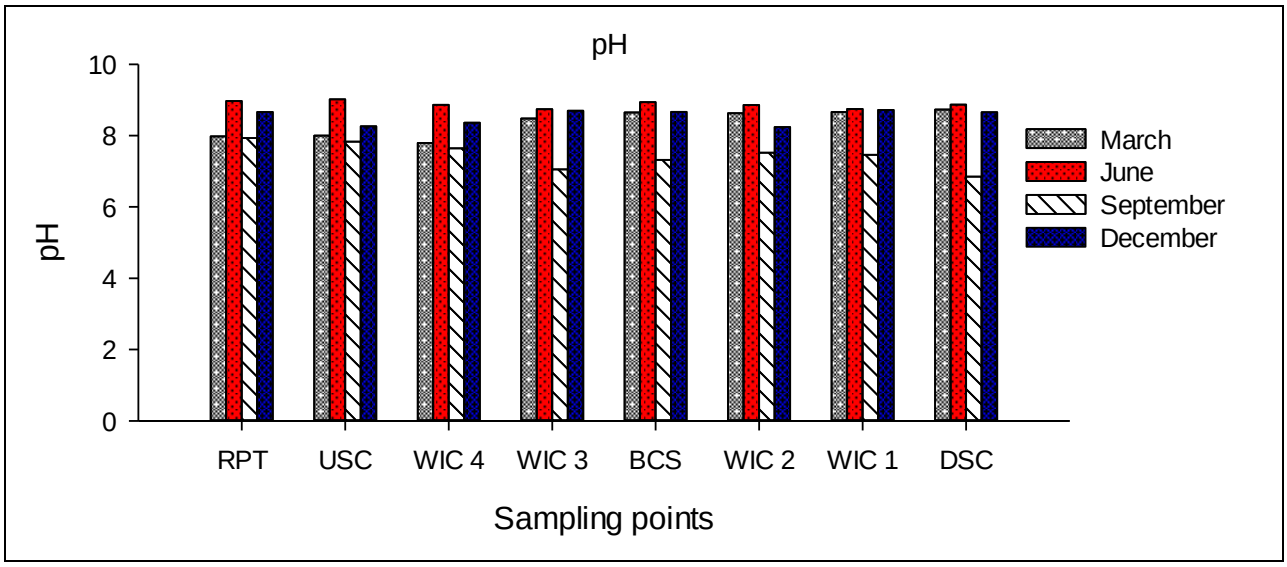

Figure 6. Mean pH at SON Fish farm area, March to December 2017.

3.1.5 Electrical conductivity (EC)

Electrical conductivity within cage area (Sampling points WIC1 to WIC4) ranged from 100.5 – 102.6 μScm^{-1} in surface water and 101.8 – 112.1 μScm^{-1} in bottom water (Table 1). In the non-cage areas (sampling points: RPT, USC, BCS and DSC), EC was in the range of 11.0 – 104.4 μScm^{-1} in surface water and 100.2 – 110.0 μScm^{-1} in bottom water (Table 1). At all sampled points both in cage and non-cage sites, conductivity was within the range recorded in Lake Victoria (Sitoki et al., 2010). Across all sampling months, conductivity was within the range (30 – 5,000 μScm^{-1}) considered acceptable for fish production (Stone et al., 2013).

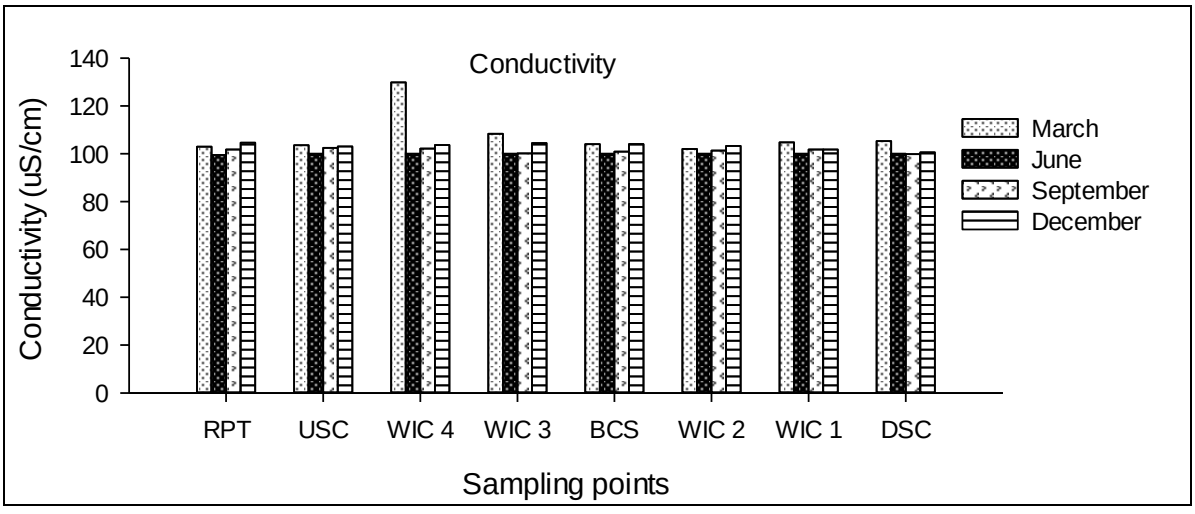

Figure 7. Mean conductivity at SON fish cage area, March to December 2017.

3.2 Nutrients and Total suspended solids (TSS)

3.2.1 Ammonium-nitrogen

The concentration of ammonium nitrogen recorded during December 2017 period was less than 0.02 mg/L at all sites (0.007 – 0.018 mg/L within the cage area, and 0.012 – 0.019 mg/L in the non-cage sites), similar to records of September (Figure 8). However, December values were slightly higher than September values for ammonium nitrogen across all sampled points, reflecting background changes in the lake (Kishe, 2004). The upper cage site (WIC3 and WIC4 sampling points) had slightly higher concentrations of ammonium nitrogen than what was recorded in the lower cage site (WIC1 and WIC 2 sampling points).

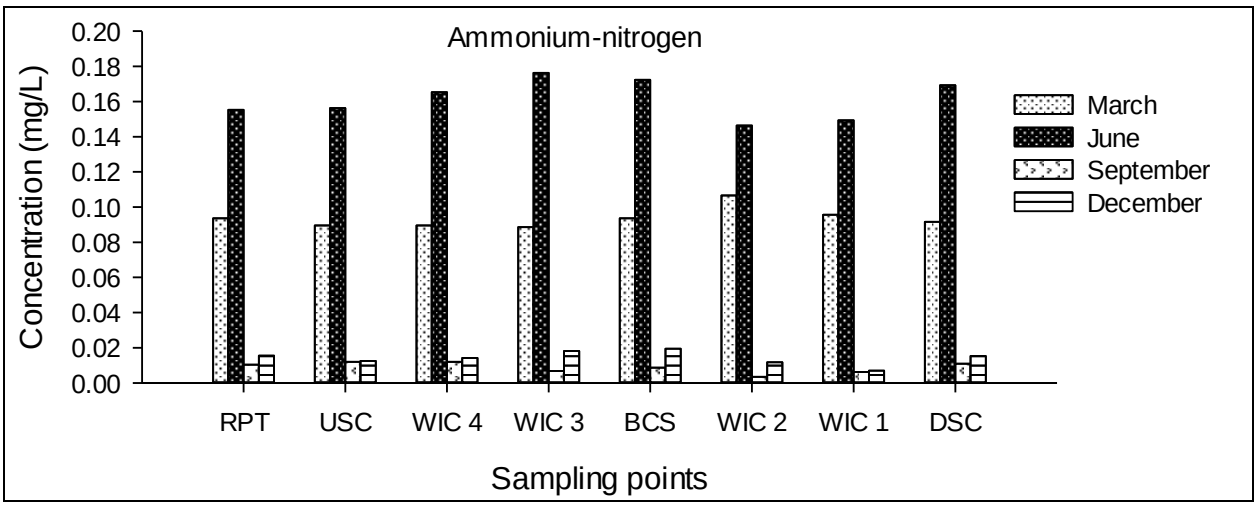

Figure 8. Mean concentrations of ammonium-nitrogen recorded in March to December 2017.

3.2.2 Nitrite nitrogen

Figure 9 shows the concentration of nitrite nitrogen across sampled points. The concentration of nitrite nitrogen ranged from 0.002 – 0.169 mg/L in the cage area, and 0.003 – 0.057 mg/L in the non-cage areas. Nitrite nitrogen concentrations recorded within cages at WIC1 and WIC3, and away from cages at BCS and DSC were higher than previously recorded. The levels of Nitrite nitrogen generally showed an increase when compared to results of September sampling period (Figure 9). Like observed in the previous months (March, June and September 2017), the concentrations recorded in the current sampling period (December 2017) at all sites remained within the range, 0.01 – 3.0 mg/L, considered suitable for fish farming (Bhatnagar & Devi, 2013).

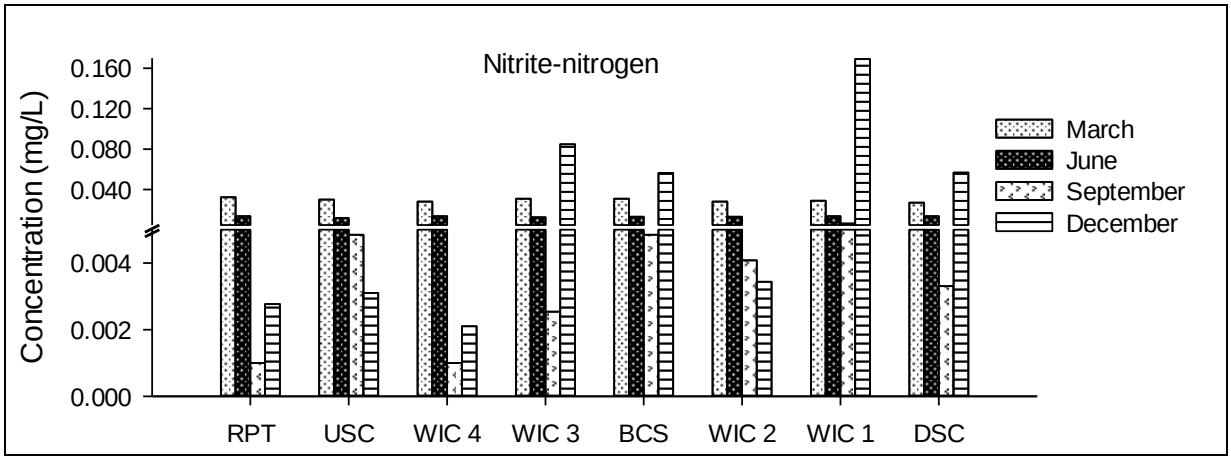

Figure 9. Mean concentrations of nitrite nitrogen at SON Fish, March to December 2017.

