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 2016

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EXECUTIVE SUMMARY

National Fisheries Resources Research Institute (NaFIRRI) undertakes quarterly monitoring of the water environment at Source of the Nile (SON) fish farm. This activity which is through a collaborative arrangement between the proprietors of SON fish farm and NaFIRRI started in 2011 and has continued up to date, with the aim of assessing possible environment changes as a result of SON fish farm operations in the area. The following key parameters were established to be monitored: water temperature, dissolved oxygen, pH, conductivity, water transparency, total suspended solids, nutrient status, algae, zooplankton, benthic macro invertebrates and fish communities.

Water and biological samples as well as field measurements were taken in December 2016 at three sites: Within the fish cages (WIC), Upstream of the fish cages (USC) and Downstream of the fish cages (DSC), as done in the previous surveys. Total depth ranged from 1.3 to 17.0 m at USC, 3.1 to 8.83 m at WIC and 3.12 to 6.0 m at DSC. Water transparency ranged from 0.85 to 1.2 m at USC, 1.12 to 1.42 m at WIC and 1.0 to 1.2 m at DSC.

The levels of other physico-chemical parameters were: pH (7.55 ± 0.06 at USC, 7.67 ± 0.007 at WIC and 7.89 ± 0.18 at DSC), Dissolved oxygen (8.91 ± 1.12 mg/L at USC, 7.57 ± 0.021 mg/L at WIC and 8.49 ± 0.44 mg/L at DSC), conductivity (106.54 ± 1.72 μScm^{-1} at USC, 103.82 ± 0.41 μScm^{-1} at WIC and 104.50 ± 0.78 μScm^{-1} at DSC), temperature (27.36 ± 0.15 ^{o}C at USC, 27.09 ± 0.53 ^{o}C at WIC and 27.75± 0.32 ^{o}C at DSC). The levels of Biochemical Oxygen Demand (BOD) increased downstream (10.67±1.93 mg/L at USC, 14.40±3.63 mg/L at WIC and 15.51 ± 2.24 mg/L at DSC).

The mean concentrations of nitrite nitrogen (0.006± 0.001 mg/L at USC, 0.011± 0.001 mg/L at WIC and 0.012± 0.0008mg/L at DSC), nitrate nitrogen (0.051± 0.019 mg/L at USC, 0.096± 0.005 mg/L at WIC and 0.098 ± 0.0039mg/L at DSC), and soluble reactive phosphorus (0.015 ± 0.001mg/L at USC, 0.0157 ± 0.0003 mg/L at WIC and 0.0157 ± 0.0007mg/L at DSC) increased downstream. Ammonium nitrogen concentration was highest at USC (0.124±0.023mg/L) followed by DSC (0.122± 0.0023 mg/L), with the lowest value recorded at WIC (0.089± 0.0097mg/L). Total nitrogen concentration was highest at USC (0.047± 0.017 mg/L) and lowest at DSC (0.033± 0.003 mg/L). Total phosphorus concentration was also highest at USC (0.272 ± 0.021 mg/L) followed by DSC (0.230± 0.051 mg/L) and WIC (0.151± 0.007mg/L). The

concentration of Total suspended solids was highest at DSC (4.56± 0.40mg/L) and lowest at USC (3.32±0.74 mg/L).

Phytoplankton abundance was highest at USC site (57.4%), which was 2.9 (20%) and 2.5 folds (22.5%) that recorded at WIC and DSC respectively. Blue-green algae dominated other algae at WIC and DSC, while green algae dominated at USC. In addition, there was a general reduction in blue-green algae abundance from over 80% across sites in September 2016 to <60% in December 2016.

Total zooplankton abundance was highest at USC (1,713,057 ind.m^{-2}) and lowest at DSC (590,316 ind.m^{-2}). Copepod abundance increased from: 676,893 to 1,625,121 ind.m^{-2} at USC, 585,061 to 942,804 ind.m^{-2} at WIC and 164,539 to 565,705 ind.m^{-2} at DSC when September and December 2016 periods were compared. Cladocera increased in abundance from: 10,324 to 37,007 ind.m^{-2} at USC; 2,425 to 10,801 ind.m^{-2} at WIC; and 808 to 3,346 ind.m^{-2} at DSC. While copepods and cladocerans increased in abundance at all sites when September and December 2016 surveys were compared, rotifers showed a decrease in abundance i.e. from: 62,887 to 50,930 ind.m^{-2} at USC, 52,007 to 27,643 ind.m^{-2} at WIC, and 27,862 to 21,266 ind.m^{-2} at DSC.

The macro-invertebrate community comprised of 8 broad taxonomic groups: Bivalvia, Gastropoda, Ephemeroptera, Trichoptera, Odonata, Diptera, Decapoda and Annelida. The highest number of taxa was recorded at WIC and DSC, each with 13 taxa. Insects were more abundant at USC (93.4%) than WIC (69.4%) and DSC (45.8%) sites, but the latter (WIC and DSC) were more species rich (4 and 7 insect species respectively) than USC (2 insect species). Pollution sensitive taxa, Ephemeroptera and Tricoptera were recorded only at WIC (total abundance of 70 ind.m^{-2}) while pollution tolerant oligochaete annelids were recorded at all sites but with highest abundance at USC (112 ind.m^{-2}) followed by WIC and DSC, each with 28 ind.m^{-2}.

Five fish species, including haplochromines (Nkejje) as a single species group, were recorded at WIC during the survey of December 2016 compared to four species previously recorded in September 2016. No fish catch was recorded from the fleet set at USC. Overall mean catch rates during the period of December 2016 were 0.3 fish/net/night and 39.8g/net/night as compared to 0.2 fish/net/night and 43.3g/net/night recorded in the previous survey of September 2016. Catch rates in December 2016 were highest at WIC site both by weight (128.3g/net/night) and numbers

(0.7 fish/net/night). The diet of fishes encountered during the survey of December 2016 comprised mostly of fish and insects, which are known natural foods of the fish species caught.

Overall, the physical water conditions: water transparency, Dissolved Oxygen, Temperature, pH, and conductivity were within the optimal ranges considered suitable for cage fish farming. The BOD levels during December 2016 across all sites were beyond the range (3.0 – 6.0 mg/L) considered optimal for normal activities of fishes. Concomitantly, higher concentrations of nitrite nitrogen, nitrate nitrogen and SRP within cages and downstream of cages were observed. The presence of higher concentrations of TP, TN and ammonium nitrogen upstream of cages (reference site) indicated minimal inputs of nutrients from SON fish cage operations. Fish abundance was highest within the cages and lowest downstream of the cages suggesting aggregation and therefore potential of cages to serve as small protection areas for wild fish. All the fish species examined had fed on naturally occurring food organisms, dominated by fish and aquatic insect larvae. Thus, cage fish farming has not yet negatively impacted the presence of natural food organisms utilized by wild fish. Parasites among wild fish caught near and away from cages were not observed during the survey of December 2016 as has been in previous surveys. Therefore, the physico-chemical parameters and biotic communities assessed indicated no major impact of SON fish farm on water quality in December 2016.

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. This activity which is through a collaborative arrangement between SON fish Ltd and NaFIRRI started in 2011 and has continued up to date, with the aim of assessing possible environmental changes as a result of SON fish farm operations in the area. This is important because the cultured fish requires water of high quality for proper growth, and therefore this collaboration offers avenues for technical back-stopping and sustainability of the enterprise. Besides that, it also enables assessment of compliance to the set regulations.

Possible impacts from fish cage farm operations include nutrient input into the water as faeces, uneaten feed and fish excretory wastes are shed into the water column (Fernandes et al., 2001). In addition, algal blooms may occur due to increased nutrient input, that stimulates primary production. 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.

Cage farming also affect the presence, abundance, diet and residence time of organisms in given vicinity (Carss, 1990; Dempster *et al.,* 2002). For instance, floating structures including cages may act as Fish Attracting Devices. In the process, other ecological interactions between cultured and wild fish may be possible. Also, farmed fish may escape and interact with wild fish resulting into spread of diseases and parasites. While outbreak of diseases among cultured fishes may be controlled through treatment, 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 three study areas: upstream of cages, within cages and downstream of cages, for the fourth quarter (October to December) undertaken in December 2016. 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

Just like in the previous surveys, 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 in a west-to-east formation, anchored by weights and buoyed by large plastic floaters). Over the years of operation of the farm, the number of fish cages has steadily increased and the area under cages has 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.

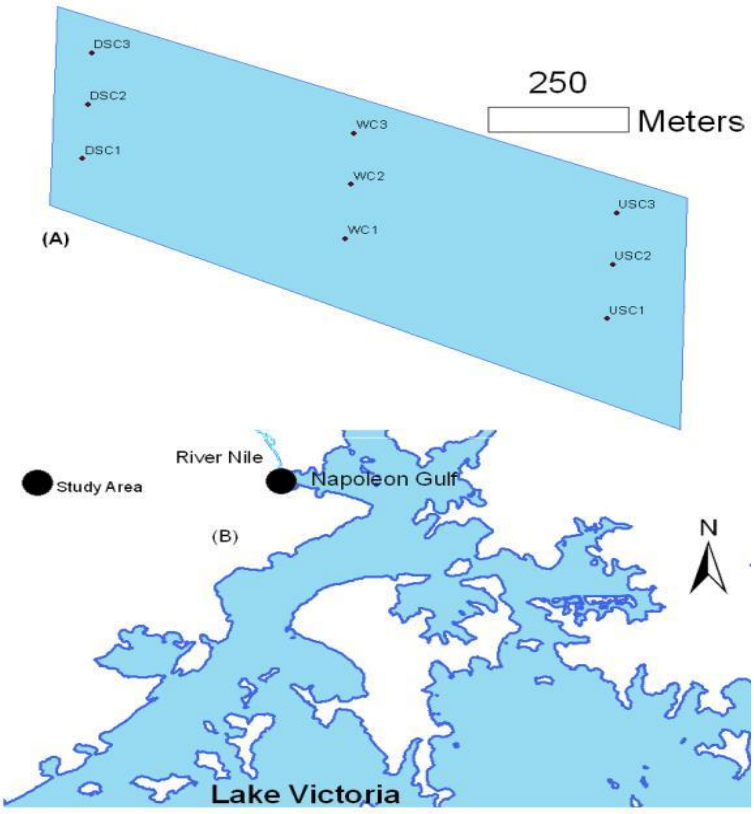

Figure 1. Schematic presentation of the study area showing location of SON Fish Farm (B) and study transects (A): USC- upstream of cages; WIC- within cages and DSC- downstream of cages.

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. All in-situ measurements were made in triplicate for the purpose of assessing variation in each parameter at each sampling point.

2.3 Physico-chemical parameters

Physico-chemical parameters (water column temperature, dissolved oxygen, pH and conductivity) were measured in-situ with a submersible multiparameter probe at each site.

2.4 Nutrient status

Water samples for the determination of nutrient concentrations and algal status were collected with a van Dorn sampler and then placed in clean, labeled plastic bottles for laboratory analysis. Water samples for determination of dissolved nutrients (i.e. Soluble Reactive Phosphorus (SRP), Ammonium nitrogen (NH_4-N), Nitrite nitrogen (NO_2-N), Nitrate nitrogen (NO_3-N) and Total Nitrogen (TN) were filtered and analyzed by spectrophotometric methods following procedures by Stantoin *et al*. (1977). Other water samples were also analyzed for total suspended solids (TSS). Water samples for determination of algal composition and biomass were placed in clean, labeled glass scintillation vials and examined using an inverted Microscope following methods by Mosille (1984) and Hotzel & Croome (1998).

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), Korovchinsky (1992) 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. The bottom type and texture was 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), Mandhal-barth, (1954), and Merritt and 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

3.1.1 Total depth and secchi depth

Total depth (TD) ranged from 1.3–17.0 m at Upstream of cages (USC), 3.1–8.83 m Within cages (WIC) and 3.12–6.0 m Downstream of cages (DSC). The lowest TD values recorded at all sites were less than the minimum 5m optimal depth required suitable for setting up fish cages according to DiFR (2015) guidelines for aquaculture operations. Mean values of TD recorded from March to December 2016 are presented in Figure 2.

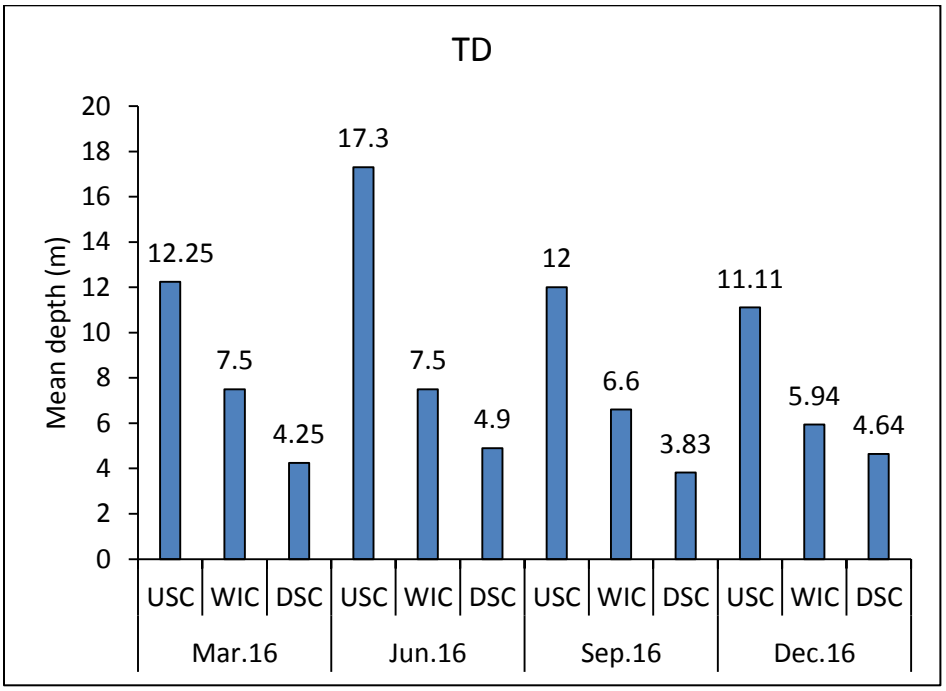

Figure 2. Mean total depths recorded in March, June, September and December 2016.

Secchi depths (SD) at USC, WIC and DSC sites ranged from 0.85 – 1.2 m, 1.12 – 1.42 m and 1.0 – 1.2 m respectively. The highest water transparency (1.42m) was recorded at WIC site while the lowest value (0.85m) was recorded at USC. Though water transparency in December 2016 was highest at WIC and lowest at USC, the values recorded (Figure 3) were comparable and within the range observed in inshore waters of Lake Victoria (Sitoki et al., 2010). Secchi depth values recorded during December 2016 sampling were lower than those recorded in the previous sampling periods for the year

2016 (Figure 3). The more solids present in the water, the less clear the water will be. Therefore, the amount of total suspended solids (TSS) particularly phytoplankton and other particulates especially from shores, and the amount of nutrients especially total phosphorus influence water transparency (Cako et al., 2013). In the current sampling period, total phosphorus concentration (Figure 13), electrical conductivity (Figure 7) and algal bio-volume (Figure 16) were highest at USC followed by DSC and lowest at WIC sites, suggesting their influence on water transparency (Ekubo & Abowei, 2011).

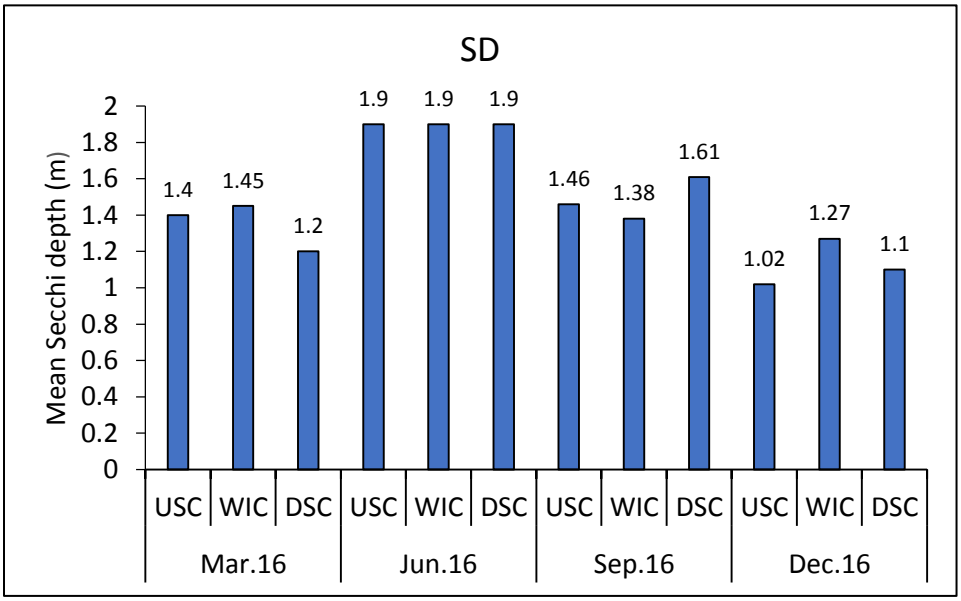

Figure 3. Mean secchi depth recorded in 2016 sampling periods.

3.1.2 Dissolved oxygen (DO)

The concentrations of dissolved oxygen across the three sites for December 2016 and previous sampling periods for 2016 are presented in figure 4. The DO values ranged from 6.3 – 10.6 mg/L at USC, 7.2 – 7.7 mg/L at WIC and 7.6 – 9.6 mg/L at DSC. Mean concentration of DO for the current sampling (December 2016) was lowest within the cages and highest upstream of the cages. High DO concentrations support fast fish growth and feed conversion (Mallya, 2007). The concentration of DO recorded in the current (December 2016) and previous sampling periods (Figure 4) in 2016 was typical of what has been observed in this area of the lake since inception of the project (NEMA,

2012; Mwebaza-Ndawula, et al., 2013) and is appropriate for fish survival (Chapman, 2000).

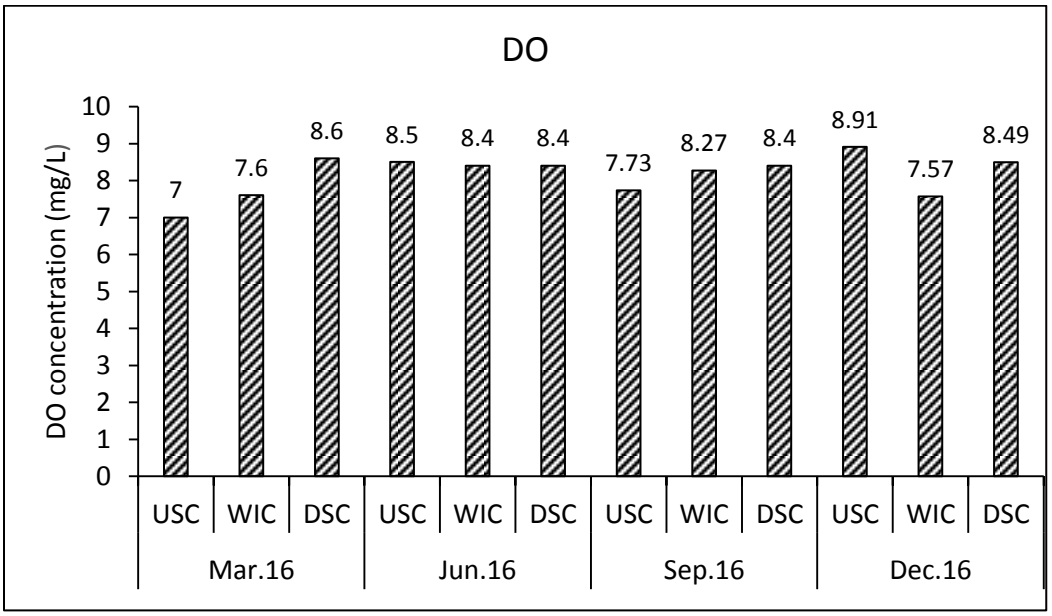

Figure 4. Mean DO concentrations recorded during 2016 sampling periods.

3.1.3 Temperature

The water temperature recorded during December 2016 was within the temperature range currently observed in Lake Victoria (Sitoki et al., 2010). Temperature for the three sites ranged from: 27.4 – 27.9 ^{o} C at USC, 25.8 – 28.5 ^{o} C at WIC and 27.2 – 28.4 ^{o} C at DSC. The lowest and highest recorded mean temperature in the current sampling were 27.09^{o} C at WIC and 27.75^{o}C at DSC respectively indicating a narrow margin between the three sites (Figure 5). The observed temperature within the cages and away from the cages lie within the optimal temperature range (25 to 32 °C) for successful cage fish farming (Bhatnagar & Devi, 2013; Kane et al., 2015).

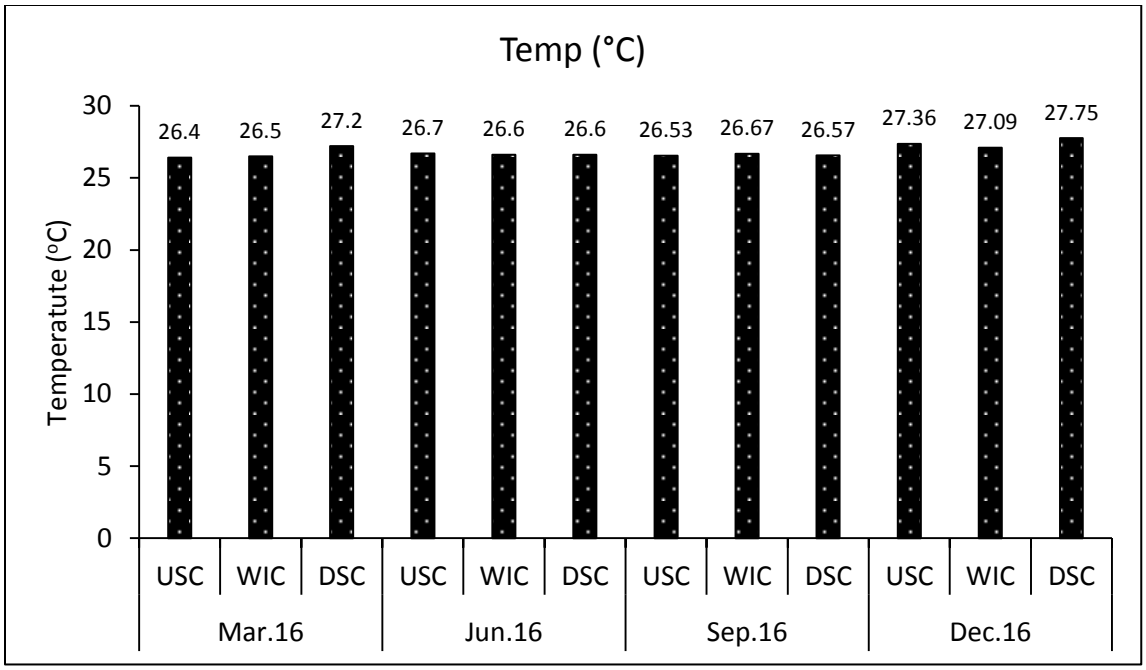

Figure 5. Mean temperature recorded in 2016 sampling periods.