3.2.3 Nitrate-nitrogen (NO_3-N)

Similar to previous records of June and September 2017, nitrate nitrogen concentration generally increased towards the downstream site, being lowest at RPT (0.041 mg/L) and highest at DSC (0.204 mg/L) (Figure 10). At all sites, nitrate concentrations of current month of December were higher than recorded in September. The sampling points: WIC3 and WIC1 in the cage area, and BCS and DSC immediately downstream, which presented the highest values of nitrite nitrogen (Figure 9), presented the highest concentrations of nitrate nitrogen (Figure 10). At all sampled points, nitrate nitrogen concentration was within the range of 0.1 – 4.5 mg/L considered desirable for fish farming (Bhatnagar & Devi, 2013; Stone et al., 2013).

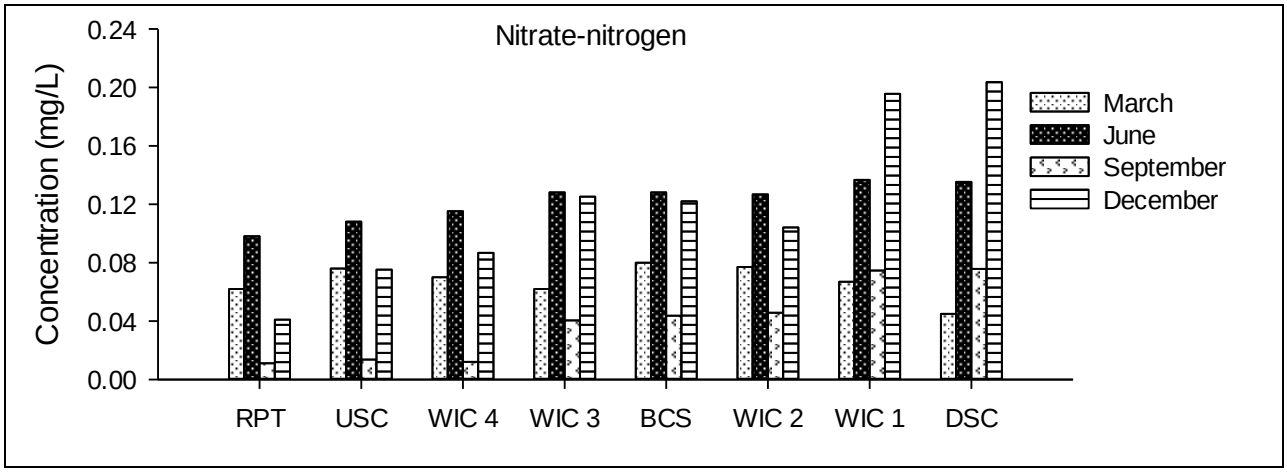

Figure 10. Mean concentrations of nitrate nitrogen at SON cage area, March to December 2017.

3.2.4 Soluble reactive phosphorus (SRP)

At all sampled sites, SRP in December period was less than 0.005 mg/L (Figure 11) and varied within narrow margin across cage sites (range: 0.003 – 0.0048) and non-cage sites (range: 0.0032 – 0.0047). Concentrations > 0.004 mg/L were recorded at WIC3 (0.0046 mg/L) and WIC1 (0.0048 mg/L) in the cage area, and at BCS (0.0044 mg/L) and DSC (0.0046 mg/L), downstream of the upper and lower cage sites respectively. Apart from RPT (reference) site where the current values of SRP (0.003 mg/L) were less than that recorded in September (0.0041 mg/L), the rest of the sampling points presented higher concentrations of SRP than previously recorded in September (Figure 11).

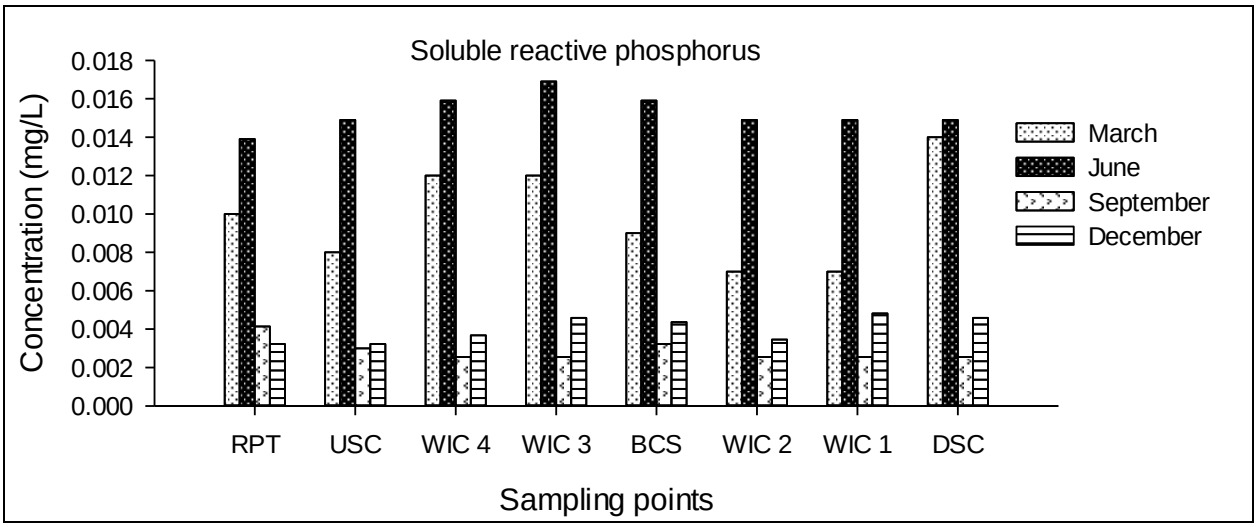

Figure 11. Mean concentration of soluble reactive phosphorus, March to December 2017 at SON Fish farm.

3.2.5 Total phosphorus (TP)

Total phosphorus includes the soluble forms of phosphorus as well as that bound up in the cells of existing phytoplankton and other microscopic aquatic organisms, organic detritus, and in part of the suspended particulate mineral material (Rissik et al., 2009). The TP concentration ranged from 0.085 – 0.107 mg/L in the cages, and 0.090 – 0.118 mg/L in the non-cage sites and was higher than recorded in September (0.038 – 0.044 mg/L in the cages and 0.04 to 0.109 mg/L away from cages). Figure 12 shows spatial and temporal variation in the concentration of TP. The highest concentration of TP (0.118 mg/L) was recorded in the non-cage sites at USC while the lowest concentration (0.085 mg/L) was recorded at WIC3, in the upper cage site. Generally, TP

concentration was higher in the non-cage sites (RPT, USC, BCS and DSC) than what was recorded in the cages (WIC1 to WIC4). In all the months sampled, the TP concentrations at all the sites (both cage and non-cage sites) remained in the range of 0.01 to 3.0 mg/L considered desirable for cultured fish (Bhatnagar & Devi, 2013).

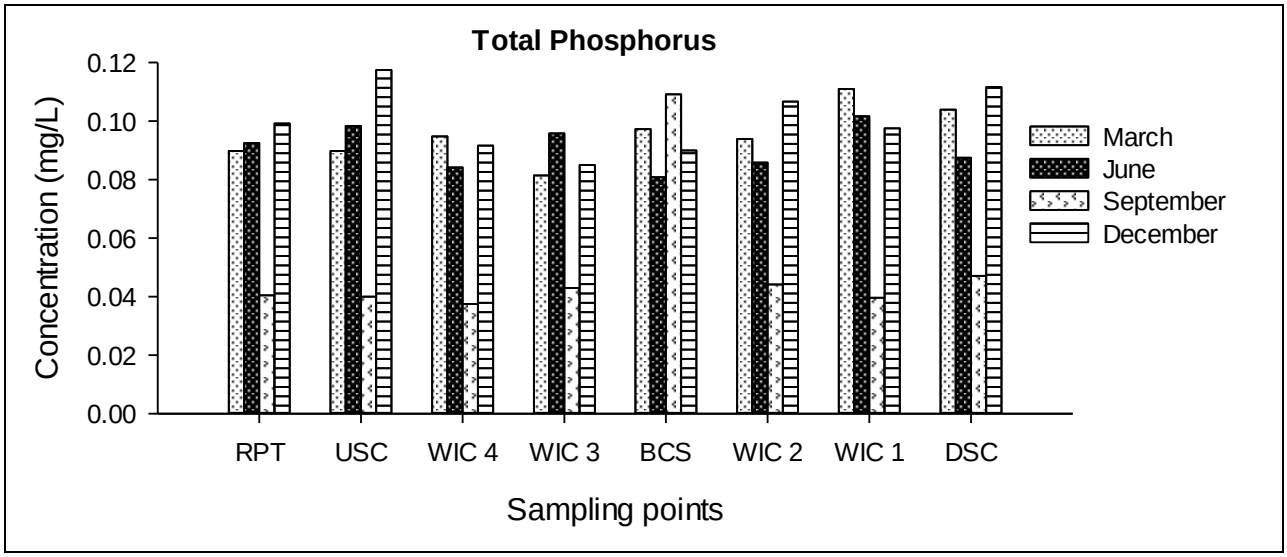

Figure 12. Mean concentrations of Total Phosphorus at SON fish, March to December 2017.

3.2.6 Total Nitrogen (TN)

The concentration of TN ranged from 0.138 – 0.553 mg/L in the cage area, and 0.421 – 0.513 mg/L in the non-cage areas (Figure 13) and was higher than what was recorded in September 2017 (0.120 – 0.158 mg/L in the cage areas, and 0.121 – 0.122 mg/L in the non-cage areas). Generally, TN was slightly higher within the cages especially at WIC1 (0.553 mg/L) in the lower cage site and WIC4 (0.523 mg/L) in the upper cage site (Figure 13). The TN concentration was very variable across sampling periods with no observed trend between cage and non-cage sites.