3.1.4 pH

The pH for December 2016 sampling ranged from 7.3 – 7.8 at USC, 7.6 – 7.7 at WIC and 7.5 – 8.7 at DSC and showed no major changes across the sites sampled. Noteworthy, the lowest pH value in the current sampling period was recorded at USC site unlike the previous sampling periods where the USC site exhibited the highest pH. The mean pH values for the current and previous months are presented in figure 6. A pH range of 6 – 9 is optimal for cage fish farming (Masser, 1999; Chapman, 2000), with 5.5 – 10 being the acceptable range (Stone et al., 2013). Alkaline condition (i.e. pH above 7.5) enhances ammonia formation which when in excess is not healthy for fish survival (Reboucas et al., 2015).

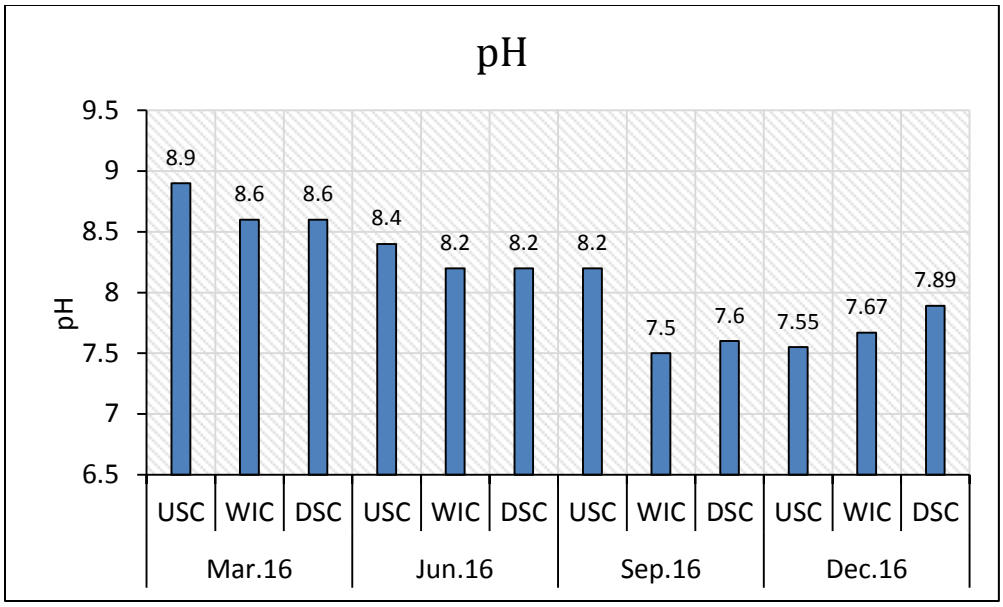

Figure 6. Mean pH recorded in 2016 sampling periods.

3.1.4 Electrical conductivity (EC)

The EC values across USC, WIC and DSC sites during December 2016 sampling ranged from 102.1 – 109.4 μScm^{-1}, 101.7 – 108.3 μScm^{-1} and 102.5 – 105.8 μScm^{-1} respectively. Similar to the results of September 2016, mean EC was highest at USC and lowest at WIC (Figure 7), with EC values of December 2016 sampling being higher than that observed in September 2016 across sites (Figure 7). However, the levels of EC in the current (December 2016) and previous sampling months (Figure 7) were low and within the range (90 to 110 μScm^{-1}) normally encountered in Lake Victoria (Sitoki et al., 2010). Low conductivity of 0 – 200 μScm^{-1} is indicative of pristine conditions (Wetzel, R. G. 1983). The observed conductivity across the sites (Figure 7) was within the desirable: 60 – 2,000 μScm^{-1} or acceptable: 30 – 5,000 μScm^{-1} ranges for fish production (Stone et al., 2013).

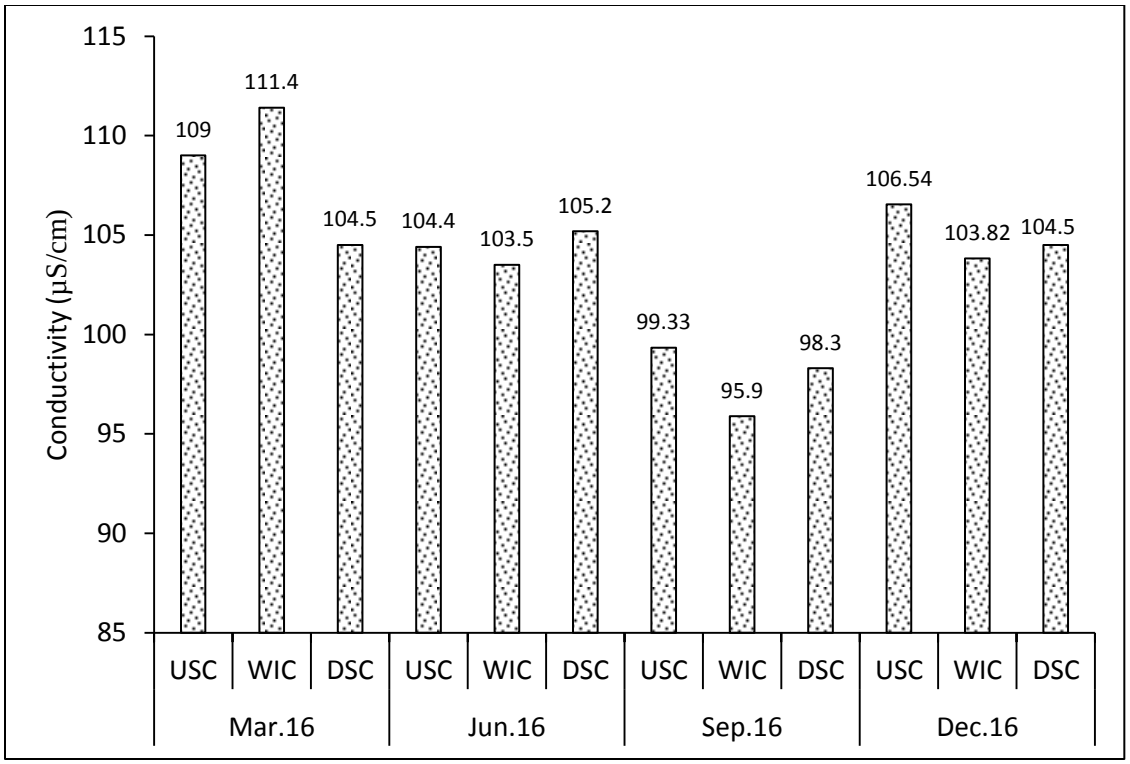

Figure 7. Mean conductivity values recorded in during 2016 sampling periods.

3.1.5 Biological Oxygen Demand (BOD)

The BOD values ranged from 7.6 – 14.2 mg/ L at USC, 7.93 – 20.50 mg/ L at WIC and 11.39 – 19.11 mg/L at DSC, and were much higher than recorded in September 2016. The mean concentrations of BOD were highest at DSC and lowest at USC site (Figure 8). The BOD levels during December 2016 across all sites were beyond the range (3.0 – 6.0 mg/L) considered optimal for normal activities of fishes and indicated higher oxygen utilization by microbial communities to break organic matter. Mean values of BOD at WIC and DSC sites were >12.0 mg/L considered to cause fish kills due to suffocation (Bhatnagar & Devi, 2013).

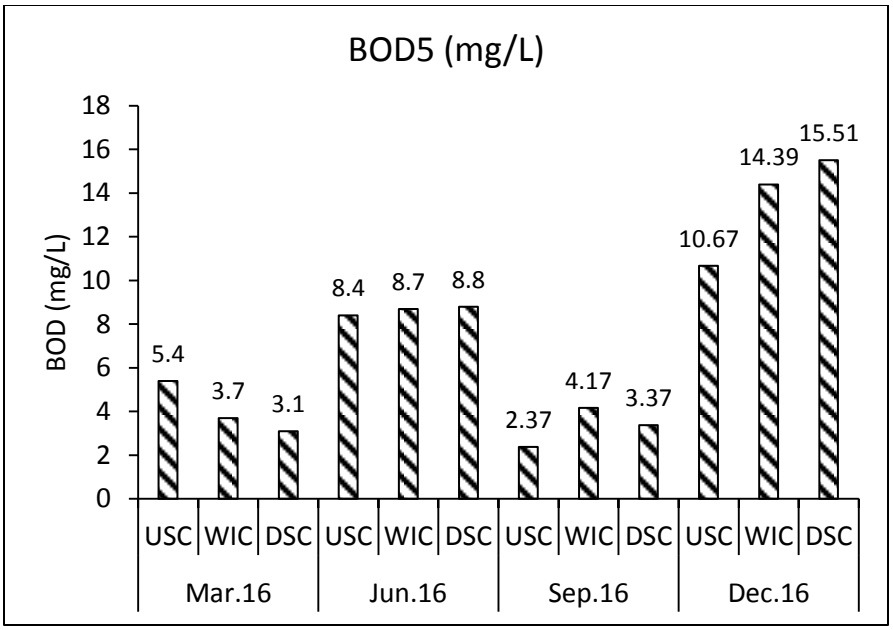

Figure 8. Mean values of biological oxygen demand recorded in 2016 sampling periods.

3.2 Nutrients and Total suspended solids (TSS)

3.2.1 Ammonium nitrogen

The Ammonium nitrogen concentration was highest at USC (mean: 0.24mg/L, range: 0.08 – 0.16mg/L) and lowest at WIC (mean: 0.089 mg/L, range: 0.07 – 0.11mg/L) site (figure 9). Concentrations of Ammonium nitrogen across the three sites were higher than those recorded during June and September 2016. Of all the water quality parameters, which affect fish, ammonia is the most important after oxygen especially in intensive systems (Ogbonna & Chinomso A, 2006). The transitions between the toxic un ionized ammonia and non-toxic ammonium ions are pH dependent. Low pH tends to favour formation of ammonium ions while higher pH leads to the production of the un ionized ammonia (Arauzo & Valladolid, 2003).

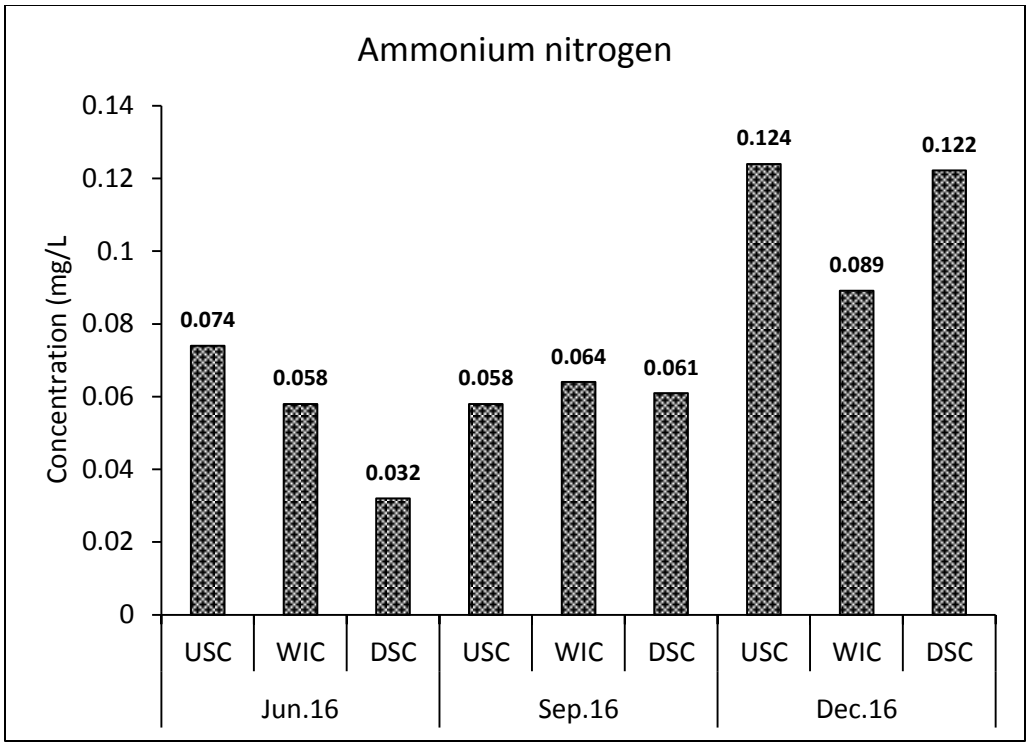

Figure 9. Mean concentrations of ammonium-nitrogen recorded in 2016.

3.2.2 Nitrite-Nitrogen (NO_2-N)

The concentration of nitrite nitrogen showed gradation from USC to DSC with the highest concentration recorded at the DSC and the lowest concentration at USC site (Figure 10). The observed levels of nitrite nitrogen recorded in December 2016 sampling were much higher than that recorded in September 2016. For both September and December 2016 sampling, higher concentrations of nitrite nitrogen were recorded at WIC and DSC than at USC (reference site). However, the concentrations of nitrite nitrogen were within the acceptable (0.03-2mg/L) and desirable (0.01-3 mg/L) ranges for fish farming (Bhatnagar & Devi, 2013).

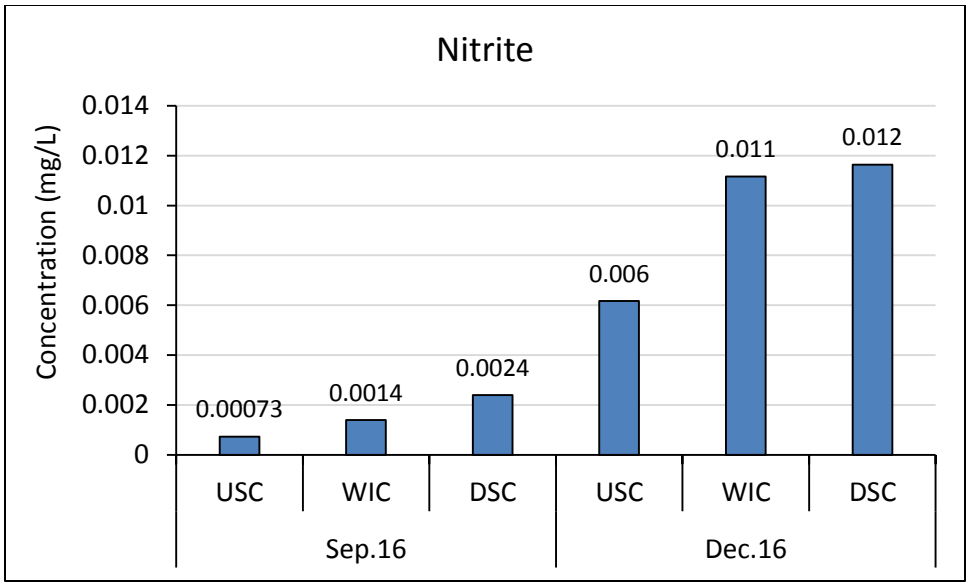

Figure 10. Mean concentrations of nitrite nitrogen, September and December 2016.

3.2.3 Nitrate-Nitrogen (NO_3-N)

The concentration of nitrate nitrogen ranged from 0.019 – 0.084 mg/L at USC, 0.086 – 0.101 mg/L at WIC and 0.093 – 0.106 mg/L at the DSC site. Mean concentration of nitrate nitrogen was highest at DSC site and lowest at USC (Figure 11) for December 2016 sampling period. Mean nitrate nitrogen concentrations at USC remained relatively constant (range: 0.05 – 0.052 mg/L) since June 2016, while the concentration at WIC and DSC showed remarkable increase (Figure 11). The observed concentrations of nitrate nitrogen were within the acceptable (0 – 100mg/L) and desirable (0.1 – 4.5 mg/L) ranges for fish farming (Bhatnagar & Devi, 2013; Stone et al., 2013).

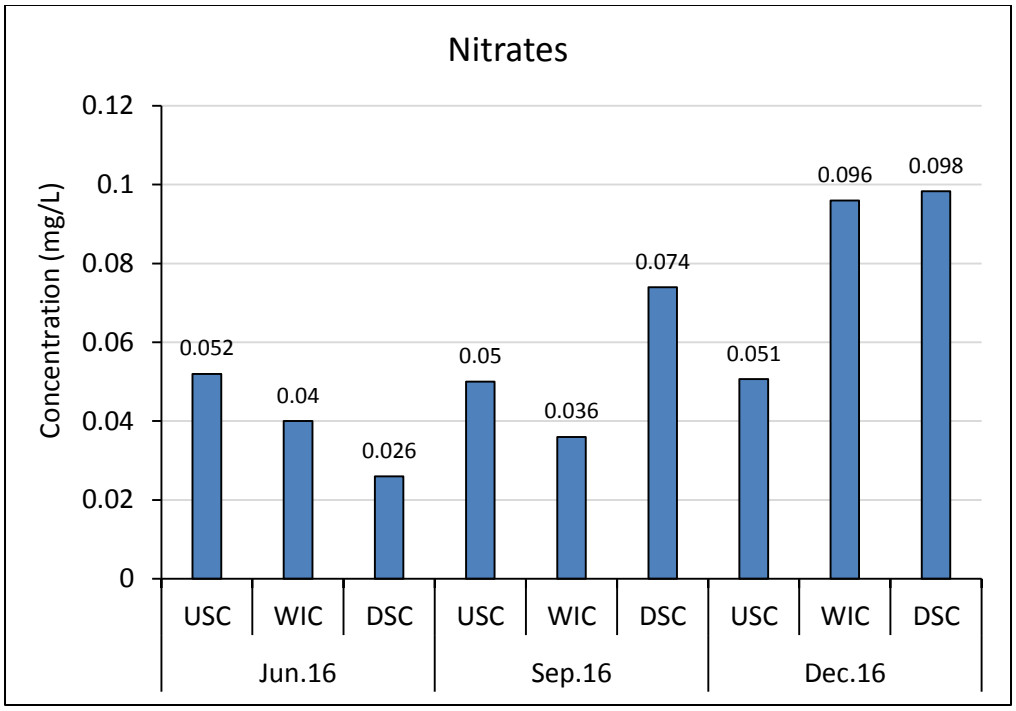

Figure 11. Mean concentrations of nitrate nitrogen in 2016 sampling periods.

3.2.4 Soluble reactive phosphorus (SRP)

The pattern of concentrations of SRP among the three sites (USC, WIC and DSC) was similar to that of nitrate nitrogen, with the highest concentration (mean: 0.016 mg/L, range: 0.0154 – 0.0164 mg/L) at WIC and lowest concentration (mean: 0.014 mg/L, range: 0.0134 – 0.0154 mg/L) at USC site. Overall, mean SRP levels at WIC and DSC sites did not show much variation, but were much higher than that recorded at USC. The SRP levels recorded in December 2016 were higher than recorded in September 2016 (Figure 12).

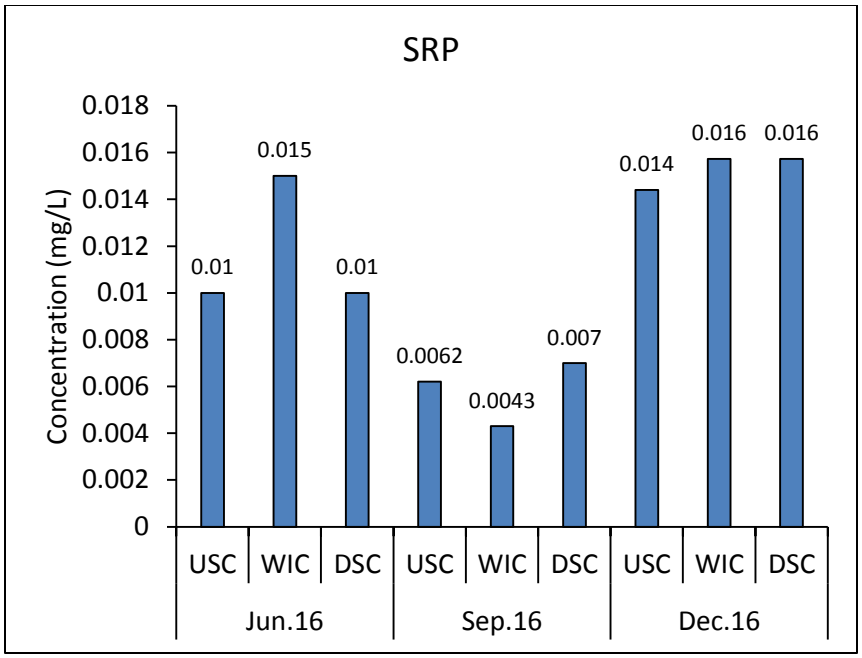

Figure 12. Mean concentration of soluble reactive phosphorus recorded in June, September and December, 2016.

3.2.5 Total phosphorus (TP)

The highest concentration (mean: 0.271 mg/L, range: 0.231 – 0.299 mg/L) of TP was recorded at USC and the lowest concentration at WIC (mean: 0.151 mg/L, range: 0.139 – 0.163 mg/L) contrary to the observations of September 2016 where WIC site exhibited the highest TP concentration (Figure 13). The concentrations of TP recorded in December doubled that recorded in September 2016 at USC and DSC, with WIC showing a slight increase (figure 13). Total phosphorus concentrations recorded were within the desirable range (0.01 – 3 mg/L) for cultured fish (Bhatnagar & Devi, 2013).

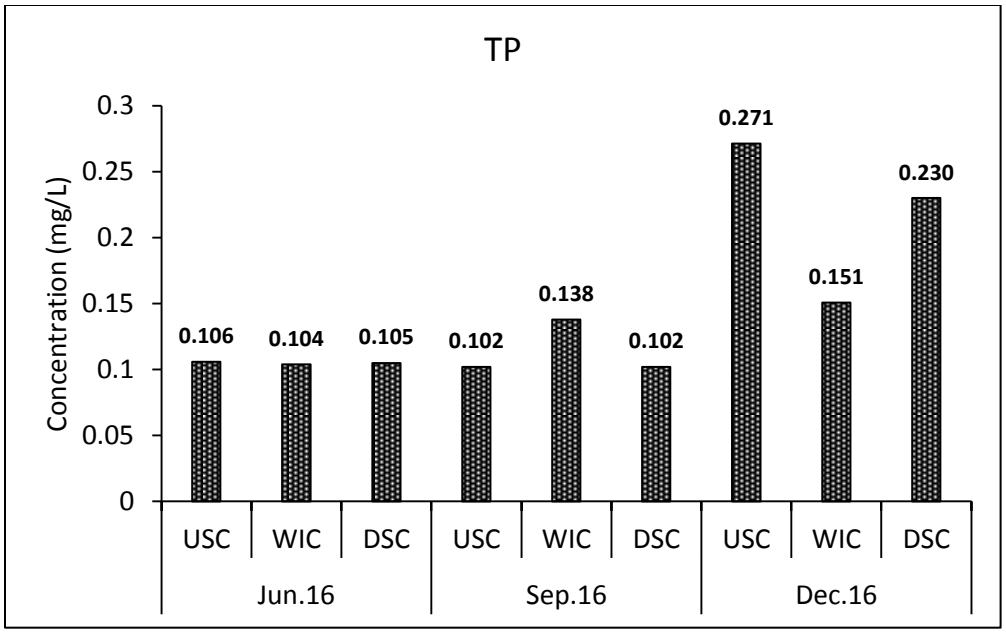

Figure 13. Mean concentrations of Total Phosphorus recorded in June, September and December 2016 sampling periods.