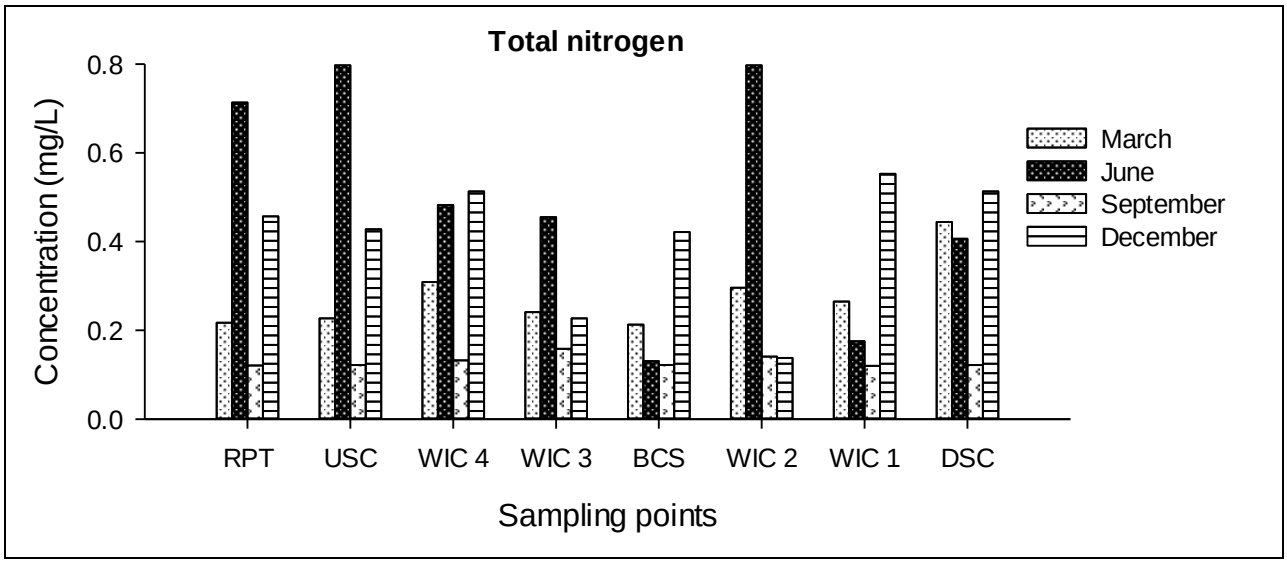

Figure 13. Mean concentration of total nitrogen (March to December 2017).

3.2.7 Total suspended solids (TSS)

The amount of TSS together with total dissolved solids (TDS) affect water transparency by reducing light penetration in the water resulting in low water transparency (Cako et al., 2013). The concentration of TSS ranged from 0.76 – 4.33 mg/L in the cage area and 0.57 – 2.76 mg/L in the non-cage areas. Figure 14 shows the concentration of TSS at different sampling points in the current and previously sampled months. Across sampling periods, TSS concentration in the current month (December 2017) was lower than recorded in September at most of the sampling points (except at WIC4). All values of TSS in all sampled points were <10mg/L recommended for cage culture (ESRF, 2015).

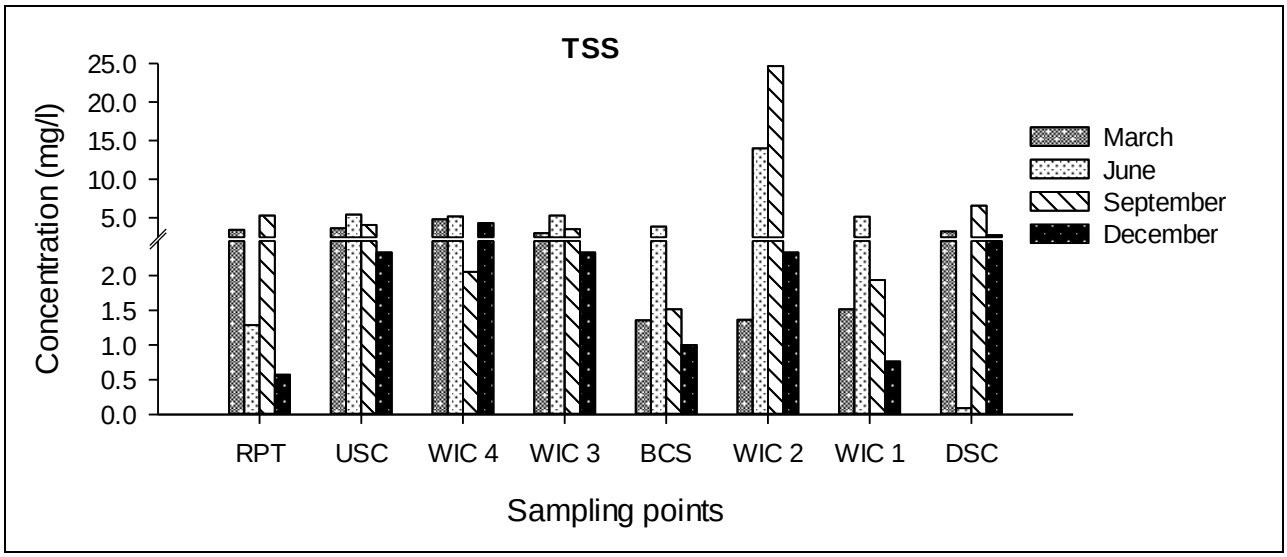

Figure 14. Mean concentration of TSS in March to December 2017

3.3 Phytoplankton species composition, abundance and distribution

The phytoplankton community was composed of blue-green algae, green algae and diatoms. The abundance of algae was higher in the non-cage areas (mean: 7.20 ± 2.14 mm^3L^{-1}, Range: 5.15 – 10.20 mm^3L^{-1}) than recorded in the cage areas (mean: 6.0 ± 0.71 mm^3L^{-1}, Range: 5.30 – 6.98 mm^3L^{-1}), similar to observations of September 2017 (< 5 mm^3L^{-1} within the cages and >5.6 mm^3L^{-1} in the non-cage sites). The highest algal biovolume (10.20 mm^3L^{-1}) was recorded at the reference (RPT) site (Figure 15). At all sampled points within and away from the cage area, algal abundance was mainly attributed to the blue-green algae which contributed >70% of total abundance. This is contrary to the observations of September 2017 where diatoms made the greatest contribution to the total algal abundance at majority of the sampling points (Figure 16).

The amount of phytoplankton in the water column is a function of the influence of nutrients and grazing organisms such as copepods. Algae requires nutrients and light for growth. Nitrogen and phosphorous have been identified as the major nutrients governing primary production and phytoplankton biomass in tropical African lakes (Bergamino et al., 2007). Typically, in Lake Victoria, the influence of nutrient and light availability on phytoplankton abundance and species composition has been reported and associated with succession in phytoplankton assemblages (Mugidde et al., 2003). Although blue-green algae can grow at lower nutrient concentrations, they tend to become more prevalent as nutrient concentrations rise, with the different species responding differently. Among blue-green algae, species such as *Anabena circinalis, Microcystis*

flos aquae, Microcystis aeruginosa and *Planktolyngybya circumcreta,* each contributed > 20% of algal abundance in some sampling sites (Appendix 1).

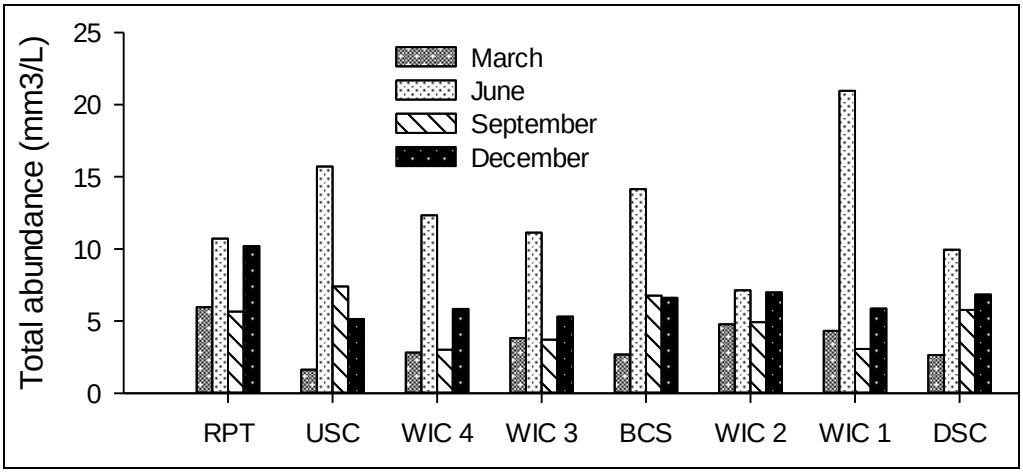

Figure 15. Total abundance of phytoplankton at sampled points expressed as bio-volume (mm^3L^{-1}).

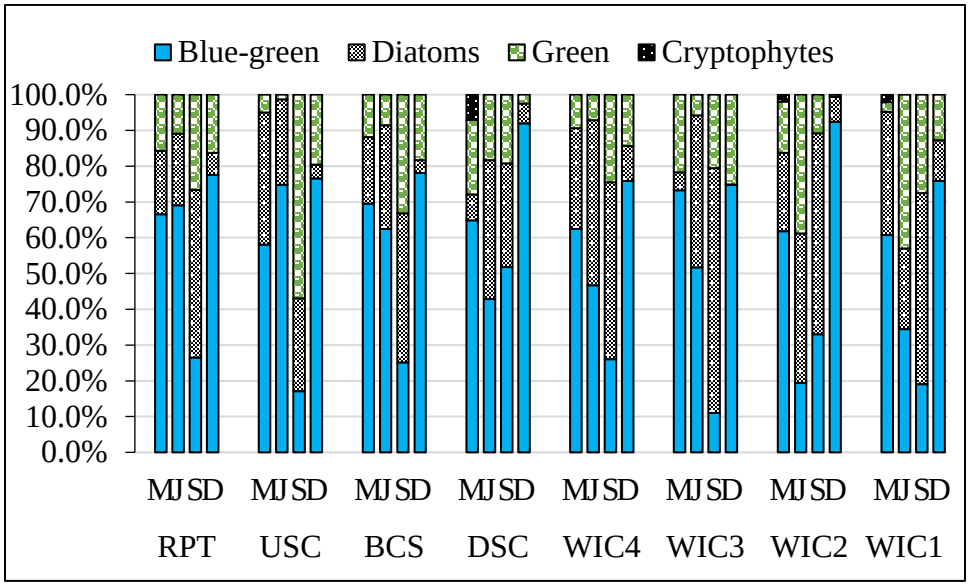

Figure 16. Percentage abundance of different phytoplankton groups. The letters M, J, S and D indicate March, June, September and December respectively.

Taxa richness was higher in the non-cage sites (RPT, USC, BCS and DSC) than what was recorded within the cage area (Table 2). Two blue-green species: *Planktolyngbya circumreta* and

Planktolyngbya limnetica were recorded at all sites in all sampling periods (100% frequency of occurrence). *Nitzschia acicularis* and *Ankistrodesmus falactus* were the most common diatom and green algae respectively. A majority of diatom and green algal species were intermittently distributed. Overall 30 genera with 62 species were recorded in December of which 11 genera belonged to the blue-green algae with 31 species, 5 to diatoms with 9 species, and 14 genera of green algae with 22 species (Table 2).

Table 2. Distribution of phytoplankton species across sampled points, December 2017.

	Sampling sampled points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Blue-green algae								
Anabaena acircularis			---+					
Anabaena circinalis	++++	+--+	++--	++++	++--	+--+	++-+	++-+
Anabaena circumcreta		-+--			---+			
Anabaenopsis tanganyikae		--+-	---+		++--			
Aphanocapsa delicatissima	-+-+	-+++	-+++	-+++	--++	---+	---+	--++
Aphanocapsa elachista	--++	---+	---+	-++-	---+	+-++	-+-+	---+
Aphanocapsa holistica			--+-	+---	---+		--+-	
Aphanocapsa incerta	+-++	+---	---+	+-++	-+-+	---+	---+	+--+
Aphanocapsa nubilium	---+	+--+	++++	-+++	--+-	-+++	+--+	++++
Aphanocapsa species	---+	-+-+	-+-+		--+-	--++	-+-+	---+
Chroococcus dispersus	---+	---+	-+++	++-+	+--+	++++	---+	+--+
Chroococcus limnetica	++++	++++	+-++	++-+	-+-+	+--+	---+	+--+
Chroococcus turgidus	-++-	-+-+	-+--	---+	-++-	---+	+--+	-+-+
Chroococcus species		--+-					--++	
Chroococcus trigonum								--+-
Coelastrum microporum	---+							
Coelomoron pusila	--++	---+	-+++	--++	---+	---+	---+	--++
Coelomoron species							---+	
Coelomoron tropicale	---+	--++	---+	--++	---+		-++-	---+
Coelosphaerium kuetzingianum	+--+	---+		+---			-+-	+--+
Coelosphaerium tropicale						---+		
Cylindrospermopsis africana			--+-					
Cylindrospermopsis sp.					--+-	-+--		
Kirchneriella species					--+-			
Merismopedia tenuissima	+-++	+--+	---+	++-+	++++	-+++	+++-	-+++
Merismopedia elegans	+-+-	--+-		+---		+---		
Merismopedia glauca	-++-	---+				--+-		--+-

	Sampling sampled points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Merismopedia granulate					---+			
Microcystis aeruginosa	---+	-+--		-+-+	-+--	--+-	-+-+	--++
Microcystis elegans					---+			
Microcystis flos-aqaue		--++	-+--		--++	---+	---+	
Microcystis wesenbergii		-+--						
Planktolyngbya circinalis					+---			
Planktolyngbya circumreta	++++	++++	++++	++++	-+++	++++	++++	++++
Planktolyngbya contortum	-+--	---+						
Planktolyngbya limnetica	++++	++++	++++	++++	++++	++++	++++	++++
Planktolyngbya simplex	-+--							
Planktolyngbya tallingi	--+-	-+++	--+-	-+--		--++	+---	-+++
Planktolyngbya undulata				+---				
Psuedonabaena limnetica	-+--		--+-	-+--	-+-+	--+-		---+
Psuedonabaena species					-+--			
Scenedesmus acuminatus	-+--							
Diatoms								
Aulacoseira ambigua	-++-							
Aulacoseira granulata	+---	-++-	--+-	-++-		-+--		-++-
Centric diatom						--+-	-+++	--+-
Cocconeis placentula				-+--				
Cocconeis species			-+--					
Cyclostephanodiscus astraca								-+--
Cyclostephanodiscus sp.						-+--		
Cyclotella kuetzingiana	-+--				-+--			
Cyclotella species	--+-	---+		-+--	--+-		---+	
Cyclotella meneghiniana						---+		
Cymbella cistula	-+--							
Epithemia argus			+---					
Fragilaria species		-+--						
Navicula gastrum	--+	+++-	-++-	--+-	++--	++--		--+-
Navicula granulate				---+				
Navicula radiosa	---+							
Navicula species	--+-				-++-			
Nitzschia acicularis	++++	+++-	++++	++++	++++	++++	++++	++++
Nitzschia closterium						-+-	-+-	
Nitzschia fonticola	+-+-	--+-	-++-	-+--	-+--	++++	-+--	-+--
Nitzschia species			-+--					
Stephanodiscus Astraea					---+			
Synedra cunningtonii		-+++		-++-	+-+-			

	Sampling sampled points							
Taxa	**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Synedra species			-+--					
Synedra ulna					-+--	-+--		
Green algae								
Actinastrum hantzschii	--++	--+-	--+-	---+	-+--	---+		
Ankistrodesmus falcatus	+-++	--++	-+++	+-+-	+-++	+-++	--++	++++
Ankistrodesmus fusiformis								+--
Ankistrodesmus setigera		---+	--+-	+-+-				
Anthrodesmus species						--+-		
Chlorella vulgaris		++--		+---	-+--	+---		+--+
Chlorella species		---+						
Chodatela species								---+
Closterium aciculare						+-+-		
Closterium Kuetzingii			--+-		--+-	--+-		
Closterium habitat	-+--						---+	---+
Closterium species		--+-			---+			-++-
Coelastrum costatum					-+--			
Coelastrum microporun					--+-			
Cosmarium species						-+--	-+--	-+--
Crucigenia fenestrate			-+--	---+		+---		
Crucigenia tetrapodean				-+--	-++-			
Didymocystis tuberculata		---+	---+					--+-
Kirchneriella obesa	--+-	--+-	+-+-		-++-		++--	-++-
kirchneriella sabsoltaria	---+				---+			
Monoraphidium contortum	++-+	-++-	-+-+	+++-	--+-	-+--	--+-	-+--
Monoraphidium sp.					--+-	--+-	-+--	
Oocystis gigas	+-++	--++		+---			-+--	+-+-
Oocystis lacustris						+---		
Oocystis species					--++		---+	
Pediastrum duplex	-+-+					--+-		
Pediastrum simplex	--+-		++--		+---	++--	-+--	
Scenedesmus arcuatus			--++					
Scenedesmus acuminatus	-+--			-+--	--+-	--+-	--+-	
Scenedesmus armatus			+-+					+---
Scenedesmus perfolatus	-+++	+++-	--+-	+---	--+-	+---	-++-	--+-
Scenedesmus quadricauda				---+	--++			
Scenedesmus species		--++			---++			
Selenestrum bibriainum		--+-		--+-				
Selenestrum species		--+-		-+--	-++-		--+-	
Staurastrum cheatoceras				--+				

		Sampling sampled points							
Taxa		**RPT**	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Staurastrum gracile		---+		-+--				--+-	
Stuarastrum granulate						-+-			
Tetraedron trigonum				---+		+---		--+-	-++-
Cryptophytes									
Cryptomonas mansonii								+---	
Cryptomonas species							+---		+---
Total number of taxa	**March**	14	11	10	18	12	17	10	15
	June	20	20	21	22	24	15	19	17
	September	24	25	23	18	26	21	15	21
	December	26	26	21	19	24	21	22	23

Note: '+' indicates presence of taxon and '–' indicates absence of taxon, in the order of March, June, September and December 2017.

3.4 Zooplankton abundance and species composition

3.4.1 Zooplankton abundance

Zooplankton taxa: Copepoda, Cladocera and Rotifera were examined as in the previous monitoring surveys. Total zooplankton abundance ranged from 982,213 – 1,310,830 ind.m^{-2} in the non-cage sites (RPT, USC, BCS and DSC), and 740,601 – 1,503,130 ind.m^{-2} in the cage areas. Although the highest abundance was recorded at WIC2 (1,503,130 ind.m^{-2}) within the cage area, the rest of sampling points within cage area (WIC1, WIC3 and WIC4) presented < 900,000 ind.m^{-2}, which was less than recorded at any sampling point in non-cage sites. Similar to observations of September 2017, the upper cage site (WIC3 and WIC4) presented lower zooplankton density (mean: 788,954 ± 68,381 ind.m^{-2}) when compared to the lower cage site (WIC1 and WIC2) with mean density of 1,128,232 ± 530,186 ind.m^{-2}. Compared to previously sampled months (March, June and September, 2017), the current sampling period exhibited higher density of zooplankton at almost all sampling points (Figure 17).

Like in the previous sampling periods, copepods were the numerically dominant group contributing more than 90% (92.69 – 97.22 %) of total zooplankton abundance at all sampled points, with no major differences between cage and non-cage areas (Figure 18). The high abundance of copepods was attributed to the abundance of the juveniles stages (copepodites and

Nauplius larvae) which contributed 83.72 – 92.78% of the total zooplankton abundance and this was mainly due to the Nauplius larvae (66.4 – 83.2 %). Cladocera relative abundance (percent contribution to total zooplankton abundance) ranged from 0.32% at USC to 3.98% at WIC3 while that of rotifers ranged from 1.55 % at WIC2 to 3.74% at DSC (Appendix 2).