3.2.6 Total Nitrogen (TN)

In December 2016 sampling, mean total nitrogen concentration was highest at USC and lowest at DSC (Figure 14). Compared to September 2016, TN concentrations recorded in December 2016 were much lower regardless of the site (Figure 14).

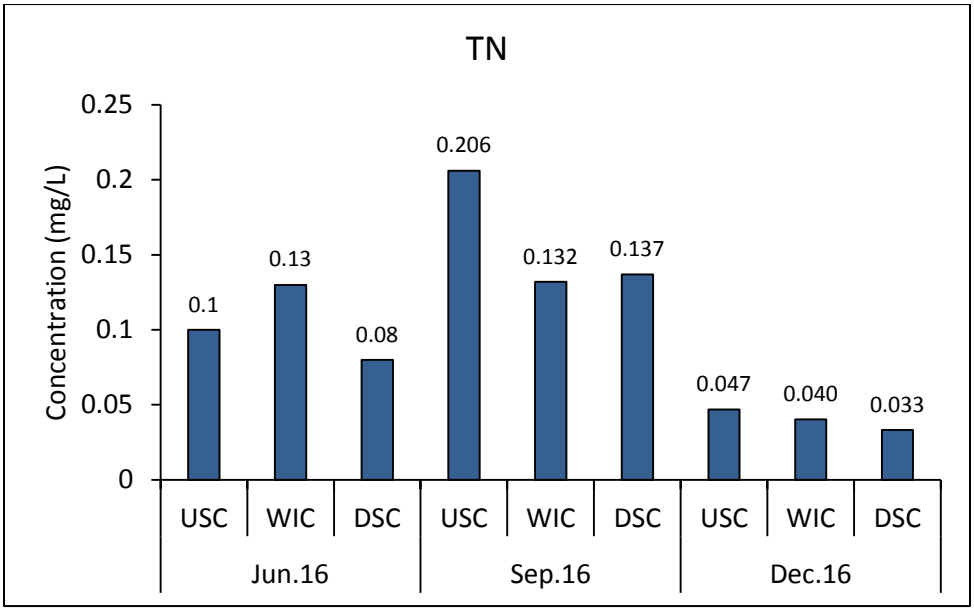

Figure 14. Mean concentration of total nitrogen (June to December 2016).

3.2.7 Total suspended solids (TSS)

Total suspended solids (TSS) are particles that are larger than 2 microns found in the water column. The concentration of TSS was highest at DSC (mean: 4.556 mg/L, range: 4.0 – 5.3 mg/L) followed by WIC (mean 3.857 mg/L, range: 3.0 – 5.0 mg/L), and lowest at USC (mean: 3.316, range: 2.5 – 4.783). A slight increase in TSS at USC and WIC sites and much more increase at DSC was recorded when compared to the previous sampling months (Figure 15). The amount of TSS affect water transparency by modifying light penetration in the water (Cako et al., 2013).

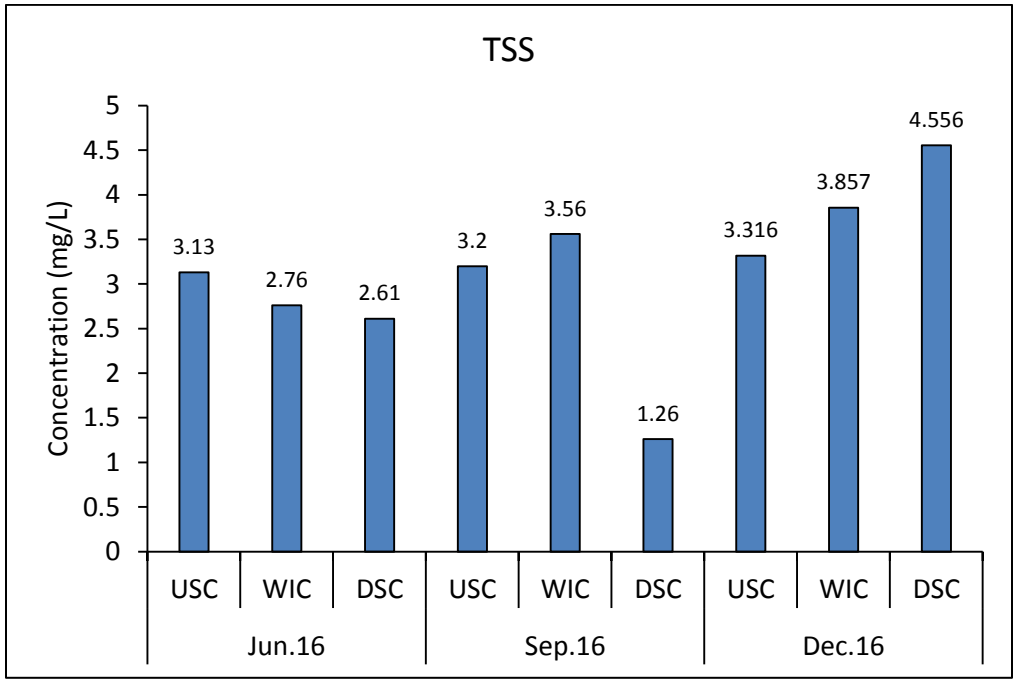

Figure 15. Mean concentration of TSS in June, September and December 2016 sampling periods.

3.3 Algae biomass and composition

3.3.1 Phytoplankton species composition, abundance and distribution

Phytoplankton abundance was highest at USC site (57.4%), which was 2.9 (20%) and 2.5 folds (22.5%) that recorded within (WIC) and downstream (DSC) cages respectively (Figures 16 and 17). However, the abundance during the previous September survey was highest at WIC (40%), followed by USC (36.1%) and DSC (23.8%); Figure 17)).

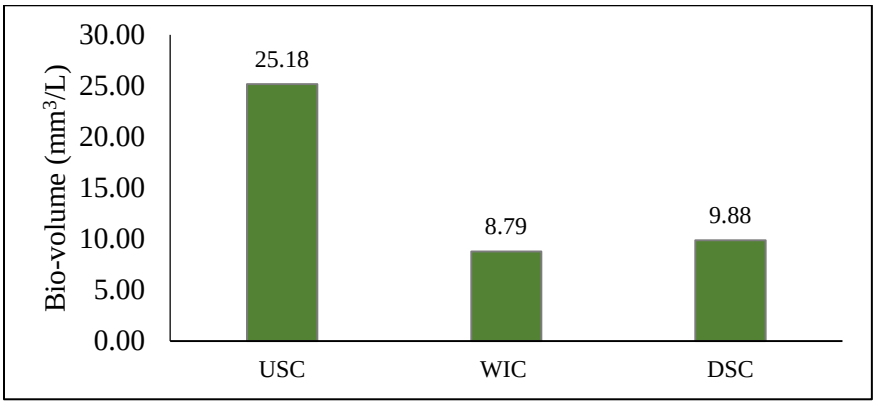

Figure 16. Phytoplankton abundance across sites expressed as bio-volume (mm^3/L), December 2016.

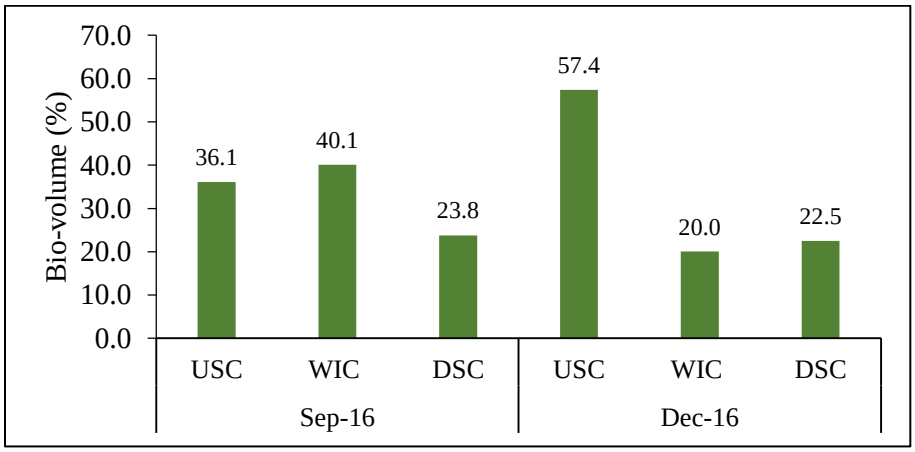

Figure 17. Phytoplankton abundance across sites expressed as bio-volume (%), September and December 2016.

Even though blue-green algae dominated other algae at WIC and DSC, green algae were highest at the control (USC) site (Figure 18). At USC, the high abundance of green algae was mainly attributed to *Oocystis lacustris* (7.1 mm^3/L) and *Monoraphidium arcuatum* (3.3 mm^3/L), blue-green by *Microcytis aeroginosa* (3.58 mm^3/L) and diatoms by *Nitzshia*

fonticola (3.04 mm^3/L). In addition, there was a general reduction in blue-green algae abundance from over 80% across sites in Sept 2016 to <60% in Dec 2016, with an increment in abundance of green algae and diatoms (19). This increment could be attributed to lower predation pressure from organisms up the food chain such as zooplankton and phytoplanktivorous fishes.

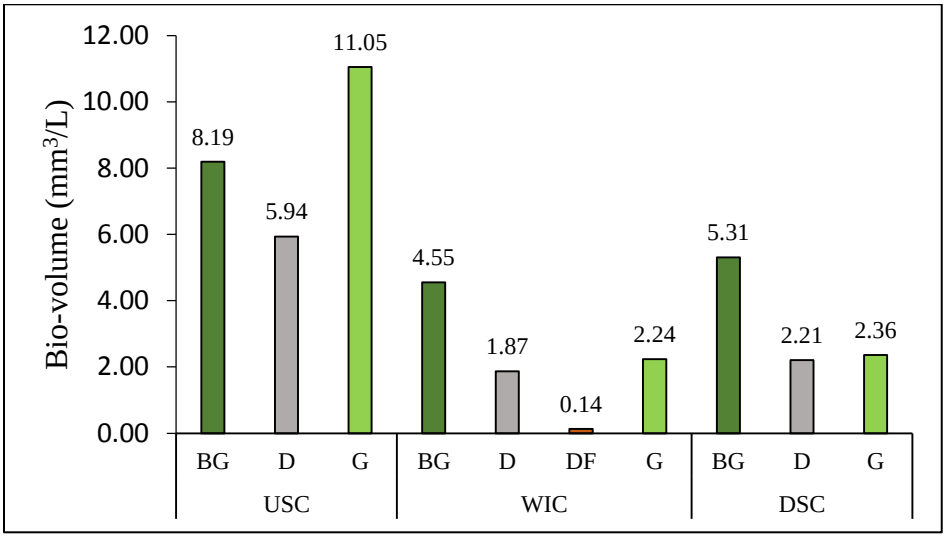

Figure 18. Phytoplankton community composition and abundance, expressed as bio-volume (mm^3/L) across sampled sites. BG; Blue-green, D; Diatoms, G; Green algae, DF; Dinoflagellates.