Copepod densities within the cage area ranged from 713,014 – 1,461,396 ind.m^{-2}, while in the non-cage areas, it ranged from 929,465 – 1,270,814 ind. m^{-2}. The abundance of cladocera was higher in the cage sites (9,196 – 33,347 ind.m^{-2}) than in the non-cage sites (4,244 – 16,370 ind.m^{-2}). In the previous sampling period of September 2017, cladocera abundance was higher in the non-cage sites (range: 11,116 – 114,551 ind.m^{-2}) and lower within cage sites (range: 6,973 – 9,431 ind.m^{-2}). In the current sampling period (December 2017), the abundance of rotifers was highest in the non-cage sites (Range: 35,772 – 44,563 ind.m^{-2}) and lowest in the cage sites (Range: 17,684 – 27,890 ind.m^{-2}). This was also the opposite of what was recorded in September 2017 period, where rotifer abundance was higher in the cage sites (range: 6,737 – 25,465 ind.m^{-2}) than recorded in non-cage sites (range: 2,695 – 18,189 ind.m^{-2}). Copepods have been recorded as the most abundant zooplankton group in Lake Victoria (Mwebaza-Ndawula, 1994).

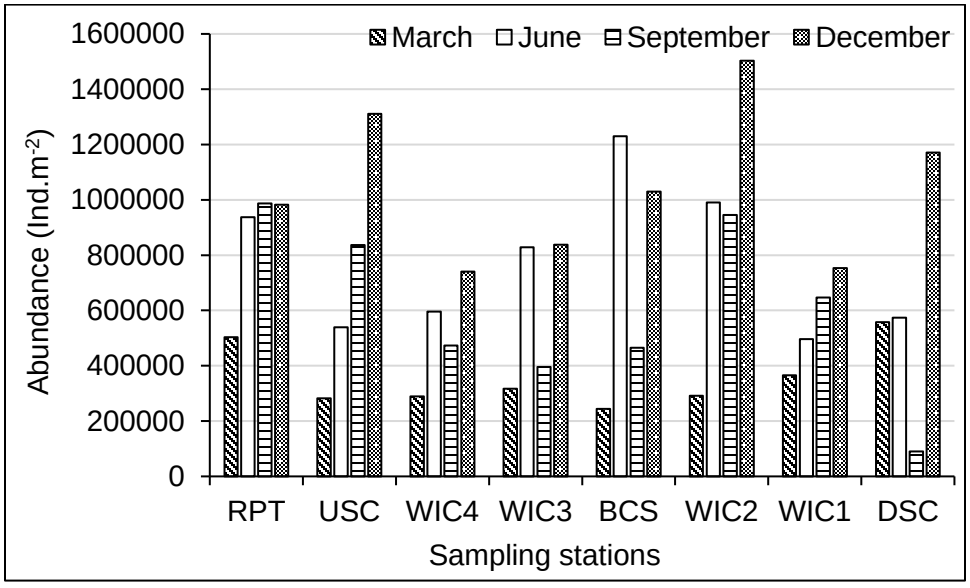

Figure 17. Mean abundance of total zooplankton across the sampling points, March to December 2017.

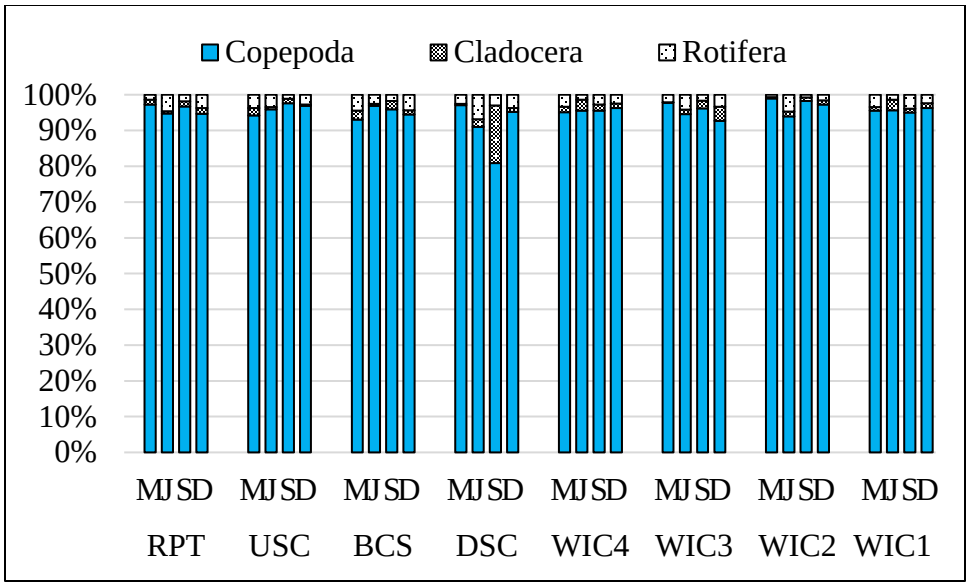

Figure 18. Percentage abundance of copepods, cladocerans and rotifers across sampling points, March to December 2017. The letters M, J, S and D, indicate March, June, September and December, respectively.

3.4.2 Zooplankton species composition and distribution

A total of 26 zooplankton species (7 copepods, 5 cladocerans and 14 rotifers) were recorded in December and this was less than recorded in September (31 species: 7 copepods, 8 cladocerans and 16 rotifers) and June (27 zooplankton species: 7 copepods, 6 cladocerans and 14 rotifers), but higher than recorded in March (20 zooplankton species: 7 copepods, 4 cladocerans and 9 rotifers). The number of species ranged from 15 to 16 in the non-cage sites and 14 to 19 in the cage sites. The highest number of zooplankton species (19 species) was recorded at WIC2 and WIC3, while the lowest number (14 species) was recorded at WIC1 and WIC4 (Table 3). Two copepod species (*Tropocyclops confinnis* and *Tropocyclops tenellus*) and Cyclopoid copepodites were recorded at all sampling points during March, June, September and December 2017 (Table 3).

Table 3. Zooplankton species composition and distribution across study sites at SON fish farm, March to December 2017.

Sampling points	RPT	USC	WIC4	WIC3	BCS	WIC2	WIC1	DSC
COPEPODA	5,6,6,5	6,5,6,4	5(6)6	4,5,5,6	5,6,4,7	4,7,5,7	4,6,5,5	3,5,4,6
Mesocyclops sp.	-++--		-+++	+-++	-+-+	-+++	++--	---++
Thermocyclops incisus	+---	+++-	+-+-	-+--	++-+	-+-+	--+-	
Thermocyclops emini	-+++	+-+-	++++	-+-+	---+	++-+	-+++	-+-+
Thermocyclops neglectus	++++	++++	++++	+-++	++++	-+++	-+++	-+++
Thermodiaptomus galeboides	++++	++++	-+-+	-+++	++++	++++	++-+	++++
Tropocyclops confinnis	++++	++++	++++	++++	++++	++++	++++	++++
Tropocyclops tenellus	++++	++++	++++	++++	++++	++++	++++	++++
Calanoid copepodites	++++	+-++	++++	++++	++++	++++	-++-	-+++
Cyclopoid copepodite	++++	++++	++++	++++	++++	++++	++++	++++
Nauplius larvae	++++	++++	++++	++++	++++	++++	++++	++-+
CLADOCERA	3,2,3,4	2,2,4,3	3,5,4,4	1,4,3,4	4,2,5,3	1,3,6,4	1,4,3,4	2,3,3,3
Bosmina longirostris	++++	++++	++++	-+++	++++	-+++	-+++	--+-
Ceriodaphnia cornuta	--++	+-+-	++++	-+++	+-+-	-+++	-+-+	-+++
Chydorus spp.					--+-			
Daphnia lumholtzi						--+-		
Daphnia lumholtzi(helm)				-+-+		--++	--+-	---+
Diaphanosoma excisum	+-++	--++	++++	++++	++++	--+-	-+-+	++-+
Moina micrura	++-+	-+++	-+++		+-++	++++	++++	+++-
Macrothrix sp.			-+--					
ROTIFERA	2,10,6,6	4,8,3,8	2,3,5,4	2,9,5,9	2,7,3,6	1,9,6,8	5,3,9,5	6,9,2,6
Ascomorpha sp.	-+--							
Asplanchna spp.	--+-			--+-		-++-	--+-	--+-
Brachionus angularis	-+++	++++	-+--	++-+		-+--	-+++	+--
Brachionus bidentatus				---+	---+	---+	---+	---+
Brachionus caudatus				---+				
Brachionus calyciflorus	-+--			-+--	-+--	-++-		-+--
Brachionus falcatus	---+	+---		-+-+		---+	+-++	---+
Brachionus forficula		---+						
Cephlodella sp.			--+-	-+--	---+	---+		
Euclanis sp	++--	-+--		-+--	-+--	-+--	+---	++--
Filinia longiseta		---+						+---
Filinia opoliensis		-+--	--+-			--+-	--++	
Hexathra				--+-		--++		
Keratella cochlearis	-+-+	-+-+	---+	-+-+	--++	-+++	--+-	-+-+
Keratella tropica	-+++	++++	+-++	+--+	++--	-+--	--+-	-+-+

Sampling points	RPT	USC	WIC4	WIC3	BCS	WIC2	WIC1	DSC
Lecane bulla	-++-	+++-	-+++	-+++	-+++	++-+	-++-	++++
Lecane luna		---+						
Polyarthra vulgaris.	-+--	-+--			--+-		+---	-+--
Synchaeta spp.	++++	---+	+-++	-+++	-+++	-+++	+-++	++-+
Trichocerca cylindrica	-+++	-+-+	-+--	-+++	++-+	-+-+	+++-	++--

Note: '+' indicates presence of taxon and '–' indicates absence of taxon, in the order of March, June, September and December, 2017.

3.5 Macro-benthic invertebrate community

3.5.1 Taxa composition and distribution

The macro-benthic community comprised of 5 classes: Bivalvia (mussels/clams), Gastropoda (snails), Insecta (insects), Hirudinea and Oligochaeta (annelids). A total of 18 taxa: 6 species of bivalves, 2 species of gastropods, 2 families of Ephemeroptera (may flies), 6 species of Diptera, and 2 classes of annelids (Hirudinea and Oligochaeta) which were not analysed any further, were recorded during the study. Taxa richness ranged from 5 – 11 taxa in the cage area, and 7 – 9 taxa in the non-cage areas (Table 4). Among molluscs, the bivalve species, *Corbicula africana* which appeared in all samples collected in all sampling points during March, June and September, was not recorded at WIC1, WIC2 and WIC3 in the cage area. However, it was recorded in all non-cage sampling sites (Table 4). Moreover, *Bellamya unicolor* (gastropod) was recorded in all samples collected during the current sampling period of December. Among Ephemeroptera, Baetidae was only recorded at WIC1 while *Povilla adusta* was recorded in most sampling points except at USC, DSC and WIC4 (Table 4). Other mayflies such as *Caenis* sp., previously recorded in most sampling points both within cage and non-cage areas during March, June and September, was not recorded during December. *Chironomus* spp. and *Chaoborus* sp. were the most widely distributed insects while oligochaetes were the most common annelids (Table 4).