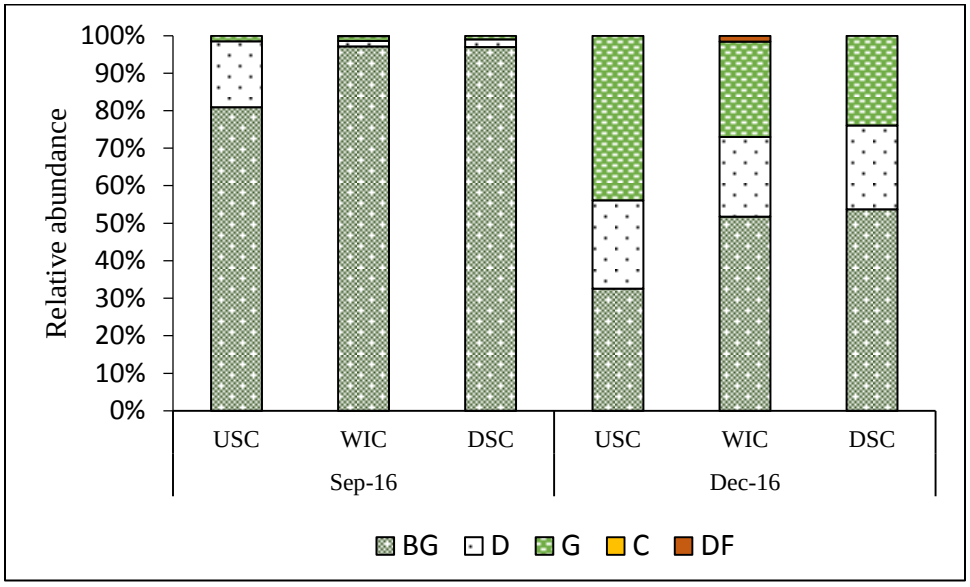

Figure 19. Phytoplankton community composition and abundance, expressed as bio-volume (%) across sampled sites in September and December 2016. BG; Blue-green, D; Diatoms, G; Green algae, DF; Dinoflagellates.

Furthermore, there was a higher species diversity (118 species) than currently where only a total of 54 species were recorded, from 29 genera (Table 1) comprising 9 from blue-green with 24 species, green algae were represented by 11 genera with 17 species, diatoms had 8 genera and 12 species while dinoflagellates were represented by only one species from one genera.

Among blue-green algae, species of *Aphanocapsa* and *Chroococcus, Coelosphaerium kuetzingianum, Planktolyngbya circumreta, Planktolyngbya limnetica, Merismopedia tenuissima* and *Planktolyngbya glauca* were common at all sites. Among green algae, *Monoraphidium contortum* and *Chlorella vulgaris* were found at all sites whereas among diatoms, *Nitzschia acicularis*, *Nitschia nyassensis* and *Cyclostephanodiscus astrea* occurred at all sites. *Ceratium hirudinella*, the only dinoflagellate was found within cages (Table 1).

Table 1: Distribution of phytoplankton species across sampled sites, Dec 2016. X indicates presence of species

Group	**Taxa**		**USC**	**WIC**	**DSC**
Blue-green	*Aphanocapsa*	*delicatissima*	x	x	x
		elachista	x	x	x
		holistica	x	x	x
		incerta	x	x	x
		nubilium	x	x	x
		species	x		
	Chroococcus	*dispersus*	x	x	x
		limnetica	x	x	x
		minutus	x	x	x
		species			x
		turgidus	x	x	
	Coelosphaerium	*kuetzingianum*	x	x	x
		microporum		x	
	Anabaenopsis	*tanganyikae*		x	
	Merismopedia	*glauca*	x	x	x
		tenussima	x	x	x
	Microcystis	*wesenbergii*			x
		aeroginosa	x	x	
		viridis		x	
		flos-aqaue	x		
	Planktolyngbya	*circumcreta*	x	x	x

		limnetica	x	x	x
	Psuedanabena	*limnetica*		x	x
	Cylindrospermopsis	*africana*	x		
Number of species			**18**	**19**	**16**
Green	*Ankistrodesmus*	*falctus*		x	x
		stegera			x
	Actinastrum	*hantzschii*		x	
	Chlorella	*vulgaris*	x	x	x
	Coelomoron	*pusillum*		x	x
		tropicale	x	x	
	Kirchneriella	*obesa*		x	x
	Monoraphidium	*contortum*	x	x	x
		arcuatum	x		
	Oocystis	*gigas*		x	x
		solitaria			x
	Scenedesmus	*acuminatus*	x	x	x
		armatus			x
		perfolatus		x	x
	Stuarsatrum	*gracile*	x	x	
	Crucigenia	*fenestrata*	x	x	
	Oocystis	*lucustris*	x		
Number of species			**8**	**12**	**11**
Diatoms	*Cyclotella*	*kuetzingiana*	x		x
		species	x	x	
	navicula	*gastrum*		x	x
	Nitzschia	*acicularis*	x	x	x
		fonticola	x		x
		mediocris	x		x
		nyassensis	x	x	x
	Rhopalodia	*musculus*		x	x
	Aulacoseira	*granulata*	x		
	Cocconeis	*placentula*	x		
	Cyclostephanodiscus	*astrea*	x	x	x
	Synedra	*cunningtonii*		x	
Number of species			**9**	**7**	**8**
Dinoflagellates	*Ceratium*	*hirundinella*		x	
Number of species				**1**	
Over-all number of species per site			**38**	**39**	**35**

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 at all sites in the current survey was higher than recorded in the previous survey of September 2016 (Figure 20). This was mainly due to the increase in abundance of copepods and cladocera at all sites. For instance, copepod abundance increased from: 676,893 to 1,625,121 ind.m^{-2} at USC, 585,061 to 942,804 ind.m^{-2} at WIC and 164,539 to 565,705 ind.m^{-2} at DSC. Cladocera increased in abundance from: 10,324 to 37,007 ind.m^{-2} at USC; 2,425 to 10,801 ind.m^{-2} at WIC; and 808 to 3,346 ind.m^{-2} at DSC. While copepods and cladocerans increased in abundance at all sites when September and December 2016 surveys were compared, rotifers showed a decrease in abundance e.g. from: 62,887 to 50,930 ind.m^{-2} at USC, 52,007 to 27,643 ind.m^{-2} at WIC, and 27,862 to 21,266 ind.m^{-2} at DSC.

Total zooplankton abundance was highest at USC (1,713,057 ind.m^{-2}) and lowest at DSC (590,316 ind.m^{-2}), a trend observed in September sampling period (Figure 20) and other studies (Dias, Takahashi, Santana, & Bonecker, 2011; Mwebaza-Ndawula et al., 2013). Copepods and Rotifers remained the main groups driving the zooplankton community whereas Cladocera consistently contributed least to the total abundance (Figure 21). For instance, >95% of total zooplankton abundance recorded in each site belonged to the taxon Copepoda (Figure 21). Copepod density (1,625,121 ind.m^{-2} at USC, 942,804 ind.m^{-2} at WIC and 565,705 ind.m^{-2} at DSC) was mainly due to the juvenile stages (Nauplius larvae: 1,077,066 ind.m^{-2} at USC, 689,200 ind.m^{-2} at WIC and 349,905 ind.m^{-2} at DSC; Cyclopoid copepodites: 237,200 ind.m^{-2} at USC, 167,980 ind.m^{-2} at WIC, and 120,857 ind.m^{-2} at DSC; and calanoid copepodites: 86,140 ind.m^{-2} at USC, 8,982 ind.m^{-2} at WIC and 6,333 ind.m^{-2} at DSC).

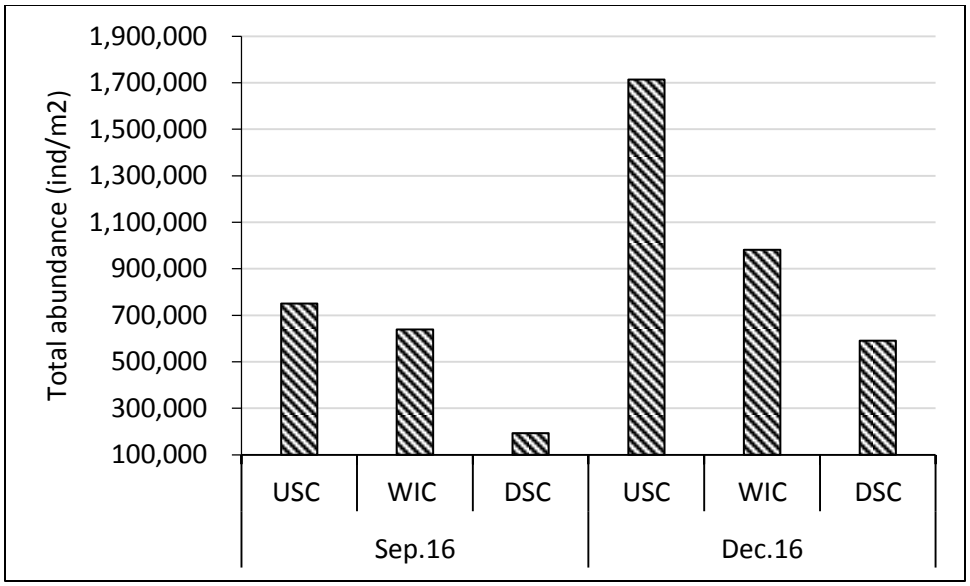

Figure 20. Mean abundance of total zooplankton across the three sites; Upstream (USC), Within (WIC) and Downstream of cages (DSC), September and December 2016.

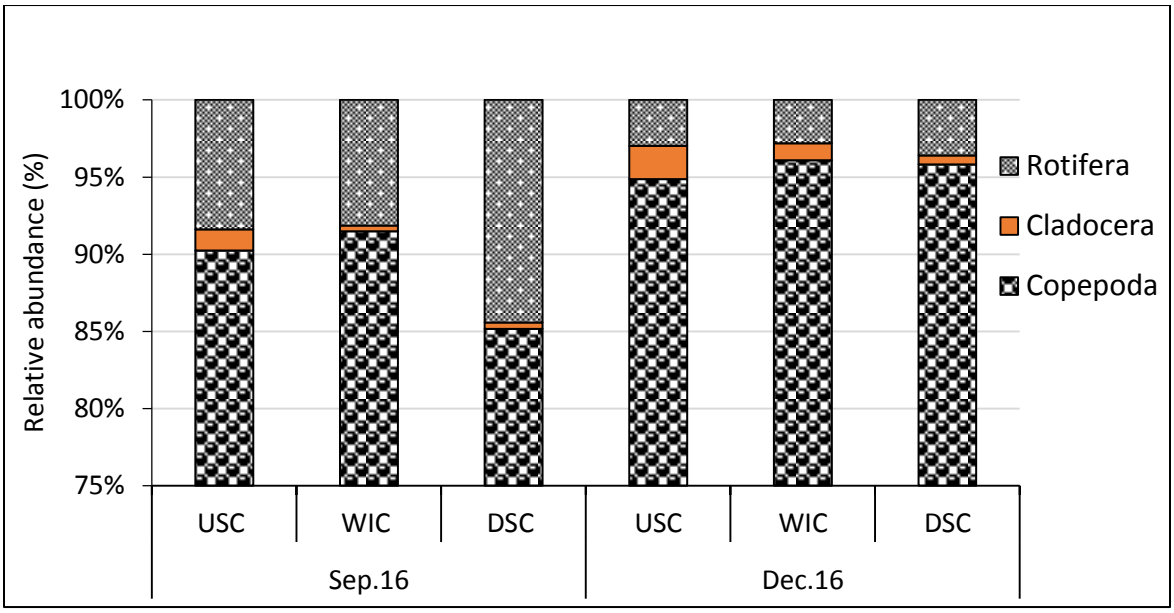

Figure 21. Percentage abundance of broad zooplankton taxa at USC, WIC and DSC, September and December 2016.

3.4.2 Zooplankton species composition

In the current survey, zooplankton community consisted of 29 species whereas 24 species were recorded in the previous September 2016 survey. The highest number of zooplankton species was recorded at WIC (25 species) dominated by rotifers that

contributed 14 species, with the USC and DSC sites each exhibiting 23 species (Table 2). Apart from *Thermocyclops incisus*, which was only recorded at USC and DSC, the rest of copepod species were encountered in all transects. Calanoid copepodites, cyclopoid copepodites and Nauplius larvae were recorded in all transects. Among the 7 cladocera species recorded in the current survey, two species: *Ceriodaphinia dubia* and *Macrothrix* sp. were encountered only at DSC site, and together with *Daphinia lumholtz* (helm), these species were not encountered in September 2016 survey. The rest of the cladocera species were recorded in all transects during December 2016 sampling period (Table 2).

A total of 15 rotifer species were recorded during December 2016 sampling period. Majority (14 species) of these species were recorded within the cage area (WIC transect). Rotifer species: *Brachionus angularis, Keratella cochlearis, Keratella tropica, Lecane bulla*, *Synchaet*a spp. and *Trichocerca cylindrica* were recorded in all transects during the current (December 2016) and previous (September 2016) surveys. *Ascomorpha* sp., and *Polyarthra vulgarius* that were not recorded during September sampling, were only recorded within the cages (WIC) transect in the current sampling (table 2).

Table 2. Zooplankton species composition and distribution across study sites at SON fish farm, 2016. + depicts presence of each taxon at the respective site.

		Sep.16			Dec.16		
GROUP	**SPECIES**	**USC**	**WIC**	**DSC**	**USC**	**WIC**	**DSC**
Copepoda	*Mesocyclops sp.*				+	+	+
	Thermocyclops emini	+	+	+	+	+	+
	Thermocyclops incisus	+	+	+	+		+
	Thermocyclops neglectus	+	+	+	+	+	+
	Thermodiaptomus galeboides	+	+	+	+	+	+
	Tropocyclops confinnis	+			+	+	+
	Tropocyclops tenellus	+	+	+	+	+	+
	Calanoid copepodites	+	+	+	+	+	+
	Cyclopoid copepodites	+	+	+	+	+	+
	Nauplius larvae	+	+	+	+	+	+
	Number of species	**6**	**5**	**5**	**7**	**6**	**7**
Cladocera	*Bosmina longirostris*	+	+		+	+	+
	Ceriodaphnia cornuta	+		+	+	+	+
	Diaphanosoma excisum	+	+	+	+	+	+
	Moina micrura	+	+		+	+	+

	Macrothrix sp.						+
	Daphinia lumholtz (helm)				+	+	+
	Ceriodaphinia dubia						+
	Number of species	**4**	**3**	**2**	**5**	**5**	**7**
Rotifera	*Asplanchna* spp.	+	+	+			
	Ascomorpha sp.					+	
	Brachionus angularis	+	+	+	+	+	+
	Brachionus calyciflorus	+	+	+	+		
	Brachionus falcatus	+	+			+	
	Brachionus bidentatus					+	+
	Euclanis sp.	+	+		+	+	+
	Filinia longiseta	+	+		+	+	+
	Filinia opoliensis	+		+	+	+	
	Keratella cochlearis	+	+	+	+	+	+
	Keratella tropica	+	+	+	+	+	+
	Lecane bulla	+	+	+	+	+	+
	Lecane luna		+		+	+	
	Synchaeta spp.	+	+	+	+	+	+
	Trichocerca cylindrica	+	+	+	+	+	+
	Trichocerca spp.		+				
	Polyarthra vulgaris					+	
	Number of species	**12**	**13**	**9**	**11**	**14**	**9**
Total number of species		**22**	**21**	**16**	**23**	**25**	**23**

3.5 Macro-benthic invertebrate community

3.5.1 Taxa composition and distribution

The macro-benthic community comprised 20 taxa/species from 8 broad taxonomic groups: Bivalvia, Gastropoda, Ephemeroptera, Trichoptera, Odonata, Diptera, Decapoda and Annelida. The highest number of taxa was recorded at WIC (13 taxa) and DSC (13 taxa) while USC exhibited 7 taxa/species. Among insect orders, Diptera dominated at DSC site where 7 taxa were recorded compared to 3 taxa at WIC and 2 taxa at USC (Table 3). Diptera species: *Chaoborus* sp. and *chironomus* spp. occurred at all sites with highest abundances (378 ind.m^{-2} and 2381 ind.m^{-2} respectively) recorded within USC transect. Four species: *Ablabesmyia* sp., *Procladius* sp., *Tanypus* sp. and *Tarnytarsus* sp. were only recorded at DSC site with abundances < 50 ind.m^{-2}, although these species have been recorded in other sites in previous sampling periods (Table 3). Pollution sensitive taxa (Ephemeroptera and Tricoptera) were only recorded at WIC site.

Ephemeroptera was represented by *Caenis* sp. and *Povilla adusta* while Tricoptera was represented by *Pseudoneureclipsis* sp. (Table 3). Among molluscs, gastropods dominated at DSC in terms of taxa richness while bivalves dominated within the cages site (WIC). During September 2016, both bivalves and gastropods taxa richness was higher at WIC site than USC and DSC sites. Annelids were only represented by members of the class Oligochaeta and these were recorded at all sites. In September 2016, annelids were recorded only at DSC, and at both USC and WIC in June 2016 (Table 3).

Table 3. Occurrence of benthic macro invertebrate taxa across the study sites at SON fish farm, 2016. U-upstream of cages, W-within cages, D- downstream of cages, + depicts presence of a taxon.

Taxa		Mar.16			Jun.16			Sep.16			Dec.16		
		U	W	D	U	W	D	U	W	D	U	W	D
Bivalvia	*Byssanodonta parasitica*		+	+	+	+		+	+			+	
	Pisidium victoriae				+								
	Caelatura monceti								+				
	Caelatura alluadi					+							
	Caelatura hauttecoeuri		+		+				+			+	
	Corbicula africana		+	+	+	+	+	+	+	+	+	+	+
	Etheria elliptica								+				
Gastropoda	*Bellamya unicolor*		+	+	+	+	+	+	+	+		+	+
	Pila ovata				+							+	
	Gabbia humerosa			+					+	+	+		+
	Melanoides tuberculata	+	+		+	+	+		+	+	+	+	+
	Biomphalaria sp.												+
	Bulinus sp.		+						+				
	Anisus natalensis								+				
Ephemeroptera	*Caenis* sp.		+		+	+		+	+	+		+	
	Povilla adusta		+	+					+	+		+	
	Leptophlebidae							+		+			
Tricoptera	Leptoceridae		+										
	Psychomyiidae			+		+			+				
	Lemnophilidae				+								
	Pseudoneureclipsis sp.								+			+	
Odonata	Libellulidae		+		+								
Diptera	*Ablabesmyia* sp.	+	+	+					+	+			+
	Chironomus spp.	+	+	+	+				+	+	+	+	+
	Cryptochironomus sp.		+										
	Procladius sp.							+					+
	Tanypus sp.	+		+	+		+						+

Taxa		Mar.16			Jun.16			Sep.16			Dec.16		
		U	W	D	U	W	D	U	W	D	U	W	D
	Tarnytarsus sp.							+	+	+			+
	Ceratopogonidea				+		+			+			
	Chaoborus sp.	+	+		+	+	+	+	+	+	+	+	+
	Chironominea	+	+		+	+		+	+	+		+	+
Decapoda	*Caridina nilotica*										+		
Annelida	Hirudinea	+		+									
	Oligochaeta		+		+	+				+	+	+	+
	Total number of taxa	7	16	10	16	10	6	9	19	14	7	13	13

3.5.2 Macro-benthic invertebrate abundance

Just like in the previous sampling periods, insects were more abundant upstream of cages (USC) than within (WIC) and downstream of cages (DSC). The abundances of three broad groups: molluscs, insects and annelids are presented in figure 22. In the current survey the contribution of insects to the total benthic macroinvertebrate abundance was 93.4% at USC, 69.4% at WIC and 45.8% at DSC. Compared to the previous months, there was an increase in insect abundance upstream of cages from 1344 ind.m^{-2} in March 2016 to 2759 ind.m^{-2} in December 2016 and a decrease in abundance from 784 ind.m^{-2} in March to 308 ind.m^{-2} in December 2016 at DSC site (Table 4). Noteworthy, order Diptera contributed 100% to the observed insect abundance in the upstream of cages (USC) site in March and December 2016 sampling periods. Though within cage site currently recorded higher insect abundance than downstream (DSC) site, lower insect abundance has been recorded within cages (WIC) than downstream of cages (DSC) site in the previous months (Table 4). The total abundance (70 ind.m^{-2}) of EPT (Ephemeroptera, Plecoptera and Trichoptera) recorded within cages (WIC) in December 2016 was lower than that (range: 168 – 308 ind.m^{-2}) recorded in the same site in the previous sampling periods (Table 4). In the current survey, the abundance of molluscs increased in an upstream – downstream direction, being lowest (84 ind.m^{-2}) at USC and highest (336 ind.m^{-2}) at DSC where it contributed 50% to the total benthic macroinvertebrate density. Annelids were more abundant at USC (112 ind.m^{-2}) followed by WIC and DSC, each with 28 ind.m^{-2} (Table 4).

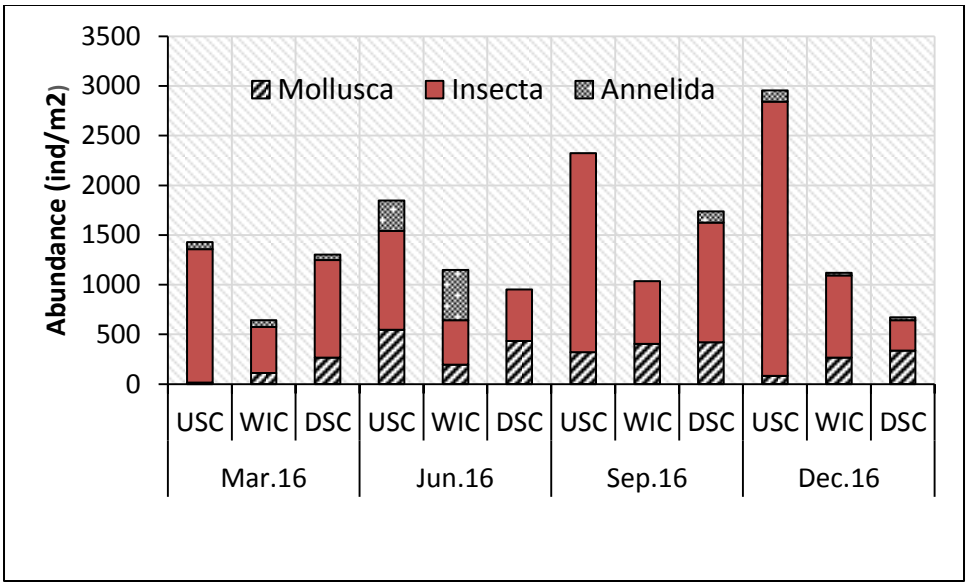

Figure 22. Total abundance of major macro invertebrates across study sites at SON fish farm, March to December 2016.

Table 4. Total abundance of macroinvertebrate classes/orders recorded in March, June, September and December 2016.

Broad groups	Mar.16			Jun.16			Sep.16			Dec.16		
	USC	WIC	DSC	USC	WIC	DSC	USC	WIC	DSC	USC	WIC	DSC
Bivalvia		56	196	308	140	168	238	112	224	42	224	210
Gastropoda		56	70	238	56	266	84	294	196	42	112	126
Ephemeroptera		112	168	28	294		28	140	378		56	
Trichoptera		84	28	14	14			28			14	
Odonata		28		14								
Diptera	1344	238	784	938	140	504	1974	462	826	2759	756	308
Oligochaeta		70		308	504				112	112	28	28

3.6 Fish species diversity, abundance and ecology

3.6.1 Fish Catch composition

A total of five fish species, including haplochromines (Nkejje) as a single species group, were recorded in the vicinity of the cages (Table 5) in the survey of December 2016 as compared to four species recorded in the previous surveys of September and June 2016. Numerically, *Synodontis afrofischeri* (41.7%) was the most abundant, followed by *Lates niloticus* (25%), haplochromine cichlids (16.7%), *Mormyrus kannume* (8.3%) and *Tilapia*

zillii (8.3%). By weight, *L. niloticus* (62.5%) was the most dominant followed by *M. kannume* (21.4%), *S. afrofischeri (11.9%), T. zillii (2.7%)* and *haplochromines* (1.4%). Four fish species were recorded from Within the cages site and three from the Downstream site. No catch was recorded from the gillnet fleet set upstream the cages (USC site). Fish abundance was highest within the cage site (75%) and lowest downstream the cage site (25%). The highest biomass (Table 6) was recorded within the cages site (95.2%) and the lowest (4.8%) from downstream the cages.