Table 4. Occurrence of benthic macro invertebrate taxa across the study sites at SON fish farm, December 2017.

	Sampling points							
	RPT	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Bivalvia								
Byssanodonta parasitica		++++		+--+	+-+	-+-+	++-+	
Corbicula africana	++++	++++	++++	+++-	++++	+++-	+++-	++++
Pisidium victoriae		+---						
Caelatura hauttecoeuri		-++-			--++		-+-+	-++-
Caelatura monceti		--+-		---+	--++	--+-	---+	--+-
Caelatura alluadi						--+-		
Aspatheria sp.		---+				--+-	--+-	
Sphaerium sp.		-++-				-+--		
Mutera sp.				---+				
Gastropoda								
Bellamya unicolor	-+-+	++++	++++	++++	++++	++++	++++	++++
Gabbia humerosa	-+--							+--
Biomphalaria sp.	-+--							
Melanoides tuberculata	++--	+-+-	++-+	++--	++++	++--	++++	+++-
Ephemeroptera								
Caenis sp.	+++-	+++-	+---	--+-	+---	++--	--+-	++--
Ephemerella sp.		+--						
Povilla adusta	+++	-+-		--+	+++	++-	-+-	
Baetis sp.	+---		+---				+--+	
Leptophlebidae	+---							
Euthraulus sp.	-+--	-+--				-+--		
Plecoptera								
Perlidae								+---
Odonata								
Phyllomacromia sp.	-+--							
Libellulidae			--+-	+---				
Diptera								
Ablabesmyia sp.	+-+-	+---	+-+-		+---	+-+-		--+-
Chironomus spp.	+-++	++-+	+++-	++++	++-+	++++	---+	++++
Clinotanypus sp.		+-++	+++-	++++	--+-	-+--		++++
Cryptochironomus sp.		--+-		+---	+---	-+--		
Procladius sp.		---+					+---	-+--
Tanypus sp.			--+-	-+-+				++++
Tarnytarsus sp.							+---	
Chironominea		--+-			-+--	+---		
Ceratopogonidae	--+-	-+--	--+-	---+				---+
Chaoborus sp.	+-++	-++-	++++	++++	--++	--++	+-+-	++++
Trichoptera								
Leptoceridae		--+-						+---
Polycentropodidae	+++-	--+-				-+--	--+-	
Dipsuedopsis sp.		--+-				--+-	-+--	
Decapoda								
Caridina nilotica	--+--					--+-		

	Sampling points							
	RPT	**USC**	**WIC4**	**WIC3**	**BCS**	**WIC2**	**WIC1**	**DSC**
Hemiptera								
Naucorids			--+					
Annelida								
Hirudinea	-+-+							
Oligochaetes	-+++	++-+	++++	++++	+-++	++++	+-+-	++++

Note: '+' indicates presence of taxon and '–' indicates absence of taxon, in the order of March, June, September and December, 2017.

3.5.2 Macro-benthic invertebrate abundance

Like recorded in the previous sampling months (June and September 2017), the reference point (RPT) exhibited the highest abundance (3,992 Ind. m^{-2}) of benthic macroinvertebrates (Figure 19). The lowest abundance (420 ind.m^{-2}) of benthos was recorded at USC, a site upstream of cages and this could be due to the low oxygen concentration recorded at this sampling point in bottom waters (Table 1). Changes produced by oxygen depletion have been found to affect benthic macroinvertebrates (Diaz and Rosenberg, 1995). Abundance of benthic invertebrates within the cage area ranged from 1,134 – 2,416 ind.m^{-2}) and this was higher than previously recorded in September (294 – 1,415 ind.m^{-2}).

Caenis sp. which was found to constitute 84% of the total abundance of benthos at RPT sampling point during September period, was not recorded at any sampled point in December period. However, *Povilla adusta* was consistently recorded at RPT and other sampling points (Table 5), although its contribution to the total abundance at RPT was low (4%) when compared to 50% during September period.

Oligochaete annelids which are reported to be very tolerant to pollution (Miserendino & Pizzolon, 2000) contributed 0 - 28 % of the abundance of benthos at cage sites and 3 - 20% at the non-cage sites (Appendix 3). Diptera made the greatest contribution at almost all sites (Appendix 3), with the percent abundance being higher in non-cage sites (40 – 86%) than what was recorded in the cage sites (37 – 82%). *Chironomus* spp. and *Chaoborus* sp. were the main contributors to the observed Diptera percentage abundance at all sites (Appendix 3).

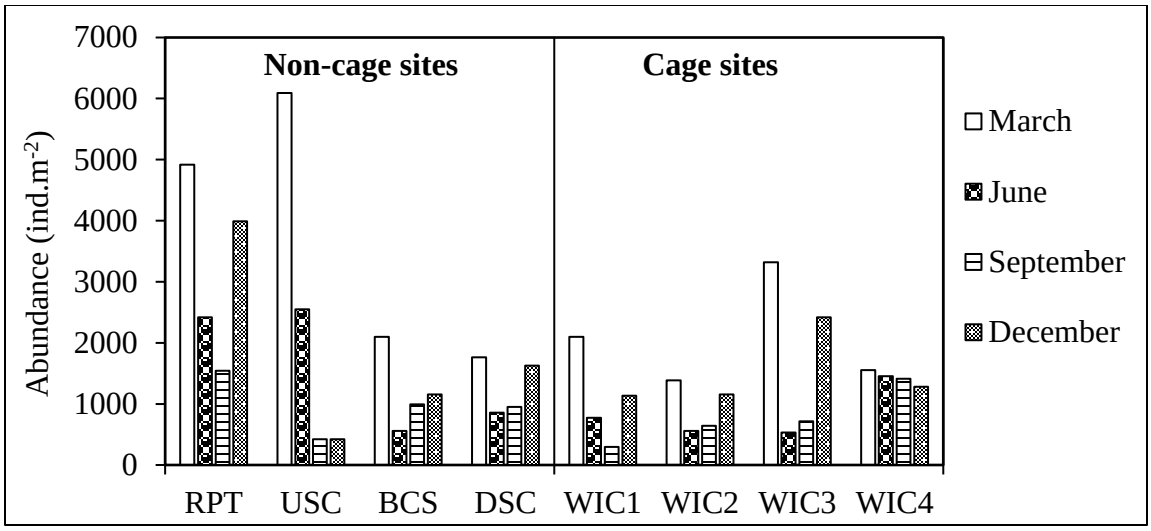

Figure 19. Temporal and spatial variation in total abundance of macro invertebrates across study sites at SON fish farm, December 2017.

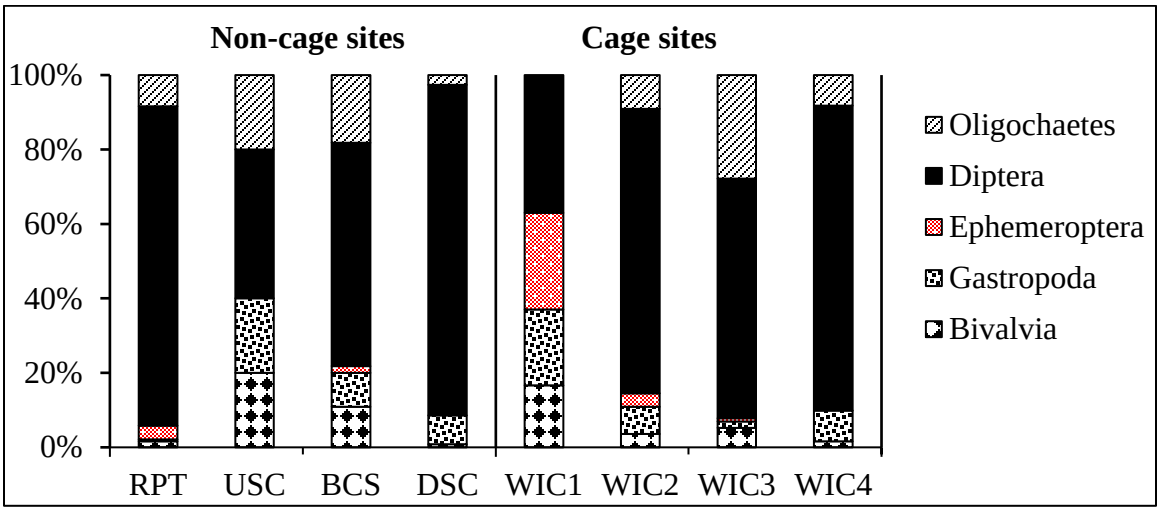

Figure 20. Relative abundance (%) of major benthic macroinvertebrate taxa recorded at SON, December 2017.

3.6 Fish species diversity, abundance and ecology

3.6.1 Fish Catch composition and abundance

A total of six fish species, including haplochromine cichlids as a single species, were recorded during December 2017 period (Table 5) compared to four fish species, recorded in the previous September 2017 period, and four species recorded in June 2017. Numerically, *Synodontis afrofischeri* was the most abundant (31.0%) followed by haplochromine cichlids (28.2%), *Synodontis victoriae* (25.4%), *Lates niloticus,* (12.7%), *Tilapia zillii* (1.4%) and *Mormyrus kannume* (1.4%). By weight, *L. niloticus* dominated the catch (54.2%) followed by *S. victoriae* (25.8%), *S. afrofischeri* (12.9%), haplochromine cichlids (5.7%), *M. kannume* (1.2%) and *T.zillii* (0.2%). Five fish species were recorded from upstream the cages site, four species from within the cage site and two species from downstream the cages. Fish abundance was highest upstream the cage site (57.4%), followed by within the cage site (33.8%)%) and the downstream site (8.5%). The highest biomass (Table 6) was recorded from upstream the cages site (70.02%), followed by within the cages site (18.3%) and the downstream site (11.7%).

Table 5. Catch rates (numbers) of fish species from SON Fish cages

Family	Species	Site	Sampling months							
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec. 2017
Mormyridae	*Mormyrus kannume*	USC	0.1	0.1			9		0.1	
		WIC				0.1	0.3			0.1
		DSC								
		All	0.01	0.03		0.03	0.1		0.02	0.02
Clariidae	*Clarias gariepinus*	USC								
		WIC								
		DSC		0.1						
		All		0.02						
Mochokidae	*Synodontis victoriae*	USC								1.6
		WIC								0.6
		DSC								
		All								0.8
	Synodontis afrofischeri	USC	0.3						0.3	0.6
		WIC			0.1	1.3				2.1
		DSC								
		All	0.1		0.03	0.4			0.1	0.9
Centropomidae	*Lates niloticus*	USC	0.5	0.3			0.3	0.1	0.8	0.4
		WIC		0.2	0.2	0.2	0.5	0.2	0.6	0.1
		DSC	0.2	0.1		0.1			0.2	0.2
		All	0.3		0,1	0.1	0.3	0.1	0.5	0.2
Cichlidae	*Tilapia zillii*	USC								0.1
		WIC								

Family	Species	Site	Sampling months							
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec. 2017
		DSC				0.1				
		All				0.04				0.04
	Oreochromis niloticus	USC								
		WIC								
		DSC			0.1					
		All			0.03					
	Haplochromines	USC	0.5				0.3			4.3
		WIC		1.5	0.5	0.3		1.3	4.0	
		DSC	0.3			0.3		1.3	6.3	0.8
		All	0.4	0.5	0.3	0.2	0.1	0.8	3.4	1.7
Overall Rates		USC	0.8	0.4			0.4	0.1	1.1	3.1
		WIC		0.2	0.4	0.7	0.8	0.5	1.8	1.8
		DSC	0.3	0.2	0.1	0.2		0.4	2.1	0.4
		All	0.6		0.2	0.3	0.4	0.3	1.7	1.8
No of species recovered		USC	4	2	0	0	2	1	3	5
		WIC	0	2	3	4	2	2	2	4
		DSC	2	2	1	3	0	1	2	2
		All	4	4	4	5	3	2	4	6

3.6.2 Catch rates/biomass estimates

As a measure of standing biomass, catch rates i.e. catch per net per night was used to indicate relative abundance of fish species. To analyze gillnet performance; the nets and thus fish species were grouped into three categories. Category (A) consisted of fishes that grow to a small adult size and are caught by nets of up to 2.5" stretched mesh. Category (B) consisted of fish that could be retained by nets of up to 4.5" while category (C) was of large fish species capable of being caught in all the nets set. In the survey of December 2017, fish catch rates, by weight, were highest upstream the cages (312.1g/net/night) followed by within the cages (81.5g/net/night) and the downstream site (52.2g/net/night). By numbers, the catch rates were highest upstream the cages (3.1 fish/net/night), followed by the within site (1.8 fish/net/weight) and lowest upstream (0.4 fish/net/night) as indicated in Table 6. Overall mean catch rates during the period of December 2017 were 1.8 fish/net/night and 148.6g/net/night as compared to 1.7 fish/net/night and 175.4g/net/night recorded in the previous survey of September 2017. Thus, the fish catch rates by numbers were higher in December 2017 but lower by weight, compared to the previous survey of September 2017. The overall catch rate for haplochromines in December 2017 were 1.7 fish/net/night and 27.5g/net/night compared to 3.4 fish/net/night and 62.3g/net/night recorded in the previous survey of September 2017.

Table 6. Catch rates by weight (g) of fish caught in SON FISH cage site.

Family	Species	Site	Sampling months							
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec. 2017
Mormyridae	*Mormyrus kannume*	USC	61.7	89.5					5.4	
		WIC				28.9	17.2			5.1
		DSC								
		All	31	31.4		9.6	5.7		1.8	1.7
Clariidae	*Clarias gariepinus*	USC								
		WIC								
		DSC		272.7						
		All		81.1						
Mochokidae	*Synodontis afrofischeri*	USC	12						8.1	25.8
		WIC			5	52				67.8
		DSC								
		All	6		2.5	17.3			2.7	31.2
	Synodontis victoriae	USC								38.6
		WIC								48.2
		DSC								
		All								62.3
Centropomidae	*Lates niloticus*	USC	191	7.4			4.5	166.6	187.5	188.0
		WIC		3.2	76.6	82.7	320.1	34.2	262.8	4.9
		DSC	5.4	0.9		1.6			8.2	48.6
		All	96		38.3	28.1	108.2	66.9	152.8	80.5
Cichlidae	*Tilapia zillii*	USC								1.6
		WIC								
		DSC								
		All				2				0.5
	Oreochromis niloticus	USC								
		WIC								
		DSC			0.1					
		All			0.03					
	Haplochromines	USC	6.6				2.3			71.3
		WIC		16	3.7	2.3		17.3	87.3	
		DSC	5.4			4		15.6	21.2	11.5
		All	6.5	5.3	1.9	2.1	0.8	11	62.3	27.5
Overall Rates		USC	262	96.8			5.2	166.6	197.8	312.1
		WIC		2.7	80.8	128.3	337.3	39.5	289.6	81.5
		DSC	6.3	278.6	5.8	6.5		4.8	38.8	52.2
		All	135		43.3	39.8	114.2	70.3	175.4	148.6
No of species recovered		USC	4	2	0	0	2	1	3	5
		WIC	0	2	3	4	2	2	2	4
		DSC	2	2	1	3	0	1	2	2
		All	4	4	4	5	3	2	4	6

3.6.3 The haplochromines

Four species of haplochromine cichlids were recorded during the survey of December 2017 compared to six species recorded in the previous survey of September 2017 (Table 7). Numerically, *Punamillia* were the most abundant (65.0%) followed by *Psammochromis riponianus* (20.0%), *Astatotilapia* "pink anal" (10.0%) and *Ptyochromis sauvagei* (5.0%). They were recovered from upstream of cage site (2 species), and downstream the cages (2 species).

Table 7. Catch rates (by numbers) of haplochromine species from SON FISH cage site.

Genus	Species	Site	Sampling months							
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec, 2017
Astatoreochromis	*A. Alluaudi*	USC								
		WIC								
		DSC							0.5	
		All							0.2	
Astatotilapia	*A. "pink anal"*	USC								0.5
		WIC							0.3	
		DSC								
		All							0.1	0.2
	Astatotilapia sp	USC	0.3	1.3			0.3			
		WIC			0.3			1	0.8	
		DSC						0.5	1.0	
		All	0.1	0.4	0.1		0.1	0.5	0.6	
	M. mbipi	USC								
		WIC		0.3					3	
		DSC	0.3						0.8	
		All	0.1	0.1					1.3	
Psammochromis	*P. riponianus*	USC	0.3							1.0
		WIC			0.3			0.3		
		DSC				0.3		0.3	3.5	
		All	0.1		0.1	0.1		0.2	1.2	0.3
Ptyochromis	*P. sauvagei*	USC								
		WIC								
		DSC						0.5	0.5	0.3
		All						0.2	0.2	0.1
Pundamilia	*Pundamilia sp*	USC								3.3
		WIC				0.3				
		DSC								
		All				0.1				1.1
Overall Contribution		USC	18				20			41.5
		WIC			40	11.1		71.4	66.7	
		DSC	33			33.3		100	92.6	50
		All	21.4	40	33.3	16.7	6.1	76.9	63.1	28.2
No of species recovered		USC	2	0	0	0	1	0	0	2

Genus	Species	Site	Sampling months							
			March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	June 2017	Sept. 2017	Dec, 2017
		WIC	0	2	2	1	0	2	3	0
		DSC	1	0	0	1	0	3	5	2
		All	3	2	2	2	1	3	6	4

3.6.4. Biology of common fish species

The stomach content of fish caught (*Synodontis afrofischeri*, haplochromines, *Synodontis victoriae*, *Lates niloticus, Tilapia zillii* and *Mormyrus kannume*) were examined so as to determine the type of food being consumed by the fish. Table 8 shows the food items recorded in the stomach of fish. Like recorded in June and September, insects were the main food items consumed by haplochromines, *Mormyrus kanuume, Synodontis afrofischeri*, and *Synodontis victoriae*. Chironomids were the main insects consumed by *Synodontis* while *Mormyrus Kanuume* fed on *Povilla*. Nine *Lates niloticus* were examined for the food items, all of which were found to have fed on *Rastrineobola argentea* (Mukene). For the only one caught *Tilapia zillii*, the stomach was found to be empty. There were no parasites on all the fish caught and examined (Table 8).

Table 8. Basic biological parameters of fish species caught from SON Fish cage site, March to December 2017.

Species/Parameters	Sampled months							
	March 2016	June 2016	Sept. 2016	Dec. 2016	March 2017	July 2017	Sept. 2017	Dec. 2017
Clarias gariepinus								
Size range - TL (cm)		77						
% mature		M						
Main food type		Odt						
Parasites found								
Number examined		1						
Lates niloticus								
Size range (cm)	9 - 47	8 - 14	17.1, 46.3	10 - 43	8.5 - 51.7	17.6 - 56.0	10.6 - 49.6	17.5 - 43.0
% mature	33.3			33.3	36.0	33.3	5.0	20
Main food type	Haps	Fish	Car	Haps	Haps	Haps	Haps	Ras
Parasites found								
Number examined	6	7	2	3	10	3	21	9
Haplochromines								
Size range (cm)	7.9 -11.5	6.7 -11.5	7.5, 8.8	8.1-10.5	8.5	8.6 - 11.2	8.1 - 13.3	8.0 - 11.4

% mature	100	50	0	100		96	77.4	87.5
Main food type	Ins	Ins	Ins	E	E	Ins	Ins	Ins
Parasites found (% infection)								
No examined	3	5	2	2	1	10	31	14
Tilapia zillii								
Size range (cm)				13.0				9.2
% mature				M				
Main food type				PM				E
Parasites found								
No examined				1				1
Mormyrus kannume								
Size range (cm)	45	49		34	17.5 - 19.9		19.7	19.2
% mature	M	M		M			M	
Main food type	Pov	Pov		Pov	Ins		Pov	Pov
Parasites found								
No examined	1	1		1	4		1	1
Oreochromis niloticus								
Size range (cm)			16.5					
% mature			0					
Main food type			Det					
Parasites found								
No examined			1					
Synodontis afrofischeri								
Size range (cm)	13 – 14		13.0	10 – 16			11.5 - 11.7	9.1- 14.6
% Mature	M		M	M			M	M
Main food type	Ins		Moll	Ras			Ins	Chir
Parasites found								
No examined	1		1	5			2	19
Synodontis victoriae								
Size range (cm)								15.5 - 20.0
% mature								M
Main food type								Chir
Parasites found								
No examined								14

M-mature, **Odt**-Odonata, **Haps**-Haplochromine, **Car**-Caridina, **Ins**-Insects, **E**- Empty, **PM**-Plant material, **Pov**- Povilla, **Det**-Detritus, **Moll**- Mollusc, **Ras**- Rastrineobola, **Chir**-Chironomid

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

In this report, the levels of water physico-chemicals, concentrations of nutrients, and composition and abundance of biological communities (algae, invertebrates and fish) around SON cage fish farm were evaluated. These parameters varied within narrow margin and were comparable across cage and non-cage sites. The physico-chemical and nutrient variables were within the recommended ranges for aquatic life. Algae at all sites was dominated (>70%) by the blue-green type while the lowest and highest zooplankton abundances were recorded within the cage area. The highest and lowest taxa richness values of benthic macro invertebrates were also recorded in the cage area while the highest and lowest abundance were recorded in the non-cage areas. Gillnet fish catch rates and biomass were highest upstream of cages and lowest at the downstream site. All the fish examined had utilized the naturally occurring food organisms. The overall observation on concentrations of nutrients, levels of physico-chemical variables, and biotic communities indicated minimal impact of cages on water quality.