Table 5. Catch rates (numbers) of fish species from SON Fish cages obtained during 2016.

Date of sampling			Mar.16	Jun.16	Sep.16	Dec.16
Family	**Species**					
Mormyridae	*Mormyrus kannume*	USC	0.1	0.1	0	0
		WIC	0	0	0	0.1
		DSC	0	0	0	0
		All	0.01	0.03	0	0.03
Clariidae	*Clarias gariepinus*	USC	0	0	0	0
		WIC	0	0	0	0
		DSC	0	0.1	0	0
		All	0	0.02	0	0
Mochokidae	*Synodontis afrofischeri*	USC	0.3	0	0	0
		WIC	0	0	0.1	1.3
		DSC	0	0	0	0
		All	0.1	0	0.03	0.4
Centropomidae	*Lates niloticus*	USC	0.5	0.3	0	0
		WIC	0	0.2	0.2	0.2
		DSC	0.2	0.1	0	0.1
		All	0.3		0,1	0.1
Cichlidae	*Tilapia zillii*	USC	0	0	0	0
		WIC	0	0	0	0
		DSC	0	0	0	0.1
		All	0	0	0	0.04
	Oreochromis niloticus	USC	0	0	0	0
		WIC	0	0	0	0
		DSC	O	0	0,1	0
		All	O	0	0.03	0
	Haplochromines	USC	0.5	0	0	0
		WIC	0	1.5	0.5	0.3
		DSC	0.3	0	0	0.3
		All	0.4	0.5	0.3	0.2

Date of sampling		Mar.16	Jun.16	Sep.16	Dec.16
Overall Rates	USC	0.8	0.4	0	0
	WIC	0	0.2	0.4	0.7
	DSC	0.3	0.2	0.1	0.2
	All	0.6		0.2	0.3
No of species recovered	USC	4	2	0	0
	WIC	0	2	3	4
	DSC	2	2	1	3
	All	4	4	4	5

3.6.2 The haplochromines

Two species of haplochromine cichlids were *recorded* during the survey of December 2016 as in the previous survey of September 2016 (Table 7). The species included *Pundamilia* sp. *and, Psammochromis riponianus* at 50% each. One species was recorded from Within the cage site and one from downstream. The haplochromines recorded during the December 2016 sampling survey belonged to two genera, namely *Psammochromis* and *Pundamilia.*

3.6.3 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 December 2016, catch rates by weight were highest Within the cages (128.3g/net/night) and lowest Downstream the cage site (6.5g/net/night). By numbers, the catch rates were also highest Within the cages (0.7 fish/net/night) and lowest Downstream (0.2 fish/net/night) as indicated in Table 2. Overall mean catch rates during the period of December 2016 were 0.3 fish/net/night and 39.8g/net/night compared to 0.2 fish/net/night and 43.3g/net/night recorded in the previous survey of September 2016. Thus, the fish catch rates by numbers were higher in December 2016 compared to the previous survey of September 2016. However, by weight, the catch rates were lower in December 2016.

The overall catch rate for haplochromines in December 2016 were 0.3 fish/net/night and 2.3g/net/night compared to 0.3 fish/net/night and 1.9g/net/night recorded in September 2016.

Table 6. Catch rates by weight (g) of fish caught in SON Fish cage site during 2016.

Date of sampling			**Mar. 16**	**Jun. 16**	**Sep.16**	**Dec. 16**
Family	**Species**	**Site**				
Mormyridae	*Mormyrus kannume*	USC	61.7	89.5	0	0
		WIC	0	0	0	28.9
		DSC	0	0	0	0
		All	31	31.4	0	9.6
Clariidae	*Clarias gariepinus*	USC	0	0	0	0
		WIC	0	0	0	0
		DSC	0	272.7	0	0
		All	0	81.1	0	0
Mochokidae	*Synodontis afrofischeri*	USC	12	0	0	0
		WIC	0	0	5	52
		DSC	0	0	0	0
		All	6	0	2.5	17.3
Centropomidae	*Lates niloticus*	USC	191	7.4	0	0
		WIC	0	3.2	76.6	82.7
		DSC	5.4	0.9	0	1.6
		All	96		38.3	28.1
Cichlidae	*Tilapia zillii*	USC	0	0	0	0
		WIC	0	0	0	0
		DSC	0	0	0	6
		All	0	0	0	2
	Oreochromis niloticus	USC	0	0	0	0
		WIC	0	0	0	0
		DSC	0	0	0.1	0
		All	0	0	0.03	0
	Haplochromines	USC	6.6	0	0	0
		WIC	0	16	3.7	2.3
		DSC	5.4	0	0	4
		All	6.5	5.3	1.9	2.1
Overall Rates		USC	262	96.8	0	0
		WIC	0	2.7	80.8	128.3
		DSC	6.3	278.6	5.8	6.5
		All	135		43.3	39.8
No of species recovered		USC	4	2	0	0
		WIC	0	2	3	4
		DSC	2	2	1	3
		All	4	4	4	5

Table 7. Catch rates (by numbers) of haplochromine species from SON Fish cage site obtained during surveys carried out in 2016.

Date of sampling			Mar.16	Jun.16	Sep.16	Dec.16
Genus	**Species**	**Site**				
Astatotilapia	*Astatotilapia sp*	USC	0.3	1.3	0	0
		WIC	0	0	0.3	0
		DSC	0	0	0	0
		All sites	0.1	0.4	0.1	0
Mbipia	*M. mbipi*	USC	0	0	0	0
		WIC	O	0.3	0	0
		DSC	0.3	0	0	0
		All sites	0.1	0.1	0	0
Psammochromis	*P. riponianus*	USC	0.3	0	0	0
		WIC	0	0	0.3	0
		DSC	0	0	0	0.3
		All sites	0.1	0	0.1	0.1
Pundamilia	*Pundamilia sp*	USC	0	0	0	0
		WIC	0	0	0	0.3
		DSC	0	0	0	0
		All sites	0	0	0	0.1
Overall Contribution		USC	18	0	0	0
		WIC	0		40	11.1
		DSC	33	0	0	33.3
		All sites	21.4	40	33.3	16.7
No of species recovered		USC	2	0	0	0
		WIC	0	2	2	1
		DSC	1	0	0	1
		All sites	3	2	2	2

3.6.4 Biology of common fish species

The following Table (Table 8) shows some of the basic biological parameters examined in fish caught around SON fish farm. The different fish species caught within and a way from cages were found to be feeding on naturally occurring natural food organisms.

Table 8. Basic biological parameters of fish species caught from SON Fish cage site in 2016.

Date of sampling		**Mar.16**	**Jun.16**	**Sept.16**	**Dec.16**
Species					
Clarias gariepinus	Size range (cm) TL	0	77	0	0
	% mature	0	Mature	0	0
	Main food type	0	Odonata	0	0
	Parasites found	0	0	0	0
	Number examined	0	1	0	0
Lates niloticus	Size range (cm)	9 – 47	8 - 14	17.1, 46.3	10 – 43
	% mature	33.3	Nil	Nil	33.3
	Main food type	Haps	Fish	Caridina	Haps
	Parasites found	0	0	0	0
	Number examined	6	7	2	3
Haplochromines	Size range (cm)	7.9 – 11.5	6.7 – 11.5	7.5, 8.8	8.1 – 10.5
	% mature	100	50	Nil	100
	Main food type	Insect	Insect	Insect	Empty
	Parasites found (% infection)	0	0	0	0
	No examined	3	5	2	2
Tilapia zillii	Size range (cm)	0	0	0	13.0
	% mature	0	0	0	Mature
	Main food type	0	0	0	Plant material
	Parasites found	0	0	0	0
	No examined	0	0	0	1
Mormyrus kannume	Size range (cm)	45	49	0	34
	% mature	Mature	Mature	0	Mature
	Main food type	Povilla	Povilla	0	Povilla
	Parasites found	0	0	0	0
	No examined	1	1	0	1
Oreochromis niloticus	Size range (cm)	0	0	16.5	0
	% mature	0	0	Nil	0
	Main food type	0	0	Detritus	0
	Parasites found	0	0	0	0
	No examined	0	0	1	0
Synodontis afrofischeri	Size range (cm)	13 – 14	0	13.0	10 – 16
	% Mature	Mature	0	Mature	Mature
	Main food type	Insect	0	Mollusk	Ras
	Parasites found	0	0	0	0
	No examined	1	0	1	5

4.0 CONCLUSION AND RECOMMENDATION

4.1 Conclusion

In this report, water quality and biotic communities around SON fish farm were assessed. The objective was to assess possible environmental changes at the cage site and downstream of cages against the upstream site (the reference). The recorded physical water conditions: water transparency, DO, Temperature, pH, and conductivity varied within narrow margins both at the control and were within the optimal ranges considered suitable for cage fish farming. The BOD levels during December 2016 across all sites were beyond the range considered optimal for normal activities of fishes. Concomitantly, higher concentrations of nitrite nitrogen, nitrate nitrogen and SRP within cages and downstream of cages was observed. However, these values were relatively low and normal for these waters. The presence of higher concentrations of TP, TN and ammonium nitrogen upstream of cages (reference site) than within and downstream of SON fish cages indicated minimal nutrient input from SON cages, and that other cages further upstream as well as activities in the catchment influenced the reference site.

Phytoplankton abundance was highest at the reference site and lowest within cages and downstream of the cages. Blue-green algae dominated other algae within cages and downstream of cages while green algae dominated at the upstream site. Total zooplankton abundance was highest at the reference (upstream site) and lowest at the downstream site. While copepods and cladocerans increased in abundance at all sites when September and December 2016 surveys were compared, rotifers showed a decrease in abundance. Benthic macro invertebrate taxa richness was highest within cages and downstream of cages and lowest at the control (upstream of cages) while highest abundance of these invertebrates was recorded upstream of cages. Pollution sensitive taxa Ephemeroptera and Tricoptera were only recorded within cages while oligochaete annelids which are tolerant to environmental disturbance and therefore indicators of poor water quality were less abundant within cages and downstream of cages than recorded upstream of cages (reference site). All these indicate improved water quality within the cage area.

Fish abundance was highest within the cages and lowest downstream of the cages suggesting aggregation and therefore potential of cages to serve as small protection areas for wild fish. In the survey of December 2016 all the fish species examined had fed on naturally occurring food organisms, dominated by fish and aquatic insect larvae. Thus, cage fish farming has not yet impacted the presence of natural food organisms utilized by wild fish. Parasites among wild fish caught near and away from cages were not observed during the survey of December 2016 as has been in previous surveys. Therefore, water quality and biotic communities assessed indicated no major impact of SON fish farm on water quality and resident organisms.

4.2 Recommendations

Though SON fish farm has two cage sites, the current and previous reports assessed physico-chemical and biotic communities around the old site that is downstream of the new site. It is recommended that the regular quarterly monitoring stretch to cover the upper site as well. A transect running through the two sites in a downstream direction would be desirable both in terms of cost and time spent on sample collection and analysis.

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