4.2 Recommendations

It is recommended that the farm continues adhering to the best aquaculture practices that are environmentally sustainable, especially continuing with fallowing or rotation of cages to allow resident organisms maintain their natural population densities, distribution and community structure in the area; reducing excess uneaten feed and other suspended materials which would impact on nutrient status of water and underlying sediment; and wise use of any chemicals in the area.

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APPENDICES

Appendix 1: Relative abundance (as percentage of total biovolume) of different species of phytoplankton, December 2017.

	SAMPLING POINTS							
TAXA	BSC	DSC	RPT	USC	WIC1	WIC2	WIC3	WIC4
BLUE-GREEN ALGAE								
Anabaena acircularis								3.03
Anabaena circinalis		14.46	38.04	17.58	8.15	18.92	35.45	
Anabaena circumcreta	24.04							
Anabaenopsis tanganyikae								0.48
Aphanocapsa delicatissima	0.71	1.61	3.08	1.22	1.61	0.67	0.44	0.54
Aphanocapsa elachista	0.17	0.23	0.40	0.92	0.54	0.27		0.13
Aphanocapsa holistica	0.47							
Aphanocapsa incerta	0.47	0.25	0.37		0.11	0.22	2.99	0.16
Aphanocapsa nubilium		0.07	0.20	0.43	0.08	0.16	1.16	0.22
Aphanocapsa species		1.15	0.62	0.61	0.51	0.90		0.35
Chroococcus dispersus	0.69	0.54	1.44	1.90	2.09	0.88	0.20	1.42
Chroococcus limnetica	5.09	1.79	3.15	1.79	3.14	1.32	4.77	2.10
Chroococcus species					4.18			
Chroococcus turgidus		0.36		0.95	0.47	0.18	0.09	
Coelastrum microporum			1.87					
Coelomoron pusila	0.49	0.60	0.32	0.79	1.67	0.23	22.51	0.56
Coelomoron species					0.56			
Coelomoron tropicale	0.37	1.07	0.12	0.63			0.75	0.35
Coelosphaerium kuetzingnium		15.83	3.54	4.91			0.92	
Coelosphaerium tropicale						1.55		
Merismopedia glauca				1.56				
Merismopedia granulate	0.76							
Merismopedia tenussima	3.65	0.15	0.79	0.68		0.58	1.71	0.17
Microcystis aeruginosa		41.30	17.55		18.33		2.75	
Microcystis elegans	2.17							
Microcystis flos-aquae	27.06			9.28	20.37	51.27		
Planktolyngbya circumcreta	2.59	4.51	4.37	9.33	8.20	6.88	0.46	32.31
Planktolyngbya contorta				0.67				
Planktolyngbya limnetica	8.82	7.02	1.68	10.00	5.86	3.44	0.58	34.08
Planktolyngbya tallingii		0.50		13.33		4.91		
Psuedonabaena limnetica	0.52	0.50						
DIATOMS								

	SAMPLING POINTS							
TAXA	BSC	DSC	RPT	USC	WIC1	WIC2	WIC3	WIC4
Centric diatom					0.82			
Cyclotella meneghiniana						0.69		
Cyclotella species				0.93	0.82			
Navicula granulate							0.05	
Navicula radiosa			3.11					
Nitzschia acicularis	2.87						0.09	
Nitzschia acircularis		5.56	3.11		9.73	5.44		9.76
Nitzschia fonticola						0.91		
Stephanodiscus Astraea	0.73							
Synedra cunningtonii				2.89				
GREEN ALGAE								
Actinastrum hantzschii			0.01			0.01	9.56	
Ankistrodesmus falactus	1.18	1.71	1.53	1.52	1.24	0.56		3.35
Ankistrodesmus stegera				0.76				
Chlorella species				0.60				
Chlorella vulgaris		0.30						
Chodatela species		0.04						
Closterium habitat		0.45			0.53			
Closterium species	0.47							
Crucigenia fenestrate							5.18	
Didymocystis tuberculata				2.83				1.25
kirchneriella sabsoltaria			0.01					
kirchneriella subsolitaria	0.06							
Monoraphidium contortum			0.30					3.11
Oocystis gigas			9.50	12.55				
Oocystis species	12.20				11.02			
Pediastrum duplex			0.79					
Scenedesmus arcuatus								4.99
Scenedesmus perfolatus			1.43					
Scenedesmus quadricauda	2.20						10.35	
Scenedesmus species	2.20			1.33				
Stuarastrum gracile			2.66					
Tetraedron trigonum								1.66
TOTAL	100	100	100	100	100	100	100	100

Appendix 2: Percent composition of zooplankton species at SON cage area, December 2017

Taxa	Non-cage area				Cage area			
	BCS	DSC	RPT	USC	WIC1	WIC2	WIC3	WIC4
COPEPODA								
Mesocyclops sp.	0.07	0.12				0.19	0.36	0.10
Thermocyclops emini	1.72	0.18	1.24		1.32	0.33	0.58	0.49
Thermocyclops incisus	0.07					0.14		
Thermocyclops neglectus	2.13	1.09	1.05	1.06	2.54	0.75	1.01	3.44
Thermodiaptomus galeboides	1.44	0.54	1.79	0.51	1.32	0.61	0.94	0.67
Tropocyclops confinnis	2.27	0.24	1.54	1.48	1.03	0.99	0.43	1.05
Tropocyclops tenellus	3.09	2.23	4.50	1.11	4.23	3.34	2.61	1.82
Calanoid copepodites	1.17	1.51	5.12	0.93		7.95	5.29	1.53
Cyclopoid copepodite	9.96	10.21	12.41	8.65	19.44	9.46	13.54	12.32
Nauplius larvae	72.60	79.05	66.98	83.21	66.39	73.46	67.92	74.88
Sub total	94.51	95.17	94.63	96.95	96.24	97.22	92.69	96.28
CLADOCERA								
Bosmina longirostris	0.28		0.19	0.14	0.28	0.38	0.94	0.48
Ceriodaphnia cornuta		0.73	0.31		0.19	0.42	0.80	0.19
Daphnia lumholtzi(helm)		0.24				0.33	0.15	
Diaphanosoma excisum	0.21	0.12	0.62	0.09	0.19		2.10	0.19
Moina micrura	0.69		0.56	0.09	0.75	0.09		0.38
Sub total	**1.17**	**1.09**	**1.67**	**0.32**	**1.41**	**1.22**	**3.98**	**1.24**
ROTIFERA								
Brachionus angularis			0.49	0.51	0.66		0.51	
Brachionus bidentatus	0.07	0.06			0.19	0.09	0.07	
Brachionus caudatus							0.07	
Brachionus falcatus		1.03	0.80		0.09	0.05	0.29	
Brachionus forficula				0.09				
Cephlodella sp.	0.14					0.05		
Filinia longiseta				1.16				
Filinia opoliensis					0.19	0.05		
Keratella cochlearis	0.89	1.28	0.74	0.46		0.14	0.72	0.86
Keratella tropica		0.54	0.93	0.19			0.43	0.48
Lecane bulla	0.48	0.24				0.09	0.58	0.38
Lecane luna				0.05				
Synchaeta spp.	2.68	0.60	0.37	0.23	1.22	0.99	0.29	0.76
Trichocerca cylindrica	0.07		0.37	0.05		0.09	0.36	
Sub total	**4.33**	**3.74**	**3.70**	**2.729**	**2.35**	**1.55**	**3.33**	**2.48**
Grand total	100	100	100	100	100	100	100	100

Appendix 3: Percent composition of benthic macroinvertebrates, December 2017

Taxa	Non-cage sites				Cage sites			
	REF	USC	BTC	DSC	WIC1	WIC2	WIC3	WIC4
Bivalvia								
Byssanodonta parasitica.		5			13	4	3	
Caelatura monceti			4		2		1	
Caelatura hauttecoeuri			2		2			
Corbicula africana	2	5	5	1				2
Mutera sp.							1	
Aspatharia sp.		10						
Sub-total	**2**	**20**	**11**	**1**	**17**	**4**	**5**	**2**
Gastropoda								
Bellamya unicolor	1	20	7	8	17	7	2	7
Melanoides tubertulata			2		4			2
Sub-total	**1**	**20**	**9**	**8**	**20**	**7**	**2**	**8**
Ephemeroptera								
Povilla adusta	4		2		24	4	1	
Baetidae					2			
Sub-total	**4**		**2**		**26**	**4**	**1**	
Diptera								
Chironomus spp.	84	25	4	3	37	31	10	
Clinotanypus sp.		5		1			1	
Procladius sp.		10						
Tanypus sp.				1			4	
Chaoborus sp.	2		56	83		45	48	82
Palpomyia sp.				1			1	
Sub-total	**86**	**40**	**60**	**89**	**37**	**76**	**64**	**82**
Annelida								
Hirudinea	5							
Oligochaetes	4	20	18	3		9	28	8
Sub-total	**8**	**20**	**18**	**3**	**0**	**9**	**28**	**8**
Over all total	100	100	100	100	100	100	100	100